XXII Brazilian Colloquium on Orbital Dynamics, 2 - 6 December, 2024

CBDO


Ilustração: New Horizons - Plutão - Caronte / NASA

Program and Book of Abstracts

National Institute for Space Research
INPE
Av. dos Astronautas, 1758
São José dos Campos, SP, Brazil

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XXII Brazilian Colloquium on Orbital Dynamics – CBDO 2024

The Brazilian Colloquium on Orbital Dynamics, CBDO, is a national meeting that has been held every two years since 1982 and brings together Brazilian researchers, professors, postgraduate and undergraduate students, as well as their foreign peers, in the areas of Theoretical and Applied Celestial Mechanics. The subfields covered by the CBDO are Dynamical and Planetary Astronomy, Orbital Mechanics and Spacecraft Attitude Control, and Dynamical Systems.

CBDO 2024 will take place in the auditorium of the Integration and Testing Laboratory (LIT) at the National Institute for Space Research, INPE, located at Av. dos Astronautas, 1758, São José dos Campos, SP, Brazil.

Organizing Committee

Scientific Committee

Antônio Fernando Bertachini de Almeida Padro / INPE
Eduardo Shirlippe Goes Leandro, UFPE - Brazil
Jorge Alfredo Correa-Otto, CONICET – Argentina
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Pryscilla Maria Pires dos Santos, UERJ – Brazil
Silvia Maria Giuliatti-Winter, UNESP – Brazil

History of the CBDO

The first CBDO was organized on the initiative of Dr. Wagner Sessin (1946 - 1997), in July 1982, at the Aeronautics Institute of Technology (ITA). This first meeting was entitled "Movements of Artificial Satellites: Theory, Determination and Applications", and its aim was to bring together researchers working in the fields of Astronomy and Space Dynamics who were involved with theoretical and applied Celestial Mechanics problems. 51 researchers and postgraduate students from the states of São Paulo, Rio de Janeiro, Paraná, Minas Gerais and Pernambuco attended the meeting. Since then, the CBDO has been held uninterruptedly every two years, and it is the main scientific event in this area held in Brazil, as well as being a reference for presentations from all over Latin America.

CBDO participants are mainly university professors, researchers, post-doctoral, postgraduate and undergraduate students. The most recent CBDOs had an average of 170 participants from various states, mainly São Paulo, Rio de Janeiro, Paraná, Santa Catarina, Minas Gerais, Pernambuco, Bahia and the Federal District. Since 1982, the CBDO has also been constantly attended by South American researchers and students, particularly from Argentina, Chile, and Uruguay. In addition, researchers from the United States, Canada, Mexico, Germany, France, Poland, Spain, Portugal, Italy, and Russia, among others, have participated through guest lectures and short courses.

You can find information about previous meetings at the following link:
http://www.astro.iag.usp.br/~dinamica/cbdo.htm

Support

São Paulo Research Foundation – FAPESP.

Acknowledgments

Brazilian Astronomical Society – SAB.

National Institute for Space Research – INPE.

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CBDO 2024 - PROGRAM

First week of December 2024

Monday, December 2nd

12:10 pm - Registration and reception of participants

1:40 pm - Opening

1:50 pm - Wagner Sessin Award

2:00 pm - Opening Talk
Italy-Brazil Joint Science and Technology Cooperation in Space Technology: the SPLASH Project (CBDO 187)
Ignazio Dimino
CIRA, Centro Italiano Ricerche Aerospaziali, Capua, CE, Italy

First session on Dynamical and Planetary Astronomy
Chairman: Silvia Giuliatti Winter

2:50 pm - Oral communication 01
The Orbital Eccentricities of Directly Imaged Companions Using Observable-based Priors: Implications for Population-level Distributions (CBDO 001)
Clarissa R. Do Ó
University of California, San Diego & University of California, Los Angeles, USA

3:10 pm - Oral communication 02
The co-orbital dynamics in binary systems (CBDO 002)
Fernando Roig
National Observatory, ON, Rio de Janeiro, RJ, Brazil

3:30 pm - Oral communication 03
Vision Transformers for identifying asteroids interacting with secular resonances (CBDO 006)
Valerio Carruba
UNESP - São Paulo State University, Guaratinguetá, SP, Brazil

3:50 pm - Coffee break

4:10 pm - Poster Session 1. CBDO 001 – CBDO 105, except oral communication.

Tuesday, December 3rd

Second session on Dynamical and Planetary Astronomy
Chairman: Sylvio Ferra Mello

8:30 am - Invited talk 1
Dynamic of Centaurs, link with the giant planets and other small body populations (CBDO 188)
Romina Paula Di Sisto
Facultad de Ciencias Astronómicas y Geofísicas, Universidad Nacional de La Plata, Argentina

9:20 am - Invited talk 2
Stellar Occultations by Trans-Neptunian Objects (CBDO 185)
Felipe Braga Ribas
Federal University of Technology of Paraná, UTFPR, Curitiba, PR, Brazil

10:10 am – Coffee Break

10:30 am - Oral communication 04
Non-transiting exoplanet characterization using TTV pattern and Deep Learning (CBDO 035)
Marco Antonio Petersem-Domingues
National Observatory, ON, Rio de Janeiro, RJ, Brazil

10:50 am - Oral communication 05
The Effect of Triton's Evolution on Neptune's Spin Axis (CBDO 039)
Rodney Gomes
National Observatory, ON, Rio de Janeiro, RJ, Brazil

11:10 am - Oral communication 06
A Hamiltonian for 1/1 rotational secondary resonances, and application to small satellites of Saturn and Jupiter (CBDO 108)
Nelson Callegari Júnior
UNESP - São Paulo State University, Rio Claro, SP, Brazil

11:30 am - Oral communication 07
Analysing the dynamics of Kepler-90 planetary system (CBDO 049)
Silvia Giuliatti Winter
UNESP - São Paulo State University, Guaratinguetá, SP, Brazil

11:50 am - Oral communication 08
Estimation of the viscosity of trans-neptunian dwarf planets through the synchronous motion of Eris (CBDO 100)
Adrián Rodríguez
Valongo Observatory, Federal University of Rio de Janeiro, UFRJ, Rio de Janeiro, RJ, Brazil

12:10 pm – Lunch

First session on Orbital Mechanics and Spacecraft Attitude Determination and Control
Chairman: Priscilla Silva

1:40 pm - Invited talk 3
Geodetic and Geophysical Characterization of Ganymede with GALA, the Ganymede Laser Altimeter (CBDO 186)
Hauke Hussmann
DLR Institute of Planetary Research, Berlin, Germany

2:30 pm - Oral communication 09
Preliminary Design of Trajectories for Rendezvous with 2001 SN263 (CBDO 210 - N)
Rodolfo Batista Negri
Federal University of São Paulo, UNIFESP, São José dos Campos, SP, Brazil

2:50 pm - Oral communication 10
Analytical Modeling of the Gravitational Potential of Irregularly Shaped Celestial Bodies considering three distinct internal structures: Application to (21) Lutetia (CBDO 025)
Marcelo L. Mota
Federal Institute of São Paulo, IFSP, Hortolândia, SP, Brazil

3:10 pm - Oral communication 11
Study of a satellite constellation for INPE's BiomeSat mission (CBDO 054)
Liana Dias Gonçalves
National Institute for Space Research, INPE, São José dos Campos, SP, Brazil

3:30 pm - Oral communication 12
Long and short-duration orbits around the Moon for different types of missions (CBDO 045)
Jean Paulo dos S. Carvalho
Federal University of Recôncavo da Bahia, UFRB, Feira de Santana, BA, Brazil

3:50 pm – Coffee Break

4:10 pm – Poster Session 2. CBDO 001 – CBDO 105, except oral communication.

Wednesday, December 4th

8:30 am - Mini-course
Optimal control of spatial trajectories using GEKKO
Jhonathan Piñeros
Space systems analyst, SAIPHER

9:10 am – Break

Second session on Orbital Mechanics and Spacecraft Attitude Determination and Control
Chairman: Rosana Araújo

9:20 am - Invited talk 4
Attitude Representations of Artificial Satellites and Applications (CBDO 190)
Maria Cecília Zanardi
UNESP - São Paulo State University, Guaratinguetá, SP, Brazil

10:10 am – Coffee Break

10:30 am - Oral communication 13
Use of a Rational Agent to determine the attitude of a Solar Sail (CBDO 056)
Lucas G. Meireles
UNESP - São Paulo State University, Guaratinguetá, SP, Brazil

10:50 am - Oral communication 14
Orbital mechanics around non-homogeneous elongated asteroids (CBDO 085)
J. D. Gutiérrez
Universidad de Zaragoza, Spain

11:10 am - Oral communication 15
Machine learning techniques for autonomous satellite guidance during terminal rendezvous operations (CBDO 128)
Rogerio Rodrigues dos Santos
UNESP - São Paulo State University, Guaratinguetá, SP, Brazil

11:30 am - Oral communication 16
Mitigating Actuator Faults in Spacecraft Formation Flying through a Reconfigurable Guidance Strategy (CBDO 130)
Willer Gomes dos Santos
Aeronautics Institute of Technology, ITA, São José dos Campos, SP, Brazil

11:50 am - Oral communication 17
Existence and Stability of Moon's Stationary Polar Orbits (CBDO 133)
Marcelo D. Marchesin
Federal University de Minas Gerais, UFMG, Belo Horizonte, MG, Brazil

12:10 pm - Lunch

Third session on Orbital Mechanics and Spacecraft Attitude Determination and Control
Chairman: Antonio F. B. A. Prado

1:40 pm - Oral communication 18
Utilizing Cosmic Microwave Background Measurements for Improved Interstellar Navigation Systems (CBDO 139)
Pedro Kukulka de Albuquerque
George Mason University, Fairfax, Virginia, USA

2:00 pm - Oral communication 19
Trade-off Families of Transfer Trajectories in the Cislunar region (CBDO 142)
Caio Jansen Accioly
Aeronautics Institute of Technology, ITA, São José dos Campos, SP, Brazil

2:20 pm - Oral communication 20
Mathematical model of the orbital elevator motion (CBDO 182)
Sergei Kupreev
RUDN University, Moscow, Russia

2:40 pm - Oral communication 21
Method of satellite constellation design for on-orbit servicing of multisatellite space systems on orbits with given parameters (CBDO 183)
Vladimir Razoumny
RUDN University, Moscow, Russia

First session on Dynamical System
Chairman: Lucas Ruiz dos Santos

3:00 pm - Invited talk 5
Decomposition of Symmetrical Classes of Central Configurations (CBDO 119)
Marcelo Pedro dos Santos.
Federal Rural University of Pernambuco, UFRPE, Recife, PE, Brazil

3:50 pm - Coffee Break

4:10 pm – Poster Session 3. CBDO 106 – CBDO 210, except oral communication.

6:30 pm - Social Barbecue at ADC/INPE

Thursday, December 5th

8:30 am - Mini-course
Optimal control of spatial trajectories using GEKKO
Jhonathan Piñeros
Space systems analyst, SAIPHER

9:10 am – Break

Second session on Dynamical System
Chairman: Marcelo Marchesin

9:20 am - Invited talk 6
Dynamics of a non-homogeneous straight segment: relative equilibria, stability, periodic solutions and singularities (CBDO 189)
Claudio Vidal
Universidad del Bío-Bío, Concepción, VIII Region, Chile

10:10 am - Coffee Break

10:30 am - Oral communication 22
Isochronous Bifurcations (CBDO 044)
Michele Mugnaine
São Paulo University, USP, São Paulo, SP, Brazil

10:50 am - Oral communication 23
Dynamical evolution of a system composed by extended deformable bodies with complex rheologies (CBDO 064)
Vitor M. de Oliveira
São Paulo University, USP, São Paulo, SP, Brazil

11:10 am - Oral communication 24
The secular tidal evolution of a binary system in the viscous regime and singular perturbation theory (CBDO 084)
Lucas Ruiz dos Santos
Federal University of Itajubá, UNIFEI, Itajubá, MG, Brazil

11:30 am - Oral communication 25
Tidal Evolution and Spin-Orbit Dynamics: The Critical Role of Rheology (CBDO 075)
Clodoaldo Ragazzo
São Paulo University, USP, São Paulo, SP, Brazil

11:50 am - Oral communication 26
On the attraction of ellipsoids and the properties of the Newtonian attraction (CBDO 125)
Alain Albouy
Observatoire de Paris, CNRS, France

12:10 pm - Lunch

Third session on Dynamical System
Chairman: Eduardo Leandro

1:40 pm - Oral communication 27
Bifurcations of a Symmetric Family of Dziobek Configurations (CBDO 129)
Michelle Gonzaga dos Santos
Federal University of Pernambuco, UFPE, Recife, PE, Brazil

2:00 pm - Oral communication 28
Perilune Poincare Maps: a NRHO’s Station Keeping Approach (CBDO 143)
Maisa Oliveira Terra
Aeronautics Institute of Technology, ITA, São José dos Campos, SP, Brazil

2:20 pm - Oral communication 29
The Veronese variety associated with Dziobek central configurations (CBDO 209)
Thiago Dias Oliveira Silva
Federal Rural University of Pernambuco, UFRPE, Recife, PE, Brazil

Third session on Dynamical and Planetary Astronomy
Chairman: Nelson Callegari Júnior

2:40 pm - Invited talk 7
Impact simulations with SPH: from exomoons to dusty ring arcs (CBDO 211 - N)
Rafael Sfair
UNESP - São Paulo State University, Guaratinguetá, SP, Brazil

3:30 pm - Oral communication 30
Stable configurations for the retrograde planet in the ν Octantis system (CBDO 089)
Alan C. Signor
IGCE, UNESP - São Paulo State University, 3506-900 Rio Claro, SP, Brazil
CFisUC, Department of Physics, University of Coimbra, 3004-516 Coimbra, Portugal

3:50 pm - Coffee Break

4:10 pm – Poster Session 4. CBDO 106 – CBDO 210, except oral communication.

Friday, December 6th

8:30 am
Mini-course
Optimal control of spatial trajectories using GEKKO
Jhonathan Piñeros
Space systems analyst, SAIPHER

9:10 am – Break

Fourth session on Dynamical and Planetary Astronomy
Chairman: Pryscilla Pires

9:20 am - Invited talk 8
NEOMOD: Dynamical Model of Near-Earth Objects from a Decade of Catalina Sky Survey Observations (CBDO 184)
David Nesvorný
Southwest Research Institute, Boulder, CO, USA

10:10 am - Coffee Break

10:30 am - Oral communication 31
Exploring the Formation of the TOI-1130 Planetary System Using a Hydrodynamic Approach (CBDO 097)
Bárbara Celi Braga Camargo
Valongo Observatory, Federal University of Rio de Janeiro, UFRJ, Rio de Janeiro, RJ, Brazil

10:50 am - Oral communication 32
A numerical analysis of planar colliding binary companions (CBDO 061)
Gabriel Caritá
National Institute for Space Research, INPE, São José dos Campos, SP, Brazil

11:10 am - Oral communication 33
Planetary resonances: properties for arbitrary eccentricities and mutual inclinations (CBDO 091)
Tabare Gallardo
Facultad de Ciencias, Udelar, Uruguay

11:30 am - Oral communication 34
On the Dynamics around Quaoar: its shape and the unstable limit (CBDO 042)
Othon Winter
UNESP - São Paulo State University, Guaratinguetá, SP, Brazil

11:50 am - Oral communication 35
Dynamic tides in the exoplanetary system CoRoT-3b (CBDO 117)
Sylvio Ferraz Mello
São Paulo University, USP, São Paulo, SP, Brazil

12:10 am - Closing Ceremony

Information about the Minicourse:

Content: The GEKKO library (in Python) will be implemented as an alternative to solve two problems of optimal control of space trajectories: orbital transfer and planetary re-entry.
- The sessions will be online on Wednesday, Thursday, and Friday between 8:30 and 9:10 pm.
- Estimated time: three 40-minute sessions.
- Requirements (desirable): Laptop with Python software, Jupyter Notebook, GEKKO, Numpy and Matplotlib libraries.

Instructor: Dr. Jhonathan Murcia Piñeros
Space systems analyst, SAIPHER

XXII Brazilian Colloquium on Orbital Dynamics - CBDO 2024
National Institute for Space Research, INPE - December 2 to 6, 2024
São José dos Campos, SP, Brazil

FINAL PROGRAM

First week of December 2024

	Time	Monday, 2	Tuesday, 3	Wednesday, 4	Thursday, 5	Friday, 6
	8:30		Invited talk 1 Romina Di Sisto CBDO 188	Mini-course Optimal control of spatial trajectories using GEKKO	Mini-course Optimal control of spatial trajectories using GEKKO	Mini-course Optimal control of spatial trajectories using GEKKO
	8:40					
	8:50					
	9:00					
	9:10			break	break	break
	9:20		Invited talk 2 Felipe Braga-Ribas CBDO 185	Invited talk 4 Maria Cecília Zanardi CBDO 190	Invited talk 6 Claudio Vidal Díaz CBDO 189	Invited talk 8 David Nesvorný CBDO 184
	9:30					
	9:40					
	9:50					
	10:00					
am	10:10		Coffee break	Coffee break	Coffee break	Coffee break
	10:20					
	10:30		Oral Comm. 4 CBDO 035	Oral Comm. 13 CBDO 056	Oral Comm. 22 CBDO 044	Oral Comm. 31 CBDO 097
	10:40					
	10:50		Oral Comm. 5 CBDO 039	Oral Comm. 14 CBDO 085	Oral Comm. 23 CBDO 064	Oral Comm. 32 CBDO 061
	11:00					
	11:10		Oral Comm. 6 CBDO 108	Oral Comm. 15 CBDO 128	Oral Comm. 24 CBDO 084	Oral Comm. 33 CBDO 091
	11:20					
	11:30		Oral Comm. 7 CBDO 049	Oral Comm. 16 CBDO 130	Oral Comm. 25 CBDO 075	Oral Comm. 34 CBDO 042
	11:40					
	11:50		Oral Comm. 8 CBDO 100	Oral Comm. 17 CBDO 133	Oral Comm. 26 CBDO 125	Oral Comm. 35 CBDO 117
	12:00					
	12:10	Registration and reception of participants	Lunch	Lunch	Lunch	Closing Ceremony
	12:20					
	12:30					
	12:40					
	12:50					
	1:00					
	1:10					
	1:20					
	1:30					
	1:40	Opening	Invited talk 3 Hauke Hussmann CBDO 186	Oral Comm. 18 CBDO 139	Oral Comm. 27 CBDO 129	
	1:50	Wagner Sessin Ward				
	2:00	Opening talk 1 Ignazio Dimino CBDO 187		Oral Comm. 19 CBDO 142	Oral Comm. 28 CBDO 143	
	2:10					
	2:20			Oral Comm. 20 CBDO 182	Oral Comm. 29 CBDO 209	
pm	2:30		Oral Comm. 9 CBDO 210			
	2:40			Oral Comm. 21 CBDO 183	Invited talk 7 Rafael Sfair CBDO 211 - N	
	2:50	Oral Comm. 1 CBDO 001	Oral Comm. 10 CBDO 025			
	3:00			Invited talk 5 Marcelo Santos CBDO 119		
	3:10	Oral Comm. 2 CBDO 002	Oral Comm. 11 CBDO 054			
	3:20					
	3:30	Oral Comm. 3 CBDO 006	Oral Comm. 12 CBDO 045		Oral Comm. 30 CBDO 089	
	3:40					
	3:50	Coffee break	Coffee break	Coffee break	Coffee break	
	4:00					
	4:10	Poster Session 1 **CBDO 001 – CBDO 105** Except oral Comm.	Poster Session 2 **CBDO 001 – CBDO 105** Except oral Comm.	Poster Session 3 **CBDO 106 – CBDO 210** Except oral Comm.	Poster Session 4 **CBDO 106 – CBDO 210** Except oral Comm.	
	4:20					
	4:30					
	4:40					
	4:50					

Instructions for preparing posters and slides

Poster stands are of the tripod type. The poster must have a rope or string to hang it from the stand and tubes at the top and bottom edges to support it. There will be no numbering and any support can be used. The maximum size of the poster is 84.1 cm wide x 118.9 cm high (standard A0).

The posters will be on display from Monday, December 2nd, until Thursday, December 5th, in the lobby of the LIT auditorium, in the following order:

- Monday and Tuesday, from 4:10 to 5:00 pm, CBDO 001 to CBDO 105, except those chosen for oral communication.
- Wednesday and Thursday, from 4:10 to 5:00 pm, CBDO 106 to CBDO 210, except those chosen for oral communication.

Posters and Slides must be written in English.

Important notices

1. INPE has some restrictions on dress. It is not allowed to enter the institute wearing open shoes, such as flip-flops, etc. Length shorts are acceptable, but small shorts are not.

2. The event will not offer free lunch and dinner. There is a restaurant a few meters from the building where the CBDO will take place. We will have a coffee break in the morning and another in the afternoon, from Tuesday to Thursday. On Monday there will only be an afternoon coffee break and on Friday there will only be a morning coffee break.

   On Wednesday 4th, there will be a dinner (barbecue) at the INPE ADC, next to the venue. Invitations will be sold to those who wish to attend at the following prices:

- Professor/Researcher	included in the registration fee.
- Postdoctoral	included in the registration fee.
- Others	R$100,00
- Accompanying	R$120,00

3. Personal laptops must be registered at the gate on the first day of entry to INPE.

Contents

Co-authors, affiliations, e-mails and other information can be found in the abstracts

CBDO 001

The Orbital Eccentricities of Directly Imaged Companions Using Observable-based Priors: Implications for Population-level Distributions

Clarissa R. Do Ó, Kelly K. O'Neil, Quinn M. Konopacky, Tuan Do, Gregory D. Martinez, Jean-Baptiste Ruffio, and Andrea M. Ghez

University of California, San Diego & University of California, Los Angeles

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The eccentricity of a substellar companion is an important tracer of its formation history. Directly imaged companions often present poorly constrained eccentricities. A recently developed prior framework for orbit fitting called "observable-based priors" has the advantage of improving biases in derived orbit parameters for objects with minimal phase coverage, which is the case for the majority of directly imaged companions. We use observable-based priors to fit the orbits of 21 exoplanets and brown dwarfs in an effort to obtain the eccentricity distributions with minimized biases. We present the objects' individual posteriors compared to their previously derived distributions, showing in many cases a shift toward lower eccentricities. We analyze the companions' eccentricity distribution at a population level, and compare this to the distributions obtained with the traditional uniform priors. We fit a Beta distribution to our posteriors using observable-based priors, obtaining shape parameters $\alpha = 1.09$ (+0.33; -0.22) and $\beta = 1.42$ (+0.33; -0.25). This represents an approximately flat distribution of eccentricities. The derived α and β parameters are consistent with the values obtained using uniform priors, though uniform priors lead to a tail at high eccentricities. We find that separating the population into high- and low-mass companions yields different distributions depending on the classification of intermediate-mass objects. We also determine via simulation that the minimal orbit coverage needed to give meaningful posteriors under the assumptions made for directly imaged planets is ≈15% of the inferred period of the orbit.

Acknowledgment
Some of the data presented herein were obtained at the W. M. Keck Observatory, which is operated as a scientific partnership among the California Institute of Technology, the University of California, and the National Aeronautics and Space Administration. The W. M. Keck Observatory was made possible by the financial support of the W. M. Keck Foundation. The authors wish to acknowledge the significant cultural role that the summit of Maunakea has always had within the indigenous Hawaiian community. The author(s) are extremely fortunate to conduct observations from this mountain. Portions of this work were conducted at the University of California, San Diego, which was built on the unceded territory of the Kumeyaay Nation, whose people continue to maintain their political sovereignty and cultural traditions as vital members of the San Diego community. C.D.O. is supported by the National Science Foundation Graduate Research Fellowship under grant No. DGE-2038238. K.K.O. is supported by the Preston Graduate Fellowship. Further support for this work at UCLA was provided by the W. M. Keck Foundation, and NSF grant AST-1909554. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Oral communication

CBDO 002

The co-orbital dynamics in binary systems

Fernando Roig (1), Cristian Giuppone (2)

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2. Universidad Nacional de Córdoba, Argentina

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Binary-like systems play a fundamental role in the understanding of the orbital dynamics of several real problems. Besides the classical binary star problem, with its applications to extra-solar planetary systems, the binary dynamics is also relevant for the analysis of satellite systems. In particular, the co-orbital motion in the context of the dynamics of binary systems presents certain peculiarities and poses some challenges in its description. In this presentation, I review the recent advances concerning the co-orbital problem, both in the circumstellar-like dynamics (S-type orbits) as in the circumbinary-like dynamics (P-type orbits). We present an analytical development of the problem, that allows to infer some general properties of the dynamics, with applications to the Saturn satellites and the Kepler-413 system.

Acknowledgments
CNPq

Oral Communication

CBDO 003

ALR_Sim_tracks - trajectory simulator software to assist the search for favourable trajectories for the exploration of the triple Asteroid 2001-SN263 from the Laser Altimeter point of view

Antonio G. V. de Brum

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This paper presents a simulator tool, named ALR_Sim_tracks, dedicated to the preliminary analysis of trajectories planned for a space mission to explore the surface of celestial bodies using optical sensors, such as a laser altimeter. The software offers a prediction of the coverage results obtainable in a simulated exploration campaign carried out along a selected/simulated trajectory, for the set of target and instrument parameters used (in qualitative and quantitative terms, including 2D/3D visualizations). The software was created to perform an analysis that would allow the identification of favourable trajectories for conducting the intended exploration of the triple asteroid 2001-SN263 during Brazil's first deep space mission (ASTER mission [1]) from the point of view of the Laser Altimeter being designed to fly in this mission, which was named ALR [2]. Because there are few tools described and available for this type of analysis in the literature, and these are generally complex, proprietary and of restricted use, this work aims to help broaden the understanding of the process involved and the access to this type of tool. The paper contains the description of the ALR_Sim_tracks software and everything involved in its operation [3]. The illustrative examples presented in this text involve the exploration of an asteroid from the point of view of a laser altimeter, because this was the initial motivation for creating the simulator. However, other optical instruments with similar operation, used to explore other types of targets (e.g. planets or moons), are also considered when suitable modelling is available.

References

[1] Macau E E N, et al (2011) The ASTER mission: exploring for the first time a triple system asteroid. Proc 62nd Int Astr Cong. On line at: <http://www.iafastro.net/iac/archive/browse/IAC-11/B4/2/10263/>.

[2] Brum A G V de, and Cruz, F C da (2017) Reviewed plan of the ALR, the laser rangefinder for the ASTER deep space mission to the triple asteroid 2001-SN263. J. Phys.: Conf. Ser. 911 012016. doi :10.1088/1742-6596/911/1/012016.

[3] Brum, A G V de (2024) ALR_Sim_tracks — Trajectory Simulator Software to Assist the Search for Favourable Trajectories for the Exploration of the Triple Asteroid 2001-SN263 From the Laser Altimeter Point of View. Qeios – open Science journal. D.O.I.: https://doi.org/10.32388/OIZDYZ.2

Acknowledgments

The author wishes to demonstrate his gratitude to the São Paulo Research Foundation - FAPESP, which supported this research (grant#2018/22672-4), also to the Planetary Research Institute of the German Aerospace Centre, in Berlin, where the research was conducted, and to the Federal University of ABC, in São Paulo, Brazil.

Poster

CBDO 004

Capture trajectories for NEAs using three-body dynamics

Dr. Priscilla Sousa-Silva, Dr. Denilson Paulo Souza dos Santos, Dr. Luiz Alberto de Paula, Júlia Gomes da Costa and Henrique Babo Terra

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Near-Earth Asteroids (NEAs) hold significant value for scientific exploration and potentially serve as a crucial resource for sustaining human space endeavors. However, their proximity to Earth also presents potential hazards. Efforts to establish trajectories for reaching, capturing, and relocating NEAs have been pursued through various approaches. While two-body dynamics have been extensively utilized to assess the feasibility of identifying and robotically returning NEAs to translunar space, expanding the scope to include many-body models offers new possibilities. The Restricted Three-Body Problem (RTBP) emerges as a promising framework for devising low-energy mission profiles. This work focuses on investigating capture trajectories for asteroids within the RTBP with and without perturbations. Building upon previous findings, we explore the potential applications of invariant objects connecting Lagrangian point orbits around L3 and L4,5 to provide low-energy transport in the vicinity of the Earth-Moon system.

References

Koon, W.S. et al., Dynamical Systems, The Three-Body Problem, And Space Mission Design. Springer-Verlag, 2006.

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Poster

CBDO 005 - A

Dimensioning and design (2D and 3D) of the laser altimeter for the ASTER Mission

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With the ALR (ASTER Laser Rangefinder) as the main topic, this work brings together the main characteristics of the instrument to produce a preliminary three-dimensional drawing with detailed views of the altimeter. ALR is part of the first Brazilian deep space mission ASTER, contributing to the investigation of the triple asteroid 2001-SN263 by collecting information on the shape, topography and mass distribution of the system's components [1]. The laser altimeter design is under the engineering coordination of UFABC in partnership with UNICAMP, and its construction involves companies from the national aerospace sector. The instrument will provide a geodetic and geophysical characterization of the targets, and it can also be used to support navigation during the encounter and approach phases with the asteroid 2001-SN263. The study carried out took into account similar devices that flew on past and/or ongoing missions, such as the BELA, for the BepiColombo [2] mission (2018 - in progress) and the OLA, created for the OSIRIS-Rex mission (2016-2023 [3]). The study of the ALR design parameters for the ASTER Mission, according to the principal references of this project, was consulted to create the preliminary design of the device, containing the side, front and top views, as part of the detailing of this instrument. In addition to the CAD drawing, a preliminary list of the internal components was indicated.

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Poster

CBDO 006 - A

Vision Transformers for identifying asteroids interacting with secular resonances

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Currently, more than 1.4 million asteroids are known in the main belt. Future surveys, like those that the Vera C. Rubin Observatory will perform, may increase this number to up to 8 million. While in the past identification of asteroids interacting with secular resonances was performed by a visual analysis of images of resonant arguments, this method is no longer feasible in the age of big data. Deep learning methods based on Convolutional Neural Networks (CNNs) have been used in the recent past to automatically classify databases of several thousands of images of resonant arguments for resonances like the ν_6, the $g - 2g_6 + g_5$, and the $s - s_6 - g_5 + g_6$. However, it has been shown that computer vision methods based on the Transformer architecture tend to outperform CNN models if the scale of the image database is large enough. Here, for the first time, we developed a Vision Transformer (ViT) model and applied it to publicly available databases for the three secular resonances quoted above. ViT architecture outperforms CNN models in speed and accuracy while avoiding overfitting concerns. If hyper-parameter tuning research is undertaken for each analyzed database, ViT models should be preferred over CNN architectures.

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Oral Communication

CBDO 007

Understanding and describing a phase transition from limited to unlimited diffusion for a billiard system

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The aim of this project is Investigate and characterize the phase transition from limited to unlimited diffusion observed in a dissipative and time-dependent oval billiard due to the variation of control parameters. According to the LRA conjecture, the existence of chaos in the dynamics with static boundary is a sufficient condition to the occurrence of Fermi acceleration when a time perturbation to the boundary is introduced, phenomenon which is not robust and a tiny dissipation is enough to suppress the unlimited energy growth and can be observed in this case. Near the phase transition, these dynamics are scaling invariant, characterizing a continuous phase transition. The central phenomenology uses a set of scaling hypotheses and a generalized homogeneous function. From them we obtain a relation between the critical exponents leading to a scaling law, which can be proved using numerical simulations or analytic descriptions.

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Poster

CBDO 008 - A

The five largest satellites of Uranus: astrometric observations spread over 29 years at the Pico dos Dias Observatory

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We present the astrometry of the five largest satellites of Uranus from observations spread over almost three decades with photographic plates and CCDs (mainly), taken at the Pico dos Dias Observatory - Brazil. All positions presented here are obtained from the reanalysis of measurements and images used in previous publications. Reference stars are those from the Gaia Early Data Release 3 (Gaia EDR3) allowing, in addition to a higher accuracy, a larger number of positions of the largest satellites as compared to our previous works. From 1982 to 1987, positions were obtained from photographic plates. From 1989 to 2011, CCDs were used. On average, we obtained DeltaAlphaCosDelta = -11 (+/-52) milli-arcseconds and Deltadelta = -14 (+/-43) milli-arcseconds for the differences in the sense observation minus ephemerides (DE435+ura111). Comparisons with different ephemerides (DE440 [1], INPOP21a [2], INPOP19a and NOE-7-2013-MAIN [3]) and results from stellar occultations indicate a possible offset in the (Solar System) barycentric position of the Uranian system barycenter. Overall, our results are useful to improve dynamical models of the Uranian largest satellites as well as the orbit of Uranus.

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Poster

CBDO 009

Assessment of Relative Motion in Autonomous Spaceflight

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In this study, we make a preliminary assessment of the use of relative motion as an observable in optical navigation. For this purpose, we apply visual odometry techniques to analyze a continuous series of images captured by spacecraft cameras. By extracting relative motion information from these images, we aim to complement the traditional line-of-sight observations used in navigation filters, such as those employed in the AutoNav of the Jet Propulsion Lab and similar systems. Our analysis focuses on evaluating the accuracy and reliability of relative motion measurements compared to line-of-sight observations. We also explore the potential benefits of incorporating relative motion data into navigation algorithms, particularly in scenarios where precise maneuvering is required, such as operations near celestial bodies with unknown shapes, including asteroid missions. Through this investigation, we seek to advance the understanding of autonomous spacecraft navigation and contribute to the ongoing efforts to improve the capabilities of robotic spacecraft operating in deep space environments.

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Poster

CBDO 010

The geomagnetic field and charge generation for satellites

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Electric charging of geocentric nanosatellites is a great challenge for space engineering. The nanosat's surface area available to install solar panels is minimal, and such area does not point toward the Sun direction full-time. An alternative conceptual solution is a reversible magnetorquer that provides electric charge during the standby time. In other words, while the magnetorquer is not operating to change the satellite attitude, the electric current induced within their coils provides electric charge to the batteries. Such a conceptual device has the advantages of i) being one bifunctional payload device and ii) providing electric charge even when the satellite orbits the zone eclipsed by the Earth. This work's main goal is to derive analytical expressions for the electric current induced by the geomagnetic field into the coils owned by a satellite. It also aims to derive analytical expressions for the harvested electric charge from the mentioned induced current. The formulation is substantiated by Faraday's laws applied to a system of three orthogonal circular coils aligned with the three principal axes of a satellite flying an arbitrary Keplerian geocentric orbit. One considers that the flux of the geomagnetic field within the area enclosed by a coil varies in time as the satellite flies around the Earth. Such varying flux gives rise to an electromotive force, from which arises the induced electric current. Finally, the expressions for electric current are integrated over the time of one orbital period so that one obtains the analytical expression for the amount of electric charge harvested in each satellite orbital revolution. It is derived in full analytical equations for the circular orbit case, and specific cases for elliptical orbits. The resultant equations and methods demonstrate that a considerable amount of charge can be harvested from the geomagnetic field, which may provide a feasible alternative/complementary path for the recharge of the satellite's battery.

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Acknowledgments
Fátima Araújo Machado

Poster

CBDO 011

Rendezvous formalism applied into final stage correction maneuverings of LEO-DRO Cislunar Transfer

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New Space missions to the Moon is a becoming reality. Many studies points out that a Lunar plant is feasible strategy for space mining, for instance. Thus, it is necessary to apply efforts on the investigation of the optimal ways to perform the orbital transfer of space vehicles from LEO up to the cislunar medium. Winter & Pires (2020) mapped a set of stable Distant Retrograde Orbits - DRO, which are suitable for selenocentric missions.Poffo (2022), employed a semi-analytical method to explore optimum orbital transfers from LEO to DRO and reached good results. Nevertheless, he found many cases in wich it is necessary to perform corrections maneuvers at the final stage of the transfer. In this context, we propose to resume the non-Hohmann maneuvers by using the rendezvous formulation, considering P2C through the implementation of a semi-analytical method executed with the Rebound integrator. Two target proposals for the rendezvous maneuver were considered, namely the DRO and a position relative to the Moon, with the former being more precise in terms of the distance from the DRO vehicle to rendezvous performed up to 10 hours before the final insertion moment. The maneuvers applied in such time interval are those of highest values of relative impulse. Due to the high number of resulting maneuvers, it was proposed filtering criteria to select the most suitable trajectories to the DRO orbital stability after insertion, with a maximum distance of 1 000 km between the vehicle and DRO, and the rendezvous impulse being at most 10% of the total for the incomplete transfer. A routine was implemented that identifies, among the transfer orbits completed with rendezvous, the points of maximum approximation to the DRO, increasing the number of trajectories that respect the filter criteria.

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Poster

CBDO 012

Numerical validation of electric charging from current induced by the geomagnetic field

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Electric charging of nano satellites is a great challenge for space engineering. They have small and not enough surface for solar panels. Also, due to fact they have low orbits, they spend a plenty fraction of their orbital period flying the shadowed region. This work proposes a conceptual magnetorquer which works as a source of electric power during the stand-by hiatus. Such device may provide electric power generated by the electric current induced by the varying flux of geomagnetic field. Also, it works around the whole orbit, even along the shadowed orbit arc. We first derive analytical expressions for the charge harvested along one orbital period for two kind of attitude kinematics. Then, we perform a validation study of the analytical results based on numerical simulation of translation and attitude kinematics. The harvested charge is evaluated from a numerical integration of the time variation of the geomagnetic field. We show a mapping of the total electric charge harvested along one orbital period for a whole set of keplerian geocentric orbits. We consider multiple scenarios of kinematics attitude.

Poster

CBDO 013 - A

Low-energy trajectories generated in the Earth-Moon system destined to the Jovian system

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Space missions to Jupiter and its moons are of great interest to the scientific community in general. A significant portion of the budget for these missions is allocated to moving the spacecraft around the Solar System. Conventional transfer methods between the terrestrial and Jovian systems involve large launch vehicles and high-energy propellant burns, and are calculated in successive solutions (patched conics) of two-body systems - where two massive bodies attract each other by gravity. However, when considering more complex regimes, such as the presence of three or more bodies, a wide range of dynamics becomes available to determine much more economical interplanetary trajectories. One that is usually considered is the Restricted Circular Three-Body Problem, which allows the gravitational interactions of the primary bodies on the spacecraft to be described by dynamical channels known as invariant manifolds. These channels result from the instability of these systems and flow from periodic orbits around Lagrangian points - characteristic spatial solutions of the differential equations. A theoretical framework on the main topics of orbital dynamics was developed, covering topics ranging from Kepler's laws and the Newtonian solution of the two-body problem to the three-body dynamics of the entire solar system, allowing these concepts to be used in numerical simulations, which were able to infer not only the energy advantage of low-energy orbits based on invariant manifolds, assistances, and gravitational resonances, but also their time disadvantage compared to conventional methods. However, this flight time could be significantly reduced by selectively increasing the propulsion cost, allowing flexibility in the application of this concept according to the type of mission considered, from small satellites with alternative propulsion to robust spacecraft.

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Poster

CBDO 014

A Magnetotorque Model with External Coils for CubeSat Attitude Control

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For a substantial portion of recent Cubesat applications, active attitude control becomes indispensable, particularly exemplified by georeferencing. This application necessitates not only constant alignment of the camera's output face with the planet but also demands high stability and disturbance minimization for quality image generation. However, the majority of conventional active attitude control models incur significant space and electrical load consumption, both of which are particularly constrained in nanosatellites. Within this context, this study endeavors to explore the feasibility of a novel magnetorquer model, incorporating square coils around the external structure of the Cubesat. This configuration aims to augment the effective coil area, thereby reducing the required current to produce equivalent torque compared to smaller-area coils typical of conventional magnetorquers situated inside the Cubesat. Consequently, this research endeavors to conduct a comparative analytical investigation into torque generation capacity relative to electrical current between commercially available Cubesat magnetorquer models and a theoretical model utilizing space-validated materials. The objective is to furnish a comprehensive comparison of energy consumption between the two models and assess whether the geometric arrangement of square coils presents a favorable alternative for nanosatellites. It is essential to underscore that this study constitutes a conceptual exploration of the aforementioned device. Additional factors, such as potential influence of the magnetic field on internal Cubesat systems, heat generation in proximity to solar panels, feasibility of physical model construction, and magnetic field impact on incident radiation, have not been addressed, underscoring the necessity for further research to achieve complete development and validation of this proposal. Given the significance of attitude control for Cubesats, the introduction of a novel magnetorquer model with square coils surrounding the external structure aims to surmount challenges related to space and energy.

Poster

CBDO 015

Characterization of the Rings of the Centaur Chariklo

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The study of the rings surrounding celestial bodies, once limited to the gas giants, has gained a new perspective with the discovery of rings around small celestial bodies, such as the centaur Chariklo. The absence of targeted space missions to investigate it requires the use of indirect methods, highlighting the method of stellar occultations. Therefore, using data derived from this method, it is necessary to address fundamental questions about the dynamics and formation of these ring structures in asteroidal objects. The rings of Chariklo exhibit variations in radial density and width along the longitude, as evidenced by Morgado et al. (2021). To investigate them, we used data from stellar occultations conducted by different observers. Through the SORA analysis package (Gomes-Júnior et al., 2022), we studied the global characteristics of the rings, focusing on longitudinal and radial variations. We analyzed the brightness variation of the star during occultations, applying advanced data analysis techniques, such as sinusoidal models as proposed by Longaretti (1989) and chi-square methods, aiming to identify oscillation patterns in the rings and understand their orbital dynamics, considering the ring's own orbital velocity, which is not precisely known. This study will allow us to investigate the possible temporal evolution of the rings and determine their stability over time. It is expected that this approach will provide relevant information about the formation and evolution of these structures, deepening our understanding of Chariklo's rings, as well as establishing a basis for comparative studies with other ring systems in smaller bodies of the Solar System.

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Acknowledgments

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Poster

CBDO 016

Orbital Precision of Himalia through Numerical Integrations and Statistical Analysis of Observations

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This study aims to enhance the determination of the orbit of the irregular satellite Himalia, using numerical integrations of observational data collected between 1906 and 2022, based on instrumental configurations and astrometric catalogs used, to obtain a more precise orbit than those available in the literature. This improvement will contribute to a better understanding of the evolution of irregular satellites in the Solar System. After a literature review, data from all astrometric observations of the irregular satellite Himalia provided by the Natural Satellites Data Center (NSDB) were collected. Each observation is being curated with details about the instrumental configurations used and the catalogs employed for astrometric reduction to determine positions such as: 'Julian date', 'right ascension', 'declination', 'catalog', 'telescope information'. This step is important for subsequent analysis and the assignment of differentiated weights. We are using the BOSS code (Brazilian Orbital Solution for Satellites) [1] for the numerical integration of the observations. In this phase, equal weights/errors are used for the observations to detect possible systematic errors [2,3]. With the first integration, it is possible to identify the residuals of each observation, which will be analyzed according to each data group. Through this analysis, the weights will be adjusted to assess their deviations and accuracies [2,3]. After obtaining the orbits through this method of integration and analysis, they will be compared with versions previously published by other studies. With this comparison, it will be possible to evaluate the precision and the improvements provided by our method of integration and reweighting of observations. It is expected to determine the orbit of Himalia with greater precision, improving the predictions of stellar occultations. The methods developed can be applied to other irregular satellites, enhancing the understanding of their orbital dynamics. This work aims to present an advanced methodology for the precise determination of Himalia's orbit, providing important data for future investigations on the evolution and physical characteristics, in addition to contributing to studies of other celestial objects in the Solar System.

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Poster

CBDO 017

Light Deflection in Stellar Occultations: A Challenge for Astrometry

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Astrometry is an area of Astronomy that aims at precisely measure of the position and movement of celestial bodies in the universe. Within these studies, we highlight events in which a body is temporarily obscured by another, preventing its light from reaching an observer; such an event is called stellar occultation. In particular, there is also the issue of the deflection of light arising from occultations, that results from the deformation that celestial bodies cause in space-time (Klioner, 2003). This causes distortion of observational results and measurements of positions and coordinates. This distortion is even more complex in cases of occultations by natural satellites, where the gravitational effect of the Sun, the planet and the satellite itself contribute to the deflection of light. Faced with these challenges, the present work aims to use physical and mathematical tools, such as the SORA package (Gomes-Júnior, et al 2022), to accurately characterize the astrometric effects of gravitational deviation during stellar occultation. Therefore, we will adopt a methodological approach that combines theoretical analysis and numerical simulations of the gravitational deviation caused by multiple objects simultaneously.

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Acknowledgments
CNPq, CAPES e FAPEMIG

Poster

CBDO 018

Qualitative analysis of the dynamic evolution of planetary systems

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Discoveries of extrasolar planetary systems have shown that the configuration of our Solar System is an exception to the rule given the number of systems with high relative inclinations, large eccentricities and high mass planets in orbits with periods of hours. Due to these peculiar characteristics, our goal is to understand the processes that led planetary systems to acquire such characteristics, through mutual gravitational interaction and with the proto-planetary disk. To verify the quality of the observational data and the stability of planetary systems over periods of at least 1 Myr, we use Hill Stability concepts that consider the configuration of the systems in terms of total energy and orbital angular momentum; To evaluate its secular movements we work with the construction of Representative Plans that bring with them information of the long period behavior of the system, based only on the mass ratio of the planets and the ratio of their semimajor axes. To analyze the temporal evolution, we use the theory of semi-analytical perturbation (Michtchenko & Malhotra, 2004) that allows us to explore systems of high eccentricities by not working with expansions in series of the disturbing function. We work with models that simulate the process of planetary migration (Michtchenko & Rodríguez, 2011), which change the orbital elements in a forced way, seeking to relate the migration trajectories with known processes, interaction of the planet with proto planetary disk, accretion of matter and tidal effects. Using the stability criteria, we selected some planetary systems to start the analysis and, after verifying their secular behavior, We started the simulations of migratory processes to understand through which configurations the system passed until arriving in the current state, considering only the variation of the total energy of the system and the orbital angular moment.

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Poster

CBDO 019

The effect of impactor mass-ratio in the accretion of Uranus and Neptune

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The origin of Uranus and Neptune is not fully understood. Although these planets may have acquired most of their masses by accreting small drifting pebbles in the Solar nebula, their inclined rotation axes – obliquities – suggest that they experienced giant impacts during their accretionary histories. Simulations modeling their accretion from giant impacts among ~5 Earth masses planetary embryos have been able to broadly reproduce their masses, mass ratio, and obliquity. However, due to angular momentum conservation, the final planets produced in these specific giant impact scenarios tend to rotate too fast, compared to the real ones. One potential solution for this problem consists of tilting these planets by invoking instead giant impacts between objects with large mass ratios (e.g. 14 Mearth and 1 Mearth). In this work, we perform a large suite of numerical simulations modeling the formation of Uranus and Neptune from accretion of planetary embryos embedded in the sun's natal disk. Our simulations start with a population of protoplanets distributed beyond the orbit of Saturn. The initial mass distribution and number of protoplanets in our simulations are treated as free parameters, allowing for a large range of mass ratios between growing protoplanets. We account for the effects of type-I migration, inclination and eccentricity tidal damping. Our preliminary results show that although the scenarios allowing for large mass ratio giant impacts can lead to slower rotating planets, the probability of collisions between objects in these same simulations is significantly reduced, compared to simulations starting with ~5 Earth mass equal planetary embryos. Our results suggest that the probability of broadly matching the masses, mass ratio, and rotation period of Uranus and Neptunes in these two formation paradigms is broadly similar.

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Poster

CBDO 020 - A

Orbital dynamics of space debris considering natural perturbations and resonance effects

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In this work, we analyze the orbital evolution of space debris to find unstable regions that can be used as reentry highways or disposal graveyard orbits using natural perturbations and a solar sail as propellants. We consider an analytical approach that takes into account six types of resonances due to oblateness and solar radiation pressure (SRP) [1]. We perform an analytical study to identify the regions of resonant inclinations and then perform numerical simulations to observe the long-period evolution of these orbital parameters, where we also consider the third-body effect [2]. We find resonance corridors that, combined with a small solar sail, contribute to amplify the growth of the eccentricity, thus decreasing the perigee of the orbit [3]. The results are presented in the form of stability maps that allow us to identify the regions of stable graveyard orbits or rapid reentry highways. We show the effect of resonant inclinations on the evolution of the eccentricity, i.e., we evaluate the perigee altitude. Furthermore, we show how this effect is amplified when a solar sail is considered, thus reducing the orbital lifetime. We also calculate the reentry time for each pair of semi-major axes and resonant inclination. Thus, we seek strategies to move the debris to the inclination zones where SRP and J2 resonances are dominant. Finally, we discuss the results obtained from these resonance effects in space debris mitigation procedures.

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Poster

CBDO 021

Machine Learning Applied to Asteroid Study in the LSST Era

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Asteroids are considered remnant material from the dynamic events which formed the Solar System. Therefore, there is a need to study not only their orbits, what has been done on a large scale in recent decades, but also to classify these celestial bodies and identify their physical characteristics. (A. V. Sergeyev & B. Carry 2021). This research aims to characterize asteroids using advanced computational methods and understand their implications for the study of the origins and evolution of the Solar System. To achieve this, the technique of Machine Learning (a programming technique which encompasses algorithms capable of analyzing data and learning from it for enhance new insights) will be used. In the context of the LSST (Large Synoptic Survey Telescope), the Vera C. Rubin Observatory will produce a voluminous amount of data (20 Terabytes per night) as its operation begins at the start of 2025. Consequently, the powerful Machine Learning codes will be of great assistance in the coming years for data analysis, as well as for the recognition of interesting objects (V. Carruba et al. 2022). Thus, we aim to develop an optimized way to classify the small bodies of the Solar System on a large scale using the Machine Learning Techniques, to facilitate the identification of those that could potentially be of interest in observing stellar occultations (such as binaries, satellites, comets, or atmospheres) and often take years to be confirmed by traditional methods.

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Poster

CBDO 022

Searching for long lasting natural orbits around moons in the Solar System

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Exploration of small bodies of the Solar System is a problem of current interest in astronomy. In that sense, it is important to find orbits to place a spacecraft such that it does not require frequent station keeping maneuvers to avoid escapes or collisions. In particular, high inclined orbits are very convenient to observe a celestial body, because they allow observations of the whole body during its natural rotation. The main problem is that high inclined orbits suffer a strong third-body perturbation that leads to high amplitude of oscillations of the inclination and eccentricity, which destroy the orbits very fast by collisions or escapes. This is particularly important when considering moons or double asteroids, because the mother planet gives strong third-body perturbations. The objective of the present work is to look for orbital configurations that combine several perturbative forces such as those from the non-sphericity of the central body and the effects due to the inclination and eccentricity of the third perturbing body to obtain long-lasting natural orbits. The presence of all the perturbations considered here can make compensations that reduce the total perturbation, which allows for longer lasting orbits. Different parameters of mass, eccentricity, and inclination of the third body are considered to obtain general results valid for the known moons of the Solar System and for new satellites yet to be discovered. These results can also be used in exo-moon systems. The simulations were carried out using the Rebound integrator, adapted to verify the possibility of ejection, collision with the main bodies, or the stability of the artificial satellite. Several configurations for the orbital elements of spacecraft, (a, e, I, ω and Ω), were considered, and several orbital regions that provide orbits longer lasting were found. All these possibilities were cataloged and the survival times of the probes were recorded, for cases of ejection and collision, in addition to recording the conditions that remained stable.

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Poster

CBDO 023

An analytical model for the dynamical evolution of two-planet extrasolar systems in wide binaries stars

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In recent years several extrasolar planetary systems have been discovered orbiting one of the stars in a wide binary star system. When the separation between the stars is less than 3000 au, the planets in these systems tend to have orbits with low eccentricity. However, when the planetary system has two planets, their orbits can range from moderate to high eccentricities. To understand this bimodal dynamical distribution of the planetary population, we have developed an analytical model to analyze the whole phase space of a hierarchical four body system.

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Poster

CBDO 024 - A

Orbital Stability of Small Satellites in Trans-Neptunian Dwarf Planet Systems

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Several satellites with dimensions of a few hundred kilometers have already been discovered orbiting dwarf planets. However, when we examine the sizes of dwarf planets, satellites considered small (a few tens of kilometers) are observed only in the system where Pluto is the dominant mass. In this research, we investigated the possibility of these small bodies existing in stable orbits around other dwarf planets in the trans-Neptunian region. The chosen study objects were Salacia, with a diameter of 846 ± 21 km (Grundy, W. M et al. 2019), Varda with a diameter of 740 ± 14 km (Souami, D. et al, 2020) and Orcus with a diameter of 910 ± 40 km (Brown, Michael E. et al, 2018), three candidates for dwarf planets, both with only one satellite already confirmed: Actaea, Ilmare and Vanth, respectively. Using MERCURY - an integrator capable of numerically solving the exact equations of motion of each component of the system - we developed the analysis of the orbital dynamics of an object of negligible mass inserted in the aforementioned systems, whose motion is governed by equations that arise in the formalism of the restricted three-body problem. We investigated which regions and orbital configurations present the greatest chance of detecting our small body with small variations of the orbital elements. This study was carried out using dynamic maps of different initial conditions of eccentricity and semi-axis, with the objective of identifying locations of chaotic motions, which represent orbital instability, where the hypothetical satellite is not expected to be observed, or even niches of stability. After constructing the maps, special attention was paid to the zones in which the initial conditions, for the semi-axis, are equivalent to the locations of resonance of average motions with the already known satellite, where the small satellite may be trapped in a region of regular motion.

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Acknowledgments
FAPERJ

Poster

CBDO 025

Analytical Modeling of the Gravitational Potential of Irregularly Shaped Celestial Bodies considering three distinct internal structures: Application to (21) Lutetia

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When studying the dynamic properties of a spacecraft orbiting an asteroid, the primary challenge during the mission design phase is to develop a mathematical model that accurately replicates the distribution conditions of the gravitational field outside the asteroid. The main goal of this study is to apply the series potential expansion method to model the gravitational potential around asteroid (21) Lutetia, considering three distinct internal structures with corresponding densities. This method allows for the explicit derivation of the potential function's homogeneous analytical expression, facilitating algebraic manipulation and enabling clear determination of the acceleration vector, which reduces computational costs in both potential calculation and orbit simulations. We explored the equilibrium points' locations and stabilities, compared them with classical polyhedra-based positions, and validated our findings against Mascon's gravitational approach. This procedure's general applicability highlights its potential for modeling other asteroids, enhancing the model with additional internal structures

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Oral communication

CBDO 026

Analytical Modeling of the Gravitational Potential of Irregularly Shaped Celestial Bodies: Application to (285263) 1998 QE2

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Modeling the gravitational potential of irregularly shaped celestial bodies poses significant challenges due to the complex mass distribution. In this study, we employ the potential series expansion method (PSEM) to investigate the gravitational potential of the asteroid (285263) 1998 QE2 as a representative example. The PSEM involves decomposing the asteroid into tetrahedral elements and analytically expressing the potential function. The accuracy and computational efficiency of the PSEM are compared with the classical polyhedron method and the tetrahedron center gravitational method. Equilibrium points and their stability are also examined. Our results demonstrate the effectiveness of the PSEM in accurately modeling the gravitational potential of irregularly shaped bodies while significantly reducing computational costs.

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Poster

CBDO 027

Investigation of orbits around the asteroid (16) Psyche

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Periodic orbits are like the skeleton of any dynamical system, providing a wealth of information about the system's global behavior. Placing a space vehicle into a periodic orbit is not only technically feasible and economically efficient for observation and other purposes, but also substantially reduces the need for corrective maneuvers. Even in quasi-periodic cases, small control interventions can transform them into periodic orbits. In this study, a numerical investigation is proposed to map quasi-periodic and/or periodic solutions applied to the orbital dynamics around Psyche [1]. Psyche is an irregular, metal-rich asteroid located in the Main Asteroid Belt between the orbits of Mars and Jupiter. Target of the Psyche mission, launched in 2023, its singularity could give us important information about the formation and origin of the Solar System. To model Psyche, an approximate potential model of an ellipsoid will be used. Using this approach, we will conduct a systematic investigation in search of these orbits, analyzing the dynamics around this body.

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Poster

CBDO 028 - A

Energy Variation of Space Debris considering Orbital Maneuvers and Ground-Based Laser

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Space debris events are increasingly common in regions where debris density reaches a critical threshold, such as in Low Earth Orbit (LEO), leading to a heightened risk of collisions. This study evaluates the efficacy of orbital maneuvers induced by ground-based lasers, which, when precisely directed, can generate a propulsive effect that alters the perigee of debris particles (1–10 cm in size) orbiting at altitudes between 100 and 1000 km. The objective is to assess the potential for these maneuvers to facilitate rapid atmospheric re-entry or adjust orbits to mitigate collision risks. We analyzed variations in orbital elements and energy using a single-pulse laser propulsion model, considering factors such as laser fluence, debris attitude, and the relative motion between the laser and debris. Results indicate that laser-induced ΔV changes are minor but can accumulate to significantly enhance re-entry energy, yielding up to a 30% change in specific orbital elements under optimal conditions. This study advances the understanding of laser-based debris mitigation techniques, highlighting their advantages over traditional methods and identifying optimal operational conditions.

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Poster

CBDO 029

Stellar Occultations observed by the CHEOPS Space Telescope

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Stellar occultation is one of the main techniques used to access important physical characteristics of Solar System objects. With it, it was possible to identify ring systems around the Centaur Chariklo, the dwarf planet Haumea, and the Trans-Neptunian Object Quaoar. Knowing such characteristics is important to uncover the origin and formation of the Solar System.
Since stellar occultation translates photometric resolution into spatial resolution, observations obtained in better photometric conditions usually provide better results. Thus, observing stellar occultations by space telescope is a natural step in using the technique. In particular, such observations avoid systematic errors caused by atmospheric fluctuations typical in ground-based observations.
In 2020, for the first time, an occultation by a TNO was predicted and observed by a spacecraft orbiting the Earth, in the case of an occultation by Quaoar observed by CHEOPS. Though with low time resolution, the photometric quality provided an important observation that helped identify a ring system around Quaoar [1]. Furthermore, we were also able to observe an occultation by Triton in October 2022 [2].
The success of this observation allowed us further use of the technique with space telescopes. It was possible to observe a stellar occultation with the James Webb telescope in 2022 [3]. CHEOPS's advantage is due to the possibility of observing the same event from space and ground-based telescopes simultaneously.
Finally, we predicted and were granted observation time, with the highest priority, for a further 14 stellar occultations in the CHEOPS AO-4 cycle. Here we report the predictions and results obtained from the observed stellar occultations with CHEOPS. Furthermore, we discuss the future of using space telescopes to observe stellar occultations.

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FAPEMIG, CNPq, CAPES

Poster

CBDO 030 – Withdrawn by the author

CBDO 031 - A

A study on the chaotic dynamics of comet 1P Halley

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The dynamics of the Solar system exhibit inherent chaos and instability. Mathematical tools, such as the maximum Lyapunov characteristic exponent (LCE) and Lyapunov time (TL), play a crucial role in providing a qualitative understanding of chaos within celestial objects, such as asteroids and moonlets. Celestial bodies with relatively small Lyapunov times have garnered significant research interest due to their stable orbits, a phenomenon referred to as stable or confined chaos. Comet 1P/Halley is a notable case of this. There are works that show that its TL is approximately 70 years, but it still remains confined to its orbit. The present work aims to analyze the chaotic dynamics of the comet based on the radial component of the maximum LCE. We show that the radial component of the maximum LCE cannot be disregarded, showing that the radial movement of the comet is chaotic, even though it remains confined to a given region of space for a certain time. We also show that the comet's angular motion is sensitive to changes in initial conditions, generating a chaotic angular motion.

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Poster

CBDO 032

OGLE-2019-BLG-1470L AB c Exoplanet Orbital Dynamics Analysis

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The exoplanet OGLE-2019-BLG-1470L AB c was discovered in 2022, using microlensing (Kuang et al., 2022), orbiting a binary star system. Through 3LS1 type modeling 4 different solutions for the system's physical parameters was found. Two solutions for when the separation between the stars in the system is greater than the Einstein radius and two solutions for when the separation between the stars of the system is smaller than Einstein radius. The mass parameters found for the stars allow the stars to be characterized as K-type stars. For OGLE-2019-BLG-14709 AB c, the mass parameters place it in the super-Jupiter category, with a mass between 5.4 Mj and 2.2 Mj. For the physical mass parameters found, the four solutions present masses of planets in the Super-Jupiter category, however the orbital parameters are discordant in the type of orbit possible for the planet, the orbit being either Type S or Type P. In the solutions who consider the separation of the stars smaller than the Einstein radius, the planet may have an S-type orbit. In the solutions where the separation of the stars is smaller than the Einstein radius, the planet probably has a P-type orbit. Based on these data, we will conduct an analysis of the system's orbital dynamics using the REBOUND software with the aim of refining the solutions obtained by microlensing. Thus we hope that we will be able to determine which of the solutions proposed by Kuang et al. 2022 is more likely from a dynamic point of view, if the planet's orbit is P-type or S-type, thus establishing a better relationship between the physical parameters of the system.

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Poster

CBDO 033

Tridimensional Dynamics of Small Satellites

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For decades, astronomers have been studying the rotation of natural satellites in our Solar System (Goldreich and Peale 1966). The rotation of a non-spherical or irregular body (called a secondary body) is disturbed due to the torque of the central body (or primary body). The current state of rotation most natural satellites is generally determined to be synchronous, where the translation and rotation periods are equal. Such a state of equilibrium must have been reached due to the action of tidal dissipative forces involving the primary and secundar. Most models and numerical simulations of the dynamic evolution of rotation consider the planar case with the satellites having a single axis of rotation. Wisdom (1984) generalized the approach to the three-dimensional case, and applied in to Saturn's Hyperion, showing that the satellite has a z-axis of chaotic rotation, and can suffer chaotic incursions. For these cases, Wisdom alerted to the problem of the existence of singularity in Euler's equations of motion and altered one of the axes of rotation so that the new equations of motion avoided the singularity and thus could be numerically solved. In this work, we deduce in detail the rotation equations in terms of Wisdom angles rather than Euler angles. We applied Everhart's RADAU integrator of order 15 (Everhart 1985) and solved the 3D rotation equations of small irregular satellites such as Saturn's Methone, Aegaeon, Anthe, and Pallene, whose shapes are well determined after the Cassini spacecraft (Thomas and Helfenstein 2020). Dense grids of initial conditions are integrated and analyzed from frequency analysis, so that dynamic stability maps are shown (see Callegari et al. 2021 and references). We confirmed with our model the already known chaotic rotation state of Hyperion, and verified the possibility of finding chaotic rotation on many small satellites within the margins of error of the satellite dimensions.

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Acknowledgments
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Poster

CBDO 034

Comparison of aerodynamic control algorithms for satellites in LEO to increase its orbital decay

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Low Earth Orbits (LEO) are crucial for positioning commercial satellites, such as Earth observation and communication constellations [1]. However, these orbits are becoming increasingly perilous due to the rising number of space debris and satellites, leading to a significant increase in collision risks [2]. This trend is alarming, with an estimated 100,000 objects expected to be placed in orbits around the Earth by 2030 [3]. Given the increasing number of objects in low Earth orbits, it is of utmost importance to take actions that mitigate collision risks and reduce the number of obsolete objects in these orbits. In light of this, this work addresses the programming of an orbital propagator, mainly aimed at implementing aerodynamic control algorithms in satellites in low Earth orbit. This propagator initially simulates the orbital behavior of satellites in LEO to implement control systems, in order to reduce the orbital lifespan of satellites. The propagator uses atmospheric data and solar flux from the NRLMSIS Atmosphere Model, as well as the chosen satellite's data, such as mass and dimensions. As an evaluation method, TLE (two-line element set) data obtained from the North American Aerospace Defense Command (NORAD) is used. Thus, the altitude data generated by the propagator over time is validated against the real data of selected satellites. Therefore, by integrating the controllers into the propagator using aerobraking maneuvers, it is expected to have more control over the satellite's orbit, manipulating its decay time and thus determining the best algorithm to reduce this time. This would be of the utmost importance as it would help mitigate collision risks and enhance the sustainability of future space missions in LEO.

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Poster

CBDO 035

Non-transiting exoplanet characterization using TTV pattern and Deep Learning

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The accelerated growth in the volume of data from astronomical surveys, including the light curves of billions of stars as input for exoplanet transit detection techniques, demands software tools capable of autonomous knowledge extraction. The use of Deep Learning techniques to help identify and characterize exoplanets has been expanded. We are training an algorithm based on deep convolutional neural networks to infer mass and period of exoplanets in a planetary system. We produced several hundred thousands of images based on transit light curves, called riverplots, from synthetic planetary systems, and trained an algorithm to learn from transit time variations (TTV) patterns of a transiting planet, caused by a non-transiting one. We included factors present in the light curves, such as limb-darkening and noise resulting from stellar activity, seeking to mitigate their impact on the predictive capacity of the algorithm. Wetested for different CNN architectures, classifying period and mass of hidden undetected non-transiting planets in simple planetary systems, consisting of a host star and only two planets, one that transits and one that does not.

Oral communication

CBDO 036

Analysis and two-dimensional modelling of diffraction effects in stellar occultations

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This research presents a methodology for analyzing light diffraction during stellar occultations by irregularly shaped celestial objects. Utilizing the computational tools SORA (Stellar Occultation Reduction and Analysis) and POPPY (Physical Optics Propagation in Python), the study constructs a numerical model to simulate the propagation of stellar light and its diffraction effects. This is crucial for interpreting the light curves that are generated when bodies like planets, asteroids, or comets transit in front of a star, temporarily obscuring it from an observer on Earth. The methodology begins with three-dimensional modeling of the occulting object using SORA, which provides an accurate representation based on its observed orientation during actual occultations. Once modeled and aligned with observational data, this configuration is imported into POPPY. Within this framework, the model undergoes a detailed simulation process examining the diffraction effects as light waves pass around the irregular shapes of the celestial object. This involves designing a shadow projection of the object, which acts as an aperture mask in the optical system. This mask is critical for accurately modeling how light is bent and scattered as it encounters the object, capturing the nuances of diffraction at various angles and positions. The resulting simulation outputs light curves detailing the intensity variations of the starlight due to the occulting body, providing valuable insights into its size, shape, and potential atmospheric features. The validation of this methodology is achieved by comparing the simulated light curves with observational data from actual stellar occultations. Ensuring a high concordance between the modeled and observed data confirms the accuracy and applicability of the model for future astronomical investigations.

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Acknowledgments
FAPEMIG, CNPq, CAPES

Poster

CBDO 037

Prediction of Gravitational Microlensing

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In the 16th century, astronomy experienced a revolution led by figures such as Galileo Galilei and Johannes Kepler, whose contributions strengthened heliocentrism and established the laws of planetary motion. Giordano Bruno, with his bold vision of the plurality of worlds, faced condemnation by the Inquisition, but his visionary ideas stimulated studies into exoplanets. The discovery of the first exoplanets in 1992 by Wolszczan and Frail [1] marked the beginning of a new era and the development of exoplanet detection techniques. The main detection techniques are planetary transit, radial velocity and gravitational microlensing. In particular, microlensing accounts for a small proportion of the number of discoveries due to its rarity, but it is important for its ability to detect more distant exoplanets, as well as being sensitive to low-mass planets. Gravitational microlensing occurs when a star (lens) bends the light coming from a background star (source), creating a temporary increase in brightness. This technique makes it possible to detect exoplanets, as the presence of a planet in the orbit of the lensed star can cause a second increase in brightness in the observed light curve. In addition, the gravitational microlensing technique is the only exoplanet detection technique we know of in which we can make predictions. Therefore, this study has developed a methodology for predicting close encounters between stars using a stellar motion propagation approach for gravitational microlensing, integrating parallaxes and radial velocities to increase the accuracy of the predictions. To do this, we used the Python programming language and data from the Gaia-DR3 catalog. Then, based on the results of Kluter et al. (2022) [2], we identified 74,590 predictions between 1974 and 2116, with 3609 coinciding with the previous results. Notably, between 2010 and 2070, the period studied previously, we found 32,114 encounters, six times more than the previous record.

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Acknowledgments
FAPEMIG, CNPq, CAPES

Poster

CBDO 038

Stellar Occultations by the Trojan (2363) Cebriones

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Stellar occultation is a phenomenon that occurs when there is an alignment between a body in the Solar System and a background star for a given observer. This moment is previously calculated using the trajectory of the body and the geocenter to estimate where the occultation can be observed from. This technique is useful for determining the size, shape, density, and even the existence of atmospheres, rings, or satellites around the occulting object. The asteroid 2363 Cebriones is a Jupiter Trojan located at the Lagrangian point L5. These asteroid orbits the Sun every 4,370 days (11.96 years), approaching a minimum distance of 5.03 AU and reaching up to 5.44 AU from the Sun (JPL, Small Body Database). It is a D-type asteroid (Grav et al., 2012), characterized by having a lower albedo, a reddish color, and a surface composed of olivine, calcite, magnetite,

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Acknowledgments
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Poster

CBDO 039 - A

The Effect of Triton's Evolution on Neptune's Spin Axis

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Euler equations for the rotation of a rigid body are introduced into a numerical integrator of n-body equations of motion, thus associating the variation of the objects' orbits in a planetary system with the variation of the frequency and direction of rotation of the body considered as central in the numerical integration. This extended integrator is applied to the problem of Triton's evolution from an originally distant and eccentric orbit, based on the model of a planetesimal binary system's disruption through its close approach to Neptune (Agnor & Hamilton, 2006). In these numerical integrations, I consider, in addition to Triton and Neptune, the latter one as the central body, also the Sun and the other three giant planets, Jupiter, Saturn and Uranus. A tidal model is also applied to model Triton's orbital decay. As a result of these simulations, it is noticed that for Triton's semi-major axes between 70 and 240 Neptune's radii and high eccentricities (0.95 to 0.98), Triton (along with the remaining objects) induces a precession to Neptune's equator with a frequency close to the Solar System's eigenfrequency s_8, thus producing a secular resonance. Numerical integrations show that, considering initially the Neptune's spin axis perpendicular to its orbital plane around the Sun, due to the aforementioned resonance, this axis can tilt up to its current inclination at around 30 degrees and even to higher values reaching up to 45 degrees. Finally, I analyze the most favorable initial orbits of Triton that can yield an increase in the inclination of Neptune's rotation axis close to the current one.

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Oral Communication

CBDO 040

Impact of Insertion Errors on the Performance of Small Satellite Constellations

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Satellite constellations, especially those composed of small satellites, are increasingly popular due to their reduced costs and flexibility in mission operations. Previous studies in the literature have analyzed optimal satellite orbits to optimize visibility and revisit times for different regions on Earth. However, a new question arises: what are the impacts of insertion errors on the orbital performance of these constellations in terms of revisit and observation time? This work investigates the consequences of orbital insertion errors on the performance of small satellite constellations dedicated to data communication. Specifically, we examine what happens to visibility time and revisit time when a satellite is inserted at a different altitude from the ideal orbit, as well as the effects of insertions with eccentricities and inclinations different from the optimal ones. The analysis includes detailed simulations to assess whether the satellites can still meet mission requirements under these non-optimal conditions or if significant errors result. Additionally, studies are conducted regarding orbital maneuvers that can correct these insertion errors. The expected results of this study will provide valuable insights into the robustness of satellite constellations against orbital deviations and contribute to the development of mitigation strategies to ensure efficiency and continuity of missions, even in scenarios of imprecise orbital insertion.

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Poster

CBDO 041

Aster Project: A New Launch Window with Multiple Swing-bys and Technological Parameters

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The Aster project aims to launch a spacecraft to the triple asteroid system 2001 SN263 to investigate and obtain information on its physical, chemical properties, etc. In this work, based on computer simulations carried out, we calculated a new launch window taking into account the use of multiple swing-by maneuvers, in order to minimize fuel consumption for the mission. The planets where the maneuvers were carried out were: Venus, Earth and Mars. After the spacecraft reached a stable orbit around the asteroid, a study was made to perform a Rendezvous to complete the mission objectives. The amount of fuel expended in the simulations was used to correct some of the spacecraft's trajectories and to perform Rendezvous in the final stage of the mission. Our results include obtaining the stable maneuver and feasibility of Rendezvous from a propulsion characterized by optimized parameters.

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Poster

CBDO 042 - A

On the Dynamics around Quaoar: its shape and the unstable limit

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Quaoar is a trans-Neptunian object with an intriguing system around it. It has two rings that are outside the expected Roche limit. The outer ring (Q1R) shows a wide range of optical depth combined with a wide range of the physical width (from a few km up to more than 100 km), while the inner ring (Q2R) is narrow (~10 km). The rings are located close to the 1:3 (Q1R) and 5:7 (Q2R) spin-orbit resonances with the central body. On the other hand, shape models based on observations suggest a 3D ellipsoidal shape, but can also accommodate topographic features of a few km. In the current work we use numerical tools in order to explore the dynamics of massless particles around Quaoar. The simulations for the nominal semi-axis of the ellipsoid proposed by Kiss et al. (2024) resulted in a wide unstable region covering the location of the inner ring (C2R). Then, we explored a range of shape possibilities in order to have the location of C2R in a stable region. They are critical in defining the inner limit of the stable regions, and the strength of the spin-orbit resonance effects. We adopted two different shape models: an ellipsoid and a sphere with a mass anomaly. For each shape model we considered a set of cases, changing the physical parameters: the semi-axis, in the case of the ellipsoid, and the radius of the mass anomaly (R_anomaly) in the other shape model. The numerical integrations allowed us to identify the radial limiting border between the unstable and the beginning of the inner stability region around Quaoar as a function of the physical parameters (semi-axis and R_anomaly). Therefore, we managed to use the stability of C2R to constrain even further the shape of Quaoar. Using Poincaré surfaces of section we also identified the main spin-orbit resonances nearby each ring.

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Oral Communication

CBDO 043

Conceptual analysis of interplanetary missions involving gravity-assisted maneuvers with the moon and the use of solar sails

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Gravity-assisted maneuvers with other planets, also known as swing-bys, are often utilized in interplanetary missions to alter the trajectory and speed of spacecraft about to the Sun to save propellant [1]. Spacecraft such as Voyager 1 and 2 (1977 -), Ulysses (1990 - 2009), and Rosetta (2004 - 2016) employed this technique with success.

Solar sails are an alternative propulsion form that does not require propellant consumption. They utilize the radiation pressure exerted by sunlight on surfaces with high reflective power attached to spacecraft. The light reflected by these surfaces transmits a propulsive force to the spacecraft [2]. The Ikaros (2010 - 2015), LightSail 1 (2015), and LightSail 2 (2019 - 2022) missions demonstrated the effectiveness of these devices.

This word explores these two concepts for planning low-cost interplanetary missions. Firstly, a spacecraft is launched toward the Moon using a natural route derived from periodic orbits around the Lagrangian equilibrium point L1 of the Earth-Moon system [3]. This route ensures a swing-by with the Moon that reduces the ΔV required to escape the Earth's gravitational field by up to 5%. Following the swing-by, a solar sail is deployed to provide continuous acceleration to the spacecraft. The effectiveness of combining these concepts is investigated by examining the limits of the ratio of spacecraft mass to sail mass and sail loading.

The results indicate that using a combination of swing-by with the Moon and solar sails reduces propellant consumption and flight time when traveling between Earth and target celestial bodies (such as planets and asteroids) compared to missions using conventional transfers, swing-by maneuvers, or solar sails only.

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Poster

CBDO 044 - A

Isochronous Bifurcations

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Isochronous islands in phase space emerge in twist Hamiltonian systems as a response to multiple resonant perturbations. According to the Poincaré-Birkhoff theorem, the number of islands depends on the system parameters and the perturbation. We analyze, how the island chains are modified as the perturbation amplitude increases. For the two-harmonic standard map and the Walker-Ford differential equation, we present bifurcations from one chain, associated with one harmonic, to the chain associated with the other harmonic.

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Oral Communication

CBDO 045 - A

Long and short-duration orbits around the Moon for diferente types of missions

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In this work, we consider orbital perturbations and the effect of resonances to analyze the orbital evolution of artificial satellites and/or space debris in lunar orbit. The goal is to find stable and/or unstable regions that can be beneficial for long and short-term orbits for different types of space missions. For example, space debris mitigation and search for frozen or near-frozen orbits. The main perturbative effects are caused by the Moon, acting as the central body, the Earth and the Sun as third bodies, and the Solar Radiation Pressure (SRP) (Carvalho et al., 2023). These effects are taken into account in the dynamic model. We consider a Selenopotential model consisting of a zonal truncation up to order 9 and sectoral and tesseral terms up to order and degree 3. We verified that the main zonal terms are J2, J7 and J9. We explore the orbital characteristics of spacecraft in long-term orbits near the Moon in a higher-order gravitational field of the Moon, thus applications have been made and compared with works that consider model of the gravitational field of high order and degree. In the SRP model we assume that the artificial satellite remains in a fixed orientation perpendicular to the Sun at all times. This satellite can be coupled to a solar sail to increase the area-to-mass ratio and thus increase the effect of the SRP. We consider an analytical approach that considers six types of resonances due to the oblateness of the Moon and SRP as described by Cook (1962) and Alessi et al. (2018). We calculate the values of the semi-major axis and resonant inclination. We perform numerical simulations considering all disturbing forces considered. Where we found two resonant regions appearing near the 60 and 120 degree inclinations that could be used to mitigate space debris. On the other hand, regions close to the 90 degree inclination (of a polar orbit) allow finding quasi-frozen orbits for low-altitude satellites around the Moon.

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Oral Communication

CBDO 046 - A

Heliotropic Orbits around the 65803 Didymos Binary Asteroid System: Effects of Zonal Harmonics, Solar Radiation Pressure, and Third-Body Perturbations

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Several missions to small bodies, such as asteroids, have been carried out in recent years, including JAXA's Hayabusa mission, which studied the asteroid 25143 Itokawa, and NASA's NEAR Shoemaker and Dawn missions, which visited asteroids 433 Eros and 4 Vesta, respectively. Currently, some NASA missions are ongoing, such as the OSIRIS-REx mission studying the asteroid Bennu, the Lucy mission investigating Jupiter's Trojan asteroids, and the Psyche mission, which will explore the asteroid Psyche. Recently, NASA's DART mission collided a probe with the asteroid Dimorphos, a small satellite of the asteroid Didymos, forming a binary asteroid system. This work proposes to investigate heliotropic inclined orbits around the moon Dimorphos, considering its non-uniform mass distribution, solar radiation pressure, and the gravitational attraction of the asteroid Didymos. Additionally, it explores orbits around the asteroid Didymos, considering the same perturbations, but treating Dimorphos as the perturbing body, using a semi-analytical model based on the averaging method applied to Lagrange's planetary equations. Heliotropic orbits are those in which the apoapsis or apocenter of the orbit points, on average, in the direction of the Sun. These orbits are considered good candidates for low-altitude scientific orbits around small bodies, whose irregular shapes make the dynamics around them complex and challenging. Recent studies have examined these orbits, considering only the effects of zonal harmonics and solar radiation pressure, without accounting for third-body perturbations. To simplify the equations and conduct an analytical study based on the considered perturbations, the double-averaging method is used, following the approach presented in Lantukh et al. (2015) and Lang et al. (2019). Additionally, in the numerical integrations, we consider the non-averaged dynamics, i.e., the equations with both short- and long-period effects.

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Poster

CBDO 047 - A

The Tesseral Resonance 3:1 in the Jacobi Ellipsoid

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In the present work, we study the dynamics of a particle in tesseral resonance around the Jacobi Ellipsoid. A qualitative analysis is carried out based on the Hamiltonian formulation of the ideal resonance problem. From a change of variables in the gravitational potential, in spherical harmonic, of the Jacobi ellipsoid we observe that the resonance equilibrium points depend solely on the geometric shape of the primary body. As a case study, we analyse the 3:1 tesseral resonance, three revolutions of the primary per orbital period, in order to determine the eccentricity value of the resonance centre, and thus, conclude if there is possible that a particle is in tesseral resonance 3:1 around the Jacobi Ellipsoid.

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Poster

CBDO 048 - A

Double lunar swing-by from periodic orbits in the restricted four-body problem

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One of the most used strategies to reach deep space is the swing-by maneuver, a type of maneuver that is already well known and used in many important missions, such as the Voyager missions. This work explores the planning of interplanetary missions using space trajectories in which two lunar swing-bys are performed, under the dynamics of the Restricted Four-Body Sun-Earth-Moon-spacecraft Problem. A spacecraft is initially inserted in a trajectory derived from a first lunar swing-by on a retrograde periodic orbit around the Lagrangian point L1 and the second lunar swing-by is performed after a maneuver on the apogee of this trajectory. The energy gain, the maximum distances achieved with this maneuver, and its costs in terms of velocity increments are presented. The results show that the double lunar swing-by is not sufficient to provide the required energy for a spacecraft to reach the planets Mars and Venus. Still, it provides gains of up to 3.6% in the increment of velocity, compared to the patched conic approximation, to reach the same distances of aphelion or perihelion.

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Poster

CBDO 049

Analysing the dynamics of Kepler-90 planetary system

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Kepler-90 system has a set of eight planets in a hierarchical structure, the size of the majority of the planets increases as increases their distance to the star. In this work, we study, through the frequency map, several Kepler-90 analogues in an attempt to analyse, in detail, how the values of the eccentricity of each planet can alter the stability of the system. The system was formed by the star and all eight planets for three different intervals of eccentricity. Our results show that for the first and second intervals ($0 < e < 10^{-3}$ and $10^{-3} < e < 10^{-2}$) all the systems are stable. However, no set of Kepler-90 system with large values of e ($10^{-2} < e < 10^{-1}$) survived up to 10^5 orbits of Kepler-90h. Therefore, the systems are stable for eccentricities up to 10^{-2}. A detailed analysis concerning the 5:4 and 3:2 mean motion resonances of the pairs Kepler-90b-c and Kepler-90d g-h planets, respectively, indicates that these resonances directly affect most of the systems. It might be as a strong resonant mean motion coupling added to a coupling of the longitude of the pericentres, with two resonant angles librating, or just a single resonant argument librating. There are also cases of intermittent behaviour. In many cases occurs the quasi-resonant influence, when at least one of the critical arguments circulates slowly.

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Oral Communication

CBDO 050 - A

Design of a Frozen Orbit for GARATÉA-L mission

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This work employs a semi-analytical theory for lunar a probe that includes the disturbing effects of zonal, tesseral, and sectorial harmonics of any order, as well as third-body attraction (particularly the Earth), developed by the authors. This theory is developed in closed form in terms of eccentricity, similar to the works of De Saedeleer (2005) and Lara et al. (2009), and, is described by new functions of eccentricity and inclination, extending the results established by Kaula (1962). To determine nominal conditions for frozen orbits, a set of non-singular variables is used to avoid singularities in eccentricity in the Lagrange equations, which allows the preliminary analysis of orbits with small eccentricities. The study involves the analysis of frozen orbits in terms of the argument of pericenter and eccentricity. The results show that such frozen orbits occur only when the argument of pericenter is equal to -90º or +90º. Under this condition, curves of eccentricity as a function of inclination are determined for specified values of the semi-major axis, which provide the mean orbital elements (semi-major axis, eccentricity, and inclination) that define the frozen orbits. As the nominal eccentricity of the GARATÉA-L mission is not close to any frozen orbit condition, a new set of orbital elements is then proposed for this mission by considering a model that includes J2 to J12 and third body perturbation for the frozen orbit conditions. The results show that the proposed trajectory passes over the center of the Aitken basin, near the South Pole, with the advantageous that, in this case, the pericenter altitude is locked over this region. The analysis of tesserals of order 2 and 3 in this proposed orbit highlights the contribution of the perturbative effects of tesserals of order 3 as the amplitude of oscillation in the eccentricity around its mean value, and, consequently, the amplitude of oscillation in the pericenter altitude increases. This effect makes the probe to reach an even smaller altitude, which can break a safe pass over the Moon surface.

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Poster

CBDO 051 - A

Semi-Analytical Theory for a Lunar Probe Orbit

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The coefficient of the second zonal harmonic J2 of the Earth's gravitational potential is significantly larger than the other coefficients. An analytical theory for the motion of artificial Earth satellites that considers only the primary zonal harmonics J2, J3, and J4 provides good results for preliminary analyses. Also, the design of frozen orbits for these satellites based on a J2-J3 model yields good results. On the other hand, a theory for analyzing the dynamics of lunar probes must include more terms of the potential since there is no significant difference in the order of magnitude of the first coefficients of the lunar gravitational potential harmonics. This becomes even more significant for low-altitude orbits, as discussed by Knežević and Milani (1998). For higher altitudes, the disturbing effects of the third body (particularly the Earth) must be added to those of the gravitational potential. The first studies on frozen lunar orbits extended the established analytical theory for artificial Earth satellites by considering the terms associated with the first zonal harmonics J2, J3 and J4, and the third-body attraction (Folta and Quinn, 2006). The present work introduces a comprehensive first-order semi-analytical theory that includes any number of zonal, tesseral, and sectorial harmonics of the gravitational potential. This solution is developed in closed form in terms of eccentricity and introduces new functions of eccentricity and inclination, extending the results established by De Saedeleer (2005). Hori's method is applied in developing the proposed theory. The Lagrange equations for the classical orbital elements are derived directly from determining the Poisson brackets involving the mean Hamiltonian function. A preliminary analysis of the GARATÉA-L mission is performed, considering the nominal orbit parameters defined by the mission proponents. A model including zonals J2 to J12, and, tesseral and sectorial harmonics up to order 3, is employed in the analysis. The results are compared with those obtained by the Cowell method, which propagates the spacecraft's motion in Cartesian coordinates. A good agreement between the results is observed.

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Poster

CBDO 052

Analysis of the asteroid Phereclos from stellar occultations

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Trojan asteroids are celestial bodies that occupy stable equilibrium points in a planet's orbit relative to the Sun. Understanding their origins is crucial for comprehending the evolution of the Solar System. Phereclos is one of these asteroids, associated with Jupiter, whose characterization can provide important insights.
To study Phereclos, we will use the technique of stellar occultations, which occurs when a celestial object passes in front of a star, temporarily blocking its light. The analysis of stellar occultations offers crucial insights into the physical properties of Phereclos, such as dimensions, atmosphere if present, shape, density, albedo, and surface characteristics. This study will analyze 4 stellar occultations of Phereclos, which occurred on four different days and locations: one in southern South America on May 15, 2021, six in Europe on June 18, 2021 (four positive and two negative), one positive near Australia on July 24, 2022, and two near Central America on September 10, 2023 (one positive and one negative). We will use the SORA package for detailed analysis of the stellar occultation observations [1].
The analysis of Phereclos' occultations will provide crucial data about its physical properties and possible origins, significantly contributing to the understanding of the formation and evolution of Jupiter's Trojans and the Solar System as a whole [2].
Finally, it is expected that the characterization of this celestial body through stellar occultations will strengthen research on the formation and evolution of the Solar System, significantly contributing to the knowledge about Jupiter's Trojans and their relevance in the context of the formation of the Solar System.

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Poster

CBDO 053 - A

Multi-objective optimization applied to a satellite constellation for the BiomeSat mission

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The BiomeSat mission is being developed by the National Institute for Space Research and aims to collect data from Brazilian territory in the visible and near-infrared bands of the electromagnetic spectrum. In addition, the satellite must be capable of receiving transmissions from environmental data collection platforms and information about vessels using the AIS system. Therefore, the BiomeSat mission complements the missions of the CBERS and Amazonia satellites, contributing to the provision of data for the planning, monitoring and control of the health conditions of Brazilian forests, in addition to assisting in the evaluation of degraded and deforested areas. The mission is currently being designed with a nano satellite of 8U dimension, with a mass of 12 kg. However, an expansion to a constellation of satellites is intended, to ensure that all objectives are achieved successfully. With the main objective of the constellation covering the entire national territory in 5 days, some constellation possibilities can be designed. Considering the selected constellation, in the present work a study will be carried out regarding the orbital maintenance of the satellites, analyzing, among other relevant information, the orbital disturbances, fuel consumption and decay time. This approach features a multi-objective optimization problem, where the aim is to minimize the total fuel consumption for orbital maintenance of all satellites, the total time spent on orbital maintenance maneuvers for all satellites and the relative positioning error between satellites. This problem consists of minimizing conflicting objectives, with the aggravating factor that the analysis is extended to all satellites that form the constellation. In this way, this work will seek, among the candidates for solving the multi-objective problem, to find the one that represents the most balanced solution.

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Poster

CBDO 054 - A

Study of a satellite constellation for INPE's BiomeSat mission

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Artificial satellite constellations have been widely used in recent years, presenting advantages when compared to a single conventional satellite in relation to, for example, increasing the performance capacity of the space system, expanding the coverage area and access area and increasing the revisit rate of observation and communication services. However, the design of a satellite constellation can be complex, since each satellite's orbit has an infinite number of options for each of the six orbital parameters. The use of small satellites makes multiple satellite missions viable and increasingly common, offering a mission return that can be comparable to missions involving a single large satellite, but with more possibilities for missions, experiments and studies. Therefore, this work proposes a study on the possibility of expanding the BiomeSat mission to a satellite constellation. The BiomeSat mission is being developed by INPE and aims to complement the institution's active missions, that is, to contribute to the objective of observing and monitoring national forests and biomes, in addition to evaluating degraded and deforested areas. The mission currently has a remote sensing small satellite, with a mass of 12 kg and a dimension of 8U. However, to expand the current objectives of the mission, in addition to significantly improving the current ones, it is intended to expand the mission to a constellation of satellites whose coverage of the entire Brazilian territory is achieved in 5 days. Therefore, the objectives of this work are defined considering this premise and corroborating the project objectives “Development of an Onboard Attitude and Orbit Control and Supervision Subsystem (ADCS) with the Use of Thruster and, Definition of a Strategy for Sandling Systemic Failures (FDIR) Applied to CubeSats”, which aims to develop missions that impose strict requirements on orbital control and advance the knowledge and development of CubeSats. For this, satellite constellation projects are found and, from the constellation design and based on figures of merit, the possibilities of constellations aiming to optimize the number of satellites, the number of orbital planes and the satellite’s altitude, characterizing a multi-objective optimization problem. From the solutions found, the most balanced option is selected.

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Oral Communication

CBDO 055 - A

Retrograde Symmetrical Periodic Orbits in the Circular Restricted 3-body Problem

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Using the “GridSearch” and "continuation by differential correction" methods to search for retrograde symmetric periodic orbits within the context of the circular restricted gravitational 3-body problem (CR3BP), we were able to find several families. In this work, we will display some of them and explore their characteristics such as their stabilities, bifurcations and whether they are in resonance with one of the primaries.

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Poster

CBDO 056 - A

Use of a Rational Agent to determine the attitude of a Solar Sail

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When considering a space vehicle powered by chemical propulsion, the main limitation to the autonomy of its mission is the amount of fuel on board the spacecraft. From the moment the fuel is completely consumed, the spacecraft becomes immaneuverable. Solar sails are an alternative to this problem because they are vehicles that use, as their form of propulsion, a natural resource widely available in our solar system interplanetary medium: solar radiation. Consequently, some trajectories unimaginable in the past are now considered to be viable options thanks to the innovations of this technology. However, a solar sail presents a great challenge when trying to determine the attitude of its reflecting surface, which has a large moment of inertia and is highly flexible. This study developed a spacecraft attitude determination system as a rational agent, capable of deciding and determining the best orientation for the sail throughout a mission, with the objective of inserting the spacecraft into a final orbit. In such a problem, the vehicle starts from any initial orbit and, considering a pre-planned target orbit, the system decides the orientation that the sail must assume throughout the mission to achieve the proposed objective. Some of the search techniques used by the agent in its decision process are Greedy Best-first search, Recursive Best-first search (RBFS) and Simplified Memory Bounded A* (SMA*). Since they are all search techniques in the 'best-first' category, it was also necessary to implement a heuristic function for the agent's decision process. In this case, the heuristic evaluates how far the spacecraft is from its target orbit. Additionally, changes in the sail orientation are considered as a cost, in order to minimize the effort of the attitude control system throughout the mission. The algorithm developed in this study allows the planning of different missions using solar sails as their main source of propulsion. These mission options range from space exploration, planetary defense or geoengineering. In this way, the algorithm makes it possible to demonstrate the great potential solar sails have when applied in space engineering.

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Oral Communication

CBDO 057

Orbital analysis of the Kiruna Meteor (2023/2/27)

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On February 27th, 2023 at 18:15:50 UTC a great meteor event occurred in Kiruna Municipality, Sweden. Using three cameras, located at Silkkimuotka, Tjautjas and Kiruna, that captured the meteor, we determine the meteor trajectory by pairing camera images. In the trajectory determination, we analyze and compare the results of all cameras combined. For each pairing camera, we performed backward numerical integration until the meteoroid
reached an altitude of 1000 km. For these simulations, we use the REBOUND package [1] considering the gravitational force and the NRLMSISE-00 atmosphere model [2] to compute the air drag force. At this point, we marked the point where the meteoroid entered the atmosphere. We then continued the numerical integration, but at this time, we considered the gravitational effects of the Sun-Earth-Moon system. We stopped the integration when the meteoroid crossed the Hill's sphere of the Earth-Sun. Then, we calculated its heliocentric orbital elements just before it entered the Earth's influence sphere. The results show an Apollo type, with the following mean values: semi-major axis of 1.41 AU, eccentricity of 0.32, and inclination of 26 degrees. To analyze the orbital evolution of the meteoroid, we extended the backward integration up to 200 years in the past, using the Rebound IAS15 integrator, and taking into account the gravitational forces of the Sun, moon, and nine planets. Although several close encounters with the Earth occurred, the meteoroid orbit shows stable behavior and remains an Apollo object during all integration time. Using prograde integration, and considering the drag atmosphere again, we estimate the strewn field for meteorites to several masses, from 0.01g to 50kg. The results show that the meteorites were dispersed around Kalyxälven river.

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Poster

CBDO 058

The Moon as a possible source of Earth's co-orbital bodies

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The Kamo'oalewa (2016 HO3) is a small body (45-60 m) with a trajectory classified as an Earth quasi-satellite and was discovered in 2016 using the Pan-STARRS 1 survey telescope on Mount Haleakala in Hawaii. Its orbit is very similar to the Earth's, with almost the same semi-major axis, an eccentricity of 0.1, and an inclination of about 8 degrees. Analysis of its spectrum suggests a silicate-based composition. However, its reddening is higher than the usual values found in inner solar system asteroids, indicating a long space weathering. Lunar-like silicates presented the best match in comparison with the spectrum of material analogs. Therefore, from the spectral analysis, one might suggest Kamo'oalewa is a piece of material that was originated from the Moon.

In the current work, we explore the dynamical aspects of such possible origin. Considering the case of a small piece of material being ejected from the Moon, we performed numerical simulations of its orbital evolution in the Earth-Moon system around the Sun. A wide range of initial conditions in terms of position and ejection velocity vector around the Moon was investigated.

Preliminary analysis of the results indicates that Earth quasi-satellite trajectories are among the outcomes. In these cases, the bodies can remain as quasi-satellites for several hundred years. A deep analysis of the conditions necessary to produce the suitable ejections from the Moon surface is under study together a mapping of the moon's surface where the ejections produce quasi-satellite objects.

We also studied a statistical analysis of objects that remained for some time as co-orbital or quasi-satellite, such as particles that collided with the Earth and the Moon, taking into account the different initial Sun-Earth-Moon geometry. An investigation of lunar craters and the probabilities of the origin of objects compatible with Kamo'olewa are also being carried out taking into account projectile velocity, impact angle and age of the craters.

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Poster

CBDO 059

Application of Orbital Correction Maneuvers by Continuous Thrust in Frozen Orbits Around Venus

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The study conducted in this work investigated the use of continuous thrust orbital correction maneuvers in frozen orbits around Venus. The objective was to analyze how the control acceleration changes based on the spacecraft's orbital elements around Venus, considering four different orbital correction strategies. The main findings are: (i) The behavior of the orbital elements (a, e, i) is similar for Venus and Mars, but the control acceleration magnitude is consistently lower for Venus, suggesting that missions around Venus would require less fuel consumption. (ii) The continuous low-thrust control method is the most energy-efficient, resulting in the lowest control acceleration magnitude. (iii) For orbits close to Venus (a<11,000 km, e>0.4, i~0° or 180°), the low-thrust method results in higher control acceleration, making it less suitable for application in this region. (iv) Considering only the zonal harmonics J2, J3, and J4 significantly increases the time required for orbital correction in orbits close to Venus, emphasizing the importance of including higher degree and higher-order spherical harmonics in these regions. (v) Polar orbits require more frequent corrections, suggesting that mission planning outside the polar region may be more attractive to reduce energy consumption, although this region is important for planetary exploration.

Poster

CBDO 060

Optimizing Hyperparameters in a Convolutional Neural Network Model for Image Analysis

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This work discusses how image analysis using artificial neural networks presents a high dimensionality, requiring specific tools such as convolutional neural networks (CNNs). CNNs comprise convolutional and subsampling layers, which aim to extract the most relevant features from the images. Although effective in image processing, the high complexity of CNN models requires precise optimization of the hyperparameters, which are the algorithm variables defined before training. These hyperparameters play a crucial role in the network's performance, as an inappropriate choice can compromise the results. The CNN model presented in this study has three convolutional layers, 3 Max Pooling layers, one flattened layer, and two dense layers in the output. The convolutional layers apply filters to identify critical parameters and reduce the size of the image, generating an activation map. The second layer minimizes the impact of small changes in the input image. In the initial configuration, 15 epochs, 512 neurons, and three convolutional layers were used, resulting in approximately ten million parameters. However, this configuration led to overfitting, where the network memorized the training data instead of generalizing it, resulting in an accuracy of only 70%. Automatic hyperparameter optimization would be the most effective approach to solving the problem of overfitting. Manual tests were carried out, with the most significant change being reducing the number of neurons in the first dense layer from 512 to 64. That resulted in an improvement in accuracy to around 97%. Finally, a study was conducted on automatic hyperparameter optimization methods using the scikit-learn and scikit optimize libraries, applied to a convolutional neural network model for identifying the dynamic regime of asteroid orbits.

Poster

CBDO 061 - A

A numerical analysis of planar colliding binary companions

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Data obtained from missions like LUCY, which observed the Dinkinesh moons, and Hayabusa, which observed the Itokawa NEO, have provided crucial information on asteroid formation. Understating the dynamics of these systems is a fundamental key in comprehending the Solar System's history, since collisions in early system formations could modify the fate of these celestial bodies. In this study, we propose that low-speed non-elastic collisions could play an important role in the formation of contact binaries. To this end, we model the dynamics of colliding binary systems using a numerical approach based on the full two-body problem (F2BP) in a planar configuration. We capture the complex interactions during collisions by verifying ellipsoid overlaps. The equations of motion were solved numerically, with collisions handled through an impulse response model. We considered non-elastic collisions using energy dissipation through an exponential model based on the relative velocity. The simulations led to three possible outcomes: merging, bounded, and escaping configurations, showcasing that collisions are a relevant mechanism of energy dissipation and could play an important role in binary system formation.

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We acknowledge the support grant 2021/08274-9 from São Paulo Research Foundation (FAPESP) and PRInt-CAPES Finance Code 001.

Oral Communication

CBDO 062

Monitoring the movement of small celestial bodies at FESJ/UNESP Station.

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A meteor monitoring station consists of a camera pointed at the sky and one (or more) computer with the Brazilian Meteor Monitoring Network (Bramon) system. The station's primary goal is to monitor objects passing through the sky in the region where the camera is pointed. The exchange of information on observations of meteors and other celestial objects between multiple stations aims to track the path of objects through the Earth's atmosphere and use the information to determine the Keplerian orbital elements. That allows for associating a given meteoroid with a comet or asteroid, understanding the characteristics of the parent object, and validating and refining the shower fluxes in the database (GURAL, 2012). The main objective of this work is to show the results of capturing meteor images obtained by the monitoring station located at FESJ/UNESP. The station is equipped with a high-sensitivity camera that captures the movement of small bodies in the night sky using UFO Capture software, improving the accuracy of meteor triangulation in a region with limited facilities. The results include analyzing the collected images using numerical algorithms written in Python with a PIN program. The data analysis provides various information, such as the trajectory and speed of the meteoroid corresponding to the meteor image.

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Poster

CBDO 063

Genetic Algorithm Simulation of Mitigation Maneuver Spacecraft-Asteroid Bennu and Yarkovsky Effect

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NEOs (Near Earth Objects) are asteroids that have trajectories close enough to Earth to potentially cross its orbit. Understanding and predicting the trajectory of these celestial bodies is crucial, considering the various natural effects that influence their movement [1]. One effect that can modify the trajectory of an NEO is the Yarkovsky Effect, discovered by the Polish civil engineer Ivan Osipovich Yarkovsky (1844-1902) [2]. An asteroid that has garnered special interest is Bennu, classified as an Apollo group object and listed as potentially hazardous by NASA due to its large diameter (490 m) and mass (7.329×10^{10} kg) [3]. To study the collisional dynamic interactions between a spacecraft and Bennu, this work developed simulations considering the Yarkovsky effect and the gravitational influence of the eight planets and the Sun. Two significant approach points between Bennu and Earth were identified: P1 and P2. At point P1, the relative distance between asteroid Bennu and Earth is approximately 748,912.64 km, representing the closest point of approach of the asteroid to the planet, subject to its gravitational influence. At point P2, the relative distance between Bennu and Earth is 5,876,313.48 km. It precedes point P1 temporally and allows interventions in the asteroid's trajectory with reduced costs. Inelastic collision simulations between the spacecraft and Bennu were performed at point P2 to determine a deflection that ensures a safe relative distance at point P1. Using the Rebound software and ephemerides from NASA's Horizons database, a high-performance genetic algorithm was developed to determine the best velocity values for the spacecraft during the collision. The results demonstrated that a spacecraft weighing 150,000 kg, with a modular velocity of approximately 548.02 km/s, is capable of deflecting the asteroid and increasing the relative distance between Earth and Bennu at point P1 to 1,500,119.89 km, a value that removes the asteroid from Earth's influence. These simulations provide valuable information for the development of effective planetary defense strategies against potential asteroid impacts, contributing to the safety of our planet from cosmic threats.

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Poster

CBDO 064

Dynamical evolution of a system composed by extended deformable bodies with complex rheologies

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In this talk, we will first briefly expose the main ideias behind the tidal theory introduced in Ref. [1] and further developed in, for example, Refs. [2] and [3]. Such theory deals with the dynamical evolution of celestial bodies by modelling the body's rheology, i.e., its physical response to external forces, in the time domain. Then we will present our newly developed open-source software which uses this theory to calculate the orbital and rotational evolution of a system composed of N deformable extended bodies with complex rheologies. Finally, we showcase our program capabilities by reproducing different dynamical phenomena in the Solar System.

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Oral Communication

CBDO 065

Island myriads in periodic potentials

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A phenomenon of emergence of stability islands in phase space was found for two periodic potentials with tiling symmetries, one square and the other hexagonal, inspired by bidimensional Hamiltonian models of optical lattices. The structures found, here termed as island myriads, resemble web-tori with notable fractality and arise at energy levels reaching that of unstable equilibria. In general, the myriad is an arrangement of concentric island chains with properties relying on the translational and rotational symmetries of the potential functions. In the square system, orbits within the myriad come in isochronous pairs and can have different periodic closure, either returning to their initial position or jumping to identical sites in neighbor cells of the lattice, therefore impacting transport properties. As seen when compared to a more generic case, i.e., the rectangular lattice, the breaking of square symmetry disrupts the myriad even for small deviations from its equilateral configuration. For the hexagonal case, the myriad was found but in attenuated form, mostly due to extra instabilities in the potential surface that prevent the stabilization of orbits forming the chains.

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Poster

CBDO 066 - A

Deep Learning Identification of Asteroids Interacting with g – s Secular Resonances

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Secular resonances refer to a resonance condition between the orbital precession frequencies of an asteroid and a planet. They can significantly affect the long-term dynamics of the asteroid, leading to orbital instabilities, collisions, and ejections of smaller objects. In this work, we focus on the g - s type resonance, which involves combinations of the asteroid's pericenter and node frequencies, g and s. We evaluate the effects of this type of resonance on the orbital elements, especially for high-inclination asteroids. Among the s-type secular resonances, one of the most important is the g-g6-s+s6, due to its effect on high-inclination asteroids like those in the Phocaea asteroid family. Our goal is to study the interaction of asteroids with this resonance while implementing deep learning models for the automatic identification of affected asteroids. Using a robust database, primarily from the inner asteroid belt, we employ convolutional neural networks (CNN) and the Vision Transformer (ViT) architecture to classify the objects. We use metrics such as accuracy, precision, and F1-score to evaluate the performance of the models, applying regularization techniques to reduce overfitting. The three CNN models showed excellent performance, but the ViT architecture stood out in terms of metrics and processing time. ViTs, although demanding in terms of memory requirements, appear to be the best option for image classification and regression for larges databases.

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Acknowledgments
MASB, FEG/UNESP

Poster

CBDO 067 - A

Surface Properties of the Jovian Trojan (58931) Palmys

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Small bodies are the objects in the Solar System that exhibit the least thermal, chemical, and tectonic evolution when compared to planets and large satellites. A study of these objects can provide answers about the origin and evolution of the Solar System. Jovian Trojans are a fascinating class of asteroids sharing the giant planet's orbit and librating around its Lagrangian points L4 and L5. (58931) Palmys is one of them and is the subject of this study. We aim to investigate the surface characteristics of this object (absolute magnitudes, topographic features, and albedo) using photometric data from the Dark Energy Survey (DES) and stellar occultation data. The DES is an astronomical survey conducted with the Blanco telescope (Chile), which carried out observations from 2013 to 2019, covering an area in the sky of approximately 5,000 square degrees. For our object of study, the DES obtained measurements that allowed us to calculate its absolute magnitude at different bands. Stellar occultation is an observational technique in which an object passes in front of a star, obscuring it from the observer's point of view. Through this technique, it is possible to estimate physical parameters of the bodies, such as their size, apparent shape in the sky plane, and topographic features. The studied trojan was observed in five stellar occultation events between 2021 and 2022. The first of these five events drew significant attention as it recorded an unusual result that could indicate a relevant topographic feature on this object's surface (such as a large depression) or that the studied object is a binary asteroid (a system of two bodies orbiting a common center of mass). Thus, in this work, we present the results obtained from DES photometry (absolute magnitudes) and stellar occultations (values of diameter and flattening). By combining this information, we also estimate the albedo of this object, which can aid in the study of the main minerals on its surface.

Poster

CBDO 068

Dynamical structure of compact planetary systems

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In the theory of terrestrial planet formation, short period, compact planetary systems are a natural outcome of runaway and oligarchic growth. In such systems, low mass planets orbit around the central star with a mean orbital separation between adjacent planets of the order of unities of their mutual Hill Radius and they can only further grow to earth-like masses through giant impacts between the planets.
In this scenario, Chambers et al. (1996) empirically obtained that the timescales for those collisions to happen had an exponential relationship with the initial orbital separation in terms of their mutual Hill Radius. Following this work, the problem of the stability of compact planetary systems has been approached from numerical, statistical and theoretical frameworks (Pu and Wu, 2015; Petit et al., 2020).
Still, we lack a broad, comprehensive study of such system's timescales dependencies to orbital and physical properties, as well as a general theory for the onset of chaos due to gravitational instabilities.
In this context we numerically integrate a number of distinct orbital configurations for compact planetary systems as means of thoroughly probing the dynamical architecture sensitivity to different sets of parameters. Such study, with the help of chaos detection tools, allows for an in depth understanding of the different orbital structures within compact planetary systems and how such structures lead to large-scale instabilities responsible for the late stage of terrestrial planets growth.

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Poster

CBDO 069

Multi-fluid hydrodynamical simulations of circumbinary planet formation via pebble accretion

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Context. Since the detection of the first known transiting circumbinary planet (CBP), Kepler-16b, by the Kepler mission, a total of 14 CBPs have been detected, raising questions about their formation and dynamical evolution.
Pebble accretion has been explored in the planetary formation around single stars and binary systems. Aims. In this work, we explore how circumbinary planets undergo pebble accretion while embedded in circumbinary discs close to the vicinity of the central binary system and the evolution and results to similar planets accreting in discs around single stars. We aim to understand the differences that might arise between both formation scenarios, to understand its consequences for the growth of the planets and the final masses of circumbinary planets versus planets around single stars.
Methods. In this work we use a modified version of the FARGO3D that treats the dust as a fluid consisting of particles with a given internal density and a fixed size, including pebble accretion onto the planet.
We simulate pebble accretion onto small planets around single and binary star systems with this multi-fluid routine, using Kepler-16 as a template. The evolution of a low mass core embedded in a gas disc with a continuous flux of pebbles passing through the system is carefully analyzed.
Results. Pebble accretion efficiency depends mostly on the size of the dust, dust-to-gas ratio, planet mass and initial orbital location. In our preliminary runs we have observed the opening of gaps in the dust disc and in the gas disc while the planet's mass is increasing due to pebble accretion. In our ongoing simulations, we are evolving both single star and binary systems with an embedded planet.
Conclusions. This work compares a single star with a binary star system in the context of planet formation and the results are relevant to understanding the different evolutionary paths the same initial setup can produce. We expect our results to show that compact circumbinary planets will be more massive than the ones around the single stars, due to the eccentric disc and planet leading to more efficient pebble accretion.

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Poster

CBDO 070

Machine learning approach for mapping stability regions around planetary systems

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The number of exoplanets increases every year and the study of the stability of extra-solar planetary systems led to a question if they could host exomoons or exorings. These studies are typically performed numerically by solving a large set of computationally expensive N-body simulations. We propose to apply Machine Learning (ML) to predict maps of stable regions of S-type orbits around planets. To identify the stable regions we perform numerical simulations of a system formed by a star, a planet, and a particle, using the Rebound package and IAS15 integrator. Each system has nine features representing the initial conditions of the orbital elements of the planet, the particle, and the mass ratio of the system. The constructed ensemble characterizes the set for training and testing ML methods; thus, based on the dataset features, the model learns the behavior of stability regions and can predict the stability of a system. In total, we run $10x10^4$ numerical systems, where stable particles comprise around 12% of the sample, resulting in an unbalanced data set. The ML training with imbalanced classes can lead to classification biases and impair the algorithms' effectiveness. To solve this problem, we used resampling methods, hyperparameter and threshold tuning. We applied 5 different supervised algorithms: Decision Tree, Random Forest, XGboost, LIGHTGBM and Histogram Gradient Boosting, achieving an accuracy of up to 98.48%,a recall and precision of 94% for stable particles and 99% for unstable particles. This approach reduces the invaluable time that would be spent in numerical simulations to a training of minutes. The idea is that the results generated by the model can be accessed publicly through a web interface, where the user can generate stability maps according to their range parameters for a system of interest.

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Poster

CBDO 071 - A

A semi-analytical approach to retrograde mean motion resonances

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Retrograde mean-motion resonances have been studied in the context of the three-body problem [1], where analytical studies of mean motion resonances are based on the expansion of the disturbing function in terms of orbital elements, but this presents some limitations, primarily due to poor convergence for high eccentricities. One way to overcome this problem is through semi-analytical studies [2,3] where a numerical averaging of the disturbing function is performed. Here, using the software Mathematica we construct a semi-analytical model for a retrograde p:q mean-motion resonance and we validate our results by comparing with numerical integrations of the equations of motion.

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Acknowledgments

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Poster

CBDO 072

Numerical Analysis of CubeSat Orbit Using Aerodynamic Perturbative Forces and Debris Monitoring in Low Earth Orbit

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CubeSats are a low-cost technology that can replace much larger equipment in space missions, especially in LEO (Low Earth Orbit). Mapping missions are those that require this equipment the most. Despite their significant advantages, CubeSats present some application difficulties, such as orbit control and satellite monitoring. Much of the literature on CubeSats focuses on decay orbits, primarily on equipment recovery. However, this study addresses issues associated with orbit monitoring and alternative forms of control. Some alternative forms of orbit control include utilizing aerodynamic forces and perturbations from other debris on the satellite or a group of satellites. Rigorous orbit monitoring is required for these methods to be properly applied. As CubeSats are very small equipment, one simulated method involves monitoring sets of debris rather than a single object. This approach reduces the number of telescopes needed for the task and enables the monitoring of multiple CubeSats when they orbit together. In this work, we aim to conduct a numerical analysis of Cubesat orbits, considering aerodynamic perturbative forces such as atmospheric drag and the flattening of the Earth, and examining how these forces affect the Keplerian elements of the orbit.

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Poster

CBDO 073 - A

Resonant interactions between objects on counter-revolving orbits

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Following our studies in the restricted 3-body problem which allowed the identification of the first small bodies on retrograde orbits in resonances with the giant planets [1,2,3], we present new results on the resonant interactions between objects on counter revolving orbits with applications to the solar system and extrasolar systems. We show that we are able to obtain a comprehensive view on the dynamics of such configurations by combining: analytic modelling of resonant interactions; precise computation of periodic orbit families and their bifurcations; and numerical simulations.

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Poster

CBDO 074

Innovative Approaches in Nanosatellite and Tether Systems for Cost-Effective Space Missions

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The deployment of large satellites requires a significant investment for their operation. Therefore, the pursuit of innovation focuses on reducing their size, thus promoting more advanced technologies and minimizing the costs of space missions. In this context, we propose a state-of-the-art study of a constellation model of nanosatellites with various purposes such as measuring the magnetic field, solar radiation pressure, and facilitating space communication. The search for innovative solutions that combine resource and material optimization has guided recent research in the space field. Systems composed of multiple bodies interconnected by cables, known as Tether Systems, have emerged as a promising idea for reducing costs in space missions. Tether Systems consist of rigid objects connected by long, flexible cables, with great potential for transporting space cargo without the use of propellants. Their applications include the space elevator and the creation of artificial gravity. This work will address the state of the art of adjacent results in the field of cable-connected structures, their feasibility, rotational dynamics, and behavior in space environments. Analytical models of systems will be used to simulate and explain the orbital dynamics and orientation of the object, while the main critical parameters related to the stability of systems employing this dynamics will be analyzed, with specific applications in nanosatellites. This will verify their applicability for connecting two satellites in Earth or lunar orbit, with applications such as space debris collection or possibly conducting the re-entry of a decommissioned object.

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Poster

CBDO 075

Tidal Evolution and Spin-Orbit Dynamics: The Critical Role of Rheology.

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This study analyzes the secular dynamics of two extended bodies in Keplerian orbits, focusing on tidal effects. It introduces formulas for energy dissipation within each body in a binary system. The equations, especially for systems like the Sun-Mercury system, can be divided into fast and slow components. A key contribution of this work is demonstrating the essential role of complex rheological models in spin-orbit resonance capture. Specifically, it highlights the necessity of a rheological model with at least two relaxation times to explain Mercury's current rotational state and the importance of Mercury's elastic rigidity on secular timescales.

Oral Communication

CBDO 076

Dynamical evolution of a debiased size distribution of Near Earth Objects

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In this research, we investigate the dynamic evolution of the population of Near Earth Objects (NEOs) within the solar system using a debiased population (Nesvorný et al., 2024). NEOs consist of bodies migrating inward from the main asteroid belt and the outer regions of the solar system. We have performed numerical simulations, over a large time span, taking into account the implementation of non-gravitational effects due to the Yarkovsky effect on the Mercury package given by Fenucci & Novaković (2022), the general relativity, the gravity of all planets of the solar system and the Sun. We adopted a hybrid integrator, which uses a mixed-variable second-order symplectic map when one body is far away from any planets or the Sun, and a Bulirsch–Stoer integrator when they come closer than 3 Hill’s radii. The spin rotation rate depends on the size of the NEO. We have divided the population into two groups: from 200m to 10km diameter with aleatory spin rates between three to twelve hours, and from 100m to 200m diameter with aleatory spins between one to twenty-four hours. We show the statistical results of collisions of NEOs with the Earth, also encounters between NEOs and the planets or the Sun, besides the most common routes and fates of this population, and their lifetimes.

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Poster

CBDO 077

Orbital dynamics of the third body in the polar V808 Aurigae

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Polars are magnetic cataclysmic variables (CVs) characterized by being close binary systems with a magnetic white dwarf (10 - 300 MG) receiving matter from its companion, a low-mass star [1]. V808 Aurigae is a polar with a planet of mass approximately eight times the mass of Jupiter orbiting the system eccentrically with an orbital period of 11 years, whose next perihelion is expected to occur in 2028 [2]. Evidence of a third body in the polars requires continuous analysis of the light curves in fast cadence, so to date only three other polars show behavior similar to V808 Aur. With the growing number of exoplanets, the study of orbital stability in multiple systems has become essential to confirm these new candidates. In this work, we study the orbital stability of V808 Aur through a set of numerical simulations of the N-body gravitational problem using the REBOUND code [3] in order to investigate the orbital evolution of the bodies. Since a stable system is one in which there are no abrupt changes in the orbital elements during the dynamical evolution of the system, we investigate the stable zones of these systems and study the variations in the semi-major axis and eccentricity elements considering the variations in the masses corresponding to the processes of the CVs.

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Poster

CBDO 078

Space Debris: Analysis and Preventive Mitigation

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Orbital debris is defined as man-made objects placed in the space environment that no longer serve a useful purpose. Making an analogy to conventional environmental impacts, the potential injection and release of orbital debris or the generation of fragments in space environments can be considered as an emission of an environmental stressor that damages the orbital natural resources that support space activities. Space sustainability is an increasingly important topic as the exploration and use of space expands, as a result of this expansion, the international community is working to develop solutions to ensure safe and responsible space exploration. It is proposed to systematically integrate the impact of debris emission on the orbital resource to broaden the scope of simplified life cycle assessment (LCA) for space systems. This work proposes a simplified study of the life cycle of space debris; simulation of clouds of space debris generated as a result of random explosions, each particle analyzed individually, in the restricted three-body problem (PRTC), where the ma

ss of each particle is negligible when compared to the mass of the primaries (Earth-Moon); analysis using numerical integrators for temporal orbit propagation and re-entry (MATLAB), debris risk assessment and mitigation analysis (DRAMA/ESA) and orbit propagation and collisions (STK/AGI) is also proposed.

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Poster

CBDO 079

Transfer of Near-Earth Objects (NEOs) to the Centaurs' region

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Centaurs are small celestial bodies in the solar system whose orbits are primarily influenced by the gravitational interaction with the giant planets. Near-Earth Objects (NEOs) are asteroids, comets, and meteoroids that reach a perihelion distance smaller than 1.3 AU. It has been investigated that the Main Asteroid Belt (MAB) is the primary source of the NEOs through the action of mean motion and secular resonances [1]. Other outer regions, such as Centaurs and TNOs, moving towards the terrestrial planet region can also contribute to the NEOs regions [2]. Liberato, Araujo, and Winter (2023) [3], investigated the dynamic evolution of 839 current large NEOs. The study identified preferred pathways for NEOs, including transfers to the regions of the Jupiter Family Comets (JFC), the Centaurs, and the Main Asteroid Belt region. Out of 839 bodies, 75 (about 9%) became Centaurs after leaving the NEOs region. Most of the NEOs that enter the Centaurs' region are quickly removed, while the remaining ones stay for a considerable amount of time. On average, they stay for nearly 2 million years. These results suggest that it is quite possible that today we may have real Centaurs that were once NEOs. Vestiges of this orbital history would be signs of surface space weathering due to prolonged exposure to the sun's proximity. In this work, we will present the extreme cases and discuss the potential implications of these findings in the current context of small celestial bodies.

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Poster

CBDO 080 – Withdrawn by the author

CBDO 081

Machine learning techniques for the design of Spinning Theter System

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It is possible to build spacecraft joining two of them with a theter. This kind of spacecraft is called Spinning Theter System (STS). It has several applications such as orbital maneuver, aerobraking, artificial gravity and so on. In this work we propose STS to payload transfer and orbit acquisition. Our model uses gravitational capture, defined as the transition from a hyperbolic orbit to a temporary elliptical orbit, and a controlled rupture of the theter. In this process one spacecraft loses orbital energy while the other one has a gain in orbital energy. The one which loses energy has its temporary elliptical orbit turned into a permanent one, while the other is spelled from the orbit. We use machine learning in a two-fold approach. First, simulation data is ingested in the training phase of multiple machine learning algorithms to build a metamodel that describes the dynamics of the spacecraft. The performance of multiple machine learning strategies is compared, and the advantage of each approach is outlined. Next, the convergence aspect of the dynamic model is evaluated based on the response of the metamodels. These models will support principal component analysis, aiming to identify the most relevant variables and evaluate them for sensitivity analysis. Finally, the subset of feasible design variables will be characterized according to the probability of convergence of the numerical methods used to integrate the dynamics over time. This heuristic identifies the most promising designs according to multiple criteria, such as minimum energy, integration stability and convergence speed.

Acknowledgments
CNPq.

Poster

CBDO 082

Multivariate analysis as a Spatial Debris mitigation strategy

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Human beings' ability to shape and influence the environment extends beyond planet Earth to the surrounding space. In the last six decades, a substantial amount of debris of various shapes and sizes has been launched into orbit, initially for scientific, communication and other technological applications. However, this debris now permeates this space, constituting a worrying "orbital curtain", with an accumulated mass that exceeds ten million tons. This excess of objects in orbit represents a growing challenge for space exploration and its related activities. As a result, there has been a growing awareness of the urgent need to restore order and security in space around the planet with regard to these objects, which are distributed in different orbital regions, classified on the basis of altitude bands (LEO, MEO and GEO). This movement has generated initiatives aimed at evaluating and improving the useful life of space equipment, such as satellites and rocket launchers. In addition, there is a growing demand for measures to limit the use of toxic or polluting materials, in order to minimize environmental impacts when these objects re-enter the Earth's atmosphere and sometimes do not completely disintegrate.

In this work, a multivariate statistical analysis of space debris will be done, along with an evaluation of the possible collisions between these objects and an analysis of their orbits.. These analyses are fundamental to more effective and sustainable management of orbital space. Studying the orbital behavior of these objects makes it possible to predict more accurately the moment of their complete disintegration or, when necessary, to anticipate possible collision trajectories with the Earth. This analytical approach can contribute significantly to the cataloging and continuous monitoring of space debris, enabling more efficient and safer planning for future launches of vehicles and equipment into space. It is therefore an essential measure to mitigate space pollution and promote the long-term sustainability of human activities in space, along with the proposal to integrate debris analysis into Life Cycle Assessment (LCA) to broaden its application to space systems, enabling the development of new mitigation strategies.

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Poster

CBDO 083 - A

Investigation about the internal structure of the trans-Neptunian asteroid Arrokoth

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The minor bodies of the Solar System have a particular dynamic behavior due mainly to their non-uniform geometry. The consequences of the irregular shape in its vicinity environment and surface are already a piece of investigation in many studies. However, the inner structure of these objects is still a point with many questions to be explored. Considering a homogeneous mass distribution and a constant spin period, this study proposes to analyze the evolution of the trans-Neptunian asteroid Arrokoth's internal structure evaluating different density values. We use the Finite Element Method to investigate static stress propagation on an elastic-plastic body under the effect of gravitational and centrifugal forces. The study aims to point out the minimal cohesive strength necessary to keep intact the internal structure of the object, mapping possible failure regions.

Acknowledgments
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Poster

CBDO 084 - A

The secular tidal evolution of a binary system in the viscous regime and singular perturbation theory

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We explore a set of differential equations for a binary system describing the tidal evolution of its orbital elements, rotational dynamics, and deformation (flattening), under the assumption that one body remains spherical while the other is slightly aspherical [1]. We apply methods of singular perturbation theory [2] to show how the dynamics of the entire system, in the viscous regime, can be approximated by the evolution of its secular equations. We also use singular perturbation theory to provide a geometrical description of the global dynamics of the system observed in numerical simulations, as well the stability and bifurcations of their equilibria [3].

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Oral Communication

CBDO 085 - A

Orbital mechanics around non-homogeneous elongated asteroids

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This work studies the dynamics around non-uniform elongated asteroids. A simple model for the gravitational potential is proposed, where the density of the asteroid changes continuously over its length. As the dynamics of a system is understood by means of its invariant objects, the qualitative behavior is explored by computing families of periodic orbits, heteroclinic and homoclinic connections, and other invariant manifolds. The results show that these objects can bifurcate as the mass distribution changes, highlighting the relevance of accounting for density and geometric properties when modelling asteroid dynamics.

Oral Communication

CBDO 086

Exocomet dynamics in the Kepler-90 extrasolar system

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The delivery of part of water and matter of astrobiological importance to planets can be carried out through comet impacts with the surface of planets. Comets are bodies made up predominantly of water and dust.
Dvorak et al. (2020) carried out a study of the dynamics of hypothetical comets in extrasolar systems. Motivated by the work of authors, we initially analyzed the dynamics and number of collisions of these bodies with planets in the Kepler-90 (K90) system. In the analysis we consider cometary reservoirs with hypothetical initial conditions under the action of the gravitational force of the planets considering three different cases of eccentricities for the planets of system. We found that approximately two percent of comets considered collided with planets and the majority of collisions being with gas giant planets, thus, water delivery is possible. Kepler-90 is an extrasolar system composed of eight planets orbiting a single star and have a hierarchical distribution, that is, the innermost planets are terrestrial planets; the intermediate ones are super-Earths and the outermost planets are gas giants. The choice of this system is mainly due to its similar arrangement to the planets in our Solar System. However, K90 is a compact system and the outermost planet has an orbital radius of approximately one astronomical unit.
In the current stage of the work, we study the formation and orbital characteristics of cometary reservoirs created during the system formation process. Therefore, we no longer consider hypothetical positions of exocomets as in the initial stage of the work. To study the formation of the reservoirs, we consider the dynamic evolutions of the planets in the Kepler-90 system during the formation process to the currently known configuration using the REBOUND N-body integrated system. We consider the accretion and migration of ice giant planets in the Solar System as a theoretical basis (Izidoro et al. 2015). Thus, we analyzed the collisions of bodies from these reservoirs with the K90 planets and compared them with previous results.

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Poster

CBDO 087 - A

Evaluation of centroiding algorithms for an autonomous star tracker

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This work presents a comparison between centroiding algorithms targeting an autonomous star tracker being developed at INPE, in terms of centroiding accuracy and computational cost. The algorithms compared include the traditional center of mass (COM) centroiding algorithms and shape fitting algorithms. This work also discusses about background level subtraction and image sensor array non-uniformity correction.

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Poster

CBDO 088 - A

Tidal evolution in dwarf planets systems

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Dwarf planets are Solar System objects orbiting the Sun that are massive enough to be in hydrostatic equilibrium but do not dynamically dominate the environments to which they belong. Most confirmed dwarf planets and all candidates are located in the trans-Neptunian region. The Pluto-Charon and Eris-Dysnomia systems exhibit synchronous rotation with their orbital motions. This rotational state is a natural consequence of tidal interactions between the dwarf planet and its main satellite. In this work, we investigate the tidal evolution of seven systems (Pluto-Charon, Eris-Dysnomia, Salacia-Actaea, Gonggong-Xiangliu, Orcus-Vanth, Varda- Ilmarë and Quaoar-Weywot) following Correia et al. (2022). We integrate the mean equations for the variation of semi-major axis, eccentricity, and rotations over four billion years to examine when and how these systems would achieve synchronous motion. Through contour plots, we analyze the parameter space to determine the optimal values for the initial rotation speed and the viscosity of the primary body. Additionally, we also investigate the evolution of the semi-major axis to establish whether migration is divergent or convergent along the tidal evolution of the systems.

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Poster

CBDO 089 - A

Stable configurations for the retrograde planet in the ν Octantis system

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More than a decade ago, several studies were published in order to investigate the nature of the periodic signal in radial velocity data for the ν Octantis binary system. The most likely explanation is the existence of a planet in a retrograde orbit with respect to the binary [1]. The ratio of the orbital periods between the potential planet and the binary is close to 5/2, so the possibility of a mean motion resonance configuration arises. Using the numerical integrator REBOUND [2], we explore the phase space through random initial conditions and assess long-term stability of the system through frequency analysis [3]. Due to its large variation and in order to compare with the Keplerian fit, we also calculate the mean value of the planet's orbital period for all initial conditions. Our analysis allows us to explore all possible configurations for the planet and to identify those which can be in resonance. This method is also useful to analyse generic multidimensional phase spaces.

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Oral Communication

CBDO 090

A Study on Space Debris Generated by a Break-Up Event

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The study of object fragmentation is fundamental for the development of space missions, as the space around the Earth has an increase in space debris over time due to fragmentation events. To contribute to studies on fragmentation and debris propagation, this work is dedicated to the study of a fragmentation model based on an exponentially decreasing mass distribution and an isotropic distribution of velocity fields, so that the lower mass debris generated by fragmentation have higher speeds and vice versa. Once the initial conditions of the debris resulting from fragmentation are obtained, the trajectory of the debris cloud is propagated. Analyzes were carried out on the mass distribution and velocities of the debris, in addition to evaluating the behavior of debris propagation.

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Poster

CBDO 091 - A

Planetary resonances: properties for arbitrary eccentricities and mutual inclinations

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The model proposed by [1] has successfully replicated the properties of planetary resonances when compared to purely numerical results (see, for example, [2], [3]). This model enables us to track the emergence and disappearance of equilibrium points as planetary orbital elements evolve over time. With this model, we can create an "atlas" of resonances, identifying regions in the space of semi-major axis (a), eccentricity (e), and inclination (i) where resonance overlaps occur, leading to chaotic evolution. Conversely, it also highlights regions where the absence of resonances results in secular evolution. Additionally, we have discovered that in some systems, isolated 1:N resonances persist amidst chaotic seas of overlapping resonances. In this work, we will present examples of resonant eccentric systems with assuming different mutual inclinations.

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Oral Communication

CBDO 092

Accretion and Uneven Depletion of the Main Asteroid Belt

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The main asteroid belt (MAB) is known to be primarily composed of objects from two distinct taxonomic classes, generically defined here as S- and C-complex. The former probably originated from the inner solar system (interior to Jupiter's orbit), while the latter probably originated from the outer solar system. Following this definition, (4) Vesta, a V-type residing in the inner MAB (a < 2.5 au), is the sole D > 500 km object akin to the S-complex that potentially formed in situ. This provides a useful constraint on the number of D > 500 km bodies that could have formed, or grown, within the primordial MAB. In this work, we numerically simulate the accretion of objects in the MAB region during the time when gas in the protoplanetary disk still existed while assuming different MAB primordial masses. We then account for the depletion of that population happening after gas disk dispersal. In our analysis, we subdivided the MAB into five subregions and showed that the depletion factor varies throughout the MAB. This results in uneven radial- and size-dependent depletion of the MAB. We show that the MAB primordial mass has to be < 2e-3 Earth Masses. Larger primordial masses would lead to the accretion of tens to thousands of S-complex objects with D > 500 km in the MAB. Such large objects would survive depletion even in the outer subregions (a > 2.5 au), thus being inconsistent with observations. Our results also indicate that S-complex objects with D > 200–300 km, including (4) Vesta, are likely to be terrestrial planetesimals implanted into the MAB rather than formed in situ.

Poster

CBDO 093 - A

Stellar Occultation Technique for studying the Trojan (1172) Aneas

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A stellar occultation occurs when there is an alignment between an observer on Earth, an occulting object of the solar system, and a background star whose flux is temporarily blocked. This is a valuable technique for studying small bodies and determining their physical parameters, such as shape, size, topography, and astrometric position, in addition to being able to indicate the presence of rings, satellites, and atmospheres. The already known characteristics of the objects can also be improved, since the technique allows the refinement of orbits and offers precision in the order of kilometers [1]. The target of this study was the asteroid (1172) Aneas, a Jupiter Trojan located at the Lagrange point L5. It has a diameter of about 118 kilometers, making it one of the largest Jupiter Trojans, and is a D-type asteroid, with a low albedo [2]. The work is based on collaboration with amateur astronomers around the world who have observed predicted stellar occultation events by Aneas. We analyzed five events that occurred between 2020 and 2022, obtained by amateur observers from Spain, France, Peru, Turkey and the USA. The analysis methodology followed the procedures in [3] and other relevant references. In summary, we used the SAOImageDS9 tool to visualize the astronomical images and manually determine the initial parameters of our analysis, and then we used the PRAIA software to perform the photometry of the data. Next, we use SORA, a Python library, to calculate the duration of each event, graphically analyze the light curve obtained by photometry, and finally find the moment of occultation. The data are optimized to obtain the best possible result, and we finally obtain the desired physical properties of Aneas, including the astrometry and shape of this body.

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Poster

CBDO 094 - A

A scenario for the origin of moons around super-Earths and their detectability

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Exomoons are natural satellites that orbit extrasolar planets. To date, more than 6,000 planets have been identified, but no exomoons have been detected yet. However, this may change with advancements in technology. In this work, we analyze the formation of moons around super-Earths, planets that have a mass greater than that mass of Earth and are smaller than gas giant planets, and a method for the possible detection of these bodies.
To analyze the formation of moons, we consider a debris disk around the planet, the disk being formed through the collision of a proto-planet with the super-Earth. We consider N-body simulations and were performed using the numerical integrator Rebound.
Regarding the disk that forms the moons, we conducted several analyses considering different parameters, such as surface density, particle size (using the alpha and beta coefficients from Kokubo et al., 2000), and the initial mass of the disk. For the moon formation process, we modeled two different collision approaches, including hard-sphere collisions and collisional accretion. In the hard-sphere, the collisions are similar to elastic collisions, while in the second case, two particles remain gravitationally bound for a specific velocity limit.
We found that, for different values of disk density (characterized by beta), assuming beta between 0 and 5 in our simulations, the final mass of the satellite varies little, despite the collision characteristics being different in different simulations and the system being chaotic.
We also generated the light curves considering different satellite sizes and different values of the semi-major axes of planets, ranging from 1 to 50 au. Regarding the duration of the eclipses, we observed that for the largest radius of the satellite considered (100 moons radius), the eclipse lasts 0.68 days, while for the smallest radius value, the eclipse duration does not change significantly, being approximately 0.53 days and the depth is minimal. For the distance of the planet from the star, the duration exceeds 3 days when the semimajor axis is greater than 40 au.

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Poster

CBDO 095 - A

Equilibrium figure for Quaoar using stellar occultation

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Quaoar is a trans-Neptunian object (TNO) orbiting the Sun at 43.51 au; it has a satellite (Weywot) and two rings that are beyond the Roche limit (Morgado and Perira, 2023). From 2011 to 2024, 15 stellar occultations constrained the shape of Quaoar, making it possible to determine a three-dimensional shape for the body, as done for Chariklo by Morgado et al. 2021; additionally, it was also possible to determine a rotation period. The results show that Quaoar has equatorial semi-axes a = 604.9 ± 2.5 km and b = 539.8 ± 2.3 km, and a polar semi-axis c = 501.9 ± 2.8 km, classifying it as a triaxial object. It has a rotation period of 17.6320 ± 0.0002 h. Quaoar mass is obtained from the orbit of its satellite, and thus its density can be calculated (ρ = 1760 ± 37 kg m−3. Assuming the premise that Quaoar is in hydrostatic equilibrium, it is conceivable that its oblateness is caused by both its rotation and tidal force from its satellite. If this is true, we can calculate Weywot's mass using the Jeans equilibrium shape (Folonier, 2022). Under this assumption, we obtain a mass of M = 4.54 × 10^18 ± 7.72 × 10^17 kg. Both the method of obtaining the dimensions and rotational properties of Quaoar and the determination of the satellite's mass will be presented in this work. These values give us a better constraint to the resonance regions, helping us understand the confinement mechanism of Quaoar's rings beyond the Roche limit.

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Poster

CBDO 096 - A

Secular dynamics of small bodies perturbed by an eccentric giant planet

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Particles under the potential of a star and disturbed by a massive planet can have different kind of evolutions. The evolution is said to be secular when the semi-major axis is fixed and the other orbital elements oscillate with determined fundamental frequencies. In this work we will present some of the evolutionary regimes existing when an eccentric planet is perturbing a non-circular and non-coplanar particle. We found a strong dependency on initial inclination for the resulting evolution and we argue that the changes in the regimes are strongly related to the frequencies of the nodal and perihelion time evolutions. Due to the lack of analytical models in the conditions we worked with, we made use of semi-analytical double averaging models of the spatial disturbing function, based on the method described by Michtchenko & Malhotra (2004), and performed numerical integrations using EVORB (Fernández et al., 2002).

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Poster

CBDO 097 - A

Exploring the Formation of the TOI-1130 Planetary System Using a Hydrodynamic Approach

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Our study examines planetary systems that feature hot Jupiter-type planets alongside super-Earth or mini-Neptune-type planets in close-in orbits [1]. Historically, these systems were rarely observed, likely due to the formation and evolutionary processes of hot Jupiters. However, recent years have seen a notable increase in the discovery of such systems. This surge in findings provides fresh perspectives on the formation and dynamics of these planetary systems, highlighting the importance of studying these configurations. In this context, our work specifically analyzes the formation of the TOI-1130 system, which includes an inner planet within a system that also hosts a hot Jupiter—a gas giant orbiting very close to its star. The primary goal is to understand how the presence of this hot Jupiter influences the formation and dynamical evolution of the inner planets. To achieve this, we use computational simulations with the FARGO 3D code [2], which solves the Navier-Stokes equations in a circumstellar gas disk. Our approach also incorporates the mutual gravitational interactions between the planets. Our methodology explores various parameters of the protoplanetary disk and analyzes the orbital trajectories of the planets to understand their evolutionary processes. We focus on elucidating the dynamic mechanisms that lead to the final configurations of planetary systems, considering scenarios of in-situ formation, migration, and planetary resonances. Simulations with the FARGO 3D code, which resolve the hydrodynamic equations in the protoplanetary disk, are essential for investigating the complex phenomena associated with planetary formation. This robust and detailed approach, although computationally demanding, offers an in-depth understanding of planet formation in systems with hot Jupiters.

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Oral Communication

CBDO 098

Development of an electronic system for a CanSat

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Due to the high cost and the difficulty of transporting objects into space, a growing need has arisen to design increasingly smaller satellites, aiming to reduce the costs and risks of missions. This has brought attention to the category of small satellites, also known as Smallsats. Simultaneously, many educational institutions have started using smaller satellites in projects for their students due to the lower financial investment required for launch, giving rise to CanSat and CubeSat in response to this demand.
Unlike the CubeSat, the CanSat is designed as a meteorological probe that can be launched by a small rocket without crossing Earth's atmosphere. This makes the project much more cost-effective and less complex compared to a CubeSat, making it an ideal entry point for beginners in the field. Therefore, the goal of this scientific research is to complete the entire production cycle of a CanSat.

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Poster

CBDO 099

Earth-to-Earth transfer via powered lunar swing-by

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This work aims to solve the problem of transferring a spacecraft from a Low Earth Orbit (LEO) to a High Earth Orbit (HEO), both circular and coplanar around Earth, using a lunar swing-by. The process begins with an initial impulsive velocity increment to place the spacecraft into a transfer trajectory with an apogee high enough to reach the Moon's gravitational sphere of influence. A swing-by maneuver, either natural or propelled, is executed near the Moon to return the spacecraft close to Earth. At the closest approach to the Moon, a second impulsive velocity increment is applied, characterizing the propelled swing-by maneuver. The third velocity increment decelerates the vehicle near Earth, placing it into the desired final orbit. Two models are employed to solve this transfer problem. The first model uses the two-body problem with the patched-conic approximation, where sections of conics are connected to approximate the trajectory, considering the gravitational influence of either Earth or the Moon in each section. The second model uses the planar circular restricted three-body problem (PCR3CP), where the gravitational fields of both Earth and the Moon are considered simultaneously. The solution involves formulating two-point boundary value problems, solved using the Newton-Raphson algorithm. An optimization problem is also proposed based on the boundary value problems' results, solved using the gradient with restoration algorithm. Additionally, a study of fuel consumption is conducted for various final HEOs, represented by the sum of velocity increments. This study compares the three-body problem model and the patched-conic approximation to classical transfers like the Hohmann maneuver and the bi-parabolic transfer. The optimized solution of the patched-conic approach shows good agreement with the PCR3CP, especially considering different Earth arrival orbit altitudes and variations in the applied impulse during the lunar swing-by. For Earth arrival altitudes exceeding 47,000 km, applying a decelerative impulse during the lunar swing-by is efficient in terms of fuel consumption compared to the classical Hohmann transfer.

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Poster

CBDO 100 – A

Estimation of the viscosity of trans-neptunian dwarf planets through the synchronous motion of Eris

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Eris is a dwarf planet located in the region beyond Neptune in the Solar System, specifically in the scattered disk. Recent observations have shown that the rotation of Eris is synchronized with the orbit of Dysnomia, its only known moon. This synchronization also occurs in the Pluto system, between the rotation of the dwarf planet and the orbit of Charon. Synchronous configurations result from the tidal evolution over timescales that depend on the physical parameters and orbital configurations of the interacting bodies. In this study, we investigate the orbital and rotational evolution in the Eris-Dysnomia and Pluto-Charon systems using the tidal creep model. By integrating the averaged equations governing variations in semi-major axis, eccentricity, and the rotations of both bodies, we identify the ranges of viscosity and initial rotation values for the dwarf planet that lead to synchronous motion over the integration timespan, depending on the system. The results of this work provide insights into the estimation of physical parameters and initial rotations of dwarf planets, which could simultaneously reveal important information about the internal composition of the distant and cold objects in the Solar System.

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Oral Communication

CBDO 101

Study of the Transport Dynamics in the Three-Body Problem

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In the last decades, the study of the transport dynamics in the Restricted Three Body Problem (RTBP) has gained relevancy due to the fact that the investigation of the transport mechanisms associated with the invariant hyperbolic manifolds, which are connected to the periodic orbits around the equilibrium points, has several practical applications in astrodynamics, specially, in space mission design with low energy.
In this context, the escape basins are crucial to understand the dynamics of the system's solutions. They provide a valuable comprehension about the transport mechanisms of particles and the system's stability through time. However, the development of these basins requires the use of numerical methods to integrate several initial conditions and evaluate if the resulting trajectories satisfy the pre-established criteria to make these basins. Even though this traditional approach might be effective, it is limited by its capability of efficiently exploring the phase space of possible solutions. In particularly, the computational cost of obtaining these basins can be extremely high.
Nevertheless, this academic work is a preliminary study of the use of heuristic methods based on genetical algorithms to determine regions with specific types of solutions for the system. These algorithms are powerful optimization methods inspired by the natural selection, widely applied in several areas including astrodynamics and celestial mechanics. Moreover, the use of genetic algorithms offers several advantages over traditional numerical methods because they are capable of exploring more efficiently the solution space, dynamically adapting through time to find optimal or suboptimal solutions.

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Poster

CBDO 102

Studying plasma with electrostatic energy analyzer with different geometries and a RF choker filter

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Plasma is a state of matter with several properties, such as electronic and ionic temperature, density, and frequency. One approach to analyze plasma is through an electrostatic analyzer, which allows determining the kinetic energy of charged particles within the plasma. In this work, an electrostatic analyzer was studied and developed in a device configured as a Helicon Plasma Thruster (HPT). The argon plasma, excited at the first 1s level, will be investigated. Additionally, we applied an RF Choke filter to reduce the noise propagated by the plasma, generated by the RF antenna used to create the plasma. Two available geometries for the electrostatic analyzer were considered: grid and flat, as well as conical. Throughout the text, we discussed which of these geometries provided the best results under our argon plasma conditions.

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Poster

CBDO 103

Rendezvous Maneuvers Optimized by Genetic Algorithm for Space Debris Removal

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The removal of space debris (space cleaning) is crucial to the safety and sustainability of space operations. Backward integration is a traditional method for planning Rendezvous maneuvers in “Space Clean” missions, but it has limitations in efficiency and reliability. This work proposes the use of a Genetic Algorithm (GA) to optimize the planning of Rendezvous maneuvers, improving mission performance. GA simulates the evolution of a population of solutions, applying crossover and mutation operators to generate new Rendezvous trajectories and selecting the most promising ones based on a multi-objective fitness function. The fitness function evaluates the efficiency of the maneuver in terms of mission time, propellant consumption and collision risk, considering dynamic perturbations and propulsion constraints. Our results showed that the GA was able to find more efficient and reliable Rendezvous solutions than backward integration, significantly reducing planning time and the risk of mission failure. The flexibility of GA allows the incorporation of several factors in the optimization process, such as propellant constraints, mission time and collision hazards, ensuring robust and realistic solutions.

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Poster

CBDO 104 - A

Testing (911) Agamemnon 3D model with new Stellar Occultations and synthetic light curve generations.

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Studying small bodies in the Solar System is crucial for understanding its early stages. Specifically, investigating the shape of Jupiter Trojans can provide us with information on their collisional past, which is related to Jupiter's early planetary migration [1]. In 2019, a stellar occultation of the Jupiter Trojan (911) Agamemnon revealed the presence of a satellite [2]. Given its scientific significance, we organized several stellar occultation campaigns in recent years, resulting in 10 positive events and a total of 15 chords. To better understand Agamemnon's shape, we compared new occultation chords and rotational light curves obtained from the Asteroid Light Curve Data Exchange Format database (ALCDEF) and the Pico dos Dias Observatory (OPD) with its 3D model provided by the Database of Asteroid Models from Inversion Techniques (DAMIT) [3]. The observed light curves were compared to synthetic curves generated by the model within its parameter uncertainties (lambda = 126 ± 5°, beta = 0 ± 5°, P = 6.58179 ± 0.00002 h). Using the Root Mean Squared Deviation method, with parallel processing and genetic algorithms, a new 1-sigma uncertainty region was inferred for each parameter (lambda = 128.81 ± 0.80°, beta > 3.95°, P = 6.581800 ± 0.000004 h). These results were used to adjust the occultation chords to the limb extremities of the 3D model using the chi-squared method. To achieve a chi-squared per degree of freedom equal to the unit, a radial dispersion of 6 km was required for the model limb. The occultation tests did not provide further restrictions on the rotational parameters, but they determined a volumetric equivalent diameter of 153.80 ± 3.44 km for Agamemnon's 3D model presented by DAMIT. To obtain a better description of Agamemnon's model considering the new data, a new three-dimensional shape was generated using the All Data Asteroid Modeling software (ADAM), resulting in a shape that better agrees with rotation and occultation data with lambda = 132.05 ± 1.11°, beta = 14.68 ± 0.79°, P = 6.581804 ± 0.000002 h, and a volumetric equivalent diameter of 149.20 ± 1.54 km.

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Poster

CBDO 105

Conception and build of a Langmuir's probe for analysis of a RF discharge generated plasma.

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A Langmuir's probe main function is to extract the electronic properties of the plasma, such as electron density, electron temperature, plasma potential and the distribution function. The information is obtained through a characteristic current-voltage curve (I-V Curve), collected through a perturbative current induced in the plasma by the probe. It is known that a low-pressure plasma can be generated by several methods, one of which is ionization by electromagnetic waves produced by an antenna. However, this ionization method causes interference in diagnostics, as the probe material is conductive. Therefore, the design and development of a probe that compensates for this signal and brings more precision to measurements is necessary. The probe that will be produced in this project consists of an insulating rod - glass and 1000mm long - that involves a conductive wire (approximately 0.3 mm), in this case tungsten, exposed to the plasma. The measurement system will consist of a probe, compensating circuit for a 13.56 MHz signal and data collection circuit. Thus, the probe will be inserted into a plasma source generated by RF at low pressure and the analyzed results will be exposed in this article.

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Poster

CBDO 106

Constraining physical and orbital parameters for possible extrasolar ring systems

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No exoplanetary ring has been confirmed yet. However, observations in 2007 of the star J1407 revealed a prolonged dimming event, which has been attributed to the passage of an inclined disk with a radial extension of 0.3 AU. This event suggests the possible presence of an exoplanetary ring system associated with an unseen secondary companion, J1407b. Similarly, the star PDS 110 experienced two notable eclipses in 2008 and 2011, each with a depth of 26% and lasting 25 days. A plausible explanation for these eclipses is the existence of a ring system around an unseen giant planet, PDS110b.

In this study, we aim to constrain some orbital and physical parameters that are not well determined by observational data alone. We applied two different approaches to study the stability of each system. First, we numerically integrated the three-body problem (star, planet, and particle), exploring millions of different initial conditions for the PDS110b system and ruling out those that did not match the observations. The most likely result indicates an almost circular orbit for the planet, with a mass greater than 35 Jupiter masses, a ring inclination of less than 60º, and a radius between 0.1 and 0.2 AU.

In the second approach, to significantly reduce computational efforts, we utilized machine learning algorithms to predict stable regions around J1407b. These algorithms achieved an accuracy greater than 93% using a dataset with only 10% of the numerical simulations required by the first approach. The results suggest that J1407b has a mass > 50 Jupiter masses, an eccentricity of approximately 0.3, and that the eclipse can be explained by both prograde and retrograde rings.

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Poster

CBDO 107

Cloud Space Debris: Behavior Analysis of Debris in Clouds and Prospection of Collection Missions

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The document examines the growing threat posed by space debris accumulated over decades of space exploration. With more than 35,000 objects in orbit, most of which are uncontrolled debris, this study analyzes the orbital evolution of a randomly generated debris cloud. The cloud is specified by a normal mass distribution, analyzing each particle individually in the context of the restricted three-body problem (Earth-Moon), where the mass of each particle is negligible compared to the primary bodies.
The study emphasizes the importance of sustainable practices in space to ensure the continuity of space activities in the future. This includes the effective management of space debris, the implementation of clean and efficient technologies, and international collaboration. Mitigating space debris is essential to promoting a safe and sustainable orbital environment for future generations.
A practical example discussed is the collision between the Iridium 33 and Cosmos 2251 satellites in 2009. This was the first recorded collision between two satellites in orbit, resulting in a large amount of debris. The report describes the predicted approach and subsequent collision, which generated thousands of pieces of debris, some of which are still in orbit. This collision illustrates the severity of the problem and the need for effective approaches to space debris mitigation.
The debris cloud is generated with 500 massive objects, normally distributed with an average of 10kg and a standard deviation of 3kg. The simulation considers perturbations such as atmospheric drag and the Earth-Moon gravitational field, using the orbital data of the CBERS 4 satellite as a reference. The conclusion highlights that particle clouds formed by explosions of natural or artificial bodies follow the same orbit as the body that generated the explosion, but their individual trajectories can be perturbed, leading to possible collisions with Earth. Managing this debris is fundamental to minimizing risks and preserving the space environment.
References are cited throughout the document, including studies on space debris mitigation and its environmental consequences. The integration of advanced technologies and international cooperation are essential to effectively address the problem, ensuring a safer and more sustainable space for the future.

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Poster

CBDO 108 - A

A Hamiltonian for 1/1 rotational secondary resonances, and application to small satellites of Saturn and Jupiter

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In this work, we study the dynamics of rotation of the small satellites Methone and Aegaeon and revisit previous works on the rotation of Prometheus, Metis, and Amalthea. In all cases, the surfaces of section computed with the standard spin–orbit model reveal that the synchronous regime with small amplitude of libration shares another large domain in the phase space. We reproduce and apply the hamiltonian theory given in Wisdom 2004 [1] to analytically characterize the detected structure as being a secondary resonance where the period of the physical libration is similar to the orbital period of the satellite. We also show that the amplitude of libration in the secondary resonance is always larger than in the case of the other mode. Since the current rotational states of these sorts of satellites should be synchronous, our results can be considered in evolutionary studies of their rotation.

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Oral Communication

CBDO 109

Stable Regions in the Kepler-80 System

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In this work we analyzed the stability regions of the planetary system Kepler-80, discovered in 2012 by the Kepler Space Telescope, in order to determine the regions that may contain small planets or asteroids. The Kepler-80 system is interesting since it has a resonant chain involving five of its six planets [1], which grants the system some stability, and it's a compact system, with the planets (Kepler-80f, Kepler-80d, Kepler-80e, Kepler-80b, Kepler-80c and Kepler-80g) being within 0.04 AU and 0.12 AU of the star [2]. Also, the star is slightly smaller than our Sun and the planets are classified as super-Earths [3]. The Mercury package was chosen to perform the numerical integrations and obtain the data necessary to analyze the system. The integrations included the star, the six planets and a set of 5000 particles located between the planets, integrated for 10^4 times the orbital period of the external planet, Kepler-80g. The grid of initial conditions a (semi-major axis) x e (eccentricity) for the particles ranged between approximately $0.04 < a < 0.11$ and $0 < e < 0.2$, with $\Delta a = 2\times10^{-4}$ and $\Delta e = 0.02$. Our results show that 1426 particles collided, and none are ejected from the system, with the ejection distance equal to 1 AU. The planets which suffered the most collisions were Kepler-80d and Kepler-80c, which are the heavier planets, and the region with the most surviving particles is $0.06 < a < 0.075$ and $0 < e < 0.2$. In this work, mean motion resonance between particles and planets will also be analyzed and presented.

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Acknowledgment
CNPQ

Poster

CBDO 110 - A

Determining the size and shape of the Trojan (1143) Odysseus through stellar occultation technique, reverse light curve analysis and 3D modeling

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The asteroid (1143) Odysseus is a minor body of the Solar System located near Jupiter's orbit, approximately 5.2 astronomical units (AU) from the Sun, classifying it as Trojan. It was discovered on January 28th 1930 by Reinmuth, K. at Heidelberg, and its physical and orbital characteristics have since been determined, including a diameter of 114.6 ± 0.6 km, a rotational period of 10.114 ± 0.079 hours, and a magnitude of 8.418 ± 0.003, among others.This study employs the technique of stellar occultations, complemented by rotation curves and reverse light curve analysis to achieve a more precise determination of its shape and dimensions. The work utilizes data from both single and multi-chord occultations as well as rotation observations from 2014 to 2021, derived from the ALCDEF Database. In addition to providing precise astrometric positions that enhance the object's ephemeris and prediction for future occultation events, such data can facilitate the construction of a 3D model with the ADAM library in the search to more accurately describe the Trojan's size, shape and dynamics.

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Poster

CBDO 111 - A

Rings diversity around Small Solar System bodies: Discoveries and Detection Limits

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Until 2013, ring systems were known only around the four giant planets. This perspective shifted when a stellar occultation revealed the presence of two rings around the minor planet (10199) Chariklo, a Centaur object. In January 2017, another occultation revealed the existence of a ring encircling the dwarf planet (136108) Haumea (Ortiz et al. 2017). The third minor body with a confirmed ring system is the big Transneptunian Object (50000) Quaoar. Intriguingly, Quaoar's ring system is far beyond the classical Roche limit (∼1,780 km). The innermost ring lies about 2,520 km from the Quaoar center, and the outermost ring lies about 4,100 km. The latter presents significant longitudinal variations concerning optical depth and width. Similarly, observations of flux variations in occultation light curves over two decades of the Centaur (2060) Chiron suggested the presence of material in its surroundings. Published works have interpreted these materials as rings, shells, and jets, but a definitive classification is premature. In this context, stellar occultations by Chiron were conducted in 2018, 2019, 2022, and 2023 to characterize the observed structure, revealing that the material around Chiron presents an evolving structure, which can result from outbursts feeding putative rings. We have also identified objects that presented outbursts and thus could be capable of hosting rings, such as the Centaurs Echeclus and 29P/Schwassmann-Wachmann 1. Stellar occultations by them were observed and used to search for rings or other confined signatures. In cases where detection was not achieved, we obtained upper limits for detecting additional structures. The results and implications presented in this talk are part of my doctoral thesis defended this year. This ongoing work can result in discovering new ring systems, other confined structures, or even small satellites around these small bodies in the solar system.

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Poster

CBDO 112

Collision Avoidance Maneuvers Optimization Using Evolutionary Algorithms

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The exponential increase in the number of satellites in orbit in recent years has led to the generation of a congested space environment dominated by both active satellites and space debris. Therefore, collision avoidance maneuvers have become crucial to ensure the safety of space assets. Due to the fact that a satellite has a limited amount of propellant for maneuvering, and the importance of continously making orbital correction maneuvers, the constant performance of collision avoidance maneuvers with high fuel consumption can reduce the satellite's lifespan and therefore must be planned to optimize fuel consumption. This research addresses the application of evolutionary algorithms, specifically genetic algorithms, with the aim of determining an orbital maneuver that, given a scenario where there is a substantial risk of collision, minimizes this risk and presents lower fuel consumption.
Given that the space environment today has a complex dynamics, with several objects in orbit, the scenario where a satellite controlled by an operations center presents within a few days one or more conjunction events involving the asset and other objects is studied. Therefore, it is necessary to plan a maneuver that mitigates the risk of collision of each conjunction. This maneuver cannot also alter the satellite's orbit in such a way as to send it on a collision course with other objects. Thus, a genetic algorithm is implemented to optimize fuel consumption in the calculation of collision avoidance maneuvers, addressing a first scenario consisting of multiple conjunctions, however disregarding the possibility of the maneuver causing a conjunction with another object. Next, the problem is studied considering objects that orbit the surroundings of the satellite. For all cases, the metric that define a conjunction is the maximum probability of collision higher that a treshold established.
In relation to the maneuver, two different burn strategies are considered: the first being a single impulse in the tangential direction to the orbit at an instant before the first conjunction and the second strategy is the performance of two impulses (one before and another after the first conjunction) in a random direction (radial, tangential and perpendicular to the orbital plane).

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Poster

CBDO 113 - A

Staging and trajectory optimization of VLM-1 satellite launch vehicle

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The insertion of a payload into orbit is a highly complex activity, largely due to the difficulties and high costs involved in the development and operation of launch vehicles. Current technology allows only a small fraction of the total mass of the launcher, usually between 1% and 4%, to be utilized as payload. To achieve this performance, it is essential that both the vehicle design, as well as each launch, are carried out in a way to best use the energy onboard the vehicle. During the design phase, one of the main activities influencing the performance of a launch vehicle is its staging definition, that is, the number of stages and the distribution of structural and propellant mass among them. During the operational phase, the greatest influence on the vehicle performance is due to its trajectory from launch to orbital insertion point. This work investigates the problems of staging and trajectory optimization of launch vehicles, two complex problems belonging to the class of optimal control problems. The approach is carried out through the so-called direct methods, where the original optimal control problem is transformed into a nonlinear programming problem. Two methodologies for the transformation are used and compared: transcription by the multiple shooting method and transcription by the Hermite-Simpson collocation method. For the resolution of the nonlinear programming problem, an extension of the algorithm of conjugate gradient with restoration for function minimization is proposed. A computational tool for solving the problems of staging and trajectory optimization of launch vehicles is implemented and used in test cases of the Brazilian Microsatellite Launch Vehicle (VLM-1), in problems with increasing complexity. The results obtained show good agreement with those from a commercial optimization tool, demonstrating the suitability of the proposed methods and the computational implementation of the optimization algorithm.

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Poster

CBDO 114

Twistless bifurcations on isochronous islands

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In Hamiltonian twist systems, isochronous islands emerge in the phase space as a response to multiple resonance perturbations. Along with the islands, secondary shearless tori appear around elliptic points and modify the nondegeneracy of the frequencies. In this research, we study the two-harmonic standard map, a twist area-preserving map composed by two resonant perturbations. From our numerical results, we observe the emergency of different isochronous islands in the phase space and, from the analysis of the internal rotation number, we can identify local shearless tori represented by an extremum point in the rotation number profile. Thus, we can observe locally nontwist properties in twist maps.

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Poster

CBDO 115

Exploring the Lambert Problem: An Analysis of Orbital Maneuvers

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The Lambert Problem, proposed by Johann Heinrich Lambert and solved by Joseph-Louis Lagrange, is crucial for orbital maneuvers. Although formulated in the 18th century, it remains relevant in areas such as orbital rendezvous, flybys, and orbit corrections. It aims to change the state of a spacecraft from an initial position and velocity at a given time to a final position and velocity at another time, with the least possible fuel consumption. This approach is essential in missions that require precision and fuel economy.
Furthermore, the research aims to compare orbital transfer methods for spacecraft. Programs in Python and Matlab were developed to implement and compare techniques for calculating bi-impulsive orbital maneuvers. The first technique uses the Lambert Problem, while the second employs restricted three-body dynamics. The analysis considers both fuel consumption and maneuver duration, including the use of genetic algorithms.
Preliminary results indicate that the Lambert Problem provides an efficient basis for initial maneuver planning. For example, a code was developed to calculate the minimum total velocity increment required for the maneuver, analyzed through the Lambert transfer in Python and Matlab. The codes yielded satisfactory results in tests, minimizing fuel consumption and optimizing the planned trajectory.

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Poster

CBDO 116

University Satellite Instrumentation - Cubesat V2

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There is an emerging demand in the engineering sectors, especially in the aeronautical, telecommunications, and aerospace sectors, for efficient, modern, and advanced solutions. The 20th century witnessed profound transformations brought about by these sectors, with rapid advancements and expanded horizons. Satellites became part of these solutions, and educational institutions were able to participate in this discussion through the creation and development of low-cost CubeSats, driving various research efforts.
The project proposed improving the previous cubesat's structure to broaden its scope of action, focusing on redesigning the structure to withstand greater stresses and more aggressive environments. The main objectives were changing the chassis due to deformations caused by high temperatures, designing new attachments and organization for the onboard electronics, making changes in the electrical design for greater safety, and creating thermal protection for the internal components.
Studies were conducted to make the cubesat capable of new challenges, such as knowledge olympiads. Aluminum alloy 1100 was chosen for meeting the requirements of low cost and ease of supply. There was also a change in the device's geometry to ensure a modular internal arrangement. The electrical design aimed at protection against polarity reversal and a more suitable power supply for long-duration missions. The device's thermal protection used materials such as Mylar and Kapton, which are common in the aerospace industry.

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Bolsa PIBIC CNPQ #5654/2022

Poster

CBDO 117

Dynamic tides in the exoplanetary system CoRoT-3b.

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COROT-3 is a system formed by a star and a massive planetary companion (a brown dwarf) with a large stellar obliquity. Notwithstanding the strong tidal interaction of the two bodies, the synchronization of the star rotation has not yet been reached: the stellar rotation is faster than the orbital period. The use of classical tidal evolution models, which do not take into account the stellar obliquity, allowed us to estimate that the stellar tidal relaxation is in the range 40-70 sec^{-1}. The first results obtained with the extension of the creep tide theory to the full 3D problem, taking the stellar obliquity into account, show the tidal bulge oscillating between the two hemispheres. Near the synchronous rotation of the companion, the rotation speed varies around a stationary value and consequently the lag also changes: the bulge may be lagging behind or advancing the rotation of the planet. The stellar obliquity oscillates around the given initial value while the planetary obliquity, assumed high initially, is damped to a smaller equilibrium value. These results correspond to times of the order of a few thousand years. The resulting high-order system of differential equation is stiff and studies of the evolution over larger spans of time needs the adoption of one approximate solution for the parametric equations responsible for the stiffness of the full system.

Oral Communication

CBDO 118 - A

Surface Characteristics of Asteroid (346724) 2011 UW158: A Large Super-Fast Rotator

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The asteroid 2011 UW158 is a potentially dangerous NEA for a possible collision with Earth. The particularity of this asteroid is its rotation period due to its size. 2011 UW158 has a rotation period of 0.61071 h, approximately 36 minutes, according to observations at the Sertão de Itaparica Astronomical Observatory. Additionally, it is 600 m in diameter, which is not commonly observed in the asteroid population. Due to this peculiar relation between its size and rotation period, we are motivated to study the dynamics on the surface of this asteroid, analyzing the regions of stability on its surface for particle retention or ejection. To measure this, the surface characteristics, as slopes, were computed across the asteroid. By definition, the slope is the supplementary angle between the normal vector of a face and the acceleration vector on that face. If it is greater than 90° , we have a possible ejection of the particle about the surface; if it is smaller than 90° , we have a possible accumulation of particles on the face. To determine the slope, the vertices and faces of the asteroid, the normal vector, and the acceleration on each face were needed. 2011 UW158 has 1,022 vertices and 2,040 faces. With a Python program, the normal vector and ten random points on each face were calculated, and with a Fortran program, the acceleration on each face was calculated. Moreover, finally, with a Python program, the slopes was computed. There are still uncertainties regarding its composition and bulk density. Then, we computed the acceleration and slope for five values of densities: 1.33g/cm3 , 2.25g/cm3 , 2.50g/cm3 , 2.80g/cm3 , and 3.50g/cm3 . Our results show that slopes greater than 90° are concentrated in the equatorial region of the asteroid and decrease with longitude, indicating that the equatorial region of the asteroid 2011 UW158 is suitable for ejecting particles from its surface. In addition, we find its surface acceleration, tilt, geopotential, center of mass distance, escape speed, and equilibrium points.

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Poster

CBDO 119

Decomposition of Symmetrical Classes of Central Configurations

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To systematically study central configurations with a symmetric set of positions, we introduce the use of finite group representation theory. This approach simplifies equations for central configurations by considering arbitrary numbers of bodies, symmetry groups and dimensions. We give applications of the theory in some cases with a complete description of the existence and which masses are possible for some classes of central configurations.

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Organizing Committee

Invited Speaker

CBDO 120 - A

On the Absence of Coorbital Satellites in the Galilean System

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To date, Saturn is the only planet with known coorbital satellite system. The existence of these coorbital satellites is explained in the literature by capture during the evolution of the satellites or by congenital formation. On the other hand, Jupiter hosts a remarkable system of massive satellites that underwent a process of formation and evolution within a disk of solids and gas, the Galilean satellites. At first, the environment where these satellites formed and their migration process could be seen as favorable for the formation or capture of coorbital satellites. However, there are no satellites coorbital to the any of the four Galilean satellites. Here, we aim to study the reasons behind this absence of satellites coorbital satellites. To do so, we performed N-body simulations using the numerical package REBOUND, simulating particles around the Galilean satellites and taking into account the gravitation interactions between the satellites and the planet, satellites with each other, and the oblateness of Jupiter. Our results show that, despite not having coorbital satellites, the coorbital regions of the Galilean satellites, considering their current architecture (inside the 4:2:1 Laplacian resonance), are stable and could host satellites. With this result, we studied whether the Galilean satellites had coorbitals in their past and lost them during their evolution. In this case, we spread particles around the coorbital regions of the Galilean satellites and explored possible resonances the satellites went through during their migration. We found that the dynamics of entering or leaving a mean motion resonance (MMR) could jeopardize the fate of pre-existing coorbital satellites, especially the 3:2 MMR between Io and Europa, and Ganymede and Callisto. We also studied the influence of smaller satellitesimals on the evolution of pre-existing coorbital satellites.

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Poster

CBDO 121

Searching for orbits around Io considering the Laplacian resonance

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The planning of space missions to visit small bodies in the Solar System has been a subject of great interest for space agencies. The main targets are the moons of Jupiter and Saturn, due to the possibility that they may support life, so the composition and geology of these moons will be investigated. In this sense, the Europa Clipper mission will have the main objective of investigating sites below the surface of the ice moon Europa that could support life. Therefore, this mission is scheduled to be launched at the end of this year and the insertion of the spacecraft into the orbit of Jupiter should take place by 2030. Another important moon to be studied is Io, because it has many Earth-like phenomena, such as intense volcanic activity, so it is a possible target for future exploration missions. In this context, the goal of this work is to study the timing of orbits around Io, considering perturbations from Jupiter and the Laplacian resonance. The effects of the non-uniform mass distribution of the Io will also be considered. The possibility of losing the spacecraft due to collisions with the surface of Io and the cases in which the probe leaves the region of interest will be investigated. It will be considered that the probe describes a three-dimensional orbit around Io. The package IAS15, which is part of the REBOUND integration package, will be used to integrate the equations of motion. The integration will be performed at the center of mass of the system and the reference plane considered will be the plane of the equator of Io. The resonant argument will be calculated at each integration step. Therefore, the best initial orbital conditions which would allow orbits with durations suitable for space missions will be mapped.

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Poster

CBDO 122 - A

Dynamics around Psyche

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The asteroid Psyche is highlighted in the literature for being one of the largest ever observed, located in the main asteroid belt, with a diameter of approximately 232 km. Classified as type M, it is speculated based on radar observations, that it is an exposed core of a primitive planet, composed mainly of iron-nickel. Although it was initially believed to have a high density, reaching values of 7.6 g/cm^3, recent studies indicate lower values. Given such uncertainty, we sought not to use a specific density, but to explore this range of possible densities for Psyche. For each case, we compute the gravitational potential employing the polyhedral method, in which the irregular shape of the object is represented using several tetrahedra, maintaining a constant density. From this potential, we determine the equilibrium points and their linear stabilities, looking for possible changes in behaviour according to the density. Since linear stability influences the time particles can remain close to the equilibrium point, we integrate orbits around Psyche and analyze the number and lifetime of particles that survive and collide with the asteroid. The concentrated mass method (MASCONS) was employed and we also took into account the radiation pressure. This analysis is essential to assist in missions that aim to orbit the asteroid to collect information, such as the Psyche Mission launched by NASA in 2023, which stands out for its objective of exploring a metallic object for the first time, unraveling the uncertainties surrounding this asteroid.

Poster

CBDO 123 - Withdrawn by the author.

CBDO 124

Dynamics of dust particles from IDP collisions in the Saturn system.

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Saturn is known for its extensive and complex ring system.. The origin and evolution of these rings are often closely associated with interactions with its moons. These satellites can produce material to the rings through particle generation when interplanetary projectiles (IDPs) collide with their surfaces. The amount of particles produced depends on the flux of these projectiles, originating from sources like comets and the Kuiper Belt objects. This flux is usually estimated from space probe data. Once ejected, the particles are influenced to many forces, including gravitational (both from the planet and the moons), electromagnetic forces, solar radiation, and plasma drag.

In this study, we propose to analyze the dust generation from Saturn's satellites, by computing the amount of dust generated by each moon through the flux of IDPs. We also compare the dust production rate for each Saturn's family, including recently discovered moons, to further analyze the mechanisms of transport and fate of particles. We validated our code using the results from Sfair \& Giuliatti Winter (2012).

To illustrate our findings, we selected two satellites from the Gallic family. Albiorix, with a radius of approximately 13 km, produces 0.141 g/s of dust, while Bebhionn, with a radius of 3 km, generates dust at a rate of 0.008 g/s. These represent the extreme values that we found for this family. In other groups, the satellite with the highest dust production rate in the Inuit group is Siarnaq, producing 0.204 g/s, and in the Nordic group, it's Ymir, with a production rate of 0.057 g/s.

Subsequently, we are analyzing the evolution of these dust particle shortly after they are ejected from the satellites. Based on previous studies of dust particle ejection from Iapetus and Phoebe, we know that the particles ejected from the satellites, influenced by the previously mentioned forces, are transported close to the planet due to the influence of solar radiation force, resulting in potential collisions with the satellites and Saturn. In our case, we detected collisions with Enceladus, Tethys, Dione, Rhea, Titan, Janus, Telesto and with the planet itself (approximately 90\% of the collisions).

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Poster

CBDO 125 - A

On the attraction of ellipsoids and the properties of the Newtonian attraction

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A classical theorem states that two confocal ellipsoids, each of them filled up with a matter with uniform density, exert the same Newtonian force on any point exterior to both of them if they have the same total mass. The particular case where one of the ellipsoids is a sphere, and thus the other one is a concentric sphere, is well known and much easier to prove. One would like to deduce the ellipsoidal case from the spherical case, and an idea is that the Newtonian attraction should have a good behavior under a linear transformation which is not an isometry. The idea is only partially successful. One should observe that a linear transformation sends two concentric spheres to two concentric ellipsoids, not to two confocal ellipsoids.
It is known that the classical Newtonian attraction has analogues in Euclidean spaces of dimension 2 or n>3, and that there are also analogues in spherical geometry (of any dimension). Linear transformations which are not isometry are not defined in spherical geometry. So it is interesting to ask if the classical theorem about confocal ellipsoids and other theorems about the attraction of ellipsoids pass to spherical geometry.
I will show that the classical theorem passes to spherical geometry if we state it for thin layers of homogeneous ellipsoids. I will follow the simplest proof I know of the classical theorem, which is based on results which are often credited to Ivory, but are more precisely due to Chasles [2] in 1838. I will discuss some related statements (see [1], [3]).

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Oral Communication

CBDO 126

Faint Young Sun Paradox: dynamic evolution and habitability

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The Faint Young Sun paradox highlights that while the Sun had roughly 70% of its current luminosity at the zero-age main sequence (ZAMS), leading to a significant decrease in solar radiation flux 4.57 billion years ago, Earth and Mars already had conditions suitable for liquid water shortly after ZAMS, as evidenced by geological findings. Proposed solutions to increase rocky planets' initial surface temperature include adding greenhouse gases to primitive atmospheres and a higher initial solar mass due to greater past mass loss, now almost negligible. Minton & Malhotra (2007) analyzed this latter proposal based on Wood et al.'s (2002) data for mass loss from young Sun-like stars, finding dM/dt ∝ t^(−2.00±0.52) except during the saturation phase. Through numerical analyses using the Monte Carlo method, a possible saturation age of 81.0 ± 37.2 Myr was found, with an estimate of mass loss at 1500 (dM/dt)⊙ resulting in a Sun 1.02% more massive, possibly up to 1.88%. Veras et al.'s (2015) relation was applied to associate mass loss with the orbital expansion of Venus, Earth, and Mars, considering planets' semi-major axes increase as the Sun loses mass. Planetary dynamics were studied using Gallardo et al.'s (2021) code (PLARES: A semi-analytical model for Planetary Resonances), finding that even the closest resonance (13:8 between Venus and Earth) was not crossed, posing no problem for the solution to the Faint Young Sun paradox. Future analyses will examine the consequences of the planets' slight approach to a slightly more massive zero-age Sun. A 1.02% mass gain would make the Sun ∼4% more luminous, impacting the habitability of Venus, Earth, and Mars, and modeling the early Solar System's radiative environment.

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Poster

CBDO 127 - A

Mapping Slopes Across the Surface of Red Asteroid (269) Justitia

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The Emirates Mission to the Asteroid Belt (EMA) will study six asteroids before reaching its final destination: the asteroid (269) Justitia, which is highly red due to organic compounds on its surface. Discovered in 2021, the 54-km wide asteroid (269) Justitia is one of two known red asteroids not commonly observed in the asteroid population of the main belt. In this study, we examined the stability regions on the surface of an asteroid for particle retention and ejection based on slopes. The slope is the angle between the normal vector of a face and the acceleration vector on that face. If the angle is greater than 90 degrees, there is a potential for particle emoticon from the surface; if it is less than 90 degrees, there is a potential for particles to accumulate on the face.
Due to uncertainties about the asteroid's composition and bulk density, we calculated the slopes for a range of density values. Our findings indicate that certain regions across the surface of the red asteroid (269) Justitia are more susceptible to ejecting particles. In contrast, others are better suited for accumulating materials, which could provide insights into the composition of the red asteroid (269) Justitia. In addition, we find its surface acceleration, tilt, geopotential, center of mass distance, escape speed, and equilibrium points.

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Poster

CBDO 128 - A

Machine learning techniques for autonomous satellite guidance during terminal rendezvous operations

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The autonomy of satellite operation is important from financial and technical perspectives. It is a key element in distributed space systems whereby two spacecraft interact autonomously to accomplish objectives, including flying in formation, rendezvous and docking [1]. Furthermore, the ability to deal with unplanned situations address the uncertainty that arise while performing long travels through the space. Safety requirements are also accomplished by autonomous strategies, since decisions are made in advance to avoid undesired scenarios and difficulties. In this context, inspired by the Autonomous Rendezvous Transform (ART) approach [2], in the present study Machine Learning (ML) strategies are considered to speed up the planning of optimal trajectories along the planning of Rendezvous and Docking movement of spacecrafts. The ML approach is a building block toward safe and trustworthy self-guided space travel. The mathematical model of the Rendezvous [3] is used to generate data which will make possible the execution of the training phase of the algorithms. It is compared the convergence of multiple strategies, and the advantage of each algorithm is pondered. Numerical results confirm that the use of Machine Learning components improves the convergence of the proposed methodology along the optimization process.

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Oral Communication

CBDO 129

Bifurcations of a Symmetric Family of Dziobek Configurations

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The modern use of bifurcation methods in Celestial Mechanics was pioneered by Julian I. Palmore (1973). Since then, bifurcation theory has proved to be an important way of obtaining new central configurations from degenerate ones. For this purpose, the masses of the bodies are typically considered to be the bifurcation parameters. Dziobek configurations are, in essence, central configurations of dimension N-2 formed by N bodies. In this work, we investigate bifurcations of a one parameter family of Dziobek configurations in the five-body problem in space, considering the exponent of the potential function of the system to be negative and less than minus one. More precisely, we consider the regular tetrahedral configuration with bodies of unit mass at the vertices and a body of arbitrary mass at the center of the tetrahedron. Given the complexity of bifurcation problems with five different parameters, we restrict our study to two particular cases of the general problem. The first problem consists of varying three vertex masses equally, while the second consists of varying two of the vertex masses equally. We use the same technique to solve both problems.
We start by applying the Liapunov-Schmidt reduction method to simplify the equations that describe these problems. Next, the equivariance of the reduced equations is used to find some solutions. To look for more solutions, we use analyticity to obtain an interesting factorization of the Taylor expansion of the functions involved. The implicit function theorem is an important tool in this process. As results, for the first problem we found four new symmetrical families of central configuration emerging from the degenerate configuration while, for the second problem, we found three new symmetrical families of central configuration bifurcating from the degenerate configuration. Despite its key role in symmetrical bifurcation theory, the Equivariant Branching Theorem was not necessary in drawing our conclusions.

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Acknowledgment

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Oral Communication

CBDO 130

Mitigating Actuator Faults in Spacecraft Formation Flying through a Reconfigurable Guidance Strategy

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Maintaining a desired formation with precise accuracy is crucial for any spacecraft formation flying mission. Unexpected spacecraft faults can cause these missions to fail, preventing the system from reverting to its intended configuration. This paper introduces and evaluates a novel recovery solution, termed Reconfigurable Guidance Strategy (RGS), designed to address the control problem of spacecraft formation flying in the presence of a permanent thruster fault. This approach autonomously reconfigures the guidance function in real-time to offset the loss of the spacecraft's actuation system. The RGS's performance and cost have been assessed in a high-fidelity simulation environment using the 42 spacecraft simulator from NASA Goddard Space Flight Center. This evaluation considered nonlinear coupled dynamics, high-order perturbation models, and actuator and sensor models. The numerical simulation results confirmed the effectiveness, feasibility, and robustness of the proposed recovery strategy.

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Oral Communication

CBDO 131

Study of the Main Challenges in the Use of the Ensemble Kalman Filter in the Attitude Estimation Problem of Spacecraft

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A space mission involves various requirements that must be taken into account to achieve its objectives with excellence. One of the fundamental requirements is the definition of how attitude estimation will be performed, so that the attitude determination and control subsystem can stabilize the vehicle and orient it in the desired directions during the mission. In this context, the present work aims to present a study on the main challenges that may be encountered when using the Ensemble Kalman Filter (EnKF) to estimate the attitude of spacecraft. These challenges are related to the level of robustness in nonlinear systems, accuracy in representing the system state uncertainty, or whether there is an ideal set of samples (ensemble) to represent the probability distribution of the system state. For the analysis, simulated telemetry and ephemeris data from a satellite with characteristics similar to those of the CBERS-4 (China-Brazil Earth-Resources Satellite) will be considered, and the attitude will be represented by the set of Euler angles.
The Ensemble Kalman Filter (EnKF) was originally proposed by Evensen (1994) as a stochastic or Monte Carlo alternative to the Extended Kalman Filter. The EnKF is an estimation technique that combines numerical model predictions with real observations to improve the accuracy of state estimates in dynamic systems. Essentially, the EnKF replaces the single state prediction of the system with a set (ensemble) of predictions. Each member of the ensemble is a possible realization of the system state, considering initial uncertainties and model errors (Evensen, 2009).
Although studies show that the EnKF is a powerful tool for state estimation in complex dynamic systems, some challenges can be encountered, such as insufficient ensemble size, inadequate updates of state estimates due to underestimation or overestimation of errors, difficulties in highly nonlinear systems, among others.

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Poster

CBDO 132 - A

Simulation of measurements for low Earth orbit satellite GPS receivers

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Satellite orbit determination can be defined as the method of determining the position and velocity (i.e., the state vector) of an orbiting object. For low Earth artificial satellites, the Global Positioning System (GPS) provides a powerful and fast means to compute orbits, by providing redundant measurements. Orbit determination based on observations from spaceborne GPS receivers can be done onboard in real time or on the ground in a postprocessing mode.
The objective of this work is to present a simulator of satellite GPS measurements, with the purpose of providing the necessary resources to test orbit determination algorithms based on GPS measurements, under controlled conditions. This simulator provides pseudorange and carrier phase measurements for a target satellite in low Earth orbit.
In order to compute the GPS measurements, the state of the target satellite is calculated using SGP4 propagator method from a given initial TLE, and each GPS satellite has its position and velocity given by interpolation of precise orbits distributed in SP3 format. Models of physical influences, such as tropospheric and ionospheric delays, clock errors, among others, are implemented [1, 2].
The effectiveness of the simulation measurement model is compared with real measurements available in some missions, like JASON or GRACE.

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Poster

CBDO 133

Existence and Stability of Moon's Stationary Polar Orbits

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Monitoring the evolution of the water reserve on the Moon became an important task to be accomplished and therefore it has motivated the search for a cheap and relatively long lasting mission to be positioned at a privileged place in order to have a good view of a Moon's pole for a reasonable amount of time. The mission we suggest, places an observatory right above a Moon's pole at a stationary position in such a way that it can be monitoring a Moon's pole continuously for as long as a predetermined period for the mission duration. For finding such a stationary position we make use of a solar sail and the repulsive photonic force of the Sun on it. We study the problem of perfect circular orbits of both the Moon around the Earth and the Earth around the Sun. We consider a rotating reference system centered at the Sun. For every instant of time, t, the Moon is located
at a certain position in relation to the Earth giving as a function of the angle psi . For such configuration we determine angles gamma and delta and hight h such that the sail probe with clock angle gamma and cone angle delta at distance h from a Moon's pole is at equilibrium. We prove there exists no such equilibria at the Hamiltonian case (i.e. gamma = 0) so we have decided to investigate numerically the existence of such equilibria near gamma= 0. We analytically show the existence and investigate the linear stability of these equilibria orbits.

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Oral Communication

CBDO 134

Dynamics of a particle around a non-spherical symmetrical body with a deep depression

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According to the data using the stellar occultation technique and other studies, there is evidence of a large crater on the surface of 2002MS4, with a depth depression of 45.1 ± 1.5 km and a linear extent of 322 ± 39 km (there was an estimate made in 2007 by the Spitzer Space Telescope that 2002MS4 has a diameter of 726 ± 126 km). This peculiar characteristic motivated us to investigate the dynamics of a set of particles around bodies with this type of anomaly on their surface. We will address the two-body problem with rotation considering its spherical shape with a crater. The system comprises a central spherical body with a large and deep crater. Following Madeira et al. (2022), we normalize the system by setting G=1, M=1 (mass of the spherically symmetric body), and R=1 (the distance between the mass center and the crater center). The system can be fully described by two free parameters: the rotation parameter of the central body λ, which represents the ratio between angular velocity and Keplerian frequency, and the mass parameter μ, which means the ratio between the "crater mass" and the spherically symmetric body mass. Our research used numerical simulations to construct a set of maps of the Poincaré surface of section in the rotating frame and to project the variation of the orbital elements a (semi-major axis) and e (eccentricity) of particles in periodic orbits in the inertial frame (studying this variation of the orbital elements will give us more information about the stable regions). The results show stability islands for values of distance larger than or equal to 2.2 R (where R represents the radius of the main body). Examining the evolution of these islands in the range $2.130 < C_J < 2.170$, it is observed that the type I periodic orbits move to longer distances as the value of C_J increases, while the resonant orbits converge towards the type I orbits. The next steps will be to analyse periodic and quasi-periodic orbits and find out more about these resonant orbits.

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Poster

CBDO 135 - A

Spacecraft Formation Flying Control Considering Solar Panel Failures and Differential Perturbations

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In recent years, the use of large monolithic satellites, in some cases, has been substituted by the use of distributed space systems, enabling space missions to achieve specific requirements that a single satellite may not accomplish. One example of distributed space systems is the spacecraft formation flying, and its definition that is most accepted in the space community was proposed by NASA Goddard Space Flight Center as "The tracking or maintenance of a desired relative separation, orientation or position between or among spacecraft" [1]. The use of spacecraft formation flying has grown in the past recent years, and the ITASAT-2 Brazilian mission (under development by the Aeronautics Institute of Technology - ITA), whose main objective is to study the space weather, is an example of this growth. In a formation flying operation, the relative motion is perturbed by the orbital environment, especially by the differential atmospheric drag and J2 when the satellite is in the Low Earth Orbit (LEO), and dynamical models for the relative motion considering such perturbations have been developed by other authors [2]. This work has been developed in Simulink/MATLAB and aims to evaluate the control effort required to control the formation flying of satellites in LEO considering differential perturbations when solar panels present failures and remain fixed in a given orientation, imposing different ballistic coefficients to the satellites. The guidance trajectory was generated using the linear solution of the Clohessy-Wiltshire equations, whereas the dynamical model developed in [2] was considered to propagate the true motion of the satellites. A Proportional-Derivative (PD) controller was set to control the formation within a defined error box. The formation flying with panel failure was successfully controlled within the error box, ensuring that the deviation remained below the defined tolerance. However, the fuel required to compensate for the solar panels failure may be prohibitive for real satellite missions.

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Poster

CBDO 136 - A

Secular Regimes in the Planetary Case of the 3-Body Problem at high (e, i).

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The secular equations for two planets with low (e,i) can be easily solved and an analytical expression for the solution can be obtained. Extending the study of these systems to cases of higher eccentricity and inclination requires resorting to semi-analytical tools as well as numerical integrators to decipher the system's evolution [1]. Part of the study of these high (e, i) systems is determining the parameters by which the classical low (e,i) secular regime remains valid. Depending on a system's initial conditions, it may evolve secularly in different ways once it leaves the classical regime. Some systems evolve directly into chaos, while others exhibit greater resilience and remain stable at higher (e, i). In our work, we explore whether instabilities in a system can be studied based on the behavior of the system's fundamental frequencies. Taking the Laplace plane as reference we studied the dependence and evolution of the fundamental frequencies with (a, e, i, ω) as well as different mass coefficients. We will discuss the different dynamical regimes we obtained and their characteristic equilibrium points.

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Poster

CBDO 137

Investigating Dynamical Structures in the TOI-178 System

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This work investigates the dynamical properties and structures of a planetary disc in the TOI-178 system, which provides a rare opportunity to study complex dynamical processes due to its unique configuration of five two-body resonances and three three-body resonances. The aim is to identify precise structures and dynamics within the disc. This was done by simulating a planetary disc with 1 million test particles over a period of 500 years. Analysis of the simulation results showed areas of low particle density, particularly between the planets TOI-178 e and f. These density dips are caused by resonances with the planets TOI-178 f and g and show similarities to the Kirkwood gaps in our Solar System. In addition, oscillations in the inclination of the test particles have been detected in the inner region of the disc. These oscillations have frequencies that, in addition to the tilt frequency of TOI-178 b, have an additional frequency that increases with the large semi-major axis. These results contribute to the understanding of dynamical processes and resonance phenomena in planetary disks and provide valuable insights into the structure and evolution of the TOI-178 system.

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Invited talk

CBDO 138

Space System Engineering Process to design orbit for an electromagnetic detection payload

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The objective of this work is to present the Space System Engineering process to design orbit for an electromagnetic detection payload used at the LOM Project (FINEP/ITA/LabGE) - “Development of Payloads for Receiving Electromagnetic Signals for Satellites – Phase 1”. The process starts with the definition of the needs of the users considering the goals and the objectives. Questions such as “What is the mass of the payload? The frequency range desirable for surveillance? Views of the ground stations? The data collection rate desirable?” are the key investigations the first time. Also, the relevant stakeholders must be identified and their main expectations must be considered.[1], [2] Once these questions have been solved, the second step is to investigate what similar space systems could be used as the reference architecture. This stage is relevant to investigate whether the operational architecture of the current space system, adapted to the parameters identified at the beginning of the process with the stakeholders, can be applied to this new mission. The third step involves designing scenarios with language and graphics models to identify with the stakeholders if the new space system can provide the expected capabilities. The experience acquired at the LOM Project shows that an electromagnetic detection payload with a mass of less than 250 kg must applied on LEO orbit. This requirement avoids lost weak signals from transmitters located at the surface. The second requirement involves temporal resolution. In this case, the polar orbit can be more useful, unless it is desirable to monitor specific areas around the Equator, where an inclined orbit could be more interesting. The third requirement considers that signals that arrive at the front end of the payload receptor must have a minimum level of information capable of being processed and stored with the characteristics necessary for identification. This implies low orbits customized to the type of emitters that one wishes to survey.

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Poster

CBDO 139

Utilizing Cosmic Microwave Background Measurements for Improved Interstellar Navigation Systems

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This research unveils a cutting-edge navigation system for deep space missions that utilizes Cosmic Microwave Background (CMB) sensor readings to enhance spacecraft positioning and velocity estimation accuracy significantly. By exploiting the Doppler-shifted CMB spectrum and integrating it with optical measurements for Celestial Navigation, this approach employs advanced data processing through the Unscented Kalman Filter, enabling precise navigation amidst the complexities of space travel. Simulation results confirm the system's exceptional precision and resilience in deep space missions, marking a significant advancement in astronautics and paving the way for future space exploration endeavors.

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Oral Communication

CBDO 140

Existence and stability of equilibrium points above the poles on the Sun-Earth-Sail Problem

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The libration points of the Sun-Planet Circular Restricted Three-Body Problem (CR3BP) are located on the plane of the ecliptic. Although these equilibrium points are fixed on the Sun-Planet referential, we can change its position by using a suitable mass/area ratio, location and attitude of a solar sail.
Through the use of a solar sail with a sail lightness number above 1 we can create equilibrium points above and below the ecliptic plane which could maintain probes that monitor the poles of a planet from a more advantageous point of view.
One of the motivations of this study is to find a way to maintain a stationary probe that would monitor the poles of Earth to collect data about the impact of global warming on the melting of the Inlandsis and Permafrosts. This motive is becoming more and more relevant with the passing of time and the increasing frequency and intensity of weather disasters around the world such as droughts, heat waves, storms, floods and cold waves. In the first semester of 2024 there were floods, which are said to be connected to climate change, in Brazil, USA, United Arab Emirates, Australia, China, Kenya, Tanzania to name a few. Beyond that, droughts are predicted to occur on all the continents of the globe in 2024. We hope that a probe on the equilibria we study could help in the surveillance of the impact of the climate change on the Polar Caps and Permafrosts.
This paper studies the equilibrium points off the ecliptic plane in the Circular Restricted Three-Body Problem with Sun Sail (CR3BPS). The study is generalized to include the cases of the planet being Earth, Venus or Mercury. We study the stability, position and conditions of existence of those equilibria.

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Poster

CBDO 141 - A

Design of a Stepper Motor-based Control System for a Stratospheric Probe Tracking Antenna

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Low Earth Orbit (LEO) missions, characterized by their short duration and low cost, offer great potential in the space sector. Utilizing small launchers, suborbital vehicles, and stratospheric balloons, these missions enable fast and responsive access to space as per the operator's demand. These missions are suitable for specific, short-term tasks, supporting larger missions, specific objectives, and academic experiments. In the academic context, the ITACUBE project, funded by CNPq and coordinated by ITA, develops satellite platforms in the CubeSat format for academic purposes. The project involves launching a payload with a scientific experiment via a stratospheric balloon, with a duration of approximately 4 hours. During the mission, telemetry data is transmitted to a ground station equipped with a directional antenna manually pointed by the operator based on altitude information and GPS coordinates sent by the probe. This manual process is exhausting and often results in data loss due to delayed corrections. This work aims to automate the tracking of the telemetry signal from the probe, ensuring continuous pointing to the signal source. A commonly used actuator for antenna pointing systems is a two-phase hybrid stepper motor (HSM), which is the ideal choice for applications that require maintaining fast and efficient positioning control and need small power supply. This work shows the design of a two-phase hybrid stepper motor-based antenna positioning control for a stratospheric probe. The system was modeled and simulated in MATLAB, and the results demonstrate that the HSM is an effective solution for the proposed control problem.

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Poster

CBDO 142

Trade-off Families of Transfer Trajectories in the Cislunar region

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The interest in cislunar space has grown enormously in recent times, with new perspectives on lunar missions and cislunar architectures, such as the Lunar Gateway Space Station and the Artemis Program, which will open the range of possibilities for more affordable and accessible lunar missions. Through the Artemis Accords, many nations, including Brazil, have signed common principles to govern the civil exploration of outer space, signaling the collaborative international effort of achieving a sustainable and robust presence on the Moon. Given this context, efficient methodologies are required to design transfer trajectory solutions in these regions, taking into account particular requirements of each mission, such as a low fuel budget for CubeSat-type missions or a low flight time restraint for human space flight. In this contribution, impulsive transfer solutions are built in the CR3BP by leveraging the hyperbolic structures of the dynamical system and a Multiple-Shooting algorithm to deliver the spacecraft from LEO to a libration point orbit. By selecting appropriate constraints, it is possible to construct families of these transfer trajectories and study the trade-off between flight time and fuel efficiency. The resulting transfer solutions obtained in the families can then be used as initial guesses for transitioning to a higher-fidelity ephemeris model.

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Oral Communication

CBDO 143

Perilune Poincare Maps: a NRHO's Station Keeping Approach

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One of the central architectures of the Artemis Program is the Lunar Gateway, one of the next future flagship missions of NASA. The lunar space station will act as a midpoint, enabling crewed and uncrewed lunar missions, as well as deep space and other destinations. The operational orbit chosen for the Gateway is based on an almost stable CR3BP periodic orbit, belonging to the Near Rectilinear Halo Orbits (NRHO). Besides the dynamical instability, additional perturbations such as other gravitational bodies and solar radiation pressure make routine station-keeping maneuvers necessary to guarantee long-term parking solutions. In the context of NRHO's, their high eccentricity creates a region of extreme gradient in phase space near Perilune. This configuration introduces large errors in the linearization of the dynamics by the State Transition Matrix (STM) in this region, which can imply miscalculations in the control delta-v maneuvers, resulting in potentially higher costs for orbit maintenance. This contribution analyzes the Linearization of Perilune Poincaré Maps to better approximate the dynamics in this sensitive region of phase space and develops a station-keeping algorithm using this approach. Different methods for station-keeping algorithms have been presented in the literature for libration point orbits, such as the Floquet Mode Control (FMC) algorithm and PACMAN, which is the one selected for the Gateway mission. Both methods are compared to the one proposed in this study, and their performance is analyzed in the CR3BP and in a higher-fidelity ephemeris model.

Oral Communication

CBDO 144

An analytical study on the solar radiation pressure and planetary oblateness perturbations over orbital dynamical systems.

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Orbital systems are characterized as a type of dynamical system. A particle orbiting a planet does so due to the influence of gravitational attraction combined with a tangential velocity along the orbital path. The physics is perfectly explained by Newtonian gravitation theory, representing a classic two-body problem, whose solution is easily obtained through analytical methods. This allows for gathering important information about the particle's dynamics, such as its angular momentum.
This work employs analytical mechanics tools to study the dynamics of a system composed of a planet and a particle, subjected to two perturbations: solar radiation pressure and planetary oblateness. The Hamilton-Jacobi equations are used to find a form for the Hamiltonian function of the perturbed system. Subsequently, computational simulations are performed in Matlab/Octave to visualize the phase space generated by this function.
Previous studies have shown that when the same pair of perturbations influence the particle in the Earth-Particle system, a bifurcation occurs in the particle's phase space at certain orbital altitudes and particle radii. This bifurcation indicates a deviation in the orbit's eccentricity, implying a significant modification in the particle's dynamics compared to what would be expected in an unperturbed system. The same behavior was also observed for particles orbiting Mars, ejected by its moons Phobos and Deimos.
The present work aims to reproduce the existing results for the Earth-Particle and Mars-Particle systems and investigate whether there is an alteration in orbital eccentricity for other dynamical systems in the solar system, specifically particles orbiting Venus, Jupiter, Saturn, Uranus, and Neptune. The perturbed Hamiltonian function is used for each system, considering the individual characteristics of each planet (mass, J2 oblateness, radius, etc.), and the phase space is generated for various orbital altitudes and particle radii.
Preliminary data show that the same type of behavior is observed in the Venus-Particle system for a particle of 1μm at an altitude of 4400 km, for a particle of 2μm at an altitude of 3115 km, and for a particle of 5μm at an altitude of 2670 km.

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Poster

CBDO 145 - A

On the topology of mean motion resonances in the full range of eccentricity and inclination

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Mean motion resonances have a great effect on the long term evolution of orbits. There are plenty of examples of its influence on the structure of planetary systems. Many small body populations are structured by them. Some examples of this are Kirkwood gaps in the Main Belt, the Jupiter Trojan population and the resonant TNOs. Resonances are also important between planets as many exoplanetary systems have been discovered to be in such configurations.
It is important to understand the structure of any given resonance and its properties in order to better understand how they will affect the long term evolution of the orbits. Generally, classical approaches for calculating the resonant disturbing function were analytical expansions only valid for some interval of eccentricities and inclinations or for particular resonances. Calculating the resonant function numerically is advantageous as it has no restrictions on orbital elements or type of resonance.
The model we apply for this work calculates semi-analytically the resonant disturbing function and calculates the Hamiltonian and the properties of any given resonance both for the restricted and the general case. We are only limited by the fast evolution of eccentricity, inclination, argument of perihelia or longitude of ascending nodes as the model assumes they stay more or less constant in a libration period [1][2].
The model calculates the resonance width, the location of the equilibrium point of the critical angle and the libration period.
Historically, resonances have been classified as symmetric if there exists one equilibrium point where the critical angle oscillates around 0° or 180°or as asymmetric if there exists two equilibrium points separated by less than 180°. Most low inclination resonances are symmetric while it is known that 1:1 and all other 1:N resonances are asymmetric.
In this work, we present the results of mapping resonance properties in the phase space (e,i). We found that the topology of a given resonance may change drastically for high eccentricity or high inclination. We also concluded that all the properties for a given resonance are strongly dependent on the orbital elements.

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Poster

CBDO 146

Formation Flying Design Applied for an Aurora Borealis Monitoring Mission

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Aurora Borealis is an optical phenomenon composed of luminous events observed in the night skies in the polar regions resulting from disturbances in the magnetosphere due to the impact of solar wind particles with the Earth's upper atmosphere, channeled by the Earth's magnetic field, which causes atmospheric molecules to become excited and emit electromagnetic spectrum, leading to the display of lights in the sky. However, there are still different implications of this phenomenon under study: high intensity auroras are often accompanied by geomagnetic storms that cause blackouts on Earth and impair the transmission of signals from the Global Navigation Satellite Systems (GNSS), but it is not yet discovered what the mechanism is responsible for the interruptions. Auroras are also known to occur on other planets and exoplanets, so the activity is an indication of active space weather conditions that can aid in learning about the planetary environment. In order to improve understanding of the phenomenon, this research aims to design a satellite formation flying solution for collecting and transmitting data for monitoring aurora borealis in northern hemisphere, an approach that allows studying the event with multipoint data collection in a reduced time interval, in order to allow analysis from the beginning of the phenomenon until its decline. To this end, the ideal number of satellites, the spacing between them, as well as the ideal topology to be used will be analyzed. From an orbital study, approaches from different altitudes, eccentricities and inclinations will also be considered. Given that at large relative distances between satellites in formation, controllers tend to fail, a study on the efficiency of different controllers from the point of view of position maintenance and propellant consumption will be carried out. The main orbital perturbations considered in the simulation: non-homogeneity terrestrial, atmospheric drag, gravitational action of the Sun and the Moon, accelerations due to solar radiation pressure and relativistic effects.

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Poster

CBDO 147

Classifying 4-body cocicular central configurations

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The problem of finding central configurations is extremely important, because these configurations provide us with the simplest possible solutions to the Newtonian n-body problem. A special case for configurations on the plane is when the bodies are cocircular, that is, they are located on a common circle. Its importance lies in the Simó-Yoccoz conjecture, as it is true for central cocircular configurations, which states that there is there is at most one co-circular central configuration of four bodies for each cyclic ordering of the masses. If we impose symmetry on the cocircular problem, we have two families of possible configurations: isosceles trapezoids and kites. In the general case, with positive masses, it can be demonstrated that, knowing only two mutual distances, the remaining four distances in a central configuration can be uniquely determined in a continuous manner. In this poster presentation, we will detail some relevant aspects of cocircular four-body central configurations following the reference Roberts and Cors (2012).

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Poster

CBDO 148 – Withdrawn by the author

CBDO 149 - A

Physical characteristics of Jupiter’s Trojans combining the stellar occultation techniques with dimensionless 3D model

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When Neptune migrated across the primordial Kuiper Belt and triggered a dynamical instability among the giant planets, most of the primordial Kuiper Belt objects were expelled and a fraction of them was captured as Jupiter Trojans [1]. Therefore, the establishment and refinement of the size-frequency distribution (SFD) and shapes of Jupiter Trojan asteroids (among other physical characteristics) is of great importance to constrain their collisional evolution models [2], and ultimately to retrieve main characteristics of the primordial Kuiper Belt population. In this context, we are starting a long term project aiming to determine precise sizes and shapes for Jupiter Trojans through stellar occultations, starting with the bigger ones and then progressively probing smaller objects. Stellar occultation techniques combined with 3D model manipulation allowed us successfully an assessment of main physical characteristics of the Jupiter's Trojan (1437) Diomedes from a 3-chord stellar occultation observed on November 1st, 2020 [3] . We improved the pole coordinates and rotation period, and scaled the 3D model in km. The rotation period (P) and pole coordinates of Diomedes (lambda, beta) from DAMIT database were lambda = 150 +/- 5 dg, beta = 5 +/- 5 dg, P = 24.4987 +/- 0.0002 h (ecliptic system). Our new values were lambda’ = 153.73 +/- 2.5 dg, beta’ = 12.69 +/- 2.6 dg, P’ = 24.498393 +/- 0.000006 h. The volume-equivalent radius was 59.4 +/- 0.3 km and the albedo was 0.030 +/- 0.004. For that reason, we are going to refine the rotational parameters and the scale values using other Diomedes occultation events simultaneously, and repeat this procedure with Trojan Priamus and Alcathous, two others among the ten biggest Trojans, which we already have a series of recent occultation events, some of them with five and nine chords in a single event for Priamus and Alcathous, respectively. These Trojans, despite there being no 3D models in the databases, there are large photometric observations spread along its orbit around the Sun, which will allow us to construct its 3D models and test it to the occultation chords.

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Poster

CBDO 150

Lunar Artificial Satellite Constellation: Geometric Prowess Optimization

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This article delves into the importance of finding the ideal configuration of lunar satellites and the crucial role that optimization processes and simulations play in the lunar groundbreaking space exploration initiative. The optimization process begins with a comprehensive analysis of the technical requirements for the lunar satellite constellation. This involves determining the number of satellites needed, their spatial distribution and the specific orbit elements they should have. Technical parameters, such as communication frequencies and data transfer rates, are also considered to ensure seamless integration with lunar missions. Simulations also play a pivotal role in testing the proposed satellite constellation under various realistic scenarios. This includes simulating communication delays, orbital adjustments, and emergency response procedures. Simulations aid in optimizing resource allocation for the satellite constellation. This involves assessing the efficiency of power distribution, fuel consumption, and data processing capabilities. By running simulations, researchers can fine-tune these parameters to ensure optimal resource utilization, prolonging the lifespan of the satellites and minimizing mission costs. Researchers can simulate potential malfunctions, collision scenarios, and communication breakdowns to devise contingency plans. This proactive approach ensures that the lunar satellite constellation is equipped to handle unexpected challenges, enhancing the overall mission success rate. In conclusion, the importance of finding an optimal satellite constellation for the Moon cannot be overstated. It is a critical component for the success of lunar exploration missions, enabling precise navigation, reliable communication, and effective resource exploration. The optimization process, coupled with simulations, ensures that the satellite constellation is not only technically and operationally sound but also aligned with the scientific goals of lunar exploration. Through rigorous testing of various scenarios, we have discerned intriguing insights into the nuanced behavior of geometric characteristics within the context of an optimal lunar artificial satellite constellation. Our efforts have unveiled not only promising leads on the desirable attributes these configurations should exhibit but also delineated the boundaries of what they should avoid. This empirical exploration has enabled us to delineate a discernible range within the parameters, shedding light on the intricate inter-
play of factors that define the geometric ideal for such satellite constellations. Within the confines of this article, we shall elucidate the primary steps undertaken during our investigative endeavors. Delving into the intricacies of our testing methodology, we aim to share the foundational insights gleaned from the examination of diverse scenarios.

Acknowledgments
FAPESP

Poster

CBDO 151

Dynamics and Control of Spacecraft Formation Flying Applied to Space-based Solar Power Missions

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Space-Based Solar Power (SBSP) has shown promise as a means of providing clean and renewable electrical energy as well as enabling distribution to resource-poor areas on Earth. The biggest advantage of the concept of collecting solar power in space and transmitting it to any location on Earth using microwaves is the ability to capture energy 24 hours a day regardless of seasonality without atmospheric losses, reducing the need for expensive solutions for energy storage. However, it is only feasible in terms of energy capture if the surface area of the solar panel exposed in space is too large. Extensive structures are expensive and unfeasible to be placed in orbit by current space launchers, as well, photovoltaic surfaces hinged in many parts increase complexity and risk of failure. At the same time, the main approaches currently study the feasibility of using geostationary satellites, but these have disadvantages that can make the mission unfeasible, such as high construction and launch costs, delay in data transmission due to the great distance and susceptibility to weather and malicious interference. As a solution, this work explores the concept of continuous coverage SBSP using sets of formations flying with a variable number of satellites and at different orbital altitudes within Walker-type constellations, obtaining the best solution and commitment to the mission. Despite many benefits, the use of formation flying is challenging with regard to ensuring the desired attitude, the relative dynamics between the satellites and the correct orbital movement due to the existence of orbital perturbations, so an in-depth study of control techniques is proposed for the correct performance of the mission using a Linear-Quadratic Regulator, Adaptive Linear-Quadratic Regulator, State Dependent Riccati Equation and Lyapunov. As a final result, the work intends to contribute with new perspectives of dynamics and formation control in formation flying, as well as to mitigate the main issues related to the project viability for the development of SBSP, proposing designs that optimize energy capture, the transmission of energy to Earth and consumption of propellant.

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Poster

CBDO 152 - A

Convergence of orbits to the stationary state for a family of two-dimensional nonlinear mappings

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We considered a family of two-dimensional nonlinear mappings described by angle and action variables and parameterized by control parameter ε that controls the intensity of nonlinearity, δ controlling the amount of dissipation and an exponent γ that is a dynamical parameter. We investigated the convergence of orbits to the stationary state through a robust phenomenological description of scaling laws at the bifurcation leading us to obtain the critical exponents that define universality classes. Renaming the variables and for specific values of the control parameter γ we recover other mappings known in the literature, such as the Fermi-Ulam, corrugated waveguide and Kepler map. The procedure used is general and may be applied in different two-dimensional mappings known in the literature.

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Poster

CBDO 153 - A

The effect of eccentricity on the insolation and habitability of exoplanets

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Forces arising from the mutual gravitational attraction between the planets have a major influence on the Earth's climate and, therefore, its habitability. An example of this is the variation in orbital eccentricity, which is one of the factors responsible for leading the Earth to periods of glaciation at regular intervals. Using the Mercury computer program and planetary secular theory, we intend to find cycles of precession and eccentricity like those known on Earth in super-Earth-type exoplanets in multi-planetary systems. We use the equation for insolation proposed by Dobrovolskis et al. 2007 to determine how variations in the eccentricity of a planet can affect the insolation received by it and consequently its habitability.

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Poster

CBDO 154 - A

Reinforcement Learning-Based Optimization of Controller Gains for Terminal Rendezvous Maneuvers

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Future space missions seek more autonomy to carry out their missions. The field of Reinforcement Learning (RL) is a subfield of the broader Machine Learning (ML). In the RL framework, an agent learns how to select actions in a given environment by interacting with it following trial and error attempts. The ultimate goal of the agent is to maximize its long-term reward. RL is a promising tool for solving non trivial control problems. In this work, the Clohessy-Wiltshire (CW) equations are employed to simulate the relative dynamics of a terminal rendezvous problem. A modern RL algorithm, namely the Twin-Delayed DDPG (TD3), is used and the agent learns how to control the spacecraft to reach the desired terminal state. Instead of neural networks, however, as commonly applied in RL works, the action output is parametrized by a conventional control law given by a proportional-derivative (PD) controller. Thus, the agent's task is to find the optimal gains to properly carry out the rendezvous maneuver. The results show a performance comparative analysis, in terms of delta-V requirements, among the TD3 and the two-impulse rendezvous method. The possibility of tuning the gains using an RL approach indicates its potential as a tool to solve real-world control problems.

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Poster

CBDO 155 – Withdrawn

CBDO 156 - A

Evolution and Stability of Low Orbits Around the Moon

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In the 50s, space exploration started with the URSS launching the space satellite Sputnik. Afterward, with the Apollo 11 mission, man landed on the Moon for the first time. Later, space missions traced the lunar potential and found traces of water at the lunar poles. At present, the Moon returns to be a focus of new missions, including the implantation of lunar bases. The bases must be installed in polar regions of the Moon, where the assistance of several other missions is necessary to carry them out, such as satellite constellations, monitoring, and communication; one of these missions is the Artemis mission, which intends to return to the Moon. Therefore, it is necessary to have a detailed study of the orbital evolution and stability around the Moon, considering its precise format. During this project, we studied the evolution and stability of a space probe under the influence of the lunar gravitational potential, considering numeric integrations out of low orbits. We adopt the numeric package Mercury (Chambers, 1999) to enable the study of the evolution of a spacecraft in the vicinity of the Moon. We made numerical simulations utilizing a model for the lunar potential expanded to second order with $J2$ and $C22$ gravitational coefficients. Developing a subroutine that computes the lunar potential up to second-order expansion was necessary. We used the flattening and ellipticity coefficients $J2$ and $C22$, respectively. We conducted numerical simulation tests considering these coefficients separately and their combination. Our results indicate that both the Moon flattening and the ellipticity significantly disturb low orbits around the Moon. By incorporating more gravitational coefficients into our model, such as the algorithm proposed by Kuga and Carrara (Kuga and Carrara et al, 2013), we can analyze the influence of these coefficients for lunar missions that will return to the Moon focused on low orbits.

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Poster

CBDO 157

Development of AI for Navigation of Space Systems Considering Orbital Dynamics and Astronomy: A Case Study with SpaceX Crew Dragon Docking Simulation

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The precision and reliability of spacecraft navigation are critical in space missions, particularly in docking maneuvers such as the SpaceX Crew Dragon docking with the International Space Station (ISS). This study focuses on the development of an artificial intelligence (AI) system designed to enhance the navigation of space systems by integrating orbital dynamics and astronomical data. The AI system aims to provide autonomous navigation and docking capabilities, ensuring accuracy and safety in complex space operations.
The core of this research involves creating algorithms that leverage machine learning techniques to process and interpret astronomical data, including star patterns and other celestial references, to determine the spacecraft's position and orientation. These algorithms are combined with models of orbital dynamics to predict and adjust the spacecraft's trajectory in real-time. The integration of these components allows the AI to autonomously navigate and perform docking procedures with minimal human intervention.
A significant portion of the study is dedicated to testing the AI system using the SpaceX Crew Dragon docking simulation with the ISS. The simulation environment, created using advanced tools like Gazebo and custom-built simulators, replicates the conditions and challenges of a real docking scenario. The AI processes input from simulated sensors, including star trackers and inertial measurement units, to continually update its positional awareness and make precise adjustments to the spacecraft's path.
Initial results from the simulation tests demonstrate that the AI system can successfully navigate the Crew Dragon and perform docking maneuvers with high accuracy. The system's ability to autonomously adjust for deviations and maintain a correct trajectory highlights its potential for improving the safety and efficiency of future space missions.
This research contributes to the field of space navigation by providing a robust AI solution that integrates orbital mechanics and astronomy for autonomous spacecraft operation. The findings have significant implications for future missions, potentially reducing the need for constant ground control intervention and paving the way for more advanced autonomous space exploration.

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Poster

CBDO 158

Space Communication Protocols: A Comprehensive Review of Standards and Technologies for Satellite and Nano Satellite Missions

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This article presents a comparative analysis of space communication protocols, focusing on the CCSDS, AX.25, LoRaWAN, and Iridium SBD standards. The main objective is to identify the most suitable protocol for a specific application in link testing with the LoRa antenna. Through a comprehensive review of the main aspects of each protocol, including simplicity, efficiency, range, power consumption, and cost, the advantages and limitations of each are highlighted. Based on this analysis, the most appropriate protocol will be selected for implementation in a link test with the LoRa antenna, aiming to meet the communication requirements of a nano satellite project. The results of this study will provide valuable insights for the effective choice and implementation of communication protocols in future space missions.

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Poster

CBDO 159 - A

The Dynamics About Trojan Asteroid (11351) Leucus: A Very Slow Rotator

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Lucy is the first space mission to explore the Jupiter Trojan asteroids. Jupiter Trojan asteroids are a key small body population found in Jupiter's L4 and L5 Lagrange points and are dynamically stable over the lifetime of the Solar System. These primitive asteroids link formation theories and dynamical models that explain how our Solar System formed. Trojans share essential characteristics with the dynamically excited Kuiper Belt populations and Neptunian Trojans. As such, Trojans may be one of the most accessible examples of the planetesimals that populated the outer protoplanetary disk.
So, in this work, we aim to explore the dynamics of the Trojan asteroid (11351) Leucus, one of the Lucy mission targets, that exhibits an exceptionally slow rotation period of 466 hours, the cause of which is unknown. This slow rotation period means it will likely get hotter during the day and colder at night than the other asteroids. We investigated Leucus' surface in detail to identify the equilibrium points' location and explore dynamic features. We assume Leucus' irregular shape is a homogeneous polyhedra. We numerically explore its dynamic characteristics by computing its irregular geopotential to study its quantities, such as geometric height, tilt, oblateness, ellipticity, surface acceleration, escape speed, and slopes. Leucus' external equilibrium points have a slight no radial symmetry due to their highly irregular shape. We identified five equilibrium points concerning its shape and spin rate: i.e., four external equilibrium points, where two are linearly stable, two are unstable, and one inner linearly stable equilibrium point with a slight offset from the Leucus centroid. The locations of external equilibrium points are far away from Leucus. Our results also indicate that the surface of Leucus' is a stable area due to the slow rotation period. In addition, their polar locations are regions of the Leucus' surface for maximum accelerations, unlike the equatorial sites, which are locations of the Leucus from minimum accelerations.

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Poster

CBDO 160 - A

Evolution of a Space Debris Cloud

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As humankind becomes increasingly reliant on satellite services, the number of space launches continues to rise each year. This growth in the space population is accompanied by increased orbital congestion, collision risks, and space debris generation.
Initially neglected, the debris accumulation problem soon became evident and a source of great concern for the global community, particularly following the first serious satellite fragmentation incident: the explosion of the Thor Ablestar second-stage rocket, which increased the population of man-made objects by about 400% in 1961 [1]. This incident was just the first of many that contributed to the overcrowding of Earth's orbit with debris, which now far outnumber operational objects in space.
Over the years, various guidelines have been developed to assess the environmental impact of space projects over their entire life cycles, an approach known as Life-Cycle Assessment. These guidelines include design measures to ensure more environmentally conscious designs, referred to as eco-design, as well as debris mitigation strategies [2]. Debris mitigation measures can be divided into avoidance measures, which focus on reducing the risk of debris generation, and sustainability measures, which aim to remove non-operating objects from highly populated and economically important orbits, such as Low Earth Orbit (LEO).
One avoidance measure involves monitoring debris objects with significant hazard potential. Tracking debris and propagating their orbits can help plan safer space missions and conduct collision avoidance maneuvers. The motion of debris generated by impacts or explosions can be analyzed collectively as a cloud of debris [3].
In this work, the evolution of a debris cloud is analyzed as a function of time based on the Restricted Three-Body Problem. The simulation propagates the orbits of the cloud elements around the Earth and generates a mesh that covers the cloud using Delaunay triangulation. The analysis considers various perturbative effects, such as J2 potential, C22, J3, and atmospheric drag. An investigation into the influence of different factors on the cloud's volume changes and the trajectories of its elements is also conducted.

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Poster

CBDO 161

Development of AI for Analysis of Public NASA Images to Discover New Celestial Bodies

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This research project aims to develop an artificial intelligence (AI) system capable of analyzing publicly available images from NASA's databases to identify and classify new celestial bodies, such as stars, exoplanets, and asteroids. Leveraging techniques from computer vision and machine learning, the AI model will process astronomical images to detect faint or previously unnoticed objects, contributing to the discovery and understanding of the universe.

The core of the project involves collecting a diverse dataset of astronomical images from NASA's repositories, including the Hubble Space Telescope archives, the Transiting Exoplanet Survey Satellite (TESS) data, and other observatory databases. Preprocessing techniques will be applied to enhance image quality and remove noise, preparing the data for analysis.

Next, a convolutional neural network (CNN) architecture will be developed and trained using the collected dataset. The CNN will learn to automatically extract features from the images and classify them into different categories, such as stars, galaxies, or unknown objects. Transfer learning approaches may be explored to leverage pre-trained models and optimize training efficiency.

The trained AI model will then be deployed to analyze new images obtained from NASA's ongoing missions or publicly contributed datasets. By scanning large areas of the sky and identifying potential candidates for further investigation, the AI system will assist astronomers in the discovery of new celestial objects and phenomena.

The effectiveness of the AI system will be evaluated through rigorous testing and validation procedures, comparing its performance against human-labeled datasets and existing automated methods for celestial object detection. Performance metrics such as accuracy, precision, and recall will be used to assess the system's ability to identify and classify celestial bodies accurately and efficiently.

Overall, this research contributes to the field of astronomy by providing a novel approach to analyzing astronomical images and discovering new celestial bodies. By harnessing the power of AI and publicly available NASA data, the project aims to advance our understanding of the universe and inspire future discoveries.

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Poster

CBDO 162 - A

Revisiting the dynamics of the Prometheus-Pandora System

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In this work, we revisit the Prometheus-Pandora system, carrying out a detailed analysis of Prometheus's current orbit [1], considering the resonant and secular perturbations with Pandora and Saturn's oblateness. We performed numerical integrations of a dense ensemble of orbits of clones of Prometheus. Through spectral analysis and interpretation of the numerical simulations in dynamical maps [2], we identified the domain for the 40:39, 40:41, and 121:118 Pandora-Prometheus resonances and show that Prometheus' orbit is currently inserted in the separatrices of the 121:118 Pandora-Prometheus resonance. Using the Laskar Diffusion Coefficient tool [3], we evaluated the chaotic behavior of Prometheus in this orbital region. Additionally, we explore Pandora's orbital neighborhood disturbed by the 4:2 Mimas-Tethys resonance, studying how this resonance influences Pandora's orbital dynamics and identifying the domain of the 3:2 Mimas-Pandora resonance. We investigated how the Pandora clones located in this resonance affect the orbital dynamics of Prometheus.

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Poster

CBDO 163 - A

Space Situational Awareness: an Overview of Satellite Collision Avoidance Maneuvers

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Space Situational Awareness (SSA) is the capability to understand and monitor the space environment to identify and predict the positions, movements, and activities of objects orbiting Earth. This includes operational satellites, space debris, and other artificial objects. SSA is crucial for ensuring the safety and sustainability of space operations, as it prevents collisions between satellites and debris and protects critical infrastructures such as communication, navigation, and meteorological systems. SSA activities involve continuously tracking objects in orbit, predicting their future trajectories, analyzing potential threats like imminent collisions, and developing strategies to mitigate these threats. Given the growth of space activity and the consequent increase in orbital debris, SSA is becoming an increasingly important concern for the international space community. The effectiveness of collision avoidance maneuvers, which include changes in spacecraft trajectories, is essential for ensuring the continuity of the space operation, avoiding debris generation, and optimizing fuel use. Therefore, given the importance in the aerospace context, this work aims to provide an overview of the main techniques and maneuvers currently used to prevent satellite collisions. The research seeks to explore the strategies in use, addressing their advantages, limitations, and potential for improvement to ensure safer and more efficient space operations, contributing to the reliability and sustainability of space operations. In addition, this work presents the avoid collision strategies considered by Brazilian space operators, such as the National Institute of Space Research (INPE) and the Space Operations Center (COPE).

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Poster

CBDO 164

Orbital and spectral analysis of the meteor captured on April 25, 2024, over the state of Mato Grosso

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On April 25, 2024, at 2:39 - UTC there was an event with a flare of Magnitude -1.07 captured by stations ISL, in São José dos Quatro Marcos, and ROO, in Rondonópolis-MT. To acquire the data, the stations used Sony PY-SH361 cameras, with a Fujinon F 0.95 lens at ISL and a Tecvoz F 1.0 lens and a 500 line/mm diffraction grating at ROO_1. Using the data obtained by the cameras, it was possible to determine the object's orbital evolution using Python software developed by the authors. The resulting heliocentric orbital parameters were semi-major axis a = 1.3 AU, eccentricity e = 0.44 and inclination i = 4.95º. In addition, the chemical composition of the object was determined by the diffraction grating attached to the ROO_1 camera, which found Sodium, Iron and Magnesium, common elements in meteoritic bodies.

Poster

CBDO 165 - A – Withdrawn by the author

CBDO 166 – A

Batch-Differential Correction for Orbit Determination

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The present work addresses the problem of orbit determination for space objects using exclusively angular position data obtained from ground-based sensors. The study applies the Batch-Differential Correction Method to assess stability amidst bias and random errors in angular and temporal data, as well as the algorithm's sensitivity to input data sample sizes. Specifically, the project processes data according to established standards (CCSDS and ISO 13526:2010) and creates initial state vectors through Initial Orbit Determination (IOD) methods, such as Gauss's method, relying solely on actual Tracking Data Messages without additional information about the object's dynamics. Subsequently, the Batch-Differential Correction Method refines the results obtained from the IOD process. This methodology is particularly useful for managing uncorrelated targets (UCT), whether previously cataloged or not, by not depending on *a priori* information about the object. Additionally, the sensitivity analysis results concerning systematic and random errors can be used in future implementations employing stochastic approaches to data processing.

Acknowledgment
ITA Space Center

Poster

CBDO 167

The three-dimensional creep tide theory - Averaged equations and applications to long-term evolution of close-in exoplanetary systems

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The 3D version of the creep tide theory has been recently presented in Congress, as well as submitted to peer review in specialized magazines (Folonier et al. 2024, submitted). The first version of the extended spatial theory exhibited the main equations for the form and orientation of the equilibrium figure, a set of five first-order o.d.e.'s known as the creep parametric equations. Furthermore, the rotational equations were presented, through which it is possible to determine the rotational dynamics of the two-body system of rigid bodies (primary and secondary).
The resulting system of creep equations is stiff and studies of the evolution over larg periods (of order of millions of years) need the adoption of an approximate solution for the parametric equations. Here, we present the analytical averaged equations, able to reduce the integration costs of the numerical solutions. Our new approach is applied to a specific known system, CoRot-3, formed by a star and a massive planetary companion (a brown dwarf) with a large stellar obliquity.

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Poster

CBDO 168 - A

Equilibrium Points and Surface Dynamics About Comet 67P/Churyumov-Gerasimenko

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Today, space missions, such as the Rosetta mission, play a crucial role in our understanding of the solar system's small bodies, shedding light on their origin and dynamic evolution. Among these celestial objects are comets, which typically form at significant distances from stars, their accretion disc material remaining largely unchanged since the formation of the planetary system. The Rosetta mission successfully flew and landed on the comet 67P/Churyumov-Gerasimenko. One of the significant aims of this mission was to understand the surface dynamics of cometary forces, which is the focus of this study.
One of the primary mission objectives was to comprehend the surface dynamics of cometary forces. This study endeavors to delve into the surface dynamics of cometary nuclei of 67P, considering the gravitation force from its irregular shape and the centrifugal force due to its rotation. The methodology, meticulously crafted, was based on computed surface dynamics features of cometary nuclei using Fortran and C subroutines. Comet 67P, a polyhedral shape model with 48.420 vertices and 96.834 faces, was the subject of our analysis. We utilized their geometric height and surface tilt angle to discern the dimensions of the comet and the irregularities on its surface.
Moreover, with the estimated bulk density and volume, we calculated the mass of the comet. Furthermore, we obtained geopotential and surface acceleration. We calculated slopes on the comet's surface from the rotation period, defined by the supplementary angle between the total acceleration vector and the normal face vector. In addition, equilibrium points and their stabilities were computed for a range of densities. Our results reveal possible regions across the comet's surface where the particles are ejected and sites where materials are accumulated. The results regarding the equilibrium points show that the equilibria are far away from the comet's surface when the density grows, keeping the same volume. This finding has significant implications for our understanding of cometary forces and surface dynamics, suggesting that the forces at play on the surface of comets significantly influence the particles at rest.

Poster

CBDO 169

Dynamics of Rotation of Small Satellites of Saturn

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The rotational dynamics of natural satellites is a branch of Celestial Mechanics that studies the rotational movement of these bodies under the action of gravitational torques. With the space explorations carried out by the Cassini-Huygens mission on Saturn, there were discoveries of new small satellites located close to the planet e.g. Methone, Aegaeon, and Anthe. There is no sure knowledge about their physical structures and through libration measurements made by the Cassini spacecraft, it is possible to determine the constitution of the interior of the satellites by comparing the results found by the probe with the analytically estimated results. This work investigated the basic rotation dynamics of small satellites with rotation around one axis with semi-axes a>b>c in the x, y, and z directions, respectively. The satellites studied were discovered by Cassini spacecraft in the last twenty years and their rotational states are analyzed numerically with initial conditions that represent synchronous rotation regimes. The basic rotational dynamics of small satellites studied in this work will be conducted utilizing the exact equation of rotational motion of satellites and, also, by the equation analytically deduced with integrable linear approximations. The first uses Fortran computational codes and data from Horizons platform, while the second is solved analytically. The rotational regimes (such as synchronism) studied analytically will be compared with the numerical results given using the section surface method. With the methodology used, it is expected to find values for the physical, forced, and optical libration for each satellite and the distributions of homogeneous layered interiors. The analyses carried out in this work for Saturn's small satellites may allow us to describe their physical structures and their possible current rotation regimes.

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Poster

CBDO 170

Asteroids were born bigger: An implication of surface mass ablation during gas-assisted implantation into the asteroid belt

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The origins of carbonaceous asteroids in the asteroid belt is not fully understood. The leading hypothesis is that they were not born at their current location but instead implanted into the asteroid belt early in the Solar System history. In this study, we investigate how the migration and growth of Jupiter and Saturn in their natal disk impact nearby planetesimals and subsequent planetesimal implantation into the asteroid belt. Unlike traditional studies, we account for the effects of surface ablation of planetesimals caused by thermal and frictional heating between the gas-disk medium and planetesimal surface, when planetesimals travel through the gas disk. We have performed simulations considering planetesimals of different compositions as water-ice rich planetesimals (composed of more than 80% water by mass), water-ice poor planetesimals (relatively dry and enstatite-like), organic-rich planetesimals, and fayalite-rich planetesimals. Our findings indicate that, regardless of the migration history of the giant planets, water-ice rich, organic-rich, and fayalite-rich planetesimals implanted into the asteroid belt generally experience surface ablation during implantation in the asteroid belt, shrinking in size. On the other hand, planetesimals with enstatite-like compositions were inconsequential to surface ablation, preserving their original sizes. By assuming an initial planetesimal size-frequency distribution (SFD), our results show that – under the effects of surface ablation – the planetesimal population implanted into the asteroid belt shows a SFD slope slightly steeper than that of the initial one. This holds true for all migration histories of the giant planets considered in this work, but for the Grand-Tack model where the SFD slope remains broadly unchanged. Altogether, our results suggest that the largest C-type asteroids in the asteroid belt may have been born bigger. High-degree surface ablation during implantation into the asteroid belt may have even exposed the cores of early differentiated C-type planetesimals.

Poster

CBDO 171 - A

Dynamics of a Solar Sail in Resonant Conditions with Solar Radiation Pressure Perturbation: Case of Mercury and Earth.

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In this work, we study the dynamics of a spacecraft equipped with a solar sail orbiting inner rocky planets, such as Mercury and Earth. We focus on the existence of double resonances, where two independent resonant angles can occur. These angles are derived from the Solar Radiation Perturbation (SRP) and involve long-period variables, such as the argument of pericenter (w), the longitude of the node (Ω), and the mean anomaly of the Sun ($l_\odot$).
For Mercury's satellites, the Sun's motion is much faster compared to the frequencies of w or Ω, which prevents the occurrence of dominant low-order double resonances. On the other hand, for Earth's satellites, $n_\odot$ is comparable to the frequencies of w and Ω, allowing the occurrence of seven low-order double resonances.
To address this type of problem, we use the averaged system, as the frequencies of interest are long-period. To do this, we average the perturbations, that is, we eliminate the mean anomaly from the problem, following ideas presented in [1]. In particular, we identified a sign error in the SRP averaging process in that article, which does not lead to significant differences as long as the SRP perturbation remains sufficiently small.
Whenever possible, we compare the results of the averaged system with the exact system. In many cases, qualitative comparisons alone can reveal good agreement, as long as time is not involved. These comparisons are especially useful in identifying promising regions that may contain frozen orbits. Once these smaller regions are identified, the exact system can be applied to find specific orbits. In this work, we identified a candidate region for frozen orbits for an Earth satellite in the (w, Ω) plane, under double resonance conditions. Additional simulations are ongoing to validate this approach.
We also highlight significant differences between averaged and exact orbits, mainly those concerning to time evolution. These differences usually arise when using the same initial conditions for both systems. In such cases, the inverse transformation, for example, Von Zeipel method [2], becomes necessary.

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Poster

CBDO 172 - N

Dynamics Study of Hippocamp: Future Resonant Scenario 13:11

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Hippocamp is the smallest of Neptune's moons, and its origin remains unclear. It is believed to have formed from the aggregation of particles following a collision suffered by Proteus. Currently, the semi-major axes of Hippocamp and Proteus are 105,283 km and 117,647 km, respectively, with their relationship being close to the 13:11 resonance. Due to tidal effects, Proteus is slowly moving away from Neptune, while Hippocamp remains largely unaffected, suggesting the system is evolving towards the 13:11 commensurability.
This study considers a system composed of Hippocamp, Proteus, Triton, the Sun, Neptune, and Neptune's oblateness. We also include the tidal effect acting on Proteus, which could lead to the system passing through the 13:11 resonance in the next 18 million years. The eccentricities of Hippocamp (1.e-5) and Proteus (4.7e-4) are very small, preventing permanent libration during this passage. According to Brozovic's data and our simulations, Hippocamp's eccentricity would need to be 35 times greater than its current value for libration to occur. We also found that any librations happen at pi and that two simultaneous librations never occur.
When tidal effects are considered, some temporary librations in Hippocamp's resonant angle are noted, but they quickly vanish, meaning there is no smooth capture scenario similar to those seen in first-order planetary satellite captures. A key factor here is the influence of Triton on the pair of moons. As the tidal effect on Proteus brings it closer to Triton, Proteus becomes increasingly disturbed by its presence, which in turn affects Hippocamp.
Our simulations indicate that the dynamics of Proteus, and especially Hippocamp, are significantly impacted, with the potential for Hippocamp to escape. Further simulations are required to confirm this scenario. However, if the secular tidal effect on Proteus persists, both Proteus and Hippocamp could eventually collapse.

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Poster

CBDO 173 - A

Assessing the Collision Potential of Space Debris after Fragmentation

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Given the increasing number of space debris, this study will commence with a detailed survey of active and inactive satellites, utilizing established databases and observation networks to analyze the regions and types of debris that have re-entered Earth's atmosphere. Following this, the study will map the orbital dynamics of selected debris fragments generated by satellite explosions. This mapping will facilitate the identification of key orbital characteristics to be integrated into the CR3BP analytical model, implemented in MATLAB. The research will focus in analysis will also evaluate potential collisions with the Earth or the Moon post-fragmentation, aiming to quantify variations in orbital energy and fragment distance relative to the lunar surface, as well as changes in relative velocity at the point of capture. Understanding these dynamics could offer critical insights into the optimal strategies for debris capture and controlled re-entry, thereby contributing to enhanced debris mitigation efforts. Ultimately, this study seeks to better characterize the orbital properties of space debris, with the goal of minimizing the risks and potential damage to the space environment.

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Poster

CBDO 174 - A

Analysis of the stable regions of the Kepler-20 system through frequency analysis

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The CoRoT and Kepler missions, the former operated by the European Space Agency (ESA) and the latter by NASA, have thus far discovered thousands of exoplanets, some of which exhibit particularly interesting characteristics from both dynamical and formation perspectives. Notably, the Kepler-20 system comprises a star of size comparable to that of the Sun, hosting five planets with masses ranging from slightly less than one Earth mass to approximately 13 Earth masses, all orbiting with semi-major axes smaller than that of Mercury when compared to the Solar System (Buchhave et al. 2016). Consequently, the atypical configuration of the Kepler-20 system itself presents significant interest for the study of its dynamics, while also potentially contributing to the understanding of the current configuration of the Solar System. To investigate the stability of the system, numerical simulations were conducted involving the five planets, along with a set of planetesimals among them, utilizing the Mercury package (Chambers 1999) and accounting solely for gravitational interactions. The results were analyzed through frequency analysis (Laskar 1993; Sidlichovsky & Nesvorny 1996), aiming to identify regions of stability and instability within the system, thereby seeking possible locations for the existence of unobserved bodies and confirming the current configuration of the system.

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Poster

CBDO 175

Particle regions around Quaoar system

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(50000) Quaoar is a trans-Neptunian object candidate for a dwarf planet. With 1100 km in diameter, eccentricity of 0.04 and mass of 1.2e21 kg, it orbits at an average distance of 43.4 au from the Sun. Quaoar has a 90 km diameter satellite named Weywot that orbits at 13300 km from its center and the recently discovered system composed of two rings that are surprisingly outside the Roche limit. Using the Rebound program, we adapted a routine to simulate sets of particles around Quaoar taking into account its non-sphericity, the influence of solar radiation pressure and the presence of the satellite Weywot. Preliminary results show that initially stable 20 micron particles escape due to the increase in eccentricity caused by solar radiation pressure. Furthermore, when the J2 of Quaoar is considered, it appears strong enough to dampen the effect of radiation pressure, causing part of the previously ejected particles to survive and/or collide with Weywot.

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Poster

CBDO 176

Revisiting derivative-free nonlinear Kalman filtering: implementation aspects of algorithms CDKF, DDKF, CKF, AND UKF

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This work aims at revisiting derivative-free nonlinear Kalman filters. The main algorithms focused are the CDKF (Central Difference Kalman Filter), DDKF (Divided Difference Kalman Filter), CKF (Cubature Kalman Filter), and UKF (Unscented Kalman Filter), which depart from different basic principles to evolve to their final algorithms (Noorgard et al., 2000; Arasaratnam e Haykin, 2009; Julier and Uhlmann, 1997). These algorithms are among the most popular used in state estimation of nonlinear systems, notably in aerospace systems. Although they are different in their basic concepts, it is overwhelming the similarity of their respective final algorithms, especially in aspects of computational implementation. Such similarities and differences in the implementation of the algorithms are emphasized in order to allow easy assessment in terms of computational complexity.

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Poster

CBDO 177 - A

Fundamentals of Dynamical Astronomy and Elementary Applications in Resonant Dynamics of Saturn's Small Satellites - The Pan-Prometheus Case

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Investigating orbital resonance among celestial bodies is fundamental for comprehending the dynamics of planetary systems. The exploration of Saturn's satellite system, facilitated by missions such as Cassini, has unveiled a myriad of new satellites, underscoring the necessity of examining their interactions. Among these discoveries, certain moons exhibit exotic orbital configurations influenced by their interactions with neighboring moons and Saturn's oblate shape. The moons Pan and Prometheus have been identified as potentially participating in a 16:15 orbital resonance; however, there are few in-depth investigations provided in the literature based on orbital dynamics and modern analysis techniques on this resonance, except in observational studies. This work aims first to study documented orbital resonances research, then particularly focus on the Pan-Prometheus pair. Building upon the foundation of previous research, the primary objective is to conduct a comprehensive analysis of orbital dynamics and to ascertain whether those satellites indeed exhibit resonance. To achieve this objective, numerical integrations were performed of the exact equations of motion for a system of N satellites under the main terms of Saturn's potential and non-central gravitational field, the simulations take into account up to seven satellites, including the coefficients J2 and J4. The simulated orbits are compared directly to the osculating orbital elements provided by the Horizons' system of ephemerides based on the instantaneous positions and velocities of the satellites obtained from the numerical simulations. We are able to see how orbits in a non ressonance state (such as Pan) behaves by scrutinizing their orbital elements over prolonged temporal spans, and anticipated outcomes encompass categorizing at what inicial values this sytem would be in ressonance. This work strides to enhance our understanding of orbital resonances among Saturnian satellites, furnishing valuable insights into the dynamics of planetary systems and describing the Pan-Prometheus dynamic.

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Poster

CBDO 178

Development of an electronic system for a CanSat

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Due to the high cost and the difficulty of transporting objects into space, a growing need has arisen to design increasingly smaller satellites, aiming to reduce the costs and risks of missions. This has brought attention to the category of small satellites, also known as Smallsats. Simultaneously, many educational institutions have started using smaller satellites in projects for their students due to the lower financial investment required for launch, giving rise to CanSat and CubeSat in response to this demand.
Unlike the CubeSat, the CanSat is designed as a meteorological probe that can be launched by a small rocket without crossing Earth's atmosphere. This makes the project much more cost-effective and less complex compared to a CubeSat, making it an ideal entry point for beginners in the field. Therefore, the goal of this scientific research is to complete the entire production cycle of a CanSat.

Acknowledgments
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Poster

CBDO 179

Current scenario of space debris removal mechanisms

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The growing expansion of the aerospace sector and its activities raises concerns about space debris, objects of anthropogenic origin that are no longer useful and orbit the Earth. The significant increase in the number of these non-functional objects requires not only mitigation, but also active removal, given the high risk of collisions they pose. The aim of this work is to carry out a bibliographical survey of the most promising debris removal mechanisms found among space agencies, whether they are in the study phase or in practical application projects. The 3 types of method worked on were ClearSpace-1, an ESA partner mission, a satellite that will pick up the debris using robotic arms and vision-based navigation system with the aid of long and short range cameras, re-entering the atmosphere along with the debris [1]; the RemoveDEBRIS microsatellite, which has a partnership with the European Union, focusing on its debris capture system using networks to de-orbit the debris [2]; and the impulse removal mechanism, an indirect way of speeding up the re-entry of space debris by a laser cannon on the Earth's surface [3], which still has no concrete projects. The results show that the research in this sector is recent, innovative and could have a positive impact on future space missions.

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Poster

CBDO 180

Space Debris Evolution: Case Studies

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Space debris are inoperative objects that orbit around the Earth, originating from human activity. This work aims to study the evolution of space debris subject to perturbations: atmospheric drag, Earth's gravitational potential, J2 and J22 coefficients, lunar-solar forces, and solar radiation pressure. The study explores the behavior of debris under these perturbations given different initial conditions, including altitudes, orbital elements, and area-to-mass ratios. For this purpose, an orbit propagator in FORTRAN, based on [1] and [2], along with the TD-88 atmospheric model, were used. After studying the effect of each perturbation in isolation, their simultaneous effects were also evaluated. The contributions found in the literature were verified for isolated perturbations. When all perturbations were applied simultaneously, the evolution of the orbital elements was observed. For example, for debris with an area-to-mass ratio of 0.045 m^2/kg at 700 km altitude, the argument of perigee and semi-major axis underwent significant changes. These results suggest the possibility of exploring these combined effects to facilitate atmospheric reentry. The study of real cases is ongoing, with the orbital elements of COSMOS 2112 debris being used for this purpose.

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Poster

CBDO 181

Quasi-critical and quasi-heliosinchronous orbits

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Space missions exploring planetary satellites have been of great scientific interest. Currently scientific missions, especially reconnaissance, can benefit greatly from the use of certain natural orbits, including frozen and heliosynchronous ones. The main objective of this work is to revisit the concept of frozen orbits from a variational perspective, proposing an alternative method based on variational calculus, dynamic programming and optimal control to search for them. And, for a specific objective, apply the proposed method to find frozen orbits around natural satellites. In the present work the following hypotheses are considered: 1) perturbations due to the Sun and third bodies are not considered; 2) the distribution of the mass of the natural satellite is not uniform; 3) the orbit of the natural satellite around its primary is circular and uniform; 4) the equatorial plane is coincident with that of the ecliptic; 5) the natural satellite is gravitationally locked by tidal forces. The equations are put into Hamiltonian form and the Hamiltonian is put into normal form using Lie-Deprit transformations

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Poster

CBDO 182

Mathematical model of the orbital elevator motion

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A fundamentally new way of movement is proposed. In the central field of gravity, there is a relationship between rotational motion relative to the mass center of the body and radial motion of the body. The principle of redistribution of total kinetic momentum is realized when an extended body with a flywheel moves in a central gravitational field. The difference in gravitational forces tends to rotate an extended body in orbit along the local vertical, creating a moment relative to the mass center of the body. This moment is balanced by the moment during accelerated rotation of the flywheel. By changing the direction of flywheel rotation, the movement of such a mechanical system in orbit can be carried out downwards or upwards, holding an extended body at a certain angle to the local vertical. Due to internal forces (for example, an electric engine), the flywheel spins up, i.e. the internal kinetic moment changes. Since the total value of the angular momentum is a constant value, the angular momentum of the mass center changes, which leads to a change in the altitude of the orbit. Having a group of flywheels with different orbital heights in the same plane, it is possible to implement a multi-stage orbital elevator for moving oncoming cargo flows without fuel consumption. Electricity from power sources (for example, solar panels) is sufficient to spin up the flywheels.

Oral Communication

CBDO 183

Method of satellite constellation design for on-orbit servicing of multisatellite space systems on orbits with given parameters

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The method of satellite constellation design for on-orbit servicing of multiple spacecraft serviced on low orbits with significantly different heights, eccentricity, and right ascension of the ascending nodes (RAAN) is presented. It is supposed that each spacecraft serviced consist of several orbital modules used for on-orbit servicing with limited Delta-V on board. The method is based on comparative analysis of RAAN relative changes for passive spacecraft and active orbital modules during the given period of time (time of on-orbit servicing). The estimation of total Delta-V for coplanar and non-complanar transfers of active orbital modules is calculated using fast numerical analytical algorithms.
The regularities of localization of optimal parameters of satellite constellation for on-orbit servicing with given limitation on on-orbit servicing time, total Delta-V and RAAN changes is shown.

Oral Communication

CBDO 184

NEOMOD: Dynamical Model of Near-Earth Objects from a Decade of Catalina Sky Survey Observations

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Catalina Sky Survey (CSS) is a major survey of Near-Earth Objects (NEOs). CSS's G96 telescope was upgraded in 2016 and detected over 10,000 unique NEOs since then. We characterize the NEO detection efficiency of G96 and use G96's NEO detections from 2013-2022 to develop a dynamical model for NEOs (NEOMOD). We estimate there are 936+/-29 NEOs with absolute magnitude H < 17.75 (diameter D > 1 km for the reference albedo p_V = 0.14) and semimajor axis a < 4.2 au. The slope of the NEO size distribution for H = 25-28 is found to be relatively shallow (cumulative index ~ 2.6) and the number of H < 28 NEOs (D > 9 m for p_V = 0.14) is found to be (1.20 +/- 0.04)x10^7, about 3 times lower than previous estimates. Small NEOs have a different orbital distribution and higher impact probabilities than large NEOs. We estimate 0.034 +/- 0.002 impacts of H < 28 NEOs on the Earth per year, which is near the low end of the impact flux range inferred from atmospheric bolide observations. Relative to a model where all NEOs are delivered directly from the main belt, the population of small NEOs detected by G96 shows an excess of low-eccentricity orbits with a = 1 - 1.6 au that appears to increase with H (~30% excess for H = 28). We suggest that the population of very small NEOs is boosted by tidal disruption of large NEOs during close encounters to the terrestrial planets. When the effect of tidal disruption is (approximately) accounted for in the model, we estimate 0.06 +/- 0.01 impacts of H < 28 NEOs on the Earth per year, which is more in line with the bolide data. The impact probability of a H < 22 (D > 140 m for p_V = 0.14) object on the Earth in this millennium is estimated to be 4.5%.

Invited speaker

CBDO 185

Stellar Occultations by Trans-Neptunian Objects

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Stellar occultations provide a powerful tool to explore objects of the outer solar system. Occultations return kilometric accuracies on the three-dimensional shape of bodies irrespective of their geocentric distances, with the potential of detecting topographic features along the limb. From the shape, accurate values of albedo can be derived, and if the mass is known, the bulk density is pinned down, thus constraining the internal structure and equilibrium state of the object. Since 2013, occultations have led to the surprising discovery of ring systems around the Centaur object Chariklo, the dwarf planet Haumea and the large trans-Neptunian object Quaoar while revealing dense material around the Centaur Chiron. This suggests that rings are much more common features than previously thought. Meanwhile, they have raised new dynamical questions concerning the confining effect of resonances forced by irregular objects on ring particles. I will review the field's current status regarding the motivations, infrastructure development and main results.

Invited Speaker

CBDO 186

Geodetic and Geophysical Characterization of Ganymede with GALA, the Ganymede Laser Altimeter

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On April 14, 2023, the JUICE (Jupiter Icy Moons Explorer) space probe was successfully launched from the ESA space centre in Kourou (French Guiana) to the Jupiter system. The aim of the mission is to study the giant planet, its magnetosphere and the Galilean moons in detail. In particular, Ganymede, the largest moon in the solar system, is in the mission's focus. After flybys of the moons Europa and Callisto, JUICE will enter in orbit around Ganymede in the final phase of the mission. The exploration of Jupiter's icy moons, under whose outer layers of ice huge water oceans are suspected, plays a major role not least in the possible evolution of life outside the Earth. For this, a detailed geodetic characterization of the moon's surface, rotation, tides, and interior structure is mandatory. Several instruments on JUICE including the camera, laser altimeter, subsurface radar, magnetometer, and the radio science package are jointly addressing this goal. The German Aerospace Centre (DLR) is responsible for the operation and scientific evaluation of the Ganymede laser altimeter (GALA). Following the launch and commissioning of the spacecraft, the functional tests of GALA has been successfully completed. Here we will summarize the goals of the GALA experiment and the methods to investigate Ganymede's evolution and present state in particular regarding a potential subsurface ocean and its physical characterization.

Invited speaker

CBDO 187 - N

Italy-Brazil Joint Science and Technology Cooperation in Space technology: the SPLASH Project

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Within the framework of the first Executive Programme for Scientific and Technological Cooperation between Italy and Brazil for the years 2022- 2024, CIRA and the University of Brasilia are involved in a joint research project on innovative mechanically deployable shape-changing re-entry aeroshells with advanced mechanisms, flexible heat shield and smart actuation.
Flexible morphing deployable aeroshells are increasingly emerging as novel and alternative concepts for the controlled re-entry and precise landing of spacecraft. This paper deals with the design, simulation and integration activities of an innovative shape-changing mechanism developed within the SPLASH (Self-DePloyable FLexible AeroSHell for de-Orbiting and Space Re-entry) project for the controlled re-entry and safe recovery of CubeSat-class vehicles for post-flight inspections and low-cost experiments. The focus is on the design, performed by CIRA, of such a mechanically deployable aeroshell consisting of a multi-hinge assembly based on a set of finger-like articulations with two-modal capabilities. The deployable surface can be modulated by a single translational actuator to adjust the lift-to-drag ratio for guided entry. Furthermore, once deployed, the system can activate eight small movable aerodynamic flaps which can be individually morphed via an SMA-based actuation to improve the capsule's manoeuvrability during the re-entry trajectory and provide additional precision during landing. Multi-body simulations of the retraction/deployment of the system, sized for a standard 12U CubeSat, are used to investigate the most critical aspects for the actual implementation of the concept. In addition, the morphing behaviour and control effect of the shape memory alloy actuation are preliminary assessed through parametric simulations.
The adaptive thermal protection system is a deployable umbrella-like heat shield consisting of structural ribs and struts that can be stowed during launch and deployed during re-entry to reduce the ballistic coefficient. A study has been initiated at the University of Brasília to assess the manufacturing feasibility of the flexible thermal protection system by filament winding. The candidate studied was a composite material consisting of a flexible silicone rubber reinforced with continuous carbon fibres. A series of theoretical and experimental samples were realized to prove the feasibility of the flexible TPS by winding a cylindrical vessel of diameter 100 mm with elliptical closures. The curing process, followed by the mandrel removal, resulted in a composite structure, whose thermal and mechanical behaviour, in addition to the properties of the impregnated tow, is strongly influenced by its trajectory. Overall, the preliminary results confirmed the feasibility of the method, while further investigations are underway for a complete characterization of the wound flexible composite.
This research is funded in part by a grant from the Italian Ministry of Foreign Affairs and International Cooperation (MAECI) and by CONFAP through the State Funding Agency (FAPs) involved.

Invited speaker

CBDO 188

Dynamic of Centaurs, link with the giant planets and other small body populations

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The region of the giant planets, of our solar system is travelled by a population of small bodies known as Centaurs. They serve as transitional objects, marking the journey from their origin in the transneptunian region to the inner solar system, where they may exhibit comet-like behavior and become Jupiter family of comets (JFCs). It is a change-prone population in a dynamical sense, but also in a physical one. A Centaur's journey begins with a crossing of Neptune's orbit, and as it ventures toward the inner solar system, it undergoes encounters with the giant planets, capture into MMRs, chaos, ZLK mechanism, which significantly alter the characteristics of their orbits. Furthermore, Centaurs experience changes in their observed physical properties, which can occur due to close encounters with planets and the tidal forces they induce, collisions, as well as the physical effects they undergo as they approach the Sun. This dual dynamical and physical adaptability makes Centaurs a key population in our solar system. In the giant planetary zone there are also other transit small body populations such as asteroids, and Trojans that leave their niches in their way to ejection of the solar system. Particularly noteworthy are coorbital objects and irregular satellites, intricately linked to the giant planets whose origins are believe to be traced back to the small distant bodies of our system.
In this talk, I will delve into the current state of knowledge concerning Centaurs and other small bodies within the giant planetary zone. The discussion will encompass their origin, dynamics, physical processes, and their interconnectedness with other minor body populations in our solar system.

Invited speaker

CBDO 189

Dynamics of a non-homogeneous straight segment: relative equilibria, stability, periodic solutions and singularities

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In this talk we study the qualitative features of an infinitesimal mass attracted by the gravitational force induced by a body modeled as a non-homogeneous straight segment. We assume that the segment rotates uniformly and considers the fixed segment a particular case. Assuming a parametrized linear density, we establish the potential by a massive straight segment, which we manage to express in closed form. For the case of the non-homogeneous rotating straight segment, we study the location, existence, and linear stability of the relative equilibria. Moreover, for the case of the non-homogeneous fixed straight segment, we determine the existence of different families of periodic orbits and analyze its singularities, and every solution not defined for all times satisfies the fact that the particle's distance to the segment tends to zero. We can state that in the onedimensional problem on the ξ-axis, all the singularities are due to collisions.

Invited speaker

CBDO 190

Attitude Representations of Artificial Satellites and Applications

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The success of space missions depends on several parameters, including the correct spatial orientation of the satellite, that is, the satellite's attitude, related to the satellite's rotational motion. The choice of parameters to represent the satellite's attitude is essential for the analyzes to be carried out, related to propagation, stability, control and attitude estimation. In this work, quaternions, Euler angles and Andoyer canonical variables will be presented. Results obtained with the use of Euler angles in the attitude propagation of spin-stabilized artificial satellites will be discussed. The attitude control of Tether satellites obtained using quaternions will be presented. The analysis of attitude stability in the libration and circulation regions will be discussed using Andoyer variables. Various attitude estimation results using different estimation methods will be compared using both Euler angles and quaternions. In a way, the choice of attitude parameterization depends on the characteristics of the satellites and the analysis to be carried out. The author of this paper has not received financial support from FAPESP in the last three years.

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Invited speaker

CBDO 191 - N

Design and Construction of a System of Magnetic Field Induced by Coils in a Vacuum Chamber for Experiments with Plasma Physics

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This work presents the planning and development of an apparatus for generating a uniform magnetic field in a vacuum chamber for plasma experiments related to space weather at the Plasma Physics Laboratory of the University of Brasília (LFP-UnB). The aim is to build a device capable of producing magnetically confined plasmas in various configurations, simulating space plasma conditions near Earth. The study focuses on waves and turbulence in Earth's magnetospheric plasma, wave-particle interactions, plasma dynamics, and magnetic confinement phenomena. A system of six coils was developed to generate the required axial magnetic field, aligned with the main axis of the cylindrical vacuum chamber, representing the interplanetary magnetic field (IMF). The project involved stages such as CAD design of the vacuum chamber, analysis of coil system theory, positioning, sizing, and distribution of coils, simulations in the Finite Element Method Magnetics (FEMM) software, structure development, and comparison of results.

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Poster

CBDO 192 - N

Software Development for METAR Data Estimation for Performance Simulation Optimization in the Aeronautical Sector

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In aeronautical performance studies, clients often provide meteorological data for analysis. However, these data are prone to noise from sensor maintenance issues or equipment problems, which can compromise simulation reliability. To address this, we developed Python software to estimate meteorological data, validate the accuracy of airport performance simulations, and analyze payload impact using METAR data from various weather stations provided by Iowa State University.

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Poster

CBDO 193 - N

Optimization of the parameters of the covariance matrices of the Extended Kalman Filter for attitude estimation of the CBERS satellite

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The CBERS-4A satellite is the latest satellite to be launched in the CBERS family and its function is of paramount importance for remote sensing of the Earth. Determining the satellite's attitude is essential to ensure the proper orientation of the solar panels, thrusters, cameras, antennas, heat sinks and to achieve a successful space mission. The Extended Kalman Filter (EKF) is a non-linear adaptation of the Kalman Filter that uses a linearized trajectory to estimate the current state and then update it. The attitude and orbit data were obtained using the PROPAT simulator for each instant of the satellite with all its intrinsic characteristics in MATLAB. In this work, the aim is to optimize the parameters of the EKF covariance matrices for satellite attitude estimation using quaternions and compare them with the results of the simulator. In order to optimize the performance of the satellite's rotational motion determination, it was decided to use an Adaptive Kalman Filter to optimize the parameters of the covariance matrices based on the updates of the innovations accompanied by the floating window method. Throughout this improvement phase, various configurations and combinations of stochastic parameters were explored, resulting in a filter that not only adapted better to the specific conditions of the simulation, but also consistently outperformed the EKF. Regarding the estimation of biases, greater difficulty was observed in presenting convergence compared to the attitude for the period and conditions used in this research.

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Poster

CBDO 194 - N

Resonance Jumps in Space Debris Dynamics: Impacts on Low Earth Orbit

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This study examines the effects of resonance on the orbital elements of space debris whose mean motion is commensurable with Earth's rotation. By applying a suitable sequence of canonical transformations, the system of differential equations describing the orbital motion is reduced to an integrable kernel. Focusing on a specific resonant angle, numerical simulations are conducted to demonstrate the variations in the orbital elements of space debris orbiting near the 15:1 resonance. The study reveals that the motion in the vicinity of the exact resonance region is highly sensitive to minor perturbations and that the resonance effect occurred primarily in near-circular orbits and at high inclinations where the J2 effect has low influence This sensitivity suggests that these regions may exhibit chaotic behavior or lead to collision-prone orbits considering different initial conditions

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Poster

CBDO 195 - N

Studying the effects of Earth's atmospheric refraction in Stellar Occultations

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The phenomenon of stellar occultation, where a Solar System object passes in front of a star, allows us to obtain precise information about the occulted object. When we analyze the variation from a star's brightness during an occultation, it's possible to determine the size, shape, density and even the presence of an atmosphere and satellite around this object. This technique has become important in characterizing Near-Earth Objects (NEOs) and their orbits, assessing the risk of collision with the Earth. However, something that can highly influence the precision from a measurement done by Stellar Occultations is the atmospheric refraction. Earth's atmosphere refracts the light from the stars, causing an error in the determination of the occulting object's position, if not corrected. The effect is stronger for objects near the horizon due to increased refraction. Despite the importance of atmospheric refraction, current models for analyzing stellar occultations generally do not consider this effect, as it is insignificant compared to the inherent uncertainties in observations and the sizes of the observed objects. However, with the increasing number of occultation observations by NEOs, it becomes necessary to refine the models of analysis to include atmospheric refraction, especially when observed near the horizon. This work aims to investigate atmospheric refraction models and determine the necessary corrections to astrometric positions obtained through stellar occultations. By considering the effects of atmospheric refraction, it will be possible to obtain even more precise positions of the occulting objects, contributing to a better determination of their orbits.

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FAPEMIG, CNPq and CAPES

Poster

CBDO 196 - N

Investigating the Parameter Space in Two-Dimensional Discrete Mappings by Lyapunov Exponents

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The study of dynamical systems holds significant academic relevance, contributing to the understanding of dynamics in various fields such as Biology, Physics, Mathematics, among others. By employing mathematical equations, it enables the examination of evolving processes, aiming to develop a theory that facilitates the comprehension and visualization of a system's behavior over time. There are several investigative tools, such as orbit diagrams, phase space, stability analysis, Lyapunov exponent analysis, parameter space, among others, which assist in exploring the dynamic behavior of many dynamical systems to classify them as chaotic. This study focused on investigating the Lyapunov exponents of a family of two-dimensional nonlinear mappings. The mapping is described in terms of action and angle variables parameterized by ϵ, which controls the intensity of nonlinearity, γ, which retrieves different mappings known in the literature according to the transformation of the dynamic variables, and δ, which denotes the intensity of dissipative effects in the system. To characterize the observed chaos in the phase space of the system, we numerically utilized Lyapunov exponents. Additionally, through the Lyapunov exponents, we constructed parameter spaces of the system, seeking a descriptive approach to regions of high dynamic complexity, identifying domains of chaotic and periodic behavior in the parameter space. In our studies, we encountered complex structures, known in the literature as shrimps, as well as other classes of structures whose organization we sought to investigate. This analysis contributes to enhancing the use of these theories in the study of nonlinear systems, paving the way for their application in various fields of knowledge, both in numerical and experimental studies across various theoretical models.

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Poster

CBDO 197 - N

New transient co-orbital asteroids of Venus

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Venus has no known natural satellites but has 9 known co-orbitals. These are objects trapped in a 1:1 mean-motion resonance with Venus. Co-orbital configurations include retrograde satellite orbits (RS), tadpole orbits (T) around the Lagrangian equilibrium points L4 or L5, and horseshoe orbits around both L4 and L5 (H). At high eccentricity or inclination, co-orbital configurations may also involve compounds of T and RS (T-RS, T-RS-T), H and RS (H-RS) orbits, or transitions between different co-orbital modes. Here we identify asteroids in 1 RS, 1 L4-tadpole, and 2 T-RS orbits, as well as 8 additional asteroids in possible temporary co-orbital status. Although the majority of these objects do not yet have well-characterized orbits, 2020 CL1 does and is very likely to be a new co-orbital asteroid. With the new candidates, Venus would have a population of 21 co-orbital asteroids, comparable to those of Mars and Earth.

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Poster

CBDO 198 - N

Practical Aspects of LCS Detection with FTLE in Astrodynamics

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The Finite-Time Lyapunov Exponent (FTLE) field is a widely used tool for identifying Lagrangian Coherent Structures (LCS) in dynamical systems. In this study, we apply FTLE to the Circular Restricted Planar Three-Body Problem (CR3BP) to investigate transport channels between regions in phase space. We explore practical aspects of the FTLE field computation and how the best settings of numerical parameters affect the result qualitatively. Our analyses demonstrate that FTLE effectively highlights LCS but also reveals limitations in accurately identifying hyperbolic manifolds. We find that FTLE can produce false positives, identifying structures that are not LCS indeed. The effects of the close approach to the primaries are discussed in the work.

Acknowledgments
CAPES e CNPq

Poster

CBDO 199 - N

Differential Algebra in the Three-Body Problem

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This work applies Differential Algebra (DA) techniques to enhance the computational efficiency in solving the Restricted Three-Body Problem (RTBP), a fundamental model in celestial mechanics. Traditional numerical methods based on floating-point arithmetic face limitations in highly nonlinear systems, often resulting in rounding and truncation errors. In contrast, DA methods offer an alternative approach by automatically generating high-order Taylor series expansions, which maintain accuracy while reducing computational cost.
The study utilizes Automatic Domain Splitting (ADS) to dynamically adjust Taylor polynomial expansions during numerical integration. This technique subdivides the computational domain when the estimated truncation error exceeds a predefined threshold, enabling accurate propagation in regions of strong nonlinearity. The method has proven effective in the analysis of equilibrium points and periodic orbits, particularly in detecting bifurcations and other critical dynamical features.
The results show that DA-based methods significantly reduce computation time by over 50% compared to floating-point approaches, while maintaining comparable precision. These techniques have been applied to calculate the coordinates and eigenvalues of Lagrange points and to map families of periodic orbits in the Circular Restricted Three-Body Problem (CRTBP). Moreover, DA provides deeper insights into system behavior, allowing for a detailed exploration of complex gravitational interactions.

Poster

CBDO 200 - N – Withdrawn by the author

CBDO 201 - N

Seismic wave propagation in loose granular media

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Asteroids and small bodies of the Solar System are thought to be agglomerates of irregular boulders, therefore cataloged as granular media and they can be considered as rubble or gravel piles. Impacts on their surface could produce seismic waves that propagate in the interior of these bodies, thus causing modifications in the internal distribution of rocks and ejections of particles and dust, resulting in a cometary-type comma.
To study the impact process in a granular media, we have performed laboratory experiments and numerical simulations in different granular material and in a wide set of physical conditions.
For the experiment, we use an acrylic box filled with granular materials such as sand, gravel and glass spheres. Pressure inside the box is controlled by a movable top wall. Impacts are created on the upper face of the box at velocities from 50 to 300 m/s. An array of accelerometers were placed at several depths in the granular material to detect the seismic wave.
Numerical simulations are performed with ESyS-Particle, a software that implements the Discrete Element Method. The numerical experiments reproduce the force loading on one of the wall to vary the pressure inside the box.
We are interested in the velocity, attenuation and energy transmission of the waves, and the dependance of these three parameters with characteristics like: impact speed, properties of the target material and the pressure in the media.
We observe a strong increase of the velocity of wave in the media with increasing confining pressure. Similar results were obtained with the propagation of waves generated by the shaker.
Extrapolating these results to the very low internal pressure, typical of km size asteroids, would imply very low wave velocities. These predictions can be confirmed with numerical experiments under low-gravity conditions.
These results are relevant to understand the outcomes of impacts in rubble/gravel pile asteroids, like the NASA DART mission. Another application of these results is related to the ejection of low-velocity dust from the so-called Activated Asteroids.
Laboratory experiments under low-gravity conditions, like in the Space Station facilities, would be very useful to confirm these results.

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Poster

CBDO 202 - N – Withdrawn by the author

CBDO 203 - N

Characterization of basins of attraction in 1D models and the extrapolation for higher dimension

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While examples of 1D fractal structures exist, the analysis of their basins remains unclear. This work seeks to enhance the visualization of these basins. Additionally, our method offers means to reduce higher dimensions in boundary regions, thereby providing valuable insights.

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Poster

CBDO 204 - N

The Influence of Disk Mass on the Fragmentation of Protoplanetary Disks

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This study analyzes the conditions under which fragmentation occurs in protoplanetary disks around stars. Protoplanetary disks are the environment where planets are formed, and understanding their dynamics and composition is essential to uncover the processes that lead to planetary formation. Using FARGO 2D [1], a software that solves the thermodynamic equations of the disk, the main objective of this work is to explore how variations in the disk's mass affect its stability, which in some cases can lead to their fragmentation. A key aspect of this analysis is the consideration of the disk's self-gravity [1], which can be decisive in triggering gravitational instabilities and leading to fragmentation. The methodology employed also accounts for the presence of a planet orbiting the disk [2], adding complexity to the disk's dynamics. Although the study is computationally demanding, its results will clarify the parameters and mechanisms involved in the fragmentation of protoplanetary disks, contributing to a deeper understanding of the initial conditions of planetary formation. The results of this study will be presented during the conference.

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Poster

CBDO 205 - N

Study of families of symmetric periodic orbits around prolate bodies

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Periodic orbits play a fundamental role in the study of dynamical systems, as they delineate large regions of stability, both resonant and non-resonant. Over the decades, different types of periodic orbits, their classifications, and evolutions have been extensively studied. This work investigates families of symmetric periodic orbits around prolate ellipsoidal bodies, considering only gravitational forces. The study focuses on objects with high non-sphericity and significant mass, such as the dwarf planet Haumea. Through numerical simulations, we identify families of periodic orbits and analyze their evolution based on parameters such as the body's shape, mass, and rotation rate. The goal is to understand how these characteristics affect orbital dynamics, aiming to describe the stability and behavior of trajectories around these bodies. The method used to find periodic orbits is based on a grid search, allowing for the identification of solutions and the mapping of stability regions in phase space.

Poster

CBDO 206 - N

On the Spin-Orbit Phase-Space of an Artificial Satellite

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Geostationary artificial Earth satellites are also usually in synchronous spinorbit state, keeping the same face pointing toward Earth, and their atitude is controlled through propulsion maneuvers. In the current work we study the spin-orbit dynamics of an elongated satellite ($a > b = c$) under the gravitational attraction of the Earth. Using the Poincaré surfaces of section technique we explore the spin-orbit phase space. The location and size of the main spin-orbit resonances are recorded, as well as the chaotic regions. The orbital eccentricity is a crucial parameter in such system. A particular attention is given to the synchronous 1:1 spin-orbit resonance. The associated periodic orbit bifurcates at a critical eccentricity value, and an analytical model is capable of reproducing its topological evolution. For practical proposes, the limiting amplitudes of oscillation of the 1:1 resonance that would fulfill the mission requirements are estimated. Then, it is made an analysis of the parameters that would be compatible with such requirements.

Poster

CBDO 207 - N

Extrasolar planets: classifications and habitable zones

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In search of finding life outside our planet, a study began on exoplanets, planets outside our solar system, were more in-depth studies were carried out on these unknown planets to discover how they form and how their orbits around the star work, to better understand how our system works, and we also seek comparisons with Earth to find situations that can find life on these planets. Most of these planets known today were discovered by the retired Kepler satellite, the method for these discoveries is the transit method that consists of monitoring the brightness level of the star, which at the moment the planet passes in front of this brightness decreases a little for a brief moment. In this study, binary systems were analyzed, systems in which two stars orbit a common center, in this case these binary systems have at least 1 exoplanet. A study was carried out on their habitable zones (which will be abbreviated throughout this work as HZ). The zone habitable area of a system is the region in which a planet similar to Earth is at a distance from the star where it would be possible to find water in the liquid state. To locate the HZ of the systems, the website http://astro.twam.info/hz/ was used. The site has a routine that generates HZ graphs when inserted some information about the stars, such as the effective temperature, luminosity and mass of each star in the desired system. We also inform you that the data relating to the orbit of the secondary star in relation to the primary, such as the semi-major axis and the eccentricity of the orbit. By finding planets in these regions, we can classify these exoplanets as possible candidates for life. Some cases like this were analyzed and became the focus of more in-depth studies to understand under what conditions these planets could be habitable.

Poster

CBDO 208 - N

Controlling telescope and image acquisition with RaspberryPI for stellar occultation observations

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From the study of small Solar System Objects, it is possible to formulate theories about their origin and dynamic evolution. One of their fundamental physical properties is their size. However, for bodies that are farthest from the Sun, like Centaurs and Transneptunian, measuring their dimensions from direct images is challenging. The Stellar Occultation Technique, which consists of observing the light flux of a star during a time interval when it is blocked by the transit of a solar system object, allows one to deduce the size and shape of the occulting object with kilometer accuracy. By recording these events, measurements of the body's profile are obtained, called “chords”. With several chords for the same event obtained in different sites, it is possible to deduce the whole profile of the occulting object. The more observers per event, the more chords are acquired, allowing better results in determining the object's shape. To facilitate the pointing and acquisition of these events by small telescopes and amateur observers, we produced a device called Astro Imaging Device (ASTRID). This device was built through undergraduate research, from the impression of its electronic circuitry to its final assembly. The ASTRID uses a RaspberryPI boarded system with the function of astrometry, telescope pointing and imaging, providing time and position registry. In this work, we present the device and its use, including the first results of stellar occultation observed with it.

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Poster

CBDO 209 - N

The Veronese variety associated with Dziobek central configurations

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In this seminar, we will define the Veronese variety related to Dziobek central configurations and use this concept to provide a new proof for the finiteness of Dziobek central configurations. Also, we will view the set of central configurations of n bodies in $\mathbb{R}^d$ as a subset of an appropriate Grassmannian variety.

Oral communication

CBDO 210 - N

Preliminary Design of Trajectories for Rendezvous with 2001 SN263

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Asteroid 2001 SN263 confirmed by the Arecibo Observatory in 2008 as a triple system, consists of an irregular central body, approximately 2.8 km in diameter, accompanied by two smaller satellites. It has been chosen as the target for Brazil's proposed first deep space mission, the Aster Mission [1]. In this study, we calculate direct transfer trajectories to 2001 SN263 using the Lambert problem and analyze launch opportunities via Porkchop plots. The ideal launch is in February 2036, requiring a total ΔV of 7.85 km/s, with a time of flight (TOF) of 1.53 years. Additionally, we applied a genetic algorithm for global optimization and pattern search for local refinement, finding optimal multiple gravity assist (MGA) trajectories. We could find an MGA solution requiring a total ΔV of 4.53 km/s, including 1.24 km/s for asteroid rendezvous, with a C3 launch energy of 10.84 km^2/s^2. This trajectory launches on October 20, 2037, utilizes gravity assists from Venus on March 23, 2038, and Earth on January 12, 2039, before arriving at the asteroid on December 7, 2040, with a total TOF of 3.13 years. Finally, we use the catalog of solutions from the MGA to find solutions for an MGA with Deep Space Maneuvers (DSM), in which the spacecraft can perform a large DSM between each trajectory leg. We catalog the most favorable trajectories, considering a launch window up to 2050, and examine the technical challenges posed by each option. Each trajectory offers unique trade-offs, which can be considered in a later detailed trajectory design.

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Oral Communication

CBDO 211 – N

Impact simulations with SPH: from exomoons to dusty ring arcs

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Collisional processes play a fundamental role in planetary system evolution, from the formation of satellite systems to the creation and modification of small body populations. These processes require sophisticated numerical tools to accurately model the complex physics involved, including material strength, equation of state, shock propagation, and gravitational reaccumulation. Smoothed Particle Hydrodynamics (SPH) has emerged as a powerful method for studying such scenarios due to its ability to handle large deformations and complex material behavior. Here, we present two applications using the GPU-accelerated SPH code miluphCUDA: (1) the formation of exomoons through giant impacts, where we explore the parameter space of collision velocity, impact angle, and mass ratio to determine the conditions required for satellite formation in exoplanetary systems, and (2) the study of collisional evolution in Saturn's G ring arc, investigating how impacts between the moonlet Aegaeon and ring particles contribute to the observed brightness variations and maintain the arc structure. Both studies demonstrate the versatility of SPH in handling different mass and size scales while accurately modeling the physics of impact processes.

Invited talk

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