44th Annual Meeting of the Division on Dynamical Astronomy of the American Astronomical Society - DDA 2013

5 - 9 May 2013

Paraty, Rio de Janeiro, Brazil

Observatório Nacional DDA AAS META MARKETING E EVENTOS

CAPES CNPq FAPERJ FAPESP

44th DDA Meeting – Paraty, Brazil – May, 2013

Program Committee

- Matija Cuk (SETI Institute) - Co-chair
- Sylvio Ferraz Mello (IAG/USP, São Paulo, SP) - Co-Chair
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- Daniela Lazzaro (ON, Rio de Janeiro, RJ) - Co-chair
- Fernando Roig (ON, Rio de Janeiro, RJ) - Co-chair
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- Gastão B. Lima Neto (IAG/USP, São Paulo, SP)
- William I. Newman (UCLA)
- Antonio F. Bertachini de A. Prado (INPE, São José dos Campos, SP)
- Teresinha de J. Stuchi (IF/UFRJ, Rio de Janeiro, RJ)
- Tadashi Yokoyama (UNESP, Rio Claro, SP)

Invited Speakers

- Cristián Beaugé (Universidad Nacional de Cordoba, Argentina)
- Pablo M. Cincotta (Universidad Nacional de La Plata, Argentina)
- Julio A. Fernández (Universidad de la República, Uruguay)
- Patryk S. Lykawka (Kinki University, Japan)
- Tatiana A. Michtchenko (IAG/USP, Brazil)
- David Nesvorny (Southwest Research Institute)
- Jerry A. Sellwood (Rutgers University) - Brouwer Award Talk

Sponsors

- Conselho Nacional de Desenvolvimento Científico e Tecnológico - CNPq
- Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - CAPES
- Division on Dynamical Astronomy - DDA/AAS
- Fundação "Carlos Chagas Filho" de Amparo a Pesquisa do Estado de Rio de Janeiro - FAPERJ
- Fundação de Amparo a Pesquisa do estado de São Paulo - FAPESP
- Instituto de Astronomia, Geofísica e Ciências Atmosféricas - IAG/USP
- Observatório Nacional - ON/MCTI

Program

DDA Business Meeting
Invitation-Only Event – – 05 May 2013 04:00 PM to 05:30 PM

Welcome Reception
Attendee Event – – 05 May 2013 06:00 PM to 08:00 PM

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100 – Exoplanets I
Oral Session – – 06 May 2013 08:00 AM to 10:05 AM

100.01 – Planet Detection and Characterization from Transit Timing Variations

David Nesvorny[1]
1. SWRI, Boulder, CO, United States.

08:00 AM-08:40 AM

100.02 – Rapid Dynamical Chaos in the Kepler-36 System

Katherine Deck[1]*, Matthew J. Holman*[2, 6]*, Eric Agol*[4]*, Joshua A. Carter*[2]*, Matthew J. Payne*[2]*, Joshua N. Winn*[1]*, Jack J. Lissauer*[3]*, Darin Ragozzine*[5]
1. MIT, Cambridge, MA, United States. 2. SAO, Cambridge, MA, United States. 3. NASA Ames, Mountain View, CA, United States. 4. University of Washington, Seattle, WA, United States. 5. University of Florida, Gainesville, FL, United States. 6. CfA, Cambridge, MA, United States.

08:40 AM-09:05 AM

100.03 – The Initial Mass Distribution for Exoplanetary Systems

Miles L. Timpe[1, 2]*, Rory Barnes*[1, 2]*, Ravi Kumar Kopparapu*[3, 2]*, Sean N. Raymond*[4, 2]*, Richard Greenberg*[5]
1. University of Washington, Seattle, WA, United States. 2. Virtual Planetary Laboratory, Seattle, WA, United States. 3. Pennsylvania State University, University Park, PA, United States. 4. Laboratoire d'Astrophysique de Bordeaux, Floirac, Bordeaux, France. 5. Lunar and Planetary Laboratory, Tucson, AZ, United States.

09:05 AM-09:25 AM

100.04 – Spin-Orbit Coupling in Exoplanetary Systems with High Mutual Inclinations

Rory Barnes[1]*, John C. Armstrong*[2]*, Pramod Gupta*[1]*, Thomas R. Quinn*[1]*, Shawn Domagal-Goldman*[3]*, Victoria Meadows*[1]
1. University of Washington, Seattle, WA, United States. 2. Weber State University, Ogden, UT, United States. 3. Goddard Space Flight Center, Greenbelt, MD, United States.

09:25 AM-09:45 AM

100.05 – Secular Evolution of Extrasolar Planetary Systems: An Extension of the Laplace-Lagrange Secular Theory

Marco Sansottera[1], *Anne-Sophie Libert*[1]
1. University of Namur, Namur, Belgium.
09:45 AM-10:05 AM

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105 – Exoplanets II

Oral Session – – 06 May 2013 10:35 AM to 11:15 AM

105.01 – Stability criteria in real planetary systems

Cristian Giuppone[1, 2], *Maria Helena Morais*[1], *Alexandre C. Correia*[1, 3]
1. Departamento de Fiisica, I3N, Aveiro, Aveiro, Portugal. 2. IATE - OAC, CORDOBA, Argentina. 3. ASD, IMCCE-CNRS UMR8028 - Observatoire de Paris, Paris, France.
10:35 AM-11:15 AM

105.02 – Secular Orbital Evolution of Compact Planetary Systems

Douglas P. Hamilton[1], *Ke Zhang*[1], *Soko Matsumura*[1]
1. Univ. of Maryland, College Park, MD, United States.
10:35 AM-11:15 AM

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101 – Asteroids I

Oral Session – – 06 May 2013 11:15 AM to 12:15 PM

101.02 – A Multi-domain Approach to Asteroid Family Halos Identification

Valerio Carruba[1], *Mariela Huaman Espinoza*[1], *Rita de Cássia Domingos*[2, 1]
1. UNESP, Guaratinguetá, SP, Brazil. 2. INPE, São José dos Campos, SP, Brazil.
11:15 AM-11:35 AM

101.04 – Quasi-satellite Orbits in the Context of Coorbital Dynamics

Vladislav Sidorenko[1], *Anton Artemyev*[2], *Anatoly Neishtadt*[2, 3], *Lev Zelenyi*[2]
1. Keldysh Institute of Applied Mathematics, Moscow, Russian Federation. 2. Space Research Institute, Moscow, Russian Federation. 3. Loughborough University, Loughborough, United Kingdom.
11:35 AM-11:55 AM

101.05 – Yarkovsky-driven Impact Predictions: Apophis and 1950 DA

Davide Farnocchia[1], *Steven R. Chesley*[1], *Paul Chodas*[1], *Andrea Milani*[2]
1. JPL/Caltech, Pasadena, CA, United States. 2. University of Pisa, Pisa, Italy.
11:55 AM-12:15 PM

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102 – Asteroids II

Oral Session – – 06 May 2013 02:00 PM to 03:40 PM

102.01 – The Obliquity Distribution of Near-Earth Asteroids

Steven R. Chesley[1], *Davide Farnocchia*[1], *Desiree Cotto-Figueroa*[2], *Thomas S. Statler*[2, 3]
1. JPL/Caltech, Pasadena, CA, United States. 2. Ohio University, Athens, OH, United States. 3. National Science Foundation, Washington, DC, United States.
02:00 PM-02:20 PM

102.02 – Radiation Recoil Effects on the Dynamical Evolution of Asteroids

Desireé Cotto-Figueroa[1], *Thomas S. Statler*[1, 2], *Derek C. Richardson*[3], *Paolo Tanga*[4]
1. Ohio University, Athens, OH, United States. 2. National Science Foundation, Arlington, VA, United States. 3. University of Maryland, College Park, MD, United States. 4. Cote d' Azur Observatory, Nice, France.
02:20 PM-02:40 PM

102.03 – Evolution of Small Binary Asteroids with the Binary YORP Effect

Julien Frouard[1]
1. Universidade Estadual Paulista - DEMAC, Rio Claro, SP, Brazil.
02:40 PM-03:00 PM

102.04 – Minimum Energy Configurations for the General 3-Body Problem

Daniel J. Scheeres[1]
1. University of Colorado, Boulder, CO, United States.
03:00 PM-03:20 PM

102.05 – Investigating Satellite Formation Around the Rapidly Rotating, Oblong Asteroid 216 Kleopatra

Frank Laipert[1], *David A. Minton*[1]
1. Purdue University, Lafayette, IN, United States.

03:20 PM-03:40 PM

103 – Stars

Oral Session – – 06 May 2013 03:40 PM to 04:40 PM

103.01 – Lack of Energy Equipartition in Globular Clusters

Michele Trenti[1]
1. University of Cambridge, Cambridge, United Kingdom.
03:40 PM-04:00 PM

103.02 – Exploring Stellar Collisions within Very Wide Binaries

Nathan A. Kaib[1], *Sean N. Raymond*[2, 3]
1. Northwestern University, Evanston, IL, United States. 2. Université Bordeaux, Floirac, France. 3. CNRS, LAB, Floirac, France.
04:00 PM-04:20 PM

103.03 – Probabilities for Solar Siblings

Mauri Valtonen[1, 2], *Aleksandr Myllari*[3], *Vadim V. Bobylev*[4], *Anisa Bajkova*[4]
1. Univ. of Turku, Turku, Finland. 2. Univ. of West Indies, Bridgetown, Barbados. 3. St.George's Univ., University Centre, Grenada. 4. Pulkovo Astronomical Observatory, St.Petersburg, Russian Federation.
04:20 PM-04:40 PM

104 – Brouwer Award Talk: Jerry Sellwood: The Spiral Structure of Galaxies

Plenary Session – – 06 May 2013 04:40 PM to 05:40 PM

104.01 – Spiral Structure in Galaxies

Jerry Sellwood[1]
1. Rutgers Univ., Piscataway, NJ, United States.
04:40 PM-04:40 PM

Business Meeting

Town Hall – – 06 May 2013 05:40 PM to 07:00 PM

Brouwer Prize Reception

Attendee Event – – 06 May 2013 07:00 PM to 08:00 PM

This session includes the same abstracts from the previous session.

200 – Comets and TNOs I

Oral Session – – 07 May 2013 08:00 AM to 10:00 AM

200.01 – Trans-Neptunian Objects as Natural Probes to the Unknown Solar System

Patryk S. Lykawka[1]
1. Kinki University , Higashiosaka, Osaka Pref., Japan, Japan.
08:00 AM-08:40 AM

200.02 – A Compound Model for the Origin of Earth's Water

Nader Haghighipour[1], *Othon Winter*[2], *André Izidoro*[2]
1. Univ. of Hawaii, Honolulu, HI, United States. 2. UNESP-Univ. Estadual Paulista, Guaratinguetá, Sao Paulo, Brazil.
08:40 AM-09:00 AM

200.03 – The Remarkable Orbit of Sungrazing Comet C/2011 W3 (Lovejoy)

Paul Chodas[1], *Zdenek Sekanina*[1]
1. JPL, Pasadena, CA, United States.
09:00 AM-09:20 AM

200.04 – Modeling of Gas and Dust Outflow Dynamics at Active Small Solar System Bodies

Eugene G. Fahnestock[1]
1. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, United States.
09:20 AM-09:40 AM

200.05 – Constraints on Mechanisms of Comet Disruption from Icy Satellite Craters and Dynamical Simulations

David A. Minton[1], *Ramon Brasser*[2], *James E. Richardson*[1]
1. Purdue University, West Lafayette, IN, United States. 2. Institute for Astronomy and Astrophysics, Academia Sinica, Taipei, Taiwan.
09:40 AM-10:00 AM

201 – Comets and TNOs II

Oral Session – – 07 May 2013 10:30 AM to 12:15 PM

201.01 – Dynamical Explanation for the Lack of Binary Asteroids Among the Plutinos

Audrey Compère[1], *David Farrelly*[2], *Anne Lemaître*[1], *Daniel Hestroffer*[3]
1. Namur Centre for Complex Systems, naXys, University of Namur, Namur, Namur, Belgium. 2. Utah State University, Logan, UT, United States. 3. IMCCE, Observatoire de Paris, UPMC, CNRS, Paris, Paris, France.

10:30 AM-10:55 AM

201.02 – The Orbits and Masses of Pluto's Satellites

Marina Brozovic[1], *Robert A. Jacobson*[1]
1. Jet Propulsion Laboratory/Caltech, Pasadena, CA, United States.

10:55 AM-11:15 AM

201.03 – Exploring the Dynamical Consequences of the Collisional Environment of the Kuiper Belt on the Orbits of Pluto's Small Satellites

Alex Gonring[1], *David A. Minton*[1]
1. Purdue University, West Lafayette, IN, United States.

11:15 AM-11:35 AM

201.04 – The Formation of Pluto's Small Satellites

Harold F. Levison[1], *Kevin J. Walsh*[1]
1. Southwest Research Inst., Boulder, CO, United States.

11:35 AM-11:55 AM

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202 – Comets and TNOs III

Oral Session – – 07 May 2013 03:00 PM to 03:40 PM

202.01 – Where is the Oort Cloud Located?

Julio Fernandez[1]
1. Departamento de Astronomía , Facultad de Ciencias - UDeLaR , Montevideo , Uruguay.

03:00 PM-03:40 PM

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203 – Rotation

Oral Session – – 07 May 2013 03:40 PM to 04:40 PM

203.01 – Effects of High Inclined and Eccentric Disturbers on the Dynamics of the Equator of an Axy-Simmetric Body

Tadashi Yokoyama[1], *Julien Frouard*[1], *Rogerio Deienno*[1]
1. Universidade Estadual Paulista, Rio Claro, Sao Paulo, Brazil.

03:40 PM-04:00 PM

203.02 – The Role of Tides in the Rotational History of Mercury

Benoit Noyelles[1], *Michael Efroimsky*[2], *Julien Frouard*[3], *Valeri V. Makarov*[2]
1. University of Namur, Namur, Belgium. 2. US Naval Observatory, Washington, DC, United States. 3. UNESP, Rio Claro, Brazil.

04:00 PM-04:20 PM

203.03 – Tidal Perturbations of the Rotation of the Moon. The Creep Tide Approach.

Sylvio Ferraz-Mello[1], *Hugo Folonier*[1]
1. IAG-Universidade de São Paulo, São Paulo, Brazil.

04:20 PM-04:40 PM

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204 – Poster Session

Poster Session – – 07 May 2013 04:40 PM to 06:40 PM

204.01 – Gravitational Capture of Small Bodies by Gas Drag Developed Using Hydrodynamic Equations

Nicole Pereira de Lima[1], *Ernesto Vieira Neto*[1]
1. Unesp, Guaratinguetá, São Paulo, Brazil.

204.02 – An Impact Generated Ring in Bianca's Orbit

Rafael Sfair[1], *Jason I. Horn*[2]
1. UNESP - FEG, Guaratinguetá, SP, Brazil, Brazil. 2. Universität Heidelberg, Heidelberg, Germany.

204.03 – Toward an Accurate Modelization of the Obliquity of Mercury

Benoit Noyelles[1], *Christoph Lhotka*[2, 1], *Sandrine D'Hoedt*[1]
1. University of Namur, Namur, Belgium. 2. Università degli Studi di Roma Tor Vergata, Roma, Italy.

204.04 – Planetesimal Accretion in Tight Binary Systems

Jorge Correa-Otto[1, 2], *Cristian Beauge*[2], *Pablo Benitez Llambay*[2], *Alejandro Martin Leiva*[3]
1. IAG-USP, Sao Paulo, Sao Paulo, Brazil. 2. IATE-OAC-UNC, Cordoba, Cordoba, Argentina. 3. OAC-UNC, Cordoba, Cordoba, Argentina.

204.05 – Planet Formation Around a Binary System Disturbed by a Third Star

Othon Winter[1], *Rita Domingoa*[2], *André Izidoro*[1]
1. UNESP, Guaratingueta, São Paulo, Brazil. 2. INPE, São José dos Campos, São Paulo, Brazil.

204.06 – Tidal Evolution in Co-orbital Configurations

Adrian Rodriguez Colucci[1], *Cristian Giuppone*[2], *Tatiana A. Michtchenko*[1]
1. Univ. Sao Paulo, IAG-USP, Sao Paulo, SP, Brazil. 2. Univ. Nacional de Cordoba, Cordoba, Cordoba, Argentina.

204.07 – Resonant Dynamics of Small Satellites in the Inner System of Saturn

Nelson Callegari[1]
1. UNESP, Rio Claro, SP, Brazil, Brazil.

204.08 – Aegaoen, the Small Satellite of Saturn, and the Production of Dust Particles

Silvia M. Giuliatti-Winter[1], *Rafael Sfair*[1], *Décio Mourão*[1]
1. UNESP, Guaratinguetá, São Paulo, Brazil.

204.09 – NEAs' Binaries and Planetary Close Encounters -Stability and Lifetime

Rosana Araujo[1], *Othon Winter*[1]
1. UNESP Univ Estadual Paulista, Guaratingueta, SP, Brazil, Brazil.

204.10 – A Study of the Low Velocity Regions Close to the Roche Lobe of Giant Planets

Ricardo Aparecido de Moraes[1], *Ernesto Vieira Neto*[1]
1. UNESP, São Paulo State University, Guaratinguetá, São Paulo, Brazil.

204.11 – Dynamics of "Jumping" Trojans: Perturbative Treatment

Vladislav Sidorenko[1], *Nikita Astrakhancev*[2]
1. Keldysh Institute of Applied Mathematics, Moscow, Russian Federation. 2. Moscow Institute of Physics and Technology, Moscow, Russian Federation.

204.12 – Stability of Frozen Orbits Around Europa

Josué Cardoso Dos Santos[1], *Rodolpho Vilhena de Moraes*[2, 1], *Jean Paulo Carvalho*[2, 1]
1. São Paulo State University, Guaratinguetá, São Paulo, Brazil. 2. Federal University of São Paulo, São José dos Campos, São Paulo, Brazil.

204.13 – Dynamical Mobility due to Close Encounter with Several Massive Asteroids. Case (10) Hygiea, (2) Pallas, and (31) Euphrosyne.

Mariela Huaman Espinoza[1], *Valerio Carruba*[1], *Rita de Cássia Domingos*[2, 1], *Fernando V. Roig*[3]
1. UNESP, Sao Paulo State University, Guaratingueta, Sao Paulo, Brazil. 2. INPE, National Institute For Space Research, Sao Jose dos Campos, Sao Paulo, Brazil. 3. ON, National Observatory, Rio de Janeiro, Rio de Janeiro, Brazil.

204.14 – Stability of Prograde and Retrograde Planets in Binary Systems

Maria Helena Morais[1], *Cristian Giuppone*[2]
1. Dept. Física Univ. Aveiro, Aveiro, Portugal. 2. Observatorio Astronómico de Córdoba, Córdoba, Argentina.

204.15 – Unraveling Janus and Epimetheus' Ring

Alexandre Pinho Dos Santos Souza[1], *Othon Winter*[1], *Rafael Sfair*[1], *Décio Mourão*[1], *Dietmar Foryta*[2]
1. Unesp, Guaratinguetá, São Paulo, Brazil. 2. UFPR, Curitiba, Paraná, Brazil.

204.16 – Lags of Prometheus and Pandora

Thamiris Santana[1], *Othon Winter*[1], *Décio Mourão*[1], *Christiano C. Cruz*[1]
1. UNESP, Guaratinguetá, SP, Brazil.

204.17 – Study of the Effect Of Radiation Pressure in Janus-Epimetheus' Rings

Décio Mourão[1], *Othon Winter*[1], *Rafael Sfair*[1], *Alexandre Pinho Dos Santos Souza*[1], *Silvia M. Giuliatti-Winter*[1], *Dietmar Foryta*[2]
1. UNESP - Univ Estadual Paulista , Guaratinguetá, SP, Brazil. 2. UFPr - Univ Federal do Paraná, Curitiba, PR, Brazil.

204.18 – Analysis on the Evolution of a Pluto-like System During Close Encounters with the Giant Planets in the Framework of the Nice Model

Pryscilla Maria Pires Dos Santos[1], *Silvia M. Giuliatti-Winter*[1], *Rodney S. Gomes*[2]
1. Unesp, Guaratinguetá, São Paulo, Brazil. 2. ON, Rio de Janeiro, Rio de Janeiro, Brazil.

204.19 – Habitability of Earth-like Planet Disturbed by a Third Body

Rita de Cássia Domingos[1], *Antonio Fernando B. Almeida Prado*[1], *Othon Winter*[2]
1. Instituto Nacional de Pesquisas Espaciais, São José dos Campos, São Paulo, Brazil. 2. Univiversidade Estadual Paulista, Guaratinguetá, São Paulo, Brazil.

204.20 – Stability Orbits Close to 433 Eros Using a Shaped Polyhedral Source
Thierry G. Chanut[1], *Othon Winter*[1]
1. FEG - UNESP, Guaratinguetá, Brazil.

204.21 – The Behavior of Regular Satellites During the Planetary Migration
Erica Cristina Nogueira[1, 2], *Rodney S. Gomes*[2], *Ramon Brasser*[3]
1. Universidade Federal Fluminense, Rio de Janeiro, Rio de Janeiro, Brazil. 2. Observatório Nacional , Rio de Janeiro, Rio de Janeiro, Brazil. 3. Institute for Astronomy and Astrophysics, Taipei, Taiwan.

204.22 – A Study of Small Satellites Captured in Corotation Resonance
Nilton Carlos Santos Araújo[1], *Ernesto Vieira Neto*[1]
1. Unesp, Guaratinguetá, São Paulo, Brazil.

204.23 – Figures of Equilibrium for Tidally Deformed Non-homogeneous Celestial Bodies
Hugo Folonier[1], *Sylvio Ferraz-Mello*[1]
1. IAG/USP, São Paulo, São Paulo, Brazil.

204.24 – Determination of Dynamical and Physical Parameters of the System CoRoT 3
Marcos Tadeu Dos Santos[1], *Sylvio Ferraz-Mello*[1], *Tatiana A. Michtchenko*[1]
1. IAG/USP, Sao Paulo, SP, Brazil.

204.25 – A Study of the Inclination of Satellites of a Planet After Spin Axis Forced Tumbling
Luiz Augusto Boldrin[1], *Othon Winter*[1], *Ernesto Vieira Neto*[1]
1. Unesp, Guaratinguetá, Brazil.

204.26 – Coorbital Formation with Earth and Theia's Origin
André Amarante[1], *Othon Winter*[1], *Masayoshi Tsuchida*[2]
1. UNESP/FEG, Guaratinguetá, São Paulo, Brazil. 2. UNESP/IBILCE, São José do Rio Preto, São Paulo, Brazil.
Contributing teams: Grupo de Dinâmica Orbital e Planetologia - GDOP

204.27 – Near-Earth Object Survey Orbit Quality Analysis
Marc W. Buie[1]
1. Southwest Research Institute, Boulder, CO, United States.

204.28 – What can Numerical Computation do for the History of Science? (Study of an Orbit Drawn by Newton on a Letter to Hooke)
Teresa Stuchi[1], *Penha Maria Cardozo Dias*[1]
1. Instituto de Fisica, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Rio de Janeiro, Brazil.

204.29 – An Absolute Radius Scale for Saturn's Rings from Cassini Occultations
Colleen McGhee[1], *Richard G. French*[1], *Robert A. Jacobson*[2], *Philip D. Nicholson*[3], *Joshua E. Colwell*[4], *Essam A. Marouf*[5], *Katherine Lonergan*[1], *Talia Sepersky*[1]
1. Wellesley College, Wellesley, MA, United States. 2. JPL, Pasadena, CA, United States. 3. Cornell University, Ithica, NY, United States. 4. University of Central Florida, Orlando, FL, United States. 5. San Jose State University, San Jose, CA, United States.

204.30 – Further explorations on binary-asteroid capture study
Helton Da Silva Gaspar[1], *Ernesto Vieira Neto*[1], *Othon Winter*[1]
1. UNESP, Sao Paulo, SP, Brazil.

204.32 – Planetesimals Grow or Disrupt? The Roll of the Uncertain Amount of Collisional Energy that Goes Into Heat
Gabriela Parisi[1, 2]
1. Instituto Argentino de Radioastronomia (IAR-CONICET), Villa Elisa, Buenos Aires, Argentina. 2. Facultad de Ciencias Astronomicas y Geofisicas UNLP, La Plata, Buenos Aires, Argentina.

204.33 – Orbital maneuvers around irregular shaped bodies
Flaviane Venditti[1], *Evandro Marconi Rocco*[2], *Antonio Fernando B. Almeida Prado*[3]
1. INPE, Sao Jose dos Campos, Sao Paulo, Brazil. 2. INPE, Sao Jose dos Campos, Sao Paulo, Brazil. 3. INPE, Sao Jose dos Campos, Sao Paulo, Brazil.

204.34 – Finding Minor Bodies with the J-PAS/J-PLUS surveys
Jorge M. Carvano[1], *Daniela Lazzaro*[1], *Fernando V. Roig*[1], *Thais Mothe-Diniz*[2], *Alvaro Alvez-Candal*[1], *Mario De Prá*[1]
1. Observatório Nacional, Rio de Janeiro, RJ, Brazil, Brazil. 2. OV/UFRJ, Rio de Janeiro, RJ, Brazil.

204.35 – Searching for Trajectories with Minimum Perturbations Around the Asteroid 2001SN263

Antonio Prado[1]
1. INPE, Sao Jose dos Campos, Brazil.

204.36 – Dynamic Rotation of Kepler-11b and 55Cnc-e with Third Body Perturbation

Filipe Batista Ribeiro[1], *Nelson Callegari*[1]
1. UNESP, Rio Claro, São Paulo, Brazil.

204.38 – Stability and Dynamics of Terrestrial Planets in Binary Star Systems - Application on Alpha Centauri

Eduardo Andrade-Ines[1], *Tatiana A. Michtchenko*[1]
1. IAG-USP, Sao Paulo, SP, Brazil.

204.39 – Rotation rate evolution in habitable super-Earths

Mario Melita[1], *Pablo Cuartas Restrepo*[2], *Jorge Ivan Zuluaga*[2], *Octavio Miloni*[3]
1. IAFE (conicet-uba), Buenos Aires, caba, Argentina. 2. Institute of Physics - Universidad de Antioquia, Medellin, Medellin, Colombia. 3. FCAGLP, La Plata, Buenos AIres, Argentina.

204.40 – Orbital characteristics of exoplanets in triple systems

Jean Paulo Carvalho[1], *Rodolpho Vilhena de Moraes*[1], *Antonio Fernando B. Almeida Prado*[2], *Othon Winter*[3]
1. UNIFESP/ICT, São José dos Campos, São Paulo, Brazil. 2. INPE, São José dos Campos, São Paulo, Brazil. 3. UNESP/FEG, Guaratinguetá, São Paulo, Brazil.

204.41 – Simulation of optimal impulsive maneuvers of a spacecraft in orbit of Mars considering constructive aspects of the propulsion system.

Evandro Marconi Rocco[1]
1. National Institute for Space Research - INPE, São José dos Campos, São Paulo, Brazil.

204.42 – Dynamics of the 3:1 Resonant Planetary Systems

Alan Alves[1], *Tatiana A. Michtchenko*[1]
1. IAG-USP, São Paulo, SP, Brazil.

204.43 – Detailed Astrometric Analysis of Pluto

Gustavo B. Rossi[1], *Roberto Vieira-Martins*[1], *Julio I. Camargo*[1], *Marcelo Assafin*[2]
1. ON-MCTI, Rio de Janeiro, Rio de Janeiro, Brazil. 2. OBSERVATORIO DO VALONGO, RIO DE JANEIRO, RIO DE JANEIRO, Brazil.

204.44 – Evaluation of the Influence of zonal and sectorial harmonics in the orbit of an lunar satellite

Liana Dias Gonçalves[1], *Evandro Marconi Rocco*[1], *Rodolpho Vilhena de Moraes*[1], *Antonio Prado*[1]
1. Instituto Nacional de Pesquisas Espaciais, São José dos Campos, São Paulo, Brazil.

204.45 – CBERS Satellites: Resonant Orbital Motions in LEO Region

Rodolpho Vilhena de Moraes[1], *Jarbas C. Sampaio*[2], *Sandro da Silva Fernandes*[3], *Edwin Wnuk*[4]
1. ICT/UNIFESP, São José dos Campos, São Paulo, Brazil. 2. UNESP, Guaratinguetá, São Paulo, Brazil. 3. ITA, São José dos Campos, São Paulo, Brazil. 4. AMU, Poznan, Poznan, Poland.

204.46 – The Astronomy Workshop

Douglas P. Hamilton[1]
1. Univ. of Maryland, College Park, MD, United States.

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300 – Planet and Satellite Formation I

Oral Session – – 08 May 2013 08:00 AM to 09:40 AM

300.01 – Distribution and Origin of Hot Planets

Cristian Beauge[1]
1. Observatorio Astronómico, Córdoba , Argentina.

08:00 AM-08:40 AM

300.02 – Dynamical Structures from Planet Formation in the Beta Pictoris Debris Disk

Mark Wyatt[1]
1. Institute of Astronomy, Cambridge, United Kingdom.

08:40 AM-09:00 AM

300.03 – Consequences of an Eccentric Fomalhaut b

Daniel Tamayo[1], *Joseph A. Burns*[1]
1. Cornell University, Ithaca, NY, United States.

09:00 AM-09:20 AM

300.04 – Problems and Promises of Pebble Accretion

Katherine A. Kretke[1], *Harold F. Levison*[1]
1. Southwest Research Institute, Boulder, CO, United States.
09:20 AM-09:40 AM

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301 – Planet and Satellite Formation II
Oral Session – – 08 May 2013 10:10 AM to 11:50 AM

301.01 – Non-uniform Distribution of Protoplanetary Bodies as a Pre-requisit for the Formation of a Low-mass Mars
André Izidoro[1], *Nader Haghighipour*[2, 3], *Othon Winter*[1], *Masayoshi Tsuchida*[4]
1. UNESP, Guaratingueta, SP, Brazil. 2. UH/IfA, Honolulu, HI, United States. 3. UH/NAI, Honolulu, HI, United States. 4. UNESP, S. J. do Rio Preto, SP, Brazil.
10:10 AM-10:30 AM

301.02 – Constraining the Primordial Orbits of the Terrestrial Planets
Kevin J. Walsh[1], *Ramon Brasser*[2], *David Nesvorny*[1]
1. Southwest Research Institute, Boulder, CO, United States. 2. Institute for Astronomy and Astrophysics, Academia Sinica, Taipei, Taiwan.
10:30 AM-10:50 AM

301.03 – A 3D Study for Binary-asteroid Captures in Jupiter System
Ernesto Vieira Neto[1], *Helton Da Silva Gaspar*[1], *Othon Winter*[1]
1. UNESP, Guaratinguetá, São Paulo, Brazil.
10:50 AM-11:10 AM

301.04 – On the Long-term Dynamical Evolution of the Main Satellites of Uranus
Emilie Verheylewegen[1], *Benoit Noyelles*[1], *Ozgur Karatekin*[2], *Anne Lemaître*[1]
1. University of Namur, Namur, Belgium. 2. Royal Observatory of Belgium, Brussels, Belgium.
11:10 AM-11:30 AM

301.05 – Orbital Evolution of Titan and Iapetus
Matija Cuk[1], *Henry C. Dones*[2]
1. SETI Institute, Mountain View, CA, United States. 2. Soutwest Research Institute, Boulder, CO, United States.
11:30 AM-11:50 AM

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302 – Planet and Satellite Formation III
Oral Session – – 08 May 2013 02:00 PM to 02:40 PM

302.01 – Records of Migration in the Exoplanet Configurations
Tatiana A. Michtchenko[1], *Adrian Rodriguez Colucci*[1], *Marcos Tadeu Dos Santos*[1]
1. Astronomy, IAG-USP, Sao Paulo, Brazil.
02:00 PM-02:40 PM

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303 – Orbits and Chaos I
Oral Session – – 08 May 2013 02:40 PM to 04:25 PM

303.01 – Chaotic Behavior Near First-order Mean Motion Resonances in the Elliptical, Planar Three Body Problem
Maryame El Moutamid[1, 2], *Bruno Sicardy*[1, 3], *Stéfan Renner*[2, 4]
1. LESIA Paris Observatory, Meudon, France. 2. IMCCE Paris Observatory, Paris, France. 3. UPMC University , Paris, France. 4. Lille 1 University , Lille, France.
02:40 PM-03:00 PM

303.02 – Retrograde Resonance in the Circular Restricted 3 Body Problem
Maria Helena Morais[1], *Fathi Namouni*[2]
1. Dept. Physics Univ. Aveiro, Aveiro, Portugal. 2. Observatoire de la Côte d’Azur, Nice, France.
03:00 PM-03:20 PM

303.03 – The Milankovitch Orbital Elements and Their Application to the Long-term Orbit Evolution of Planetary Satellites Subject to Radiation and Gravitational Perturbations
Aaron Rosengren[1], *Daniel J. Scheeres*[1]
1. University of Colorado at Boulder, Boulder, CO, United States.
03:20 PM-03:45 PM

303.04 – Time-varying Geometric Orbital Elements of Saturn's Moons
Matthew S. Tiscareno[1]
1. Cornell Univ., Ithaca, NY, United States.

03:45 PM-04:05 PM

303.05 – About Hohmann Transfer with Orbital Plane Change

Ángel Rincón[1], *Patricio Rojo*[1], *Sttiwuer Diaz*[2]
1. Universidad de Chile, Santiago, Region Metropolitana, Chile. 2. Universidad Simon Bolivar, Caracas, Distrito Capital, Venezuela.
Contributing teams: Departamento de Astronomia (UC), Departamento de Fisica (USB).
04:05 PM-04:25 PM

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204 – Poster Session

Poster Session – – 08 May 2013 04:30 PM to 06:30 PM

This session includes the same abstracts from the previous session.

Banquet

Attendee Event – – 08 May 2013 07:00 PM to 09:30 PM

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400 – Orbits and Chaos II

Oral Session – – 09 May 2013 09:00 AM to 09:40 AM

400.01 – Chirikov and Nekhoroshev Diffusion Estimates: Bridging the Two Sides of the River

Pablo Cincotta[1]
1. FCAG/UNLP, La Plata (Bs As) , Argentina.
09:00 AM-09:40 AM

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401 – Rings and Satellites I

Oral Session – – 09 May 2013 09:40 AM to 10:20 AM

401.02 – Edge Waves and Nonlinear Mode Coupling in Saturn’s B Ring

Glen R. Stewart[1]
1. Univ. of Colorado, Boulder, CO, United States.
10:00 AM-10:20 AM

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402 – Rings and Satellites II

Oral Session – – 09 May 2013 10:50 AM to 12:10 PM

402.01 – Kronoseismology: Probing Saturn's Interior via its Rings

Philip D. Nicholson[1], *Matthew M. Hedman*[1], *Richard G. French*[2]
1. Cornell Univ., Ithaca, NY, United States. 2. Wellesley College, Boston, MA, United States.
10:50 AM-11:10 AM

402.02 – Non-circular Features in Saturn's Rings from Cassini Occultations

Richard G. French[1], *Philip D. Nicholson*[2], *Joshua E. Colwell*[3], *Essam A. Marouf*[4], *Katherine Lonergan*[1], *Colleen McGhee*[1], *Talia Sepersky*[1]
1. Wellesley College, Wellesley, MA, United States. 2. Cornell University, Ithaca, NY, United States. 3. University of Central Florida, Orlando, FL, United States. 4. San Jose State University, San Jose, CA, United States.
11:10 AM-11:30 AM

402.03 – Delving into D-ring Dynamics: Probes of Saturn's Interior and Clues to its Recent History

Matthew M. Hedman[1], *Joseph A. Burns*[1], *Philip D. Nicholson*[1], *Mark R. Showalter*[2], *Matthew S. Tiscareno*[1]
1. Cornell Univ., Ithaca, NY, United States. 2. SETI Institute, Mountain View, CA, United States.
11:30 AM-11:50 AM

402.04 – The Orbits of the Regular Jovian Satellites, Their Masses, and the Gravity Field of Jupiter

Robert A. Jacobson[1]
1. JPL, Pasadena, CA, United States.
11:50 AM-12:10 PM

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403 – Closing Session

Oral Session – – 09 May 2013 12:10 PM to 12:30 PM

Author Index

Abstracts

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100 – Exoplanets I

100.01 – Planet Detection and Characterization from Transit Timing Variations

David Nesvorny[1]

1. SWRI, Boulder, CO, United States.

The gravitational interactions of planets in the systems where at least one planet is transiting can be detected by monitoring the deviations of transit times from a linear ephemeris. This method, known as the Transit Timing Variations (TTVs), can be used to confirm multi-transiting systems, determine the planetary masses and orbits, and detect additional non-transiting planets in the systems where at least one planet is transiting. I will discuss how the basic properties of TTVs relate to the dynamical structure of a planetary system. I will illustrate the TTV method on Kepler-46b,c and other examples where it yielded interesting results.

100.02 – Rapid Dynamical Chaos in the Kepler-36 System

Katherine Deck[1], Matthew J. Holman[2, 6], Eric Agol[4], Joshua A. Carter[2], Matthew J. Payne[2], Joshua N. Winn[1], Jack J. Lissauer[3], Darin Ragozzine[5]

1. MIT, Cambridge, MA, United States. 2. SAO, Cambridge, MA, United States. 3. NASA Ames, Mountain View, CA, United States. 4. University of Washington, Seattle, WA, United States. 5. University of Florida, Gainesville, FL, United States. 6. CfA, Cambridge, MA, United States.

The Kepler-36 system, with planets on 13.8 and 16.2 day orbits, is a dynamically packed two-planet system. The strong interactions between the planets allow us to solve for their orbital configuration. By studying the evolution of a statistically representative set of 10,000 initial conditions, we determined that these planets are evolving chaotically with a Lyapunov time of only 10 years. The rapidity of the chaos is due to the interaction of the 29:34 mean motion resonance with the nearby first order 6:7 resonance, in contrast to the usual case in which secular terms in the Hamiltonian play a dominant role. We find that this short Lyapunov time, relative to the orbital periods of the planets, does not necessarily imply a similarly short timescale for orbital instability. In particular, there exists a single contiguous region of phase space, accounting for ~4.5% of the sample of initial conditions studied, where planetary orbits are long-lived. These initial conditions are those which satisfy the Hill stability criterion by the largest margin, indicating that Hill stability can provide important clues for studying more stringent, but less well-understood, orbital stability limits. I will discuss new numerical and analytical work connecting orbital instability to resonance overlap, including the application of the standard resonance overlap criterion to the problem of two massive planets.

100.03 – The Initial Mass Distribution for Exoplanetary Systems

Miles L. Timpe[1, 2], Rory Barnes[1, 2], Ravi Kumar Kopparapu[3, 2], Sean N. Raymond[4, 2], Richard Greenberg[5]

1. University of Washington, Seattle, WA, United States. 2. Virtual Planetary Laboratory, Seattle, WA, United States. 3. Pennsylvania State University, University Park, PA, United States. 4. Laboratoire d'Astrophysique de Bordeaux, Floirac, Bordeaux, France. 5. Lunar and Planetary Laboratory, Tucson, AZ, United States.

The initial mass distribution for exoplanet systems, prior to the onset of planet-planet scattering, has yet to be adequately constrained. Scattering has previously explained a broad range of observed properties, such as large eccentricities, packing, and mean-motion resonances, and hence is an appealing theory. Likewise, a new study has shown that planet-planet scattering is also capable of reproducing the apsidal behavior of observed systems. Scattering is strongly dependent on the initial distribution of planetary masses, which recent results suggest may follow a power law relation. We present the results of numerical simulations of scattering-produced multiple planet systems arising from different initial power law mass distributions, extending down to 1 Earth mass. We test which of these power law distributions most accurately reproduces the observed mass distribution. We find that our simulations are able to reproduce the observed mass distribution, but fail to reproduce the observed eccentricity distribution. We repeat our analysis at increasing initial mutual inclinations, but find that our results do not vary significantly as a result. This suggests that the initial mass distribution is described by a relation more intricate than a global power law, and therefore we explore more complex approaches with which we might constrain the initial mass distribution.

100.04 – Spin-Orbit Coupling in Exoplanetary Systems with High Mutual Inclinations

Rory Barnes[1], John C. Armstrong[2], Pramod Gupta[1], Thomas R. Quinn[1], Shawn Domagal-Goldman[3], Victoria Meadows[1]

1. University of Washington, Seattle, WA, United States. 2. Weber State University, Ogden, UT, United States. 3. Goddard Space Flight Center, Greenbelt, MD, United States.

The discovery of a 30 degree mutual inclination for Upsilon Andromedae c and d suggests that a significant fraction of exoplanetary systems may possess similar architectures. Moreover, numerical models of planet-planet scattering, which successfully reproduce the observed eccentricity distribution, predict large mutual inclinations as well. Perturbations between planets can drive rapid evolution in orbital inclination and longitude of ascending node, which in turn alters the obliquity and precession rate. In some cases, direct gravitational torques between planets can also be significant, further complicating the picture. We present case studies of these effects in anticipation of future discoveries of non-planar systems. As the climates of habitable planets are sensitive to spin properties, we focus on them and specifically examine the planets orbiting Gl 581 and Gl 667C.

100.05 – Secular Evolution of Extrasolar Planetary Systems: An Extension of the Laplace-Lagrange Secular Theory

Marco Sansottera[1], Anne-Sophie Libert[1]

1. University of Namur, Namur, Belgium.

In this work, we study the secular dynamics of exoplanetary systems consisting of two coplanar planets. In particular, we investigate the effects of the proximity to a mean motion resonance on the secular behavior of the planets. In order to obtain a good description of the secular dynamics, a straightforward method is to include in the unperturbed Hamiltonian the average of the perturbation over the fast angles; this is the so-called approximation at order one in the masses. However, if the system is near a mean motion resonance, the frequencies of the quasi-periodic flow given by this Hamiltonian are quite different from the true ones. Therefore we look for an approximation of the secular Hamiltonian up to order two in the masses, removing the main perturbation depending on the fast angles via a Kolmogorov-like normalization step. The approximation of lowest order in the eccentricities of the secular Hamiltonian is essentially the one considered in the Lagrange-Laplace theory. Following a quite standard procedure, we construct a high order Birkhoff normal form for the Hamiltonian using the Lie series method. Considering the Hamiltonian in non-resonant Birkhoff normal form, the equations of motion take a very simple form, being function of the actions only. So, using the secular frequencies that are easily computed, the long term motion of the planets can be easily integrated analytically. By comparing the semi-analytical results based on the secular approximation, with the dynamics of the complete system, we can better understand whether resonant contributions dominate the evolution of the planets or not. This leads to a simple criterion to discriminate between three categories of systems: : (i) secular systems (HD 11964, HD 74156, HD 134987, HD 163607, HD 12661 and HD 147018); (ii) systems near a mean-motion resonance (HD 11506, HD 177830, HD 9446, HD 169830 and υ Andromedae); (iii) systems really close to or in a mean-motion resonance (HD 108874, HD 128311 and HD 183263). Finally, a similar analysis is performed for systems that are in a mean-motion resonance.

105 – Exoplanets II

105.01 – Stability criteria in real planetary systems

Cristian Giuppone[1, 2], Maria Helena Morais[1], Alexandre C. Correia[1, 3]

1. Departamento de Fiisica, I3N, Aveiro, Aveiro, Portugal. 2. IATE - OAC, CORDOBA, Argentina. 3. ASD, IMCCE-CNRS UMR8028 - Observatoire de Paris, Paris, France.

We present results of main existing stability criteria, derived for circular orbits, in real multi-planetary systems. We identified those which appear to better explain the observations, and empirically extend it to eccentric orbits with some success. Our results suggest that mean-motion resonances are indeed at the origin of chaos in the orbital motion, but that the main selection factor appears to be the minimal distance between two bodies and not their semi-major axis. We also derive simple expressions that can be used to put rapid constraints on the stability zones of multi-planetary systems.

105.02 – Secular Orbital Evolution of Compact Planetary Systems

Douglas P. Hamilton[1], Ke Zhang[1], Soko Matsumura[1]

1. Univ. of Maryland, College Park, MD, United States.

Recent observations have shown that at least some close-in exoplanets maintain eccentric orbits despite short tidal circularization timescales. We explore gravitational interactions with a more distant planetary companion as a possible cause of these unexpected nonzero eccentricities focusing, for simplicity, on a planar two-planet system. We show that dissipation shifts the two normal eigenmode frequencies and eccentricity ratios of the standard secular theory slightly, and that each mode decays at its own rate. Tidal damping of the eccentricities drives orbits to transition relatively quickly between periods of pericenter circulation and libration, and the planetary system settles into a locked state in which the pericenters are nearly aligned or nearly antialigned. Once in the locked state, the eccentricities of the two orbits decrease very slowly due to tides rather than at the much more rapid single-planet rate, and thus eccentric orbits, even for close-in planets, can often survive much longer than the age of the system. Assuming that an observed inner planet on an elliptical orbit is apsidally-locked to a more distant, and perhaps unseen companion, we provide a constraint on the mass, semi-major axis, and eccentricity of the companion. We find that the observed two-planet system HAT-P-13 is in just such an apsidally-locked state, with parameters that obey our constraint well. We also survey close-in single planets, some with and some without an indication of an outer companion. None of the dozen systems that we investigate provide compelling evidence for unseen companions. Instead we suspect that i) orbits are in fact circular, ii) tidal damping rates are much slower than we have assumed, or iii) a recent event has excited these eccentricities. Our method should prove useful for interpreting the results of both current and future planet searches.

101 – Asteroids I

101.02 – A Multi-domain Approach to Asteroid Family Halos Identification

Valerio Carruba[1], Mariela Huaman Espinoza[1], Rita de Cássia Domingos[2, 1]

1. UNESP, Guaratinguetá, SP, Brazil. 2. INPE, São José dos Campos, SP, Brazil.

It has been recently shown that large families are not limited to what found by the hierarchical clustering methods (HCM) in the domain of proper elements (a,e,sin(i)), that seems to be biased to find compact, relatively young clusters, but that there exists an extended population of objects with similar taxonomy and geometric albedo, that can extend to much larger regions in proper elements and frequencies domains: the family ``halo''. Numerical simulations can be used to provide estimates of the age of the family halo, that can then be compared with ages of the family obtained with other methods. Determining a good estimate of the possible orbital extension of a family halo is therefore quite important, if one is interested in determining its age and, possibly, the original ejection velocity field. Previous works have identified families halos by an analysis in proper elements domains, or by using SDSS-MOC 4 multi-band photometry to infer the asteroid taxonomy, or by a combination of the two methods. The limited number of asteroid for which geometric albedo was known until recently discouraged in the past the extensive use of this additional parameter, which is however of great importance in identifying an asteroid taxonomy. The new availability of geometric albedo data from the WISE mission for about 100,000 asteroids significantly increased the sample of object for which such information, with some errors, is now known. In this work we proposed a new method, already used by Carruba (2013) for the Hygiea family halo, to identify families halos in a multi-domain space composed by proper elements, SDSS-MOC 4 principal components data, and WISE geometric albedo for the whole main belt. The new method is quite effective in determining objects belonging to a family halo, with a percentage of less than 3% of likely interlopers, and results that are quite consistent in term of taxonomy and geometric albedo of the halo members.

101.04 – Quasi-satellite Orbits in the Context of Coorbital Dynamics

Vladislav Sidorenko[1], Anton Artemyev[2], Anatoly Neishtadt[2, 3], Lev Zelenyi[2]

1. Keldysh Institute of Applied Mathematics, Moscow, Russian Federation. 2. Space Research Institute, Moscow, Russian Federation. 3. Loughborough University, Loughborough, United Kingdom.

The investigations on long-term evolution of asteroid’s orbits are crucial to understanding the route through which the present configuration of the Solar system came to be. The so-called coorbiting asteroids (which share their orbits with major planets) attract the special attention in this connection: are they the primordial remnants of the building blocks of the corresponding major planet or are they the 'migrants' from the other parts of the Solar system? The most well known examples of co-orbits in natural objects are provided by Trojan groups of asteroids and by asteroids moving in horseshoe orbits. These asteroids are precluded from having relatively close encounters with their host planets. However, there exists another class of coorbiting objects in which the opposite is true: they remain very near to the host planet eternally or, at least, for long enough time. Since typically they never enter the planet’s Hill sphere, they cannot be considered as satellites in the usual sense of the word. In order to emphasize this specific they are called quasi-satellites (QS). We explore the properties of QS-orbits under the scope of the restricted spatial circular three-body problem. Via double numerical averaging, we construct evolutionary equations which describe the long-term behaviour of the orbital elements of an asteroid. Special attention is paid at possible transitions between the motion in a QS-orbit and that in another type of orbit available in the 1:1 mean motion resonance. To illustrate the typical rates of the orbital elements's secular evolution, the dynamics of the near-Earth asteroid 2004GU9 was studied. This asteroid will keep describing a QS-orbit for the next several hundreds of years. This work was supported by the grant of the Russian Academy of Sciences Presidium Program 22: 'Fundamental problems of research and exploration of the Solar system'.

101.05 – Yarkovsky-driven Impact Predictions: Apophis and 1950 DA

Davide Farnocchia[1], Steven R. Chesley[1], Paul Chodas[1], Andrea Milani[2]

1. JPL/Caltech, Pasadena, CA, United States. 2. University of Pisa, Pisa, Italy.

Orbit determination for Near-Earth Asteroids presents unique technical challenges due to the imperative of early detection and careful assessment of the risk posed by specific Earth close approaches. The occurrence of an Earth impact can be decisively driven by the Yarkovsky effect, which is the most important nongravitational perturbation as it causes asteroids to undergo a secular variation in semimajor axis resulting in a quadratic effect in anomaly. We discuss the cases of (99942) Apophis and (29075) 1950 DA. The relevance of the Yarkovsky effect for Apophis is due to a scattering close approach in 2029 with minimum geocentric distance ~38000 km. For 1950 DA the influence of the Yarkovsky effect in 2880 is due to the long time interval preceding the impact. We use the available information on the asteroids' physical models as a starting point for a Monte Carlo method that allow us to measure how the Yarkovsky effect affects orbital predictions. For Apophis we map onto the 2029 close approach b-plane and analyze the keyholes corresponding to resonant close approaches. For 1950 DA we use the b-plane corresponding to the possible impact in 2880. We finally compute the impact probability from the mapped probability density function on the considered b-plane.

102 – Asteroids II

102.01 – The Obliquity Distribution of Near-Earth Asteroids

Steven R. Chesley[1], Davide Farnocchia[1], Desiree Cotto-Figueroa[2], Thomas S. Statler[2, 3]

1. JPL/Caltech, Pasadena, CA, United States. 2. Ohio University, Athens, OH, United States. 3. National Science Foundation, Washington, DC, United States.

Direct estimates of the Yarkovsky effect on near-Earth asteroids (NEAs) indicate that detectable semimajor axis drift rates are approximately 2-4 times more likely to be negative than positive (Nugent et al., AJ 144, 2012; Farnocchia et al., Icarus in press, 2013). The Yarkovsky effect induces a semimajor axis drift rate that is proportional to the cosine of the obliquity, and thus the excess of negative drift rates suggests an excess of retrograde rotation among the NEAs. This reinforces an earlier result from light curve inversion techniques (La Spina et al., Nature 428, 2004). The retrograde excess is presumed to arise from the nu6 resonance, which is situated near the inner edge of the main belt. Main-belt asteroids that are Yarkovsky-driven into the near-Earth region via the nu6 resonance must have a negative semimajor axis drift and therefore retrograde rotation, leading to an overabundance of retrograde rotators, even though other source regions may have parity between retrograde and direct rotators. The Yarkovsky detections do not directly shed light on the relative presence of mid-range obliquities, which tend to have low drift rates and therefore fail to yield statistically significant drift estimates, but they do present significantly different selection effects when compared to light curve inversions. We present preliminary results from our effort to derive independent constraints on the obliquity distribution of NEAs based on the distribution of estimated semimajor axis drift rates among the NEA population and their associated uncertainties. Our approach to solving the inverse problem starts by deriving the drift rates and associated signal-to-noise ratios for a semi-synthetic NEA population that assumes a parameterized obliquity distribution. The parameters are adjusted until the simulated distributions match the observed distributions, yielding not only an estimated distribution, but also uncertainties and correlations among the relevant model parameters. The results have the potential to offer constraints on the spin axis evolution of NEAs after they enter the near-Earth region.

102.02 – Radiation Recoil Effects on the Dynamical Evolution of Asteroids

Desireé Cotto-Figueroa[1], Thomas S. Statler[1, 2], Derek C. Richardson[3], Paolo Tanga[4]

1. Ohio University, Athens, OH, United States. 2. National Science Foundation, Arlington, VA, United States. 3. University of Maryland, College Park, MD, United States. 4. Cote d' Azur Observatory, Nice, France.

We present the results of the first simulations that self-consistently model the YORP effect on the spin states of dynamically evolving aggregates. We follow the evolution of aggregate objects computing the sequence of spin states and YORP torques through which they evolve as the changing spin alters their shape, which subsequently changes the YORP torques. Previous analyses of the basic behavior of the YORP effect have led to the idea of the 'YORP cycle'. However, the rotation rates of asteroids obtained from optical light curves suggest that most asteroids are aggregates and Statler [2009] has shown that the YORP effect has an extreme sensitivity to the topography of asteroids (Icarus 202, 501-513). If the spin-driven reconfiguration leads to a shape of the aggregate that is nearly symmetric, the YORP torques could become negligibly small or even vanish. This would imply a self-limitation in the evolution of the spin state and the objects would not follow the classical YORP cycle. Moreover, subsequent reconfigurations could lead to a random walk making the evolution of the spin state completely stochastic. An extensive and statistical analysis of the simulations is conducted to determine whether or not the spin evolution is stochastic and whether the YORP effect is self-limiting. We aim to identify particular behaviors of aggregate objects under the influence of the YORP effect. We present results of their shape evolution including the types, magnitudes and frequencies of movement and shedding of material. We also identify the common characteristics of those objects that have mass loss episodes and of those that exhibit a similar behavior in their spin state or shape evolutions.

102.03 – Evolution of Small Binary Asteroids with the Binary YORP Effect

Julien Frouard[1]

1. Universidade Estadual Paulista - DEMAC, Rio Claro, SP, Brazil.

Small, Near-Earth binaries are believed to be created following the fission of an asteroid spun up by the YORP effect. It is then believed that the YORP effect acting on the secondary (Binary YORP) increases or decreases the binary mutual distance on 10^5 yr timescales. How long this mechanism can apply is not yet fully understood. We investigate the binary orbital and rotational dynamics by using non-averaged, direct numerical simulations, taking into account the relative motion of two ellipsoids (primary and secondary) and the solar perturbation. We add the YORP force and torque on the orbital and rotational motion of the secondary. As a check of our code we obtain a ~ 7.2 cm/yr drift in semi-major axis for 1999 KW4 beta, consistent with the values obtained with former analytical studies. The synchronous rotation of the secondary is required for the Binary YORP to be effective. We investigate the synchronous lock of the secondary in function of different parameters ; mutual distance, shape of the secondary, and heliocentric orbit. For example we show that the secondary of 1999 KW4 can be synchronous only up to 7 Rp (primary radius), where the resonance becomes completely chaotic even for very small eccentricities. We use Gaussian Random Spheres to obtain various secondary shapes, and check the evolution of the binaries with the Binary YORP effect.

102.04 – Minimum Energy Configurations for the General 3-Body Problem

Daniel J. Scheeres[1]

1. University of Colorado, Boulder, CO, United States.

We outline and detail all minimum energy configurations that can exist in the Full 3-Body Problem when the bodies are modeled as finite density spheres. Depending on the mass fraction of each body we find that different sequences of bifurcations cannot occur under the monotonic increase of angular momentum. We also find specific patterns for how the sequence of fission events in a three body system must occur, and see that under gravitational force alone elements of this fission sequence are fixed independent of mass fraction. The results also provide strong constraints that self-gravitating granular mechanics simulations must respect.

102.05 – Investigating Satellite Formation Around the Rapidly Rotating, Oblong Asteroid 216 Kleopatra

Frank Laipert[1], David A. Minton[1]

1. Purdue University, Lafayette, IN, United States.

Located in the asteroid belt, Kleopatra is an approximately 200 km long object shaped much like a dog bone. Recent observations have determined that two moons are in orbit about Kleopatra. Currently, it is not known how these moons, designated S/2008 ((216)) 1 and S/2008 ((216)) 2, came to orbit the asteroid, or how long these satellites have existed. Owing to the gravitational dynamics that result from Kleopatra's unusual shape and high spin rate, several equilibrium points exist near the asteroid, similar to the Lagrange points that result from the three-body dynamics in the Earth-Moon system. Using an ellipsoidal approximation for Kleopatra's gravity field, we show that a special class of trajectories pass through these equilibrium points and result in orbits very similar to the observed satellites. We use the unusual gravitational environment around Kleopatra to investigate a novel satellite formation mechanism. We combine simulations of particles moving in Kleopatra's gravity field with models of the collisional history of Kleopatra in the main belt to determine whether it is feasible for a satellite to form out of the material ejected from collisions over the lifetime of Kleopatra.

103 – Stars

103.01 – Lack of Energy Equipartition in Globular Clusters

Michele Trenti[1]
1. University of Cambridge, Cambridge, United Kingdom.

It is widely believed that globular clusters evolve over many two-body relaxation times toward a state of energy equipartition, so that velocity dispersion scales with stellar mass as ??m^{-?} with ?=0.5. I will show instead that this is incorrect, using a suite of direct N-body simulations with a variety of realistic initial mass functions and initial conditions. No simulated system ever reaches a state close to equipartition. Near the center, the luminous main-sequence stars reach a maximum ?_{max} ~0.15±0.03. At large times, all radial bins convergence on an asymptotic value ?_{?}~0.08±0.02. The development of this ``partial equipartition'' is strikingly similar across simulations, despite the range of different initial conditions employed. Compact remnants tend to have higher ? than main-sequence stars (but still ?< 0.5), due to their steeper (evolved) mass function. The presence of an intermediate-mass black hole (IMBH) decreases ?, consistent with our previous findings of a quenching of mass segregation under these conditions. All these results can be understood as a consequence of the Spitzer instability for two-component systems, extended by Vishniac to a continuous mass spectrum. Mass segregation (the tendency of heavier stars to sink toward the core) has often been studied observationally, but energy equipartition has not. Due to the advent of high-quality proper motion datasets from the Hubble Space Telescope, it is now possible to measure ? for real clusters. Detailed data-model comparisons open up a new observational window on globular cluster dynamics, structure, evolution, initial conditions, and possible IMBHs. A first comparison of my simulations to observations of Omega Cen yields good agreement, supporting the view that globular clusters are not generally in energy equipartition. Modeling techniques that assume equipartition by construction (e.g., multi-mass Michie-King models) are thus approximate at best.

103.02 – Exploring Stellar Collisions within Very Wide Binaries

Nathan A. Kaib[1]*, Sean N. Raymond*[2, 3]
1. Northwestern University, Evanston, IL, United States. 2. Université Bordeaux, Floirac, France. 3. CNRS, LAB, Floirac, France.

In a previous work (Kaib et al. 2013), we showed that on Gyr timescales, stellar orbits of very wide binaries are often driven to very high eccentricities. In many instances, the resulting periastron passages are close enough for the two stars to destabilize one another's planetary system. In much rarer occurrences, the binary orbit becomes so eccentric that the two stars actually collide. We use numerical simulations to estimate the rate of stellar collisions within very wide binaries and then compare this rate to other known sources of stellar collisions within the Milky Way. Furthermore, we attempt to use Li abundances and stellar rotation rates to potentially identify such collision remnants among the Milky Way's thin disk population. Finally, we also investigate whether tidal dissipation during extremely close stellar encounters within very wide binaries can give rise to populations of other more exotic binary stars.

103.03 – Probabilities for Solar Siblings

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We have shown previously (Bobylev et al. 2011) that some of the stars in the Solar neighborhood today may have originated in the same star cluster as the Sun, and could thus be called Solar Siblings. In this work we investigate the sensitivity of this result to Galactic models and to parameters of these models, and also extend the sample of orbits. There are a number of good candidates for the Sibling category, but due to the long period of orbit evolution since the break-up of the birth cluster of the Sun, one can only attach probabilities of membership. Bobylev,V.V., Bajkova, A.T., Mylläri, A. & Valtonen,M. 2011, Astronomy Letters 37, 550

104 – Brouwer Award Talk: Jerry Sellwood: The Spiral Structure of Galaxies

104.01 – Spiral Structure in Galaxies

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I present a general assessment of our understanding of the origin of spiral patterns in galaxies. While the problem is still not fully solved, the dynamics of differentially rotating disks presents many subtle phenomena that are multiple facets of the overall behaviour. The picture that may ultimately emerge is one in which the spiral patterns are true instabilities of a non-smooth disk, and the saturation and decay of one instability seeds the growth of another. Future ground- and space-based surveys to measure the kinematics and chemistry of stars across the Milky Way will yield data that could confirm or refute these ideas.

200 – Comets and TNOs I

200.01 – Trans-Neptunian Objects as Natural Probes to the Unknown Solar System

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Trans-Neptunian objects (TNOs) are solar system small bodies that move beyond the orbit of Neptune in a region known as the trans-Neptunian belt (or Edgeworth-Kuiper belt). TNOs are believed to be the remnants of a collisionally, dynamically and chemically evolved protoplanetary disk from which the planets formed during the early solar system. Therefore, the study of the physical and dynamical properties of TNOs can reveal important clues about the properties of that disk, planet formation, and other evolutionary processes that occurred over the last 4.5 Gyr. TNOs exhibit surprisingly wide ranges of orbital eccentricities and inclinations, and can be grouped into four main dynamical classes of resonant, classical, scattered, and detached objects. In addition, peculiar groupings of objects have been identified within TNO classes, and a number of objects possess peculiar orbits. A better understanding of the origin, orbital evolution, and properties of the main dynamical classes of TNOs is crucial to achieve a "complete" view of the history of the solar system. Several theoretical models have addressed the dynamics of TNOs and their relation to other small body populations, but many unsolved questions remain given that the constraints currently available are still limited. After a brief review on the dynamical stability and the role of resonances in the trans-Neptunian region, I will show the importance of particular groups of TNOs in providing important details for a better understanding of that region and the formation and dynamical evolution of the giant planets. In particular, emphasis will be given to the properties of the dynamically stable populations of Trojan asteroids in the outer solar system, including a discussion on the presence/absence of such populations about the planets. Also, details about (collisional) families and other peculiar subpopulations within the trans-Neptunian belt will provide further clues on the dynamical/collisional environment over the last 4.5 Gyr. In sum, I will show that theoretical studies of these stable small body populations and analysis of their orbital evolution across the entire protoplanetary disk can yield precious information about the history of the solar system.

200.02 – A Compound Model for the Origin of Earth's Water

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The origin of Earth's water is one of the most outstanding issues in understanding the formation and evolution of our solar system. Comets have long been considered the most likely source of water on Earth. However, elemental and isotopic arguments suggest a very small contribution from these objects. Other sources have also been proposed, including local adsorption of water vapor onto dust grains in the primordial nebula and delivery through planetesimals and planetary embryos, among which the latter has become more prominent. However, no sole source of water provides a satisfactory explanation for Earth's water as a whole. In view of that we have developed a compound model incorporating both the principal endogenous and exogenous sources of water, and investigating their implications for terrestrial planet formation and water-delivery to Earth. Comets are also considered in the final analysis, as it is likely that at least some of Earth's water has cometary origin. We analyzed our results comparing two different water distribution models, and complemented our study using D/H ratio, finding possible relative contributions from each source. We have found that our compound model shows an advantage in the time and amount of water delivered to the Earth's accretion zone when compared with the water delivery through planetary embryos. We present our analysis and discuss our model in more detail.

200.03 – The Remarkable Orbit of Sungrazing Comet C/2011 W3 (Lovejoy)

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On Nov. 27, 2011, a bright, new member of the Kreutz system of sungrazing comets was discovered, designated C/2011 W3 (Lovejoy). During the 18 days remaining before perihelion, 116 ground-based astrometric observations were made, along with a several dozen from spacecraft observing the Sun. Unfortunately, pre-perihelion data alone was not sufficient for an accurate determination of the orbital period, and the spaceborne astrometric observations were not sufficiently accurate to help. Surprisingly, the comet survived perihelion, but it clearly underwent major changes: the nuclear condensation completely disappeared within days, and a narrow spine tail formed. Post-perihelion ground-based astrometry from Rob McNaught was referenced to the sunward tip of the spine tail, but it could not be used successfully in orbit solutions. We show that the spine tail was a synchronic feature which originated from the terminal disintegration of the nucleus, on Dec. 17.6 +/- 0.2 UT (Sekanina & Chodas, 2012). In a new technique, we derive astrometric positions of the missing nucleus via two constraints: first, that it would lie on the extrapolated spine tail, and second, that it would lie on a line of orbital-period variation, obtained by forcing a range or orbital periods to sets of elements based on pre-perihelion astrometry. The resulting osculating orbital period is 698 +/- 2 years, which shows that C/2011 W3 cannot be a fragment of any sungrazer observed since the 17th century, and must be a member of the expected new 21st-century cluster of bright Kreutz-system sungrazers, predicted by Sekanina & Chodas (2007).

200.04 – Modeling of Gas and Dust Outflow Dynamics at Active Small Solar System Bodies

Eugene G. Fahnestock[1]
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We present methodology and results from our recent effort in modeling the gas outflow from the surfaces of primitive/active small solar system bodies, and modeling the dynamics of dust particles entrained by that flow. We based our initial simulation capability on the COMA software package, developed ?1995-1999 for ESA to enable studies preparatory to Rosetta. Rather than integrate the derived software for gas and dust dynamics simulation 'into the loop' within high-fidelity 6DOF integration of a rendezvoused spacecraft's dynamics, we created simple tools, or 'interfaces', computationally efficient enough to be brought into the loop, yet capturing the variety of ways in which gas and lifted dust can potentially perturb guidance, navigation, and control (GN&C) performance and surface observation performance. For example, these interfaces are called in the loop to compute noise models for degradation by the dust of imagery and lidar navigation observables. The same applies for degradation of science instrument observations of the surface. Accurate spacecraft dynamics propagation is necessary for mission design, while both that and the observables modeling are required for end-to-end simulation and analysis of navigation and control to the designed close-proximity trajectories. We created interfaces with increasing levels of fidelity, ultimately sufficiently approximating the full flow-field of gas and dust activity; both diffuse background activity (with spatial variation in relation to sun direction) and concentrated jet activity (with spatial and temporal variation through masking to the regions of jet activity in the body-fixed frame and modeling body rotation). We show example results using these tools for two representative design reference missions involving 9P/Tempel 1 and 67P/C-G. This work should be of interest to anyone in the DDA community considering involvement in such mission scenarios. It may also be extended in the near future to cases of intentional generation of outgassing, dust, and debris by surface perturbation, ranging from weak (as in comet surface sample collection) to strong (as in experiments involving crater- and ejecta-generating energetic events such as blasts or kinetic impactors).

200.05 – Constraints on Mechanisms of Comet Disruption from Icy Satellite Craters and Dynamical Simulations

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1. Purdue University, West Lafayette, IN, United States. 2. Institute for Astronomy and Astrophysics, Academia Sinica, Taipei, Taiwan.

Using a Monte Carlo code that simulates cratered terrain evolution (CTEM) we find that the cratering records of the icy satellites of Saturn appear to have been created from a two impactor populations. The least heavily cratered, and thus youngest, terrains are best reproduced by a population of objects whose size-frequency distribution for D<~7 km objects is very shallow (depleted in small objects), while the most heavily cratered, and thus oldest, terrains may be reproduced by a mixture of a this shallow population and a steeper population (rich in small objects). We dub these two end-member population states as 'ARS' (Ancient, Rich in Small bodies) and 'MDS' (Modern, Depleted in Small bodies). For D>~7 km impactors, these two populations appear to be indistinguishable from each other. We hypothesize that these two populations represent a single population of impactors originating in the scattered disk of the Kuiper belt that initially resembled the ARS population, and that the MDS population is derived from the ARS population by size-dependent depletion of small bodies. Because the ARS population cratered saturnian satellites early in solar system history, whatever depletion mechanism acts to convert ARS to MDS in the modern solar system was not effective then. Here we explore whether or not the changing dynamical environment of the outer solar system due to the migration of giant planets early in solar system history could be responsible for the change in the depletion rate of small outer solar system impactors. In particular, we show that the average Centaur lifetime may have been considerably shorter during the epoch of giant planet migration than now, which may imply that small comet disruption occurs when cometary bodies are Centaurs, prior to becoming JFCs, and that the shorter lifetime of Centaurs in the early solar system reduced their probability of depletion before becoming Saturn system impactors.

201 – Comets and TNOs II

201.01 – Dynamical Explanation for the Lack of Binary Asteroids Among the Plutinos

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Binary asteroids are really common among the trans-Neptunians. However, they seem to be scarce among the Plutinos, i.e. the part of the Kuiper belt population situated inside the 3:2 mean-motion resonance with Neptune. Our hypothesis is that this phenomenon, unexplained up to now, is due to the impact of the 3:2 resonance on the formation of Kuiper belt binaries. Numerical simulations are done in the context of the 2+2 bodies problem (here, Sun, Neptune and two asteroids). As is known, mean-motion resonances between a planet and an asteroid usually have the effect of increasing the eccentricity of the asteroid. Therefore, we include the increase of the eccentricity of the centre of mass of the binary system due to the resonance in the simulations. Chaos maps (obtained using the MEGNO chaos indicator) and histograms of residence times for tests particles are computed in order to analyse the behavioural differences of potential Kuiper belt binaries inside and outside the resonance. The results suggest the following: the stable zones in the MEGNO maps are mainly disrupted in the resonant eccentric case and the number of binary asteroids created in the resonant eccentric case is significantly lower than in the non-resonant one. This provides a clue to explain the lack of binaries among the Plutinos.

201.02 – The Orbits and Masses of Pluto's Satellites

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We report on the numerically integrated orbital fits of Pluto's satellites, Charon, Nix, Hydra, and S/2011 (134340) 1, to an extensive set of astrometric, mutual event, and stellar occultation observations over the time interval April 1965 to July 2011. The observations of Charon relative to Pluto have been corrected for the Pluto center-of-figure center-of-light (COF) offset due to the Pluto albedo variations. The most recently discovered satellite S/2012 (134340) 1 is fit with a precessing ellipse because its observation set is insufficient to constrain a numerically integrated orbit. The Pluto system mass is well determined with the current data. However, the Charon's mass still carries a considerable amount of the uncertainty due to the fact that the primary source of information for the Charon mass is a small quantity of absolute position measurements that are sensitive to the independent motions of Pluto and Charon about the system barycenter. We used bounded-least squares algorithm to try to constrain the masses of Nix, Hydra, and S/2011 (134340) 1, but the current dataset appears to be too sparse for mass determination. The long-term dynamical interaction among the satellites does yield a weak determination of Hydra's mass. We investigated the effect of more astrometry of S/2012 (134340) 1 on the mass determination of the other satellites and found no improvement with the additional data. We have delivered ephemerides based on our integrated orbits to the New Horizons project along with their expected uncertainties at the time of the spacecraft encounter with the Pluto system. Acknowledgments: The research described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

201.03 – Exploring the Dynamical Consequences of the Collisional Environment of the Kuiper Belt on the Orbits of Pluto’s Small Satellites

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Nix, Hydra, P4, and P5 have presented problems to those wishing to determine how these four small satellites entered into their currently observed orbits about Pluto. It is largely believed that these satellites were formed through the Charon-generating impact on Pluto, but how could these satellites have ended up in their current orbits? And, why are the satellites’ orbits very close to, but not exactly within, mean motion resonances? We used new information about the Kuiper belt size distribution to make our own investigation into the orbital and collisional history of the satellites of Pluto over the age of the Solar System. With this new information, we generated a new model of the collisional evolution of Kuiper belt objects. These time histories were used to help determine whether collisions between these satellites and other objects within the Kuiper belt, and its various dynamical subpopulations, could have been important over their lifetimes. Scenarios were looked into using the current status of the modern Kuiper Belt, and the early Kuiper belt both before, during, and after its depletion due to giant outer planet migration. Work with collisional simulations also included the possibility of satellite destruction with mass distribution between the satellites and/or a coalescence of the debris to reform the destroyed satellite. We analyzed the importance of collisions between objects of the Kuiper belt and the four smallest satellites of Pluto throughout their lifetimes in determining their currently observed status.

201.04 – The Formation of Pluto's Small Satellites

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The Pluto systems is one of extremes. In addition to Pluto, the system contains at least 5 satellites. Charon is the most massive, being more than 1/9 the mass of Pluto. This makes it the most massive satellite, relative to the primary, of any other planet or dwarf-planet in the Solar System. The other satellites are much smaller - having radii that are probably significantly less than 50 km. They are on nearly-circular, co-planer orbits. Perhaps one of their most intriguing characteristics is that they are all close to n:1 mean motion resonances (MMRs) with Charon. In particular, Nix, P4, and Hydra are close to the 4:1, 5:1, and 6:1 MMR, respectively. (There is as yet no good orbit for P5). Observations are good enough for Nix and Hydra to conclude that while the are near their respective resonances, they do not appear to actually be librating in them. This a been a challenge for theories of their formation. I will review the formation and evolution of Pluto's family of satellites. In addition, I will present some new work exploring a heretofore unexplored dynamical mechanism that might help explain the puzzling orbits of the small satellites.

202 – Comets and TNOs III

202.01 – Where is the Oort Cloud Located?

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The Oort cloud is the outermost population of the solar system. Our knowledge of its size and space structure relies on the single natural probe we have so far available, namely the new comets that are steadily injected by the tidal force of the galactic disk and passing stars. To learn about the places where new comets come from, it is essential to compute good original orbits and to understand how these may be affected by nongravitational (ng) forces. Distant comets (perihelion distance q > ~3 au) are found to be little affected by ng forces, unless they are very small (radii < ~ a few tenths km) and/or hyperactive (due to a highly volatile substance like CO or CO_2). We discuss these problems in this presentation, and try to assemble a consistent picture of the Oort cloud, consisting of the inner Oort cloud (IOC) and the outer Oort cloud (OOC). The distribution of original energies of distant new comets (perihelion distances q> ~3 au presumably little affected by nongravitational forces) show that the boundary between the IOC and the OOC lies around an energy 30×10^{-6} au^{-1} or a semimajor axis ~ 3.3×10^4 au. New comets from the OOC show an uniform distribution of perihelion distances q, as expected for a thermalized Oort cloud comet population, while comets from the IOC show an increase of the rate of perihelion passages with q, as expected for comets whose perihelion distances evolve slowly under the action of external pertubers, and have to overcome the Jupiter-Saturn barrier to reach the inner planetary region.

203 – Rotation

203.01 – Effects of High Inclined and Eccentric Disturbers on the Dynamics of the Equator of an Axy-Simmetric Body

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In this work we consider the rotational long term dynamics of an axy-simmetric body under the action of a high inclined and eccentric disturber. The problem is written in terms of Andoyer canonical variables (L,G,H, l,g,h), with respect to an independent inertial frame. Since A=B (moments of inertia), the l angle is an ignorable variable, so that spin-orbit resonance is ruled out. Therefore the Hamiltonian can be averaged in the mean anomaly of the orbital motion of the disturber. An extra average is still possible in g as it is a fast Andoyer variable. In order to have a first and rough idea of the real dynamics, the disturber is assumed in a simplified precessing keplerian motion (Henrard & Schwanen, 2004) . Then the Hamiltonian is reduced to a problem of one degree of freedom and the level curves show a gross idea of the basic dynamics. In particular the curves show interesting equilibrium points, some of them are related to Cassini's second law. Depending on the mass and eccentricity or inclination of the disturber, a strong resonance between h and longitude of the node of the disturber can appear. This resonance can cause interesting variations of the inclination of the plane normal to the angular momentum of the perturbed body. Finally, numerical integrations of the complete averaged problem are performed. In particular, we study the possible cumulative effects of temporary satellites when they orbit their host planet in high inclined and eccentric orbit. These satellites (planetesimals) might have existed during the planetary migration but due to Lidov-Kozai resonance they should have ejected after some time.

203.02 – The Role of Tides in the Rotational History of Mercury

Benoit Noyelles[1]*, Michael Efroimsky*[2]*, Julien Frouard*[3]*, Valeri V. Makarov*[2]
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The rotational state of Mercury is unique in the Solar System, in that this planet is locked into the 3:2 spin-orbit resonance, the spin period being two thirds of the orbital one. It is known that the eccentricity of Mercury (0.206) assists entrapment, through widening the resonance. Nevertheless, the exact way in which the system was caught into the resonance remains to be determined. Employment of a simplistic tidal model called the MacDonald torque leads to a small probability of capture (less than 5%) in crossing the resonance, wherefore several crossings of the resonance are required to get the current 3:2 resonance with a satisfying confidence (Correia and Laskar 2004, Nature, 429:848). We revisit the problem of Mercury's tidal despinning, using the Darwin-Kaula expansion for the torque over the tidal modes. (Sometimes this series is called the Darwin torque.) The expansion is combined with a realistic tidal dissipation law, i.e, with a realistic frequency-dependence of the ratio k_2/Q , where k_2 is the quadrupole Love number, while 1/Q is the inverse tidal quality factor defined as the sine of the semidiurnal tidal phase lag. The tidal law comprises two bands. At lower frequencies, the response of the body is overwhelmingly viscoelastic, so the frequency dependence is that appropriate to the Maxwell body. At higher frequencies, defect-unpinning mechanisms come into play, and the material behaves as the Andrade body. The physics-based description of the tidal reaction of Mercury is then combined with a statistically relevant set of time evolutions of Mercury's eccentricity. Under employment of the combined Andrade/Maxwell model of tides, entrapment into the 3:2 spin-orbit resonance during the first crossing becomes the most probable scenario. This makes the 3:2 spin-orbit resonance likely to be older than usually thought. Our results are consistent with those obtained by Makarov (2012, ApJ, 752:73) who, too, based his analysis on the combined Andrade/Maxwell model, though computed orbits somewhat differently and kept the eccentricity fixed.

203.03 – Tidal Perturbations of the Rotation of the Moon. The Creep Tide Approach.

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In this communication we report results from the application to the study of the rotation of the Moon of the creeping tide theory just proposed (Ferraz-Mello, Cel. Mech. Dyn. Astron., submitted. ArXiv astro-ph 1204.3957). The choice of the Moon for the first application of this new theory is motivated by the fact that the Moon is one of the best observed celestial bodies and the comparison of the theoretical predictions of the theory with observations i may validate the theory or point out the need of further improvements. Particularly, the tidal perturbations of the rotation of the Moon – the physical libration of the Moon – have been detected in the Lunar Laser Ranging measurements (Williams et al. JGR 106, 27933, 2001). The major difficulty in this application comes from the fact that tidal torques in a planet-satellite system are very sensitive to the distance between the two-bodies, which is strongly affected by Solar perturbations. In the case of the Moon, the main solar perturbations - the Evection and the Variation - are more important than most of the Keplerian oscillations, being smaller only than the first Keplerian harmonic (equation of the centre). Besides, two of the three components of the Moon's libration in longitude whose tidal contributions were determined by LLR are related to these perturbations. The results may allow us to determine the main parameter of a possible Moon's creeping tide. The preliminary results point to a relaxation factor (?) 2 to 4 times smaller than the one predicted from the often cited values of thr Moon's quality factor Q (between 30 and 40), and points to larger Q values.

204 – Poster Session

204.01 – Gravitational Capture of Small Bodies by Gas Drag Developed Using Hydrodynamic Equations

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The giant planets of the Solar System have two kinds of satellites, the regular and the irregular ones. The irregular ones are supposed to come from other regions were captured by the planet. Using the dynamics of the three-body problem it is possible to explain the gravitational capture of these satellites except for the fact that these captures are only temporary. For this reason it is necessary an additional effect to turn these temporary captures into a permanent ones. In this work we will explore the gas drag mechanism. In the last stage of the giant planets formation a gas envelope formed around each one of them. During the flyby of the satellite this envelope can dissipate energy enough to make it a "prisoner" of the planet. We have made some simulations considering the classical case. In these simulations the classical gas was characterized by ordinary differential equations that describe the velocity and density of it. However this model is a simplified case. To make our model more realistic we use the hydrodynamic model. Thus some modification in the early code were required. One important code changes was the way used to describe the gas. In this new model a region (called cell) and not a point is used to characterize the gas. After making some adjusts we have checked the precision of cells and verified its correlation with other parameters. At this step we have to test the new code trying to reproduce and improve all results obtained before. Meanwhile we are using the software Fargo that creates the hydrodynamic gas to be used as input in the code. After this analysis we will let the gas evolve in time in order to acquire a higher level of realism in this study.

204.02 – An Impact Generated Ring in Bianca's Orbit

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The Portia group is a set of nine small satellites densely packed within 2 and 3 radii of Uranus, and some of these moons are related to faint rings: the nu ring orbits between Portia and Rosalind, while the mu ring peak is aligned with the orbit of Mab. Sfair & Giuliatti Winter (2012) showed that the alignment and the triangular radial profile of the mu ring may be explained by a combination of the dust ejection caused by the bombardment of micrometeoroids onto the surface of Mab, and the subsequent effects of the planetary oblateness and the solar radiation force acting upon the grains. In spite of all members of the Portia family are subject to a similar flux of impactors and forces, so far there is no evidence of other ring paired with a satellite. A possible exception is Bianca, the innermost member of the family, and therefore less sensitive to observations. With an appropriate size for a ring-producing moon, our calculations suggests that the bombardment may provide material to the surroundings at a rate of 40 g/s. The solar radiation force effects can be noticed in an asymmetrical triangular distribution of the ejected grains, and in the slight offset between the density peak of the resulting ring and Bianca's orbit. In our numerical simulations the dust grains can survive in the region up to 8000 years, when all dust particles are removed by collisions with the source body. This survival time allows us to estimate an upper limit of 1E-4 for the optical depth of this hypothetical ring, but a more accurate model is necessary to place better constrains for future observations.

204.03 – Toward an Accurate Modelization of the Obliquity of Mercury

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The measurement of the obliquity of Mercury is a crucial step for the knowledge of the interior of the planet. In particular, it gives straightforwardly the polar moment of inertia C. A recent measurement by Margot et al. (2012) gives an obliquity of 2.04 +/- 0.08 arcmin, yielding C = (0.346 +/- 0.014) MR2 using a famous formula due to Peale (1969). This formula considers the second-degree spherical harmonics of the gravity field of Mercury, and constant orbital quantities. Thanks to MESSENGER, we have today a much better knowledge of the gravity field, up to the fourth-degree. This is the opportunity to revisit the modelization of the obliquity of Mercury, in using at the same time an analytical and numerical approach. The analytical approach is a new derivation of the Cassini State 1, and considers the influence of the gravity coefficients J3 and J4. The numerical approach involves the slow time variations of the orbital elements and allows a Laplace-Plane free study. This accurate model shows that the error due to the theory in the inversion of the obliquity is very small, C being possibly 0.345 MR2 instead of 0.346.

204.04 – Planetesimal Accretion in Tight Binary Systems

Jorge Correa-Otto[1, 2], Cristian Beauge[2], Pablo Benitez Llambay[2], Alejandro Martin Leiva[3]
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We present a study on the accretion process of planetesimals in tight binary systems. We develop an analytical model that considers the effects of both the gas disk and the stellar companion on the planetesimals motion. The model was then applied to the ?-Cephei binary system, with minimal relative separation between the stars of 12 AU and a planet around the main star at ?2 AU. Our study allowed us to determine the dynamics of planetesimals in a low eccentricity non-precessing gas disk. The evolution of a large number of particles of different sizes was considered. Then, we calculated the relative encounters velocities between pairs of planetesimals, in order to determine whether their magnitudes remained below the disruption limit. We have found that all planetesimals, independently on their sizes, were able to accrete in the distances 2-3 AU from the primary star.

204.05 – Planet Formation Around a Binary System Disturbed by a Third Star

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Recently several multiple star systems (double, triple and quadruple) were found to host planets. In the literature are found several works on planetary formation around binary systems. In the present work we evaluate some possible conditions needed in order to form rocky planets around a binary star disturbed by a third star. First, we identify the location of a stable region of massless particles. Then, we numerically simulate the whole system taking into account a distribution of planetesimals and/or embryos that interact with each other producing larger bodies. This study is made considering a range of different values for the separation of the binary (d) and also for the semi-major axis (a3) and eccentricity (e3) of the perturbing star. The results are presented in terms of the final mass and location of the remaining bodies as a function of d, a3, e3. We also make a discussion on the conditions needed for the formation of terrestrial planets in the habitable zone for this kind of triple star systems.

204.06 – Tidal Evolution in Co-orbital Configurations

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We study the orbital evolution of a two co-orbital planet system which undergo tidal interactions with the central star. Our main goal is to investigate the final outcome of a system originally evolving in a 1:1 resonant configuration when the tidal effect acts to change the orbital elements. Preliminary results of the numerical simulations of the exact equations of motions indicate that, at least for equal mass planets, the combined effect of resonant motion and tidal interaction leads the system to orbital instability, including collisions between the planets. We discuss the cases of two hot super-Earths and two hot-Saturn planets, comparing with the results of dynamical maps.

204.07 – Resonant Dynamics of Small Satellites in the Inner System of Saturn

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The dynamics of fictitious and real small satellites located between the major Saturnian is investigated through analysis of numerical simulations of ensembles of orbits taken around the current position of the satellites.

Emphasis is given in the region between the regular satellites Mimas and Enceladus, where the satellites Methone, Anthe and Pallene are present. Fourier spectra of these orbits are obtained in order to numerically estimate regular and chaotic orbits in the frequency domain. We show that the phase space is complex, with a great deal of two and three-body mean-motion resonances close to the current positions of the satellites. We also give a detailed description of the mean motion resonances involving Methone, Anthe, Pallene and Mimas and Enceladus. This work is an extension of previous research on resonant dynamics of regular system of Saturn (Callegari and Yokoyama 2010, Planetary and Space Science).

204.08 – Aegaoen, the Small Satellite of Saturn, and the Production of Dust Particles

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Recent images sent by the Cassini spacecraft showed a dense region immerse in the G ring of Saturn, an arc. Further analysis detected the presence of a small satellite, named Aegaeon, with a radius smaller than 1km embedded in this arc. This satellite could be responsible for the maintenance of the ring, and also the arc, by generating particles thought collisions with interplanetary objects onto its surface. In this work we analysed the amount of the particles generated during these collisions in this environmental system. The dynamics which evolve the satellite Aegaeon, in resonance with the satellite Mimas, and the small dust particles located at the arc of the G ring will also be analysed. This system will be under the effects of the Solar Radiation Pressure and the gravity coefficient of the planet Saturn. From the analytical model, which is summarized in Sfair & Giuliatti Winter (2012), and assuming the typical mass flux at Saturn to be 1.8 X 10^{-16} kg/(ms ^{2}) and the nominal parameters of the planet and the satellite (Aegaeon), we could determine the ejecta yield (Y) and the mass production rate (M+). These values are found to be Y=21153.86 and M+ = 5.9 X 10^{-6} kg/s . The dust particles, after being ejected from the surface of Aegaoen, are disturbed by the effects of the solar radiation force. By numerical simulating a sample of small particles of different sizes (1, 5 and 10µm) we verified that most of them collide with the satellite. The set of 1µm sized particles collide with Aegaeon in less than 100years. The effects of the solar radiation force remove the larger particles from the corotation resonance with Mimas and spread them all over the G ring. From M+ we estimate that Aegaeon produce about 10^{4}kg of dust particles in 100years. The results obtained by comparing the analytical model and the numerical simulations will be presented.

204.09 – NEAs' Binaries and Planetary Close Encounters -Stability and Lifetime

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In the present work we considered the effects of close encounters, suffered by hypothetical NEAs binaries, with Earth, Mercury and Venus, in order to determine the stability of their satellites as a function of the encounter conditions. In addition, knowing the conditions that leads to the loss (by ejection or collisions) of the most internal satellites, we are able to estimate the frequency of such encounters, and thus, determine the expected lifetime of the NEAs binaries. The methodology consisted on numerically simulate a system composed by the Sun, the planets of the Solar System, and a sample of 2100 NEAs, for a period of 10 Myr (predict NEAs' lifetime). All close encounters with the planets closer than 100 planet's radius were registered. The next step consisted on simulate a representative sample of those registered close encounters, through numerical integration, considering the planet, the asteroid that perform the close encounter, and a cloud of satellites around the asteroid. The largest radial distance for which all the satellites survive (no collision or ejection) was defined as the critical radius - Rc, given as a function of the encounter parameters (relative velocity and impact parameter). For the Earth, we found that the close encounters with impact parameter and relative velocity capable to remove the most internal satellites of the NEAs (Rc < 5 km), are very frequent. We found that 93% of the asteroids of the group Atens suffer an encounter within this limit in 10 Myrs, and that 50% of these encounters happen in approximately 330.000 years. For the Apollos we found that 60% of the asteroids suffer such encounters, and that 50% of then happen in approximately 700.000 years. Such results indicate that, in fact, the lifetime of the binaries is strongly influencied by the planetary close encounters, proving to be significantly shorter than the predicted lifetime of the NEAs. The contribution of the planets Mercury and Venus will be presented, separatelly, for the groups Atens, Apollo and Amor. Thus, we discuss the role of planetary encounters in the dynamic of NEAs binaries.

204.10 – A Study of the Low Velocity Regions Close to the Roche Lobe of Giant Planets

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It is believed that satellites of giant planets were formed soon after its own planets, from material which was not accreted on the planet in its last formation phase. Our work analyzes some special regions near the Roche lobe of giant planets, regions which have low velocities. With numerical simulations we try to find some evidence which could allow us to affirm that these regions are, indeed, favorable for the formation of satellites. For the computational procedures, we use the hydrodynamic numerical integrator FARGO 2D, and we simulated two different situations during the formation of a planet with of Jupiter characteristics, then we considered that the planet in question has been formed with core accretion, in other words, first the planet has been formed with an inner solid core and then, it was surrounded by a gaseous envelope. We simulated a two-dimensional, non-self-gravitating disc, the viscous and tidal torques are considered in the simulations. In our first situation, we simulated only the hydrodynamic gas around the planet to prove the existence of the low velocity regions close to the Roche lobe. Once the existence of the interest regions were verified, we begin the simulation with particles. This simulation is the most interest to us, because in this simulation we will find, or not, the necessary evidences of the satellite formation in the studied regions. Thus, we simulated particles near the regions where low velocities were found, trying to reproduce what would be the formation of satellites in these locations, we are waiting the end of these simulations to finally make a detailed analysis of the results, and provide sufficient data to prove, or not, that these kind of regions are possibles sites for satellite formation.

204.11 – Dynamics of “Jumping” Trojans: Perturbative Treatment

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The term “jumping” Trojan was introduced by Tsiganis et al. (2000) in their studies of long-term dynamics exhibited by the asteroid 1868 Thersites: as it turned out, this asteroid may pass from the librations around L4 to the librations around L5. One more example of “jumping” Trojan was found by Connors et al. (2011): present librations of the asteroid 2010TK7 around Earth’s libration point L4 preceded by its librations around L5. We explore the dynamics of “jumping” Trojans under the scope of the restricted spatial circular three-body problem. Via double numerical averaging, we construct evolutionary equations which describe the long-term behavior of the orbital elements of these asteroids. Our work was supported by the grant of the Russian Academy of Sciences Program: 'Fundamental problems of research and exploration of the Solar system'.

204.12 – Stability of Frozen Orbits Around Europa

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A planetary satellite of interest at the present moment for the scientific community is Europa, one of the four largest moons of Jupiter. There are some missions planned to visit Europa in the next years, for example, Jupiter Europa Orbiter (JEO, NASA) and Jupiter IcyMoon Explorer (JUICE, ESA). In this work we are formulating theories and constructing computer programs to be used in the design of aerospace tasks as regards the stability of artificial satellite orbits around planetary satellites. The studies are related to translational motion of orbits around planetary satellites considering polygenic perturbations due to forces, such as the nonspherical shape of the central body and the perturbation of the third body. The equations of motion will be developed in closed form to avoid expansions in eccentricity and inclination. For a description of canonical formalism are used the Delaunay canonical variables. The canonical set of equations, which are nonlinear differential equations, will be used to study the stability of orbits around Europa. We will use a simplified dynamic model, which considers the effects caused by non-uniform distribution of mass of Europa (J2, J3 and C22) and the gravitational attraction of Jupiter. Emphasis will be given to the case of frozen orbits, defined as having almost constant values of eccentricity, inclination, and argument of pericentre. An approach will be used to search for frozen orbits around planetary satellites and study their stability by applying a process of normalization of Hamiltonian. Acknowledges: FAPESP

204.13 – Dynamical Mobility due to Close Encounter with Several Massive Asteroids. Case (10) Hygiea, (2) Pallas, and (31) Euphrosyne.

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Orbital mobility caused by close encounters with massive asteroid are known to be a mechanism able to change proper elements of asteroids in the orbital proximity of (1) Ceres and (4) Vesta. Changes in a, e and i caused by the long-term effect of close encounters with (4) Vesta may have contributed to the diffusion of some V- type objects outside the Vesta family, whose current orbits cannot be easily explained in terms of migration induced by other mechanisms, such as the Yarkovsky effect, interaction with mean-motion or secular, or the interplay of both. Recently, it has been shown (Carruba et al. 2012) that drift rates caused by close encounters with massive asteroids may change significantly on time-scales of ~30 Myr. In this work we focus our attention on the case of diffusion caused by the other most massive bodies in the main belt as: (2) Pallas, (10) Hygiea, and (31) Euphrosyne, the third, fourth, and one of the most massive highly inclined asteroid in the main belt, respectively. By performing simulations with symplectic integrators we studied the problem of scattering caused by close encounters with the asteroids aforementioned, when only the massive asteroids (and the eight planets) are considered, and when also other massive main belt asteroids and non-gravitational forces are accounted for. We found relatively small values of drift rates for encounters with (2) Pallas and we confirm that orbital scattering by this highly inclined object is indeed a minor effect. However, we obtained values of drift rates for changes in proper semi-major axis a caused by (10) Hygiea and (31) Euphrosyne larger than what was found for scattering by (4) Vesta in Carruba et al. (2012). These high rates may have had repercussions on the orbital evolution and age estimates of their respective families.

204.14 – Stability of Prograde and Retrograde Planets in Binary Systems

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We present a recently published article (Morais & Giuppone 2012, MNRAS 424, 52-64) where we investigate stability of coplanar prograde and retrograde planet orbits within binary systems. Although previous numerical stability studies regarding prograde planets existed, retrograde planets were never investigated before. However, retrograde planets within binary systems could form via Kozai interaction with the companion star or via capture from a passing star. We showed that retrograde planets are stable up to distances much closer to the companion star than prograde planets. We proved that instability is due to mean motion resonances (MMRs), either eccentricity forcing at individual MMRs or caused by overlap of nearby MMRs. We concluded that the observed enhanced stability of retrograde planets with respect to prograde planets is due to essential differences between the phase-space topology of retrograde versus prograde resonances (p/q prograde MMR is of order p-q while p/q retrograde MMR is of order p+q).

204.15 – Unraveling Janus and Epimetheus' Ring

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Nowadays it is very common to find ejecta from collisions between atmosphereless satellites and hypervelocity meteoroids as a replenishment for faint rings. Even though this effect is broadcast in the literature, in all these cases the source of ejecta is a single satellite. In this work it is shown an attempt to explain the existence of a ring that has a pair of coorbital satellites as sources, the Janus and Epimetheus' ring (we call J-E ring for short). Some simulations have indicated that in a few decades this ring would disappear due to collisions of particles with satellites. We consider quite improbable that images have been acquired in a peculiar time that the ring remains in the system. Therefore it is necessary to find out a mechanism that gives a good explanation for the origin of particles replenishing ring. To explain the existence of the ring using such hypothesis we consider that the most important characteristic of produced particles in this study is their lifetime and how good light scatterer they can be. According to Mie theory, a good scatterer is a particle with radius between 1 and 13 ?m . On the other hand the only sizes of particles which linger time enough to contribute indeed for observation are those between about 8 and 20 ?m. In order to confirm that this ring is explained by such process it was necessary to convert the particles distribution into detected intensity (I/F), using Chandrasekhar's transmission equation, and to compare it with the same quantity, obtained from Cassini images photometry. By using a proper set of particles (sizes between 8 and 13 ?m) we were able to obtain quite good agreement between both values (I/F ? 10^{-7}). Therefore, the contribution of ejecta from both satellites can explain the existence of the J-E ring.

204.16 – Lags of Prometheus and Pandora

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Observational data obtained during Saturn's ring plane crossing of 1995 indicated angular lags for the predicted positions of Prometheus and Pandora. Using additional observational data the lags were confirmed, with Prometheus about 19 degrees ahead and Pandora about 25 degrees behind their predicted longitudes. Chaotic motion associated to a 121:118 mean motion resonance between the two satellites is the theory currently accepted to explain these lags. In the present work we return to this problem proposing that an analysis of the temporal evolution of the semi-major axis of the satellites in order to explain the lags. Due to the secular interaction between the satellites their apsidal lines are periodically anti-aligned every 6.2 years, producing close encounters between the two bodies. During these moments there is a stronger interaction that produces variations in their semi-major axis. The main point is that the data used to propagate the orbits of the satellites was obtained near to the moment of one of these close approaches.

204.17 – Study of the Effect Of Radiation Pressure in Janus-Epimetheus' Rings

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Coorbitais systems are composed of objects that oscillates in tadpole or horseshoe orbits around the Lagrangian equilibrium points. Saturn is the only planet in the Solar System with known coorbital satellite systems. One of them is the Janus-Epimetheus system, in which the coorbitals librate in a large horseshoe and have similar masses. In this system Epimetheus oscilate over a wide horseshoe that includes the points lagrangian L4, L5, and L3, but because the satellites have comparable mass Janus also perform a smaller horseshoe. Thus, it is necessary to abandon the restricted problem, and to consider the masses of the three bodies involved. In 2005, Cassini spacecraft detected the presence of a ring embedded in the orbit of Janus and Epimetheus (Porco et al 2011). The stability of this system has been studied by Williams and Murray (2011), showing that in this system particles are removed due to collisions with the satellites. We studied the longevity of a Saturn ring-system immersed in the Janus-Epimetheus, considering the effect of radiation pressure and the oblateness of Saturn. We integrate a set of particles of sizes between 1 and 100 microns in radius, scattered around the orbit of Janus, Epimetheus, and disturbed both by the satellite and the oblateness of Saturn in terms of J2, J4 and J6. During the integration we follow the trajectory of each particle, up to the instant in which they are either ejected from the coorbital region or collide with some of the massive bodies. Without the disturbance due to radiation pressure, most of the particles collide with Epimetheus over less than 100 years, and the other part collide with Janus. With the effect of radiation pressure, the particles smaller than 7 microns are removed from the ring region before 80 days of integration, while those larger than 7 microns are not significantly affected by radiation pressure, thus colliding with the satellites.

204.18 – Analysis on the Evolution of a Pluto-like System During Close Encounters with the Giant Planets in the Framework of the Nice Model

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The planetary migration of the giant planets as suggested by the often called Nice model (Tsiganis et al. 2005) creates a dynamical mechanism to reproduce the distribution of objects currently observed in the Kuiper Belt. Through this mechanism the planetesimals within the disk interior to ~35 AU, were delivered to the belt after a temporary eccentric phase of Neptune's orbit. At this time the region interior to 1:2 mean motion resonance (MMR) with Neptune is no longer chaotic, then bodies transported from orbits closer to the Sun outward can remain trapped (Levison et al. 2008). Having in mind that there were multiple planetesimal-planet encounters in the Nice scenario, we performed N-body simulations,following close encounters histories of bodies trapped in the 2:3 MMR with Neptune after 4.5Gy in the framework of the aforementioned model, to analyze if Pluto-like systems are not destroyed (i.e. the satellites remain bound to Pluto), and if the satellites preserve their nearly-circular and nearly co-planar orbits. The results naturally put some constraints in the formation of Pluto-Charon binary and Pluto's small satellites, with the latter ones having their origin still unclear. The first author is financially supported by Fapesp/2009/18262-6.

204.19 – Habitability of Earth-like Planet Disturbed by a Third Body

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In this work, we investigate the habitability of “Earth-like” exoplanets disturbed by a giant planet. The assumptions used here are the same ones of the restricted elliptic three-body problem, which means that there is a central main body, a disturbing body in an elliptical orbit and a third body with a negligible mass both around this main body. First, we consider a habitable zone of 0.9 to 1.37 AU. Then, we numerically simulate the whole system taking into account a distribution of massless particles. This study is made considering a range of different values for semi-major axis, eccentricity and inclination of the disturbing body. In particular, the so-called critical angle of the third-body disturbing, which is a value for the inclination such that any near-circular orbit with inclination below this remains near circular, is discussed for Earth-like planets into habitable zone. The results obtained show that orbits of a habitable Earth-like planet is still possible if the disturbing body has low inclination and/or eccentricity. This means that the planet would be located within the habitable zone. However, high eccentricity and/or inclination for disturbing body imply that Earth-like planet orbit changes to a highly eccentric orbit with pericenter and/or apocenter distances outside the habitable zone on short time-scales.

204.20 – Stability Orbits Close to 433 Eros Using a Shaped Polyhedral Source

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A general characteristic of celestial minor planets as asteroids, objects of several recent studies, is the fact of having highly irregular shape. The recent observations and space probes that pass close to the asteroids with orbits near the Earth (NEOs) have shown the existence of binary and triple asteroid systems. The existence of these moons can be explained due to their irregular shape. One of the techniques used in the past decade to determine the shape with a good accuracy and estimate certain physical features (volume, mass, moments of inertia) of asteroids is the polyhedral model method. The aim of this study is to rebuild the shape and determine the physical characteristics of the asteroid 433 Eros using data from December 1998 observations of the probe NEAR-Shoemaker (Near Earth Asteroid Rendezvous). In our computations we use a code that avoids singularities from the line integrals of a homogeneous arbitrary shaped polyhedral source and is accurate. This code evaluates the gravitational potential function and its first and second order derivatives. Then, we find the location of the equilibrium points through the pseudo-potential energy and zero velocity curves. We also show the differences in the potential between our model and a point mass. Finally, taking the rotation of asteroid 433 Eros into consideration, we analyze the environment orbit dynamics compared with the analytical model.

204.21 – The Behavior of Regular Satellites During the Planetary Migration

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The behavior of the regular satellites of the giant planets during the instability phase of the Nice model needs to be better understood. In order to explain this behavior, we used numerical simulations to investigate the evolution of the regular satellite systems of the ice giants when these two planets experienced encounters with the gas giants. For the initial conditions we placed an ice planet in between Jupiter and Saturn, according to the evolution of Nice model simulations in a ‘jumping Jupiter’ scenario (Brasser et al. 2009). We used the MERCURY integrator (Chambers 1999) and cloned simulations by slightly modifying the Hybrid integrator changeover parameter. We obtained 101 successful runs which kept all planets, of which 24 were jumping Jupiter cases. Subsequently we performed additional numerical integrations in which the ice giant that encountered a gas giant was started on the same orbit but with its regular satellites included. This is done as follows: For each of the 101 basic runs, we save the orbital elements of all objects in the integration at all close encounter events. Then we performed a backward integration to start the system 100 years before the encounter and re-enacted the forward integration with the regular satellites around the ice giant. These integrations ran for 1000 years. The final orbital elements of the satellites with respect to the ice planet were used to restart the integration for the next planetary encounter (if any). If we assume that Uranus is the ice planet that had encounters with a gas giant, we considered the satellites Miranda, Ariel, Umbriel, Titania and Oberon with their present orbits around the planet. For Neptune we introduced Triton with an orbit with a 15% larger than the actual semi-major axis to account for the tidal decay from the LHB to present time. We also assume that Triton was captured through binary disruption (Agnor and Hamilton 2006, Nogueira et al. 2011) and its orbit was circularized by tides during the ~500 million years before the LHB. References: Agnor & Hamilton 2006, Nature 441, 192 Brasser et al. 2009, A&A 507, 1053 Chambers 1999, Mon. Not. R. Astron. Soc. 304, 793 Nogueira et al. 2011, Icarus 214, 113

204.22 – A Study of Small Satellites Captured in Corotation Resonance

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Currently we find in the solar system several types of celestial objects such as planets, satellites, rings, etc.. The dynamics of these objects have always been interesting for studies, mainly the satellites and rings of Saturn. We have the knowledge that these satellites and rings undergo various types of orbital resonances. These resonances are responsible for the formation of numerous structures in the rings such as, for example, almost the entire structure of A ring. Thus we see how important it is to examine the nature of these resonant interactions in order to understand the characteristics observed in the satellites and rings of Saturn. In this work we highlight the corotation resonance, which occurs when the velocity pattern of the potential disturbing frequency is equal to the orbital frequency of a satellite. In the Saturnian system there are three satellites, Aegaeon, Anthe and Methone that are in corotation resonance with Mimas. In this paper we study, through numerical simulations, corotation resonance of the G ring arc of Saturn with Tethys and Mimas, while Mimas is migrating. Ours initial results show that no particles escape from the corotational resonance while Mimas migrate, that is, it is very robust. We also show the effects and consequences of Tethys migration on Mimas and de G arc.

204.23 – Figures of Equilibrium for Tidally Deformed Non-homogeneous Celestial Bodies

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Several theories of tidal evolution, since the theory developed by Darwin in the XIX century, are based on the figure of equilibrium of the tidally deformed body. Frequently the adopted figure is a Jeans prolate spheroid. In some case, however, the rotation is important and Roche ellipsoids are used. The main limitations of these models are (a) they refer to homogeneous bodies; (b) the rotation axis is perpendicular to the plane of the orbit. This communication aims at presenting several results in which these hypotheses are not done. In what concerns the non-homogeneity, the presented results concerns initially bodies formed by N homogeneous layers and we study the non sphericity of each layer and relate them to the density distribution. The result is similar to the Clairaut figure of equilibrium, often used in planetary sciences, but taking into full account the tidal deformation. The case of the rotation axis non perpendicular to the orbital plane is much more complex and the study has been restricted for the moment to the case of homogeneous bodies.

204.24 – Determination of Dynamical and Physical Parameters of the System CoRoT 3

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The two main tools to determine the dynamical and physical parameters of exoplanet systems are the radial velocity (RV) measurements and, when available, transit timings. The two techniques are complementary: The RV's allow us to know some of the orbital elements while the transit timings allow us to obtain the orbital inclination and planetary radius, impossible of obtain from the RV, and to resolve the indetermination in the determination of the planet mass from the RV's. The space observation of transiting planets is however not limited to transit times. They extend to long periods of time and are precise enough to provide information on variations along the orbit. Besides the effects of stellar rotation, deserve mention the Doppler shift in the radiation flux, as consequence of stellar movement around the center of mass, or Beaming Effect (BE); the Ellipsoidal Variability (EV) due to the tidal deformation of the star due to the gravitation of its close companion; and the Reflection (ER) of the stellar radiation incident on the planet and re-emitted to the observer. In the case of large hot Jupiters, these effects are enhanced by the strong gravitational interaction and the analysis of the light variation allows us independent estimates of the mass and radius of planet. The planetary system CoRoT 3 is favorable for such analysis. In this case, the secondary is a brown dwarf whose mass is of the order of 22Mj. We show results obtained from the analysis of 35 RV measurements, 236999 photometric observations and 11 additional RV observations made during a transit to determine the star rotation via the Rossiter-McLaughlin effect. The results obtained from this determination are presented in this communication. The results are compared to those resulting from other determinations.

204.25 – A Study of the Inclination of Satellites of a Planet After Spin Axis Forced Tumbling

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In order to analyze the theory of satellite loss resulting from a giant impact on Uranus, we decided to do few a study about this problem using forced tumbling of the spin axis of planet. We used two different kinds of forced tumbling to simulate the obliquity variation: linear variation and damped variation. To do this, we made numerical simulations of N-body problem with J2 oblateness coefficient of the central body. First, we studied the relation of the time tumbling of Uranus' spin axis and the semi-major axis of the hypothetical satellite with a specific final inclination. In both cases the results are a power law. Later we study the final inclination of the satellite in relation to the number of collisions (pseudo collision). And finally we studied the final inclination of several different initial conditions (orbital elements) of the satellites. We concluded that the initial inclination and initial longitude of ascending node are important to the final satellite inclination. For future studies we want implement a more realistic model using the attitude equations of the central body and study the origin of the obliquity of the others planets of the solar system.
Aknowledments: FAPESP, CAPES and CNPq.

204.26 – Coorbital Formation with Earth and Theia's Origin

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The most accepted hypothesis of the origin of the Moon, it could have been born from debris generated by a big collision between the proto-Earth and a proto-planet of similar size to Mars, known as Theia. Simulations showed that if this impact happened in the last stages of Earth's formation, one can reproduce the lack of iron in the Moon, the masses of the Earth and Moon and the angular momentum of the current Earth-Moon system (Canup and Asphaug, 2001). To this end, the collision must have occurred in a particular way. The angle between the vectors speeds of Earth and Theia should be small, and the magnitudes of these vectors should be similar. Therefore, it was proposed that the bodies would be sharing the same orbit, in others words, Earth and Theia should be coorbitals, so that the impact velocity and impact would be low subtle (Belbruno and Gott, 2005). In this work we study the possibility of forming a body with mass similar to Mars and coorbital of the Earth. The dynamic system considered is formed by the Sun, the Earth and a cloud of planetesimals in the region coorbital to Earth. The cloud of planetesimals always was initially distributed randomly in a sector around L4 or L5. The sector is delimited by an arc of 80°, centered on the lagrangian point with orbital radius within the limits of larger orbit horseshoe predicted by the theory (Dermott and Murray, 1981a). In the simulations we consider that all planetesimals have the same initial mass and adopt different clouds of planetesimals, with 1000 planetesimals, each one with initial mass of 10^(-12) to 10^(-8) solar masses, with 5000 planetesimals, each one with initial mass from 10^(-12) to 10^(-9) solar masses. We did three independent simulations for each case. The results of numerical simulations of this work showed that it is unlikely the coorbital formation of a body with the mass of Mars. We are still doing tests to identify other parameters to form Theia. All these results will be presented in this work.

204.27 – Near-Earth Object Survey Orbit Quality Analysis

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The Sentinel Mission is currently under development by the B612 Foundation and Ball Aerospace. The mission concept is based on a space-based infrared telescope in an independent orbit similar to that of Venus. Being in an orbit interior to the Earth greatly reduces the time to complete the survey of the near-Earth region compared to a similar survey that could be accomplished from ground-based or orbiting observatory near the Earth. One of the key mission design elements is the cadence of observation. This involves the tiling pattern for how the instrument field-of-view maps out the sky and the repeat interval between successive observations. This presentation will show a quantitative analysis of orbit determination from this type of platform and show how the expected distribution of NEOs will be observed and the orbit qualities that will result. From this analysis, limits can then be placed on the degree of confusion that the cadence can tolerate before linking different epochs becomes problematic.

204.28 – What can Numerical Computation do for the History of Science? (Study of an Orbit Drawn by Newton on a Letter to Hooke)

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On a letter to Robert Hooke, Isaac Newton drew the orbit of a mass moving under a constant attracting central force. How he drew the orbit may indicate how and when he developed dynamic categories. Some historians claim that Newton used a method contrived by Hooke; others that he used some method of curvature. We prove geometrically: Hooke's method is a second order symplectic area preserving algorithm, and the method of curvature is a first order algorithm without special features; then we integrate the hamiltonian equations. Integration by the method of curvature can also be done exploring geometric properties of curves. We compare three methods: Hooke's method, the method of curvature and a first order method. A fourth order algorithm sets a standard of comparison. We analyze which of these methods best explains Newton's drawing.

204.29 – An Absolute Radius Scale for Saturn's Rings from Cassini Occultations

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The Cassini mission has provided a remarkable opportunity to investigate the structure and dynamics of the Saturn ring system at the sub-km radial scale, using hundreds of individual stellar and radio occultations from the UVIS, VIMS, and RSS instruments. From precise measurements of ring and gap edges, we have been able to determine the orbital characteristics of over one hundred features in the rings. A crucial step in the orbital

determination is the establishment of a highly accurate radius scale for the rings. This is compounded by uncertainties in the positions of the occulted stars, km-scale trajectory errors in the spacecraft location, and inexact knowledge of the direction and precession rate of Saturn's pole. We have taken an iterative approach in which we identify a set of 30 or so putative circular, equatorial features, solve for along-track trajectory errors for each occultation, and use this best-fitting orbital solution to establish the reference system for determination of the orbits of non-circular ring features. Using thousands of individual measurements of rings in the Cassini data, we have determined an absolute radius scale for each contributing occultation with an accuracy of about 200 m for the C and B rings and the Cassini Division. This enables us to detect and measure very small dynamical effects such as weak normal modes in ring edges, and to determine the phases of density waves, including very short wavelength outer Lindblad resonances in the C ring, as reported at this meeting. We calculate the sensitivity of the radius scale to the assumed pole direction and precession rate. Ultimately, we will combine these results with Voyager, HST, and pre-Cassini Earth-based occultation measurements to refine our knowledge of Saturn's pole direction and precession.

204.30 – Further explorations on binary-asteroid capture study

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We have invested efforts on the study of the binary-asteroids capture mechanism by Jupiter in order to assess its plausibility as a source phenomenon for the irregular Jovian moons. This mechanism consist in the energy exchanges during the rupture process of the binary. We began studying the coplanar case and we showed the prograde irregular Jovian moos' orbital shape was reproduced without the need of any other artifact, as gas dissipation for instance. Then, we extended such study to the 3D case. Most of the captured objects presented incompatible inclinations distribution to that observed for the known irregular Jovian moons, but there was some simulated satellites which have orbital elements similar to the actual satellites. We concluded that such result was a consequence of the adopted method to obtain the initial conditions. In the present work, we explored further initial conditions parameters by using a different approach. In special, we test the hypothesis of the Jovian irregular moons have their origins from the same region as the Hilda's family. The captured objects features are discussed in terms of the adopted parameters for the initial conditions.

204.32 – Planetesimals Grow or Disrupt? The Roll of the Uncertain Amount of Collisional Energy that Goes Into Heat

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It is usually accepted that terrestrial planets and cores of giant planets are formed through accretion of planetesimals. It is generally assumed that primordial 1-10 km-sized planetesimals are formed through coagulation processes and continue to agglomerate via pairwise mergers before being incorporated into the protoplanets. It was shown that planetesimals growth requires a very cold disk during all the accretionary epoch at all locations (Parisi 2013, Planet. Space Sci. 75, 96; and references therein). However, simulations of accretion in the terrestrial and giant planets region show that planetesimals of 10-100 km reach values of the eccentricity which lie at the planetesimals disruption eccentricity limit obtained by Parisi (2013). A key factor in all fragmentation models is the fraction of impact kinetic energy partitioned into kinetic energy of the fragments (the so called ? factor). The main problem in fragmentation models is that the amount of energy that is dissipated into heat at any collision is unknown. Experimental results suggest that ?? 0.1 is an appropriate choice which has been used in many papers concerning planetary accretion, planetesimal fragmentation, Kuiper Belt objects and asteroids collisional evolution, and satellite disruption (e.g. Parisi 2013 and references therein). In this work, we explore if planetesimals suffer growth or disruption as they collide for a wide range of the unknown parameter ? and discuss the relevance of this ad hoc parameter to discriminate between growth and disruption.

204.33 – Orbital maneuvers around irregular shaped bodies

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In the solar system there are many small bodies called asteroids. The large majority of these bodies are located in the asteroid belt, between the orbits of the planets Mars and Jupiter. The Near- Earth Objects, or NEOs, are objects with perihelion below 1.3AU, which include comets and asteroids. The NEOs are considered to have orbits passing close to the Earth's orbit and, in the case of asteroids, are called Near-Earth Asteroids (NEAs). Among the NEAs there are bodies considered potentially hazardous asteroids (PHAs), whose minimum orbit intersection distance with Earth is 0.05AU and that have absolute magnitude (H) of 22, which would mean an asteroid of at least 110-240 meters, depending on its albedo. One of the major characteristic of the asteroids is the irregular shape, causing the dynamics of orbits around these bodies to be different from a spherical shaped one. The fact that an object is not spherical generates a perturbation on the gravitational field. The disturbing force can be determined considering the shape of the specific body. A satellite orbiting this body would suffer the effects of this perturbation, but knowing the disturbing force, it's possible to correct and control the orbit according to the desired mission. The polyhedron method is a traditional way to model an asteroid by dividing the object into smaller parts. The data used on this work are composed by a combination of triangular faces. The total disturbing force is a sum of the force on each piece of the model. Therefore, after the simulations are obtained, it's possible to apply the desired corrections of the perturbation using continuous low thrust in closed loop, making it possible to perform maneuvers near these bodies. One of the important applications of the study shown above is in the ASTER mission, that is under study by INPE and several other Brazilian academic institutions, which goal is to send a spacecraft to an asteroid and then to remain in orbit around it.

204.34 – Finding Minor Bodies with the J-PAS/J-PLUS surveys

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The JPAS/J-PLUS is a joint Spanish-Brazilian project that aims to map an area of the sky of 8000 square degrees, in order to measure, with unprecedented accuracy, the redshifts of a large sample of extragalactic objects up magnitude 23. It involves the installation of two telescopes on the Javalambre Mountains, in Spain. The T250 telescope will have an aperture of 250cm and will be equipped with a camera with a 3 square degree field of view and will use a set of 56 filters (54 narrow band + 2 wide band) covering the 0.3-1.0 micron range, while the T80 telescope (presently on commissioning phase) will have a camera with 2 square degree field of view and will use a set of 12 narrow and intermediate band filters covering the same wavelength range. During its execution, the surveys will also observe a large number of minor Solar System bodies. Here we will discuss the expected efficiency of the J-PLUS survey in finding minor bodies.

204.35 – Searching for Trajectories with Minimum Perturbations Around the Asteroid 2001SN263

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The present paper has the goal of mapping trajectories that presents low fuel consumption for station-keeping maneuvers around the asteroid 2001SN263. This asteroid is a system composed by three bodies that are in an elliptic orbit around the Sun. The main reason to study those trajectories is that, currently, there are several institutions in Brazil studying the possibility of a mission to send a spacecraft to this asteroid. There are many important scientific studies that can be made around those bodies. The approach used in the present paper is based in the integral over the time of the perturbing forces acting in the spacecraft. This integral measures the total effect of the perturbations in the spacecraft. It is assumed that orbits with lower values for this quantity will take longer to have the orbit changed significantly and so it will demand less fuel consumption for station-keeping. This integral is a characteristic of the set of perturbations considered and the particular orbit of the spacecraft, so it does not depend on the technique or type of engine used for the orbital maneuvers. So, this quantity can be seen as one criterion to select possible orbits for the spacecraft. The results will show the dependence of this index with the initial relative geometry of the bodies, so a study was made considering an average over the initial positions of the perturbing bodies, which are specified by the true anomalies of the Sun and the main body of the asteroid system at the initial time. So, orbits that are more suitable regarding the perturbations suffered by the spacecraft are shown.

204.36 – Dynamic Rotation of Kepler-11b and 55Cnc-e with Third Body Perturbation

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In this work was studied the problem of rigid body rotation and "spin-orbit" resonances. Emphasis was placed in the applications to the exoplanets Kepler-11b and 55Cnc-e both belonging to multiple planetary systems. Initially it was considered the orbit of the planet not perturbed by a third-body in the star-planet system. In this case the eccentricity and semi-major axis of the planet are constants. To analyze the dynamics of rotation was used the technique of surface section. Next, was considered the action of a third body, a more realistic model for planetary rotation. To analyze the dynamics in the disturbed case was used the technique of FFT, since the technique of surface sections is no longer applicable. The results of unperturbed and perturbed cases were compared.

204.38 – Stability and Dynamics of Terrestrial Planets in Binary Star Systems - Application on Alpha Centauri

Eduardo Andrade-Ines[1], Tatiana A. Michtchenko[1]
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Binary stars are frequent in the universe, with about 50% of the known main sequence stars being located at a multiple star system (Abt, 1979). Even though, they are universally thought as second rate sites for the location of exo-planets and the habitable zone, due to the difficulties of detection and high perturbation that could prevent planet formation and long term stability. In this work we show that planets in binary star systems can have regular orbits and remain on the habitable zone. We introduce a stability criterium based on the solution of the restricted three body problem and apply it to describe the short period planar and three-dimentional stability zones of S-type orbits around each star of the Alpha Centauri system. We develop as well a semi-analytical secular model to study the long term dynamics of fictional planets in the habitable zone of those stars and we verify that planets on the habitable zone would be in regular orbits with any eccentricity and with inclination to the binary orbital plane up until 35 degrees. We show as well that the short period oscillations on the semi-major axis is 100 times greater than the Earth's, but at all the time the planet would still be found inside the Habitable zone.

204.39 – Rotation rate evolution in habitable super-Earths

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The search for habitable planets in our neighborwood is one of the most exiting challenges for planetary sciences at present. The recent discovery of Earth-like planets inside the habitable zone of their host stars is an incentive to try to understand how the physical conditions for habitability evolve in these kind of objects. Super Earths, already discovered, GJ581d and GJ667Cc, are possibly habitable because they are located in a close-in orbit (0.22 AU and 0.125 AU respectively), arround low mass stars. The gravitational interaction between the planets and its host stars produce tides that modify their orbits and their rotation periods. We consider the evolution of the tidal torque and the rotation rate as dependent of the rheological properties of the planet's mantle. Several experiments are performed to study the rotation evolution, depending on the the parameters of the rheological model as well as initial conditions. The main interest goal of our investigation is to understand the spin-orbit evolution produced by the gravitational tides between the host star and a close planet and the impact of the rotation rate variation in the thermal and magnetic evolution of the planet.

204.40 – Orbital characteristics of exoplanets in triple systems

Jean Paulo Carvalho[1], Rodolpho Vilhena de Moraes[1], Antonio Fernando B. Almeida Prado[2], Othon Winter[3]
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More than 20% of the 'Hot-Jupiters' (extrasolar planets with Jovian mass and orbits very close to the central star) are in retrograde orbit with respect to the total angular momentum of the system. The Kozai-Lidov Mechanism, based on secular theory, has been proposed as a mechanism that plays an important role in producing such orbits by several authors. In the present work we study the secular dynamics of a triple system composed by a Sun-like central star and a Jupiter-like planet, which are under the gravitational influence of a further perturbing star (brown dwarf), using the Eccentric Kozai-Lidov Mechanism. The main goal is to study the orbital evolution of the planet. In special, we investigate the orientation (inclination) and the shape (eccentricity) of its orbit. One key feature explored is the time needed for the first flip in its orientation (prograde to retrograde). The gravitational potential is developed in closed form up to the fourth order. In order to develop the long-period disturbing potential the double-averaged method is applied. We have compared the secular evolution of systems with and without the fourth order part of the disturbing potential.

204.41 – Simulation of optimal impulsive maneuvers of a spacecraft in orbit of Mars considering constructive aspects of the propulsion system.

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The goal of this work is calculate and simulate orbital maneuvers of a spacecraft in orbit of Mars considering constructive aspects of the propulsion system and trajectory control in closed loop. Initially, ideal thrusters capable of applying forces of infinite magnitude are considered. The ideal thruster allows instantaneous variation of velocity. Thus the optimum impulsive maneuvers are obtained, from the point of view of fuel consumption, by the solution of Lambert Problem (Two Point Boundary Value Problem). Then these maneuvers are simulated, but now considering a more realistic model of the propulsion system. Due to the impossibility of application of an infinite thrust the orbital maneuver must be distributed in a propulsive arc around the position of the impulse determined by solution of the Lambert Problem. In this propulsive arc continuous thrust is applied, limited to the maximum capacity of the thrusters. However, the effect of the propulsive arc is not exactly equivalent to the application of an impulsive thrust, the difference produces a deviation in the final orbit with respect to the reference orbit. This deviation depends on the magnitude of the impulse required, the capacity of the propulsion system and the characteristics of the trajectory control system. The evaluation of this deviation is extremely relevant in the analysis of a spacecraft mission and in the dimensioning of the trajectory control system. Therefore in this study the influence of the thrusters capacity in the trajectory error was evaluated, when considered a more realistic model instead of ideal case represented by the impulsive approach.

204.42 – Dynamics of the 3:1 Resonant Planetary Systems

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Many of the discovered exoplanetary systems are involved inside mean-motion resonances. In this work we focus on the dynamics of the 3:1 mean-motion resonant planetary systems. Our main purpose is to understand the dynamics in the vicinity of the apsidal corotation resonance (ACR) which are stationary solutions of the resonant problem. We apply the semi-analytical method (Michtchenko et al., 2006) to construct the averaged three-body Hamiltonian of a planetary system near a 3:1 resonance. Then we obtain the families of ACR, composed of symmetric and asymmetric solutions. Using the symmetric stable solutions we observe the law of structures (Ferraz-Mello,1988), for different mass ratio of the planets. We also study the evolution of the frequencies of $?_1$, resonant angle, and ??, the secular angle. The resonant domains outside the immediate vicinity of ACR are studied using dynamical maps techniques. We compared the results obtained to planetary systems near a 3:1 MMR, namely 55 Cnc b-c, HD 60532 b-c and Kepler 20 b-c.

204.43 – Detailed Astrometric Analysis of Pluto

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Pluto is the main representant of the transneptunian objects (TNO's), presenting some peculiarities such as an atmosphere and a satellite system with 5 known moons: Charon, discovered in 1978, Nix and Hydra, in 2006, P4 in 2011 and P5 in 2012. Until the arrival of the New Horizons spacecraft to this system (july 2015), stellar occultations are the most efficient method, from the ground, to know physical and dinamical properties of this system. In 2010, it was evident a drift in declinations (about 20 mas/year) comparing to the ephemerides. This fact motivated us to remake the reductions and analysis of a great set of our observations at OPD/LNA, in a total of 15 years. The ephemerides and occultations results was then compared with the astrometric and photometric reductions of CCD images of Pluto (around 6500 images). Two corrections were used for a refinement of the data set: diferential chromatic refraction and photocenter. The first is due to the mean color of background stars beeing redder than the color of Pluto, resulting in a slightly different path of light through the atmosphere (that may cause a difference in position of 0.1”). It became more evident because Pluto is crossing the region of the galactic plane. The photocenter correction is based on two gaussians curves overlapped, with different hights and non-coincident centers, corresponding to Pluto and Charon (since they have less than 1” of angular separation). The objective is to separate these two gaussian curves from the observed one and find the right position of Pluto. The method is strongly dependent of the hight of each of the gaussian curves, related to the respective albedos of charon and Pluto. A detailed analysis of the astrometric results, as well a comparison with occultation results was made. Since Pluto has an orbital period of 248,9 years and our interval of observation is about 15 years, we have around 12% of its observed orbit and also, our observations were made when Pluto was near its periapsis. With the corrections made, the ephemeris, when recalculated, shall not present sistematic drifts near the temporal interval in wich contains our observational data, allowing the determination of local adjustments at the Pluto orbit.

204.44 – Evaluation of the Influence of zonal and sectorial harmonics in the orbit of an lunar satellite

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A study evaluating the influence of the lunar gravity potential on the orbit of an artificial satellite is performed varying the values for degree and order from 1 to 100. The gravitational potential is modeled using spherical harmonics according to the model presented in Konopliv (2001). This model provides the components x, y and z for the gravity acceleration at each position of the satellite along the orbit. Comparing the gravity acceleration from a central field and the gravitational acceleration provided by Konopliv the disturbing velocity increment applied to the vehicle is obtained, and hence the Keplerian elements of perturbed orbit of the satellite are calculated allowing the analysis of the orbital motion. Maneuvers of correction and maneuvers of transfer for lunar satellites are simulated considering disturbances due to non-uniformity of the Moon gravitational potential in order to control the trajectory using a continuous propulsion system controlled in close loop. The behavior along the time of the orbital elements, fuel consumption and thrust applied to the satellite are analyzed.

204.45 – CBERS Satellites: Resonant Orbital Motions in LEO Region

Rodolpho Vilhena de Moraes[1], Jarbas C. Sampaio[2], Sandro da Silva Fernandes[3], Edwin Wnuk[4]

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The space between the Earth and the Moon has several artificial satellites and space debris in some resonance. Synchronous satellites in circular or elliptical orbits have been studied in literature, including the analysis of resonant orbits characterizing the dynamics of these satellites. In general, some resonant angles associated to the exact resonance are considered in the numerical integration, with the purpose to describe the resonance defined by the commensurability between the mean motion of the object and the Earth’s rotation angular velocity. However, the tesseral harmonics Jlm produce multiple resonances in the exact resonance and in the neighborhood of the exact resonance, and, some disturbances in the orbital motions of objects are not described. In this work, the TLE (Two-Line Elements) of the NORAD (North American Defense) are studied observing the resonant objects orbiting the Earth in LEO (Low Earth Orbit) region. Analyzing the cataloged objects, the CBERS satellites are studied observing resonance effects which compose your orbits. The time behavior of the orbital elements, resonant period and resonant angles are considered and possible regular and irregular motions are analyzed. About 60 space debris produced by the CBERS-1 satellite mission are studied analyzing the reentry of these objects in the Planet.

204.46 – The Astronomy Workshop

Douglas P. Hamilton[1]

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The Astronomy Workshop (http://janus.astro.umd.edu) is a collection of interactive online educational tools developed for use by students, educators, professional astronomers, and the general public. The more than 20 tools in the Astronomy Workshop are rated for ease-of-use, and have been extensively tested in large university survey courses as well as more specialized classes for undergraduate majors and graduate students. Here we briefly describe the tools most relevant for the Professional Dynamical Astronomer. Solar Systems Visualizer: The orbital motions of planets, moons, and asteroids in the Solar System as well as many of the planets in exoplanetary systems are animated at their correct relative speeds in accurate to-scale drawings. Zoom in from the chaotic outer satellite systems of the giant planets all the way to their innermost ring systems. Orbital Integrators: Determine the orbital evolution of your initial conditions for a number of different scenarios including motions subject to general central forces, the classic three-body problem, and satellites of planets and exoplanets. Zero velocity curves are calculated and automatically included on relevant plots. Orbital Elements: Convert quickly and easily between state vectors and orbital elements with Changing the Elements. Use other routines to visualize your three-dimensional orbit and to convert between the different commonly used sets of orbital elements including the true, mean, and eccentric anomalies. Solar System Calculators: These tools calculate a user-defined mathematical expression simultaneously for all of the Solar System's planets (Planetary Calculator) or moons (Satellite Calculator). Key physical and orbital data are automatically accessed as needed.

300 – Planet and Satellite Formation I

300.01 – Distribution and Origin of Hot Planets

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Close-in (or Hot) planets, usually defined as those having semimajor axes a < 0.1 AU (or orbital periods P < 10 days), are the easiest to detect, both with radial velocity (RV) surveys and transits. More than 300 members are currently known, and a much larger number of candidates has been proposed from transits. Since it is believed that these bodies cannot have been formed in-situ, they constitute an interesting population from which to derive information about orbital migration and dynamical evolution of planetary systems in general. In this talk we review some recent results on the dynamical characteristics of close-in planets, including the existence of both resonant and near-resonant configurations, planet multiplicity, eccentricity distribution and inclinations with respect to the stellar equator. We discuss how disk-induced migration, planet-planet scattering and tidal effects may help us explain several of these dynamical traits, although others are still poorly understood. Finally, we analyze the similarities and differences found in small (Earth to Neptune) and large (Jovian) size planets, and how these may reflect different evolutionary histories.

300.02 – Dynamical Structures from Planet Formation in the Beta Pictoris Debris Disk

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The star beta Pictoris hosts one of the brightest debris disks. Images of this disk showed a warp and brightness asymmetries that have been interpreted as evidence for perturbations from a recently formed planet on an inclined orbit (Augereau et al. 2001), and from collisions of a growing planetary embryo (Telesco et al. 2005). Since that time a planet has been imaged in the disk (Lagrange et al. 2010), and new high resolution imaging of the disk structure has been obtained at multiple wavelengths. This talk will describe a new model for the dynamical interaction of planets with the disk to determine if the multiple and diverse structures seen in the images can be explained in a single model that clarifies the status of planet formation throughout the disk.

300.03 – Consequences of an Eccentric Fomalhaut b

Daniel Tamayo[1]*, Joseph A. Burns*[1]
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Kalas et al. (2008) detected an exoplanet candidate Fomalhaut b in scattered optical light using HST. Based on the object's large flux, Kalas et al. interpret the measurements as due to a vast circumplanetary disk of dust that greatly enhances Fomalhaut b's scattering cross-section, though other investigators have proposed alternate models. In projection, Fomalhaut b coincides with a belt of debris. ALMA observations (Boley et al. 2012) that are sensitive to mm-size grains show that this belt is both narrow in radial extent and vertically thin. Furthermore, new HST astrometry incorporating two additional epochs (Kalas et al. 2013, AAS) suggest Fomalhaut b is in an extremely eccentric orbit (e ~ 0.8). One would expect strong dynamical coupling between such an eccentric Fomalhaut b and the associated debris belt, yet the belt seems to be relatively dynamically cold. We are performing calculations and simulations that show the consequences of different mass planets on Fomalhaut's dust ring in order to constrain the planetary mass. We will present the results of our ongoing numerical integrations.

300.04 – Problems and Promises of Pebble Accretion

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Despite the large number of exoplanets indicating that planets are a common outcome of the star formation process, theoretical models still struggle to explain how ~10 Earth mass rocky/icy embryos can form within the lifetimes of gaseous circumstellar disks. Recently, aerodynamic-aided accretion of ``pebbles," particles ranging from millimeters to decimeters in size, has been suggested as a potential solution to this long-standing problem. Local simulations, simulations which look at the detailed behavior of these pebbles in the vicinity of a planetary embryo, have shown that the potential planetary growth rates can be surprisingly fast. If one assumes that most of the mass in a protoplanetary disk resides in these pebble-sized particles, a Mars mass core could grow to 10 Earth masses in only a few thousand years. However, these local studies cannot investigate how this accretion process behaves in the more complicated, multi-planet environment. We have incorporated a prescription of this pebble accretion into LIPAD, a Lagrangian code which can follow the collisional/accretional/dynamical evolution of a planetary system, to investigate the how this pebble accretion will manifest itself in the larger planet formation picture. We discuss how these more comprehensive models present challenges for using pebble accretion to form observed planetary systems.

301 – Planet and Satellite Formation II

301.01 – Non-uniform Distribution of Protoplanetary Bodies as a Pre-requisit for the Formation of a Low-mass Mars

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Models of terrestrial planet formation have been successful in producing terrestrial-class planets with sizes in the range of Venus and Earth. However, these models have generally failed to produce Mars-sized objects. The body that is usually formed around Mars' semimajor axis is, in general, much more massive than Mars. Only when Jupiter and Saturn are assumed to have very eccentric orbits, or alternately, if they have experienced a wide inward-then-outward migration in a gas-rich phase, simulations have been able to produce Mars-like bodies. In this work, we have examined a different scenario for the formation of Mars in which a local depletion in the density of the protosolar nebula results in a non-uniform formation of embryos and ultimately the formation of Mars-sized planets around 1.5 UA. We have carried out extensive numerical simulations of the formation of terrestrial planets in such a disk for different scales of the local density depletion, and for different orbital configurations of giant planets. Our simulations point to the possibility of the formation of Mars-sized bodies around 1.5 AU, specifically when the scale of the disk local mass-depletion is moderately high (50-75%). In these systems, Mars analogs are formed from the protoplanetary materials that originate in the region of disk where there is no local mass-depletion. Results also indicate that Earth-sized planets can form around 1 AU with a substantial amount of water due to accretion of water-rich material originated from past 2 AU. We present the results of our study and discuss their implications for the formation of terrestrial planets in our solar system.

301.02 – Constraining the Primordial Orbits of the Terrestrial Planets

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Many observations suggest that there was an epoch of orbital instability among the Giant Planets in the Solar System, leading to a rapid change of their orbital architecture. This instability is thought to have occurred after the Terrestial Planets had formed ('late'), and therefore their orbits were subject to perturbations owing to the changing secular structure of Solar System. We aim to quantify the changes suffered by the Terrestrial Planet's orbits during a number of different Giant Planet migration scenarios. It has been previously shown that the changing proper precession frequency of Jupiter (g5) during its migration may, at times, have been equal to that of some of the Terrestrial Planets (where their proper eccentricity eigenfrequencies are denoted by g1..g4). This typically results in rapid excitation of the smaller bodies orbits' to levels well above today's values, sometimes destabilizing the entire Terrestrial Planet system. This led to a proposed scenario whereby Jupiter rapidly migrated due to close scattering encounters with an Ice Giant planet (dubbed 'jumping Jupiter'; some models even include the ejection of an Ice Giant from the Solar System). This migration is expected to be so rapid, or the jump so extreme, that the important resonance crossings (where g5 = g1..g4) are minimized or skipped over entirely. However, even in the most rapid migration scenarios, or those that include a jump over all resonance crossings, there is still some excitation of the terrestrial planets. We therefore quantify the total dynamical excitement gained by the system of Terrestrial Planets under the ideal case in which all resonance crossings are skipped, as well as many cases where one or two resonances are crossed. We also test specific simulations from the literature of jumping-Jupiter Giant Planet evolutions. The conclusion of this work is that the Terrestrial Planets very likely experienced dynamical excitement of their orbits during the migration of the Giant Planets. Thus, immediately prior to this evolution, their orbits were necessarily more dynamically cold, which has implications for models of planet formation.

301.03 – A 3D Study for Binary-asteroid Captures in Jupiter System

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Most of the satellites of the Solar system are the so called irregular satellites. These satellites are described by their large orbits, high eccentricities and high inclinations, most are retrograde. Due to their irregular orbits, it is believed that they not have formed in situ, but captured. With the three body model we know that gravitational capture is a temporary event. Thus an auxiliary mechanism is necessary to aid the capture to become permanent. Here we study the rupture of binaries asteroids as a mechanism to aid the gravitational capture. Due to energy exchanges, a captured binary-asteroid could disrupt when inside the gravitational sphere of influence of the planet and one of the binaries could be trapped as a irregular satellite. We will show in this work that some of the final orbits of the captured partner are close to some actual irregular satellites of Jupiter. Acknowledgements: we wish to thanks CNPq and FAPESP for the grants.

301.04 – On the Long-term Dynamical Evolution of the Main Satellites of Uranus

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Voyager II mission that explored the Uranian system and its main satellites in 1986, revealed a combination of geophysical and dynamical abnormalities. These abnormalities can be explained as a set by a complete orbital-thermal model: in particular the resurfacing of Miranda combined with its high orbital inclination (~4.338°) currently observed could be explained by a capture in the past in a 3:1 mean motion resonance with Umbriel. The dynamical part of the problem has already been studied by several authors 20 years ago (Dermott et al. 1988; Tittemore & Wisdom 1989; Malhotra 1990; Moons & Henrard 1993) and revisited by us with other powerful numerical tools (Verheylewegen et al. 2013, submitted). We have in particular analyzed the different secondary resonances that the system might have encountered. In parallel, we are working on a thermal model using the evolution of the temperature inside the satellite, with radiogenic and tidal heating sources. The analytical expressions of the viscosity and the rigidity allow to compute new tidal parameters at each step of the evolution to inject them in the orbital part of the model. The objective is to show the first results of the combination of the two parts during the evolution through the mean-motion resonance 3:1 between Miranda and Umbriel.

301.05 – Orbital Evolution of Titan and Iapetus

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Titan and Iapetus are the most distant sizable moons of Saturn and are therefore less affected by tides than Saturn's inner moons. However, their orbits are decidedly excited, with Titan having an appreciable eccentricity of 0.03 (despite the likely strong tidal dissipation within Titan) and Iapetus having a large inclination of 8 degrees. Their relatively large distance from Saturn and the resulting importance of solar perturbations have led to suggestions that the Great Inequality of Jupiter and Saturn has excited these moons' orbits (Bills and Nimmo, 2005). In order to test this hypothesis, we have constructed a new numerical integrator, SIMPL (Symplectic Integrator for Moons and Planets), where both the planetary and the satellite system are integrated simultaneously using the algorithm of Chambers et al.(2002). SIMPL also includes dissipative forces like planetary and satellite tides, and parametrized planetary migration. We find that planetary near-resonances are invariably too weak to affect the orbits of Titan and Iapetus to the necessary degree, and conclude that the source of excitation is most likely within the system. We note that Titan and Iapetus are just interior to their mutual 5:1 mean-motion resonance, which was not crossed if the tidal parameter Q/k_2 of Saturn was about 10^5, but the resonance was certainly encountered if Q/k_2=5000, as claimed by Lainey et al.(2012). Our ongoing integrations show great promise of this resonance for exciting the eccentricity of Titan and inclination of Iapetus, and we will present more definitive results at the meeting. Preliminary results indicate that the original orbit of Iapetus may have been moderately excited, most likely during planetary migration. This research is supported by NASA Outer Planets Research Program award NNX11AM48G.

302 – Planet and Satellite Formation III

302.01 – Records of Migration in the Exoplanet Configurations

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When compared to our Solar System, many exoplanet systems exhibit quite unusual planet configurations; some of these are hot Jupiters, which orbit their central stars with periods of a few days, others are resonant systems composed of two or more planets with commensurable orbital periods. It has been suggested that these configurations can be the result of a migration processes originated by tidal interactions of the planets with disks and central stars. The process known as planet migration occurs due to dissipative forces which affect the planetary semi-major axes and cause the planets to move towards to, or away from, the central star. In this talk, we present possible signatures of planet migration in the distribution of the hot Jupiters and resonant exoplanet pairs. For this task, we develop a semi-analytical model to describe the evolution of the migrating planetary pair, based on the fundamental concepts of conservative and dissipative dynamics of the three-body problem. Our approach is based on an analysis of the energy and the orbital angular momentum exchange between the two-planet system and an external medium; thus no specific kind of dissipative forces needs to be invoked. We show that, under assumption that dissipation is weak and slow, the evolutionary routes of the migrating planets are traced by the stationary solutions of the conservative problem (Birkhoff, Dynamical systems, 1966). The ultimate convergence and the evolution of the system along one of these modes of motion are determined uniquely by the condition that the dissipation rate is sufficiently smaller than the roper frequencies of the system. We show that it is possible to reassemble the starting configurations and migration history of the systems on the basis of their final states, and consequently to constrain the parameters of the physical processes involved.

303 – Orbits and Chaos I

303.01 – Chaotic Behavior Near First-order Mean Motion Resonances in the Elliptical, Planar Three Body Problem

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We investigate the behavior of two bodies ? and ?' orbiting a massive central body in a common plane, near a first order mean motion resonance m+1:m, where m is an integer. We obtain a system with two critical resonant angles ? = (m+1)?' -m? - ? and ?' = (m+1)?' -m? - ?', where ? and ? are the mean longitude and the longitude of periapsis of ?, respectively, and the primed quantities apply to ?'. The aims of the presentation is (1) to discuss the integrability of this two-degree of freedom system. When there are no secular precession terms, the integrability of the system stems from the existence of a second integral of motion, besides the Hamiltonian. We show that this second integral is a modified version of the Jacobi constant, where the orbital eccentricity of ? (or ?') is replaced by the relative eccentricity between the two orbits. When the central potential is not anymore Keplerian (due for instance to the oblateness of the central body), then the differential orbital precession of ? and ?' destroys that modified Jacobi constant. The second goal is (2) to rescale the restricted problem (? = 0) so that it depends upon two parameters only: the distance between the two resonances and the mass of ?'. While the problem is integrable when the distance is zero, we show numerically that a chaotic motion appears when the distance is small and different from zero. For large distances, the system tends again toward an integrable system solved using adiabatic invariance arguments.

303.02 – Retrograde Resonance in the Circular Restricted 3 Body Problem

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Recently we showed that within a binary system, retrograde planets are stable up to distances much closer to the companion star than prograde planets (Morais & Giuppone 2012, MNRAS 424, 52-64). The enhanced stability of retrograde planets with respect to prograde planets is due to retrograde resonances being weaker than prograde resonances. Indeed, at mean motion ratio p/q, a prograde resonance is of order p-q while a retrograde resonance is of order p+q. While prograde resonances have been widely studied, the particular features of retrograde resonances were not yet known. Therefore, using the framework of the CR3BP, we explored the phase-space topology in the vicinity of the 2/1, 1/1 and 1/2 retrograde resonances. Here, we will describe in detail this work together with some examples / applications.

303.03 – The Milankovitch Orbital Elements and Their Application to the Long-term Orbit Evolution of Planetary Satellites Subject to Radiation and Gravitational Perturbations

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In his monumental work on the astronomical theory of paleoclimates, Milutin Milankovitch (1879-1958) reformulated the classical method of perturbation of elements using the two vectorial integrals of the unperturbed two-body problem--the angular momentum (areal) vector and the Laplace vector. The vectorial integrals describe the spatial orientation, geometrical shape, and size of the osculating Keplerian orbit, and, together with the sixth scalar integral that represents the motion in time, constitutes a complete set of orbital elements. These elements are particularly useful in finding the first-order long-period and secular variations by averaging over the fast variables of the system. The application of the Milankovitch elements to the determination of oblateness and tidal effects leads to the equations for perturbed elements in which the small numerical divisors, the eccentricity and the sine of the inclination, are not present (Musen, P., J. Geophys. Res., 66, 1961; Allan, R.R., and Cook, G.E., Proc. R. Soc. A, 280, 1964). Tremaine et al. (AJ, 137, 2009) used the Milankovitch elements to study the classical Laplace plane, a region of space where the secular evolution of orbits driven by the combined effects of these forces is zero, so that the orbits are ``frozen.'' This talk will reintroduce the Milankovitch elements, present a completely nonsingular form of them, and show their application to the long-term orbit evolution of irregular satellites, binary asteroids, and other planetary systems. We will also show how the Laplace plane equilibrium can be generalized to accommodate non-gravitational forces, such as solar radiation perturbations.

303.04 – Time-varying Geometric Orbital Elements of Saturn's Moons

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The orbital elements of Saturn's moons are a moving target. Not only do they change with time due to gravitational interactions among the moons, but the familiar osculating elements are often not physically meaningful because of Saturn's large oblateness. Starting with numerical orbit integrations constrained by ground-based and spacecraft observations (e.g., Jacobson et al. 2008, AJ), we express the orbits of Saturn's moons in terms of the physically meaningful 'epicyclic elements' derived in several papers by Borderies (Rappaport) and Longaretti, obtaining them from the Cartesian position and velocity at each moment in time via the algorithm of Renner and Sicardy (2006, CeMDA). Our purpose is twofold: Firstly, Saturn's rings respond to myriad resonances with the moons, and the location and phase of those resonances depend on each moon's mean motion, argument of pericenter, etc. By obtaining time series for these quantities in forms that directly reflect the motion of the perturbers as seen by the rings, we enable more precise study of ring resonances. Resonances due to Mimas, Janus, and Epimetheus, and perhaps also Prometheus and Pandora, change with time in such a way as to result in observable effects in spiral waves and edge locations (e.g., Tiscareno et al. 2006, ApJL; Spitale and Porco 2009, AJ). Secondly, by means of Fourier analysis and wavelet analysis, we investigate the frequencies that govern the evolution of the geometric orbital elements, and even how those frequencies themselves may change with time, thus casting light on the interactions among moons, as well as on the relation between orbital and rotational motion.

303.05 – About Hohmann Transfer with Orbital Plane Change

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Contributing teams: Departamento de Astronomia (UC), Departamento de Fisica (USB).

We analitically studied the generalized Hohmann orbital transfer by considering non coplanar and elliptical orbits instead of planar and circular. It was done in order to find the transfer orbit that minimizes the energy and therefore the missing mass of a satellite through the application of two non-tangential impulses. We found an analytical expression that leads to minimize the fuel cost after assuming some reasonable physical constraints. Finally, we discuss some possible configurations and applications to our model.

400 – Orbits and Chaos II

400.01 – Chirikov and Nekhoroshev Diffusion Estimates: Bridging the Two Sides of the River

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In this talk I will present a strong link between heuristic and formal theories of chaotic diffusion in Hamiltonian system. A specific relationship between Chirikov's 'diffusion theory' and Nekhoroshev's formal description (normal forms developments and estimates) will be shown for a specific toy Hamiltonian. A relationship between the optimal remainder of the normal form development, R, and Chirikov's diffusion coefficient, D, suggested by Efthymiopoulos: D~R^2(1+p), where p<1 in case of a single resonance is obtained from both, theoretical and numerical means. This is a rather suggestive result, since several published and unpublished applications of chaotic diffusion in asteroidal dynamics in the Solar System as well as in exoplanets that considered Chirikov's theory to compute diffusion, has been objected by several researchers in the field, mainly due to the lack of rigorous estimates of Chirikov's formulation, and it was suggested to use Nekhoroshev''s theory. The obtained results supported by several refined numerical experiments, that agree with former results obtained by Eftymiopoulos considering the Froeshlé Hamiltonian without invoking Chirikov's formulation, suggest that both 'theories' are complementary and not antagonist. In this direction we believe that these results provide a bridge between both 'sides of the river'.

401 – Rings and Satellites I

401.02 – Edge Waves and Nonlinear Mode Coupling in Saturn’s B Ring

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The Cassini spacecraft has been in orbit about the planet Saturn since 2004. During the past 8 years we have been able to observe the changing shape of the outer edge of Saturn’s B ring, which exhibits multiple modes of oscillation in addition to the expected azimuthal wave number m = 2 signature associated with an orbital resonance with the satellite Mimas. In particular, the B ring edge has a slowly precessing m = 1 eccentric mode as well as rapidly rotating components with m = 3, 4 and 5 (Nicolson et al. 2011 and 2012 DDA abstracts). These additional modes are driven by nonlinear couplings with the resonantly forced mode via gravitational forces between ring particles. The process is analogous to side band instabilities that are well known in nonlinear optics. This nonlinear coupling exchanges energy between the different modes which may explain why the amplitude and phase of the m = 2 mode has been observed to vary over time. The radial profile of the edge modes are calculated by first mapping the semi-infinite radial domain of the ring edge onto a finite interval and then expanding the radial dependence in terms of truncated series of Chebyshev polynomials for each edge mode. The use of Chebyshev polynomials facilitates the computation of self-gravity interactions because the logarithmic potential is separable in terms of these polynomials. We can effectively measure the mass of ring particles at the B ring edge because the four-year modulation period of the m = 2 mode is found to be sensitive to the surface density at this location.

402 – Rings and Satellites II

402.01 – Kronoseismology: Probing Saturn's Interior via its Rings

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Saturn's rings exhibit a wealth of density and bending waves which are mostly attributable to inner Lindblad and vertical resonances with external satellites. There is, however, a set of wavelike features in the C ring which do not fall near any known satellite resonances (Rosen etal. 1991; Baillie etal 2011). Moreover, these waves appear to propagate radially inwards, suggesting that they arise at outer Lindblad resonances (OLRs). Marley & Porco (1993) proposed that these waves might be driven by resonances with Saturn's internal modes of oscillation, specifically low-order f-modes with predicted rotation periods of order 5 hours. However, a lack of information on the aziumthal structure (number of spiral arms, m) and angular frequency of the waves made specific identifications impossible. Using stellar occultation data from the Cassini VIMS instrument acquired between 2005 and 2009, we have successfully measured both `m' and the angular pattern speed for 6 of these waves. We find that all 6 waves are consistent with density waves driven at OLRs, with $2 <= m <= 4$. Their angular rotation periods are consistent with those calculated by Marley & Porco (1993) for sectoral (ie., m=l) f-modes in Saturn, and are expected to provide significant new constraints on the planet's interior structure and rotation state. Currently unexplained is the existence of multiple f-modes with different pattern speeds but the same value of `m'.

402.02 – Non-circular Features in Saturn's Rings from Cassini Occultations

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Occultation observations of Saturn's rings over the course of Cassini's orbital mission have provided hundreds of high-resolution profiles of the entire ring system. By combining precise measurements of individual ring features from Cassini UVIS and VIMS stellar and RSS radio occultation experiments, we have determined the orbits of ringlets and gaps with unprecedented accuracy, revealing a host of weak dynamical effects at work. Using a set of quasi-circular features to establish the absolute radius scale of the rings to sub-km accuracy, we have determined the orbital characteristics of prominent non-circular ringlets and gaps in the C ring, including the sharp-edged Titan and Maxwell ringlets, dozens of B ring features, and nearly twenty Cassini Division features. We find a host of free normal modes, over 60 in number, including inner Lindblad resonances at the inner edges of rings and outer edges of gaps, and outer Lindblad resonances at outer ring edges and inner gap edges. We also find convincing evidence of Ttian's forced m=1 normal mode within 1000 km orbital radius of the Titan ringlet in the C ring, and of Mimas's forced m=2 mode throughout the Cassini Division, with the observed amplitudes and phases matching those expected from these interactions. The quality of the data and the accuracy of the orbit determinations make it possible to detect normal modes with radial amplitudes as small as 150 m, and typical rms residuals of 250 m.

402.03 – Delving into D-ring Dynamics: Probes of Saturn's Interior and Clues to its Recent History

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Saturn's D-ring is the innermost component of Saturn's ring system, lying between 5000 and 15,000 km above Saturn's cloud tops. This region exhibits complex optical depth variations on a range of spatial scales, and several of its features either move or evolve over time. For example, a narrow ringlet near the D-ring's inner edge has a finite eccentricity, and its pericenter steadily precesses around the planet. Further from Saturn, there are spiral vertical corrugations that have become more and more tightly wound over the course of the Cassini mission due to differential apsidal precession and nodal regression. Since these eccentric ringlets and spiral patterns occur very close to the planet, the relevant precession rates are especially sensitive to the higher-order components of the planet's gravitational field. We can therefore use these features to derive new constraints on parameters like J6 or J8, although sensitivity analyses indicate that alternative parameterizations of the gravity field may be more useful. The detailed investigations of these structures required to obtain precise constraints on the local precession rates also revealed new aspects of how these features may be generated. In particular, we have found that the vertical corrugation is overprinted on a spiral optical depth variation. Both of these patterns likely originated from a single event in 1983 that not only tilted the ring but also distorted the relevant ring particles' orbits. Furthermore, the observed trends in the corrugation's wavelength across the D and C rings suggest that different parts of the rings may have become tilted at slightly different times. If we assume that this ring-tilting event involved interplanetary debris crashing into the rings, then these findings should provide new information about the trajectory of the impacting material.

402.04 – The Orbits of the Regular Jovian Satellites, Their Masses, and the Gravity Field of Jupiter

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At the end of the Galileo mission, we produced ephemerides for the Galilean and inner Jovian satellites based on numerical integrations of their orbits fit to a variety of Earth-based and spacecraft observations. A necessary byproduct of this effort was improved knowledge of the satellite masses and Jupiter's gravity field. The Earth-based observation set spanned the years 1967---2001 and included: Earth-based astrometry, satellite mutual eclipses and occultations, and satellite eclipses by Jupiter. The spacecraft observations included: Doppler tracking, radiometric range, very-long baseline interferometry, and optical navigation imaging from Pioneer 10, Pioneer 11, Voyager 1, Voyager 2, Ulysses, Galileo, Cassini. To support the Juno mission, currently enroute to Jupiter, we have begun an update of the satellite ephemerides. We are reprocessing all of the observations used in our earlier analysis but with improved software and procedures developed in recent years to support the Cassini mission at Saturn. Moreover, we have extended the Earth-based astrometry back to 1891 and forward to 2012 and have expanded the set of mutual eclipses and occultations to include those obtained in 1997, 2002/2003, and 2009. We have also added the imaging observations made by the New Horizons spacecraft during its 2007 flyby of Jupiter. In this paper we report on the status of our ephemeris update and compare our current results with those obtained at the end of the Galileo mission.