Program Schedule and Abstract Book

2016 DDA Meeting

May 22 - 26, 2016

The Program Report was last updated May 14, 2016 at 01:12 AM EDT. To view the most recent meeting schedule online, visit https://dda47.abstractcentral.com/planner.jsp

Sunday, May 22, 2016

You have nothing scheduled for this day

Monday, May 23, 2016

Time	Session or Event Info
9:00 AM-9:10 AM, Wilson Hall 126 (Vanderbilt University), **100. Welcome Address: Kelly Holly-Bockelmann (DDA Chair)**, Oral Session	
9:10 AM-10:40 AM, Wilson Hall 126 (Vanderbilt University), **101. Planet Formation and Migration**, Oral Session, Chair: Renu Malhotra, renu@lpl.arizona.edu, Univ. of Arizona	
9:10-9:25 AM	**101.01. Origins of Hot Jupiters, Revisited** K. Batygin; P. Bodenheimer; G. Laughlin
9:25-9:40 AM	**101.02. The In Situ Formation of Giant Planets at Short Orbital Periods** A.C. Boley; B. Gladman; A. Granados Contreras
9:40-9:55 AM	**101.03. Kepler-223: A Resonant Chain of Four Transiting, Sub-Neptune Planets** S. Mills; D.C. Fabrycky; C. Migaszewski; E.B. Ford; E. Petigura; H.T. Isaacson
9:55-10:10 AM	**101.04. On the Nature and Timing of Giant Planet Migration in the Solar System** C.B. Agnor
10:10-10:25 AM	**101.05. WASP-47: a Hot Jupiter with Close Friends** J. Becker; F.C. Adams
10:25-10:40 AM	**101.06. Dynamical Origins of the Kepler Dichotomy** C. Spalding; K. Batygin
11:10 AM-12:30 PM, Wilson Hall 126 (Vanderbilt University), **102. Tidal Dynamics and Moon Formation**, Oral Session, Chair: Alice Quillen, alice.quillen@gmail.com, Univ. of Rochester	
11:10-11:45 AM	**102.01. Brouwer Award Lecture: Anelastic tides of close-in satellites and exoplanets** S. Ferraz-Mello
11:45-12:00 PM	**102.02. Obliquity Variations of a Rapidly Rotating Venus** B.L. Quarles; J.W. Barnes; J.J. Lissauer; J.E. Chambers; M.M. Hedman
12:00-12:15 PM	**102.03. On the rotation of viscoelastic satellites** B. Noyelles
12:15-12:30 PM	**102.04. Did the Kozai Resonance Help Form Pluto's Small Moons?** M. Cuk; H.C. Dones; D. Nesvorny; K.J. Walsh
2:00 PM-3:00 PM, Wilson Hall 126 (Vanderbilt University), **103. Stability of Many-body Systems/Non-Conservative System**, Oral Session, Chair: Fred Adams, fca@umich.edu, University of Michigan	

2:00-2:15 PM	**103.01. Hill Stability in the Finite Density N-Body Problem** D.J. Scheeres
2:15-2:30 PM	**103.02. REBOUNDx: A library for adding additional effects to N-body simulations** D. Tamayo; H. Rein; P. Shi
2:30-2:45 PM	**103.03. Slimplectic Integrators: Variational Integrators for Nonconservative systems** D. Tsang
2:45-3:00 PM	**103.04. High eccentricity MMRs in the circular planar restricted three-body problem** X. Wang; R. Malhotra
3:15 PM-3:25 PM, Wilson Hall 126 (Vanderbilt University), **104. Monday Poster Talks**, Poster Session	
3:15-3:17 PM	**104.01. Simulating tidal evolution and encounters with mass-spring models** A.C. Quillen; J. Frouard; C. Ebinger; D. Giannella; M. Efroimsky; J. Shaw
3:17-3:19 PM	**104.02. The Structural Evolution of Forming and Early Stage Star Clusters** K. Jaehnig; N. Da Rio; J.C. Tan
3:19-3:21 PM	**104.03. Galaxy Transformation from Flyby Encounters** C. Davis
3:21-3:23 PM	**104.04. Galaxy cluster collision speeds as a test of LCDM: possible systematics & how to avoid them** I. Banik; H. Zhao
3:45 PM-4:30 PM, Wilson Hall 126 (Vanderbilt University), **105. Effects of Unseen Planets**, Oral Session, Chair: Daniel Scheeres, scheeres@colorado.edu, University of Colorado	
3:45-4:00 PM	**105.01. Effect of Unseen Planets on Secular Interactions** C.L. Van Laerhoven
4:00-4:15 PM	**105.02. Interaction Cross Sections and Survival Probabilities for Proposed Solar System Member Planet Nine** F.C. Adams; G. Li
4:15-4:30 PM	**105.03. Dynamics of the Most Distant Kuiper Belt Objects** K. Volk; R. Malhotra; X. Wang
4:40 PM-5:40 PM, Wilson Hall 126 (Vanderbilt University), **DDA Business Meeting**, Attendee Event	

Tuesday, May 24, 2016

Time	Session or Event Info
9:00 AM-10:40 AM, Wilson Hall 126 (Vanderbilt University), **200. Special Session: Impact of Astrometry on Dynamics I**, Oral Session, Chair: Alice Monet, alicemonet@gmail.com, U.S. Naval Obs. (retired)	
9:00-9:35 AM	**200.01. HSTPROMO and the Dynamics of the Local Group** G. Besla

9:35-9:50 AM	**200.02. Effects of dynamical evolution on the internal kinematical properties of star clusters** M. Tiongco; E. Vesperini; A. Varri
9:50-10:25 AM	**200.03. Local stellar kinematics from large astrometric surveys: mapping the Galactic phase-space substructure** S. Lepine
10:25-10:40 AM	**200.04. Determination of Precise Pre-Main-Sequence Stellar Properties through Stellar and Disk Orbital Dynamics** K. Stassun
11:10 AM-12:45 PM, Wilson Hall 126 (Vanderbilt University), **201. Special Session: Impact of Astrometry on Dynamics II**, Oral Session, Chair: Alice Monet, alicemonet@gmail.com, U.S. Naval Obs. (retired)	
11:10-11:45 AM	**201.01. Is astrometry enough? Deflection relevant Near Earth Object characterization efforts in Europe** S. Eggl
11:45-12:00 PM	**201.02. Solar system object observations with Gaia Mission** M. Kudryashova; P. Tanga; F. Mignard; B. CARRY; O. Christophe; P. DAVID; D. Hestroffer
12:00-12:15 PM	**201.03. Scout: short-arc orbit analysis and hazard assessment for newly discovered asteroids** D. Farnocchia; S.R. Chesley; M. Micheli
12:15-12:30 PM	**201.04. LAGEOS Solar Radiation Force: Contribution from Cube-Corner Retroreflection** V.J. Slabinski
12:30-12:45 PM	**201.05. Why the Greenwich Meridian Moved** P.K. Seidelmann; G.H. Kaplan
2:00 PM-3:30 PM, Wilson Hall 126 (Vanderbilt University), **202. Multiplanet Systems: Stability and Characterization I**, Oral Session, Chair: Craig Agnor, C.B.Agnor@qmul.ac.uk, Queen Mary University of London	
2:00-2:15 PM	**202.01. Orbital Eccentricity and the Stability of Planets in the Alpha Centauri System** J.J. Lissauer; B.L. Quarles
2:15-2:30 PM	**202.02. Orbital Stability of High Mass Planetary Systems** S.J. Morrison; K.M. Kratter
2:30-2:45 PM	**202.03. The Stability of Tightly-packed and Evenly-spaced Planetary Systems** A. Obertas; C.L. Van Laerhoven; D. Tamayo
2:45-3:00 PM	**202.04. Eccentricity Inferences in Multi-planet systems with Transit Timing: Degeneracies and Apsidal Alignment** D. Jontof-Hutter; C.L. Van Laerhoven; E.B. Ford
3:00-3:15 PM	**202.05. Discovery of Triple Star Systems through Dynamical Eclipse Timing Variations with Kepler Eclipsing Binaries** K.E. Conroy
3:15-3:30 PM	**202.06.** **Tidal Q of a Super Earth: Dynamical Constraints from the GJ 876 System** A. Puranam; K. Batygin

3:30 PM-3:40 PM, Wilson Hall 126 (Vanderbilt University), **203. Tuesday Poster Talks**, Poster Session	
3:30-3:32 PM	**203.01. Modelling evolution of asteroid's rotation due to the YORP effect** O. Golubov; V. Lipatova; D.J. Scheeres
3:32-3:34 PM	**203.02. A dusty ringlet with connections to both Prometheus and the F ring** M.M. Hedman; B. Carter
3:34-3:36 PM	**203.03. URAT Parallax Catalog: the largest parallax catalog since Hipparcos** C.T. Finch; N. Zacharias
4:10 PM-4:55 PM, Wilson Hall 126 (Vanderbilt University), **204. Multiplanet Systems: Stability and Characterization II**, Oral Session, Chair: Craig Agnor, C.B.Agnor@qmul.ac.uk, Queen Mary University of London	
4:10-4:25 PM	**204.01. The mass distribution function of planets in the Galaxy** R. Malhotra
4:25-4:40 PM	**204.02. Cometary Source for the Strange Behavior of KIC 8462852** E. Bodman; A.C. Quillen
4:40-4:55 PM	**204.03. KELT-9b: A Case Study in Dynamical Planet Ingestion by a Hot Host Star** K.A. Collins; K. Stassun; B.S. Gaudi; T.G. Beatty; G. Zhou; D.W. Latham; A. Bieryla; J.D. Eastman; R. Siverd; J.R. Crepp; J. Pepper
7:00 PM-10:00 PM, Wilson Hall 126 (Vanderbilt University), **Public event at Dyer Observatory (optional): Panel discussion on Exoplanets**, Open Event	

Wednesday, May 25, 2016

Time	Session or Event Info
9:00 AM-10:35 AM, Wilson Hall 126 (Vanderbilt University), **300. Special Session: Dynamics of Disks and Rings I**, Oral Session, Chair: Matthew Tiscareno, matt@seti.org, SETI Institute	
9:00-9:35 AM	**300.01. Planetary rings and astrophysical discs** H. Latter
9:35-9:50 AM	**300.02. Keeping the Edges Sharp I: Honing the Theory of Narrow Rings** D.P. Hamilton; T. Rimlinger; J.M. Hahn
9:50-10:05 AM	**300.03. Structure of the Asteroid Belt from the Gas Giants' Growth and Chaotic Dynamics** A. Izidoro; S.N. Raymond; A. Pierens; A. Morbidelli; O. Winter; D. Nesvorny
10:05-10:20 AM	**300.04. Establishing different size distributions in the asteroid belt** S.A. Jacobson; A. Morbidelli
10:20-10:35 AM	**Abstract Withdrawn**

11:00 AM-12:40 PM, Wilson Hall 126 (Vanderbilt University), **301. Special Session: Dynamics of Disks and Rings II**, Oral Session, Chair: Matthew Tiscareno, matt@seti.org, SETI Institute	
11:00-11:35 AM	**301.01. Warps and Streams --- Pushing and lifting material out of the midplane from galactic and circumstellar disks** A.C. Quillen
11:35-12:10 PM	**301.02. Chemodynamical signatures of radial migration in the Milky Way** S. Loebman
12:10-12:25 PM	**301.03. Galaxy Disks in the Balance: Vertical Settling as a Result of Inside-Out Growth** J.C. Bird; S. Kazantzidis; A. Brooks; F. Governato; D.H. Weinberg; S. Loebman
12:25-12:40 PM	**301.04. Steady, Near-exponential Galaxy Disks Produced by Scattering Processes** C. Struck; B. Elmegreen
2:00 PM-3:30 PM, Wilson Hall 126 (Vanderbilt University), **302. Dynamics of Galaxies and Around Supermassive Black Holes**, Oral Session, Chair: Sarah Loebman, sloebman@umich.edu, University of Michigan	
2:00-2:15 PM	**302.01. Predicting the Velocity Dispersions of the Dwarf Satellite Galaxies of Andromeda** S.S. McGaugh
2:15-2:30 PM	**302.02. Anomalous Motions in the Local Group: Evidence of a Past Milky Way–Andromeda Flyby?** I. Banik; H. Zhao
2:30-2:45 PM	**302.03. Bar Formation from Galaxy Flybys** K. Holley-Bockelmann; M. Lang; M. Sinha
2:45-3:00 PM	**302.04. Orbits in N-body bars and the origin of the X-shapes in boxy-peanut bulges** M. Valluri
3:00-3:15 PM	**302.05. Gas clouds as dynamical probes of the accretion flow around SgrA*** A. Madigan
3:15-3:30 PM	**302.06. Orbit of the OJ287 black hole binary as determined from the General Relativity centenary flare** M. Valtonen; A. Gopakumar; S. Mikkola; S. Zola; S. Ciprini; K. Matsumoto; K. Sadakane; M. Kidger; K. Gazeas; K. Nilsson; A. Berdyugin; V. Piirola; H. Jermak; K. Baliyan; R. Hudec; D. Reichart
4:00 PM-5:45 PM, Wilson Hall 126 (Vanderbilt University), **303. Dynamics of Small Solar System Bodies**, Oral Session, Chair: Christa Van Laerhoven, cvl@cita.utoronto.ca, University of Arizona	
4:00-4:15 PM	**303.01. Could the Craters on the Mid-Sized Moons of Saturn Have Been Made by Satellite Debris?** H.C. Dones; J. Alvarellos; E.B. Bierhaus; W. Bottke; M. Cuk; P. Hamill; D. Nesvorny; S.J. Robbins; K. Zahnle

4:15-4:30 PM	**303.02. Orbital and Rotational Dynamics of Pluto's Small Moons** M.R. Showalter; H.A. Weaver; J.R. Spencer; S. Porter; D.P. Hamilton; R.P. Binzel; M.W. Buie; W.M. Grundy; F. Nimmo; R.A. Jacobson; M. Brozovic; H.B. Throop; S. Stern; C.B. Olkin; L. Young; K. Ennico; T. New Horizons Science Team
4:30-4:45 PM	**303.03. The fate of debris in the Pluto-Charon system** R. Smullen; K.M. Kratter
4:45-5:00 PM	**303.04. Himalia and Phoebe: Little moons that punch above their weight** D. LI; A. Christou
5:00-5:15 PM	**303.05. Designing Asteroid Impact Scenario Trajectories** P. Chodas
5:15-5:30 PM	**303.06. Spin State Equilibria of Asteroids due to YORP Effects** O. Golubov; D.J. Scheeres; V. Lipatova
5:30-5:45 PM	**303.07. Low-Energy Asteroid and Comet Transit Analysis using Isolating Blocks** R.L. Anderson; P. Chodas; R.W. Easton; M.W. Lo

Thursday, May 26, 2016

Time	Session or Event Info
9:00 AM-10:30 AM, Wilson Hall 126 (Vanderbilt University), **400. Saturn and Saturn's Rings I,** Oral Session, Chair: Douglas Hamilton, dphamil@umd.edu, Univ. of Maryland	
9:00-9:15 AM	**400.01. Propeller peregrinations: Ongoing observations of disk-embedded migration in Saturn’s rings** M.S. Tiscareno
9:15-9:30 AM	**400.02. Keeping the Edges Sharp II: Honing Simulations of Narrow Rings** T. Rimlinger; D. Hamilton; J.M. Hahn
9:30-9:45 AM	**400.03. Kronoseismology III: An update on Saturn-driven waves in the C ring** P.D. Nicholson; R.G. French; M.M. Hedman
9:45-10:00 AM	**400.04. An array of asymmetries in Saturn's structure revealed by its rings** M.M. Hedman; P.D. Nicholson; M. El Moutamid; S. Graven
10:00-10:15 AM	**400.05. Tesseral resonances in the rings of Saturn** M. El Moutamid; P.D. Nicholson; M.M. Hedman; P.J. Gierasch; J.A. Burns; R.G. French
10:15-10:30 AM	**400.06. Physical characteristics of "wisps" in the outer edge of the Keeler Gap in Saturn's rings** E. Arnault; M.S. Tiscareno
11:00 AM-11:45 AM, Wilson Hall 126 (Vanderbilt University), **401. Saturn and Saturn's Rings II,** Oral Session, Chair: Douglas Hamilton, dphamil@umd.edu, Univ. of Maryland	

11:00-11:15 AM	**401.01. The Gravity Field of Saturn and the Mass of the Saturnian Rings at the end of the Cassini Mission** R.A. Jacobson; M. Brozovic; D.C. Roth
11:15-11:30 AM	**401.02. 4-km body(ies?) embedded in Saturn's Huygens Ringlet** J.N. Spitale; J.M. Hahn; D. Tamayo
11:30-11:45 AM	**401.03. Persistent pattern speeds in Saturn's D ring** R. Chancia; M.M. Hedman

Final ID: 101.01

Origins of Hot Jupiters, Revisited

K. Batygin; [1]; *P. Bodenheimer;* [2]; *G. Laughlin;* [2];
1. California Institute of Technology, Pasadena, CA, United States.
2. UC Santa Cruz, Santa Cruz, CA, United States.

Abstract (2,250 Maximum Characters): Hot Jupiters, giant extrasolar planets with orbital periods less than ~10 days, have long been thought to form at large radial distances (a > 2AU) in protoplanetary disks, only to subsequently experience large-scale inward migration to the small orbital radii at which they are observed. Here, we propose that a substantial fraction of the hot Jupiter population forms in situ, with the Galactically prevalent short-period super-Earths acting as the source population. Our calculations suggest that under conditions appropriate to the inner regions of protoplanetary disks, rapid gas accretion can be initiated for solid cores of 10-20 Earth masses, in line with the conventional picture of core-nucleated accretion. The planetary conglomeration process, coupled with subsequent gravitational contraction and spin down of the host star, drives sweeping secular resonances through the system, increasing the mutual inclinations of exterior, low-mass companions to hot Jupiters. Accordingly, this formation scenario leads to testable consequences, including the expectation that hot Jupiters should frequently be accompanied by additional non-transiting planets, reminiscent of those observed in large numbers by NASA’s Kepler Mission and Doppler velocity surveys. High-precision radial velocity monitoring provides the best prospect for their detection.

Final ID: 101.02

The In Situ Formation of Giant Planets at Short Orbital Periods

A. C. Boley; [1]; *B. Gladman;* [1]; *A. Granados Contreras;* [1];
1. The University of British Columbia, Vancouver, BC, Canada.

Abstract (2,250 Maximum Characters): We propose that two of the most surprising results so far among exoplanet discoveries are related: the existences of both hot Jupiters and the high frequency of multi-planet systems with periods P < 200 days. In this paradigm, the vast majority of stars rapidly form along with multiple close-in planets in the mass range of Mars to super-Earths/mini-Neptunes. Such systems of tightly packed inner planets are metastable, with the time scale of the dynamical instability having a major influence on final planet types. In most cases, the planets consolidate into a system of fewer, more massive planets, but long after the circumstellar gas disk has dissipated. This can yield planets with masses above the traditional critical core of ~10 Mearth yielding short-period giants that lack abundant gas. A rich variety of physical states are also possible given the range of collisional outcomes and formation time of the close-in planets. However, when dynamical consolidation occurs before gas dispersal, a critical core can form that then grows via gas capture into a short-period gas giant. In this picture the majority of Hot and Warm Jupiters formed locally, rather than migrating down from larger distances.

Final ID: 101.03

Kepler-223: A Resonant Chain of Four Transiting, Sub-Neptune Planets

S. Mills; [1]; *D. C. Fabrycky;* [1]; *C. Migaszewski;* [2]; *E. B. Ford;* [3]; *E. Petigura;* [4]; *H. T. Isaacson;* [5];

1. University of Chicago, Chicago, IL, United States.
2. Nicolaus Copernicus University, Jurija Gagarina, Poland.
3. The Pennsylvania State University, State College, PA, United States.
4. California Institute of Technology, Pasadena, CA, United States.
5. University of California, Berkeley, Berkeley, CA, United States.

Abstract (2,250 Maximum Characters): Surveys have revealed an abundance of multi-planet systems containing super-Earths and Neptunes in few-day to few-month orbits. Orbital periods of pairs of planets in the same system occasionally lie near, but generally not exactly on, ratios of small integers (resonances), allowing for the detection of the planets perturbing each other. There is debate whether in situ assembly or significant inward migration is the dominant mechanism of their formation. Simulations suggest migration creates tightly-packed, resonant systems, often in chains of resonance. Of the hundreds of multi-planet systems of sub-Neptunes, there is weak statistical enhancement near resonances, but no individual system has been identified that requires migration. Here we describe dynamical modeling of the system Kepler-223, which has a series of resonances among its four planets. We observe transit timing variations (TTVs), model them as resonant angle librations, and compute long-term stability, combining these analyses to constrain dynamical parameters and planetary masses. The detailed architecture of Kepler-223 is too finely tuned for formation by scattering, whereas numerical simulations demonstrate its properties are natural outcomes of the migration hypothesis. Similar systems could be destabilized by many mechanisms contributing to the observed period distribution. Planetesimal interactions in particular are thought to be responsible for establishing thecurrent orbits of the four giant planets in our own Solar System by disrupting a theoretical initial resonant chain like that actually observed in Kepler-223.

Final ID: 101.04

On the Nature and Timing of Giant Planet Migration in the Solar System

C. B. Agnor; [1];
1. School of Physics and Astronomy, Queen Mary University of London, London, United Kingdom.

Abstract (2,250 Maximum Characters): Giant planet migration is a natural outcome of gravitational scattering and planet formation processes (Fernandez & Ip 1984). There is compelling evidence that the solar system's giant planets experienced large-scale migration involving close approaches between planets as well as smooth radial migration via planetesimal scattering. Aspects of giant planet migration have been invoked to explain many features of the outer solar system including the resonant structure of the Kuiper Belt (e.g., Malhotra 1993, Levison et al. 2008), the eccentricities of Jupiter and Saturn (Tsiganis et al. 2005, Morbidelli et al. 2009), the capture of Jupiter's Trojan companions (Morbidelli et al. 2005) and the capture of irregular planetary satellites (e.g., Nesvorny et al. 2007) to name a few. If this migration epoch occurred after the formation of the inner planets, then it may also explain the so-called lunar Late Heavy Bombardment (Gomes et al. 2005). This scenario necessarily requires coeval terrestrial and migrating giant planets. Recent N-body integrations exploring this issue have shown that giant planet migration may excite the terrestrial system via nodal and apsidal secular resonances (e.g., Brasser et al. 2013), may drive the terrestrial planets to crossing orbits (Kaib & Chambers 2016) or alternatively leave the inner solar system in a state closely resembling the observed one (Roig et al. 2016). The factors accounting for the large range of outcomes remain unclear. Using linear secular models and N-body simulations I am identifying and characterising the principal aspects of giant planet migration that excite the terrestrial planets' orbits. I will present these results and discuss how they inform the nature and timing of giant planet migration in the solar system.

Final ID: 101.05

WASP-47: a Hot Jupiter with Close Friends

J. Becker; [1]; *F. C. Adams;* [1];
1. Astronomy, University of Michigan, Ann Arbor, MI, United States.

Abstract (2,250 Maximum Characters): WASP-47 was observed in Campaign 5 of the extended Kepler mission, K2. We report the discovery of two nearby planetary companions in this system, with periods of roughly 0.8 days and 9 days, respectively. This system is the first (and, at the date of writing this abstract, only) hot Jupiter to be found to have such nearby companions, one of which was detectable through the transit timing variations of the hot Jupiter. Using the K2 photometry and the results of several follow-up measurements, we will discuss the architecture of this intriguing system and the implications its detection has on our understanding of the formation and migration of hot Jupiters.

Final ID: 101.06

Dynamical Origins of the Kepler Dichotomy

C. Spalding; [1]; *K. Batygin;* [1];
1. Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA, United States.

Abstract (2,250 Maximum Characters): An overabundance of single-transiting planetary systems relative to those with multiple transits within the Kepler dataset, has been interpreted as evidence for mutual inclinations between planetary orbits. The physical origins of this so-called "Kepler Dichotomy," however, remain elusive. Here we show that the observed prevalence of single-planet systems is a direct consequence of secular evolution of initially planar multi-planet systems that orbit stars whose spin-axes are inclined with respect to the protoplanetary disks they host. Such primordial misalignments arise naturally within the disk-hosting stage by way of gravitational torques from stellar companions, and have been previously invoked as explanations for the commonness of spin-orbit misalignments in hot Jupiter systems. Accordingly, our model places the early dynamical evolution of hot super-Earths and hot Jupiters into a unified theoretical framework.

Final ID: 102.01

Brouwer Award Lecture: Anelastic tides of close-in satellites and exoplanets

S. Ferraz-Mello; [1];
1. Institute of Astronomy, Geophysics and Atmospheric Sciences, University of São Paulo, São Paulo, SP, Brazil.

Abstract (2,250 Maximum Characters): This lecture reviews a new theory of the anelastic tides of celestial bodies in which the deformation of the body is the result of a Newtonian creep inversely proportional to the viscosity of the body and, along each radius, directly proportional to the distance from the actual surface of the body to the equilibrium. The first version of the theory (AAS/DDA 2012; CeMDA 2013), was restricted to homogeneous bodies. It was applied to many different bodies as the Moon, Mercury, super-Earths and hot Jupiters. An improved version (AAS/DDA 2014) included also the loss of angular momentum due to stellar winds and was applied to the study of the rotational evolution of active stars hosting massive companions. One more recent version (Folonier et al. AAS/DDA 2013; DPS 2015) allowed for the consideration of layered structures and was applied to Titan and Mercury. The resulting anelastic tides depend on the nature of the considered body. In the case of low-viscosity bodies (high relaxation factor), as gaseous planets and stars, the results are nearly the same of Darwin's theory. For instance, in these cases the dissipation grows proportionally to the tidal frequency. In the case of high-viscosity rocky satellites and planets (low relaxation factor), the results are structurally different: the dissipation varies with the tidal frequency following an inverse power law and the rotation may be driven to several attractors whose frequencies are 1/2, 1, 3/2, 2, 5/2,… times the orbital mean-motion, even when no permanent triaxiality exists.

Final ID: 102.02

Obliquity Variations of a Rapidly Rotating Venus

B. L. Quarles; [1, 3]; *J. W. Barnes;* [2]; *J. J. Lissauer;* [1]; *J. E. Chambers;* [4]; *M. M. Hedman;* [2];
1. NASA Ames Research Center, Moffett Field, CA, United States.
2. University of Idaho, Moscow, ID, United States.
3. University of Nebraska at Kearney, Kearney, NE, United States.
4. Carnegie Inst. of Washington, Washington, DC, United States.

Abstract (2,250 Maximum Characters): Venus clearly differs from Earth in terms of its spin and atmospheric composition, where the former is controlled by solid-body and atmospheric thermal tides. However, this may have been different during earlier stages of planetary evolution, when the Sun was fainter and the Venusian atmosphere was less massive. We investigate how the axial tilt, or obliquity, would have varied during this epoch considering a rapidly rotating Venus. Through numerical simulation of an ensemble of hypothetical Early Venuses, we find the obliquity variation to be simpler than a Moonless Earth (Lissauer et al., 2012). Most low-obliquity Venuses show very low total obliquity variability comparable to that of the real Moon-influenced Earth.

Final ID: 102.03

On the rotation of viscoelastic satellites

B. Noyelles; [1];
1. University of Namur, Namur, Belgium.

Abstract (2,250 Maximum Characters): Most of the natural satellites are thought to be synchronous. For some of them, the presence of a thin, outer crust coating a global ocean motivates the consideration of their elasticity for modeling their rotation. Some attempts have been made to include it as an additional effect in the rotational theories. Actually, the shapes of these bodies are partly fossil, partly due to internal processes, and partly due to the tidal and rotational distortions, driving them to the hydrostatic equilibrium.

I here present a fully consistent model of viscoelastic rotation of these bodies, in which the tensor of inertia is time-dependent and ruled by these distorting effects. The influence of the different frequencies affecting the motion of the satellite and the tidal parameters is considered. For that, I use an iterative numerical algorithm, in which the tensor of inertia and the rotational variables are decomposed under a quasi-periodic form. The motion of the satellite is modeled with planetary ephemerides, and the frequency-dependency of the tides is based on the Maxwell model. This results in an improved theory of the librations and the obliquity, which I validate by analytical calculations. I show that not only the amplitudes of these quantities are affected, but also their phases. I finally apply this theory on Mimas and Epimetheus, for which librations have been measured. This implies an updated interpretation of their interiors.

Final ID: 102.04

Did the Kozai Resonance Help Form Pluto's Small Moons?

M. Cuk; [1]; *H. C. Dones;* [2]; *D. Nesvorny;* [2]; *K. J. Walsh;* [2];
1. SETI Institute, Mountain View, CA, United States.
2. SwRI, Boulder, CO, United States.

Abstract (2,250 Maximum Characters): The origin of the small moons of Pluto is currently poorly understood. They most likely originated from debris ejected from Pluto and Charon during their formation in the giant impact. However, the moons' large separation from Pluto and massive past tidal evolution of Charon make it very hard to emplace collisional fragments on circular orbits in the 40-60 Pluto radii zone where the four small moons are found. Here we propose that the Pluto system has a parallel in the triple Trans-Neptunian Object (TNO) 1999 TC36. Both systems have large obliquities, and have additional components outside the inner binary that probably formed in a giant impact and has likely gone through a rapid tidal evolution immediately following formation. Our hypothesis is that loosely bound ejecta from giant impacts can experience strong perturbations from the Sun (the ``Kozai resonance'') as long as major axes of their elongated orbits are perpendicular to the binary's heliocentric orbit. This process could decouple the debris from the inner boundary long enough for the inner binary to evolve tidally and prevent further Kozai oscillations through its quadrupole moment. If the debris is dominated by one large fragment, a triple can form (as in the case of 1999 TC36), while a large population of fragments would experience collisions and make a disk surrounding the inner binary (as in the case of Pluto). At the meeting we will present numerical simulations of this process using numerical integrator COMPLEX which includes both tides and solar perturbations, and can integrate dynamics of satellites on crossing orbits.

Final ID: 103.01

Hill Stability in the Finite Density N-Body Problem

D. J. Scheeres; [1];
1. University of Colorado, Boulder, CO, United States.

Abstract (2,250 Maximum Characters): A Celestial Mechanics system is Hill Stable if its components cannot escape from each other. Such stability is difficult to prove for general Celestial Mechanics problems with $N \geq 3$ bodies interacting with each other. This is in part due to the ability of two bodies to come arbitrarily close to each other, freeing kinetic energy that can be used for an additional body to escape. When considering bodies with finite density, meaning that they have finite sizes and their mass centers cannot come arbitrarily close to each other, this pathway to escape has specific limits that make the determination of Hill Stability feasible. This opens up new definitions of Hill Stability that can be used to determine energetic thresholds at which a rubble pile body with sufficient angular momentum can shed mass components of various sizes. This talk will review recent advances in Hill Stability with direct application to the interaction of self-gravitating rubble pile bodies.

Final ID: 103.02

REBOUNDx: A library for adding additional effects to N-body simulations

D. Tamayo; [1, 2]; *H. Rein;* [1]; *P. Shi;* [3];

1. University of Toronto at Scarborough, Scarborough, ON, Canada.
2. Canadian Institute of Theoretical Astrophysics, Toronto, ON, Canada.
3. University of Toronto, Toronto, ON, Canada.

Abstract (2,250 Maximum Characters): Many astrophysical applications involve additional perturbations beyond point-source gravity. We have recently developed REBOUNDx, a library for adding such effects in numerical simulations with the open-source N-body package REBOUND.

Various implementations have different numerical properties that in general depend on the underlying integrator employed. In particular, I will discuss adding velocity-dependent/dissipative effects to widely used symplectic integrators, and how one can estimate the introduced numerical errors using the operator-splitting formalism traditionally applied to symplectic integrators.

Finally, I will demonstrate how to use the code, and how the Python wrapper we have developed for REBOUND/REBOUNDx makes it easy to interactively leverage powerful analysis, visualization and parallelization libraries.

Final ID: 103.03

Slimplectic Integrators: Variational Integrators for Nonconservative systems

D. Tsang; [1];
1. University of Maryland, College Park, MD, United States.

Abstract (2,250 Maximum Characters): Symplectic integrators are widely used for long-term integration of conservative astrophysical problems due to their ability to preserve the constants of motion; however, they cannot in general be applied in the presence of nonconservative interactions. Here we present the “slimplectic” integrator, a new type of numerical integrator that shares many of the benefits of traditional symplectic integrators yet is applicable to general nonconservative systems. We utilize a fixed-time-step variational integrator formalism applied to a newly developed principle of stationary nonconservative action (Galley, 2013, Galley et al 2014). As a result, the generalized momenta and energy (Noether current) evolutions are well-tracked. We discuss several example systems, including damped harmonic oscillators, Poynting–Robertson drag, and gravitational radiation reaction, by utilizing our new publicly available code to demonstrate the slimplectic integrator algorithm. Slimplectic integrators are well-suited for integrations of systems where nonconservative effects play an important role in the long-term dynamical evolution. As such they are particularly appropriate for cosmological or celestial N-body dynamics problems where nonconservative interactions, e.g., gas interactions or dissipative tides, can play an important role.

Final ID: 103.04

High eccentricity MMRs in the circular planar restricted three-body problem

X. Wang; [1, 2]; *R. Malhotra;* [1];

1. Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, United States.
2. Tsinghua University, Beijing, Beijing, China.

Abstract (2,250 Maximum Characters): Mean motion resonances [MMRs] play an important role in the evolution of the solar system and have significantly influenced the population of the minor planets. Most previous theoretical analyses of mean motion resonances have focused on the low eccentricity regime, but with new discoveries of high eccentricity resonant minor planets and even exoplanets, there is increasing motivation to examine the dynamics of MMRs in the high eccentricity regime. Here we report on a study of the high eccentricity regime of MMRs in the circular planar restricted three-body problem. Numerical analysis of several important interior and exterior resonances are performed for a wide range of secondary-to-primary mass ratio μ, and for a wide range of eccentricity of the particle. The surface of section of a vs. ψ is used to study the stable resonant regions, where a is the semi-major axis and ψ is the angle between the planet and the particle at periapse; the usual resonant argument is an integer multiple of ψ. We find that for each resonant ratio, the center and extent of stable librations of ψ changes depending upon the eccentricity and mass ratio μ. Some libration centers that are stable at lower eccentricity become unstable and chaotic at higher eccentricity. However, large new stable islands reappear at higher eccentricity, albeit at shifted libration centers. We discuss the mass and eccentricity dependence of the centers and widths of stable resonance zones.

Final ID: 104.01

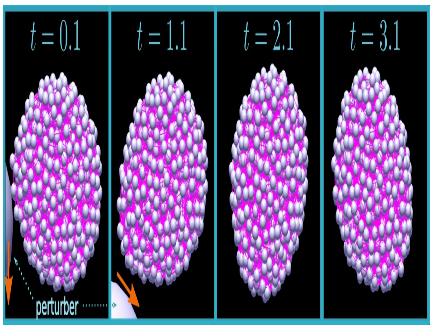
Simulating tidal evolution and encounters with mass-spring models

A. C. Quillen; [1]; *J. Frouard;* [2]; *C. Ebinger;* [1]; *D. Giannella;* [1]; *M. Efroimsky;* [2]; *J. Shaw;* [1];

1. Physics and Astronomy, Univ. of Rochester, Rochester, NY, United States.
2. Naval Observatory, Washington DC, DC, United States.

Abstract (2,250 Maximum Characters): We have recently found that we can directly simulate tidal spin down of viscoelastic objects using damped springs within an N-body code. But there is a 30% discrepancy between the torque analytically predicted and that numerically measured and we still have not identified the cause!

Close tidal encounters among large planetesimals and moons were more common than impacts. Using a mass spring model within an N-body simulation, we simulate the deformation of the surface caused by a close tidal encounter and find tidal encounters can induce sufficient stress on the surface to cause brittle failure of an icy crust. Simulated fractures can extend a large fraction of the radius of body. Strong tidal encounters may be responsible for the formation of long graben complexes and chasmata in ancient terrain of icy moons such as Dione, Tethys, Ariel and Charon.



Final ID: 104.02

The Structural Evolution of Forming and Early Stage Star Clusters

K. Jaehnig; [1]; *N. Da Rio;* [1]; *J. C. Tan;* [1];
1. University of Florida, Gainesville, FL, United States.

Abstract (2,250 Maximum Characters): We study the degree of angular substructure in the stellar position distribution of young members of Galactic star-forming regions, looking for correlations with distance from cluster center, surface number density of stars, and local dynamical age. To this end we adopt the catalog of members in 18 young (~1-3 Myr) clusters from the Massive Young Star-Forming Complex Study in Infrared and X-ray (MYStIX) Survey and the statistical analysis of the Angular Dispersion Parameter, δADP. We find statistically significant correlation between δADP and physical projected distance from the center of the clusters, with the centers appearing smoother than the outskirts, consistent with more rapid dynamical processing on local dynamical, free-fall or orbital timescales. Similarly, smoother distributions are seen in regions of higher surface density, or older dynamical ages. These results indicate that dynamical processing that erases substructure is already well-advanced in young, sometimes still-forming, clusters. Such observations of the dissipation of substructure have the potential to constrain theoretical models of the dynamical evolution of young and forming clusters.

Final ID: 104.03

Galaxy Transformation from Flyby Encounters

C. Davis; [1];
1. Astrophysics, Vanderbilt University, Nashville, TN, United States.

Abstract (2,250 Maximum Characters): Galaxy flybys are transient encounters where two halos interpenetrate and later detach forever. Although these encounters are surprisingly common—even outnumbering galaxy mergers for massive halos at the present epoch—their dynamical effects have been largely ignored. Using idealized collisionless N-body simulations of flyby encounters, it has been shown that a galaxy flyby can excite a bar and spin up the halo. Here, we compare the structural properties of recent flybys to that of recent mergers and isolated systems within the Illustris Simulation.

Final ID: 104.04

Galaxy cluster collision speeds as a test of LCDM: possible systematics & how to avoid them

I. Banik; [1]; *H. Zhao;* [1];
1. Physics and Astronomy, University of Saint Andrews, Saint Andrews, Fife, United Kingdom.

Abstract (2,250 Maximum Characters): The formation of structure may have been more efficient than expected in the concordance LCDM model. This is suggested by the early formation of the El Gordo cluster, but perhaps even more so by the high collision velocity of the two components of the Bullet Cluster. Unfortunately, the collision is mostly within the plane of the sky. With proper motions near-impossible to observe at $z = 0.3$, the collision speed estimate comes from modelling of the shock created in the gas by the collision. Also important is the separation of the gas and dark matter, inferred from comparing X-ray images with weak gravitational lensing maps. I will describe how the collision speed may be measured directly using the Moving Cluster Effect (MCE). This is based on the time-dependent potential of the cluster making double images of a background galaxy have different redshifts. I'll also explain some of the systematics that may affect such a measurement and some strategies that may reduce these. Measurements using the MCE may allow a much more reliable test of LCDM based on how often such fast collisions between galaxy clusters actually occur. More info: MNRAS, vol 450, page 3155

Final ID: 105.01

Effect of Unseen Planets on Secular Interactions

C. L. Van Laerhoven; [1];
1. Canadian Institute for Theoretical Astrophysics, Toronto, ON, Canada.

Abstract (2,250 Maximum Characters): A great number of multi-planet extra-solar systems are now known thanks to both transit and radial velocity surveys. The long-term eccentricity and inclination behavior of many of these systems is readily described by classical second-order secular theory in which the eccentricity and inclination of each planet is a sum of contributions from several eigenmodes. The underlying structure of the eigenmodes, that is, how much each planet is affected by a given eigenmode, depends on only the masses and semi-major axes of the planets, and the mass of the star. When discerning the dynamics of a system it is usually assumed that the known planets are the only planets in the system, or at least that any other planets are distant enough to not strongly affect the known planets. However, the secular structure might change significantly if there are one or more additional, unseen planets in the system. I will discuss how the secular structure of several observed multi-planet systems changes when an additional planet is added to the system, and how that change in the secular structure depends on the mass and distance of the additional planet.

Final ID: 105.02

Interaction Cross Sections and Survival Probabilities for Proposed Solar System Member Planet Nine

F. C. Adams; [1]; *G. Li;* [2];
1. University of Michigan, Ann Arbor, MI, United States.
2. Center for Astrophysics , Cambridge, MA, United States.

Abstract (2,250 Maximum Characters): Motivated by the report of a possible new planetary member of the Solar System, this work calculates cross sections for interactions between passing stars and this proposed Planet Nine. Evidence for the new planet is provided by the orbital alignment of Kuiper Belt objects, and other Solar System properties, which suggest a Neptune-mass object on an eccentric orbit with semimajor axis \anine = 400 - 1500 AU. With such a wide orbit, Planet Nine has a large interaction cross section, and is susceptible to disruption by passing stars. Using a large ensemble of numerical simulations, and Monte Carlo sampling, we calculate the cross sections for different classes of orbit-altering events: [A] scattering the planet into its proposed orbit from a smaller orbit, [B] ejecting it from the Solar System from its current orbit, [C] capturing the planet from another system, and [D] capturing a free-floating planet. Results are presented for a range of orbital elements with planetary mass of 10 Earth masses. Removing Planet Nine from the Solar System is the most likely outcome. Specifically, we obtain ejection cross sections \sigma=4.2\times10^6 AU^2 (4.3\times10^4 AU^2) for environments corresponding to the birth cluster (field). With these cross sections, Planet Nine is likely to be ejected if the Sun resides within its birth cluster longer than \Delta{t} > 100 Myr. The probability of ejecting Planet Nine due to passing field stars is of order 1 percent over the age of the Sun. Probabilities for producing the inferred Planet Nine orbit are comparable (a few percent).

Final ID: 105.03

Dynamics of the Most Distant Kuiper Belt Objects

K. Volk; [1]; *R. Malhotra;* [1]; *X. Wang;* [1];
1. University of Arizona, Tucson, AZ, United States.

Abstract (2,250 Maximum Characters): We investigate the evolution of the most distant known Kuiper belt objects (KBOs) under the secular and resonant effects of the known planets in the Solar System as well as under the influence of a massive, unseen distant planet. The orbits of these distant KBOs evolve on a wide range of timescales (from millions to billions of years); most important are the changes in the objects' perihelion distances which can dramatically change the relative domination of secular or resonant effects on their orbital evolution. Motivated by the period ratios of the distant KBOs, which are near simple integer ratios, we examine the properties of mean motion resonances with a hypothetical, unseen planet; we discuss how the uncertainties in the observed objects' orbits compare to the widths of these hypothesized resonances. We also examine the timescales for secular orbital evolution and the timescales for scattering through close encounters in the models with and without the hypothetical planet to assess the case for such a planet.

Final ID: 200.01

HSTPROMO and the Dynamics of the Local Group

G. Besla; [1];
1. University of Arizona, Tucson, AZ, United States.

Abstract (2,250 Maximum Characters): Our understanding of the dynamics of our Local Group of galaxies has changed dramatically over the past few years owing to significant advancements in astrometry and our theoretical understanding of galaxy structure. I will provide an overview of key contributions by the Hubble Space Telescope to this evolving picture. In particular, I will highlight the HSTPROMO team's proper motion measurements of key players in the Local Group, such as the fastest (Leo I) and most massive (LMC and SMC) satellites of the Milky Way and the first ever direct proper motion measurement of M31. These results have met with controversy, challenging preconceived notions of the orbital dynamics of key components of the Local Group. I will further highlight the importance of HST's continued role in this field in the era of Gaia.

Final ID: 200.02

Effects of dynamical evolution on the internal kinematical properties of star clusters

M. Tiongco; [1]; *E. Vesperini;* [1]; *A. Varri;* [2];
1. Astronomy, Indiana University, Bloomington, IN, United States.
2. University of Edinburgh, Edinburgh, Scotland, United Kingdom.

Abstract (2,250 Maximum Characters): The observational characterization of the internal kinematics of Galactic globular clusters will soon reach an unprecedented level of richness, thanks to the synergy between the astrometric data provided by Gaia and HST, and a number of ESO/VLT spectroscopic programs. Such a wealth of information on the three-dimensional velocity space of star clusters, offers the unique opportunity to address a number of open questions on the phase space evolution of collisional stellar systems.

Driven by these motivations, I will present some highlighted results of a large survey of N-body simulations aimed at exploring the long-term dynamical evolution of the kinematical properties of tidally limited star clusters. First, I will discuss of the evolution of the anisotropy in velocity space, with particular attention to the dependence on the cluster initial structural properties and dynamical history. I will then focus on the implications of cluster dynamical evolution and loss of stars on its internal rotation. Such an enriched picture of the kinematical properties of star clusters offers a solid bedrock for addressing a range of exciting new questions related to the dynamics of multiple stellar populations in globular clusters. In this context, I will illustrate some results on the internal rotational velocity profiles and the evolution of the differences in the rotation of different stellar populations.

Final ID: 200.03

Local stellar kinematics from large astrometric surveys: mapping the Galactic phase-space substructure

S. Lepine; [1];

1. Dept. Physics and Astronomy, Georgia State University, Atlanta, GA, United States.

Abstract (2,250 Maximum Characters): The potential of future large astrometric catalogs for mapping the velocity-space distribution of local stars in the Galaxy is illustrated with a kinematic study of K and M dwarfs in the SUPERBLINK catalog of 2.5 million stars with large proper motions (mu>40 mas/yr). Low mass K and M dwarfs, found in abundance thanks to the faint magnitude limit of the catalog (V<20) provide the densest possible sampling of the [(X,Y,Z),(U,V,W)] phase-space, making them well-suited to map out substructure (so-called "streams") in the velocity-space distributions, as well as variations in said distribution over >100 parsec scale distances. The SUPERBLINK proper motion catalog thus provides kinematic data for ~1.5 million M dwarfs from the Galactic disk population, located within 200 parsecs of the Sun, and for ~180,000 K and M (sub)dwarfs from the Galactic halo population, all within 500 parsecs of the Sun. While the disk dwarfs show clear signs of velocity-space substructure, the distribution of halo subdwarf does appear to be relatively smooth ("streamless") in contrast. Evidence for spatial variations at the few hundred parsec scale is also discussed. The current and unfortunately "blurry" view of the local velocity-space distribution promises to be set in much sharper focus with the upcoming availability of data from the GAIA mission.

Final ID: 200.04

Determination of Precise Pre-Main-Sequence Stellar Properties through Stellar and Disk Orbital Dynamics

K. Stassun; [1];

1. Vanderbilt University, Nashville, TN, United States.

Abstract (2,250 Maximum Characters): We summarize the current state-of-the-art in the measurement of direct, precise stellar masses at pre-main-sequence ages through the analysis of eclipsing binary orbits and circumstellar disk dynamics. We highlight two key issues: (1) The masses determined from disk dynamics require more precise distance determinations that should become available from Gaia soon, and (2) many eclipsing binaries appear disturbed by the presence of tertiary companions that inject heat into and puff up one or both of the inner binary stars, however the dynamical mechanism by which orbital energy is injected as heat remains unknown.

Final ID: 201.01

Is astrometry enough? Deflection relevant Near Earth Object characterization efforts in Europe

S. Eggl; [1, 2];
1. IMCCE - Observatoire de Paris, Paris, France.
2. UPMC, Paris, France.

Abstract (2,250 Maximum Characters): ESA's Gaia mission heralds a new era in the field of astrometry. In particular, solar system science will not only benefit from an unprecedented precision of direct observations of objects by the Gaia satellite, the Gaia astrometric catalog is going to improve the accuracy of ground based measurements far beyond the mission's lifetime. The ensuing boost in the quality of astrometric data grants, for instance, access to detecting weak non-gravitational accelerations experienced by solar system objects. Those, in turn, are vital for long term ephemeris calculations and especially for asteroid impact probability estimates.

Accurately measuring non-gravitational drift rates is only half the battle, though. Convincingly linking model predictions for non-gravitational effects with the motion of minor planets constitutes the other half, as such a link requires a deep understanding of the shape, spin state and physical properties of minor planets. In this contribution I discuss the requirements on the physical characterization of asteroids for an accurate long term prediction of orbits, the calculation of collision probabilities with terrestrial planets, as well as a successful asteroid deflection should it become necessary. Moreover, current European efforts to procure such data for potentially hazardous asteroids are presented.

Final ID: 201.02

Solar system object observations with Gaia Mission

M. Kudryashova; [1]; *P. Tanga;* [2]; *F. Mignard;* [2]; *B. CARRY;* [2]; *O. Christophe;* [2]; *P. DAVID;* [2]; *D. Hestroffer;* [1];
1. IMCCE/Paris Observatory, Paris, France.
2. UNS-CNRS-Observatoire de la Cote d'Azur, Nice, France.

Abstract (2,250 Maximum Characters): After a commissioning period, the astrometric mission Gaia of the European Space Agency (ESA) started its survey in July 2014. Throughout passed two years the Gaia Data Processing and Analysis Consortium (DPAC) has been treating the data. The current schedule anticipates the first Gaia Data Release (Gaia-DR1) toward the end of summer 2016. Nevertheless, it is not planned to include Solar System Objects (SSO) into the first release. This is due to a special treatment required by solar system objects, as well as by other peculiar sources (multiple and extended ones). In this presentation, we address issues and recent achivements in SSO processing, in particular validation of SSO-short term data processing chain, GAIA-SSO alerts, as well as the first runs of SSO-long term pipeline.

Final ID: 201.03

Scout: short-arc orbit analysis and hazard assessment for newly discovered asteroids

D. Farnocchia; [1]; *S. R. Chesley;* [1]; *M. Micheli;* [2, 3];
1. JPL, Caltech, Pasadena, CA, United States.
2. ESA, NEOCC, Frascati, RM, Italy.
3. SpaceDyS, Cascina, PI, Italy.

Abstract (2,250 Maximum Characters): It typically takes a few days for a newly discovered asteroid to be officially recognized as a real object. This time is needed to collect additional data and make sure the observations belong to an actual asteroid rather than being an artifact or corresponding to an artificial object. However, asteroids could experience an Earth close approach or even an impact only a few days or less after the discovery observations, as in the cases of 2008 TC3 and 2014 AA, i.e., the only two asteroids discovered before an Earth impact. In such cases, a rapid identification of the close approach or impact dramatically improves the chances of securing the asteroid's trajectory with additional observations prior to impact. Scout is an automated system that provides an orbital and hazard assessment for new potential asteroid discoveries within minutes after the observations are available. Since the time interval covered by the observations is generally short, perhaps only a few hours or even less, there are severe degeneracies in the orbit estimation process. To overcome these degeneracies Scout relies on systematic ranging, a technique that scans the poorly constrained space of topocentric range and range rate, while the plane-of-sky position and motion are directly tied to the recorded observations. This scan allows us to identify the possible orbits and the regions corresponding to collision solutions, as well as potential impact times and locations. From the probability distribution of the observation errors, Scout derives a probability distribution in the orbital space and in turn estimates several metrics of interest, e.g., probability of an Earth impact, of a close approach to Earth, and of being a mission-accessible target.

Final ID: 201.04

LAGEOS Solar Radiation Force: Contribution from Cube-Corner Retroreflection

V. J. Slabinski; [1];
1. U.S. Naval Observatory, Washington, DC, United States.

Abstract (2,250 Maximum Characters): The surface of a spherical LAGEOS satellite contains 426 Cube Corner Reflectors (CCRs) for the retro-reflection of incident laser ranging beams back to their source. For practical reasons, the number of CCRs is finite, so their distribution over the surface is not perfectly uniform.

At any time, the ~9 CCRs near the sub-solar point on the LAGEOS surface will also retroreflect incident sunlight back toward the Sun. This concentration of reflected sunlight into a parallel beam increases the resulting radiation force on the satellite over what occurs for the usual broad-beam specular and diffuse reflection by ordinary surfaces. Because of the non-uniform CCR distribution, the retroreflection of sunlight (and hence the solar radiation force on the satellite) varies with the Sun aspect angle, even when averaged over the spin period. The Sun aspect angle is the co-latitude of the sub-solar surface point measured from the spin pole.

We use ray tracing of sunlight through the CCRs to determine the Sun angle dependence of the solar radiation force and the resulting variation in secular perturbation rates for the LAGEOS orbit, especially for the eccentricity elements. We investigate the possibility of using the observed variations in the eccentricity vector as a check on the spacecraft spin-axis attitude. Attitude information is important for computing radiation-force perturbations to the orbit node when determining the Lense-Thirring effect.

Final ID: 201.05

Why the Greenwich Meridian Moved

P. K. Seidelmann; [1]; *G. H. Kaplan;* [2];
1. Univ. of Virginia, Charlottesville, VA, United States.
2. U S Naval Observatory, Washington, DC, United States.

Abstract (2,250 Maximum Characters): In 1884, the International Meridian Conference recommended that the prime meridian “to be employed as a common zero of longitude and standard of time-reckoning throughout the globe” pass through the “centre of the transit instrument at the Observatory of Greenwich”. Today, tourists visiting its meridian line must walk east approximately 102 meters before their satellite-navigation receivers indicate zero longitude. This offset is attributable to the difference between astronomical and geodetic coordinates. Specifically, the longitude shift can be accounted for by the deflection of the vertical in the east-west direction at Greenwich, along with an imposed condition of continuity in astronomical time. The coordinates of satellite-navigation receivers are provided in reference frames that are related to the geocentric reference frame introduced by the *Bureau International de l'Heure* (BIH) in 1984. This BIH Terrestrial System (BTS 84) provided the basis for orientation of all subsequent geocentric reference frames, including all realizations of the World Geodetic System 1984 (WGS 84) and the International Terrestrial Reference Frame (ITRF). Despite the lateral offset of the original and current zero-longitude lines at Greenwich, the orientation of the meridian plane used to measure Universal Time has remained essentially unchanged.

Final ID: 202.01

Orbital Eccentricity and the Stability of Planets in the Alpha Centauri System

J. J. Lissauer; [1]; *B. L. Quarles;* [2];
1. NASA Ames Research Center, Moffett Field, CA, United States.
2. University of Nebraska at Kearney, Kearney, NE, United States.

Abstract (2,250 Maximum Characters): Planets on initially circular orbits are typically more dynamically stable than planets initially having nonzero eccentricities. However, the presence of a major perturber that forces periodic oscillations of planetary eccentricity can alter this situation. We investigate the dependance of system lifetime on initial eccentricity for planets orbiting one star within the alpha Centauri system. Our results show that initial conditions chosen to minimize free eccentricity can substantially increase stability compared to planets on circular orbits.

Final ID: 202.02

Orbital Stability of High Mass Planetary Systems

S. J. Morrison; [1]; *K. M. Kratter;* [1];
1. Univ. of Arizona, Tucson, AZ, United States.

Abstract (2,250 Maximum Characters): In light of the observation of systems like HR 8799 that contain several planets with planet-star mass ratios larger than Jupiter's, we explore the relationships between planet separation, mass, and stability timescale for high mass multi-planet systems detectable via direct imaging. We discuss the role of overlap between 1st and sometimes 2nd order mean motion resonances, and show how trends in stability time vary from previous studies of lower mass multi-planet systems. We show that extrapolating empirically derived relationships between planet mass, separation, and stability timescale derived from lower mass planetary systems misestimate the stability timescales for higher mass planetary systems by more than an order of magnitude at separations near the Hill stability limit. We also address what metrics of planet separation are most useful for estimating a system's dynamical stability. We apply these results to young, gapped, debris disk systems of the ScoCen association in order to place limits on the maximum mass and number of planets that could persist for the lifetimes of the disks. These efforts will provide useful constraints for on-going direct imaging surveys. By setting upper limits on the most easily detectable systems, we can better interpret both new discoveries and non-dectections.

Final ID: 202.03

The Stability of Tightly-packed and Evenly-spaced Planetary Systems

A. Obertas; [1]; *C. L. Van Laerhoven;* [2]; *D. Tamayo;* [1, 2];

1. University of Toronto, Toronto, ON, Canada.

2. Canadian Institute for Theoretical Astrophysics, Toronto, ON, Canada.

Abstract (2,250 Maximum Characters): Many of the multi-planet systems discovered to date have been notable for their compactness, with neighbouring planets closer together than any in the Solar System. Interestingly, planet hosting stars have a wide range of ages, suggesting that such compact systems can survive for extended periods of time. We have used numerical simulations to investigate how quickly systems go unstable in relation to the compactness of a system. So far, we have focused on hypothetical systems of Earth-mass planets on evenly spaced orbits (in mutual Hill Radii). In general, the further apart the planets are initially, the longer it takes for a pair of planets to undergo a close encounter. We recover the results of previous studies, showing a linear trend in the initial planet spacing between 3-8 Hill Radii and the log of close encounter time. However, investigating thousands of simulations reveals further, more detailed structure superimposed on this relationship. We discuss the impact of this structure and the implications on the stability of compact multi-planet systems.

Final ID: 202.04

Eccentricity Inferences in Multi-planet systems with Transit Timing: Degeneracies and Apsidal Alignment

D. Jontof-Hutter; [1]; *C. L. Van Laerhoven;* [2]; *E. B. Ford;* [1];
1. Pennsylvania State University, State College, PA, United States.
2. Canadian Institute for Theoretical Astrophysics, Toronto, ON, Canada.

Abstract (2,250 Maximum Characters): Hundreds of multi-transiting systems discovered by the Kepler mission show Transit Timing Variations (TTV). In cases where the TTVs are uniquely attributable to transiting planets, the TTVs enable precise measurements of planetary masses and orbital parameters. Of particular interest are the constraints on eccentricity vectors that can be inferred in systems of low-mass exoplanets.

The TTVs in these systems are dominated by a signal caused by near-resonant mean motions. This causes the well-known near-degeneracy between planetary masses and orbital eccentricities. In addition, it causes a degeneracy between the eccentricities of interacting planet pairs.

For many systems, the magnitude of individual eccentricities are weakly constrained, yet the data typically provide a tight constraint on the posterior joint distribution for the eccentricity vector components. This permits tight constraints on the relative eccentricity and degree of alignment of interacting planets.

For a sample of two and three-planet systems with TTVs, we highlight the effects of these correlations. While the most eccentric orbital solutions for these systems show apsidal alignment, this is often due to the degeneracy that causes correlated constraints on the eccentricity vector components. We compare the likelihood of apsidal alignment for two choices of eccentricity prior: a wide prior using a Rayleigh distribution of scale length 0.1 and a narrower prior with scale length 0.02. In all cases the narrower prior decreased the fraction of samples that exhibited apsidal alignment. However, apsidal alignment persisted in the majority of cases with a narrower eccentricity prior. For a sample of our TTV solutions, we ran simulations of these systems over secular timescales, and decomposed their eccentricity eigenmodes over time, confirming that in most cases, the eccentricities were dominated by parallel eigenmodes which favor apsidal alignment.

Final ID: 202.05

Discovery of Triple Star Systems through Dynamical Eclipse Timing Variations with Kepler Eclipsing Binaries

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1. Vanderbilt University, Nashville, TN, United States.

Abstract (2,250 Maximum Characters): We present a catalog of precise eclipse times and analysis of third-body signals among 1279 close binaries in the latest Kepler Eclipsing Binary Catalog. For these short-period binaries, Kepler's 30 minute exposure time causes significant smearing of light curves. In addition, common astrophysical phenomena such as chromospheric activity, as well as imperfections in the light curve detrending process, can create systematic artifacts that may produce fictitious signals in the eclipse timings. We present a method to measure precise eclipse times in the presence of distorted light curves, such as in contact and near-contact binaries which exhibit continuously changing light levels in and out of eclipse. We identify 236 systems for which we find a timing variation signal compatible with the presence of a third body. These are modeled for the light travel time effect and the basic properties of the third body are derived. We summarize the overall distribution of mutual orbital inclination angles, which together now provide strong confirmation of the basic predictions of dynamical evolution through Kozai Cycles and Tidal Friction.

Final ID: 202.06

Tidal Q of a Super Earth: Dynamical Constraints from the GJ 876 System

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Abstract (2,250 Maximum Characters): GJ 876 is an M-dwarf star 15 light-years from Earth and is the closest known star to harbor a multi-planetary system. This system stands out as an extraordinary member of the extrasolar planetary aggregate, due to the rapid dynamical chaos exhibited by the Laplace resonance of the outer three planets, and the high eccentricity of the non-resonant inner planet. While the origins of chaotic motion within this system are well understood, the mechanism through which the innermost planet maintains its high eccentricity in face of tidal dissipation remains elusive. In this work, we used analytic methods and numerical simulations to show that angular momentum transfer between the resonant chain and the innermost planet stochastically pumps the eccentricity of latter. In light of such interactions, the innermost planet's eccentricity constitutes an observable proxy for its tidal circularization timescale. Quantitatively, our analysis yields a tidal Q of order a few thousand for an extrasolar super-Earth, GJ 876d.

Final ID: 203.01

Modelling evolution of asteroid's rotation due to the YORP effect

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Abstract (2,250 Maximum Characters): The Yarkovsky--O'Keefe--Radzievskii--Paddack (or YORP) effect is influence of light pressure on rotation of asteroids. It is the most important factor for evolution of rotation state of small asteroids, which can drastically alter their rotation rate and obliquity over cosmologic timescales.

In the poster we present our program, which calculates evolution of ratation state of small asteroids subject to the YORP effect. The program accounts for both axial and obliquity components of YORP, takes into account the thermal inertia of the asteroid's soil, and the tangential YORP. The axial component of YORP is computed using the model by Steinberg and Sari (AJ, 141, 55). The thermal inertia is accounted for in the framework of Golubov et al. 2016 (MNRAS, stw540). Computation of the tangential YORP is based on a siple analytical model, whose applicability is verified via comparison to exact numeric simulations.

We apply the program to different shape models of asteroids, and study coupled evolution of their rotation rate and obliquity.

Final ID: 203.02

A dusty ringlet with connections to both Prometheus and the F ring

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Abstract (2,250 Maximum Characters): Prometheus is a small satellite of Saturn that orbits between the planet's main rings and the narrow and dusty F ring. Prometheus' complex interactions with the F-ring material have been investigated in some detail using data from the Cassini and Voyager spacecraft, but the moon's influences on other nearby dusty rings are still largely unexplored. Here we examine a very faint ringlet that can be seen in high-phase images of the region around Prometheus' orbit taken by the Cassini spacecraft. These data reveal that the mean radius of this ringlet is close to Prometheus' semi-major axis, suggesting that it consists of material co-orbiting with that moon. However, images taken at different times and longitudes also reveal that the ringlet is eccentric, and its apsidal precession rate is not that expected for material close to Prometheus' orbit (semi-major axis of 139,380 km). Instead, the ringlet appears to be precessing at the same rate as the F-ring (mean radius around 140,200 km). The structure and dynamics of this ringlet therefore probably involve interactions with both Prometheus and the F ring.

Final ID: 203.03

URAT Parallax Catalog: the largest parallax catalog since Hipparcos

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Abstract (2,250 Maximum Characters): The first USNO Robotic Astrometric Telescope catalog (URAT1) was released in April 2015. For determining parallaxes we did go beyond that and utilize all Northern Hemisphere URAT observations. These data include all individual exposures from April 2012 to June 2015 giving a larger epoch baseline for determining parallaxes over the 2-year span of URAT1 published data. The URAT Parallax Catalog (UPC) is a supplement to 'Parallax Results From URAT Epoch Data' (Finch and Zacahrias 2016) where we explain the procedures and focus on stars with a parallax of 40 mas or larger. Here we release all significant parallaxes from the URAT northern epoch data.
The UPC contains 112177 parallaxes covering the magnitude range 6.56 to 16.93 in the URAT band-pass north of -12.752 deg declination. The over 40 million formal URAT parallax solutions have been compared to entries in the Hipparcos Catalog, The Yale Parallax Catalog, (Finch and Zacharias 2016), MEarth parallaxes and SIMBAD database, respectively to obtain prior published parallaxes and star name information. We release the 58,677 URAT parallaxes which have a match to either of those catalogs without implementing any extra cuts. For the stars with no prior published parallax we implement a set of stringent cuts to reduce possible erroneous parallaxes resulting in over 53,000 new trigonometric parallaxes from URAT data alone with a high level of confidence. The average parallax precision is 10.8 mas and 4.3 mas for stars having a known parallax and stars without a prior known parallax respectively.

Final ID: 204.01

The mass distribution function of planets in the Galaxy

R. Malhotra; [1];
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Abstract (2,250 Maximum Characters): I will describe some deductions about the planet mass function from the observational data of exoplanets and theoretical considerations of dynamical stability of planetary systems. The Kepler mission has carried out a systematic survey for planets in the Galaxy, and obtained data on several hundred exo-planetary systems. Analysis of these data indicates that planetary orbital separations have an approximately log-normal distribution. Taken together with plausible ansatzs for the dynamical stability of multi-planet systems, it appears that the planet mass function is peaked in logarithm of mass, with the most probable value of log m/M_Earth ~ (0.6 − 1.0). A modest extrapolation finds that Earth mass planets are about ~1000 times more common than Jupiter mass planets, and that the most common planets in the Galaxy may be of lunar-to-Mars mass.

This research was supported by NSF (grant AST-1312498) and NASA (grant NNX14AG93G).

Final ID: 204.02

Cometary Source for the Strange Behavior of KIC 8462852

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Abstract (2,250 Maximum Characters): We investigate the plausibility of a cometary source of the unusual transits observed in the KIC 8462852 light curve. A single comet of similar size to those in our solar system produces a transit depth of order 10^{-3} lasting less than a day which is much smaller and shorter than the largest dip observed (~20% for ~3 days) but a large, closely traveling cluster of comets can fit the observed depths and durations. We find that a series of large comet swarms with all but one on the same orbit provides a good fit for the KIC 8462852 data during Quarters 16 and 17 but does not explain the large dip observed during Quarter 8 well. However, the transit dips only loosely constrain the orbits and can be fit by swarms with periastrons differing by a factor of 10. To reach a transit depth of ~0.2, the comets need to be in a close group of ~30 if ~100 km in radius or in a group of ~300 if ~10 km. The total number of comets required to fit all the dips is ~70 ~100 km or ~700 ~10 km comets. A single comet family from a tidally disrupted Ceres-sized progenitor or the start of a Late Heavy Bombardment period explains the last ~60 days of the unusual KIC 8462852 light curve. It is possible for the comet swarm to be on a ~750 day orbit and also cause the dip in Quarter 8. However, the distribution of the comets necessary to fit the dip does not agree with expected comet distribution from a Late Heavy Bombardment period or a tidally disrupted body.

Final ID: 204.03

KELT-9b: A Case Study in Dynamical Planet Ingestion by a Hot Host Star

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Abstract (2,250 Maximum Characters): Nearly all of the known transiting extra-solar planets orbit stars with masses similar to, or less massive than, the Sun. Such stars typically do not evolve substantially over their hydrogen-fusion lifetime of roughly 10 billion years or more. In contrast, stars much more massive than the Sun evolve on much shorter timescales, and thus the planets they host represent important test cases for how such systems evolve as their parent stars expand -- perhaps engulfing their planets. Most planetary systems orbiting such massive stars have been found around stars that have already exhausted their core hydrogen, cooled, swelled, and likely erased the knowledge of their progenitor close-in planetary systems. In contrast, KELT-9b is a "hot Jupiter" orbiting a star with a mass of 2.2 Msun. The star is still unevolved and therefore still very hot (surface temperature ~ 10,000 K) and therefore the planet is extremely hot. The planet is on a near-polar orbit, likely resulting in orbital precession that will be detectable within a few years. Given the extreme planet temperature, large planet-to-star radius ratio, large planetary atmospheric scale height, and short orbital period, this system is an exceptionally good target for follow-up studies of the planet's atmosphere, which may exhibit unusual photochemistry due to the extreme amounts of high-energy radiation it receives.

Final ID: 300.01

Planetary rings and astrophysical discs

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Abstract (2,250 Maximum Characters): Disks are ubiquitous in astrophysics and participate in some of its most important processes. Of special interest is their role in star, planet and moon formation, the growth of supermassive black holes, and the launching of jets. Although astrophysical disks can be up to ten orders of magnitude larger than planetary rings and differ hugely in composition, all disks share to some extent the same basic dynamics and many physical phenomena. This review explores these areas of overlap. Topics covered include disk formation, accretion, collisions, instabilities, and satellite-disk interactions.

Final ID: 300.02

Keeping the Edges Sharp I: Honing the Theory of Narrow Rings

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Abstract (2,250 Maximum Characters): Most of the rings that encircle Saturn, Uranus, and Neptune are very narrow structures with typical radial widths of just a few kilometers. Such extreme sharpness is surprising, as even slightly different orbital periods should allow ring particles to continually jostle one another in collisions that preserve angular momentum while

inexorably draining energy. Sharp edges should blur as rings spread in response to collisions and yet they do not. The generally accepted solution to this dilemma is to bracket each narrow ring with a pair of shepherding satellites that can pump energy back into the ring to replace that lost by collisions. But only a disappointing two of roughly twenty narrow rings actually have known attendant satellites. We present a compelling alternative in which the slight eccentricities and inclinations of narrow ringlets act as internal energy sources that can be tapped to prevent ring spreading. When unattended circular rings dissipate energy they must spread radially in order to preserve angular momentum. By contrast, eccentric or inclined rings have an extra degree of freedom that can be exploited to prevent radial spreading; energy is dissipated while keeping z-component of angular momentum, sqrt(a(1-e^2))cos(i), constant by simply decreasing the overall eccentricity (e) and/or inclination (i) of the entire ring. A real narrow ring moves inward as a unit, circularizes, and drops into the equatorial plane in a process that deters radial spreading for millions or billions of years. Using secular theory with dissipation (Zhang et al. 2013), we show that narrow rings are secular eigenstates in which ellipses are nested with pericenters almost, but not exactly aligned. The misalignment of pericenters is crucial in allowing energy dissipation to be shared evenly across the ring. We predict ring surface densities that are roughly constant across the ring's width, in contrast to profiles expected for shepherded rings. Rimlinger et al. (this meeting) present numerical simulations that critically test these findings.

Final ID: 300.03

Structure of the Asteroid Belt from the Gas Giants' Growth and Chaotic Dynamics

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Abstract (2,250 Maximum Characters): The structure of the asteroid belt holds a record of the Solar System's dynamical history. The current belt only contains 10^{-3} Earth masses yet the asteroids' orbits are dynamically excited, with a large spread in eccentricity and inclination. The belt is also chemically segregated: the inner belt is dominated by dry S-types and the outer belt by hydrated C-types. Here we propose a new model in which the asteroid belt was always low-mass and was partially populated and sculpted by the giant planets on chaotic, resonant orbits. We first show that the compositional dichotomy of the asteroid belt is a simple consequence of Jupiter's growth in the gaseous protoplanetary disk. As Jupiter's core rapidly grew by accreting gas, orbits of nearby planetesimals were perturbed onto Jupiter-crossing trajectories. A significant fraction (~10%) of objects in the neighborhood exterior of Jupiter's orbit were implanted by gas drag into the outer parts of the asteroid belt as C-types. While the gas giants were likely in mean motion resonance at the end of the gaseous disk phase, we show that small perturbations may have driven them into a chaotic but stable state. After the dissipation of the gaseous disk, stochastic variations in the gas giants orbits caused resonances to chaotically jump across the main belt and excite the asteroids' orbits. Our results suggest that the early Solar System was chaotic and introduce a simple framework to understand the origins of the asteroid belt.

Final ID: 300.04

Establishing different size distributions in the asteroid belt

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Abstract (2,250 Maximum Characters): While gas is present in the protoplanetary disk, aerodynamic drag circularizes, equatorializes and shrinks planetesimal orbits. The strength of this effect is size-dependent effecting smaller planetesimals more severely. During planet formation debris from giant impacts amongst the growing terrestrial embryos can be transported to the asteroid belt via scattering events and secular resonances. The effectiveness of this transport is strongly size dependent due to the aforementioned gas drag. Thus transported debris in the asteroid belt can have a strong size sorting. Further processing due to collisions and YORP-induced rotational fission during the lifetime of the solar system must be taken into account before a model population of debris can be compared to suspected planetary debris in the asteroid belt, such as the A-type asteroids. Furthermore, scenarios such as the Grand Tack may establish size distributions since they predict that S-type asteroids are transported from an inner planetesimal disk while C-type asteroids are transporeted from an outer planetesimal disk.

Final ID: 301.01

Warps and Streams --- Pushing and lifting material out of the midplane from galactic and circumstellar disks

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Abstract (2,250 Maximum Characters): Sub-structures such as warps and streams in the vertical distribution of gas and dust can manifest as spiral shaped structures, twists in the velocity field, vertical streaming motions, X-shapes, and quasiperiodic dips in light curves. I will review and contrast physical mechanisms for lifting material out of the mid-plane in galactic and circumstellar disks including instabilities, resonant mechanisms and tidal excitations.

Final ID: 301.02

Chemodynamical signatures of radial migration in the Milky Way

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Abstract (2,250 Maximum Characters): Recent analysis of the SDSS-III/Apache Point Observatory Galactic Evolution Experiment (APOGEE) Data Release 12 stellar catalog has revealed that the Milky Way's (MW) metallicity distribution function (MDF) changes shape as a function of radius, transitioning from being negatively skewed at small Galactocentric radii to positively skewed at large Galactocentric radii. I will discuss the dynamical process that has likely generated this chemical signature: radial migration. Using a high-resolution, N-body+SPH simulation, I will illustrate how the changing skewness arises from radial migration—metal-rich stars form in the inner disk and subsequently migrate to the metal-poorer outer disk. These migrated stars represent a large fraction (> 50%) of the stars in the outer disk; they populate the high-metallicity tail of the MDFs and are, in general, more metal-rich than the surrounding outer disk gas. The simulation also reproduces another surprising APOGEE result: the spatially invariant high-[α/Fe] MDFs. This arises in the simulation from the migration of a population formed within a narrow range of radii (3.2 ±1.2 kpc) and time (8.8 ± 0.6 Gyr ago), rather than from spatially extended star formation in a homogeneous medium at early times. These results point toward the crucial role radial migration has played in shaping our MW.

Final ID: 301.03

Galaxy Disks in the Balance: Vertical Settling as a Result of Inside-Out Growth

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6. University of Michigan, Ann Arbor, MI, United States.

Abstract (2,250 Maximum Characters): Over the last decade or more, both observations and simple physical models have established that disk galaxies grow first in their central regions and then form stars at larger radii from higher angular momentum gas. These galaxies grow "inside-out"; their half-mass and scale radii increase with time. Meanwhile, recent high-resolution, hydrodynamic simulations find that the vertical kinematics of the ISM are set by hydrostatic balance between the density and scale heights of both gas and stars. We combine these ideas of inside-out growth and hydrostatic equilibrium to show that as galaxies grow in radial extent, their mass-weighted vertical extent and vertical velocity dispersion must decrease. This has dramatic observational consequences. We use state of the art galaxy formation simulations to first establish that newly-formed stars have vertically isothermal kinematics that vary with the local midplane density as predicted from hydrostatic balance. The midplane density of the exponential disk decreases with radius, thus stars born at larger radii form with smaller vertical energies. We then show that the disk forms both inside-out and upside-down, i.e., the vertical velocity dispersion of the disk decreases with time as more stellar mass is added at larger radii. This kinematic evolution is at odds with the traditional ``disk heating'' paradigm in which the disk is continuously heated due to various scattering mechanisms. Upside-down formation, however, matches the ``era of disk settling'' observational results reported by recent IFU surveys of high-redshift disk galaxies. In addition, we find that the shape of the present-day stellar age-velocity relationship (AVR), long thought to be strong evidence of continuous disk heating, naturally arises from Upside-Down formation, providing a viable solution to the classic Milky Way ``heating problem''. We conclude that simple physical arguments demand disk galaxies form Upside-Down, resolving the tension between observations of stellar kinematics in high-redshift galaxies and the Milky Way.

Final ID: 301.04

Steady, Near-exponential Galaxy Disks Produced by Scattering Processes

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Abstract (2,250 Maximum Characters): Exponential surface brightness profiles are ubiquitous in galaxy disks over a wide range of Hubble types and masses. Radial migration and scattering via bars, waves, clumps and satellites have been discussed as causes, but most of these cannot account for the full range of the phenomenon. Numerical models of clump scattering show that this process can produce near-exponential or core-Sérsic profiles in a variety of circumstances, also suggesting a connection to bulge and elliptical galaxy profiles. Density profile forms do not depend on the specifics of the scattering processes, but stellar kinematics and profile evolution rates do. Analytic models, with a power-law times a Sérsic profile form, can satisfy Jeans equations in cases dominated by either halo potentials (outer disk) or self-gravity (inner disk).

Final ID: 302.01

Predicting the Velocity Dispersions of the Dwarf Satellite Galaxies of Andromeda

S. S. McGaugh; [1];
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Abstract (2,250 Maximum Characters): Dwarf Spheroidal galaxies in the Local Group are the faintest and most diffuse stellar systems known. They exhibit large mass discrepancies, making them popular laboratories for studying the missing mass problem. The PANDAS survey of M31 revealed dozens of new examples of such dwarfs. As these systems were discovered, it was possible to use the observed photometric properties to predict their stellar velocity dispersions with the modified gravity theory MOND. These predictions, made in advance of the observations, have since been largely confirmed. A unique feature of MOND is that a structurally identical dwarf will behave differently when it is or is not subject to the external field of a massive host like Andromeda. The role of this "external field effect" is critical in correctly predicting the velocity dispersions of dwarfs that deviate from empirical scaling relations. With continued improvement in the observational data, these systems could provide a test of the strong equivalence principle.

Final ID: 302.02

Anomalous Motions in the Local Group: Evidence of a Past Milky Way–Andromeda Flyby?

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Abstract (2,250 Maximum Characters):

The expansion of the Universe is not homogeneous. In the Local Group (LG), Andromeda (M31) is approaching the Milky Way (MW) at ~110 km/s. To turn around the cosmic expansion locally to this extent, their combined mass must lie in a narrow range of values. This constrains the gravitational field in the LG. I will describe recent calculations (arXiv:1506.07569) solving test particle trajectories in this gravitational field. The major perturber to the LG, Centaurus A, is directly included in our model. Final radial velocities (RVs) are compared with observed RVs of LG dwarf galaxies.

We find a major discrepancy for all plausible initial MW and M31 masses. Although few objects have RVs much below the predictions of the best-fitting model, some have RVs much above them, by as much as 110 km/s. We find that these galaxies tend to lie within a plane. This plane aligns closely with the planes of satellite galaxies recently discovered around M31 and the MW.

We suggest that the observations can be explained by a past flyby encounter between these galaxies. This doesn't arise in LCDM but does in MOND. In this context, a simple calculation suggests that their planes of satellites can be formed tidally with their observed orientations only if the MW and M31 orbit within a particular plane. Our analysis of much more distant non-satellite galaxies with anomalously high RVs implies they prefer a very similar plane. The flyby time implied by the positions and velocities of these galaxies (~9 Gyr ago) roughly agrees with the time expected from a MOND calculation of the MW–M31 orbit. Interestingly, the velocity dispersion of the MW's disk increased suddenly at around this time, forming its thick disk.

Final ID: 302.03

Bar Formation from Galaxy Flybys

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Abstract (2,250 Maximum Characters): Both simulations and observations reveal that flybys—fast, one-time interactions between two galaxy halos—are surprisingly common, comparable to galaxy mergers. Since these are rapid, transient events with the closest approach well outside the galaxy disk, it is unclear if flybys can transform the galaxy in a lasting way. We conduct collisionless N-body simulations of three coplanar flyby interactions between pure-disk galaxies to take a first look at the effects flybys have on disk structure, with particular focus on stellar bar formation. We find that some flybys are capable of inciting a bar; bars form in both galaxies during our 1:1 interaction and in the secondary during our 10:1 interaction. The bars formed have ellipticities >0.5, sizes on the order of the scale length of the disk, and persist to the end of our simulations, ~5 Gyr after pericenter. The ability of flybys to incite bar formation implies that many processes associated with secular bar evolution may be more closely tied with flyby interactions than previously thought.

Final ID: 302.04

Orbits in N-body bars and the origin of the X-shapes in boxy-peanut bulges

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Abstract (2,250 Maximum Characters): Orbits in N-body bars were classified using an automated orbit classification method. We show that the well known prograde x1 orbit family originates from the same parent orbit as the box orbits in stationary and rotating triaxial ellipsoids. Nearly 70% of bar orbits are box orbits arising from the long-axis orbit and consequently have little net angular momentum in the bar frame (contrary to the standard view that x1 orbits have significant prograde motions). A small fraction of bar orbits (~7%) are long axis tubes that behave exactly like those in triaxial ellipsoids: they are tipped about the intermediate-axis due to the Coriolis force, with the sense of tipping determined by the sign of their angular momentum about the long axis. No orbits parented by prograde periodic x2 orbits are found in the pure bar model, but a tiny population (~2%) of short axis tube orbits parented by retrograde x4 orbits are found. When a central point mass representing a supermassive black hole (SMBH) is grown adiabatically at the center of the bar, orbits in the immediate vicinity of the SMBH are precessing Keplerian orbits (PKOs) which belong the same major families (short axis tubes, long axis tubes and boxes) occupying the bar at larger radii. Since orbits associated with the box family have three independent fundamental orbital frequencies, they are the most adaptable in shape and are therefore easily deformed to produce the boxy/peanut shape. In particular the resonant boxlet orbits (e.g. those associated with x1-banana, “fish/pretzel orbits” 3:2 resonance and the “brezel orbits” 5:3 resonance) are able to produce the X-shape or boxy-peanut shape that is see in edge-on bars. For the Milky Way bar we show that several of these boxlet orbits reproduce velocity separations observed in the red-clump stars on the near and far sides of the galactic center. This work is funded in part by University of Michigan’s Office of Research, HST-AR-13890.001 and NSF award AST-0908346.

Final ID: 302.05

Gas clouds as dynamical probes of the accretion flow around SgrA*

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Abstract (2,250 Maximum Characters): Sgr A* is our closest example of an accreting supermassive black hole. Important aspects of how the gas makes its way to the black hole, and why its so radiatively inefficient, remain unknown however. In this talk, I will discuss how we can use the change in orbital parameters of the G1 and G2 gas clouds as they move through the accretion flow to probe the gas at a critical range of radii.

Final ID: 302.06

Orbit of the OJ287 black hole binary as determined from the General Relativity centenary flare

M. Valtonen; [1]; *A. Gopakumar;* [2]; *S. Mikkola;* [1]; *S. Zola;* [3, 4]; *S. Ciprini;* [5, 6]; *K. Matsumoto;* [7]; *K. Sadakane;* [7]; *M. Kidger;* [8]; *K. Gazeas;* [9]; *K. Nilsson;* [1]; *A. Berdyugin;* [1]; *V. Piirola;* [1]; *H. Jermak;* [10]; *K. Baliyan;* [11]; *R. Hudec;* [12, 13]; *D. Reichart;* [14];

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Abstract (2,250 Maximum Characters): OJ287 goes through large optical flares twice each 12 years. The times of these flares have been predicted successfully now 5 times using a black hole binary model. In this model a secondary black hole goes around a primary black hole, impacting the accretion disk of the latter twice per orbital period, creating a thermal flare. Together with 6 flares from the historical data base, the set of flare timings determines uniquely the 7 parameters of the model: the two masses, the primary spin, the major axis, eccentricity and the phase of the orbit, plus a time delay parameter that gives the extent of time between accretion disk impacts and the related optical flares. Based on observations by the OJ287-15/16 Collaboration, OJ287 went into the phase of rapid flux rise on November 25, on the centenary of Einstein's General Relativity, and peaked on December 5. At that time OJ287 was the brightest in over 30 years in optical wavelengths. The flare was of low polarization, and did not extend beyond the optical/UV region of the spectrum. On top of the main flare there were a number of small flares; their excess brightness correlates well with the simultaneous X-ray data. With these properties the main flare qualifies as the marker of the orbit of the secondary going around the primary black hole. Since the orbit solution is strongly over-determined, its parameters are known very accurately, at better than one percent level for the masses and the spin. The next flare is predicted to peak on July 28, 2019.

Detailed monitoring of this event should allow us to test, for the first time, the celebrated black hole no-hair theorem for a massive black hole at the 10% level. The present data is consistent with the theorem only at a 30% level. The main difficulty in observing OJ287 from Earth at our predicted epoch is its closeness to the sun. Therefore, it is desirable to monitor OJ287 from a space-based telescope not in the vicinity of Earth. Unfortunately, this unique opportunity for testing the above celebrated theorem of General Relativity using OJ287 will not be available again until after several orbital cycles.

The full list of participants in the OJ287-15/16 Collaboration is found in ApJL 819, L37, 2016.

Final ID: 303.01

Could the Craters on the Mid-Sized Moons of Saturn Have Been Made by Satellite Debris?

H. C. Dones; [1]; *J. Alvarellos;* [5]; *E. B. Bierhaus;* [3]; *W. Bottke;* [1]; *M. Cuk;* [2]; *P. Hamill;* [6]; *D. Nesvorny;* [1]; *S. J. Robbins;* [1]; *K. Zahnle;* [4];

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Abstract (2,250 Maximum Characters): Saturn's mid-sized moons have usually been assumed to be primordial. However, Charnoz et al. (2011) and Crida and Charnoz (2012) showed that the steep trend of mass vs. distance of the moons out to Rhea is consistent with the spreading of an early massive ring (e.g., Canup 2010) beyond Saturn's Roche limit. In this model, Rhea would have formed before Dione, then Tethys, then Enceladus, and finally Mimas. These moons would still be billions of years old, but with Mimas forming perhaps 1 Gyr after Rhea.

Cuk et al. (2016) investigated the dynamical evolution of the mid-sized saturnian moons due to tides. They infer that the moons have migrated little. Tethys and Dione probably did not cross their 3:2 resonance, but the system likely did cross a Dione-Rhea 5:3 resonance and a Tethys-Dione secular resonance. These crossings would have happened recently; for Q = 1500 (Lainey et al. 2012), within the past 100 Myr. Cuk et al. suggested that a previous generation of moons underwent an orbital instability, perhaps due to a solar evection resonance, leading to collisions between them. Today's moons would have reaccreted from the debris. This model implies that most craters on the moons were formed by this debris, with impacts taking
place at much lower speeds than applies for impacts by comets.

Many crater properties, such as the depth-to-diameter ratio (Bray and Schenk 2015) and the amount of melting and vaporization (Kraus et al. 2011), depend on the impact velocity. We will discuss how measurements of craters in Cassini images of saturnian moons can be used to distinguish between the Cuk et al. scenario and the view in which the largest craters are made by comets and planetocentric debris makes only smaller craters (Alvarellos et al. 2005).

We thank the Cassini Data Analysis Program for support.

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Final ID: 303.02

Orbital and Rotational Dynamics of Pluto's Small Moons

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Abstract (2,250 Maximum Characters): Four small moons, Styx, Nix, Kerberos and Hydra, orbit the central binary planet comprising Pluto and Charon. Showalter and Hamilton (Nature 522, 45-49, 2015) analyzed Hubble Space Telescope (HST) data from 2010-2012 to explore some of the dynamical consequences of orbiting a binary planet. They noted evidence for a chaotic rotation of Nix and Hydra, and identified a possible three-body resonance between Styx, Nix and Hydra. We revisit the dynamics of the outer moons based on the data from the New Horizons flyby of July 2015, combined with three more years of HST data. As New Horizons was approaching Pluto, the LORRI camera regularly imaged the moons over a period of approximately 100 days. It also resolved the moons in closeup images, revealing details about the moons' sizes, shapes and surface properties. The LORRI data set has made it possible to derive light curves, rotation rates and pole orientations unambiguously. The moons rotate much faster than they orbit and have high obliquities, suggesting that tidal de-spinning has not played the dominant role in their rotational evolution; impacts may also have played an important role. We will discuss the latest conclusions from a joint analysis of the LORRI and HST data sets, combined with new dynamical simulations. This work was supported by NASA's New Horizons project and by Space Telescope Science Institute.

Final ID: 303.03

The fate of debris in the Pluto-Charon system

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Abstract (2,250 Maximum Characters): Pluto has recently been thrust into the spotlight with the fly-by of New Horizons. This dwarf planet and its moons provide an opportunity to study circumbinary dynamics close to home. We perform N-body simulations of a test-particle disk around the Pluto-Charon binary to study the fate of debris that should result from the formation of the Pluto-Charon binary. We not only investigate the stability and time evolution of debris within the Pluto system, but also track ejected debris to see where it may collect in the solar system. By studying the dynamics of the Pluto-Charon system, we may be able to place constraints on the cratering rates from its natal disk and identify tracers of the formation of this system.

Final ID: 303.04

Himalia and Phoebe: Little moons that punch above their weight

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Abstract (2,250 Maximum Characters): Small bodies in the solar system are usually treated as massless particles. While a sufficient approximation for many purposes, the small but finite mass of some of these (mass ratio $\mu=10^{-10}-10^{-8}$ of primary) can have observable consequences on the local population. Numerical experiments have shown this to be true for the orbital neighbourhood of Himalia, a prograde irregular moon of Jupiter (Christou 2005). In a recent demonstration of the same mechanism in a different context, Novaković et al. (2015) showed that the dwarf planet Ceres activates its own secular resonances, causing the long-term diffusion of asteroids in the middle part of the Main Belt.

Seeking to better understand the dynamics caused by “internecine” interactions, we have constructed a semi-analytical model of a test particle’s secular evolution in the Sun-Planet-massive moon-particle restricted 4-body problem. By combining the Kozai-Lidov formalism with a model of coorbital motion valid for non-planar & non-circular orbits (Namouni 1999) we have overcome the difficulty in treating the interaction between potentially-crossing neighbouring orbits.

We have applied this model to the cases of (a) J6 Himalia, a jovian irregular satellite ($\mu\simeq 2\times 10^{-9}$) and the largest in a family of five moons, and (b) S9 Phoebe, a retrograde irregular moon of Saturn with $\mu=1.5\times 10^{-8}$ which, curiously, is not associated with a family (Ćuk et al. 2003). We observe numerous instances of capture into secular resonances where the critical angle is a linear combination of the relative nodes and apses of the particle and the perturber. In particular we are able to reproduce the libration of the differential node found by Christou (2005). We generate fictitious families of test particles around Himalia and Phoebe and find that, while ~8% of local phase space is occupied by these resonances for Himalia, this figure is ~16% for Phoebe. We confirm these results using N-body integrations of the full equations of motion. During the meeting, we will show examples of orbital evolution in the resonances, describe the principal features of the dynamics and discuss the implications for the long-term evolution of families of small bodies.

Final ID: 303.05

Designing Asteroid Impact Scenario Trajectories

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Abstract (2,250 Maximum Characters): In order to study some of the technical and geopolitical issues of dealing with an asteroid on impact trajectory, a number of hypothetical impact scenarios have been presented over the last ten years or so. These have been used, for example, at several of the Planetary Defense Conferences (PDCs), as well as in tabletop exercises with the Federal Emergency Management Agency (FEMA), along with other government agencies. The exercise at the 2015 PDC involved most of the attendees, consisted of seven distinct steps ("injects"), and with all the presentations and discussions, took up nearly 10 hours of conference time. The trajectory for the PDC15 scenario was entirely realistic, and was posted ahead of the meeting. It was made available in the NEO Program's Horizons ephemeris service so that users could , for example, design their own deflection missions. The simulated asteroid and trajectory had to meet numerous very exacting requirements: becoming observable on the very first day of the conference, yet remaining very difficult to observe for the following 7 years, and far enough away from Earth that it was out of reach of radar until just before impact. It had to be undetectable in the past, and yet provide multiple perihelion opportunities for deflection in the future. It had to impact in a very specific region of the Earth, a specific number of years after discovery. When observations of the asteroid are simulated to generate an uncertainty region, that entire region must impact the Earth along an axis that cuts across specific regions of the Earth, the "risk corridor". This is important because asteroid deflections generally move an asteroid impact point along this corridor. One scenario had a requirement that the asteroid pass through a keyhole several years before impact. The PDC15 scenario had an additional constraint that multiple simulated kinetic impactor missions altered the trajectory at a deflection point midway between discovery and impact. This talk will describe a few recent impact scenarios and outline techniques for finding trajectories that satisfy the complex constraints.

Final ID: 303.06

Spin State Equilibria of Asteroids due to YORP Effects

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Abstract (2,250 Maximum Characters): Spins of small asteroids are controlled by the Yarkovsky--O'Keefe--Radzievskii--Paddack (YORP) effect. The normal version of this effect has two components: the axial component alters the rotation rate, while the obliquity component alters the obliquity. Under this model the rotation state of an asteroid can be described in a phase plane with the rotation rate along the polar radius and the obliquity as the polar angle. The YORP effect induces a phase flow in this plane, which determines the distribution of asteroid rotation rates and obliquities.

We study the properties of this phase flow for several typical cases. Some phase flows have stable attractors, while in others all trajectories go to very small or large rotation rates. In the simplest case of zero thermal inertia approximate analytical solutions to dynamics equations are possible. Including thermal inertia and the Tangential YORP effect makes the possible evolutionary scenarios much more diverse. We study possible evolution paths and classify the most general trends. Also we discuss possible implications for the distribution of asteroid rotation rates and obliquities.

A special emphasis is put on asteroid (25143) Itokawa, whose shape model is well determined, but who's measured YORP acceleration does not agree with the predictions of normal YORP. We show that Itokawa's rotational state can be explained by the presence of tangential YORP and that it may be in or close to a stable spin state equilibrium. The implications of such states will be discussed.

Final ID: 303.07

Low-Energy Asteroid and Comet Transit Analysis using Isolating Blocks

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Abstract (2,250 Maximum Characters): It is well known that asteroids and comets typically capture or transit near a planet by traveling through the L_1 and L_2 libration point gateways. These regions are therefore key to understanding the mechanism by which these captures, transits, and potential impacts occur. Recently, Anderson, Easton, and Lo (2015) explored the L_2 region in the Earth-Moon system using isolating blocks in the circular restricted three-body problem (CRTBP). Isolating blocks provide a theoretically rigorous method for computing the invariant manifolds of libration point periodic orbits and all possible transit trajectories at a particular Jacobi constant in the CRTBP. Using isolating block methods allows us to directly compute and study the transit trajectories used by comets and asteroids in the low-energy regimes common for these types of bodies. In this study, both L_1 and L_2 isolating blocks are computed for the Sun-Earth and Sun-Jupiter CRTBP systems to compute trajectories transiting near the Earth and Jupiter. Statistics based on transit time, periapse passages, and exit location are first computed. Then individual trajectory solutions corresponding to different trajectory types are analyzed. The transit trajectories are also characterized using their orbital elements and compared to known comets and asteroids. These results show that the invariant manifolds of the orbits in the isolating block control and guide the dynamics of comets and asteroids as they temporarily capture between the L_1 and L_2 region of a planet or satellite.

Reference: Anderson, R. L., R. W. Easton, M. W. Lo (2015), AAS/AIAA Astrodynamics Conf., AAS 15-615.

Final ID: 400.01

Propeller peregrinations: Ongoing observations of disk-embedded migration in Saturn’s rings

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Abstract (2,250 Maximum Characters): The "propeller" moons within Saturn's rings are the first objects ever to have their orbits tracked while embedded in a disk, rather than moving through empty space (Tiscareno et al. 2010, ApJL). The km-sized "giant propellers" whose orbits have been tracked in the outer-A ring, as well as their smaller 0.1-km-sized brethren swarming in the mid-A ring, are not seen directly; rather, their locations are inferred by means of the propeller-shaped disturbances they create in the surrounding ring material (Tiscareno et al. 2006, Nature; Sremcevic et al. 2007, Nature; Tiscareno et al. 2008, AJ). The orbits of giant propellers are primarily Keplerian, but with clear excursions of up to several degrees longitude over a decade of observations. Most theories that have been proposed to explain the non-Keplerian motion of propeller moons (e.g., Pan et al. 2012, MNRAS; Tiscareno 2013, P&SS) rely on gravitational and/or collisional interactions between the moon and the surrounding disk, and thus hold out the prospect for directly observing processes that are important in protoplanetary scenarios and other disk systems. We will review the current dynamical models and report on recent ongoing observations by the Cassini imaging camera.

Final ID: 400.02

Keeping the Edges Sharp II: Honing Simulations of Narrow Rings

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Abstract (2,250 Maximum Characters): It has long been believed that shepherd satellites are necessary to keep narrow rings confined. While a pair of nearby satellites brackets Saturn's F ring and Uranus' Epsilon ring, dozens of other ringlets observed around the outer three planets seem to be unattended. Hamilton et al. (this meeting) have argued analytically that eccentric or inclined rings can maintain their sharp edges for millions or even billions of years despite continually dissipating energy. Here, we present numerical integrations showing isolated eccentric ringlets that do not spread; our model includes only the gravity from an oblate planet, ring self-gravity, and viscosity. We use the symplectic integrator epi_int written by Hahn & Spitale (2013).
For narrow rings, the weak perturbation forces that we study act on secular rather than orbital timescales. Therefore, we find that we can use an unusually long timestep, in which these weak forces are applied once every ~30 orbits, with good energy and angular momentum conservation. Long timesteps allow us to run simulations that might otherwise take hours or even days in a matter of minutes. We present comparisons between simulations with identical initial conditions but varying timesteps to show that our approach is appropriate for this class of problems. This technique of speeding up numerical integrations works for any symplectic integrator, requiring only that the forces be weak and that the timescale of interest be long. Problems well suited to this approach (those with only secular and drag forces) include tidally-damped exoplanets and dust grains subject to radiation pressure and Poynting-Robertson drag.

Final ID: 400.03

Kronoseismology III: An update on Saturn-driven waves in the C ring

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Abstract (2,250 Maximum Characters): In previous work (Hedman & Nicholson [2013] Astron. J. 146, 12; Ibid [2014] MNRAS 444, 1369; French et al. [2016] Icarus, in press) we have identified 9 inward-propagating density waves in Saturn's C ring with outer Lindblad resonances (OLRs) generated by internal oscillations in Saturn. The oscillations involved are sectoral f-modes (ie., fundamental modes with l = m) with m = 1, 2, 3, 4 and 10. In addition, 5 outward-propagating waves between radii of 84,800 and 86,600 km have been identified as density waves driven by 3:2 tesseral resonances with fixed gravitational anomalies within the planet. (See Hedman et al., this conference.)

We have now examined additional C ring waves from the catalog of Baillie et al. [2011], in an attempt to identify several weaker and shorter-wavelength waves in the inner C ring. We use a modified version of our previous wavelet-based technique to coadd phase-corrected spectra from multiple occultations, using trial values of \`m\` and the pattern speed to predict their relative phases. This enables us to detect waves too weak to see in individual occultations. To date, 6 new waves have been identified. Two appear to be due to additional saturnian f-modes, with m = 2 and m = 9. The other 4 waves appear to be a new variety: outward-propagating bending waves driven at outer vertical resonances (OVRs) with Saturn internal oscillations with l = m + 1. We find waves with m = 4, 7, 8 & 9. All of the newly-identified waves are at radii less than 77,000 km and only the m = 4 OVR is near the location predicted by Marley & Porco [1993].

Final ID: 400.04

An array of asymmetries in Saturn's structure revealed by its rings

M. M. Hedman; [1]; *P. D. Nicholson;* [2]; *M. El Moutamid;* [2]; *S. Graven;* [1];
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2. Cornell University, Ithaca, NY, United States.

Abstract (2,250 Maximum Characters): Previous investigations of high-resolution stellar occultation data obtained by the Cassini spacecraft have revealed that Saturn's C ring contains numerous density waves that are probably generated by structures inside the planet. In particular, five features were attributed to long-lived asymmetries in the planet's gravity field because they had pattern speeds similar to the range of rotation rates found in Saturn's winds. Using wavelet-based techniques, we have performed a more comprehensive search for similar structures, and found that the above five waves are just the most obvious members of an entire population of ring disturbances spread over several thousand kilometers of the C ring. These structures should provide new insights into the dynamics of Saturn's deep atmosphere.

Final ID: 400.05

Tesseral resonances in the rings of Saturn

M. El Moutamid; [1]; *P. D. Nicholson;* [1]; *M. M. Hedman;* [2]; *P. J. Gierasch;* [1]; *J. A. Burns;* [1]; *R. G. French;* [3];
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2. Idaho University, Moscow, ID, United States.
3. Wellesley college, Wellesley, MA, United States.

Abstract (2,250 Maximum Characters): We will present a study of the behavior of the A, B, C and D rings using images and occultation data obtained by the Cassini spacecraft over a period of 8 years from 2006 to 2015. We have identified a variety of free and forced normal modes at the edge of the A ring, with values of "m" ranging from 3 to 18 and appropriate pattern speeds (El Moutamid et al, 2016). These modes may represent waves trapped in resonant cavities at the edge (Spitale and Porco 2010, Nicholson et al 2014). Moreover, Hedman et al. (2009) have identified structures in the D ring and the Roche division which appear to rotate with Saturn. These may represent Tesseral resonances associated with inhomogeneities in Saturn's interior.

We are now searching for wave-like signatures in the main rings which are not associated with edges but also related to the rotation period of Saturn. We have identified several signatures consistent with other Tesseral resonances. These signatures may provide information about differential rotation in Saturn's interior.

Final ID: 400.06

Physical characteristics of "wisps" in the outer edge of the Keeler Gap in Saturn's rings

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Abstract (2,250 Maximum Characters): We present a catalog of detected `wisps', small protrusions of material (0.5 to 2 km) into the Keeler Gap of Saturn's rings from the gap's outer edge. Wisps are characterized by a sharp trailing edge followed by a slow gradation back into the edge on the leading side, typically extending between 0.1 and 1 degree of longitude (240 to 2400 km). Fewer than 1% of observed wisps deviate from this morphology, the variants having either the sharp edge on the leading side (reversed) or having a more complex morphology (often roughly symmetric about the feature's midpoint).

Focusing on a suite of images taken between Feb 2009 and May 2009, we measure the Daphnis-relative motion of the wisps to be 0.102 +- 0.002 deg/day, which indicates a semimajor axis ~1km inward of the Keeler Gap outer edge (for which the Daphnis-relative mean motion is 0.114 deg/day). We conclude that wisps are most likely the signatures of moonlets ejected from the ring into the Keeler Gap.

Final ID: 401.01

The Gravity Field of Saturn and the Mass of the Saturnian Rings at the end of the Cassini Mission

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Abstract (2,250 Maximum Characters): Following its flyby of Titan on 2016 November 29, Cassini will begin a set 20 high inclination orbits, known as the F-ring orbits, that pass over the ring plane and have periapses near the F-ring. The final Titan flyby on 2017 April 22 will redirect the spacecraft into the proximal orbits, a series 22 orbits with periapses between the innermost D-ring and the upper layer of Saturn's atmosphere. The proximal orbits will be strongly perturbed the gravitational field of Saturn and slightly perturbed by the gravity of rings. The ring gravity will also affect the F-ring orbits. This paper presents the results of an analysis of simulated radiometric data acquired during the final 42 Cassini orbits. We investigate the sensitivity of the data to the ring mass and gravitational harmonics of the planet. We limit the simulated data quantity to the DSN coverage currently being requested by the Cassini Project augumented by several critical passes expected to be obtained from ESA southern hemisphere stations. We assume a data accuracy consistent with projected effects of solar plasma. In the dynamical model of the spacecraft motion we account for non-gravitational accelerations caused by the planned momentum management to be performed with Reaction Wheel Assembly and thrusters, by the Radioisotope Thermo-electric Generator, and by solar radiation pressure. We use a weighted-least squares procedure to obtain estimates of spacecraft's state, masses of the rings, the gravity harmonics, and the non-gravitational accelerations. We find that the final orbits of the Cassini mission should yield high accuracy estimates of the gravitational harmonics through J12 and statistically meaningful estimates of the A- and B-ring masses.

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 Adminstration.

Final ID: 401.02

4-km body(ies?) embedded in Saturn's Huygens Ringlet

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Abstract (2,250 Maximum Characters): Saturn's 20-km-wide Huygens ringlet, located ~250 km exterior to the B ring, displays unusual kinematics, as evidenced by a time variable width-relation. The cause of this behavior is not clear, but may be related to the presence of large embedded bodies (Spitale and Hahn 2016). The largest such bodies produce half-propeller-shaped disturbances originating at the inner edge of the ringlet, whose radial widths imply a size of ~4 km, based on simple scaling from A-ring propellers. Here, we show that a numerical N-body model of the ringlet with a 4-km body embedded near the inner edge produces features that are consistent with the observed half propellers.

Final ID: 401.03

Persistent pattern speeds in Saturn's D ring

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Abstract (2,250 Maximum Characters): Saturn's D ring is the innermost part of Saturn's ring system. Due to its close proximity to the planet, it is sensitive to perturbing forces caused by asymmetries in Saturn's interior and magnetic field. Using high-phase-angle images obtained by the Imaging Science Subsystem (ISS) over the course of the entire Cassini mission we investigate the region between 71000-73000 km from Saturn's center. Previous studies have shown that this region contains azimuthal brightness variations generated by periodic perturbing forces with frequencies close to Saturn's rotation rate (nearly twice the local orbital period). These structures are not due to a single resonance, but instead involve a complex network of patterns drifting past one another over time. Some of these could be caused by asymmetries in Saturn's magnetosphere, which have rotation rates that have been observed to change over the course of the Cassini mission. However, some patterns may be generated by perturbations from long-lived gravitational anomalies inside the planet that move at speeds comparable to Saturn's winds. By comparing observations taken over several years we can distinguish the patterns caused by each phenomenon. We identify multiple structures with nearly constant pattern speeds that would appear to be due to persistent structures inside the planet. Strangely, the rotation rates required to produce these D ring structures are different from those responsible for generating waves in the C ring (where the local orbital rate is roughly 3/2 Saturn's rotation rate).