Partnership, and the Vatican Observatory for the consistent allocation of telescope time over the last 12 years of this project.

Author(s): Stephen C. Tegler[1], William Romanishin[2], Guy Consolmagno[3]
Institution(s): *1. Northern Arizona University, 2. University of Oklahoma, 3. Vatican Observatory*

106.06 – Lightcurve Studies of Trans-Neptunian Objects from the Outer Solar System Origins Survey using the Hyper Suprime-Camera

Lightcurves can reveal information about the gravitational processes that have acted on small bodies since their formation and/or their gravitational history.
At the extremes, lightcurves can provide constraints on the material properties and interior structure of individual objects.
In large sets, lightcurves can possibly shed light on the source of small body populations that did not form in place (such as the dynamically excited trans-Neptunian Objects (TNOs)).
We have used the sparsely sampled photometry from the well characterized Outer Solar System Origins Survey (OSSOS) discovery and recovery observations to identify TNOs with potentially large amplitude lightcurves.
Large lightcurve amplitudes would indicate that the objects are likely elongated or in potentially interesting spin states; however, this would need to be confirmed with further follow-up observations.
We here present the results of a 6-hour pilot study of a subset of 17 OSSOS objects using Hyper Suprime-Cam (HSC) on the Subaru Telescope.
Subaru's large aperture and HSC's large field of view allows us to obtain measurements on multiple objects with a range of magnitudes in each telescope pointing.
Photometry was carefully measusured using an elongated aperture method to account for the motion of the objects, producing the short but precise lightcurves that we present here.
The OSSOS objects span a large range of sizes, from as large as several hundred kilometres to as small as a few tens of kilometres in diameter.
We are thus investigating smaller objects than previous light-curve projects have typically studied.

Author(s): Mike Alexandersen[1], Susan D Benecchi[6], Ying-Tung Chen[1], Megan Elizabeth Schwamb[4], Shiang-Yu Wang[1], Matthew Lehner[1], Brett Gladman[8], JJ Kavelaars[5],Jean-Marc Petit[3], Michele T Bannister[9], Stephen Gwyn[2], Kathryn Volk[7]
Institution(s): *1. Academia Sinica Institute of Astronomy and Astrophysics (ASIAA), 2. Canadian Astronomy Data Centre, 3. CNRS / Observatoire De Besançon, 4. Gemini Observatory, 5. National Research Council of Canada, 6. Planetary Science Institute, 7. University of Arizona, 8. University of British Columbia, 9. University of Victoria*

106.07 – ALMA Observations of TNOs

Some of the most fundamental properties of TNOs are still quite poorly constrained, including diameter and density. Observations at long thermal wavelengths, in the millimeter and submillimeter, hold promise for determining these quantities, at least for the largest of these bodies (and notably for those with companions). Knowing this information can then yield clues as to the formation mechanism of these bodies, allowing us to distinguish between pairwise accretion and other formation scenarios.
We have used the Atacama Large Millimeter/Submillimeter Array (ALMA) to observe Orcus, Quaoar, Salacia, and 2002 UX25 at wavelengths of 1.3 and 0.8 mm, in order to constrain the sizes of these bodies. We have also used ALMA to make astrometric observations of the Eris-Dysnomia system, in an attempt to measure the wobble of Eris and hence accurately determine its density. Dysnomia should also be directly detectable in those data, separate from Eris (ALMA has sufficient resolution in the configuration in which the observations were made). Results from these observations will be presented and discussed.

Author(s): Bryan J. Butler[2], Michael E. Brown[1]
Institution(s): *1. Caltech, 2. NRAO*

106.08 – Taking The Measure of Makemake's Moon

We present the discovery and characterization of S/2015 (136472) 1, a satellite of the dwarf planet Makemake. The satellite was discovered in Hubble Space Telescope (HST) imagery collected in spring of 2015, found at a separation of 0.57” and ~1,300 times fainter than Makemake at the discovery epoch. The system was imaged in two visits separated by two days, and the satellite was visible in the first visit but undetectable in the second. Previous HST satellite searches also did not reveal S/2015 (136472) 1. Current observations constrain the satellite’s orbit to be near an edge-on configuration, placing the system near a mutual event season. Follow-up observations will permit the measurement of Makemake’s mass and density, as well as identify whether there is an upcoming mutual event season. We will discuss the current state of characterization of the system and its implications for Makemake’s bulk, thermal, and surface properties, spin state, and the origin of S/2015 (136472) 1. Finally, we will address the current state of understanding regarding the population of dwarf planet satellites.

Author(s): Alex Harrison Parker[3], Marc W. Buie[3], Will Grundy[1], Keith S. Noll[2]
Institution(s): *1. Lowell Observatory, 2. NASA GSFC, 3. Southwest Research Institute*

106.09 – 2003 $_{AZ}$84: Size, shape, albedo and first detection of topographic features

We analyze two multi-chord stellar occultations by the Trans-Neptunian Object (TNO) 2003 AZ84 observed on February 3, 2012 and November 15, 2014.
They provide different elliptical limb fits that are consistent to within their respective error bars, but could also suggest a possible precession of the object (assumed here to be a Maclaurin spheroid). The derived equatorial radius and oblateness are R_e = 393 ± 7 km and ε = 0.057 in 2014 and R_e = 414 ± 13 km and ε = 0.165 in 2012, respectively. Those results are consistent with single-chord events observed in January 2011 and December 2013.
The figures above provide geometric visual albedos of $p_{V(2014)}$ = 0.112 ± 0.008 and $p_{V(2012)}$ = 0.114 ± 0.020. Using the Maclaurin assumption, combined with possible rotational periods of 6.67 h and 10.56 h, we estimate density upper limits of 1.89 ± 0.16g/cm^3 and 0.77 ± 0.07g/cm^3 for the two dates, respectively.
The 2014 event provides (for the first time during a TNO occultation) a grazing chord with a gradual disappearance of the star behind 2003$_{AZ}$84's limb that lasts for more than 10 seconds. We rule out the possibility of a localized dust concentration as it would imply very high optical depth for that cloud. We favor a local topographic feature (chasm) with minimum width and depth of 22 ± 2.5 km and 7 ± 2.0 km, respectively. Features with similar depths are in fact observed on Pluto's main satellite, Charon, which has a radius of about 605 km, comparable to that of 2003$_{AZ}$84.

Author(s): Alex Dias-Oliveira[17], Bruno Sicardy[13], Jose-Luis Ortiz[4], Felipe Braga-Ribas[2], Roberto Vieira-Martins[17], Gustavo BENEDETTI Rossi[17], julio camargo[17], Marcelo Assafin[16], Altair Gomes-Júnior[16], Tapas Baug[19], Thyagarajan Chandrasekhar[19], Rene Duffard[4], Zhao Ergang[1], Shashikiran Ganesh Ganesh[19], Yasukazu Ikari[6], Puji Irawati[9],Rajmal Jain[19], Zhu Liying[1], Andrea Richichi[9], Qian

Shengbang[1], Raoul Behrend[11], Zouhair Benkhaldoun[8], Noah Brosch[23], Ahmed Daassou[8], Avishay Gal-Yam's[22], Rubén Garcia-Lozano[15], Michael Gillon[3], Emmanuel Jehin[3], Shai Kaspi[23], Alain Klotz[21], Jean Lecacheux[13], Putra Mahasena[18], Jean Manfroid[3], Ilan Manulis[22], Alain Maury[20], Vijay Mohan[5], Nicolas Morales[4], Claudine Rinner[8], françoise Roques[13], Amar Sharma[10], Stefano Sposetti[11], Paolo Tanga[12], Audrey Thirouin[7], Frederic Vachier[14], Thomas Widemann[13]
Institution(s): *1. Chinese Academy of Sciences, 2. Federal University of Technology - Parana (UTFPR / DAFIS), 3. Institut d'Astrophysique, de Geophysique et Oceanographie, 4. Instituto de Astrofsica de Andaluca-CSIC,, 5. IUCAA Girawali Observatory,, 6. Japan Occultation Information Network, 7. Lowell Observatory, 8. Moroccan Oukaimeden Sky Survey, 9. National Astronomical Research Institute of Thailand,, 10. Nikaya Observatory, 11. Observatoire de Geneve, 12. Observatoire de la Côte d'Azur, 13. Observatoire de Paris/LESIA, 14. Observatoire de Paris?IMCCE, 15. OBSERVATORIO ASTRONÓMICO BUSOT, 16. Observatorio do Valongo/UFRJ, 17. Observatório Nacional, 18. Observatorium Bosscha, 19. Physical Research Laboratory, 20. San Pedro de Atacama Celestial Explorations, 21. Universite de Toulouse,, 22. Weizmann Institute of Scienc, 23. Wise Observatory*

107 – Planetary Rings I: Saturn Propellers and Particle Properties

107.01 – Propeller peregrinations: Ongoing observations of disk-embedded migration in Saturn's rings

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.

Author(s): Matthew S. Tiscareno[1]
Institution(s): *1. SETI Institute*
Contributing team(s): Cassini Imaging Team

107.02 – Simulating the Librational Behaviour of Propeller Moons In The Saturnian Ring System

The propeller structure Blériot orbiting in the outer A ring of the Saturnian ring system has been one of the tremendous discoveries of the spacecraft Cassini [Tiscareno et al., 2010, ApJL]. The reconstruction of the orbital evolution of Blériot from recurrent observations in the ISS images yielded a systematic offset motion from the expected Keplerian orbit. This offset motion can be well described by three sinusoidal harmonics with amplitudes and periods of 1845, 152, 58 km and 11.1, 3.7 and 2.2 years, respectively [Sremčević et al., 2014, EPSC]. Oscillatory deviations from the Keplerian orbit are a known phenomenon for the Saturnian moons, which can be explained by resonant interactions with other moons [Spitale et al., 2006, AJ] and which look similar to the observation of Blériot.
In this work we present our results from N-Body simulations, where we integrated the orbital evolution of a test particle, orbiting at the radial position of the propeller Blériot and 15 other moons of Saturn. Our simulation yield, that gravitational interactions with the larger moons result in reasonable and observable frequencies, but the resulting amplitudes of the librations are by far too small to explain the observations. Further mechanisms are needed, to amplify the amplitudes of the forced librations -- as e.g. by moonlet-ring interactions. Inspired by the recent work of Pan and Chiang [2010, ApJL; 2012, AJ] we introduce an alternative, physically more reasonable model. In our model, the moonlet is allowed to be slightly displaced with respect to its created gaps, resulting in a repulsive force. As a result, the moonlet's longitude starts to oscillate. In the presence of the additional external forcing by the outer moons the libration amplitude gets amplified, if the forcing frequency is close to the eigenfrequency of the system. Applying our model to Blériot, we can indeed reproduce a libration period of 13 years with an amplitude of about 2000 km.

Author(s): Michael Seiler[1], Martin Seiss[1], Holger Hoffmann[1], Frank Spahn[1]
Institution(s): *1. University of Potsdam*

107.03 – Analyzing Bleriot's propeller gaps in Cassini NAC images

Among the great discoveries of the Cassini mission are the propeller-shaped structures created by small moonlets embedded in Saturn's dense rings. These moonlets are not massive enough to counteract the viscous ring diffusion to open and maintain circumferential gaps, distinguishing them from ring-moons like Pan and Daphnis.
Although one of the defining features of propeller structures, well-formed partial gaps have been resolved by the Imaging Science Subsystem Narrow Angle Camera onboard the Cassini spacecraft only for the largest known propeller named Bleriot. We analyze images of the sunlit side of Saturn's outer A ring showing the propeller Bleriot with clearly visible gaps. By fitting a Gaussian to radial brightness profiles at different azimuthal locations, we obtain the evolution of gap minimum and gap width downstream of the moonlet.
We report two findings:

1) Numerical simulations indicate that the radial separation of the partial propeller gaps is expected to be 4 Hill radii (Spahn and Sremcevic, 2000, A&A). We infer Bleriot's Hill radius to be a few hundred meters, consistent with values given by Sremcevic et al. (2014, DPS) and Hoffmann et al. (2015, Icarus).
2) In order to estimate the ring viscosity in the region of Saturn's outer A ring, where Bleriot orbits, we fit several model functions (one example being the analytic solution derived by Sremcevic, Spahn and Duschl, 2002, MNRAS) describing the azimuthal evolution of the surface density in the propeller gap region to the data obtained from the image analysis. We find viscosity values consistent with the parameterization of ring viscosity by Daisaka et al. (2001, Icarus), but significantly lower than the upper limit given by Esposito et al. (1983, Icarus)

Author(s): Holger Hoffmann[2], Cheng Chen[1], Martin Seiß[2], Nicole Albers[3], Frank Spahn[2]
Institution(s): *1. 1.Graduated Institute of Astronomy, National Central University, 2. Institute of Physics and Astronomy, Universty of Potsdam, 3. LASP/University of Colorado*
Contributing team(s): Nic

107.04 – Hydrodynamic simulations of moonlet induced propellers and the size of Blériot