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The Kuiper Belt Electronic Newsletter

Edited by: Joel Wm. Parker

ekonews@boulder.swri.edu www.boulder.swri.edu/ekonews

CONTENTS

NEWS & ANNOUNCEMENTS

NEW HORIZONS KUIPER BELT EXTENDED MISSION
SCIENCE PLANNING OPPORTUNITY

The centerpiece of the proposed New Horizons Kuiper Belt Extended Mission (NH-KEM) is the very close flyby of the 20-40 km wide KBO 2014 MU69 on 1 January 2019. NH-KEM will also observe ~20 other KBOs at phase angles and/or at resolutions not otherwise possible, producing a unique database of KBO phase curves, satellite searches, and ring searches.

On July 1 NASA approved the NH-KEM, which included plans to reach out to the planetary community for ideas to optimize the scientific return. The NH Project is holding two KEM WebEx workshops, one from 1-3 pm EDT on Sep 13 and one from 1-4 pm EDT on Oct 10, to discuss potential community involvement in planning the NH-KEM. If you are interested in participating in these workshops, please send an email ASAP to the NH Project Scientist, Hal Weaver (`hal.weaver@jhuapl.edu`). He will then provide you with further details about these workshops.

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There were 284 new TNO discoveries announced since the previous issue of *Distant EKOs*:

2010 LB136, 2010 MQ116, 2010 OO127, 2010 RD188, 2010 RE188, 2010 RF188,
2010 SS43, 2010 TA192, 2010 TD192, 2010 TE192, 2010 TF192, 2010 TG192,
2010 TJ182, 2010 TK192, 2010 TL182, 2010 TM182, 2010 TN182, 2010 VV224,
2010 VW224, 2010 VX224, 2011 BS163, 2011 BV163, 2011 CX119, 2011 OA60,
2011 UK413, 2011 VJ24, 2011 XJ4, 2012 BV154, 2012 BW154, 2012 BY154, 2012 CS57,
2012 DA99, 2012 DB99, 2012 DW98, 2012 DX98, 2012 DZ98, 2012 FK84, 2012 HL85,
2012 JH67, 2012 KW51, 2012 SB67, 2012 TC324, 2012 TD324, 2012 TE324, 2012 TF324,
2012 UB178, 2012 UC178, 2012 UE178, 2013 AQ183, 2013 BN82, 2013 CD223,
2013 EC138, 2013 EH154, 2013 EJ154, 2013 FR28, 2013 HU156, 2013 HV156,
2013 HW156, 2013 HY156, 2013 HZ156, 2013 JV65, 2013 JW65, 2013 LY35, 2013 MA12,
2013 NK24, 2013 NL24, 2013 NM24, 2013 PV74, 2013 PW74, 2013 PX74, 2013 TM159,
2013 UF15, 2013 UK15, 2013 VF24, 2013 XB26, 2013 XC26, 2013 XD26, 2014 AL55,
2014 AM55, 2014 BV64, 2014 BW64, 2014 BX64, 2014 BZ57, 2014 CO23, 2014 CQ23,
2014 DD143, 2014 DE143, 2014 DF143, 2014 DH143, 2014 DJ143, 2014 DK143,
2014 DL143, 2014 DM143, 2014 DN143, 2014 DO143, 2014 DP143, 2014 DR143,
2014 DU143, 2014 EA52, 2014 FG72, 2014 GA54, 2014 GB54, 2014 GC54, 2014 GE54,
2014 GF54, 2014 GJ54, 2014 GK54, 2014 GM54, 2014 GS53, 2014 GT53, 2014 GU53,
2014 GW53, 2014 GX53, 2014 GY53, 2014 GZ53, 2014 HB200, 2014 HD200, 2014 HT199,
2014 HU199, 2014 HV199, 2014 HW199, 2014 HX199, 2014 HZ199, 2014 JH80, 2014 JJ80,
2014 JK80, 2014 JL80, 2014 JN80, 2014 JO80, 2014 JP80, 2014 JQ80, 2014 JR80,
2014 JS80, 2014 JT80, 2014 JV80, 2014 KC102, 2014 KD102, 2014 KS101, 2014 KT101,
2014 KU101, 2014 KV101, 2014 KW101, 2014 KX101, 2014 KY101, 2014 LO28,
2014 LP28, 2014 LQ28, 2014 LR28, 2014 LS28, 2014 LT28, 2014 MA70, 2014 MB70,
2014 MC70, 2014 MD70, 2014 ME70, 2014 MF70, 2014 MG70, 2014 MH70, 2014 MY69,
2014 MZ69, 2014 NA66, 2014 NB66, 2014 NC66, 2014 NY65, 2014 NZ65, 2014 OA394,
2014 OB394, 2014 OC394, 2014 OD394, 2014 OE394, 2014 OF394, 2014 OG394,
2014 OH394, 2014 OK394, 2014 OL394, 2014 OM394, 2014 OV393, 2014 OZ393,
2014 PS70, 2014 QA442, 2014 QW441, 2014 QX441, 2014 QY441, 2014 QZ441,
2014 RQ63, 2014 SH349, 2014 SJ349, 2014 SK349, 2014 TA86, 2014 TB86, 2014 TC86,
2014 TD86, 2014 TW85, 2014 TX85, 2014 TY85, 2014 TZ85, 2014 UO224, 2014 UP224,
2014 UQ224, 2014 US224, 2014 UT224, 2014 UU224, 2014 VU37, 2014 VW37,
2014 WA509, 2014 WA510, 2014 WB509, 2014 WB510, 2014 WC509, 2014 WC510,

2014 WD509, 2014 WE509, 2014 WE510, 2014 WF509, 2014 WF510, 2014 WG509, 2014 WG510, 2014 WH509, 2014 WJ509, 2014 WK510, 2014 WL509, 2014 WM509, 2014 WN509, 2014 WO509, 2014 WO510, 2014 WP509, 2014 WP510, 2014 WQ509, 2014 WQ510, 2014 WR509, 2014 WR510, 2014 WS509, 2014 WT509, 2014 WU509, 2014 WV509, 2014 WW509, 2014 WX509, 2014 WY509, 2014 WZ509, 2014 XR40, 2014 XS40, 2014 XT40, 2014 XU40, 2014 YA50, 2014 YB50, 2014 YC50, 2014 YG50, 2014 YJ50, 2014 YZ49, 2015 AH281, 2015 AJ281, 2015 AK281, 2015 AL281, 2015 AN281, 2015 BA519, 2015 BE519, 2015 BF519, 2015 BG519, 2015 BL518, 2015 BM518, 2015 BN518, 2015 BO518, 2015 BP518, 2015 BQ518, 2015 BR518, 2015 BS518, 2015 BT518, 2015 BU518, 2015 BV518, 2015 BW518, 2015 BX518, 2015 BY518, 2015 BZ518, 2015 CL62, 2015 FL345, 2015 FM345, 2015 FN345, 2015 FO345, 2015 FP345, 2015 FR345, 2015 FS345, 2015 GQ50, 2015 GS50, 2015 OV79

and 173 new Centaur/SDO discoveries:

2010 DN93, 2010 MR116, 2010 PP81, 2010 TB192, 2010 TU191, 2010 TV191, 2010 XE91, 2011 BR163, 2011 BT163, 2011 BU163, 2011 CW119, 2011 CY119, 2011 GM89, 2011 LZ28, 2011 OB60, 2011 UH413, 2011 UJ413, 2011 WJ157, 2011 YN79, 2012 BA155, 2012 BX154, 2012 BZ154, 2012 DY98, 2012 EE18, 2012 FL84, 2012 HK85, 2012 OL6, 2012 UD178, 2013 AP183, 2013 AR183, 2013 AS183, 2013 AT183, 2013 CE223, 2013 FN28, 2013 FS28, 2013 FT28, 2013 GJ138, 2013 HX156, 2013 KZ18, 2013 MY11, 2013 MZ11, 2013 OR11, 2013 PU74, 2013 QQ95, 2013 TC146, 2013 UE15, 2013 UH15, 2013 UJ15, 2013 YJ151, 2014 AN55, 2014 CN23, 2014 CP23, 2014 DB143, 2014 DC143, 2014 DQ143, 2014 DT143, 2014 EZ51, 2014 FB72, 2014 FC72, 2014 FE72, 2014 FF72, 2014 FH72, 2014 FJ72, 2014 FK72, 2014 FL70, 2014 FL72, 2014 FM72, 2014 GD54, 2014 GH54, 2014 GL54, 2014 GP53, 2014 GQ53, 2014 GR53, 2014 GV53, 2014 HA200, 2014 HC200, 2014 HE200, 2014 HF200, 2014 JB80, 2014 JC80, 2014 JD80, 2014 JE80, 2014 JF80, 2014 JG80, 2014 JM80, 2014 JU80, 2014 JW80, 2014 JX80, 2014 KA102, 2014 KB102, 2014 KR101, 2014 KZ101, 2014 LM28, 2014 LN28, 2014 LU28, 2014 LV28, 2014 MJ70, 2014 MX69, 2014 NV65, 2014 NW65, 2014 NX65, 2014 OJ394, 2014 ON394, 2014 OO394, 2014 OP394, 2014 OQ394, 2014 OR394, 2014 OS394, 2014 OW393, 2014 OX393, 2014 OY393, 2014 PQ70, 2014 PR70, 2014 QB442, 2014 QC442, 2014 QV441, 2014 SD350, 2014 SR349, 2014 SS349, 2014 SU349, 2014 SV349, 2014 SW349, 2014 SY349, 2014 SZ349, 2014 TV85, 2014 UR224, 2014 UV224, 2014 UW224, 2014 UY224, 2014 WD510, 2014 WH510, 2014 WJ510, 2014 WK509, 2014 WL510, 2014 WM510, 2014 WN510, 2014 WS510, 2014 WV508, 2014 WW508, 2014 WX508, 2014 WY508, 2014 WZ508, 2014 XO40, 2014 XP40, 2014 XQ40, 2014 XV40, 2014 XW40, 2014 XX40, 2014 YD50, 2014 YE50, 2014 YF50, 2014 YH50, 2014 YK50, 2014 YX49, 2014 YY49, 2015 AM281, 2015 BB519, 2015 BC519, 2015 BD518, 2015 BD519, 2015 BF518, 2015 BG518, 2015 BH518, 2015 BH519, 2015 BJ518, 2015 BK518, 2015 DV224, 2015 DW224, 2015 DX224, 2015 FK345, 2015 FQ345, 2015 GR50, 2016 NM56

Reclassified objects:

2003 FM129 (TNO → SDO)
2003 HM57 (TNO → SDO)
2003 UA414 (TNO → SDO)
2003 UJ292 (TNO → SDO)
2005 GX206 (TNO → SDO)
2005 NU125 (TNO → SDO)
2005 XN113 (TNO → SDO)

2009 JZ18 (SDO → TNO)
2010 VX11 (SDO → TNO)
2012 GU11 (Centaur → SDO)
2012 KU50 (SDO → TNO)
2014 WT69 (SDO → TNO)
2015 SP20 (TNO → SDO)
2016 FN59 (TNO → SDO)
2016 GR206 (SDO → Centaur)

Objects recently assigned numbers:
1999 CD158 = (469306)
2000 PE30 = (469333)
2001 HY65 = (469361)
2001 KB77 = (469362)
2001 QF298 = (469372)
2001 XD255 = (469421)
2001 XP254 = (469420)
2002 GG166 = (469442)
2002 GV31 = (469438)
2003 FE128 = (469505)
2003 FF128 = (469506)
2003 HC57 = (469509)
2003 QA91 = (469514)
2003 YW179 = (469584)
2004 HF79 = (469610)
2004 PT107 = (469615)
2005 EF298 = (469705)
2005 EZ296 = (469704)
2005 GB187 = (469707)
2005 GE187 = (469708)
2005 PU21 = (469750)
2006 HJ123 = (469987)
2006 RC103 = (470027)
2006 SG369 = (470083)
2007 JH43 = (470308)
2007 JK43 = (470309)
2007 OC10 = (470316)
2007 XV50 = (470443)
2008 CS190 = (470523)
2008 LP17 = (470593)
2008 NW4 = (470596)
2008 OG19 = (470599)
2010 EK139 = (471143)
2010 EO65 = (471136)
2010 ET65 = (471137)
2010 FB49 = (471149)
2010 FC49 = (471150)
2010 FD49 = (471151)
2010 FE49 = (471152)
2010 GF65 = (471155)

2010 HE79 = (471165)
2010 JC80 = (471172)
2010 PK66 = (471196)
2010 VW11 = (471210)
2011 AC72 = (471237)
2011 FY9 = (471272)
2011 GM27 = (471288)
2011 JF31 = (471318)
2011 KT19 = (471325)
2011 OD16 = (471335)
2011 ON45 = (471339)
2012 CE17 = (471513)
2012 CG = (471512)
2013 FC28 = (471921)
2013 PH44 = (471931)
2013 RM98 = (471954)
2014 FU71 = (472231)
2014 FW71 = (472232)
2014 GE45 = (472235)
2014 QN441 = (472262)
2014 SR303 = (472265)
2014 UM33 = (472271)
2015 DB216 = (472651)
2015 FZ117 = (472760)

Deleted/Re-identified objects:
2011 FW62 = 2015 AJ281
2014 HU195

Current number of TNOs: 1769 (including Pluto)
Current number of Centaurs/SDOs: 678
Current number of Neptune Trojans: 17

Out of a total of 2464 objects:
698 have measurements from only one opposition
652 of those have had no measurements for more than a year
308 of those have arcs shorter than 10 days
(for more details, see: `http://www.boulder.swri.edu/ekonews/objects/recov_stats.jpg`)

PAPERS ACCEPTED TO JOURNALS

Finding Planet Nine: Apsidal Anti-alignment Monte Carlo Results

C. de la Fuente Marcos[1] and R. de la Fuente Marcos[1]

[1] Apartado de Correos 3413, E-28080 Madrid, Spain

The distribution of the orbital elements of the known extreme trans-Neptunian objects or ETNOs has been found to be statistically incompatible with that of an unperturbed asteroid population following heliocentric or, better, barycentric orbits. Such trends, if confirmed by future discoveries of ETNOs, strongly suggest that one or more massive perturbers could be located well beyond Pluto. Within the trans-Plutonian planets paradigm, the Planet Nine hypothesis has received much attention as a robust scenario to explain the observed clustering in physical space of the perihelia of seven ETNOs which also exhibit clustering in orbital pole position. Here, we revisit the subject of clustering in perihelia and poles of the known ETNOs using barycentric orbits, and study the visibility of the latest incarnation of the orbit of Planet Nine applying Monte Carlo techniques and focusing on the effects of the apsidal anti-alignment constraint. We provide visibility maps indicating the most likely location of this putative planet if it is near aphelion. We also show that the available data suggest that at least two massive perturbers are present beyond Pluto.

Published in: Monthly Notices of the Royal Astronomical Society, 462, 1972 (2016 October 21)

For preprints, contact carlosdlfmarcos@gmail.com

or on the web at http://mnras.oxfordjournals.org/content/462/2/1972.abstract

and http://arxiv.org/abs/1607.05633

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Corralling a Distant Planet with Extreme Resonant Kuiper Belt Objects

R. Malhotra[1], K. Volk[1], and X. Wang[1]

[1]Lunar and Planetary Laboratory, The University of Arizona, Tucson, AZ 8572, USA

The four longest period Kuiper Belt objects have orbital periods close to integer ratios with each other. A hypothetical planet with an orbital period of ∼17,117 years and a semimajor axis ∼665 au would have N/1 and N/2 period ratios with these four objects. The orbital geometries and dynamics of resonant orbits constrain the orbital plane, the orbital eccentricity, and the mass of such a planet as well as its current location in its orbital path.

Published in: The Astrophysical Journal Letters, 824, L22 (2016 June 20)

For preprints, contact renu@lpl.arizona.edu

or on the web at http://iopscience.iop.org/article/10.3847/2041-8205/824/2/L22/meta

and http://arxiv.org/abs/1603.02196

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New Extreme Trans-Neptunian Objects: Towards a Super-Earth in the Outer Solar System

Scott S. Sheppard[1] and Chadwick Trujillo[2]

[1] Carnegie Institution for Science, Department of Terrestrial Magnetism, 5241 Broad Branch Rd. NW, Washington, DC 20015, USA

[2] Northern Arizona University, NAU Box 6010, Flagstaff, AZ 86011, USA

We are conducting a wide and deep survey for extreme distant solar system objects. Our goal is to understand the high perihelion objects Sedna and 2012 VP113 and determine if an unknown massive planet exists in the outer solar system. The discovery of new extreme objects from our survey of some 1080 square degrees of sky to over 24th magnitude in the r-band are reported. Two of the new objects, 2014 SR349 and 2013 FT28, are extreme detached trans-Neptunian objects, which have semi-major axes greater than 150 AU and perihelia well beyond Neptune ($q > 40$ AU). Both new objects have orbits with arguments of perihelia within the range of the clustering of this angle seen in the other known extreme objects. One of these objects, 2014 SR349, has a longitude of perihelion similar to the other extreme objects, but 2013 FT28 is about 180 degrees away or anti-aligned in its longitude of perihelion. We also discovered the first outer Oort cloud object with a perihelion beyond Neptune, 2014 FE72. We discuss these and other interesting objects discovered in our ongoing survey. All the high semi-major axis ($a > 150$ AU) and high perihelion ($q > 35$ AU) bodies follow the previously identified argument of perihelion clustering between 290 and 40 degrees as first reported and explained as being from an unknown massive planet by Trujillo and Sheppard (2014), which some have called Planet X or Planet 9. We now report that the longitude of perihelion is significantly correlated with the argument of perihelion and orbit pole angles for extreme objects and find there are two distinct extreme clusterings anti-aligned with each other. This correlation is further evidence of an unknown massive planet on a distant eccentric inclined orbit, as extreme eccentric objects with perihelia on opposite sides of the sky (180 degree longitude of perihelion differences) would have their closest approaches to the inclined planet at opposite points in their orbits, thus making the extreme objects prefer to stay away from opposite ecliptic latitudes to avoid the planet (i.e. opposite argument of perihelia or orbit pole angles).

To appear in: The Astronomical Journal

For preprints, contact `sheppard@dtm.ciw.edu`

or on the web at `http://arxiv.org/abs/1608.08772`

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Discovery of a New Retrograde Trans-Neptunian Object: Hint of A Common Orbital Plane for Low Semi-Major Axis, High Inclination TNOs and Centaurs

Ying-Tung Chen[1], Hsing Wen Lin[2], Matthew J. Holman[3], Matthew J. Payne[3], Wesley C. Fraser[4], Pedro Lacerda[5], Wing-Huen Ip[2,6], Wen-Ping Chen[2], Rolf-Peter Kudritzki[7], Robert Jedicke[7], Richard J. Wainscoat[7], John L. Tonry[7], Eugene A. Magnier[7], Christopher Waters[7], Nick Kaiser[7], Shiang-Yu Wang[1], and Matthew Lehner[1]

[1] Institute of Astronomy and Astrophysics, Academia Sinica, P. O. Box 23-141, Taipei 106, Taiwan

[2] Institute of Astronomy, National Central University, 32001, Taiwan

[3] Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, USA

[4] Queen's University Belfast, Astrophysics Research Centre, Belfast, UK

[5] Max-Planck-Institut für Sonnensystemforschung, Justus-von-Liebig-Weg 3, D-37077 Göttingen, Germany
[6] Space Science Institute, Macau University of Science and Technology, Macau
[7] Institute for Astronomy, University of Hawaii at Manoa, Honolulu, HI 96822, USA

Although the majority of Centaurs are thought to have originated in the scattered disk, with the high-inclination members coming from the Oort cloud, the origin of the high inclination component of trans-Neptunian objects (TNOs) remains uncertain. We report the discovery of a retrograde TNO, which we nickname "Niku", detected by the Pan-STARRS 1 Outer Solar System Survey. Our numerical integrations show that the orbital dynamics of Niku are very similar to that of 2008 KV_{42} (Drac), with a half-life of $\sim$ 500 Myr. Comparing similar high inclination TNOs and Centaurs ($q > 10$ AU, $a < 100$ AU and $i > 60°$), we find that these objects exhibit a surprising clustering of ascending node, and occupy a common orbital plane. This orbital configuration has high statistical significance: 3.8-σ. An unknown mechanism is required to explain the observed clustering. This discovery may provide a pathway to investigate a possible reservoir of high-inclination objects.

Published in: The Astrophysical Journal Letters, 827, L24 (2016 August 20)
For preprints, contact `ytchen@asiaa.sinica.edu.tw`
or on the web at `https://arxiv.org/abs/1608.01808`

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Tracking Neptune's Migration History through High-Perihelion Resonant Trans-Neptunian Objects

Nathan A. Kaib[1] and Scott S. Sheppard[2]
[1] HL Dodge Department of Physics & Astronomy, University of Oklahoma, Norman, OK 73019, USA
[2] Department of Terrestrial Magnetism, Carnegie Institution for Science, 5241 Broad Branch Road, NW, Washington, DC 20015, USA

Recently, Sheppard et al. (2016) presented the discovery of seven new trans-Neptunian objects with moderate eccentricities, perihelia beyond 40 AU, and semimajor axes beyond 50 AU. Like the few previously known objects on similar orbits, these objects' semimajor axes are just beyond the Kuiper belt edge and clustered around Neptunian mean motion resonances (MMRs). These objects likely obtained their observed orbits while trapped within MMRs, when the Kozai-Lidov mechanism raised their perihelia and weakened Neptune's dynamical influence. Using numerical simulations that model the production of this population, we find that high-perihelion objects near Neptunian MMRs can constrain the nature and timescale of Neptune's past orbital migration. In particular, the population near the 3:1 MMR (near 62 AU) is especially useful due to its large population and short dynamical evolution timescale. If Neptune finishes migrating within $\sim$100 Myrs or less, we predict over $\sim$90% of high-perihelion objects near the 3:1 MMR will have semimajor axes within 1 AU of each other, very near the modern resonance's center. On the other hand, if Neptune's migration takes $\sim$300 Myrs, we expect $\sim$50% of this population to reside in dynamically fossilized orbits over $\sim$1 AU closer to the Sun than the modern resonance. We highlight 2015 KH_{162} as a likely member of this fossilized 3:1 population. Under any plausible migration scenario, nearly all high-perihelion objects in resonances beyond the 4:1 MMR (near 76 AU) reach their orbits well after Neptune stops migrating and comprise a recently generated, dynamically active population.

To appear in: The Astrophysical Journal
For preprints, contact `nathan.kaib@ou.edu`
or on the web at `http://arxiv.org/abs/1607.01777`

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Discovery of a Makemakean Moon

Alex H. Parker[1], Marc W. Buie[1], Will M. Grundy[2], and Keith S. Noll[3]

[1] Southwest Research Institute, 1050 Walnut Street, Suite 300, Boulder, CO 80302, USA

[2] Lowell Observatory, Flagstaff, AZ, USA

[3] NASA Goddard Space Flight Center, Greenbelt, MD, USA

We describe the discovery of a satellite in orbit about the dwarf planet (136472) Makemake. This satellite, provisionally designated S/2015 (136472) 1, was detected in imaging data collected with the Hubble Space Telescope's Wide Field Camera 3 on UTC 2015 April 27 at 7.80±0.04 mag fainter than Makemake and at a separation of 0.57 arcsec. It likely evaded detection in previous satellite searches due to a nearly edge-on orbital configuration, placing it deep within the glare of Makemake during a substantial fraction of its orbital period. This configuration would place Makemake and its satellite near a mutual event season. Insufficient orbital motion was detected to make a detailed characterization of its orbital properties, prohibiting a measurement of the system mass with the discovery data alone. Preliminary analysis indicates that if the orbit is circular, its orbital period must be longer than 12.4 days and must have a semimajor axis $\gtrsim$21,000 km. We find that the properties of Makemake's moon suggest that the majority of the dark material detected in the system by thermal observations may not reside on the surface of Makemake, but may instead be attributable to S/2015 (136472) 1 having a uniform dark surface. This "dark moon hypothesis" can be directly tested with future James Webb Space Telescope observations. We discuss the implications of this discovery for the spin state, figure, and thermal properties of Makemake and the apparent ubiquity of trans-Neptunian dwarf planet satellites.

Published in: The Astrophysical Journal Letters, 825, L9 (2016 June 27)

Preprints available on the web at `http://arxiv.org/abs/1604.07461`

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Recent Tectonic Activity on Pluto Driven by Phase Changes in the Ice Shell

Noah P. Hammond[1], Amy C. Barr[2], Edgar M. Parmentier[1]

[1] Department of Earth, Environmental, and Planetary Sciences Brown University, 324 Brook St., Box 1846 Providence, RI 02912, USA

[2] Planetary Science Institute, Tucson, AZ, USA

The New Horizons spacecraft has found evidence for geologic activity on the surface of Pluto, including extensional tectonic deformation of its water ice bedrock see Moore et al. (2016). One mechanism that could drive extensional tectonic activity is global surface expansion due to the partial freezing of an ocean. We use updated physical properties for Pluto and simulate its thermal evolution to understand the survival of a possible subsurface ocean. For thermal conductivities of rock less than 3 W m^{-1} K^{-1}, an ocean forms and at least partially freezes, leading to recent extensional stresses in the ice shell. In scenarios where the ocean freezes and the ice shell is thicker than 260 km, ice II forms and causes global volume contraction. Since there is no evidence for recent compressional tectonic features, we argue that ice II has not formed and that Pluto's ocean has likely survived to present day.

Published in: Geophysical Research Letters, 43, 6775 (2016 July 16)

Preprints available on the web at `https://arxiv.org/abs/1606.04840`

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Photometric Measurements of H_2O Ice Crystallinity on Trans-Neptunian Objects

T. Terai[1], Y. Itoh[2], Y. Oasa[3], R. Furusho[4], and J. Watanabe[4]

[1] Subaru Telescope, National Astronomical Observatory of Japan, 650 North A'ohoku Place, Hilo, HI 96720, USA

[2] Center for Astronomy, University of Hyogo, 407-2 Nishigaichi, Sayo-cho, Sayo-gun, Hyogo 679-5313, Japan

[3] Faculty of Education, Saitama University, 255 Shimo-Okubo, Sakura, Saitama 338-8570, Japan

[4] National Astronomical Observatory of Japan, 2-21-1 Osawa, Mitaka, Tokyo 181-8588, Japan

We present a measurement of H_2O ice crystallinity on the surface of trans-neptunian objects (TNOs) with near-infrared narrow-band imaging. The newly developed photometric technique allows us to efficiently determine the strength of an 1.65-μm absorption feature in crystalline H_2O ice. Our data for three large objects, Haumea, Quaoar, and Orcus, which are known to contain crystalline H_2O ice on the surfaces, show a reasonable result with high fractions of the crystalline phase. It can also be pointed out that if the H_2O-ice grain size is larger than $\sim$20 μm, the crystallinities of these objects are obviously below 1.0, which suggest the presence of the amorphous phase. Especially, Orcus exhibits a high abundance of amorphous H_2O ice compared to Haumea and Quaoar, possibly indicating a correlation between bulk density of the bodies and surface crystallization degree. We also found the presence of crystalline H_2O ice on Typhon and 2008 AP129, both of which are smaller than the minimum size limit for inducing cryovolcanism as well as a transition from amorphous to crystalline through the thermal evolution due to the decay of long-lived isotopes.

Published in: The Astrophysical Journal, 827, 65 (2016 Aug 10)

Preprints available on the web at `http://arxiv.org/abs/1606.04150`

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Formation of Centaurs' Rings through Their Partial Tidal Disruption during Planetary Encounters

Ryuki Hyodo[1,2], Sébastien Charnoz[1,3], Hidenori Genda[4], and Keiji Ohtsuki[2]

[1] Institut de Physique du Globe, F-75005 Paris, France

[2] Department of Planetology, Kobe University, Kobe 657-8501, Japan

[3] Université Paris Diderot, F-75013 Paris, France

[4] Earth-Life Science Institute, Tokyo Institute of Technology, Tokyo 152-8550, Japan

Centaurs are minor planets orbiting between Jupiter and Neptune that have or had crossing orbits with one or more giant planets. Recent observations and reinterpretation of previous observations have revealed the existence of ring systems around 10199 Chariklo and 2060 Chiron. However, the origin of the ring systems around such a minor planet is still an open question. Here, we propose that the tidal disruption of a differentiated object that experiences a close encounter with a giant planet could naturally form diverse ring-satellite systems around the Centaurs. During the close encounter, the icy mantle of the passing object is preferentially ripped off by the planet's tidal force and the debris is distributed mostly within the Roche limit of the largest remnant body. Assuming the existence of a 20-50 wt% silicate core below the icy mantle, a disk of particles is formed when the objects pass within 0.4-0.8 of the planet's Roche limit with the relative velocity at infinity 3-6 km/s and 8 hr initial spin period of the body. The resultant ring mass is 0.1%-10% of the central object's mass. Such particle disks are expected to spread radially, and materials spreading beyond the Roche limit would accrete into satellites. Our numerical results suggest that ring formation would be a natural outcome of such

extreme close encounters, and Centaurs can naturally have such ring systems because they cross the orbits of the giant planets.

Published in: The Astrophysical Journal Letters, 828, L8 (2016 September 1)
Preprints available on the web at http://arxiv.org/abs/1608.03509

PAPERS RECENTLY SUBMITTED TO JOURNALS

Measuring Temperature and Ammonia Hydrate Ice on Charon in 2015 with Keck/OSIRIS Spectra

B.J. Holler[1], L.A. Young[2], M.W. Buie[2], W.M. Grundy[3], J.E. Lyke[4], E.F. Young[2], and H.G. Roe[3]

[1] Laboratory for Atmospheric and Space Physics, University of Colorado at Boulder, 1234 Innovation Dr., Boulder, CO 80303, USA

[2] Southwest Research Institute, 1050 Walnut St. #300, Boulder, CO 80302, USA

[3] Lowell Observatory, 1400 W. Mars Hill Rd., Flagstaff, AZ 86001, USA

[4] W.M. Keck Observatory, 65-1120 Mamalahoa Hwy., Kamuela, HI 96743, USA

In this work we investigated the longitudinal (zonal) variability of H_2O and ammonia (NH_3) hydrate ices on the surface of Charon through analysis of the 1.65 μm and 2.21 μm absorption features, respectively. Near-infrared spectra presented here were obtained between 2015-07-14 and 2015-08-30 UT with the OSIRIS integral field spectrograph on Keck I. Spectra centered on six different sub-observer longitudes were obtained through the Hbb (1.473-1.803 μm) and Kbb (1.965-2.381 μm) filters. Gaussian functions were fit to the aforementioned bands to obtain information on band center, band depth, full width at half maximum, and band area. The shift in the band center of the temperature-dependent 1.65 μm feature was used to calculate the H_2O ice temperature. The mean temperature of the ice on the observable portion of Charon's surface is 45$\pm$14 K and we report no statistically significant variations in temperature across the surface. We hypothesize that the crystalline and amorphous phases of water ice reached equilibrium over 3.5 Gyr ago, with thermal recrystallization balancing the effects of irradiation amorphization. We do not believe that cryovolcanism is necessary to explain the presence of crystalline water ice on the surface of Charon. Absorption from ammonia species is detected from 12-290° longitude; combined with the hemisphere-scale ammonia distribution from New Horizons, ammonia species appear to be uniformly distributed across Charon. Ongoing diffusion of ammonia through the rocky mantle and upper layer of water ice is one possible mechanism for maintaining its presence in Charon's surface ice. Reduced Charon spectra corrected for telluric and solar absorption are available as supplementary online material.

Submitted to: Icarus
For preprints, contact bryan.holler@colorado.edu
or on the web at http://arxiv.org/abs/1606.05695

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OSSOS: IV. Discovery of a Dwarf Planet Candidate in the 9:2 Resonance

Michele T. Bannister[1], Mike Alexandersen[5], Susan D. Benecchi[7], Ying-Tung Chen[5], Audrey Delsanti[8], Wesley C. Fraser[9], Brett J. Gladman[4], Mikael Granvik[10], Will M. Grundy[12], Aurélie Guilbert-Lepoutre[3], Stephen D.J. Gwyn[2], Wing-Huen Ip[14,15], Marian Jakubik[16], R. Lynne Jones[17], Nathan Kaib[18], J.J. Kavelaars[1,2], Pedro Lacerda[9], Samantha Lawler[2], Matthew J. Lehner[5,20,21], Hsing Wen Lin[14], Patryk Sofia Lykawka[23], Michael Marsset[8,24], Ruth Murray-Clay[25], Keith S. Noll[26], Alex Parker[27], Jean-Marc Petit[3], Rosemary E. Pike[1,5], Philippe Rousselot[3], Megan E. Schwamb[31], Cory Shankman[1], Peter Veres[30], Pierre Vernazza[8], Kathryn Volk[6], Shiang-Yu Wang[5], and Robert Weryk[29]

[1] Department of Physics and Astronomy, University of Victoria, Elliott Building, 3800 Finnerty Rd, Victoria, BC V8P 5C2, Canada

[2] NRC-Herzberg Astronomy and Astrophysics, National Research Council of Canada, 5071 West Saanich Rd, Victoria, BC V9E 2E7, Canada

[3] Institut UTINAM UMR6213, CNRS, Univ. Bourgogne Franche-Comté, OSU Theta F25000 Besançon, France

[4] Department of Physics and Astronomy, University of British Columbia, Vancouver, BC, Canada

[5] Institute for Astronomy & Astrophysics, Academia Sinica; 11F AS/NTU, National Taiwan University, 1 Roosevelt Rd., Sec. 4, Taipei 10617, Taiwan

[6] Department of Planetary Sciences/Lunar & Planetary Laboratory, University of Arizona, 1629 E University Blvd, Tucson, AZ 85721, USA

[7] Planetary Science Institute, 1700 East Fort Lowell, Suite 106, Tucson, AZ 85719, USA

[8] Aix Marseille Université, CNRS, LAM (Laboratoire d'Astrophysique de Marseille) UMR 7326, 13388, Marseille, France

[9] Astrophysics Research Centre, Queen's University Belfast, Belfast BT7 1NN, United Kingdom

[10] Department of Physics, P.O. Box 64, 00014 University of Helsinki, Finland

[12] Lowell Observatory, Flagstaff, Arizona, USA

[14] Institute of Astronomy, National Central University, Taiwan

[15] Space Science Institute, Macau University of Science and Technology, Macau

[16] Astronomical Institute, Slovak Academy of Science, 05960 Tatranska Lomnica, Slovakia

[17] University of Washington, Washington, USA

[18] HL Dodge Department of Physics & Astronomy, University of Oklahoma, Norman, OK 73019, USA

[20] Department of Physics and Astronomy, University of Pennsylvania, 209 S. 33rd St., Philadelphia, PA 19104, USA

[21] Harvard-Smithsonian Center for Astrophysics, 60 Garden St., Cambridge, MA 02138, USA

[23] Astronomy Group, School of Interdisciplinary Social and Human Sciences, Kindai University, Japan

[24] European Southern Observatory (ESO), Alonso de Córdova 3107, 1900 Casilla Vitacura, Santiago, Chile

[25] Department of Physics, University of California, Santa Barbara, CA 93106, USA

[26] NASA Goddard Space Flight Center, Code 693, Greenbelt, MD 20771, USA

[27] Southwest Research Institute, Boulder, Colorado, USA

[29] Institute for Astronomy, University of Hawaii, 2680 Woodlawn Drive, Honolulu HI 96822, USA

[30] Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA

[31] Gemini Observatory, Northern Operations Center, 670 North A'ohoku Place, Hilo, HI 96720, USA

We report the discovery and orbit of a new dwarf planet candidate, 2015 RR_{245}, by the Outer Solar System Origins Survey (OSSOS). 2015 RR_{245}'s orbit is eccentric (e=0.586), with a semi-major axis near 82 au, yielding a perihelion distance of 34 au. 2015 RR_{245} has $g - r = 0.59 \pm 0.11$ and absolute magnitude $H_r = 3.6 \pm 0.1$; for an assumed albedo of $p_V = 12\%$ the object has a diameter of ~ 670 km. Based on astrometric measurements from OSSOS and Pan-STARRS1, we find that 2015 RR_{245} is securely trapped in the 9:2 mean-motion resonance with Neptune. It is the first TNO identified in this resonance. On hundred-Myr timescales, particles in 2015 RR_{245}-like orbits depart

and sometimes return to the resonance, indicating that 2015 RR_{245} likely forms part of the long-lived metastable population of distant TNOs that drift between resonance sticking and actively scattering via gravitational encounters with Neptune. The discovery of a 9:2 TNO stresses the role of resonances in the long-term evolution of objects in the scattering disk, and reinforces the view that distant resonances are heavily populated in the current Solar System. This object further motivates detailed modeling of the transient sticking population.

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A Ninth Planet Would Produce a Distinctly Different Kuiper Belt

S.M. Lawler[1], C. Shankman[2], N. Kaib[3], M.T. Bannister[2], B. Gladman[4], and J.J. Kavelaars[1,2]

[1] National Research Council of Canada, Astronomy & Astrophysics Program, 5071 West Saanich Rd, Victoria, V9E 2E7, Canada

[2] Department of Physics and Astronomy, University of Victoria, PO Box 1700, STN CSC Victoria, BC V8W 2Y2, Canada

[3] HL Dodge Department of Physics & Astronomy, University of Oklahoma, Norman, OK 73019, USA

[4] Department of Physics and Astronomy, University of British Columbia, 6224 Agricultural Road, Vancouver, BC V6T 1Z1, Canada

The orbital element distribution of trans-Neptunian objects (TNOs) with large pericenters has been suggested to be influenced by the presence of an undetected, large planet at 200 or more AU from the Sun. We perform 4 Gyr N-body simulations with the currently known Solar System planetary architecture, plus a 10 $M_{\oplus}$ planet with similar orbital parameters to those suggested by Batygin and Brown (2016) or Trujillo and Sheppard (2014), and a hundred thousand test particles in an initial planetesimal disk. We find that including a distant superearth-mass ninth planet produces a substantially different orbital distribution for the scattering and detached TNOs, raising the pericenters and inclinations of moderate semimajor axis (50 ¡ a ¡ 500 AU) objects. We test whether this signature is detectable via a simulator with the observational characteristics of four precisely characterized TNO surveys. We find that the qualitatively very distinct Solar System models that include a ninth planet are essentially observationally indistinguishable from an outer Solar System produced solely by the four giant planets. We also find that the mass of the Kuiper Belt's current scattering and detached populations is required be 3-10 times larger in the presence of an additional planet. Wide-field, deep surveys targeting inclined high-pericenter objects will be required to distinguish between these different scenarios.

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OTHER PAPERS OF INTEREST

The Analemma Criterion: Accidental Quasi-satellites are Indeed True Quasi-satellites

C. de la Fuente Marcos[1] and R. de la Fuente Marcos[1]

[1] Apartado de Correos 3413, E-28080 Madrid, Spain

In the Solar system, a quasi-satellite is an object that follows a heliocentric path with an orbital period that matches almost exactly with that of a host body (planetary or not). The trajectory is of such nature that, without being gravitationally attached, the value of the angular separation between host and quasi-satellite as seen from the Sun remains confined within relatively narrow limits for time-spans that exceed the length of the host's sidereal orbital period. Here, we show that under these conditions, a quasi-satellite traces an analemma in the sky as observed from the host in a manner similar to that found for geosynchronous orbits. The analemmatic curve (figure-eight-, teardrop-, ellipse-shaped) results from the interplay between the tilt of the rotational axis of the host and the properties of the orbit of the quasi-satellite. The analemma criterion can be applied to identify true quasi-satellite dynamical behaviour using observational or synthetic astrometry and it is tested for several well-documented quasi-satellites. For the particular case of 15810 (1994 JR_1), a putative accidental quasi-satellite of dwarf planet Pluto, we show explicitly that this object describes a complex analemmatic curve for several Plutonian sidereal periods, confirming its transient quasi-satellite status.

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For preprints, contact `carlosdlfmarcos@gmail.com`
or on the web at `http://mnras.oxfordjournals.org/content/462/3/3344.abstract`
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