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Mutual events in the Cold Classical transneptunian binary system Sila and Nunam

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ABSTRACT

Hubble Space Telescope observations between 2001 and 2010 resolved the binary components of the Cold Classical transneptunian object (79360) Sila–Nunam (provisionally designated 1997 CS_{29}). From these observations we have determined the circular, retrograde mutual orbit of Nunam relative to Sila with a period of 12.50995 ± 0.00036 days and a semimajor axis of 2777 ± 19 km. A multi-year season of mutual events, in which the two near-equal brightness bodies alternate in passing in front of one another as seen from Earth, is in progress right now, and on 2011 February 1 UT, one such event was observed from two different telescopes. The mutual event season offers a rich opportunity to learn much more about this barely-resolvable binary system, potentially including component sizes, colors, shapes, and albedo patterns. The low eccentricity of the orbit and a photometric lightcurve that appears to coincide with the orbital period are consistent with a system that is tidally locked and synchronized, like the Pluto–Charon system. The orbital period and semimajor axis imply a system mass of $(10.84 \pm 0.22) \times 10^{18}$ kg, which can be combined with a size estimate based on Spitzer and Herschel thermal infrared observations to infer an average bulk density of $0.72^{+0.37}_{-0.23}$ g cm^{-3}, comparable to the very low bulk densities estimated for small transneptunian binaries of other dynamical classes.

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1. Introduction

Observation of mutual eclipses and occultations between components of a binary system is a powerful technique for remote characterization of small and distant objects. Mutual events have been used to constrain binary asteroid mutual orbits, shapes, and densities (e.g., Descamps et al., 2007), to monitor volcanic activity on the jovian satellite Io (e.g., Rathbun and Spencer, 2010), and to distinguish surface compositions and map albedo patterns on Pluto and Charon (e.g., Binzel and Hubbard, 1997). It would be valuable if mutual event observation techniques could be brought to bear on many more transneptunian objects (TNOs), since their remote locations in the Kuiper belt and their small sizes make them particularly challenging to investigate using other observational techniques. Already, mutual events have been observed in the contact (or near-contact) binary system 139775 (Sheppard and Jewitt, 2004; Lacerda, 2011) and in the Haumea triple system (Ragozzine and Brown, 2010; although in that system the large contrast between Haumea and satellite sizes and their non-tidally locked spin states greatly complicates interpretation of mutual event data). With more and more transneptunian binaries (TNBs) being discovered (e.g., Noll et al., 2008a), the likelihood grows for additional TNB mutual events in the near future, but observations are unlikely without advance knowledge of their mutual orbits. Planning for mutual event observations is one of many motivations for the ongoing campaign of TNB orbit determination from which this paper arises (see http://www.lowell.edu/~grundy/tnbs).

Most known TNBs inhabit the “Classical” sub-population of TNOs orbiting the Sun on relatively low-inclination, low-eccentricity orbits not in mean-motion resonance with Neptune (Elliot et al., 2005; Gladman et al., 2008). Although they are less dynamically excited than other TNO orbits, Classical TNO orbits have been further subdivided into dynamically “Hot” and “Cold” Classical subgroups based on the inclinations of their heliocentric orbits (e.g., Brown, 2001; Gulbis et al., 2010; although Peixinho (2008) argues that the Tisserand parameter could be a better criterion). Binaries

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are particularly abundant among the low inclination Classical TNOs, or "Cold Classicals" (Stephens and Noll, 2006; Noll et al., 2008b). These objects are of particular interest for having accreted relatively far from the young Sun, perhaps near their present-day locations with semimajor axes in the 42–47 AU range. This contrasts with other dynamical classes of TNOs populated by objects thought to have formed much closer to the Sun prior to emplacement into their current orbits by dramatic events early in Solar System history (e.g., Levison et al., 2008). Cold Classicals are thus seen as offering a window into conditions in the outermost parts of the nebular disk. The Cold Classical sub-population has itself recently been divided into "kernel" and "stirred" sub-components (Petit et al., 2011), where the "kernel" is a concentration of Cold Classical objects with semimajor axes near 44 AU and eccentricities near 0.06. The significance of this clump and its relation to circumstances in the protoplanetary nebula and/or subsequent dynamical erosion of the Kuiper belt is not yet clear.

In addition to their high rate of binarity, other intrinsic properties of Cold Classical TNOs also appear to be distinctive. Their distribution of colors in reflected sunlight looks more uniformly red than the broader mix of colors seen among other dynamical classes (e.g., Trujillo and Brown, 2002; Tegler et al., 2003; Gulbis et al., 2006; Peixinho et al., 2008). Many of the Cold Classical binaries consist of near-equal brightness components, unlike the more asymmetric pairings seen elsewhere (Noll et al., 2008b). Their magnitude frequency distribution is much steeper than that of more excited TNOs (Bernstein et al., 2004; Fuentes and Holman, 2008; Fraser et al., 2010). This distribution is often taken as a proxy for their size frequency distribution, although without knowledge of albedos, the absolute normalization between brightness and size is uncertain. Indeed, albedos reported for Cold Classical TNOs are higher than is typical of small TNOs on more excited orbits (Grundy et al., 2005a; Stansberry et al., 2008; Brucker et al., 2009; Vilenius et al., 2012). However, Cold Classicals tend toward the faint limit of what can be investigated with available observational techniques for estimating albedos. If this population actually had a broad distribution of albedos, the small sample of them studied thus far would likely be biased in favor of higher albedo objects (e.g., Parker et al., 2011). More work is needed to resolve this issue, and also to investigate whether the distinctive properties of Cold Classicals are features of just the "kernel" or "stirred" sub-components, or are shared among both. About a fifth of known Cold Classical binaries fall into the Petit et al. (2011) "kernel" region of orbital element space, roughly on par with the ratio of "kernel" to all Cold Classicals, so at least this characteristic does not seem to be confined to one or the other subgroup.

Based on its heliocentric orbital elements, the Sila and Nunam system is probably a member of the Cold Classical group. We say "probably" because the Cold and Hot Classical sub-populations overlap in orbital element space. A low inclination heliocentric orbit is required for membership in the Cold Classical group, but does not exclude membership of the Hot population. From debiased Deep Ecliptic Survey (DES) observations (Elliot et al., 2005), Gulbis et al. (2010) described the separate inclination distributions of the Hot and Cold Classical groups, enabling the probability of Cold Classical membership to be estimated as a function of inclination, as shown in Fig. 1. For the system's mean inclination $\langle i_\odot \rangle = 3.84°$ (relative to the invariable plane, and averaged over a 10 Myr integration), this translates into a 76% probability of Cold Classical membership. This calculation neglects the different brightness distributions of Hot and Cold groups (e.g., Petit et al., 2011), but the brightness of the Sila and Nunam system is typical of the DES sample, so errors from this source are not expected to be large. Increasing confidence that it belongs to the Cold Classical group are its identification as a binary with near-equal brightness components (Stephens and Noll, 2006). If binary probabilities for Hot and Cold Classicals are taken as 2.9% and 29%, respectively (Noll et al., 2008b), then the fact of Sila and Nunam's binarity boosts the system's probability of belonging to the Cold Classical group to 97%, via Bayes' Theorem. Consideration of the system's red coloration (Barucci et al., 2000) would increase the odds of Cold Classical membership still further. At 43.9 AU, Sila and Nunam's mean heliocentric semimajor axis $\langle a_\odot \rangle$ is consistent with the Petit et al. (2011) "kernel" group, but its mean eccentricity $\langle e_\odot \rangle = 0.013$ is lower than the 0.03–0.08 eccentricity range of the Petit et al. model kernel cluster, suggesting membership in the "stirred" Cold Classical group.

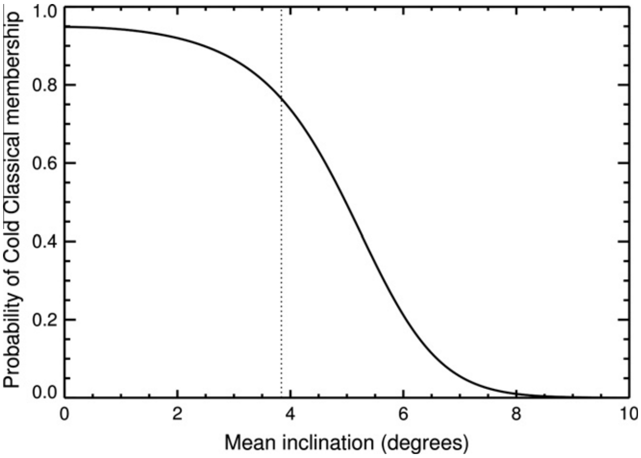

Fig. 1. Probability of Cold Classical membership as a function of mean inclination relative to the invariable plane for Classical TNOs, based on inclination distributions from Gulbis et al. (2010). The vertical dotted line is for the mean heliocentric orbital inclination of Sila and Nunam, indicating a 76% probability of Cold Classical membership on the basis of its inclination alone.

Being among the brightest of the probable Cold Classical TNOs, the Sila and Nunam system has been targeted for more detailed study by many groups, using a variety of observational techniques. For instance, Grundy et al. (2005b) obtained a low resolution near-infrared spectrum at the Keck telescope, showing an absence of deep ice absorption bands. Photometric observations by Rabinowitz et al. (2009) and Verbiscer et al. (2010) revealed that the system exhibits a narrow opposition spike. Stansberry et al. (2008), Müller et al. (2010), and Vilenius et al. (2012) reported thermal infrared observations from Spitzer and Herschel Space Observatories, constraining the size and pointing to a visual albedo in the range of 0.06–0.10. This paper reports on the determination of the mutual orbit of Sila and Nunam along with additional information that can be learned from knowledge of this orbit and from observing the mutual events it produces.

2. Astrometric observations

The Hubble Space Telescope (HST) acquired images of Sila and Nunam through five different programs, each using a different instrument: 9110 (STIS), 9386 (NICMOS/NIC2), 10514 (ACS/HRC), 11178 (WFPC2/PC), and 11650 (WFC3/UVIS). We measured relative astrometry of the two components from these observations by fitting a pair of point-spread-functions (PSFs) generated by Tiny Tim (Krist and Hook, 2004) to the two components in each image. Astrometric uncertainties were estimated from the scatter of PSF-fits to a series of dithered frames obtained during each HST visit to the system (except for the program 9110 STIS observations, where only a single frame was acquired during each visit). Details of these procedures have been published previously, and in the interest of brevity we refer interested readers to those papers (e.g., Grundy

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