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The Dynamical State of the Dinkinesh - Selam Binary

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The Lucy spacecraft encountered the Main Belt asteroid (152830) Dinkinesh on 01 November 2023 revealing it to be a binary system with a first-of-its-kind contact binary secondary, now named Selam. However, despite the novelty of Selam's structure, most aspects of the Dinkinesh system can be considered typical in the broader context of similar Main Belt (MB) and Near-Earth Asteroid (NEA) binary systems.

Groundbased lightcurve photometry and imaging by Lucy throughout its encounter were employed to constrain Dinkinesh's spin state. Ground-based lightcurves obtained from November 2022 to February 2023 showed a lightcurve with an amplitude of 0.39 magnitudes and a period of T = 52.67±0.04 hrs [1]. Lucy's L'LORRI instrument imaged the system during the encounter. Most relevant for understanding the spin state are resolved images obtained during the short period around close approach and a series of unresolved images obtained hourly from +4 hours to +95 hours after close approach at a phase angle of approximately 60°. The Lucy data have the advantage of a known configuration for the components that can be used to interpret the lightcurve.

Imaging during close approach was able to identify retrograde rotation of the primary, Dinkinesh, ruling out a doubly synchronous system. No indication of rotation was observed for the secondary, Selam. Thus, interpretation of the combined lightcurve data requires separating the lightcurves of the two components. Using an iterative process, it was possible to identify a period for the primary of 3.7387 ± 0.0013 hr [2,3] with a relatively low amplitude as seen in Figure 1a. After subtracting this from the combined lightcurve, Selam's period is determined as 52.04±0.14 hrs with almost a factor of two amplitude (figure 1b). This is consistent with the period found from the longer time-baseline, lower-uncertainty ground-based observations and indicates a singly synchronous system. Furthermore, eclipse mutual events are observed spaced half a rotation apart, shown by the red data points. The timing of these eclipses indicates that the satellite orbit is retrograde and nearly in the plane of Dinkinesh's heliocentric orbit.

Tidal forces, YORP, and BYORP, play a role in shaping the dynamics of the system. Tidal alignment of the long axis of a satellite radial to the primary occurs rapidly, typically $t_{sync} < 10^5$ yr [4,5]. Spin-pole and orbit-pole reorientation by YORP has a timescale of less than 1 Myr for the spin-pole to approach 0/180° [5,6]. A more comprehensive simulation [7] finds the current spin state and semimajor axis is consistent with tidal and radiative forces operating on 1-10 Myr timescales. These times are consistent with the ~few Myr age of the surfaces as estimated from crater counts [8].

With a period of 52.67±0.04 hrs and a semimajor axis of 3.11±0.05 km, as measured from flyby

imaging, the system mass is found to be M_{sys} = 4.95 ± 0.25 × 10^{11} kg [4]. Assuming the components have equal densities and using volumes derived from imaging and shape models [9], the system angular momentum can then be derived. This can be compared to the angular momentum of an object with the system mass spinning at maximum frequency corresponding to a period of ~2.13 hours [10]. The ratio of the current angular momentum to the maximum possible is written as a_L. When this ratio has a value near one, it points to formation from a spin-up fission event [11]. For Dinkinesh we find a_L = 0.88±0.2.

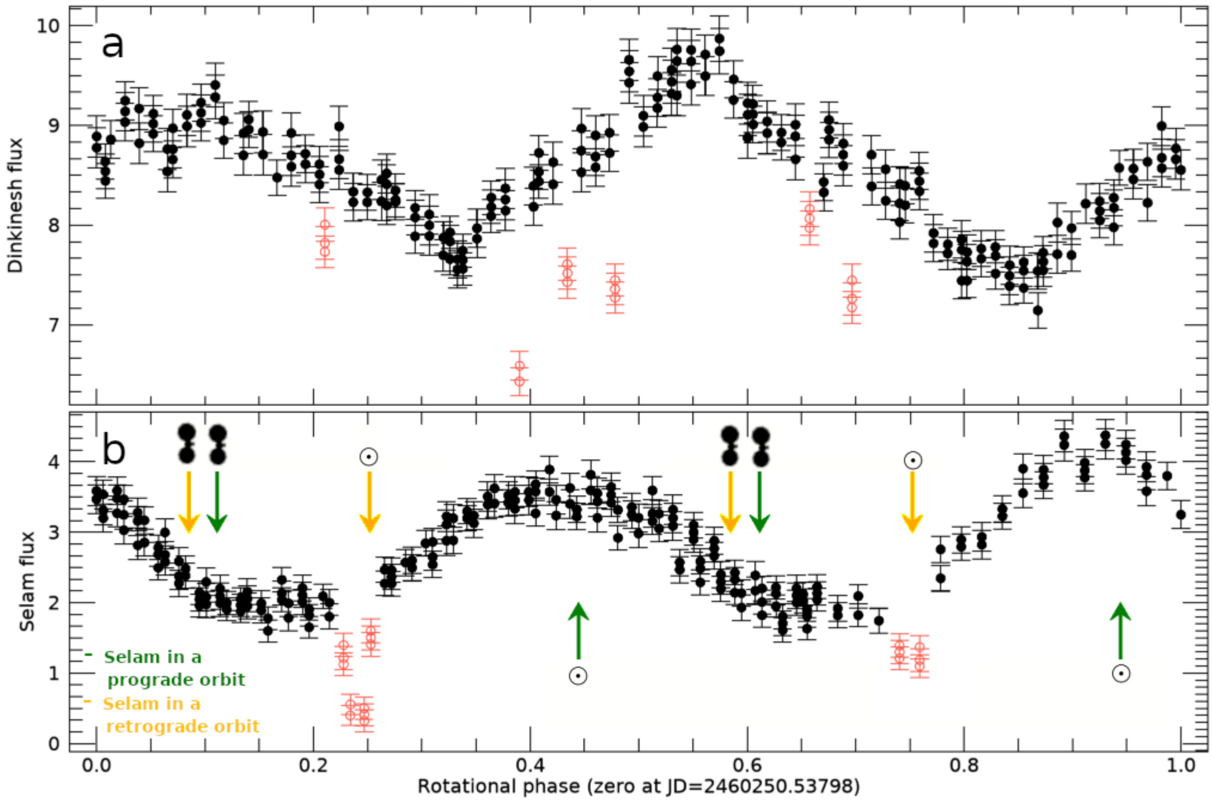

Figure 1. The separate lightcurves of Dinkinesh (panel a) and Selam (panel b) are shown plotted as flux vs. rotational phase. In this figure, reproduced from [4], the period for Dinkinesh is 3.7387±0.0013 hrs and that for Selam is 52.04±0.14 hrs. Red data points indicate observed mutual events. The Sun symbol icon with arrows shows where mutual eclipse events should be seen, yellow for a retrograde orbit and green for prograde. Only a retrograde orbit is consistent with the lightcurve. Mutual events as seen from Lucy are also indicated. None were seen indicating that the inclination of Selam's orbit must be less than ~4° based on the geometry of Lucy's trajectory relative to that of Dinkinesh.

Taken altogether, the dynamical state of the Dinkinesh–Selam binary is fully consistent with formation via YORP spin up triggering a mass-shedding event and formation of a debris ring that later evolves to form both the observed equatorial ridge and the satellite. Dinkinesh shares properties with many similar systems [12,13,14] that, it can be assumed, have followed a similar evolutionary path. However, as only the second such system to be studied at close range by spacecraft, Dinkinesh shows that additional levels of previously unnoticed complexity may be common features in this class of object.

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References: [1] Mottola, S. et al. (2023) MNRAS, 524, L1-L4. [2] Buie, M. et al. (2024), LPSC 2024. [3] Levison, H. et al. (2024), Nature, in press. [4] Jacobson, S. A. and Scheeres, D. J. (2011) Icarus, 214, 161. [5] Pravec, P. et al. (2012) Icarus, 218, 125. [6] Statler, T. (2015) Icarus, 248, 313. [7] Merrill C. C., et al. (2024) A&Ap 684, L20. [8] Marchi et al. (2024), LPSC 2024. [9] Preusker, F. et al. (2024) LPSC 2024. [10] Pravec, P., and Harris, A. W. (2000) Icarus 148, 1, 12-20. [11] Pravec, P. and Harris, A. W. (2007) Icarus, 190, 250. [12] Pravec, P. et al. (2016) Icarus 267, 267-295. [13] Pravec, P. et al. (2012) Icarus, 218, 125. [14] Johnston, W. R. (2019) NASA Planetary Data System.

Lucy Team: The many dedicated members of the Lucy science and engineering team.