The dynamics of binary NEAs and their evolution: Perspectives from the KW4 investigation

Eugene G. Fahnestock (University of Michigan), Daniel J.Scheeres (University of Michigan)

As part of the KW4 investigation, full-detail numerical simulations of the coupled rotational and orbital dynamics of KW4's components indicated that the system exists in an excited state, following complex internal motions that match multiple dynamic modes with different periods. Such excited dynamic configurations should not be atypical for binary NEAs. We have investigated the likely excitation sources, specifically incorporating a third body's perturbing effects during a flyby or perihelion passage. Results of high fidelity simulations of such passages clearly show that for such systems with low perihelia, solar gravity perturbation excites the longest period dynamic mode as expected, while results are less clear for excitation of the shorter period modes.

The former is a variant of a Cassini state rarely observed elsewhere in the solar system but perhaps common in small binaries, which is well understood through conservation of angular momentum, and a consequence of oblateness of the larger component, Alpha. The latter modes follow from the triaxiality of the smaller component, Beta. Independent of the excitation level of such systems, which determines the amplitudes of these motions, their frequencies can be analytically related to the Alpha oblateness and Beta triaxiality body mass properties, allowing for remote estimation of inertia parameters. We have developed these analytic relationships and achieved partial verification of them against the observation-supported full-detail simulations of KW4, although results point toward the need for relaxing the assumptions behind the simple analytic formulae and employing a more rigorous method, capturing further shape detail, for best mass properties estimation independent of observed shape.

KW4 has also informed our understanding of the formation and evolution of such systems. KW4 Alpha's proximity to its rotational stability limit suggests a fairly recent formation from spin-up and disruption of a loosely bound precursor, due to some combination of tidal torque in flybys and/or YORP torque. Also, the system may have rapidly evolved from formation to its present state through a momentum transfer mechanism driven by YORP and involving regolith transport on Alpha, with accompanying resurfacing. This would be an interesting form of dynamic interaction between low speed `ejecta' particles and the binary components. The exotic trajectory dynamics of more conventional ejecta particles or a spacecraft in the KW4 system, as revealed through new numerical simulations, should also apply broadly to small body binaries, and foresee both unique challenges and unique in-situ observation opportunities for rendezvous missions to such a pair.