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Physical Model of Near-Earth Asteroid (1917) Cuyo and Detection of a Mass-Lofting Event

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Abstract

We are conducting a programme of optical lightcurve observations of NEAs to detect YORP-induced rotational accelerations [1-3]. For this we use optical photometry from a range of small to medium size telescopes. This is supplemented by thermal-IR observations and thermophysical modelling to ascertain expected YORP strengths for comparison with observations. For selected objects, we use radar data to determine shape models. We will present our latest results for one of the largest NEAs in our sample – NEA (1917) Cuyo [4]. We also report observations of excess emission at thermal-IR wavelengths interpreted as a surface mass shedding event in December 2005 [5]. We find that the size of the resulting dust cloud is consistent with theoretical predictions of frequent mass shedding events caused by radiation torques, and that material can be lost from Cuyo's equator by centrifugal forces.

1. Observational Campaign

Optical photometry and the search for YORP: The primary source for the optical lightcurve observations of Cuyo was from an ESO Large Programme at the NTT from April 2010 to April 2013 (11 lightcurves). Additional data were obtained from: the ESO 2.2 m telescope (Chile) (4 lightcurves, February 2-21, 2012); the JPL 0.6 m telescope at Table Mountain Observatory (USA) (6 lightcurves); the Palomar 5 m (USA) (1 lightcurve). We also used previously-published data when available (see [4] for full list), to provide a total lightcurve time span of 24 years (1989-2013) for our shape and spin-state analysis.

Thermal observations and thermophysical modelling: Mid-IR observations provide valuable constraints on size, albedo and surface roughness, required to model the YORP effect, as well as thermophysical properties. We have a parallel programme to obtain mid-IR photometry for all targets that are sufficiently bright for detection with the VISIR instrument on ESO's 8.2m VLT. Here, we also utilize archival Spitzer IRS data on Cuyo in our analysis. YORP effect predictions are made using the Advanced Thermophysical model (ATPM), e.g. [6], with shape models from our lightcurve analysis.

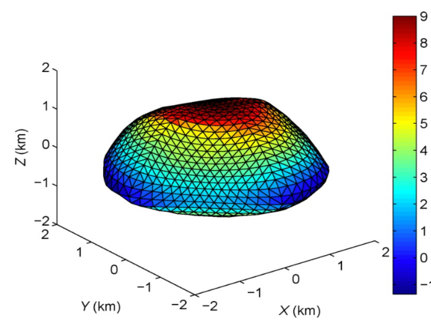

Figure 1. (1917) Cuyo shape model indicating negative effective gravity near the equator [5]. This was produced using the nominal shape model of Cuyo [4] with a density of 2 g cm^{-3}. Negative effective gravities indicate regions where surface material can be ejected by centrifugal forces. g_E is 9.81 m s^{-2}.

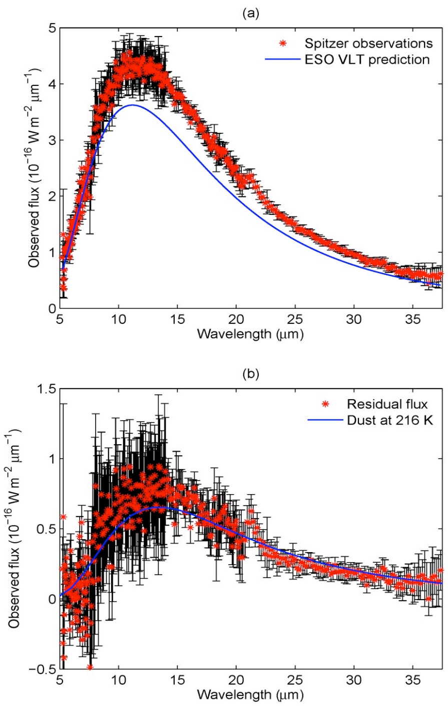

Figure 2. Thermal-infrared fluxes of (1917) Cuyo and its dust cloud taken with the Spitzer IRS on 14 December 2005 [5]: a) Spitzer data compared with a prediction of Cuyo's thermal emission based on the best-fit physical properties determined from 2011 ESO VLT observations using the ATPM [6] with the nominal shape model of Cuyo [4]; b) residual (observed – predicted) dust cloud flux compared with the best-fit black-body spectrum of 216 ± 4 K.

2. Results and Conclusions

Shape, Spin-State and Thermal Modelling: Over the 24-year time-period of our photometry data we find that the rotation period of Cuyo is constant at 2.6897642 ± 0.000004 hours. We developed a convex lightcurve-inversion shape model for Cuyo that suggests the presence of an equatorial ridge, typical for an evolved system close to shedding mass due to fast rotation (Fig. 1). Thermophysical modelling with the ATPM [6] provides constraints on the geometric albedo, $p_V = 0.24 \pm 0.07$, the effective diameter $D_{eff} = 3.15 \pm 0.08$ km, and thermal inertia, $\Gamma = 44 \pm 9$ J m^{-2} s$^{-1/2}$ K^{-1}. This enabled a YORP strength prediction of $\nu = (-6.39 \pm 0.96) \times 10^{-10}$ rad/day^2. The low value of YORP predicted by means of thermophysical analysis, consistent with the results of the lightcurve study, might be due to the self-limiting properties of rotational YORP, possibly involving movement of sub-surface and surface material. This may also be consistent with the surface compositional variation that we see [4]. Lowry et al. [7] reported that newer optical data from 2014-2017 [8, 9] implied that Cuyo was experiencing a rapid spin-down, much larger than can be explained by YORP. However, we acquired new photometry data in January-March 2019 which are fully consistent with the model presented here, with perhaps the exception of a small positive spin-up due to YORP.

Detection of Mass-Lofting Event: Combining archival Spitzer IRS spectra, our VLT thermal observations and thermophysical modelling, we detect a thermal excess which is most likely due to material leaving the surface of Cuyo (Fig. 2) [5]. Applying a polyhedral gravity field model to the shape model of Cuyo, and a density of 2 g cm^{-3} that might be expected for an S-class rubble pile, we find that 4.4 ± 1.6 % of Cuyo's surface exhibits negative effective gravity (Fig. 1). Furthermore, this indicates that Cuyo's body may also require internal cohesive forces to remain stable.

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