EPSC Abstracts
Vol. 12, EPSC2018-801, 2018
European Planetary Science Congress 2018

Thermal Inertia of Binary Near-Earth Asteroids

B. Rozitis (1), E. C. Brown (2), S. F. Green (1), S. C. Lowry (3), A. Fitzsimmons (4), A. Rozek (3), C. Snodgrass (1), P. Weissman (5) and T. Zegmott (3).
(1) The Open University, UK (benjamin.rozitis@open.ac.uk), (2) University of Oxford, UK, (3) University of Kent, UK, (4) Queens University Belfast, UK, (5) Planetary Science Institute, Arizona, USA.

Abstract

Binary asteroids represent approximately 15% of the near-Earth asteroid population, and their study can provide important insights into the physical processes that act on all asteroids. From thermophysical modelling of 7 binary near-Earth asteroids, we determined that their average thermal inertia value was 150 ± 50 J m^{-2} K^{-1} $s^{-1/2}$, which implies that small grains are preferentially kept during their formation.

1. Introduction

Approximately 15% of near-Earth asteroids are inferred to be binaries [1], and they represent an interesting and important asteroid sub-population to study. In particular, the presence of a satellite allows the mass and bulk density of a binary asteroid system to be determined through Kepler's laws after studying the secondary's orbit about the primary. By studying their orbital configurations, most binary asteroids have low bulk density values (i.e. ~1 to 2 g cm^{-3}) and high macro-porosity values (i.e. ~40-60 %), which implies that they are rubble-piles and not solid coherent bodies. Furthermore, the primaries within binary systems are also rapidly rotating (i.e. rotation periods of 2 to 4 hours), which gives strong insights into how they formed and the physical processes that affect all asteroids in general.

It is now generally accepted that most binary near-Earth asteroids are formed by YORP-induced rotational mass loss rather than by gravitational disruption during a close planetary encounter [2]. Light-curve and radar observations of binary asteroids reveal that the rapidly rotating primaries have a "spinning top" shape with a prominent equatorial ridge (e.g. 1999 KW4 is a classic example), and that the secondaries are on stable circular orbits about their primaries [3]. Numerical simulations of rubble-piles steadily spun-up by YORP demonstrate how mass gradually lost from a primary asteroid re-accumulates in a circular orbit about it to form a small secondary [2]. The shape deformation induced on the simulated primary produces a "spinning top" shape that strongly resembles that seen in radar observations of binary near-Earth asteroids.

At present, the numerical models do not specify what type of material is preferentially lost from the primary asteroid to form the secondary asteroid. If the primary asteroid has no cohesion then small regolith grains would be preferentially lost because the asteroid's gravity is less effective at holding onto them compared to larger regolith grains. This would then leave behind large regolith grains on the primary asteroid's surface. However, if the primary asteroid has a significant degree of cohesion then large regolith grains would be preferentially lost because cohesive forces are stronger for smaller regolith grains [4]. So, in contrast to the no-cohesion case, this would then leave behind small regolith grains.

To identify what regolith grain size is preferentially left behind on the primary asteroid surface, the thermal inertia of the asteroid's surface can be determined from thermal-infrared observations and thermophysical modelling. This is because thermal inertia (i.e. a material's resistance to temperature change) can be used as a qualitative measure of the regolith grain size (i.e. low and high thermal inertia values arise from small and large regolith grains, respectively). Previous work by [5] has used a distribution of 12 NEATM beaming parameters of 8 binary near-Earth asteroids to infer that their mean thermal inertia value was 480 ± 70 J m^{-2} K^{-1} $s^{-1/2}$. This is more than double the mean value of 200 ± 40 J m^{-2} K^{-1} $s^{-1/2}$ inferred in equivalent work for solitary near-Earth asteroids [6], and suggests that binary near-Earth asteroids preferentially have large regolith grains on their surfaces. However, our previous work involving full thermophysical modelling for 3 binary near-Earth asteroids, i.e. (1862) Apollo [7], (175706) 1996 FG3 [8], and (276049) 2002 CE26 [9], has found a much lower mean thermal inertia value of ~140 J m^{-2} K^{-1} $s^{-1/2}$, which instead suggests that small regolith grains are preferentially left on their surfaces. To resolve this apparent discrepancy, we measured the thermal inertia values of an additional 4 binary near-Earth asteroids using thermal-infrared observations and thermophysical modelling, i.e. for (3671) Dionysus, (66391) 1999 KW4, (153491) 2001 SN263, and (185851) 2000 DP107 (see Table 1).

2. Thermal-IR Observations

We utilised archive NEOWISE data for (3671) Dionysus, NASA IRTF data for (153491) 2001 SN263, and Spitzer Space Telescope data for (185851) 2000 DP107 for the thermophysical modelling of those binary asteroids. Additionally, we obtained new observations of (66391) 1999 KW4 on 27th May 2016 using the VISIR instrument located on ESO's VLT telescope in Chile. The observations were obtained in imaging mode for wavelengths of 8.7-12.5 μm. The images were reduced using the VISIR image processing pipeline, and photometry was performed using standard techniques on the reduced images to give the measured asteroid fluxes.

3. Thermophysical Modelling

To determine the thermal inertia values of the 4 additional binary near-Earth asteroids studied, thermophysical modelling was performed using the ATPM [10] with their previously published shape models and pole orientations. In particular, the ATPM computes the surface temperature distribution of an asteroid by solving 1D heat conduction for each triangular facet of the asteroid shape model. A surface boundary condition is included for each facet that ensures conservation of energy between incoming radiation (i.e. direct solar illumination plus scattered light between facets), heat conducted into the sub-surface (i.e. dictated by thermal inertia), and radiated energy (i.e. thermal emission). Rough surface thermal-infrared beaming is also included by a fractional coverage of hemispherical craters. Model surface temperature distributions are produced for a range of thermal inertia values, and the model emitted flux is derived by summing the Planck function across facets visible to the observer. The model fluxes are then compared against the measured fluxes using χ^2 fitting to find the best-fit parameters and their uncertainties.

4. Summary and Conclusions

Based on the 7 asteroids studied in Table 1, the average thermal inertia value for a binary near-Earth asteroid was found to be 150 ± 50 J m^{-2} K^{-1} s$^{-1/2}$. This is at the lower end of the average value of 385 ± 225 J m^{-2} K^{-1} s$^{-1/2}$ determined for 12 solitary near-Earth asteroids via thermophysical modelling [11], and is significantly less than the previously reported value of 480 ± 70 J m^{-2} K^{-1} s$^{-1/2}$ [5]. This implies that fine-grained regolith is preferentially kept during the formation of binary asteroids by YORP spin-up.

Table 1: Summary of the binary near-Earth asteroids studied in this and previously published work.

Binary Asteroid	Spectral Type	Size (km)	Source
Apollo	Q	1.6	Reference [7]
Dionysus	C	1.1	This work
1999 KW4	S	1.3	This work
2001 SN263	B	2.5	This work
1996 FG3	C	1.7	Reference [8]
2000 DP107	S	0.9	This work
2002 CE26	C	3.5	Reference [9]

Acknowledgements

BR acknowledges support from the Royal Astronomical Society in the form of a research fellowship. Based on observations performed at the ESO Paranal Observatory in Chile (program ID 197.C-0816). Also based on data products from NEOWISE and the Spitzer Space Telescope, which are operated by the Jet Propulsion Laboratory/ California Institute of Technology under contracts with NASA.

References

[1] Pravec, P. and Harris, A. W.: Icarus, Vol. 190, pp. 250-259, 2007.
[2] Walsh, K. J. *et al.*: Nature, Vol. 454, pp. 188-191, 2008.
[3] Ostro, S. J. *et al.*: Science, Vol. 314, pp. 1276-1280, 2006.
[4] Scheeres, D. J. *et al.*: Icarus, Vol. 210, pp. 968-984, 2010.
[5] Delbo, M. *et al.*: Icarus, Vol. 212, pp. 138-148, 2011.
[6] Delbo, M. *et al.*: Icarus, Vol. 190, pp. 236-249, 2007.
[7] Rozitis, B. *et al.*: A&A, Vol. 555, id. A20, 2013.
[8] Wolters, S. D. *et al.*: MNRAS, Vol. 418, pp. 1246-1257, 2011.
[9] Rozitis, B. *et al.*: MNRAS, Vol. 477, pp. 1782-1802, 2018.
[10] Rozitis, B. and Green, S. F.: MNRAS, Vol. 415, pp. 2042-2062, 2011.
[11] Delbo, M. *et al.*: Asteroids IV, University of Arizona Press, pp. 107-128, 2015.