THERMAL EMISSION LIGHT-CURVES OF RAPIDLY ROTATING ASTEROIDS. B. Rozitis[1,2], J. Emery[2], S. Lowry[3], A. Rozek[3], S. Wolters[1], C. Snodgrass[1] and S. Green[1], [1]Department of Physical Sciences, The Open University, Milton Keynes, UK (benjamin.rozitis@open.ac.uk), [2]Department of Earth and Planetary Sciences, University of Tennessee, Knoxville, US, [3]Centre for Astrophysics and Planetary Science, University of Kent, Canterbury, UK.

Introduction: Asteroids range from a few meters in size up to 1000 kilometers across, and therefore represent an extraordinarily wide range of gravity regimes in which physical processes operate. These physical processes include gravitational and rotational forces, collisions, granular and regolith dynamics, thermal processing of absorbed sunlight, and other non-gravitational effects. Rapidly rotating asteroids (i.e. rotation periods of less than 3 hrs) are unusual bodies where their own self-gravity is balanced or exceeded by rotational centrifugal forces, which allow the effects of other important physical processes acting on these asteroids to be distinguished. Characterizing these asteroids at thermal wavelengths using Spitzer/IRAC offers a unique insight into the physical processes that shape and drive the Solar System.

Asteroid Geophysics: Asteroids are believed to be a mixture of monolithic bodies (e.g. Eros) and rubble-piles (e.g. Itokawa) that can be covered with or without a regolith layer. Despite their very low gravitational environments, they exhibit a number of geological processes involving granular matter [1]. Therefore, the physical behavior of asteroids has traditionally been described by gravitational and frictional forces within a granular material [2]. Based on this assumption, rubble-pile asteroids have a critical spin limit (~2.3 hrs for a spherical asteroid) at which their own self-gravity is balanced by rotational centrifugal forces. If a rubble-pile asteroid rotated faster than this then it would fly apart if only gravity was holding it together.

More recently, it has been predicted that inter-grain cohesive forces (in the form of van der Waals forces) should play an equally important role as gravity and friction on asteroids [3][4]. Cohesive forces can give a rubble-pile asteroid additional structural strength, which can prevent its rotational breakup if its spin exceeds the critical spin limit. This was proven to be the case for the 1.3 km near-Earth asteroid 1950 DA [5], which was shown to be a rubble-pile asteroid that was rotating faster than its critical spin limit (i.e. 2.1 hrs versus 2.3 hrs). 1950 DA has about half of its surface experiencing negative effective gravity but requires just 64 Pa of cohesive strength to hold itself together. Cohesive forces are stronger for fine-grained material (due to their inverse square dependence on the grain diameter), and therefore large rocks are preferentially lost first as an asteroid is spun-up. This is opposite to the gravity and friction only case where fine-grained material is preferentially lost first.

Thermal emission light-curves obtained by Spitzer/IRAC can distinguish between the different mass-loss behaviors by identifying, through thermal inertia measurements, what material is preferentially kept and lost on a rapid rotator (see Fig. 1). Thermal inertia is a measurement of a material's resistance to temperature change, and can be used to infer the presence or absence of fine-grained surface material [6].

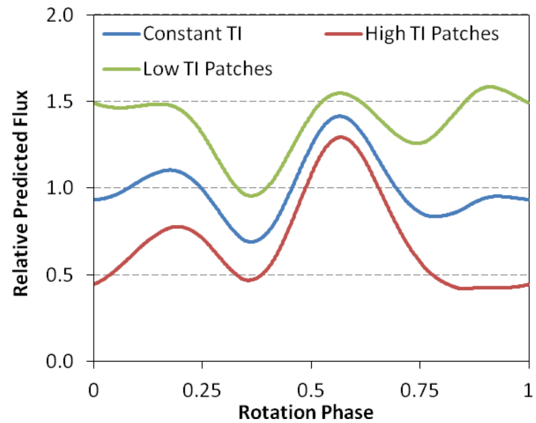

Figure 1: Example thermal emission light-curves of 1998 RS2 at 4.5 µm predicted by ATPM [7][8]. Blue curve produced by a constant thermal inertia value of 200 SI units across the surface (i.e. the average value for a km-sized asteroid; [6]). Red curve produced by patches of high thermal inertia (2000 SI units) where effective gravity is negative (see Fig. 2). Green curve produced by patches of low thermal inertia (100 SI units) instead at negative effective gravity.

Asteroid YORP Effect: Rapidly rotating asteroids smaller than 40 km in size are believed to have acquired their fast rotation rates by the YORP effect. The anisotropic reflection and thermal re-emission of sunlight from their irregular shapes results in a net photon torque causing spin-up over relatively short timescales [9]. Therefore, it has recently been realized that the YORP effect is one of the principal driving forces in the physical evolution of small asteroids. Indeed, YORP spin-up of rubble-pile asteroids can produce shape and surface morphology changes, and continued YORP spin-up can lead to binary asteroid formation [2]. It can also cause rotational fission leading to the production of unbound asteroid pairs [10].

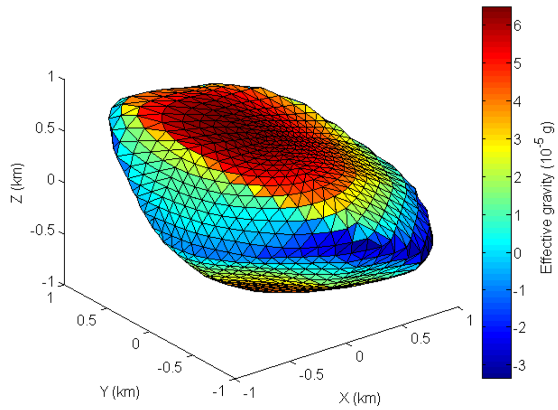

Figure 2: Example effective surface gravity map of 1998 RS2. This was produced using its known rotation period of 2.13 hr and an assumed bulk density of 2.5 g cm^{-3}. Its pointed ends experience negative effective gravity (~13% of the total surface area) because rotational centrifugal forces exceed self-gravity at those locations.

To date, the YORP effect has been detected on five near-Earth asteroids by observing phase shifts in their rotational light-curves obtained over several years [11][12][13][14][15]. It has also been demonstrated that the YORP effect is highly sensitive to subtle shape [16], surface roughness [8], and internal bulk density [15] variations, and more detections and characterizations of the YORP effect are required to constrain theoretical and dynamical models.

To increase the number of YORP detections by an order of magnitude, a European Southern Observatory (ESO) Large Program (LP) was awarded 82 nights on the 3.6 m New Technology Telescope (NTT) during 2010-2014 to constrain the YORP effect on 38 rapidly rotating near-Earth asteroids (PI Stephen Lowry; Program IDs 185.C-1033, 185.C-1034). To aid this program, thermal emission observations can help to constrain theoretical predictions of the YORP effect by measuring the thermal flux that drives this effect. In particular, Spitzer/IRAC thermal emission light-curves can constrain the diameter and surface roughness variations to which the YORP effect is highly sensitive.

Spitzer/IRAC Program and Goals: We have been using Spitzer/IRAC to obtain simultaneous 3 and 4 μm light-curves of 20 rapidly rotating asteroids with periods under 3 hrs at high SNR and high temporal resolution (Spitzer Proposal ID #11097). For each asteroid, these observations will:

- Identify and constrain spatial variations in thermal inertia and surface roughness.
- Determine what kind of surface material is preferentially kept and lost.
- Determine the relative roles that gravitational, rotational centrifugal, and cohesive forces play.
- Constrain the physical properties that drive the YORP effect.

The selected targets consist of 16 near-Earth asteroids from the ESO LP that are observable by Spitzer during cycle 11, and 4 asteroids that have archival shape and spin axis information from previous light-curve [17] and radar studies. This sample should be sufficiently diverse to investigate how asteroid geophysics and the YORP effect vary between asteroids. Finally, to date, no thermal emission light-curves of small asteroids have been obtained with both high SNR and high temporal resolution, and therefore the Spitzer/IRAC observations to be obtained on these 20 asteroids will represent a unique dataset.

The latest results from this Spitzer/IRAC program will be presented and discussed at the meeting.

References: [1] Murdoch N. et al. (2013) *MNRAS*, *433*, 506-514. [2] Walsh K. J. et al. (2012) *Icarus*, *220*, 514-529. [3] Scheeres D. J. et al. (2010) *Icarus*, *210*, 968-984. [4] Sánchez P. and Scheeres D. J. (2014) *M&PS*, *49*, 788-811. [5] Rozitis B. et al. (2014) *Nature*, *512*, 174-176. [6] Delbo M. et al. (2007) *Icarus*, *190*, 236-249. [7] Rozitis B. and Green S. F. (2011) *MNRAS*, *415*, 2042-2062. [8] Rozitis B. and Green S. F. (2012) *MNRAS*, *423*, 367-388. [9] Rubincam D. P. (2000) *Icarus*, *148*, 2-11. [10] Pravec P. et al. (2010) *Nature*, *466*, 1085-1088. [11] Lowry S. C. et al. (2007) *Science*, *316*, 272-274. [12] Kaasalainen M. et al. (2007) *Nature*, *446*, 420-422. [13] Ďurech J. et al. (2008) *A&A*, *489*, L25-L28. [14] Ďurech J. et al. (2012) *A&A*, *547*, A10. [15] Lowry S. C. et al. (2014) *A&A*, *562*, A48. [16] Statler T. S. (2009) *Icarus*, *202*, 502-513. [17] Ďurech J. et al. (2010) *A&A*, *513*, A46.

Acknowledgements: This work is based on observations made with the Spitzer Space Telescope, which is operated by the Jet Propulsion Laboratory, California Institute of Technology under a contract with NASA. Support for this work was provided by NASA through an award issued by JPL/Caltech. We also gratefully acknowledge support from the European Southern Observatory (ESO), the UK Science and Technology Facilities Council (STFC), and the Royal Astronomical Society (RAS).