Photometric survey of inner V-type asteroids
In the search for HED meteorites parent bodies

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Main Objectives

Most Howardite-Eucrite-Diogenite (HED) meteorites (analogues to V-type asteroids) are thought to originate from asteroid (4) Vesta. However some HEDs show distinct oxygen isotope ratios and therefore are thought to originate from other asteroids. In this study we try to **identify asteroids that may represent parent bodies of those mismatching HEDs**. In particular we aim at identifying V-type asteroids in the inner main asteroid belt having rotational, dynamical and/or spectral properties not relating to those of (4) Vesta. More specifically the main goals of this research are to:

- Select large V-type asteroids in the inner main belt based on SDSS data
- Determine their rotational state (prograde vs retrograde)
- Study their rotational, dynamical and spectral characteristics

Introduction

Isotopically anomalous HEDs may be fragments from non-Vesta V-type asteroids. The anomalous HED Bunburra Rockhole has a dynamical origin that traces back to the inner Main Belt [5]. Thus **there might be V-type asteroids in the inner main belt not related to Vesta**. Nesvorny et al. 2008 [6] simulated (see Fig. 1) the escape paths from Vesta and its family showing that typical Vesta fugitives in the inner main asteroid belt have to have retrograde rotations and physical and thermal parameters that maximize the Yarkovsky force in order to evolve to scattered orbits within 1-2 Gys (age of the Vesta collisional family). Therefore large asteroids outside the Vesta family having thermal and rotational properties minimizing the Yarkovsky drift or showing drift direction towards (4) Vesta are the best candidates for non-Vestoidal V-type asteroids. **In this study we focus on determining the spin properties of inner V-type asteroids to help better understand the dynamical evolution of those objects and whether they originate from Vesta or other body**.

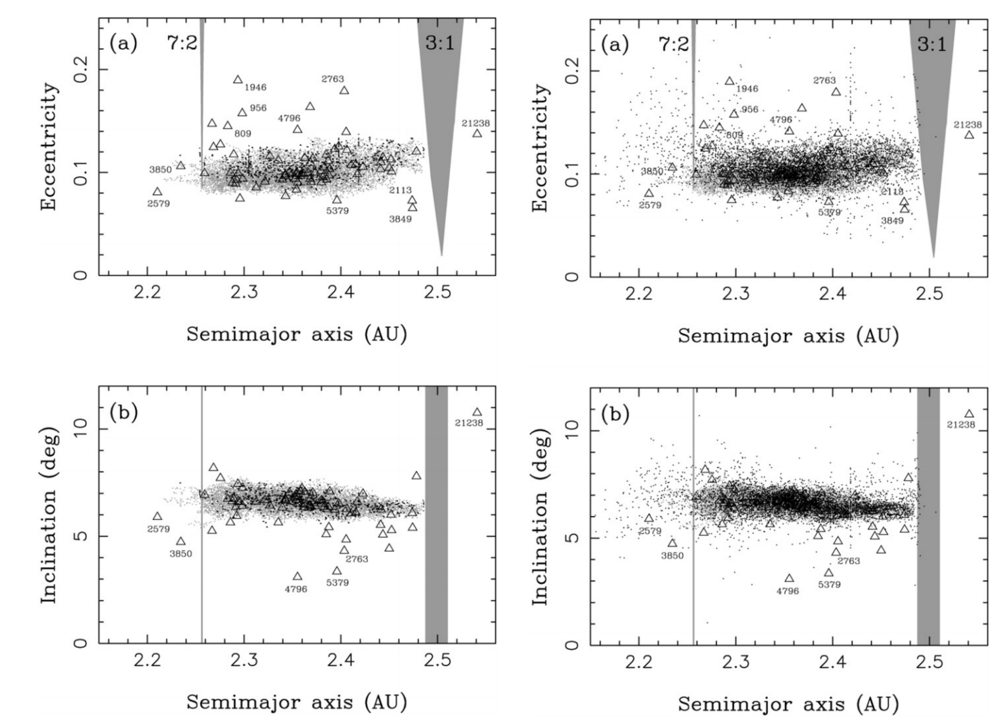


Figure 1: Figure adopted from Nesvorny et al. (2008), Icarus, 193(1), 85-95. Distribution of proper orbital elements of test objects at the start (left) and end (right) of dynamical integration.

Results

0.1 Target selection

For this survey we have selected around 30 V-type asteroids outside the Vesta dynamical family (Fig 2). The V-type candidates were selected based on the SDSS data [4]. For practical reasons we focus on asteroids with rotational periods < 12h and objects for which some previous data is available. To perform full light curve inversion data from a minimum 4 oppositions are required.

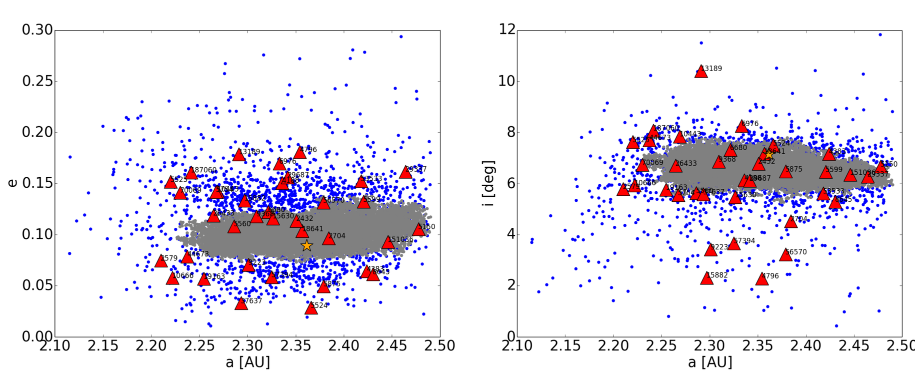


Figure 2: Distribution of orbital elements of selected target V-types in the inner main belt (red triangles), Vesta family members (grey), SDSS V-type candidates (blue). Asteroid (4) Vesta is denoted with a star.

0.2 Photometry and Spectroscopy

In the first step of this survey we use a lightcurve analysis method to **determine sense of rotation for the targeted asteroids**. In particular we are determining changes in synodic period around the opposition. **Prograde rotators have their synodic period increasing when they move away from opposition (minimum at opposition) and retrograde rotators decreasing (maximum synodic period at opposition)** - this is a purely geometrical effect (See Fig 3). The amount of the change in synodic period depends on spin orientation of the rotational pole. Below we present preliminary result for our first few targets. The photometric data were collected at the Lowell Observatory 1.1m Hall and 1.8m Perkins telescopes and the spectroscopy at the 4.3m Discovery Chanel Telescope (DCT). The data for (4796) Lewis and (5150) Fellini are best explained by a prograde rotation. whereas for asteroid (5875) Kuga we find that the data are best explained by retrograde rotation. Assuming that the rotational spins were not modified by random collisions or the Yarkovsky-O'Keefe-Radzievskii-Paddack (YORP) effect the prograde rotating objects were drifting outwards (towards larger semi-major axis) and the retrograde inwards (towards smaller semi-major axis). Therefore the origin of (5150) Fellini can be easier explained by migration from (4) Vesta than the origin of (4796) Lewis and (5875) Kuga. However to fully understand the origin of this object full dynamical integration (including Yarkovsky effect and resonances) is needed. Additional data will also help confirm the sense of rotation. For two objects (5525) 1991 TS4 and (18641) 1998 EG10 we have revised their rotational periods. For asteroid (18641) 1998EG10 we find shorter (P=5.24612 $\pm$ 0.00024) rotational period than previously determined [8] and for asteroid (5525) 1991 TS4 our estimated period is about twice as long (P=14.0758 h $\pm$0.0001) as previous estimations [9].

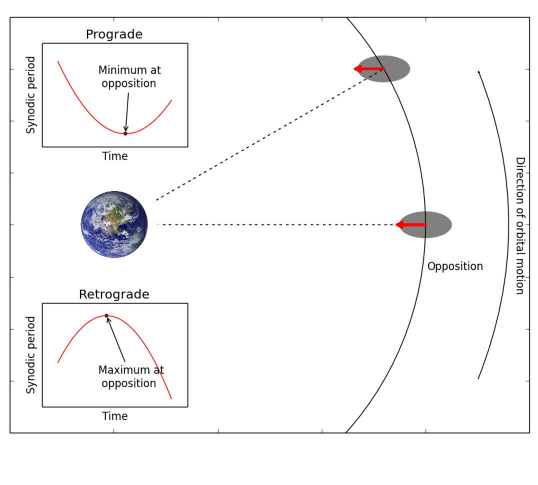


Figure 3: Method of determining the sense of rotation relies on measuring changes in asteroid synodic rotational period

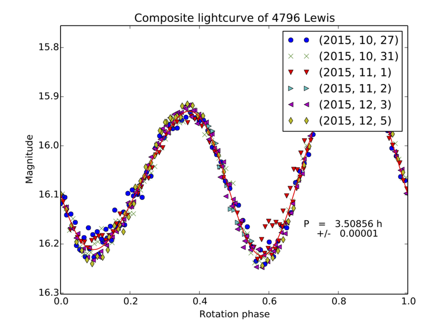
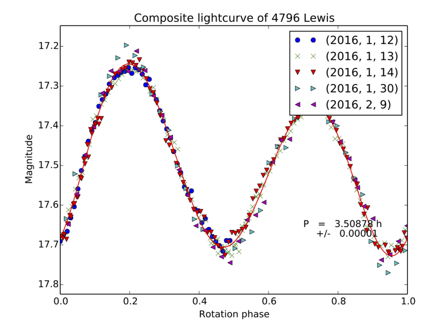
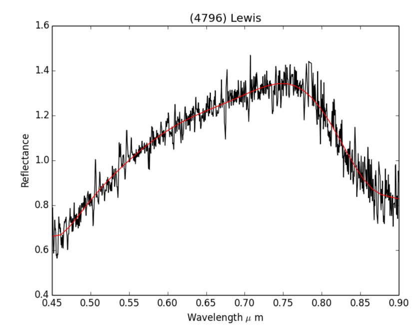
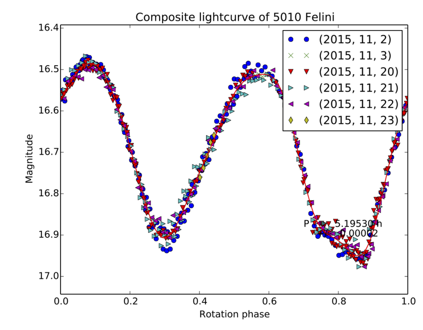
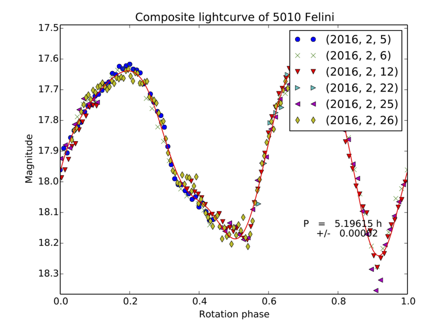
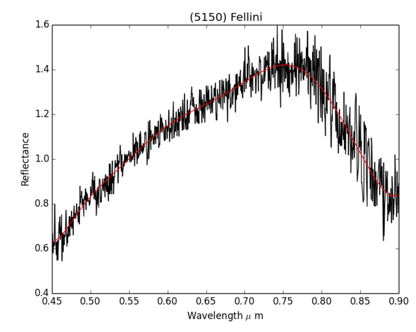
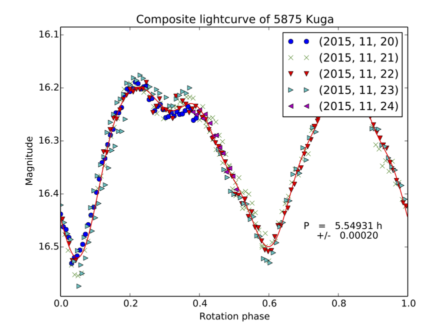
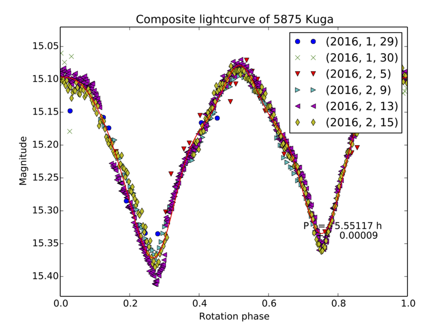
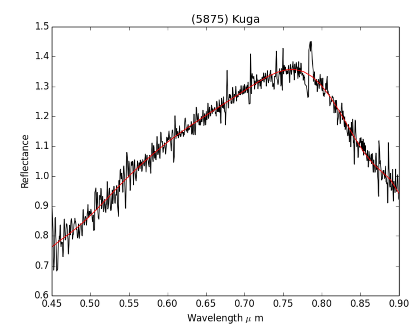
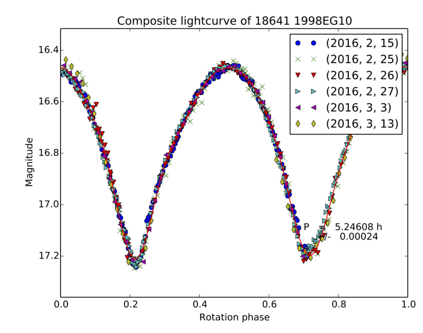
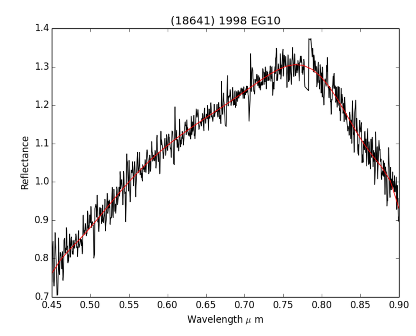
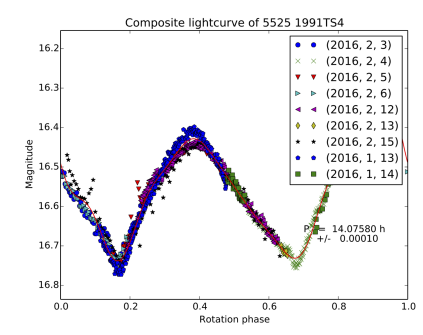
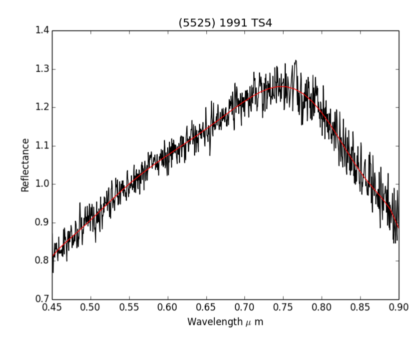
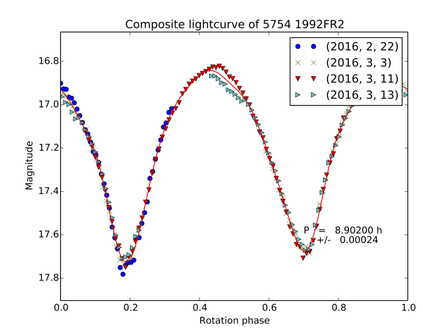
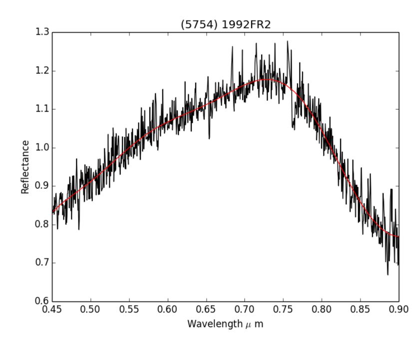
Lightcurve: epoch 1	Lightcurve: epoch 2	Spectra	Opp.	Rot.	Yark. drift
			2015/11/07	Likely prograde	Toward Vesta
			2015/11/12	Likely prograde	Away form Vesta
			2016/01/26	Likely retrograde	Toward Vesta
			2016/02/16	New rot. period	
			2016/02/07	New rot. period	
			2016/04/17		

Table 1. Lightcurves, spectra, date of opposition, rotational properties and direction of the Yarkovsky drift.

Conclusions

- Both prograde and retrograde rotating objects are present in the region Data for two asteroids: (4796) Lewis and (5150) Fellini are consistent with prograde rotation and data for (5875) Kuga are consistent with retrograde rotation.
- Asteroids (4796) Lewis and (5875) Kuga are our first good candidates for non-Vesta origin V-type asteroid, however we note that full dynamical integration has to be performed to fully understand the origin of those objects.
- We have revised rotational period for asteroids (5525) 1991 TS4 and (18641) 1998 EG10.
- There is no obvious distinctive spectral signatures between the observed prograde asteroids and typical V-types
- More data are necessary!

0.3 Future work

Because large amount of data gathered from various oppositions is needed this is a long term project. Our future work includes:

- Determining sense of rotation for asteroids from different V-type populations (inner, mid and outer main belt, inner belt low inclination objects, etc.) and population statistics
- Determining spectral characteristic in those V-type populations
- Performing full lightcurve inversion to determine detailed spin and shape properties of those objects
- Full dynamical integration (including Yarkovsky and gravitational forces) for interesting objects

References

[1] Solontoi et al. (2012), Icarus, 220 (2), 577-585 [2] Hammergren et al. (2011), LPSC, 1608, 2821 [3] Moskovitz et al. (2010), Icarus, 208(2), 773-788 [4] Oszkiewicz et al. (2014), AA, 572, A29, 12 [5] Spurny et al. (2012), MAPS, 47(2), 163-185 [6] Nesvorny et al. (2008), Icarus, 193(1), 85-95 [7] Oszkiewicz et al. (2015), AA, 584, A18, 14 [8] Clark M. (2008), MPB, 53 (4), 152-154 [9] Behrent (2016) http://obswww.unige.ch/~behrend/page5cou.html#005525