All About A-type Asteroid 446 Aeternitas

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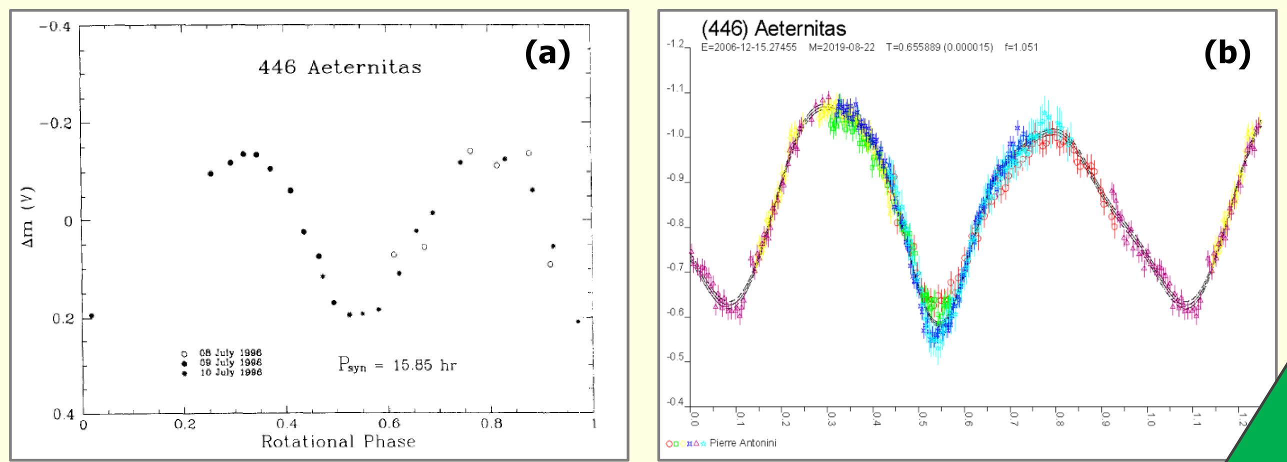
Introduction

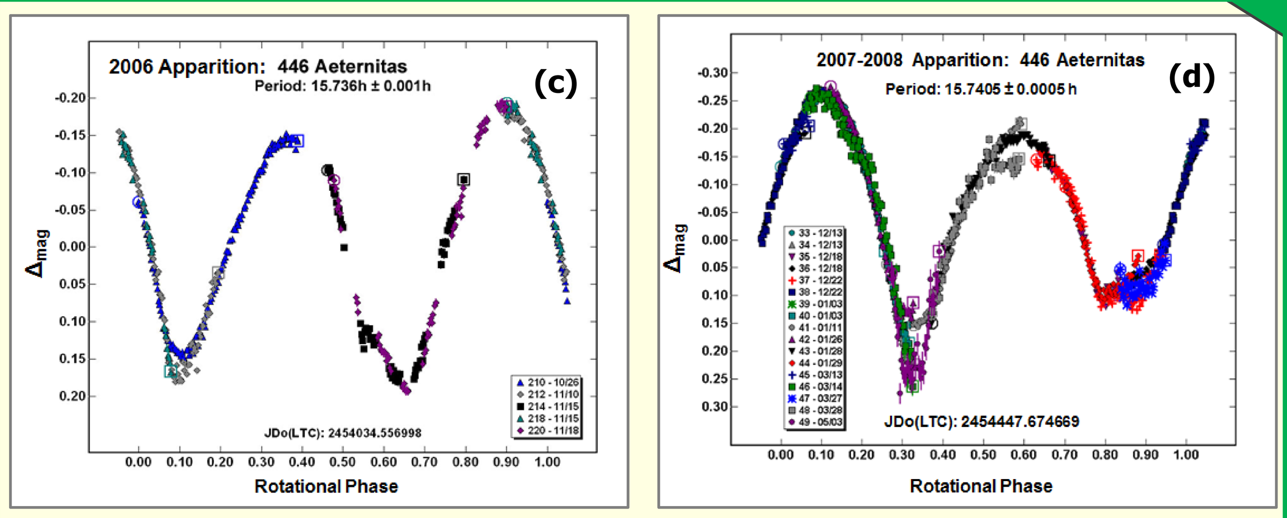
Asteroid dynamical work has suggested that differentiated asteroids, precursors of metallic (core), olivine (mantle), and basaltic (crustal) fragments, may have formed in the terrestrial planet region and are now interlopers to the main-belt. Based on the geochemical diversity of iron meteorites, at least ~108 asteroid parent bodies experienced partial or total melting, hence differentiation and core formation, within the first few Myr of solar system history. However, aside from chips of 4 Vesta (Vestoids and HED meteorites), mantle and crustal fragments from differentiated asteroids are rare. Mantle fragments are represented in the asteroid population by taxonomic A-types, but these *pure-olivine* and *olivine-rich* objects remain cryptic among the spectrally observed asteroids. Here, we present data from several observational campaigns, acquired mostly using ground-based telescopes, for *olivine-rich* A-type asteroid 446 Aeternitas.

The main-belt asteroid Aeternitas (a = 2.79 AU) was discovered in 1899 by Wolf and Schwassmann. Knowledge regarding the physical properties of this object has greatly increased over the past three decades. Inversion techniques using our photometric lightcurves collected over three apparitions yield a refined sidereal rotation period of 15.73743 ± 0.00005 h, and generated a convex-hull shape model of the asteroid. Our results reveal that Aeternitas is a prograde rotator with an angular shape, and is likely a collisional fragment. Accordingly, for mantle material to be exposed the parent asteroid must be fragmented or its interior exposed via collisions.

Visible and near-infrared (VISNIR) spectra indicate that Aeternitas is an *olivine-rich* A-type with an ol/(ol+px) ratio of 0.92, with a minor (~8%) pyroxene component. Several inferences of mineral chemistry derived from these spectra suggest Mg-rich olivine compositions, analogous to pallasite meteorites. However, recent results suggest that the R-chondrites are a possible meteorite analog. We performed NEATM thermal modeling utilizing WISE (12 and 22 µm) data, employing refined absolute magnitude and slope parameter values. These results provide new estimates for effective diameter (D_{eff}) 56 ± 3 km, geometric albedo (p_v) 0.167 ± 0.030, infrared albedo (p_{ir}) 0.403 ± 0.040, and beaming parameter (η) 1.48 ± 0.10 for Aeternitas.

The Lightcurves





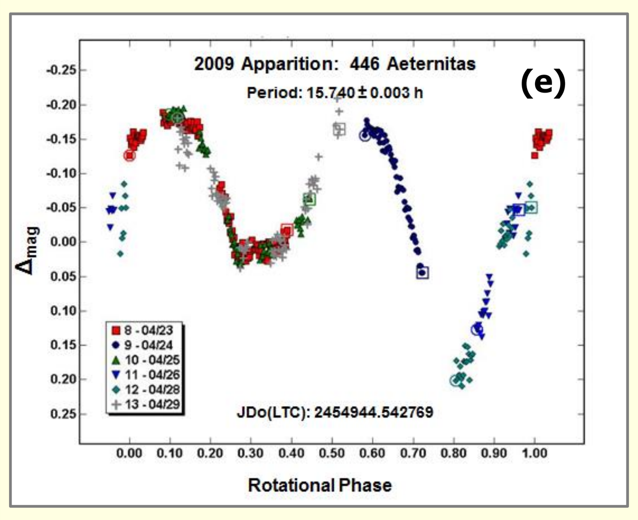


Figure 1. – Reported rotational periods from photometric lightcurves for 446 Aeternitas. **(a)** from Florczak *et al.*, 1997 **(b)** from Behrend - Observatoire de Genève website, 2006 **(c)** from Fauerbach *et al.*, 2008 **(d)** from Lucas *et al.*, 2012 **(e)** from Lucas *et al.*, 2011. Lightcurve data in **(c,d,e)** were inverted to produce the shape model of this asteroid.

The Spectrum

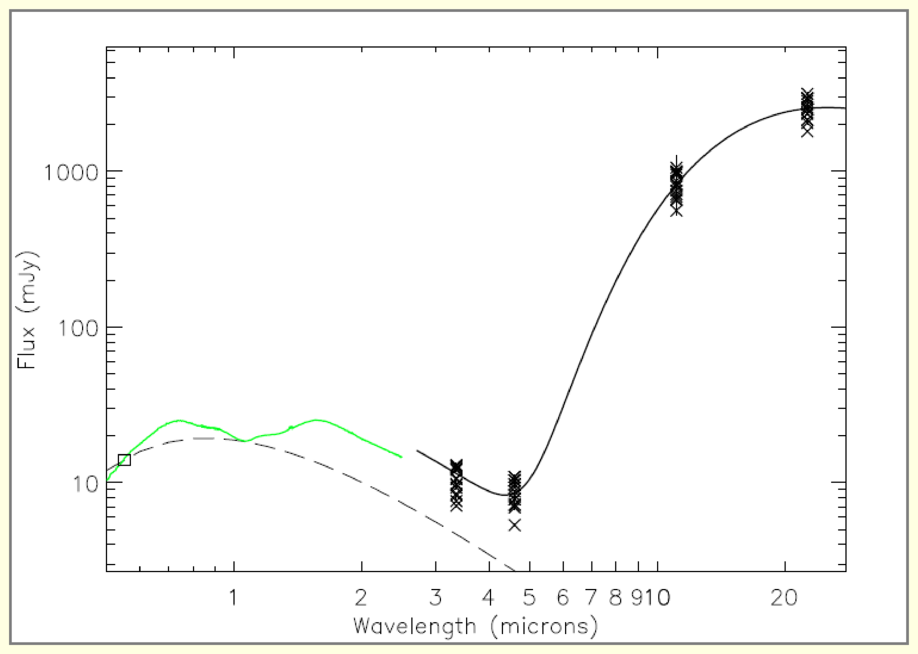


Figure 2. – VISNIR spectrum (green) and WISE IR fluxes (**black x's**) of 446 Aeternitas with reflected + NEATM model fit (**black line**). VIS data is from SMASS II (Bus and Binzel, 2002), NIR data is from (Sunshine *et al.*, 2007), IR fluxes (3.4, 4.6, 12, 22 µm) from WISE (Mainzer *et al.*, 2011).

The Shape Model

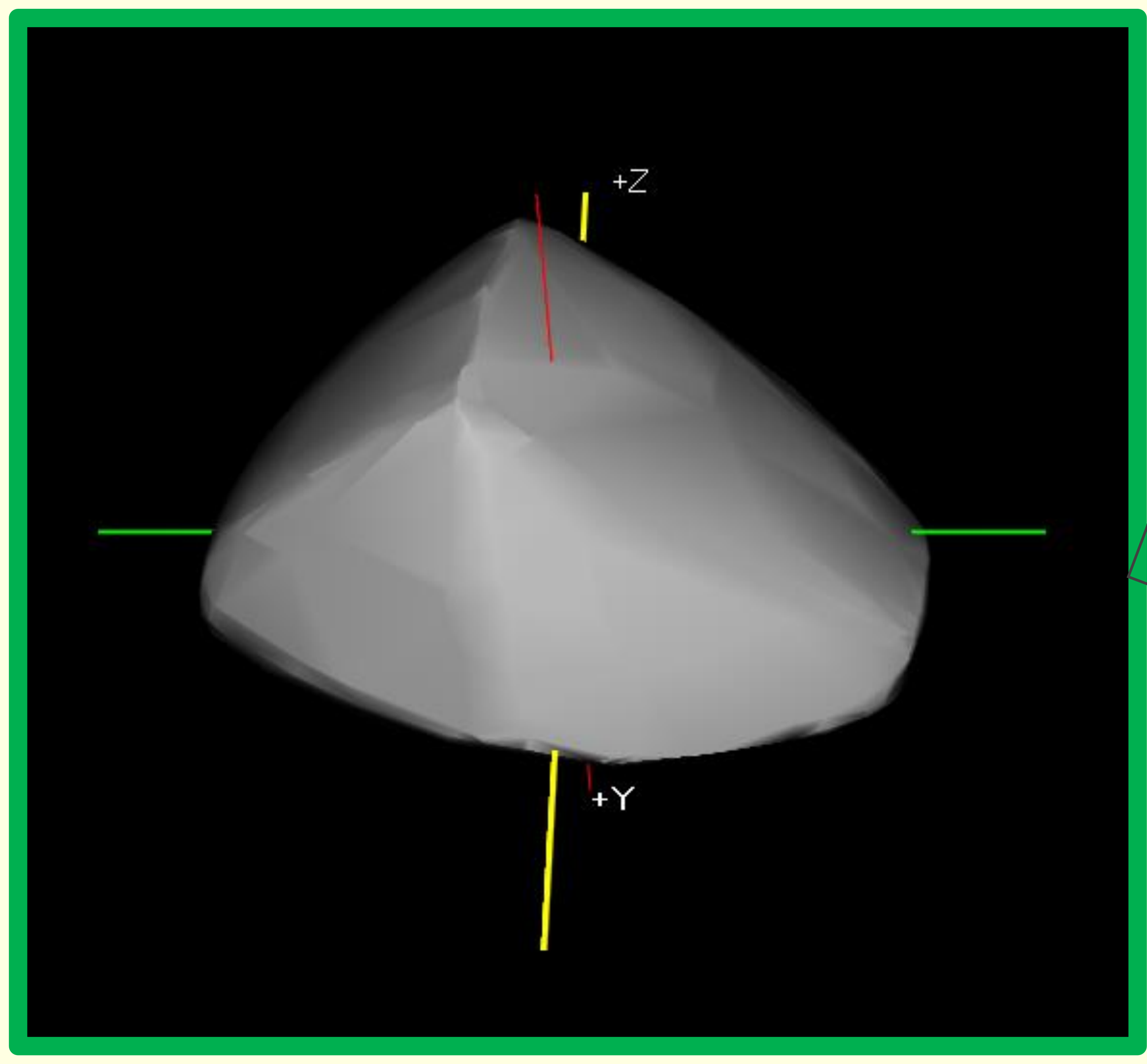


Figure 3. – Shape model of 446 Aeternitas shown in ecliptic view with pole solution (z-axis) of β = +52º, λ = 356º indicated. In this view the observer and asteroid are on the ecliptic plane (asteroid on ascending or descending node of orbit) with phase angle of 0º. The diameter of Aeternitas is 56 ± 3 km for scale.

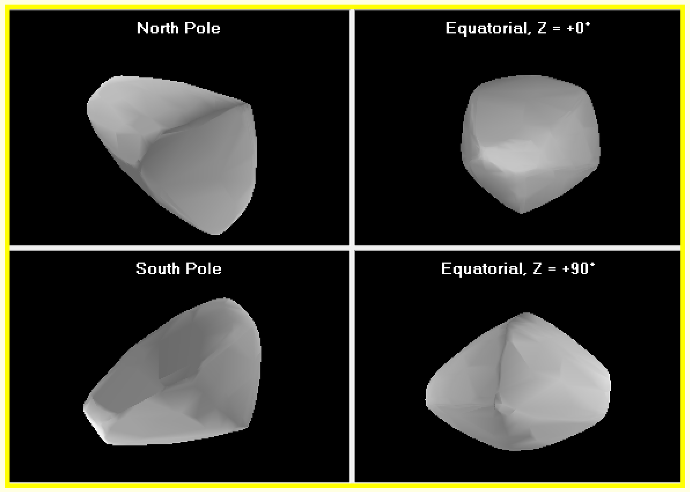


Figure 4. – Shape model of 446 Aeternitas from four different viewing geometries (Lucas *et al.*, 2012). Aeternitas is a prograde rotator with a distinct angular shape. Planar areas in the convex hull shape model suggest concavities, possibly large craters or saddles. The diameter of Aeternitas is 56 ± 3 km for scale.

Table 1. – Parameters for the derived shape model of 446 Aeternitas. A total of 1787 photometric data points were used in the lightcurve inversion technique to produce the shape model.

Asteroid	β	λ	Per. (h)	Obs. Years	Phase Range	N_{lc}	χ^2	rms Δ (mag)
446 Aeternitas	+52º	356º	15.73743	2006-09	6.8º-17.6º	28	0.3126	0.0134

β and λ are the ecliptic latitude and longitude of the pole
Obs. Years - the length of time the observations span
N_{lc} denotes the number of lightcurves used
χ^2 denotes the chi-square value of the model fit
rms Δ - the rms deviation of the model fit

➢ In order for mantle material to be exposed, a differentiated parent body must be fragmented or its deep interior exposed by large impacts (Reddy *et al.*, 2005) → resolve shapes of known A-type asteroids to determine if their morphology is consistent with collisionally-derived fragments.

The Meteorite Analogues

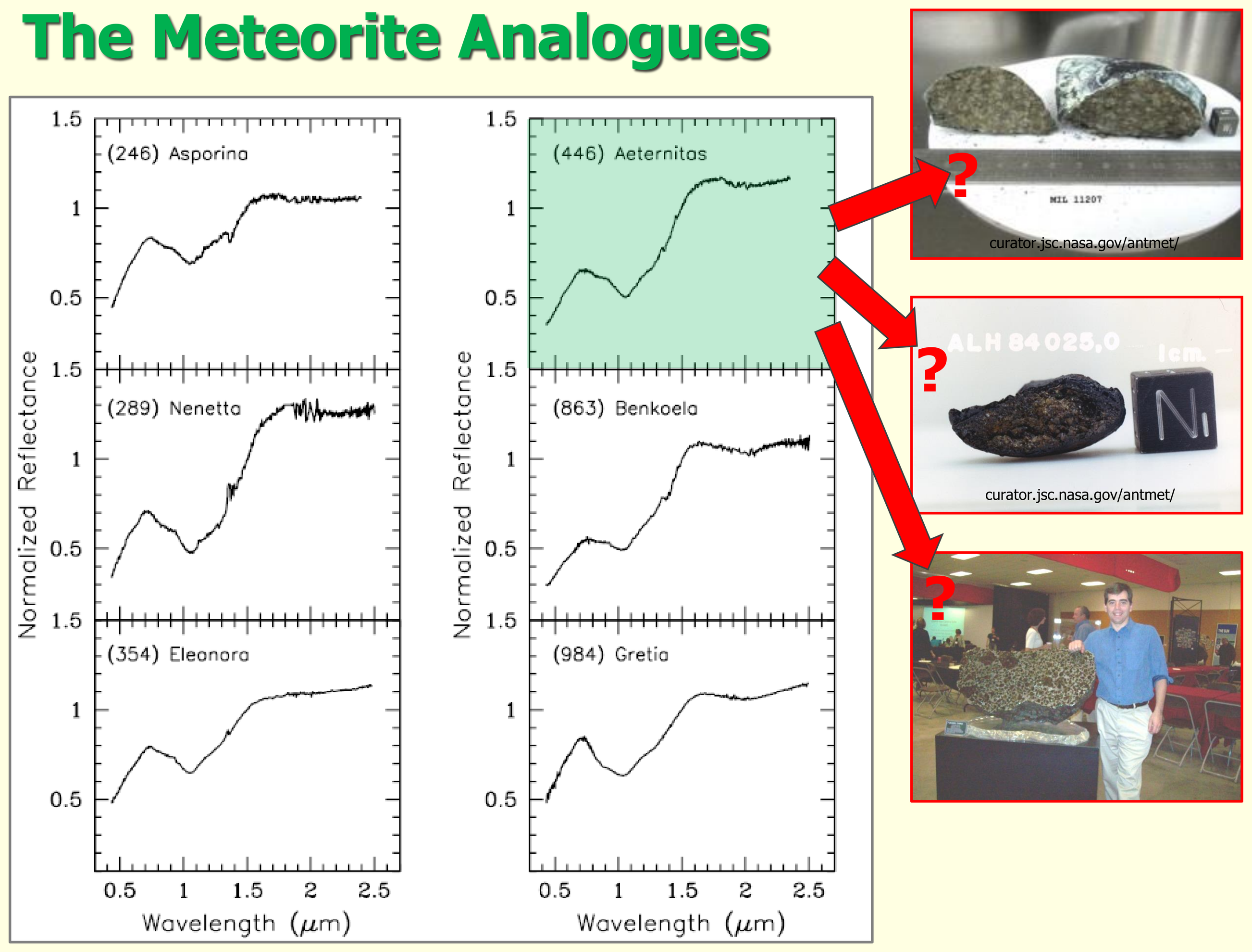


Figure 5. – VISNIR spectra of six olivine-dominated asteroids, 2 µm absorption bands due to pyroxene are absent for three asteroids (left) and are thus *pure-olivine* A-types, three asteroids (right) display slight absorptions due to pyroxene and are thus *olivine-rich* A-types (Sanchez *et al.*, 2013). Three possible olivine-rich meteorite analogues for 446 Aeternitas (green) are shown above; R chondrites (top), brachinites (middle), and pallasites (bottom).

The Thermal Model

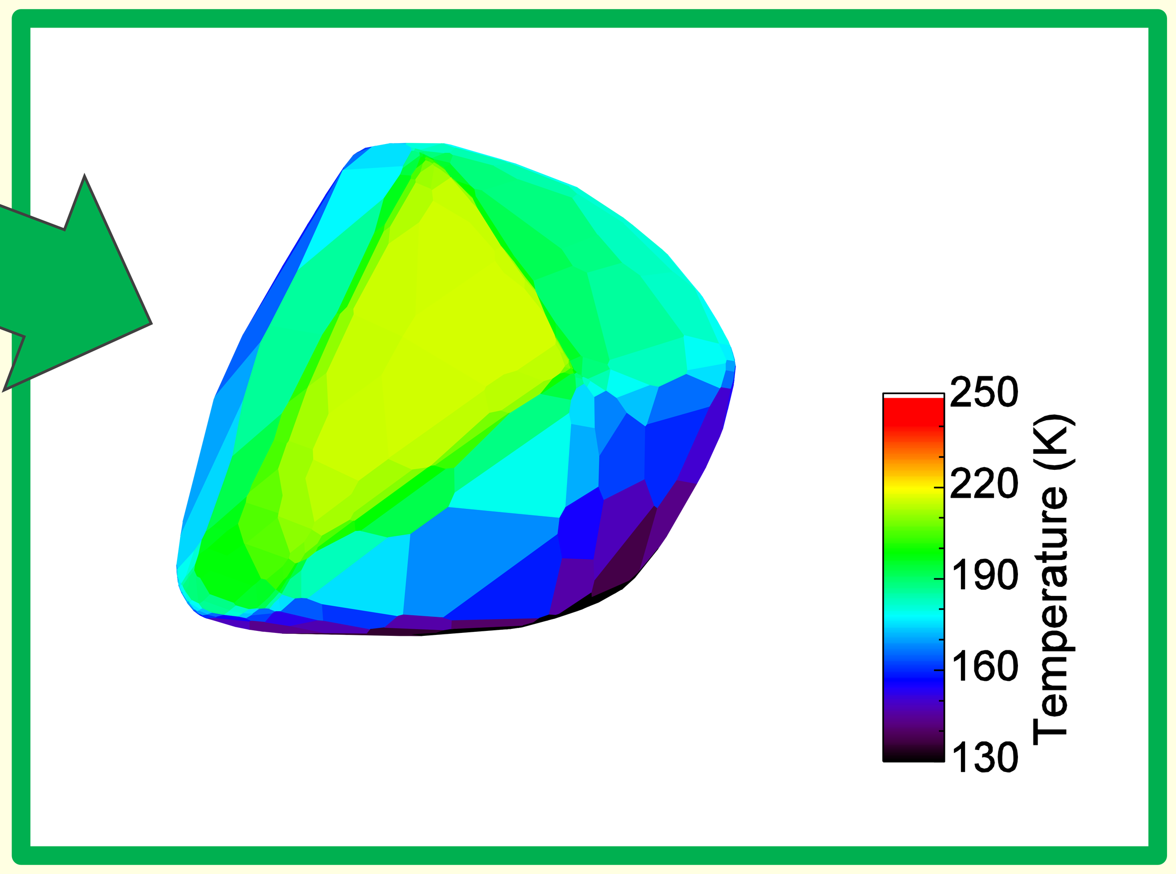


Figure 6. – Derived thermal model for 446 Aeternitas for the date 2010-04-05.552 and a heliocentric distance of 2.57 AU. The rotational pole (z-axis) is to the upper left in this view.

Figure 7. – 22 µm fluxes with a model thermal rotational lightcurve. A thermal inertia (γ_T) of 200 J m^{-2} K^{-1} s$^{-0.5}$ provides the best amplitude fit with the fluxes.

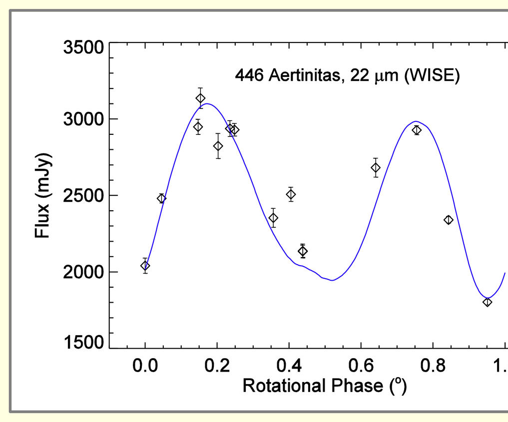


Table 2. – Mineralogical and physical parameters for Aeternitas.

Asteroid	ol/ (ol+px)	LCP/ (LCP+HCP)	Taxonomy Bus-DeMeo	Gaffey S-subtype	D (km)	p_v	p_{ir}	η	γ_T
446 Aeternitas	0.92	0.90	A	SI	56±3	0.167 ±0.030	0.403 ±0.040	1.48 ±0.10	~200

Acknowledgements

Partial support for this research has been provided by: a NASA Space Grant Fellowship (M.S.) to Lucas administered through the Florida Space Grant Consortium (FSGC), a Geological Society of America (GSA) Graduate Student Research Grant to Lucas, and a Oscar R. Ashley Fellowship through the Graduate School of the University of Tennessee. Special thanks to organizations that provided travel funding to Lucas to present this work: the Southeastern Section of the Geological Society of America, the Graduate Student Senate (GSS) of the University of Tennessee, and the Department of Earth & Planetary Sciences at the University of Tennessee.

This publication makes use of data products from the Wide-field Infrared Survey Explorer, which is a joint project of the University of California, Los Angeles, and the Jet Propulsion Laboratory/California Institute of Technology, funded by the National Aeronautics and Space Administration.

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