Shapes and Multiplicities of Vesta Family Asteroids

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Project Overview:

- Multi-apparition Photometric study of Vesta family (asteroids dynamically and chemically linked to Vesta).

- **Motivation** – To understand the Vesta family formation from a cratering impact event. Observational data is being acquired to ascertain whether family members are re-accumulated rubble piles or intact, ejected spall fragments.

- **Family Members observed**
  - 34 Asteroids Observed
  - 22 Periods Derived
  - 10 Studied in detail (multi-apparition light-curves and/or at multiple solar phase angles)

- **Facilities used:** 1.8 m VATT (VORG); UH 2.2m, 1m CTIO (NOAO); 0.35 m Etscorn; MRO 2.4-meter.
2511 Patterson

$P = 4.141 \pm 0.001$ hours

Rotational Phase (hours)
3155 Lee: Binary Lightcurve Model?

Synthetic lightcurve code written by W. H. Ryan and C. T. Martinez
3155 Lee: March 2004

- P = 8.312 ± 0.001 hours

Rotational Phase (hours)
Primary Occultation Model

Synthetic lightcurve code written by
W. H. Ryan and C. T. Martinez
January 2003 (Residuals): Binary

Secondary/Primary diameters = 0.43 ± 0.01
Primary Diameter ~ 6 km (H ~ 12.5)
Primary Rotational Period = 3.84 hours
Orbital Period = 36.57 ± 0.03 hours

Mean density = 2.2 ± 0.4 g/cm³
(Basalt ~ 2.9 g/cm³)

(Ryan, Ryan & Martinez 2004)
Celle Follow-up: October 2005

(Short period subtracted - folded with P = 36.57 hrs)
Not every occultation is due to a binary companion!
3703 Volkonskaya: December 2000

Another binary (periodicity ~24hrs), but needed more data to reliably model the system.

Spectral Class: V-type
(R. Binzel, private communication)
Follow-up work, but still unable to acquire complete coverage of the 2 occultation events. Additional Volkonskaya data thanks to Fumi Yoshida (NAOJ), Bisei Staff, Shigeru Takahashi (Lulin), Mansur Ibrahimov (Maidanak).
Confirmation: 3703 Volkonskaya is a Binary!

- Finally—a robust confirmation (7 nights) of periodic attenuations for 3703 Volkonskaya in May 2006 at CTIO 1-meter telescope.
- Size Ratio: ~0.38 - 0.47
- Periodicity: ~24 hr (Potential orbital periods of ~24 hr or 48 hr).
Current Strategy:

- Focus efforts on acquisition and analysis of multi-apparition data of our previously observed objects to understand photometric properties of Vesta chips and perform shape modeling.

- Concentrate on follow-up observations and analysis of previously identified unusual objects (including binaries).

- Search for new Vesta chip binaries via extended monitoring of fast rotators (P ~4 hr or less).

- Identify new periods as observing schedule permits.
Summary

• Two definitive binary systems in the Vesta family (Celle, Volkonskaya).

• At least 2 other “unusual” objects (Lee, Yurlov).

• Studying photometric properties of selected objects in detail prior to shape modeling of the Vesta chips.

Models of the Vesta family’s formation via a subcatastrophic collisional event, or events, and its subsequent dynamical evolution, must contain some probability for the creation of binary systems.
Future Work: MRO 2.4-meter Telescope

CD07 Alicante, Spain, June 26 - 29, 2007
January 2003 (Intensity Subtraction)
Analysis of 5 Jan. 2003 Event

\[ |\Delta m| = 2.5 \log \left( \frac{A_p + A_s}{A_p} \right) \]

\[ \frac{d_s}{d_p} = \sqrt[10]{10^{\frac{\Delta m}{2.5}}} - 1 \]

\[ \Delta m = 0.185 \pm 0.005 \Rightarrow \frac{d_s}{d_p} = 0.43 \pm 0.01 \]
Analysis of 5 Jan. 2003 Event

\[
\sin \theta = \frac{\frac{1}{2}(\beta d_p + d_s)}{a} \quad (\beta = 1 \text{ for equatorial transit})
\]

\[
\frac{\Delta t_{tot}}{T} 360° = 2\theta + \alpha
\]

\[
\Rightarrow \frac{a}{d_p} = \frac{\beta + \frac{d_s}{d_p}}{\sin \left[ \frac{\Delta t_{tot}}{T} 180° - \frac{\alpha}{2} \right]} = 3.35 \pm 0.20
\]
Analysis of 5 Jan. 2003 Event

\[
\sin \theta = \frac{\frac{1}{2}(\beta d_p - d_s)}{a} \quad (\beta = 1 \text{ for equatorial transit})
\]

\[
\frac{\Delta t_{\text{plat}}}{T} \quad 360^\circ = 2\theta + \alpha
\]

\[
\Rightarrow \frac{a}{d_p} = \frac{\beta - \frac{d_s}{d_p}}{\sin \left[ \frac{\Delta t_{\text{plat}}}{T} \frac{180^\circ - \alpha}{2} \right]} = 3.40 \pm 0.23
\]
Summary: 3782 Celle Binary System

- Secondary/Primary diameters = 0.43 ± 0.01
- Primary Diameter ~ 6 km (H ~ 12.5)
- Primary Rotational Period = 3.84 hours
- Orbital Period = 36.57 ± 0.03 hours
- Semi-major axis/primary diameter = 3.4 ± 0.2
- Mean density = 2.2 ± 0.4 g/cm³
  (Basalt ~ 2.9 g/cm³    HED Meteorites ~ 2.9-3.3 g/cm³)
Constraints on the Vesta Family’s Age?

Assuming that the Celle binary system was created when the family formed (diameters ~3 to 6 km), the lifetime against collisional disruption for bodies in this size range is about $10^9$ years.

Bottke et al. (2005)