Spitzer Observations of ARM Targets 2009 BD and 2011 MD

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Motivation – Asteroid Retrieval Mission (Option A)

Small number of potential targets with suitable orbits, even less objects with known diameters and other physical properties

Idea: thermal infrared observations can be used to characterize potential target asteroids
Spitzer Space Telescope Observations

- has been used before to characterize NEOs (e.g., Trilling et al. 2010)
- Spitzer provides an **unprecedented sensitivity** in the thermal infrared

Two candidate mission targets were observable with Spitzer in 2013/2014:

- **2009 BD** ($\Delta v = 3.9$ km s$^{-1}$)
- **2011 MD** ($\Delta v = 4.2$ km s$^{-1}$)

For comparison:

- Itokawa: $\Delta v = 4.6$ km s$^{-1}$
- Moon: $\Delta v = 6.0$ km s$^{-1}$
2011 MD – Spitzer Observations

Observed 2014 February 11 for 19.9 hrs (18.3 hrs on-source) in IRAC Ch2

2011 MD – Spitzer Observations

Observed 2014 February 11 for 19.9 hrs (18.3 hrs on-source) in IRAC Ch2

Comove map (681 individual frames)

measured flux density at 4.5 µm:

0.60 ± 0.27 µJy

2011 MD – Thermophysical and Orbital Modeling

- Thermophysical Model
  - Surface temperature distribution through insolation and heat conduction
  - Observing geometry
  - Flux density
  - Surface properties
  - Absolute magnitude (H)
  - Obliquity
  - Spin period

2011 MD – Thermophysical and Orbital Modeling

Thermophysical Model
- surface temperature distribution through insolation and heat conduction
- observing geometry
- flux density
- surface properties
- albedo
- diameter
- thermal inertia

Dynamical Model
- non-gravitational forces (solar radiation pressure, Yarkovsky force)
- astrometric observations (e.g., Micheli & Tholen 2014)
- absolute magnitude (H)
- obliquity
- spin period (Ryan & Ryan 2012)
- diameter
- bulk density

Yarkovsky Effect:

- an-isotropic emission of heat affects orbit
- most effective on small asteroids

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Bulk density
- diameter
- thermal inertia
- albedo

2011 MD – Results

diameter: 6 (+4/-2) m (3σ: 2-26 m)
geometric albedo: 0.3 (+0.4/-0.2) (3σ: ≥ 0.02)

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- **Geometric albedo:** 0.3 (+0.4/-0.2) (3σ: ≥ 0.02)
- **Bulk density:** 1.1 (+0.7/-0.5) g cm$^{-3}$ (3σ: 0.2-5.0 g cm$^{-3}$)
- **Total mass:** 110 (+240/-60) t (3σ: 10-2500 t)
- **Macroporosity:** ≥ 0.65

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- **Macroporosity**: \(\geq 0.65\)

**2011 MD is a rubble-pile asteroid**

2009 BD – Spitzer Observations

Observed 2013 October 13 for 25 hrs (22.2 hrs on-source) in IRAC Ch2

2009 BD was not detected

Flux density $\leq 0.78 \, \mu$Jy (3$\sigma$)

Comove map (800 individual frames)

2009 BD – Thermophysical and Orbital Modeling

approach similar to 2011 MD:

- generate random synthetic asteroids and compare with upper-limit flux density
- wealth in astrometric data puts stronger constraints on orbital model
  - Yarkovsky drift detected
  - thermal inertia can be constrained

2 physically possible solutions!
2009 BD – Results

Artist's Interpretation – still in progress

2009 BD high-$\Gamma$ / 2011 MD

highly porous rubble pile structure

2009 BD low-$\Gamma$

regolith-covered monolithic body
Conclusion

Neither body is a simple monolithic piece of rock
Appendix
Comparison with Larger Asteroids

![Graph comparing the bulk density and macroporosity of asteroids 2011 MD and 2009 BD, with data points for High-Γ and Low-Γ categories.](image)
# Results Overview

## Physical Properties of 2009 BD

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Low-(\Gamma) Solution</th>
<th>High-(\Gamma) Solution</th>
<th>2011 MD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter (d) (m)</td>
<td>2.9 ± 0.3</td>
<td>4 ± 1</td>
<td>6 (+4/-2)</td>
</tr>
<tr>
<td>Albedo (p_V)</td>
<td>0.85^{+0.20}_{-0.10}</td>
<td>0.45^{+0.35}_{-0.15}</td>
<td>0.3 (+0.4/-0.2)</td>
</tr>
<tr>
<td>Obliquity (\gamma) (°)</td>
<td>170^{+10}_{-15}</td>
<td>180^{+0}_{-5}</td>
<td></td>
</tr>
<tr>
<td>AMR (\Psi) (×10^{-4} m² kg⁻¹)</td>
<td>1.8^{+0.3}_{-0.2}</td>
<td>2.2^{+0.4}_{-0.2}</td>
<td></td>
</tr>
<tr>
<td>Bulk density (\rho) (g cm⁻³)</td>
<td>2.9^{+0.5}_{-0.5}</td>
<td>1.7^{+0.7}_{-0.4}</td>
<td>1.1 (+0.7/-0.5)</td>
</tr>
<tr>
<td>Macroporosity (%)</td>
<td>10^{+20}_{-10}</td>
<td>45^{+15}_{-30}</td>
<td>&gt; 0.65</td>
</tr>
<tr>
<td>Total mass (metric tons)</td>
<td>36^{+10}_{-8}</td>
<td>55^{+30}_{-25}</td>
<td>110 (+240/-60)</td>
</tr>
<tr>
<td>Thermal inertia (\Gamma) (SI units)</td>
<td>30^{+20}_{-10}</td>
<td>2000 ± 1000</td>
<td></td>
</tr>
</tbody>
</table>

**Note.** Uncertainties depict the 1σ confidence interval.
2009 BD – Diameter Distributions

2009 BD – Obliquity/Chi2 Distributions
2009 BD – Density/Chi2 Distributions