Spitzer Observations of ARM Targets 2009 BD and 2011 MD

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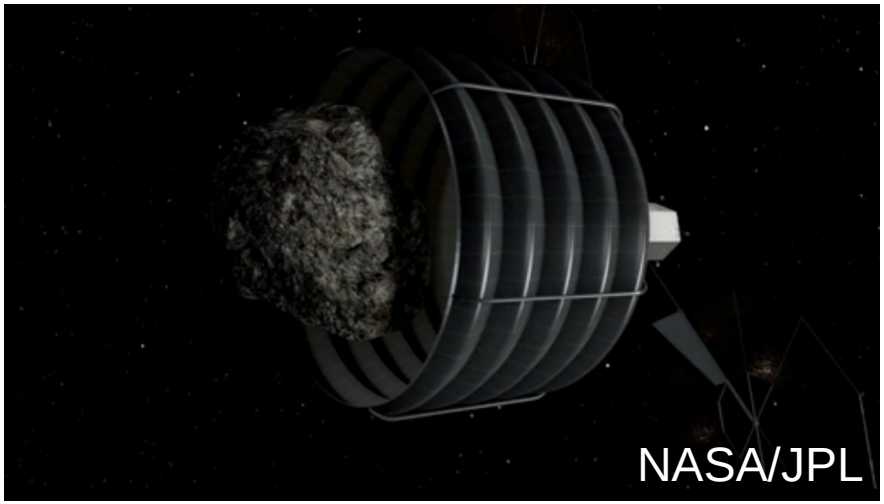
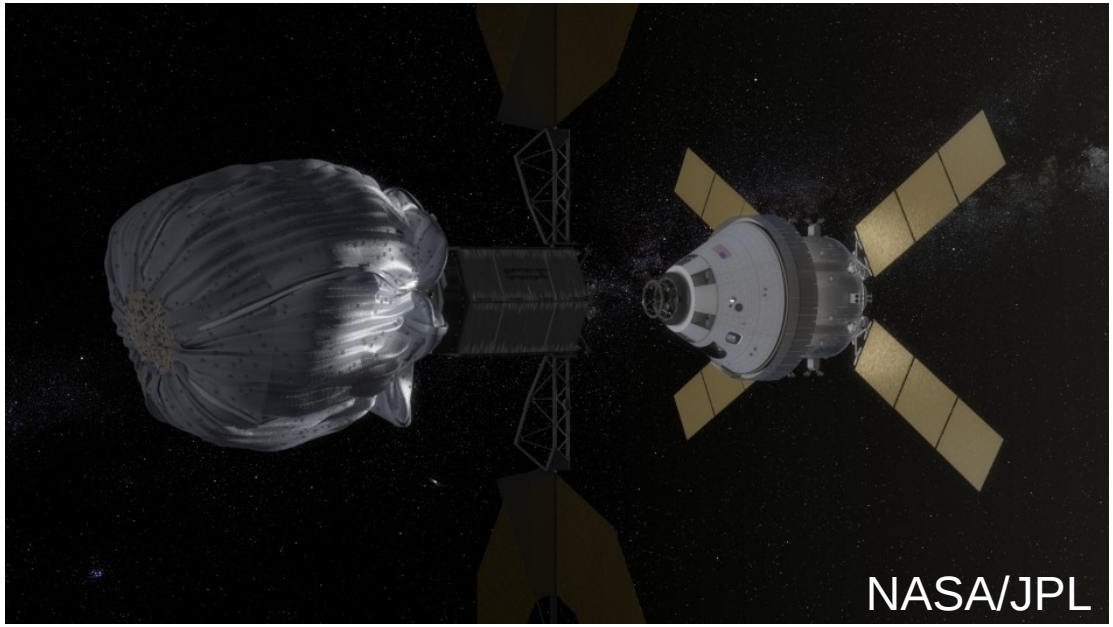
SBAG 11, July 30, 2014

NORTHERN ARIZONA UNIVERSITY

Motivation – Asteroid Retrieval Mission (Option A)



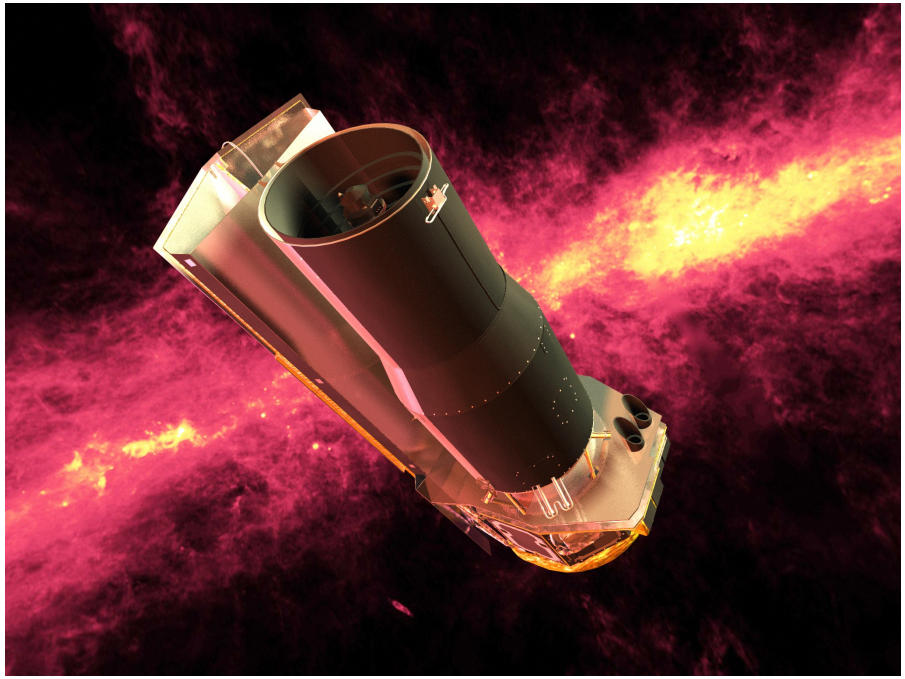


Small number of potential targets with suitable orbits, even less objects with known diameters and other physical properties

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:

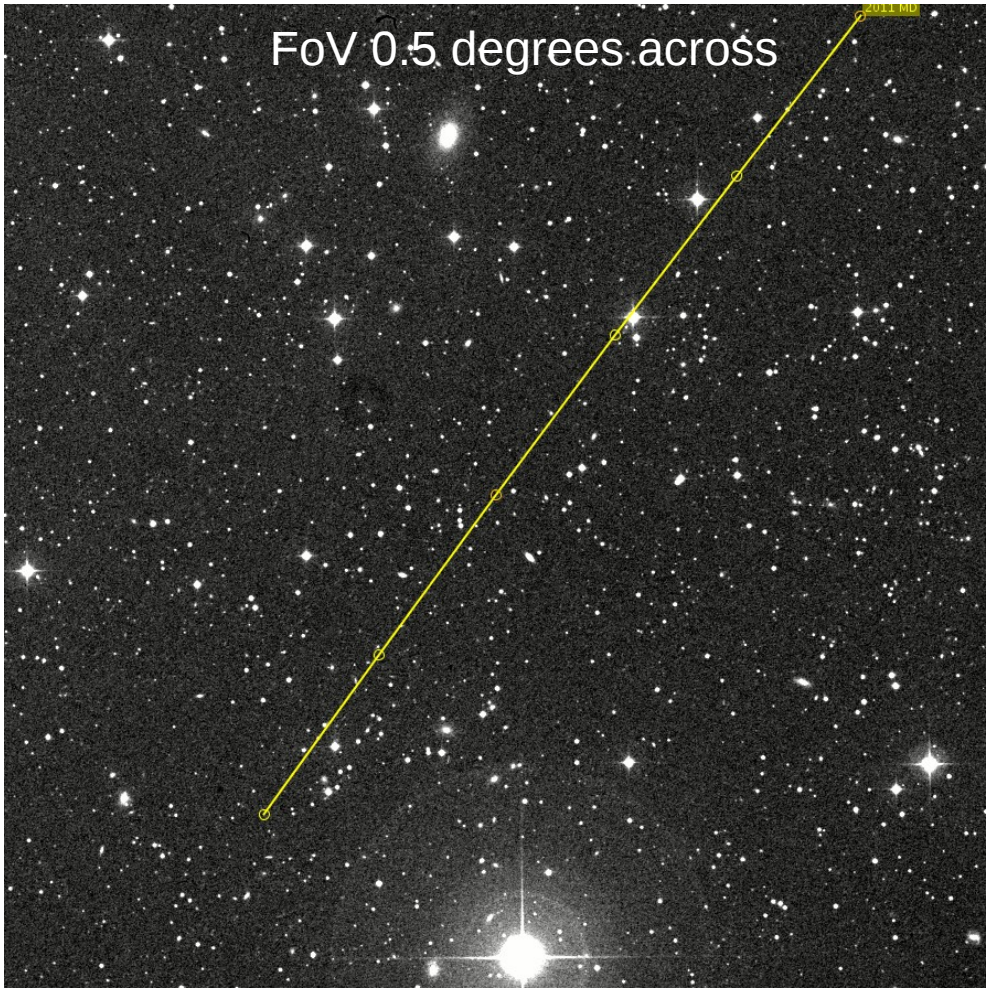
2009 BD ($\Delta v = 3.9$ km s^{-1})

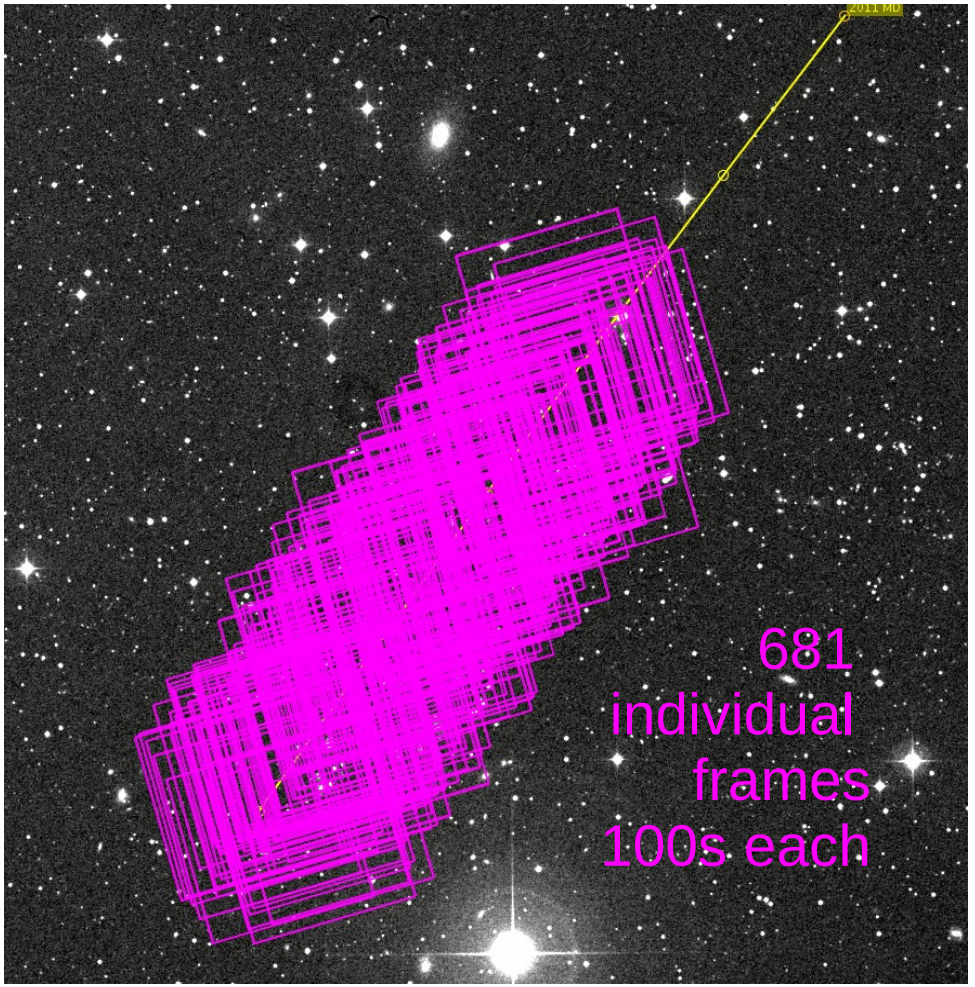
2011 MD ($\Delta v = 4.2$ km s^{-1})

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





Mommert, Farnocchia, Hora et al. 2014, ApJL, 789, 22

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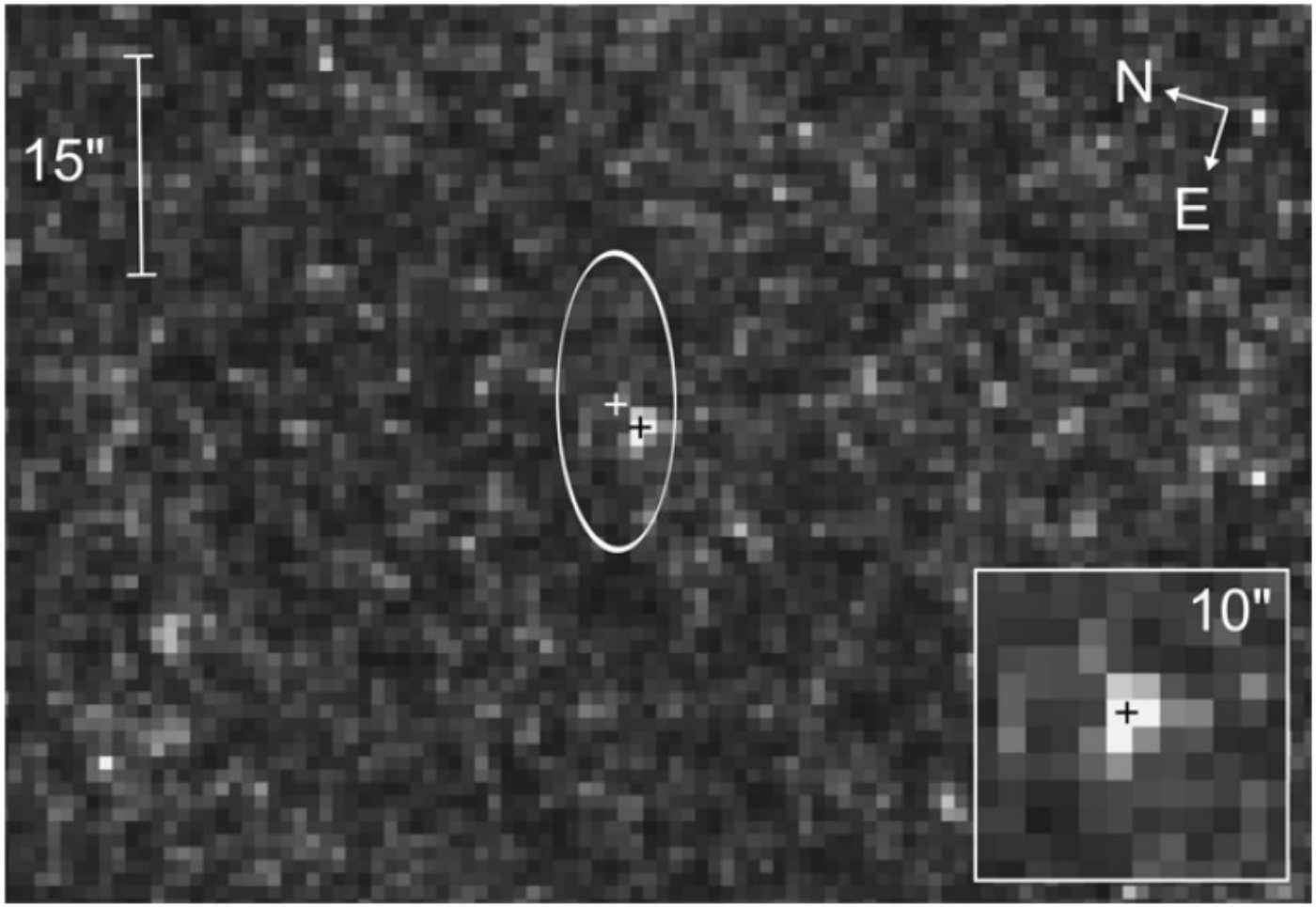


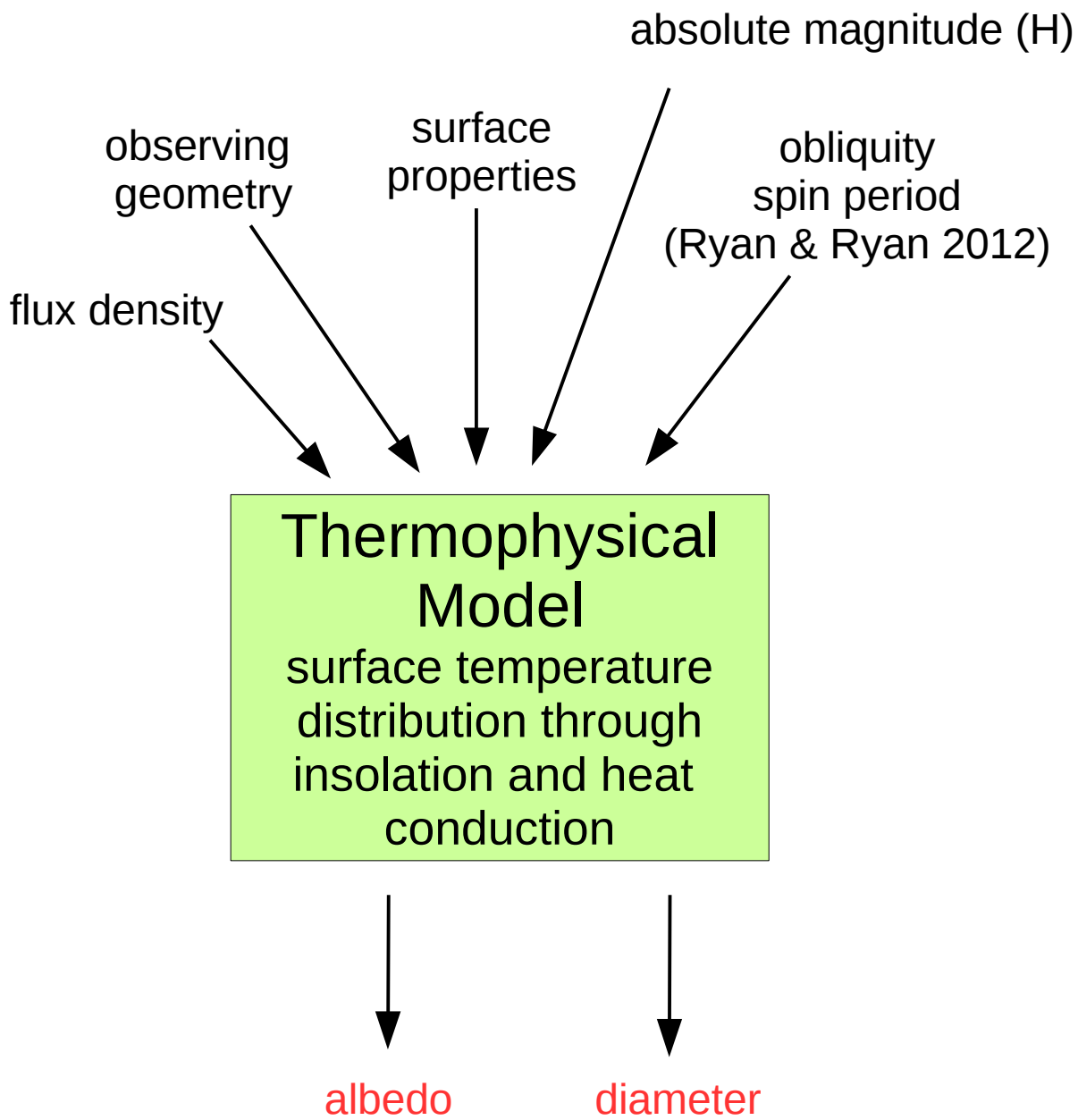
measured flux density at 4.5 μm:

0.60 ± 0.27 μJy

Comove map (681 individual frames)

Mommert, Farnocchia, Hora et al. 2014, ApJL, 789, 22

2011 MD – Thermophysical and Orbital Modeling



Mommert, Farnocchia, Hora et al. 2014, ApJL, 789, 22

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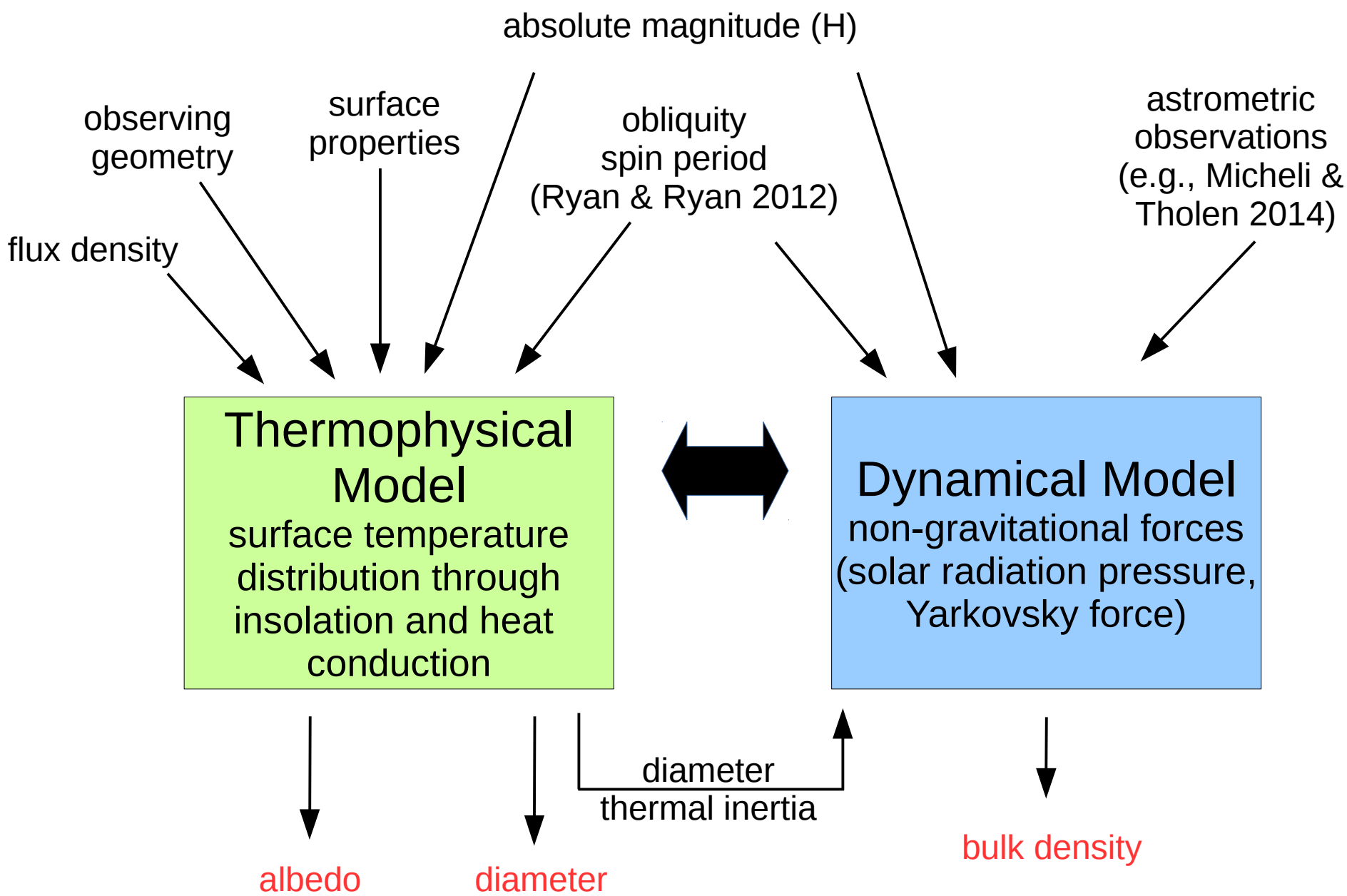

Mommert, Farnocchia, Hora et al. 2014, ApJL, 789, 22

2011 MD – Thermophysical and Orbital Modeling

absolute magnitude (H)

observing geometry

flux density

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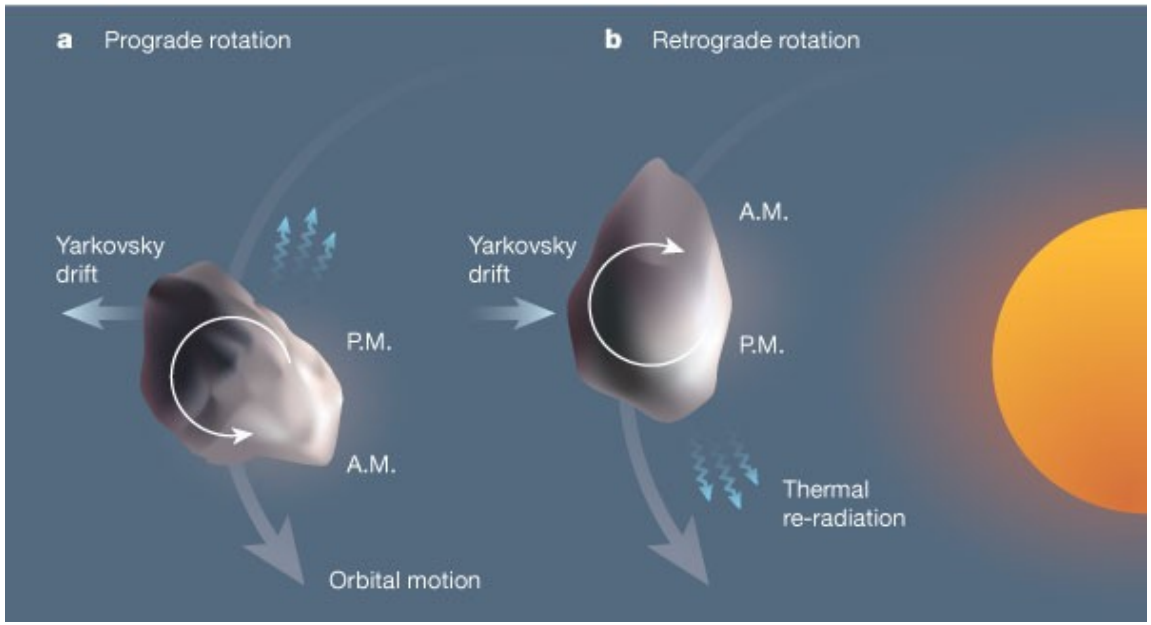
Yarkovsky Effect:



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

thermal inertia

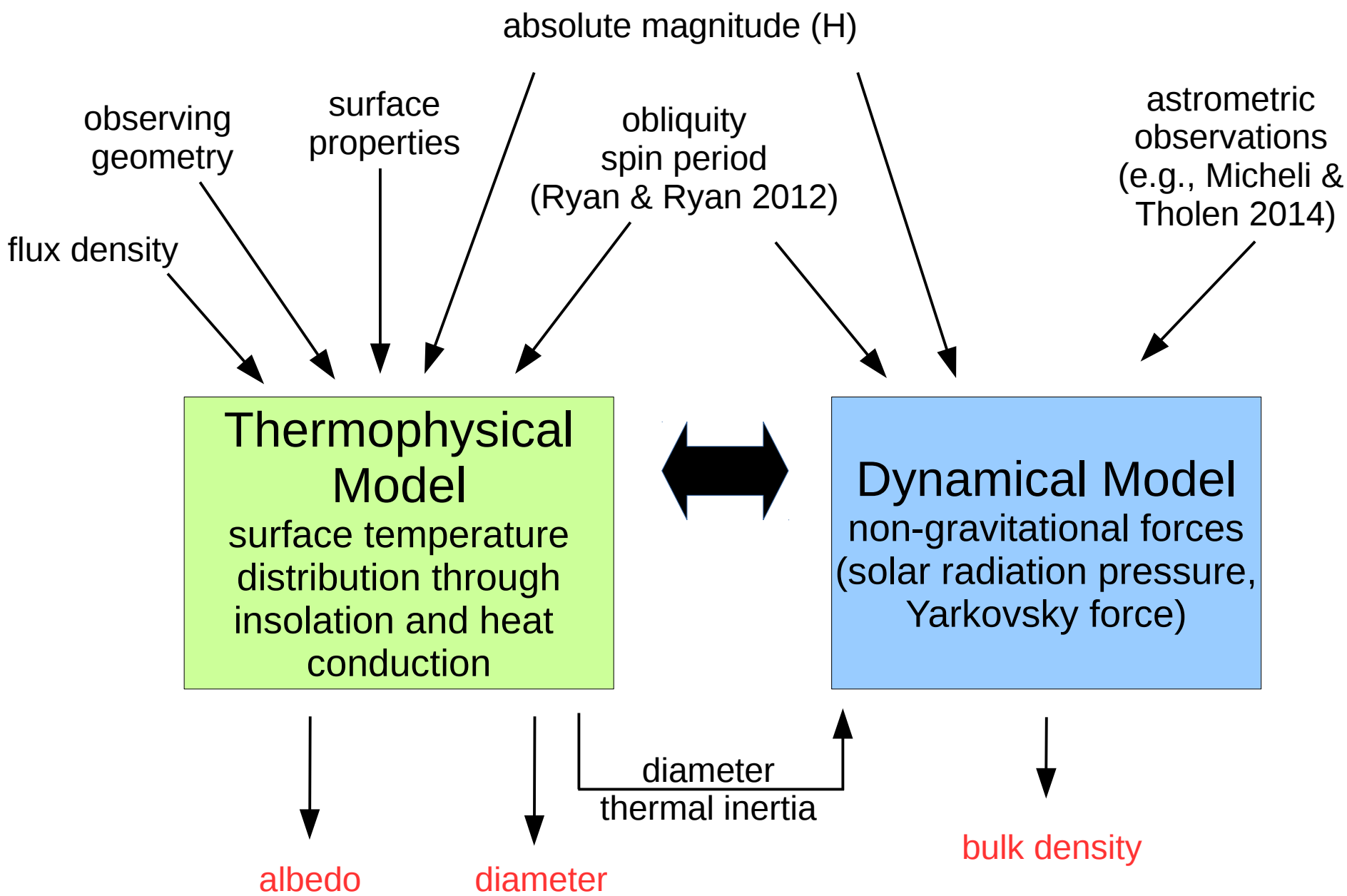
albedo

diameter

bulk density

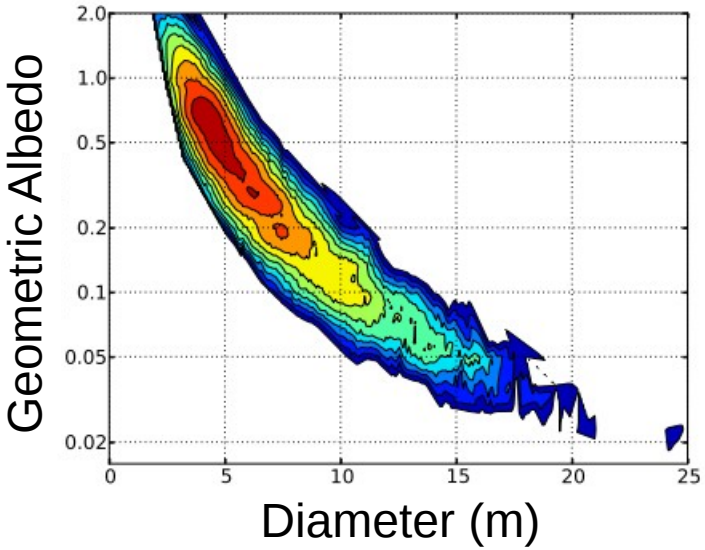
Mommert, Farnocchia, Hora et al. 2014, ApJL, 789, 22

2011 MD – Thermophysical and Orbital Modeling



Mommert, Farnocchia, Hora et al. 2014, ApJL, 789, 22

2011 MD – Results

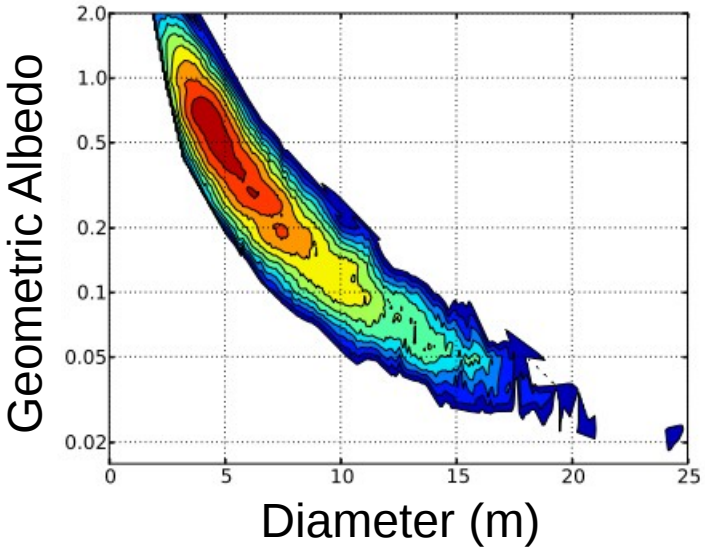


diameter: 6 (+4/-2) m (3σ: 2-26 m)

geometric albedo: 0.3 (+0.4/-0.2) (3σ: ≥ 0.02)

Mommert, Farnocchia, Hora et al. 2014, ApJL, 789, 22

2011 MD – Results



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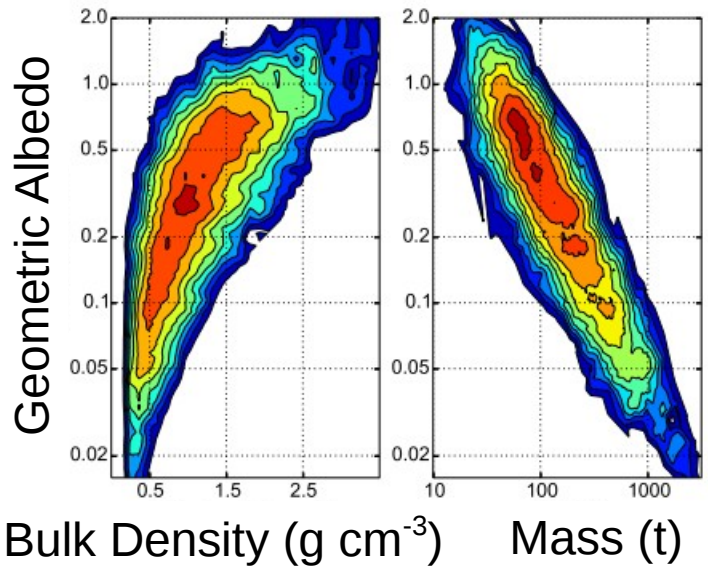


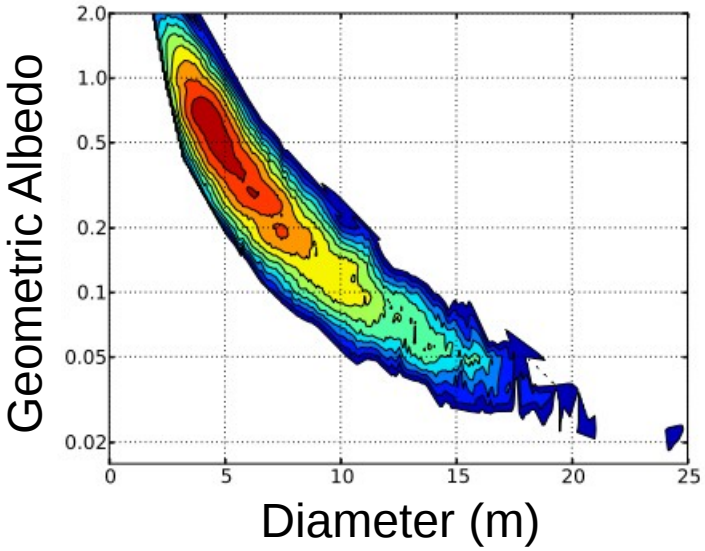
bulk density: 1.1 (+0.7/-0.5) g cm^{-3} (3σ: 0.2-5.0 g cm^{-3})

total mass: 110 (+240/-60) t (3σ: 10-2500 t)

macroporosity ≥ 0.65

Mommert, Farnocchia, Hora et al. 2014, ApJL, 789, 22

2011 MD – Results



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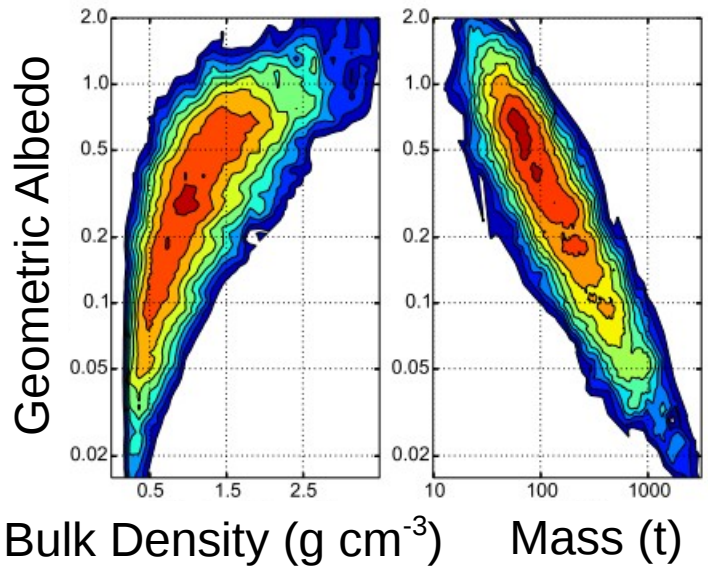

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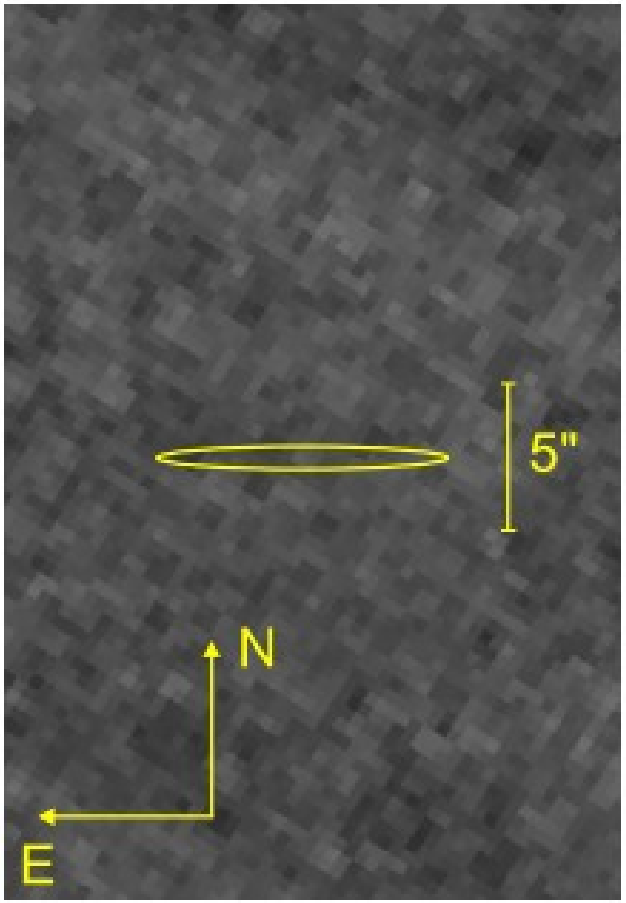
macroporosity ≥ 0.65

2011 MD is a rubble-pile asteroid

Mommert, Farnocchia, Hora et al. 2014, ApJL, 789, 22

2009 BD – Spitzer Observations

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



Comove map (800 individual frames)

2009 BD was not detected

Flux density ≤ 0.78 μJy (3σ)

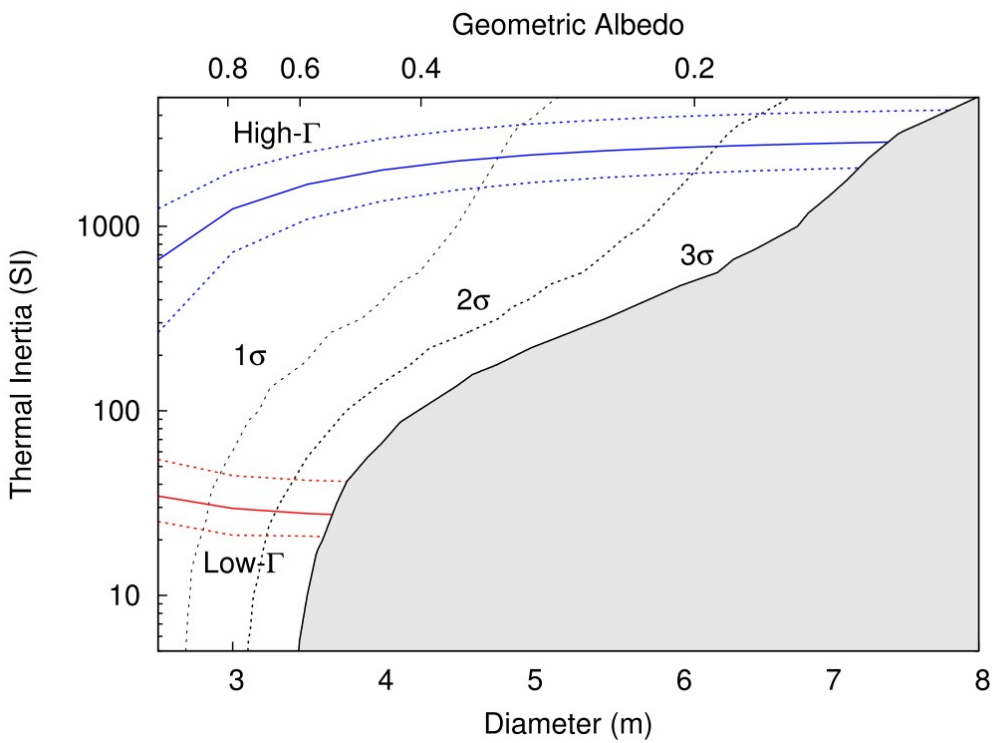
Mommert, Hora, Farnocchia et al. 2014, ApJ, 786, 148

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



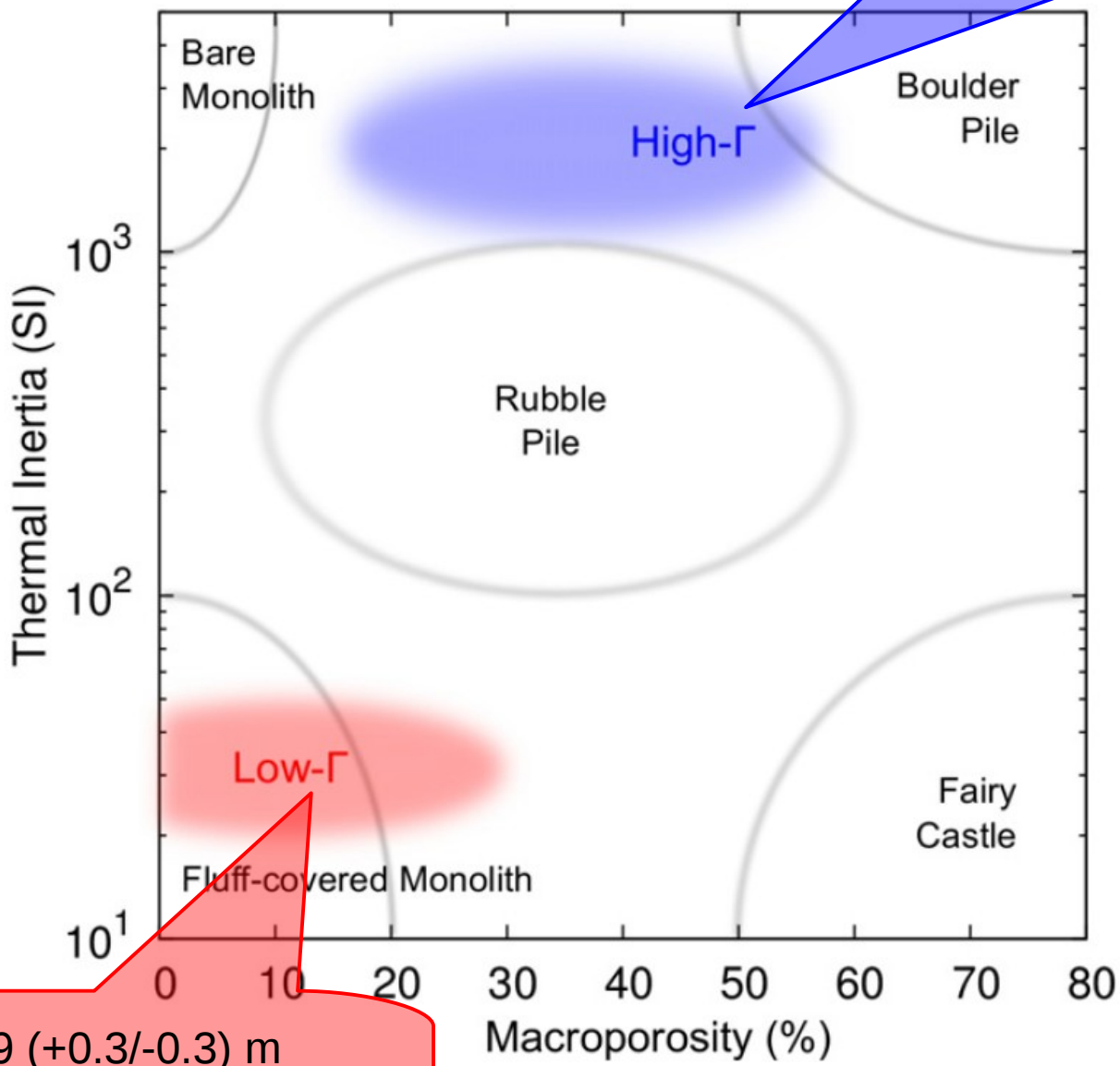
2 physically possible solutions!

Mommert, Hora, Farnocchia et al. 2014, ApJ, 786, 148

2009 BD – Results

diameter: 4 (+1/-1) m

albedo: 0.45 (+0.35/-0.15)



diameter: 2.9 (+0.3/-0.3) m

albedo: 0.85 (+0.20/-0.10)

Mommert, Hora, Farnocchia et al. 2014, ApJ, 786, 148

Artist's Interpretation – still in progress

2009 BD high-Γ / 2011 MD

?

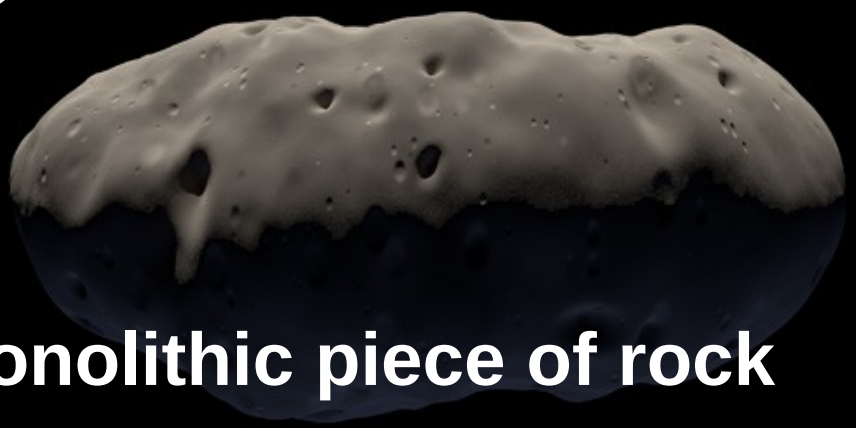
2009 BD low-Γ

highly porous rubble pile structure

regolith-covered monolithic body

Conclusion

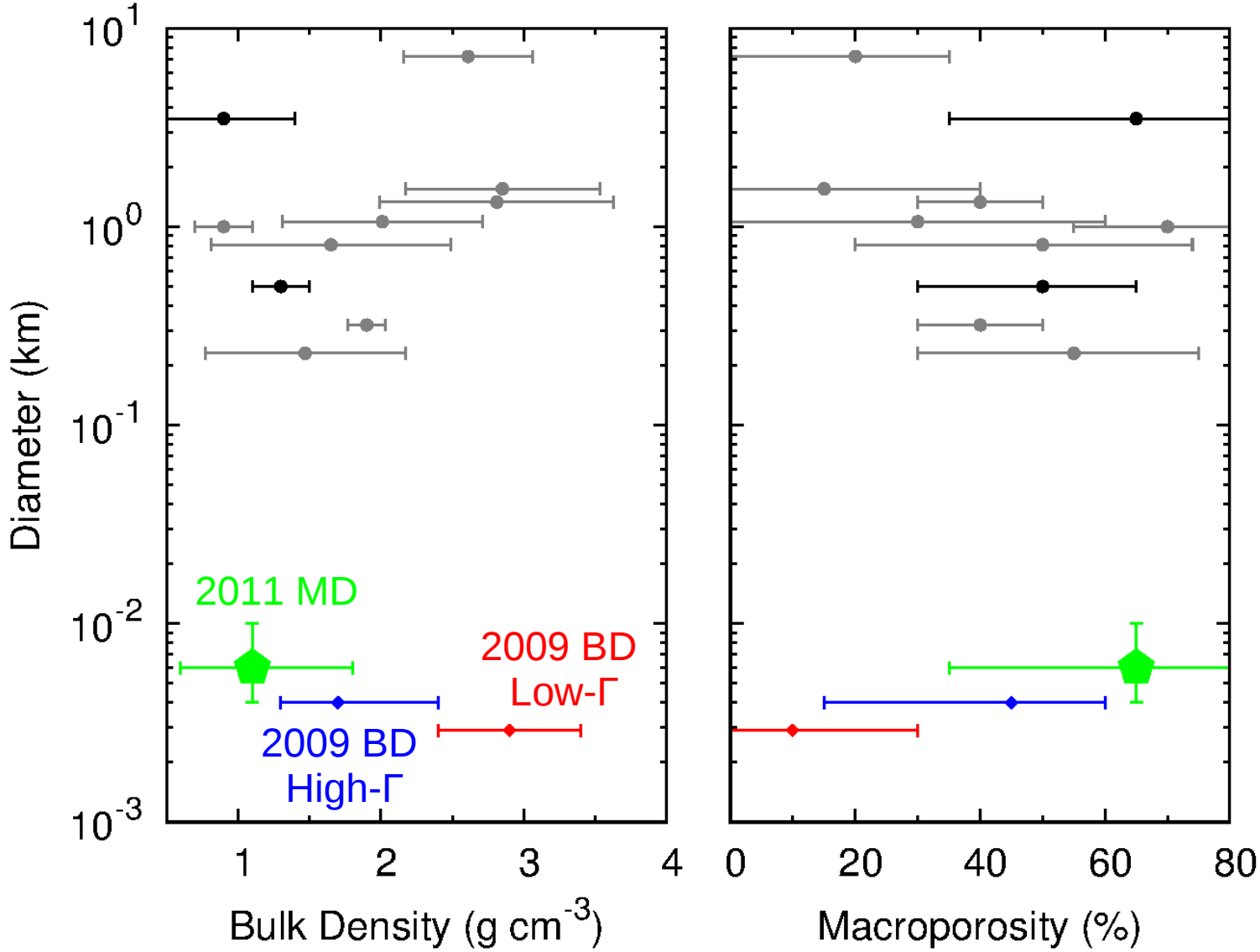
?



Neither body is a simple monolithic piece of rock

Appendix

Comparison with Larger Asteroids



Results Overview

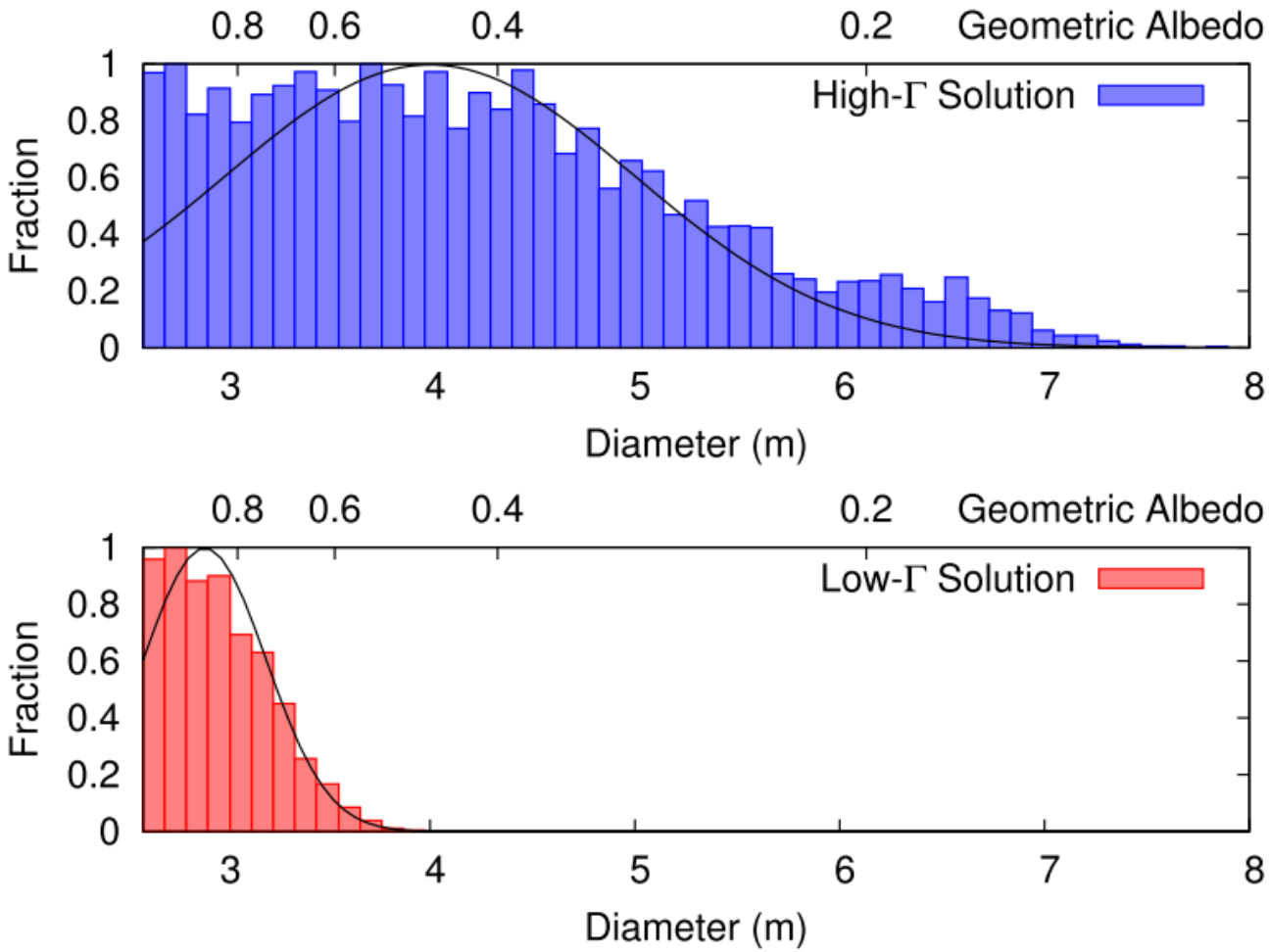
Physical Properties of 2009 BD

Parameter	Low-Γ Solution	High-Γ Solution	**2011 MD**
Diameter d (m)	2.9 ± 0.3	4 ± 1	6 (+4/-2)
Albedo p_V	$0.85^{+0.20}_{-0.10}$	$0.45^{+0.35}_{-0.15}$	0.3 (+0.4/-0.2)
Obliquity γ (°)	170^{+10}_{-15}	180^{+0}_{-5}	
AMR Ψ ($\times 10^{-4}$ m^2 kg^{-1})	$1.8^{+0.3}_{-0.2}$	$2.2^{+0.4}_{-0.2}$	
Bulk density ρ (g cm^{-3})	$2.9^{+0.5}_{-0.5}$	$1.7^{+0.7}_{-0.4}$	1.1 (+0.7/-0.5)
Macroporosity (%)	10^{+20}_{-10}	45^{+15}_{-30}	> 0.65
Total mass (metric tons)	36^{+10}_{-8}	55^{+30}_{-25}	110 (+240/-60)
Thermal inertia Γ (SI units)	30^{+20}_{-10}	2000 ± 1000	

Note. Uncertainties depict the 1σ confidence interval.

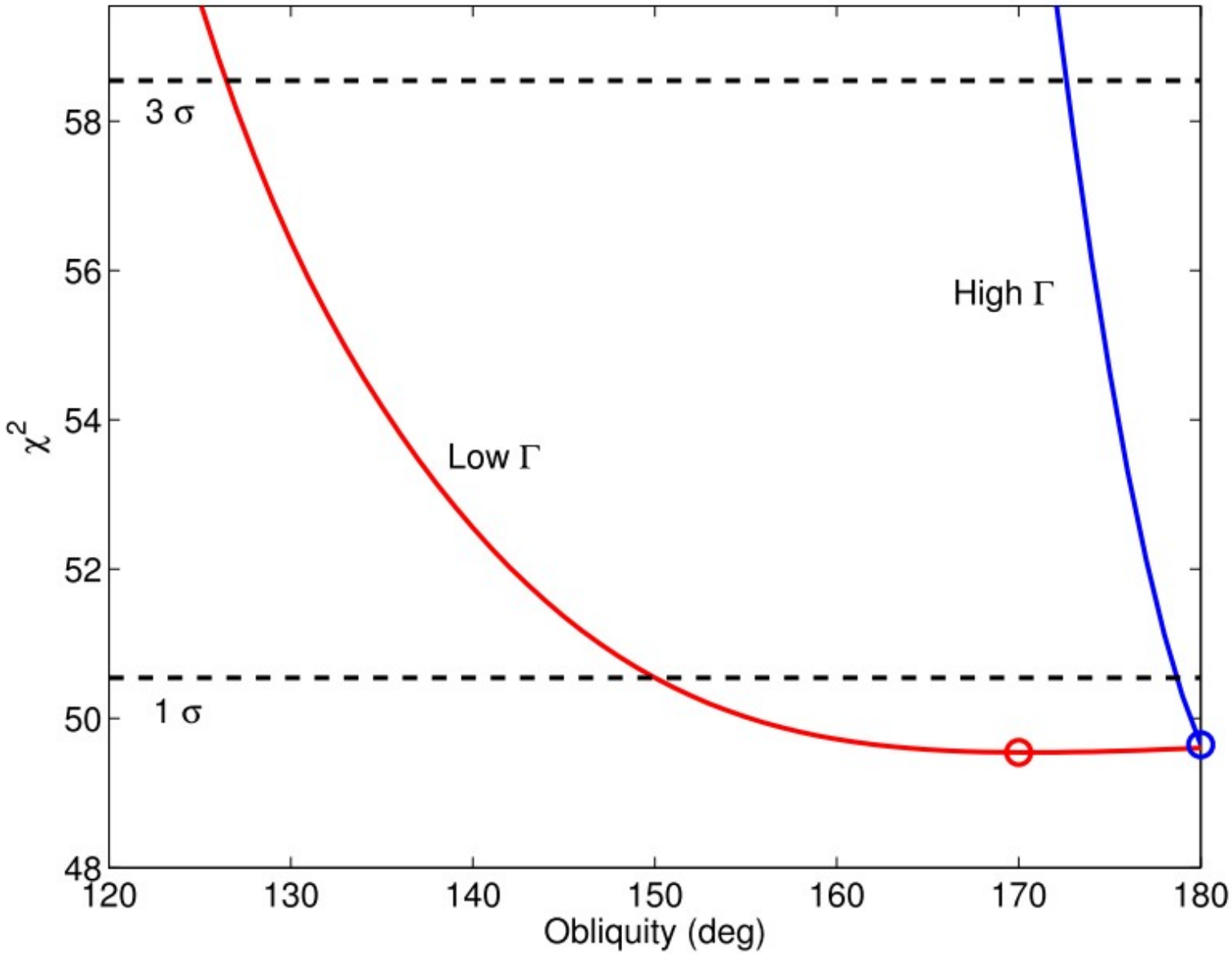
Mommert, Farnocchia, Hora et al. 2014, ApJL, 789, 22
Mommert, Hora, Farnocchia et al. 2014, ApJ, 786, 148

2009 BD – Diameter Distributions



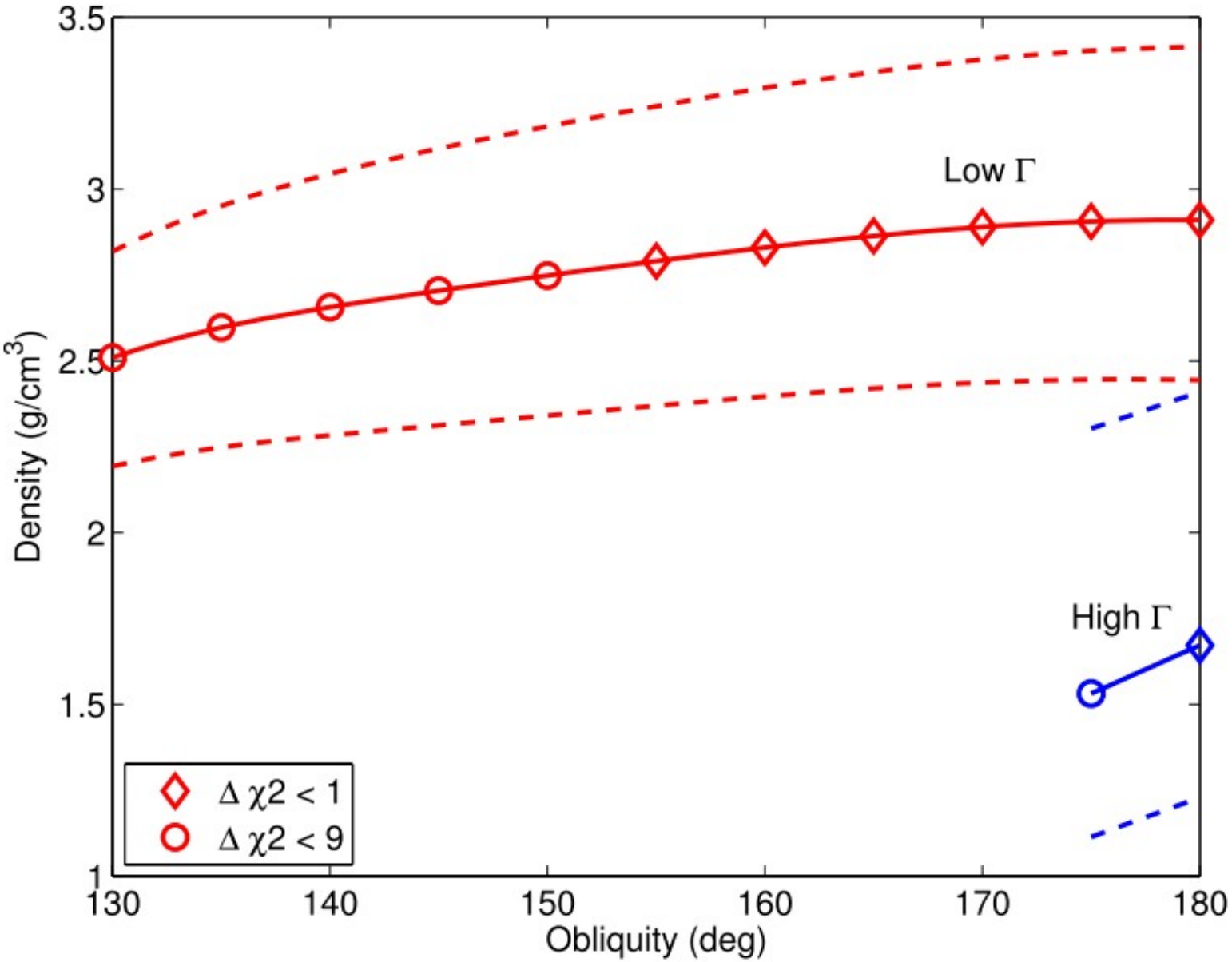
Mommert, Hora, Farnocchia et al. 2014, ApJ, 786, 148

2009 BD – Obliquity/Chi2 Distributions



Mommert, Hora, Farnocchia et al. 2014, ApJ, 786, 148

2009 BD – Density/Chi2 Distributions



Mommert, Hora, Farnocchia et al. 2014, ApJ, 786, 148