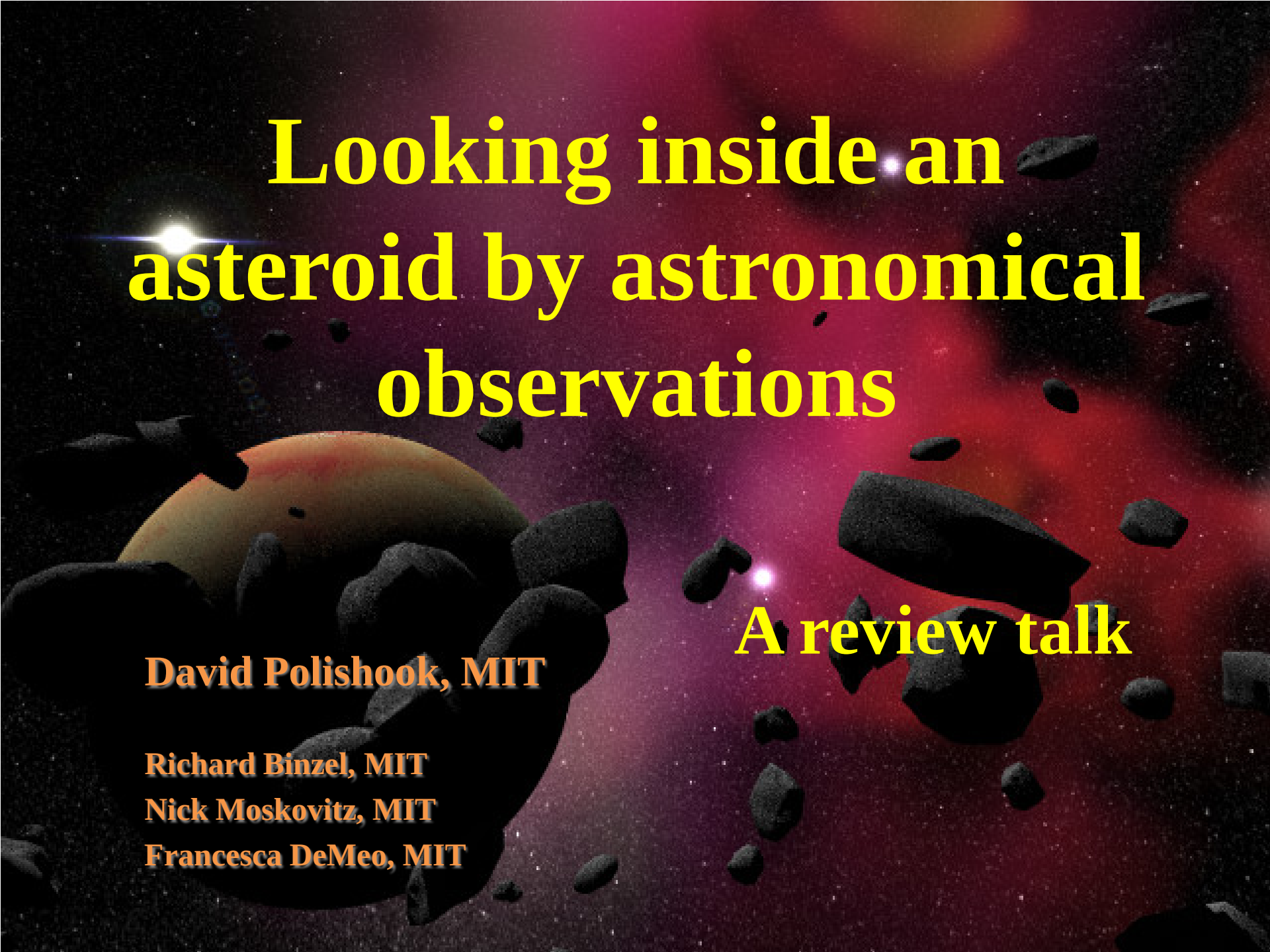


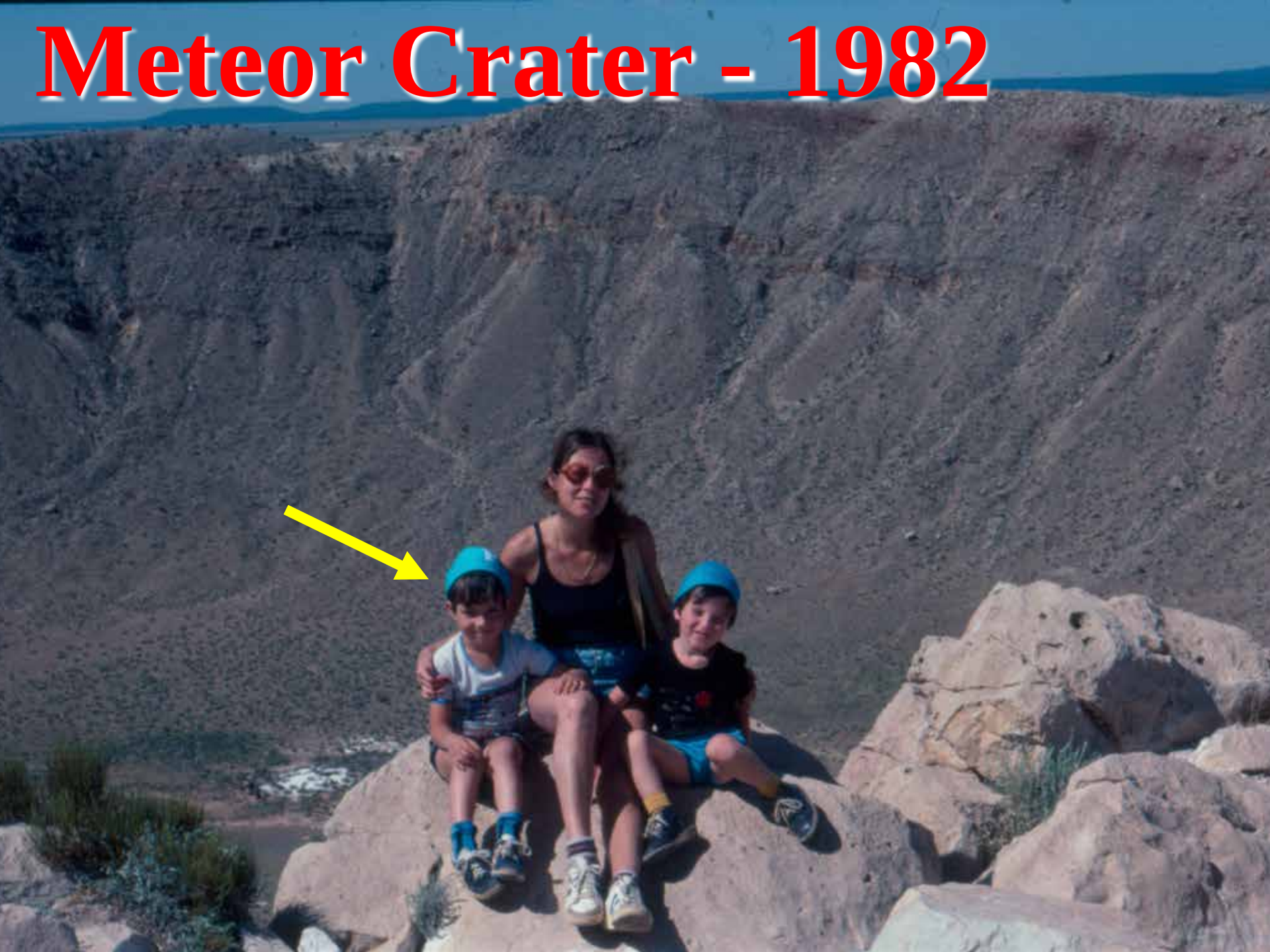
Looking inside an asteroid by astronomical observations

A review talk

David Polishook, MIT

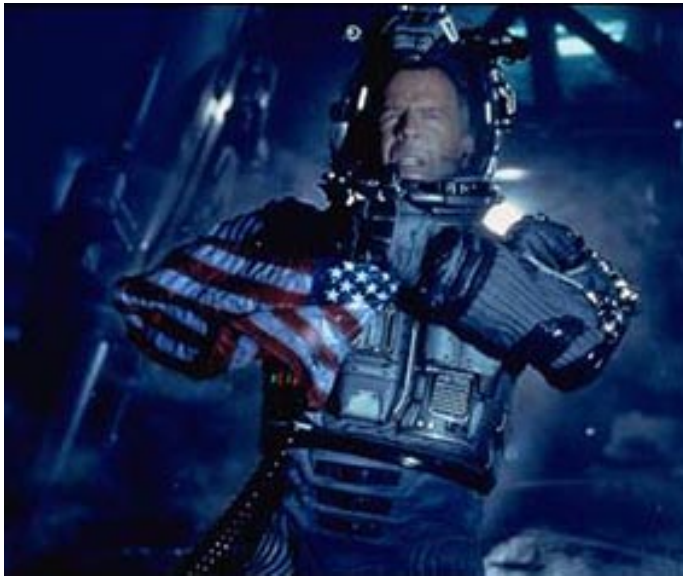
Richard Binzel, MIT
Nick Moskovitz, MIT
Francesca DeMeo, MIT

Meteor Crater - 1982



NEA mitigation is interested in asteroid parameters

- Size
- Shape
- Rotational parameters
- Thermal parameters
- Composition
- Density
- Porosity
- Internal structure



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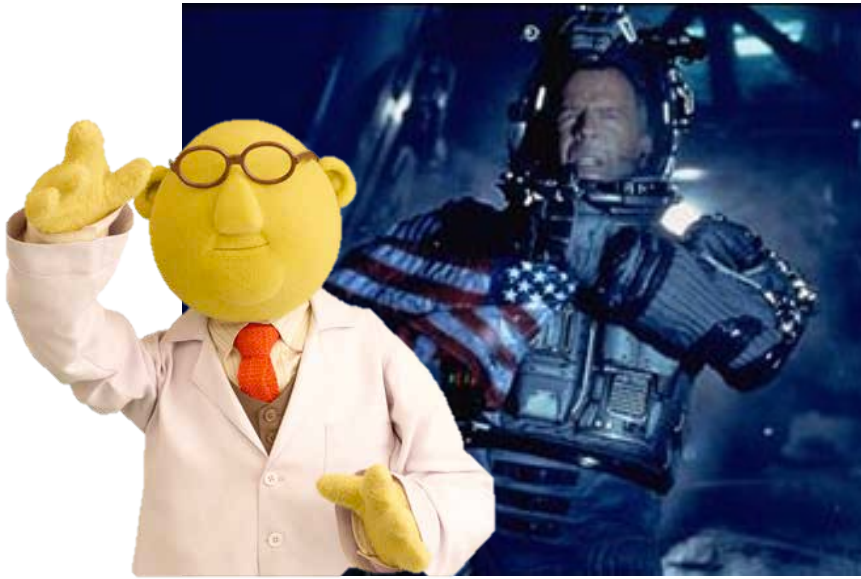
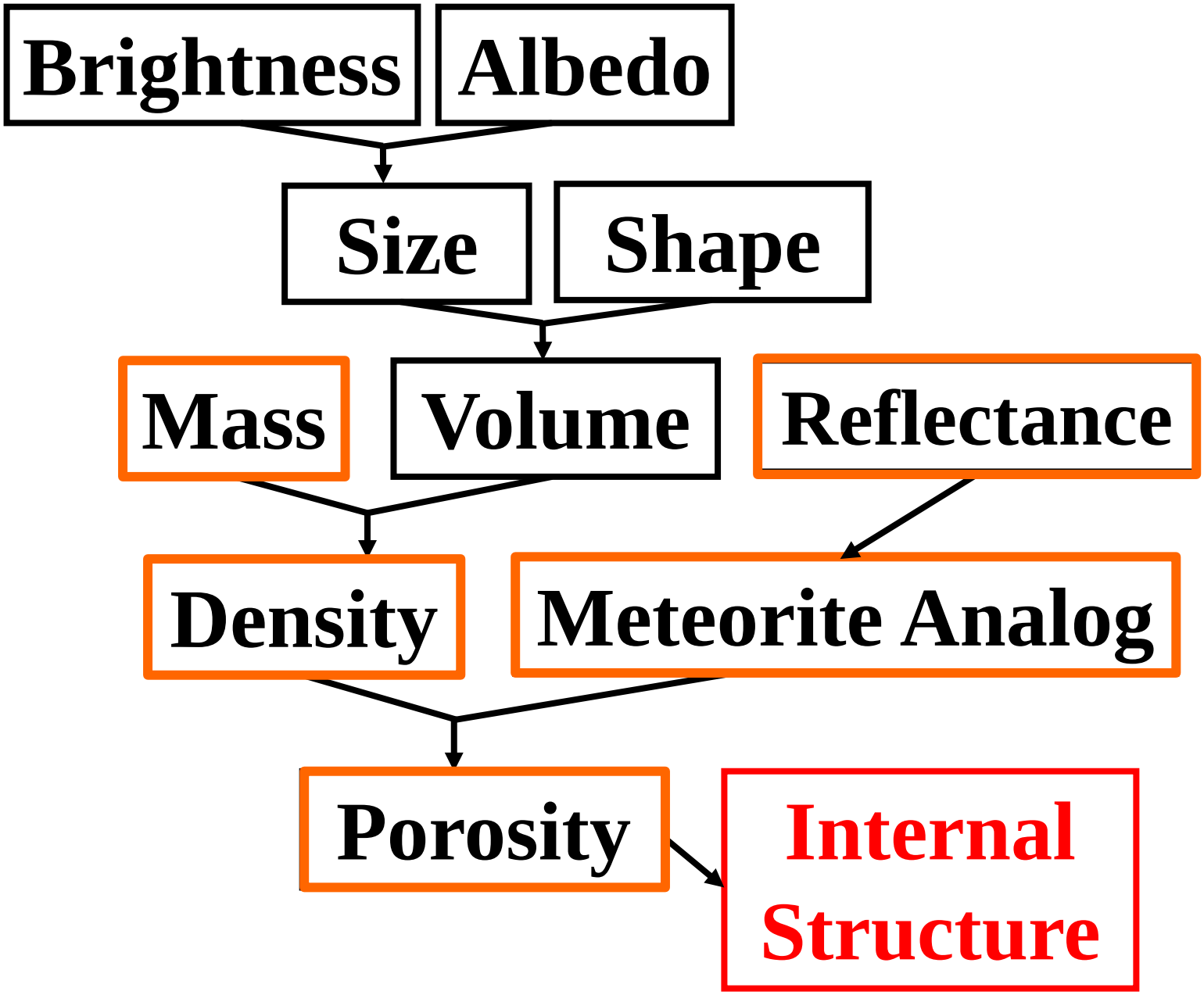


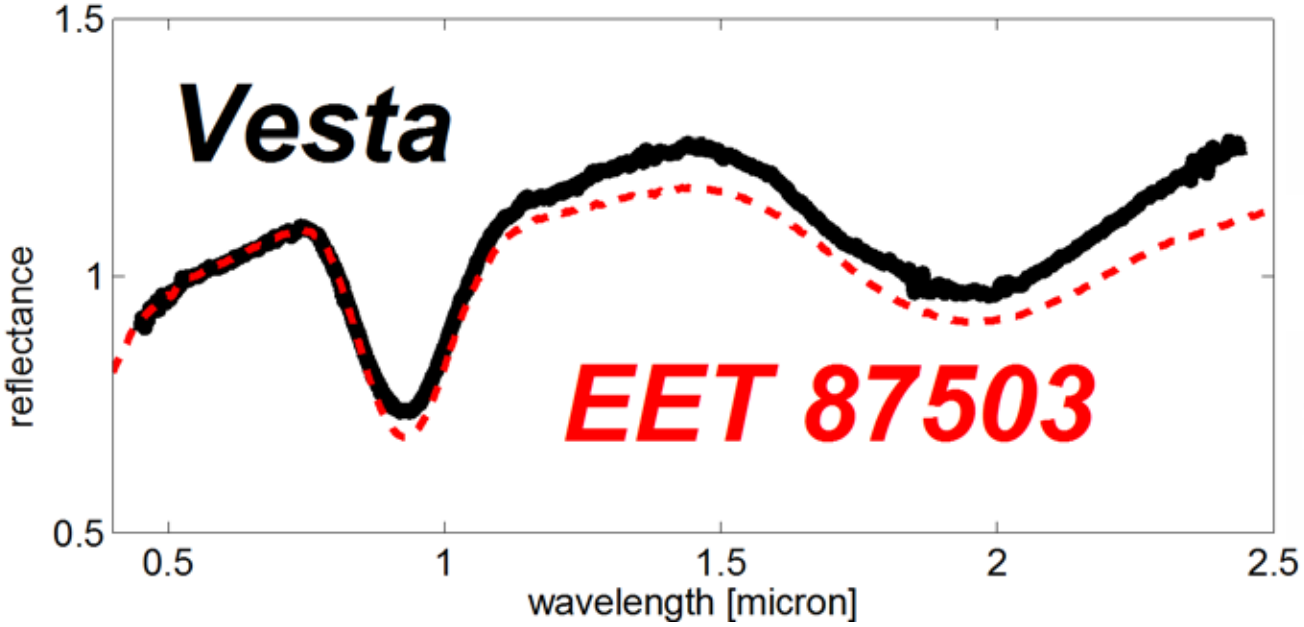
Option 1: use a spaceship

Option 2: use a telescope

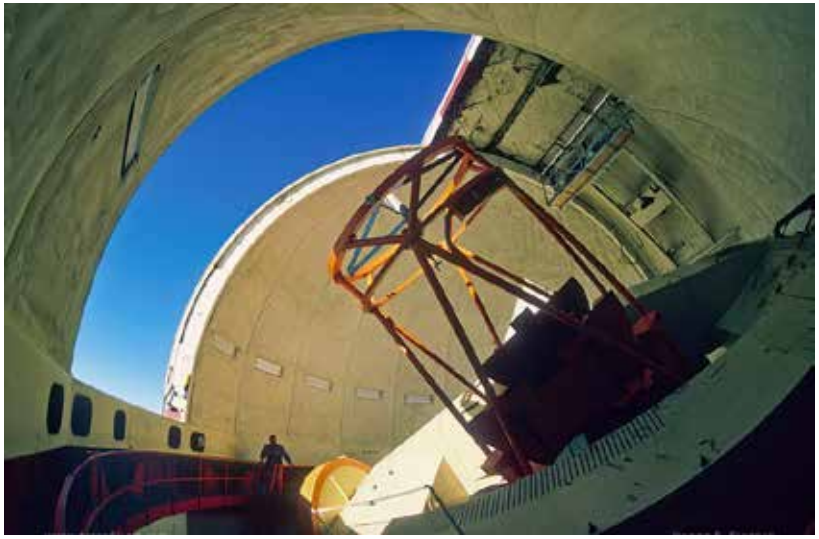

Brightness
Albedo
Size
Shape
Mass
Volume
Reflectance
Density
Meteorite Analog
Porosity
Internal Structure

surface reflectance

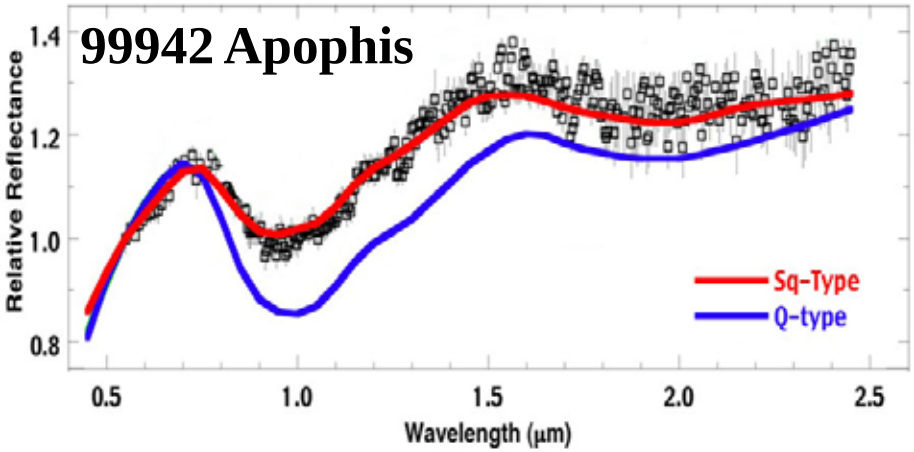
- **Spectroscopy – measuring how the asteroid reflects the sunlight as a function of the wavelength.**
- **Compare with reflectance of meteorites.**



SMASS

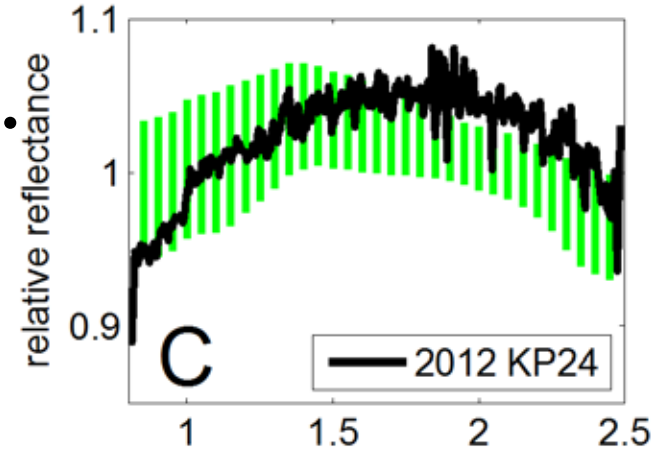


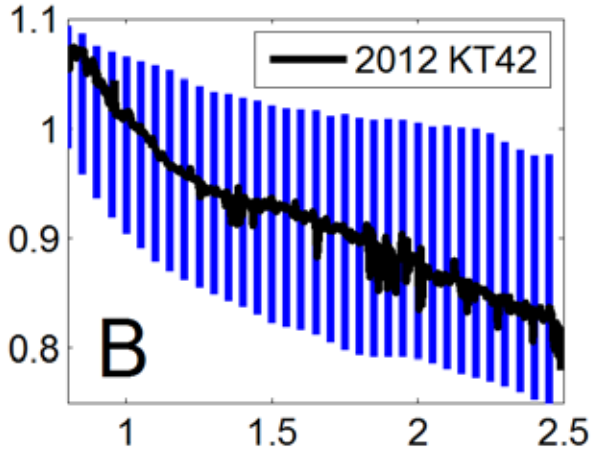
- **Near-IR spectroscopy (0.8 to 2.5 micron).**
- **Telescope: 3-m, IRTF, Hawaii.**
- **MBAs and NEAs.**
- **Since 2000.**
- **~1,000 spectra.**
- **http://smass.mit.edu/**



NEAs are varied

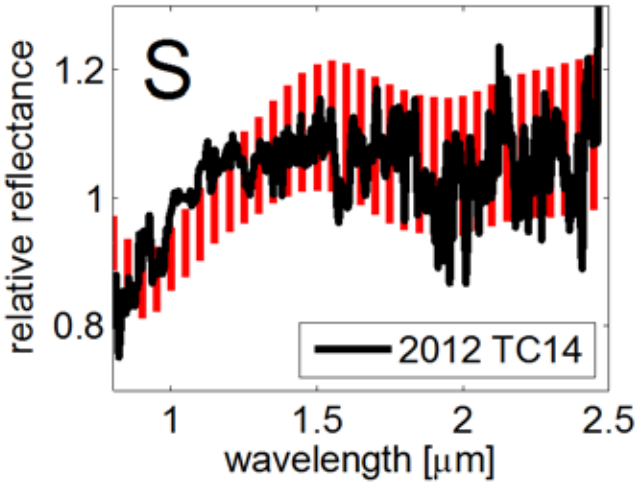
D=20 m.
9 Earth
-radii

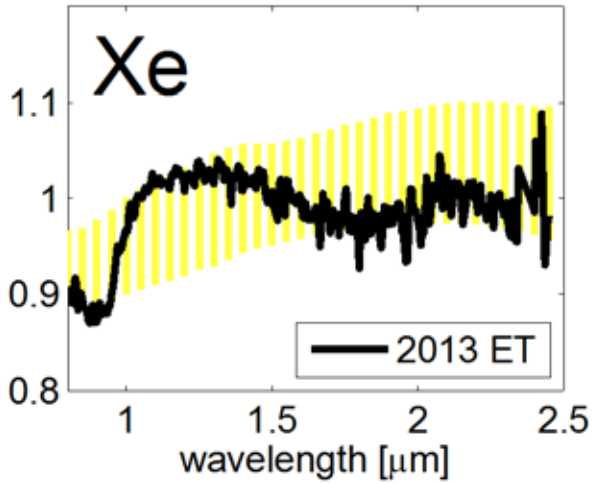




D=6 m.
3 Earth
-radii

D=15 m.
15 Earth
-radii

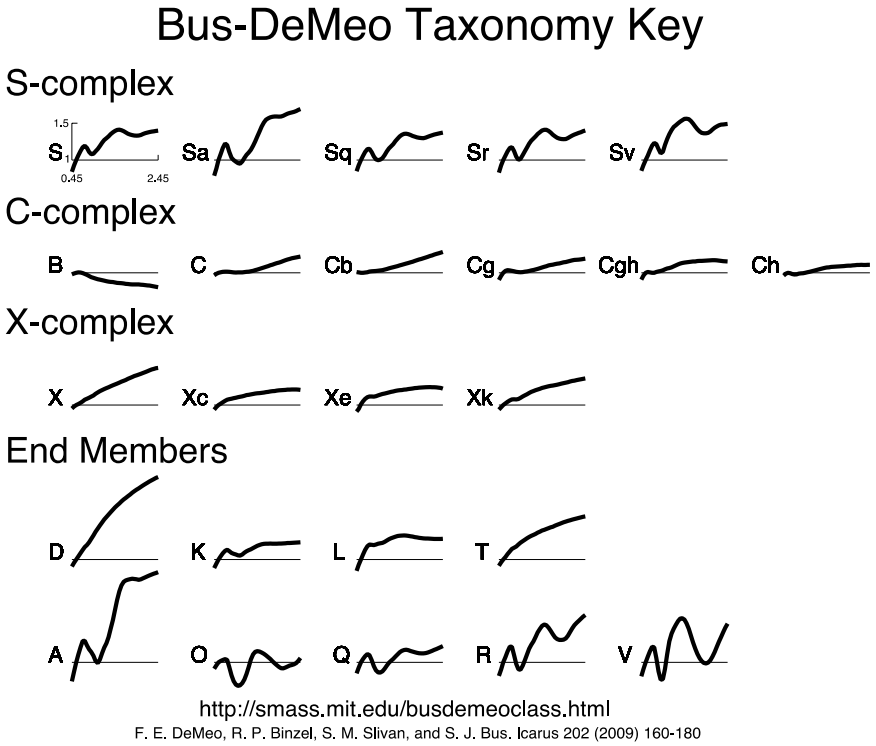




D=10 m.
60 Earth
-radii

The Meteoritic Connection

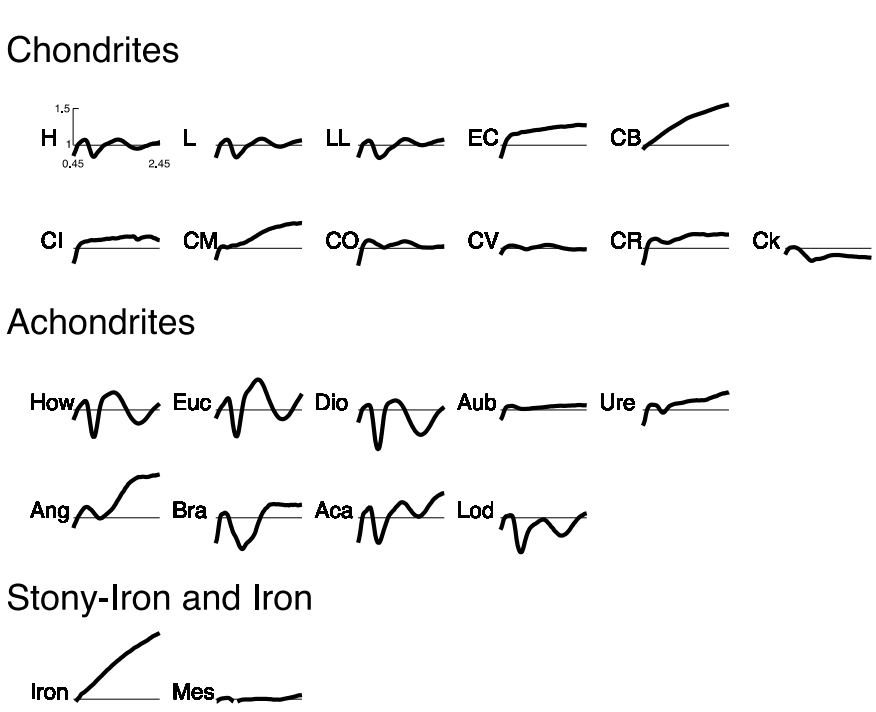
Asteroids



http://smass.mit.edu/busdemeoclass.html

F. E. DeMeo, R. P. Binzel, S. M. Slivan, and S. J. Bus. Icarus 202 (2009) 160-180

Meteorites



Courtesy of P. Vernazza

Meteorite		ρ
Ord. chondrites	H	3.42 ± 0.18
Ord. chondrites	L	3.36 ± 0.16
Ord. chondrites	LL	3.22 ± 0.22
Carb. Chondrites	CI	1.60 ± 0.03
Carb. Chondrites	CM	2.25 ± 0.08
Carb. Chondrites	CR	3.10
Carb. Chondrites	CO	3.03 ± 0.19
Carb. Chondrites	CV	2.79 ± 0.06
Carb. Chondrites	CK	2.85 ± 0.08
Enstatites	EH	3.47 ± 0.21
Enstatites	EL	3.46 ± 0.32
Achondrites	HED	3.25 ± 0.26
Stony-Iron	Pal	4.76 ± 0.10
Stony-Iron	Mes	4.35 ± 0.02
Stony-Iron	Ste	4.18 ± 0.10
Iron	Ata	4.01 ± 0.04
Iron	Hex	7.37 ± 0.14
Iron	Oct	7.14 ± 0.13

Asteroid taxonomy

S

C / X

X

V

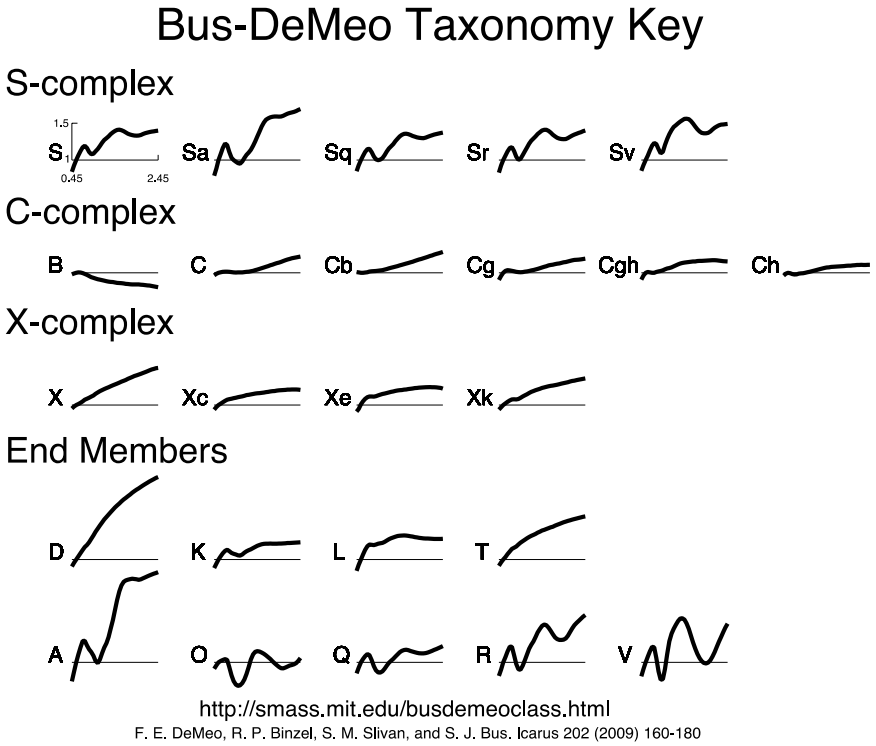
X

X

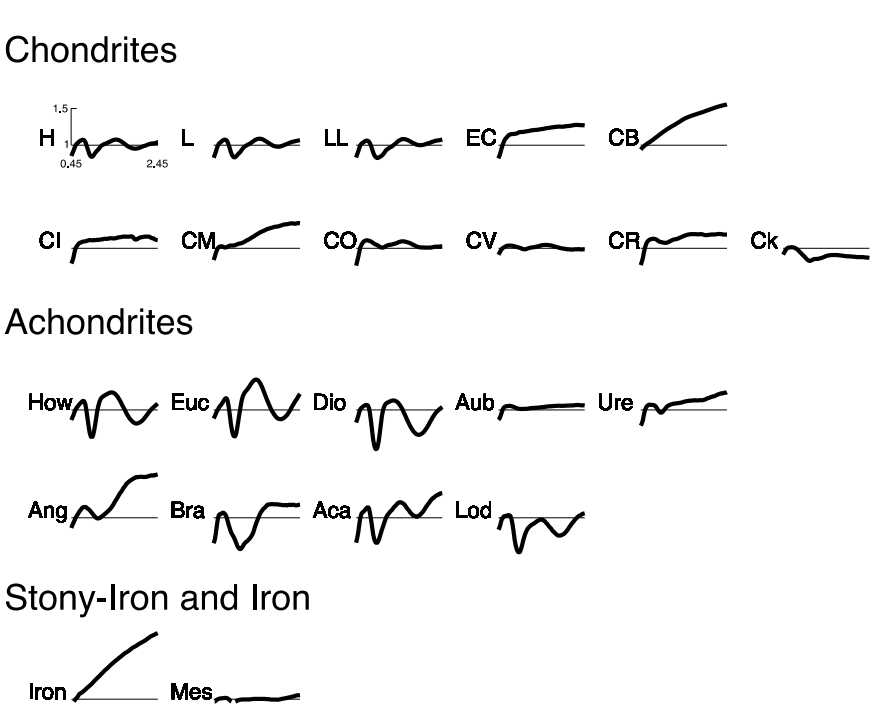
Carry 2012

The Meteoritic Connection

Asteroids



Meteorites



Courtesy of P. Vernazza

- **Need to find the missing links!!!**

Almahata Sitta

Meteorite

=

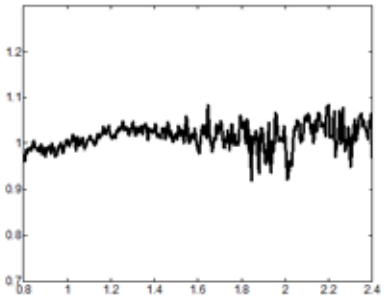
2008 TC_3

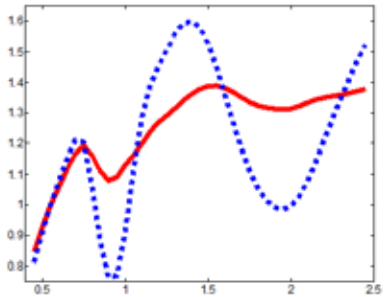
asteroid

Finding Fragments of Asteroid 2008 TC3 in the Nubian Desert

hotos by Peter Jenniskens, SETI Institute. http://www.nasa.gov/topics/solarsystem/tc3)

Caveats…

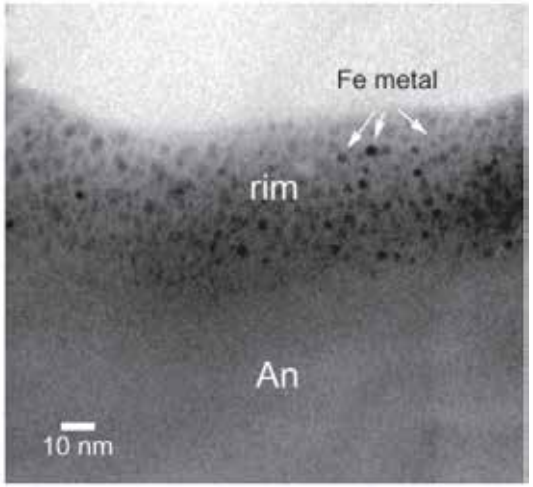


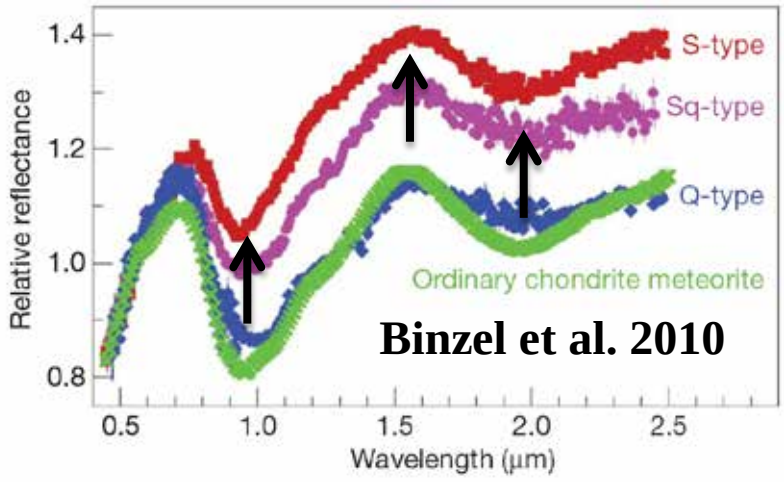


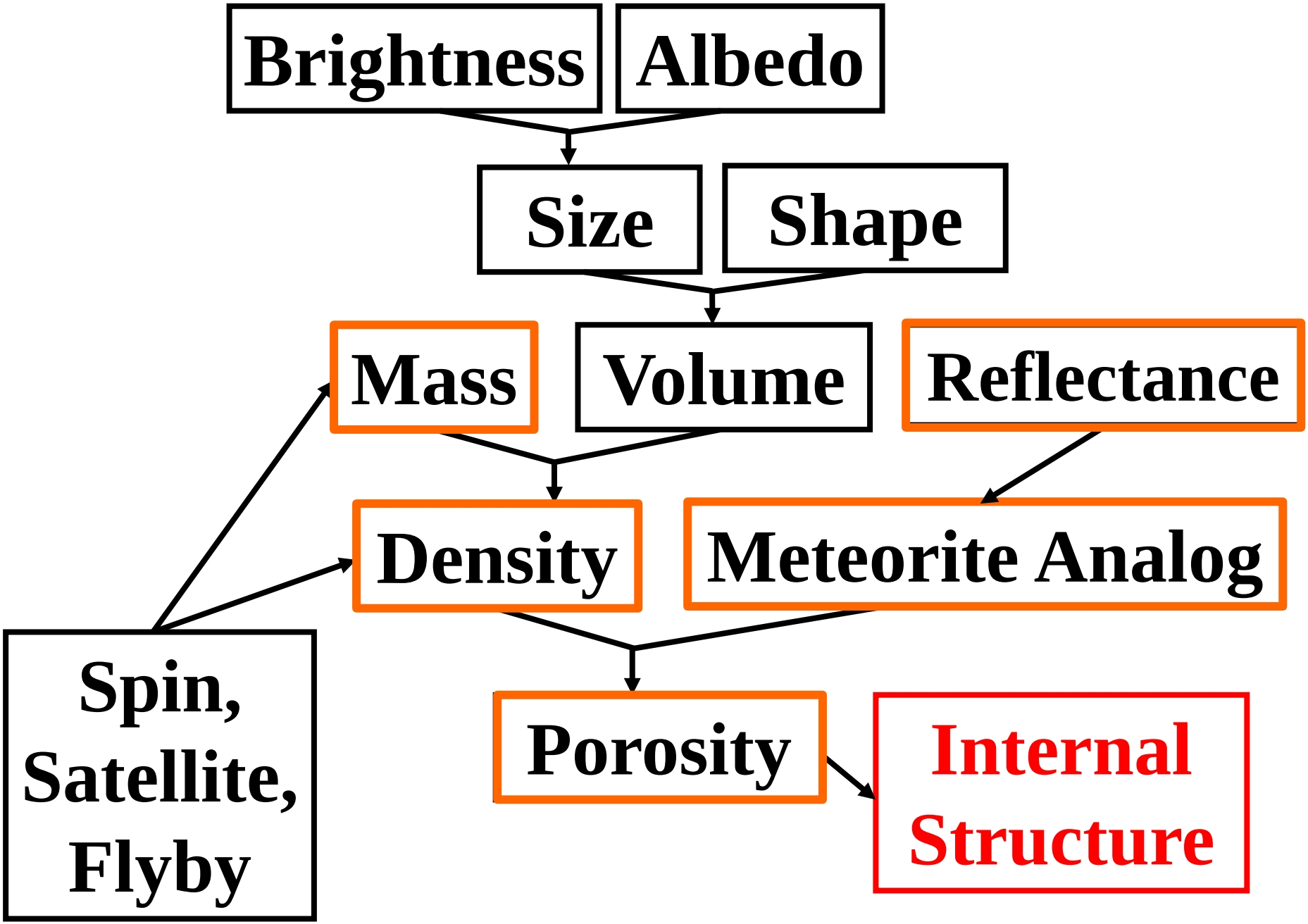
- features needed.
- high S/N needed… - large **R** telescopes
- Full wavelength range is needed (Vis+IR+…)
- Time modifies spectra – by *space weathering*!
- **Does composition reveal the structure?**

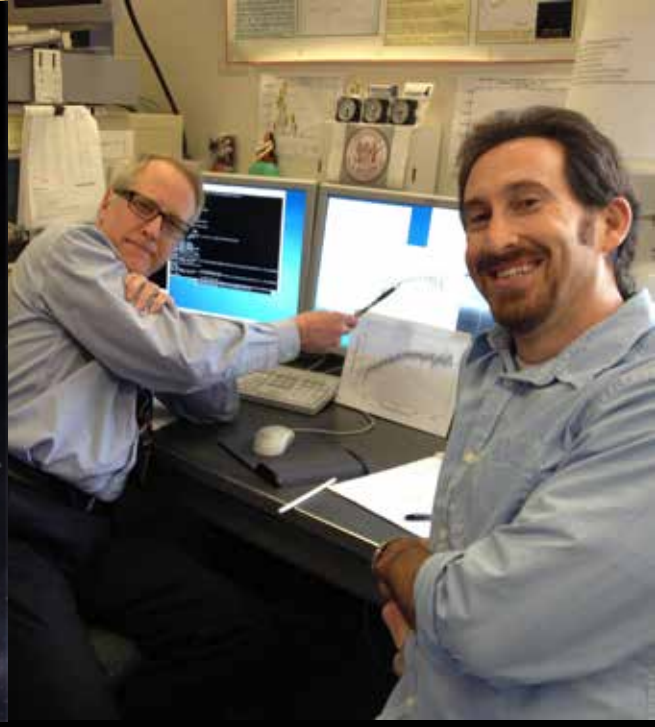
No!

Confirmed!



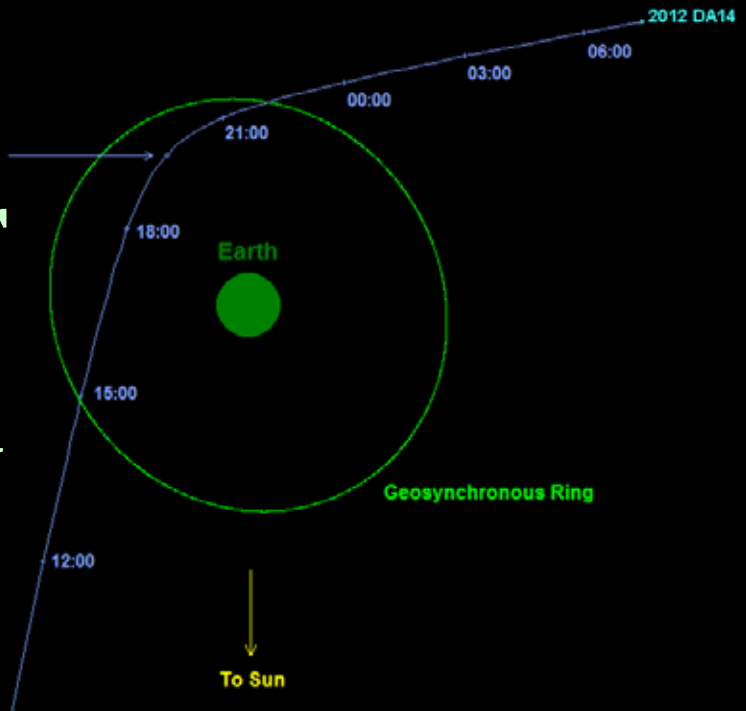



Brightness
Albedo
Size
Shape
Mass
Volume
Reflectance
Density
Meteorite Analog
Spin, Satellite, Flyby
Porosity
Internal Structure

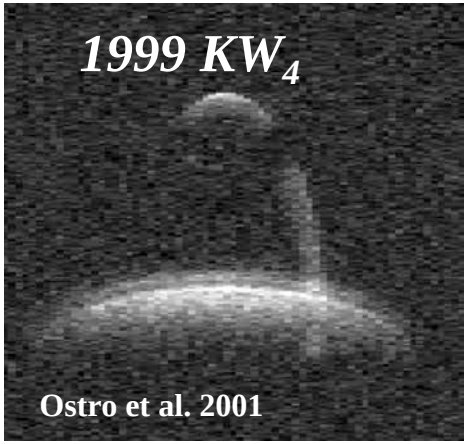


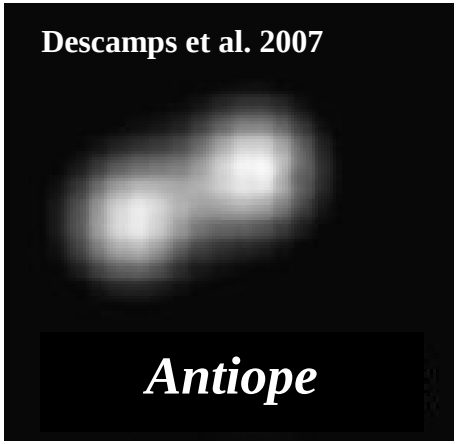
How flybys can reveal asteroid interior

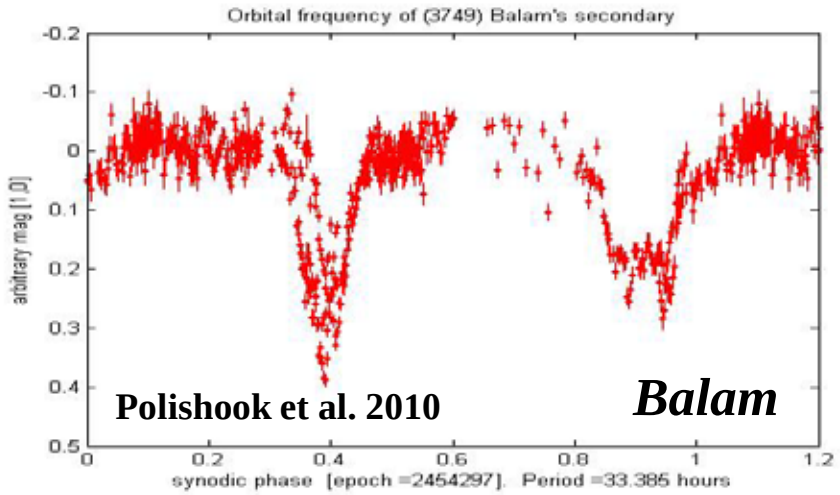
Wait for the next talk by Dr. Nick Moskovitz…



Binary asteroids as scales







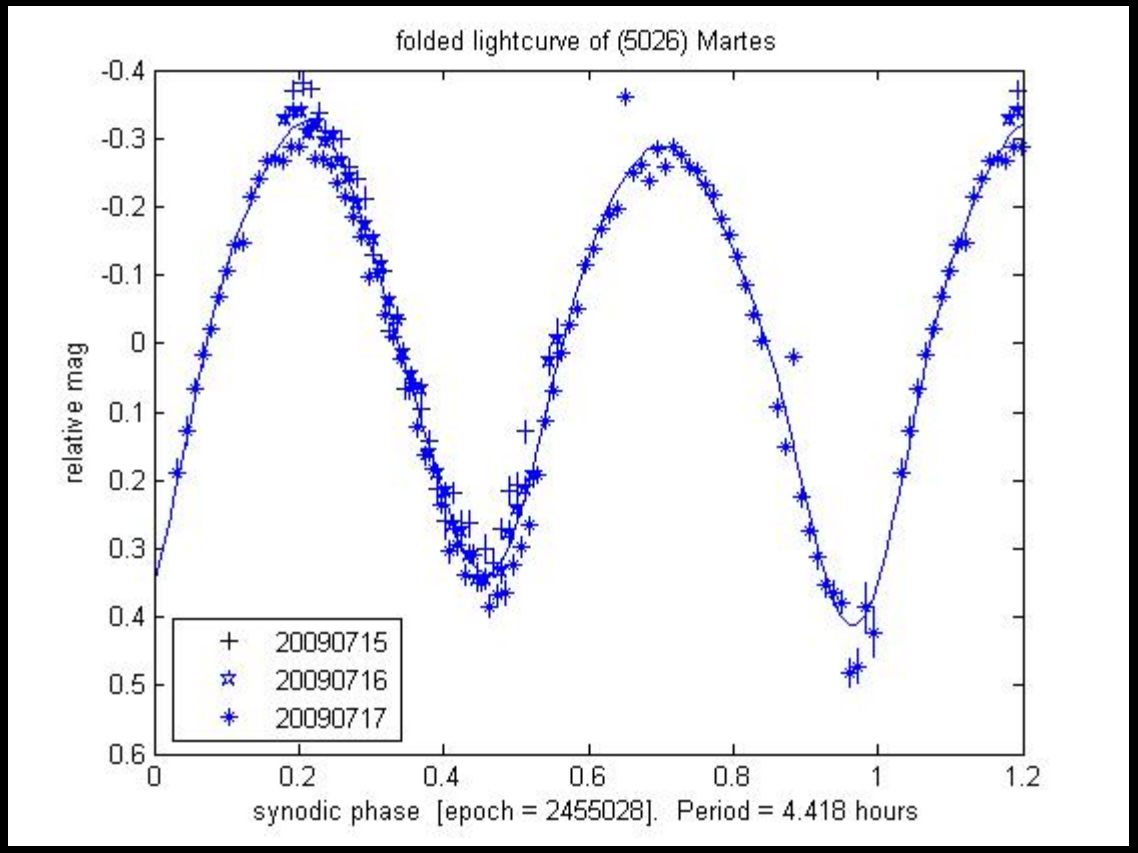
Measure asteroid mass by Kepler's III Law

$$\frac{P^2}{a^3} = \frac{4\pi^2}{G(M_1 + M_2)}$$

All around the Solar System: MBAs, NEAs, TNOs

~15% of NEAs are binary asteroids

Measure the spin



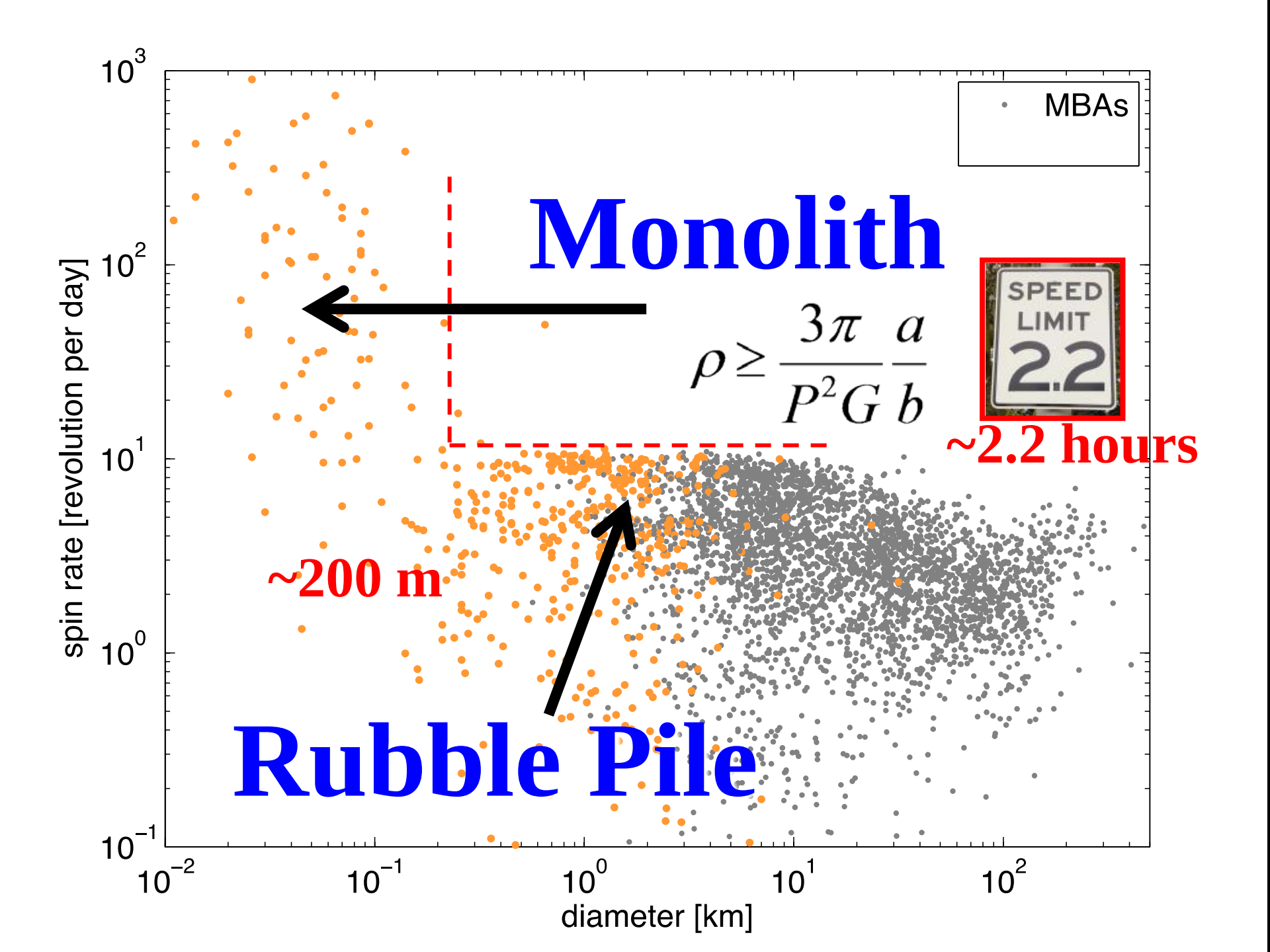
Brightness as function of time

Asteroids have an irregular shape…

…Potatoids

Frequency = Rotation period of the asteroid

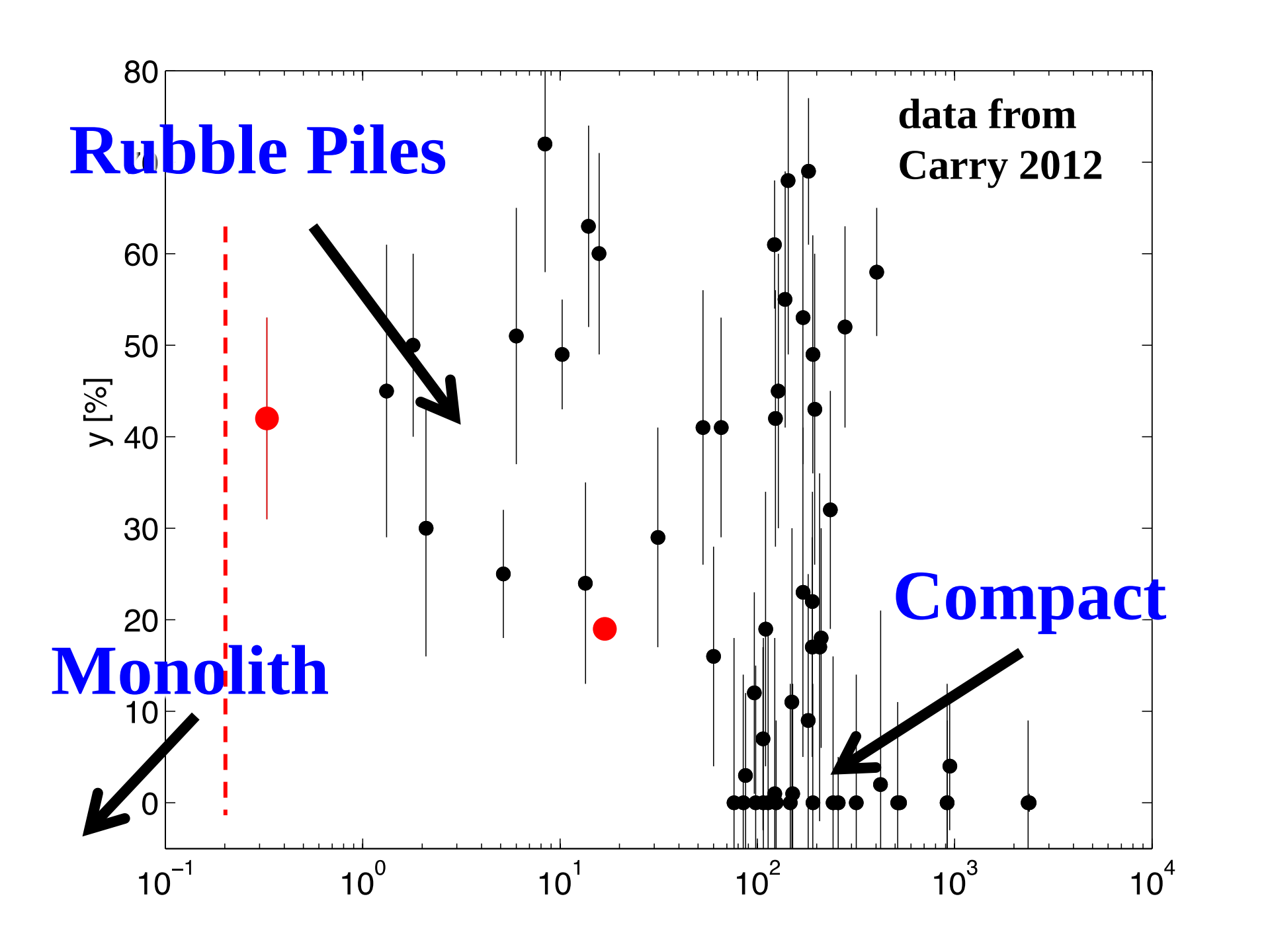
Amplitude = Shape of the asteroid

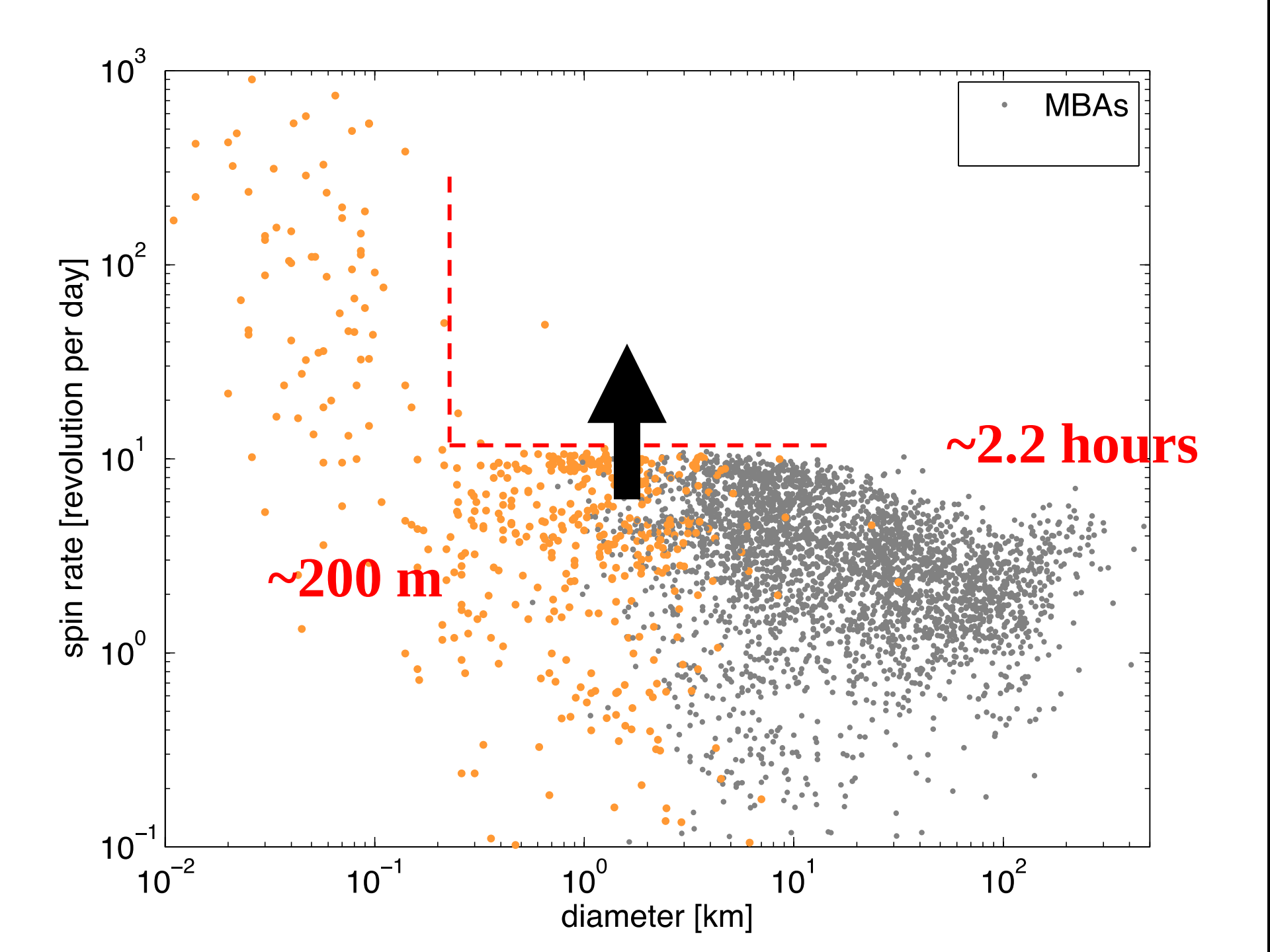

MBAs
Monolith
$\rho \geq \frac{3\pi}{P^2 G} \frac{a}{b}$
SPEED LIMIT 2.2
~2.2 hours
~200 m
Rubble Pile
spin rate [revolution per day]
diameter [km]
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-1}
10^0
10^1
10^2

Rubble pile confirmed

Hayabusha

- Ord. Chon. density: ~3.3 g/cm^3
- Itokawa density: 1.9 g/cm^3


Rubble Piles
data from
Carry 2012
Compact
Monolith
y [%]
80
60
50
40
30
20
10
0
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}

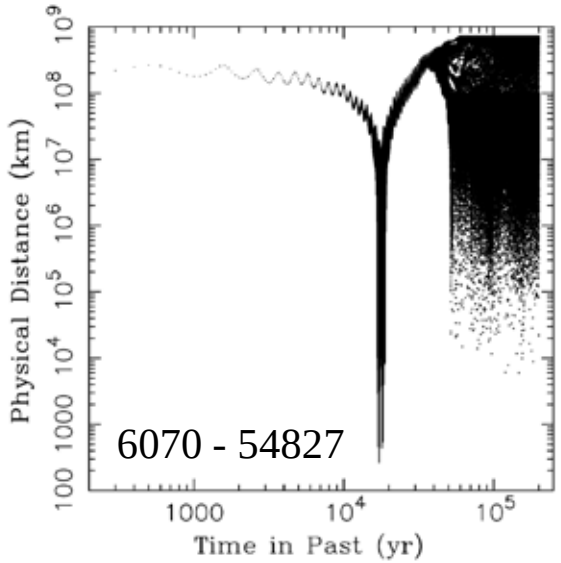

MBAs
~2.2 hours
~200 m
spin rate [revolution per day]
diameter [km]
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-1}
10^0
10^1
10^2

Separated Pairs of Asteroids

- **Have identical orbits (*Vokrouhlicky* & *Nesvorny*, 2008).**

	Asteroid	d (m s^{-1})	a (AU)	e	i (deg)	Ω (deg)	ω (deg)	M (deg)
63440	2001 MD30	0.23	1.93809628	0.0885952	19.98645	229.53463	205.5398	53.0882
	2004 TV14	...	1.93809783	0.0885978	19.98632	229.53426	205.5597	49.8702

- **Were at the same physical space in the last 1 My.**
- **Some got separated ~10 Ky ago!**
- **Probably had a same progenitor.**
- **Spin-up -> disruption & separation.**



Formation of asteroid pairs

Asteroid spun-up by the YORP effect.

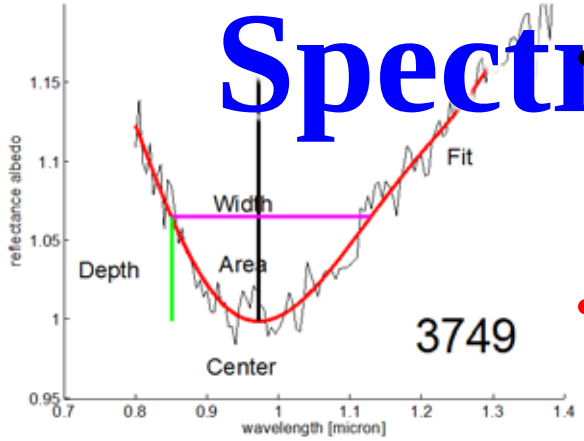
Rubble pile -> *fission!*

An asteroid pair is formed.

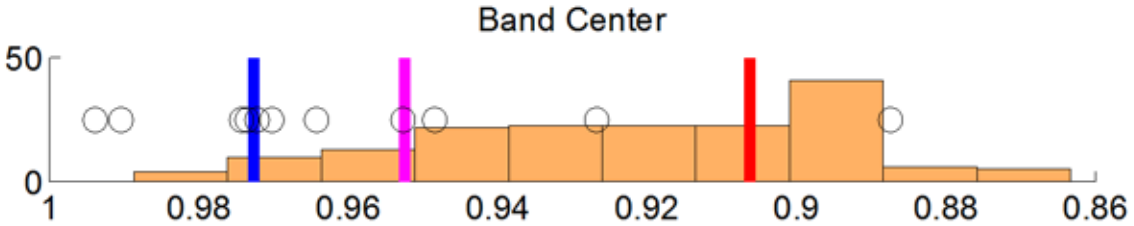
In 10^6y their orbits are altered enough and cannot be recognized as pairs.

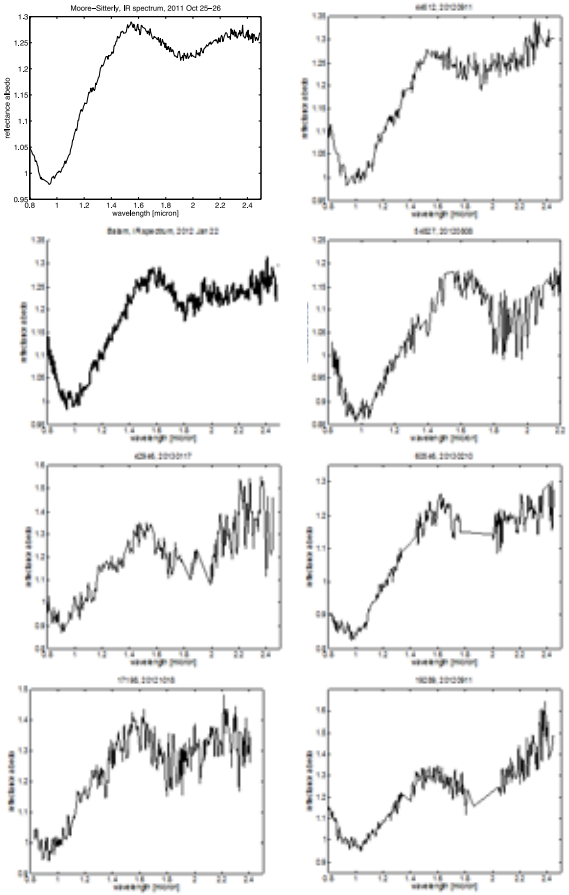
Are they really that young?

Spectroscopic survey of Pairs



- **The 1-micron band parameters of pairs are similar to those of Ord. Chondrite / Q-type asteroids than to S-type asteroids.**
- **Conclusion: Pairs have fresh, un-weathered, surfaces. Their age < 1 Myr.**





Brightness

Albedo

Size

Shape

Mass

Volume

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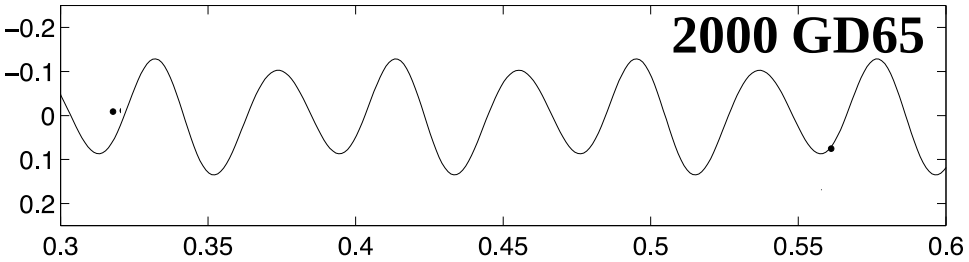
Meteorite Analog

Spin, Satellite, Flyby

Porosity

Internal Structure



Low porosity

10^2

Ord. Chondrite

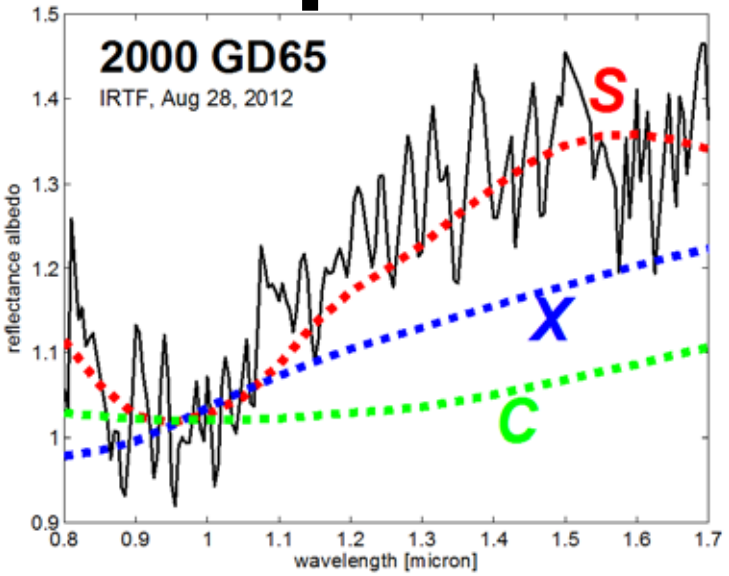
10^1

P=1.957 h

D~2 km

$$\rho \geq \frac{3\pi}{P^2 G} \frac{a}{b}$$

ρ≥3.6 gr cm^{-1}



1. An iron rubble-pile

2. A large monolith

10^0 10^1 10^2