Everything I Know About Asteroids Inside 1 AU

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MMT Observatory
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Why SOFIA?

Telescopic observations in the infrared are strong component of remote sensing of asteroids

- Complement of instrumentation
- Altitude above much of Earth's atmosphere reduces telluric water interference
- Solar exclusion angle of SOFIA smaller than other space-based assets, allows access to solar system objects within 1 AU, includes

  NEAs

  Vulcanoids

Two Reasons to be Interested in Near-Earth Asteroids:

I. Science:

Asteroids are likely bodies in the Solar System formed in different locations than the Earth…

Thus, they are windows into formation conditions and processes that occurred in the early Solar System

Near-Earth Objects:

Near-Earth Asteroids - asteroids located between the orbits of Venus and Mars (estimated 6800 currently known)

Near-Earth Comets (Earth-Approaching Comets) - >115 known

PHOs - Potentially Hazardous Objects:

A PHO is a small body that has the potential to impact the Earth at some future time

By definition, these are NEOs passing within 0.05 AU of Earth's orbit

Currently, about 20% of the discovered NEAs are PHOs

PHAs - Potentially Hazardous Asteroids:

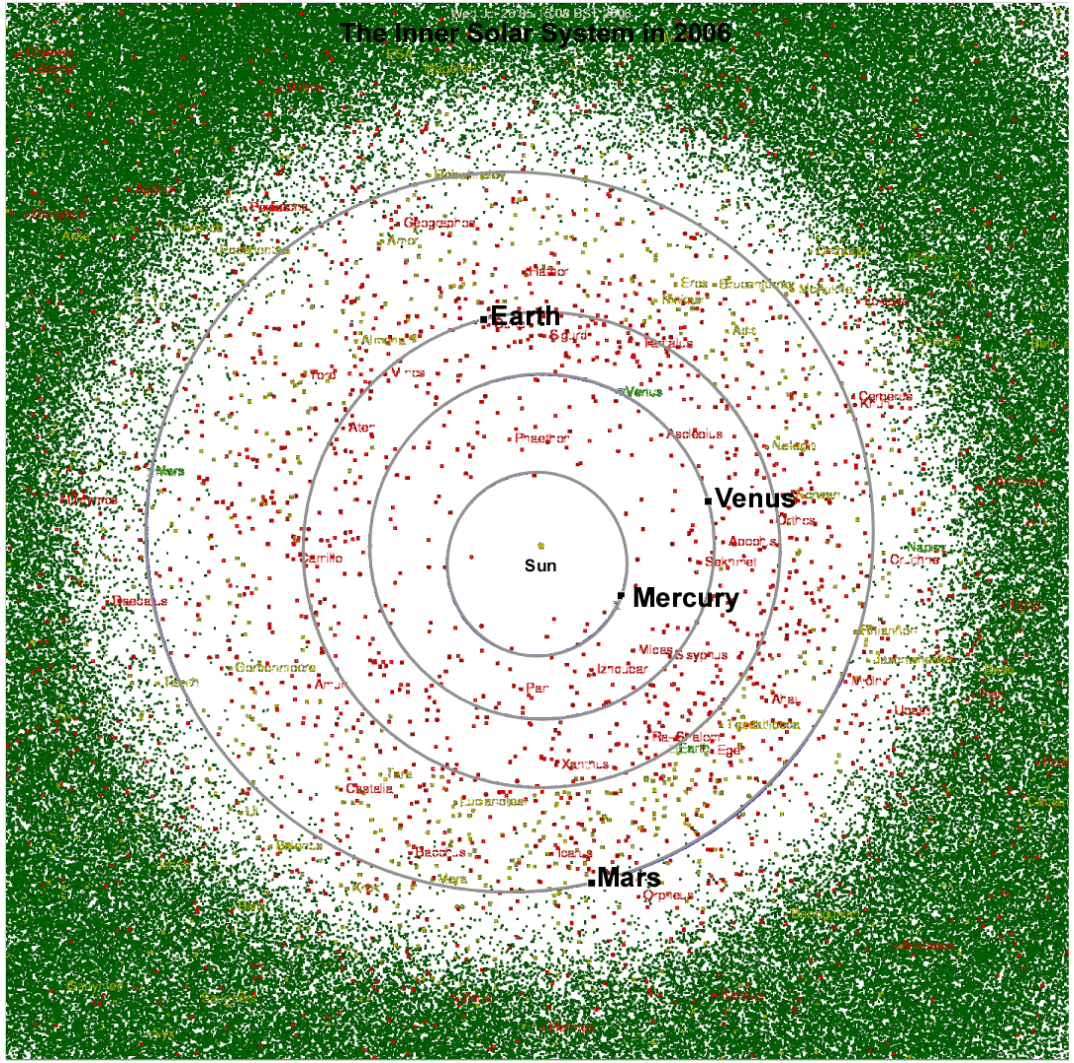
The PHAs are the NEA subset of the collective PHOs

History of Known NEO Population

2006

Earth Crossing

Outside Earth's Orbit



Known
- **338,186 minor planets**
- **4159 NEOs**
- **789 PHOs**

New Survey Will Likely Find @ > 140m

- **66,000+ NEOs**
- **18,000+ PHOs**

Scott Manley

5/11/23

Courtesy L. Johnson

Where do NEAs reside in near-Earth space?

Apollos: perihelia < 1.017 AU; mean semi-major axis a > 1 AU; most PHAs are Apollos

Amors: 1.017 AU < perihelia < 1.3 AU; cross Mars' orbit

Atens: a ≤ 1.0 AU, aphelia > 0.983 AU, orbits that cross Earth orbit ≤ 500 known, ~20% PHAs

Apohele's/Arjuna/A-something: both perihelia and aphelia < 1.0 AU, very difficult to observe, 5 are known, 4 are also suspected

How Do NEAs Get to Near-Earth Space?

Transient population: current population est. < 10 Myr old

Delivery to near-Earth space:

Primary method: Impact destroys parent body: smaller pieces transported to resonance, such as 3:1 Kirkwood Gap, ν_6 resonance, to near-Earth space

Yarkovsky effect: thermal thrust effect

YORP (Yarkovsky-O'Keefe-Radzievskii-Paddack): thermal torque effect

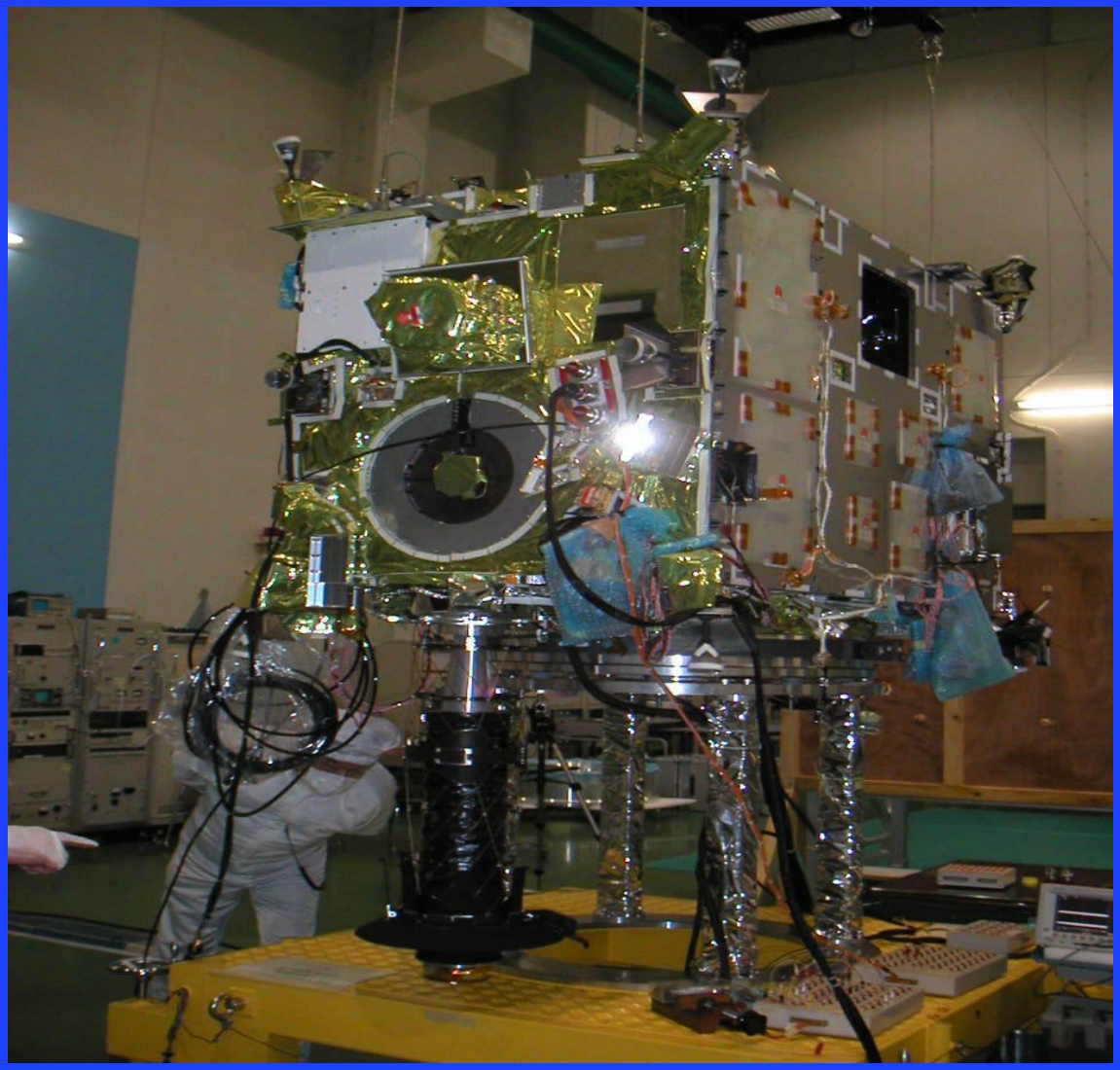
The majority of asteroids entering the inner Solar System hit the Sun or are ejected by close encounter of bad kind with Jupiter; only 1% become NEAs

The NEAs constitute a transient population: what does it look like?

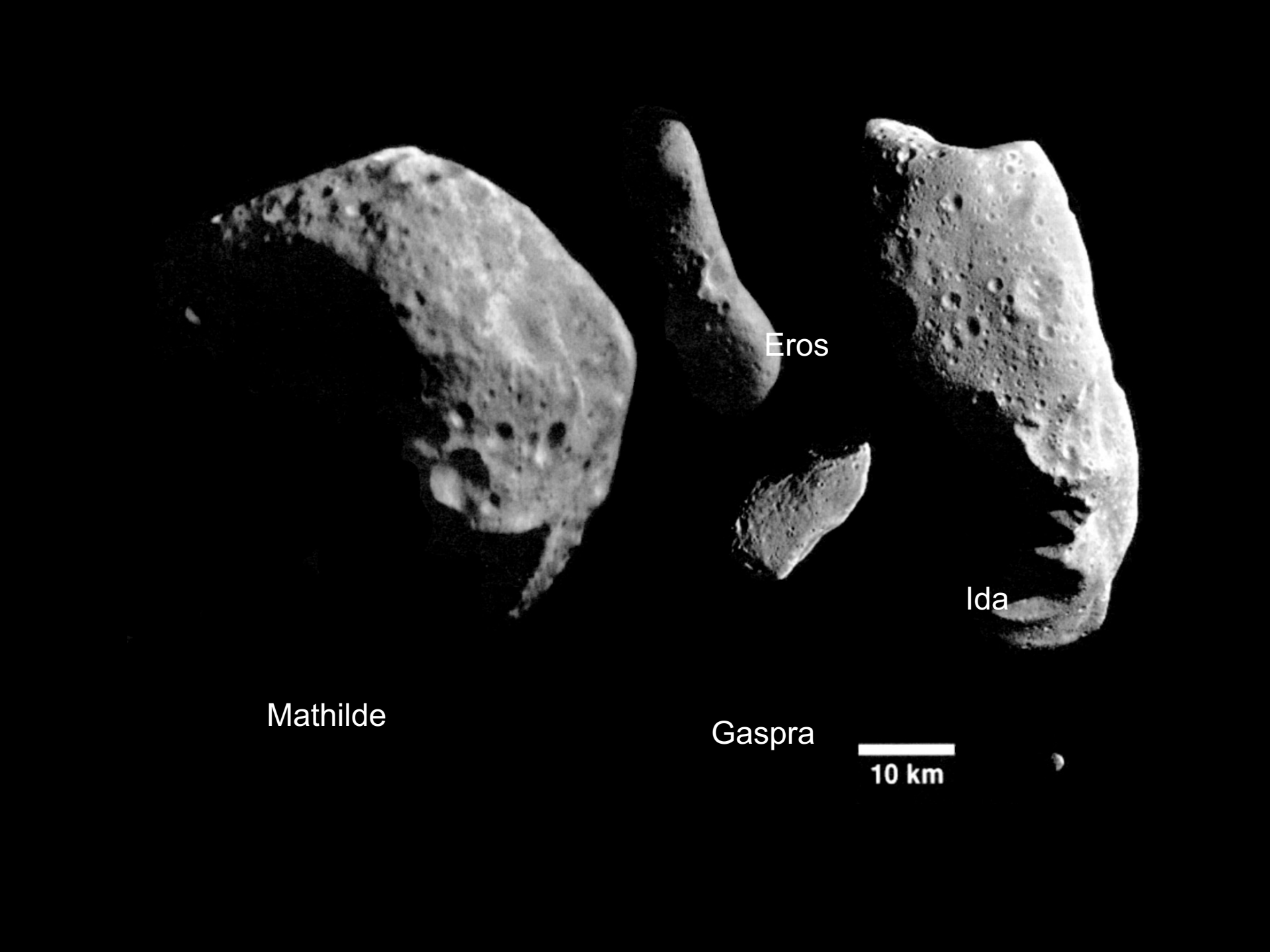
A macro look at physical state of the NEAs

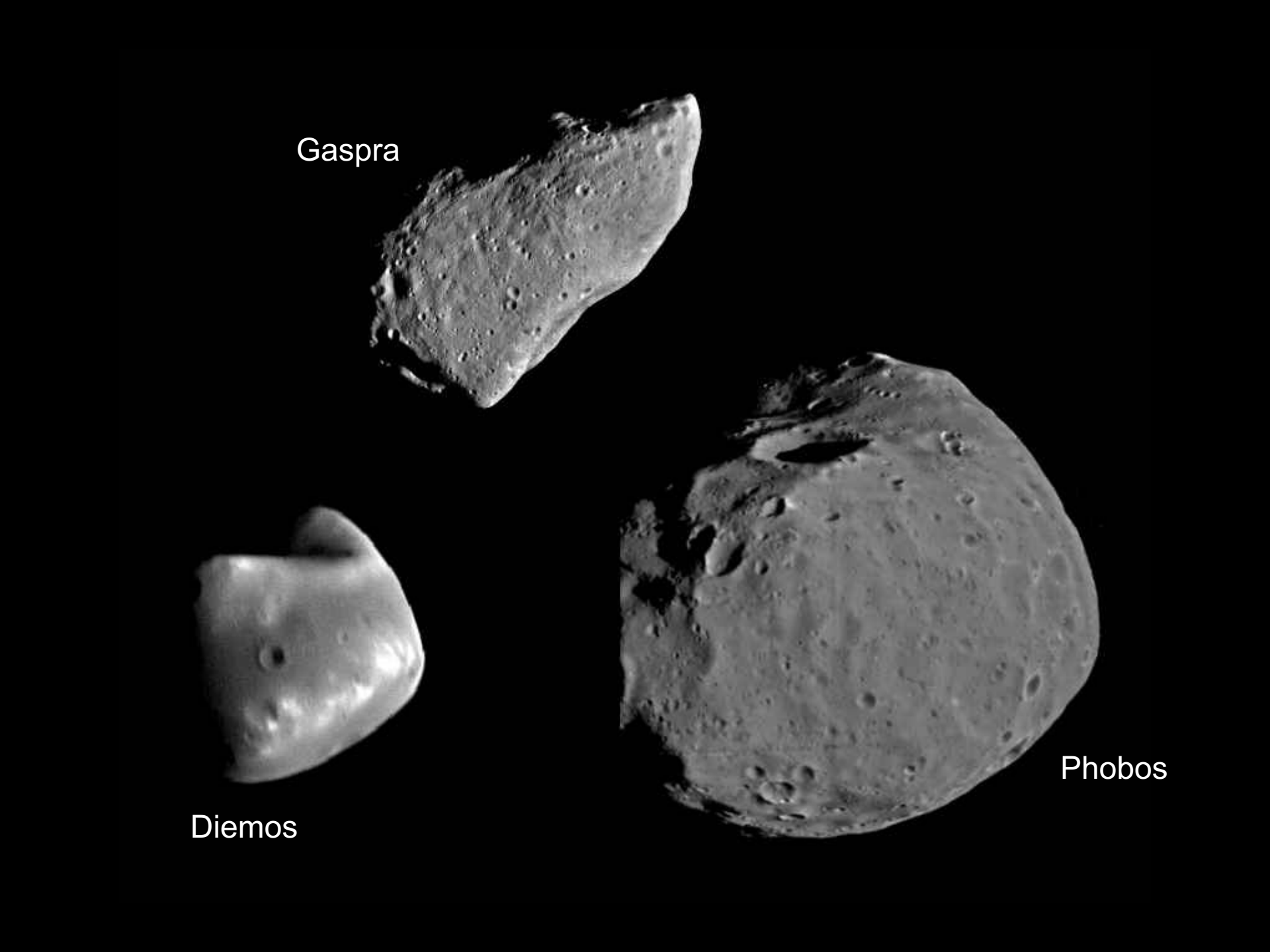
Composition/mineralogy

“There is more diversity in the Solar System than there is in the brains of bright theorists!”
Andre Brahic



Japanese Hayabusa mission to orbit, land, and return a sample of NEA 25143 Itokawa in 2005


Eros
Ida
Mathilde
Gaspra
10 km


Gaspra
Diemos
Phobos


433 Eros

Itokawa Surface Features @ +270 deg. Longitude

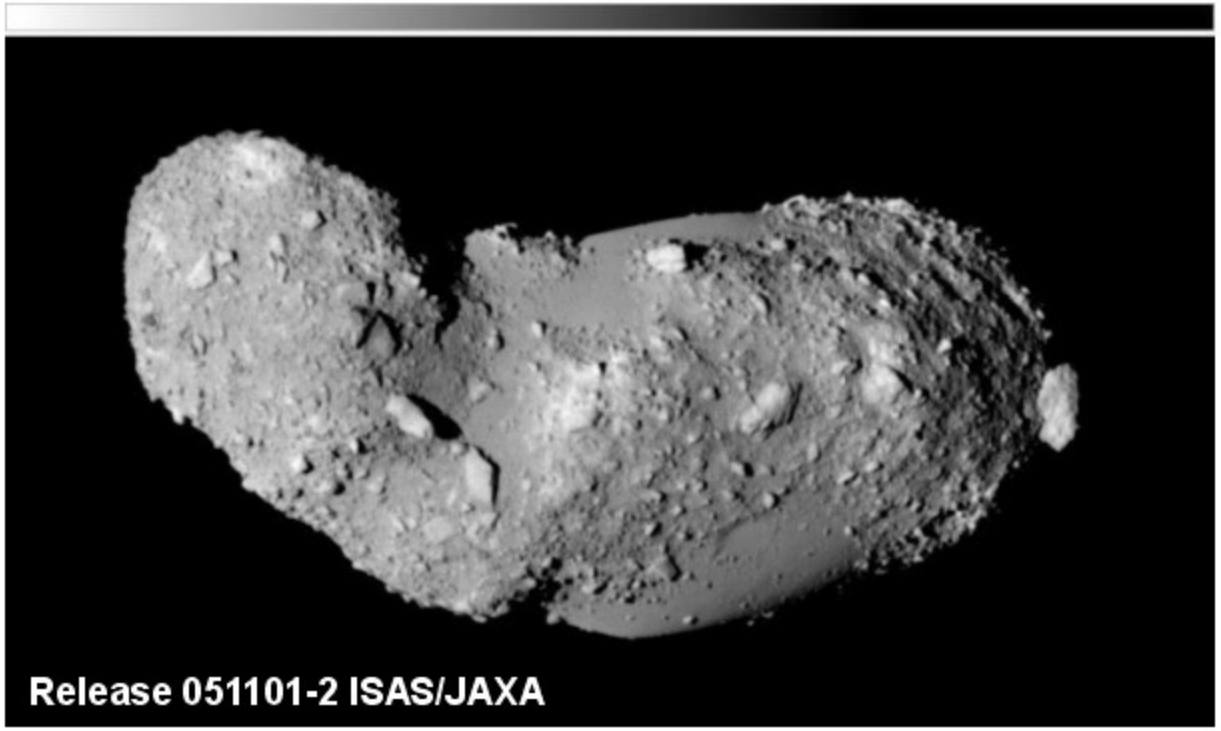


図4　イトカワの +270 度面

Itokawa Surface Features @ +90 deg. Longitude

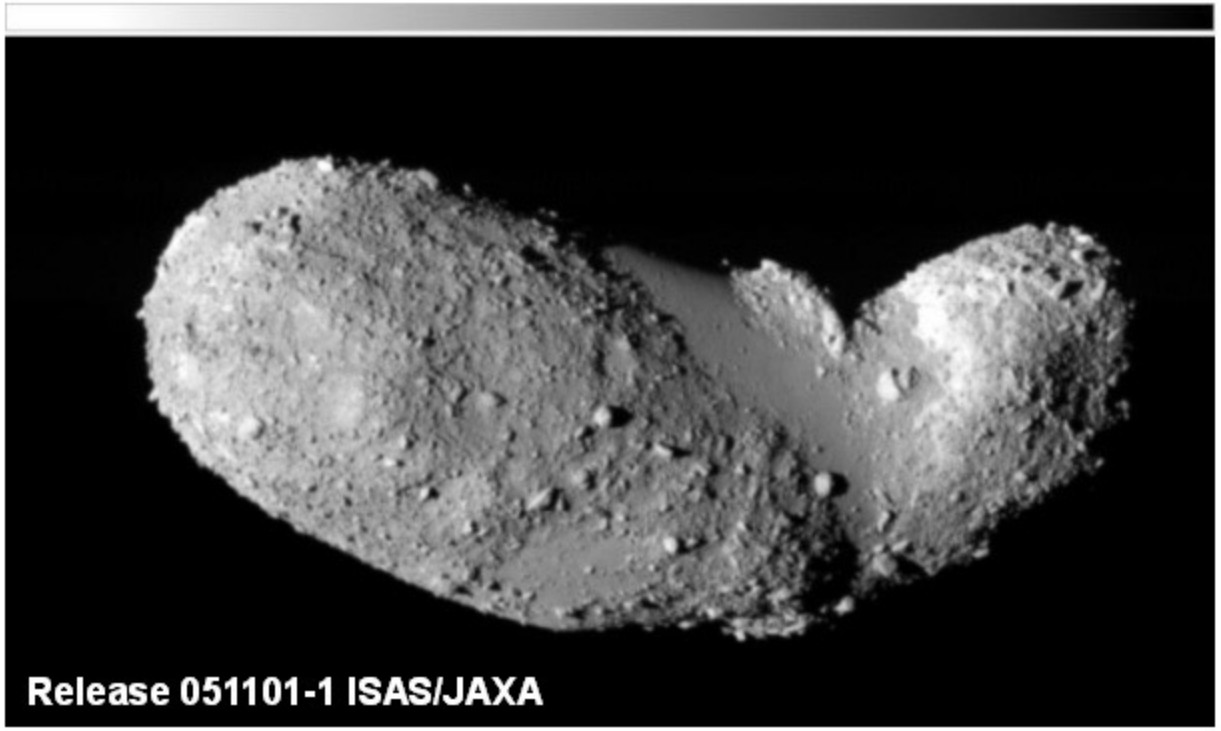
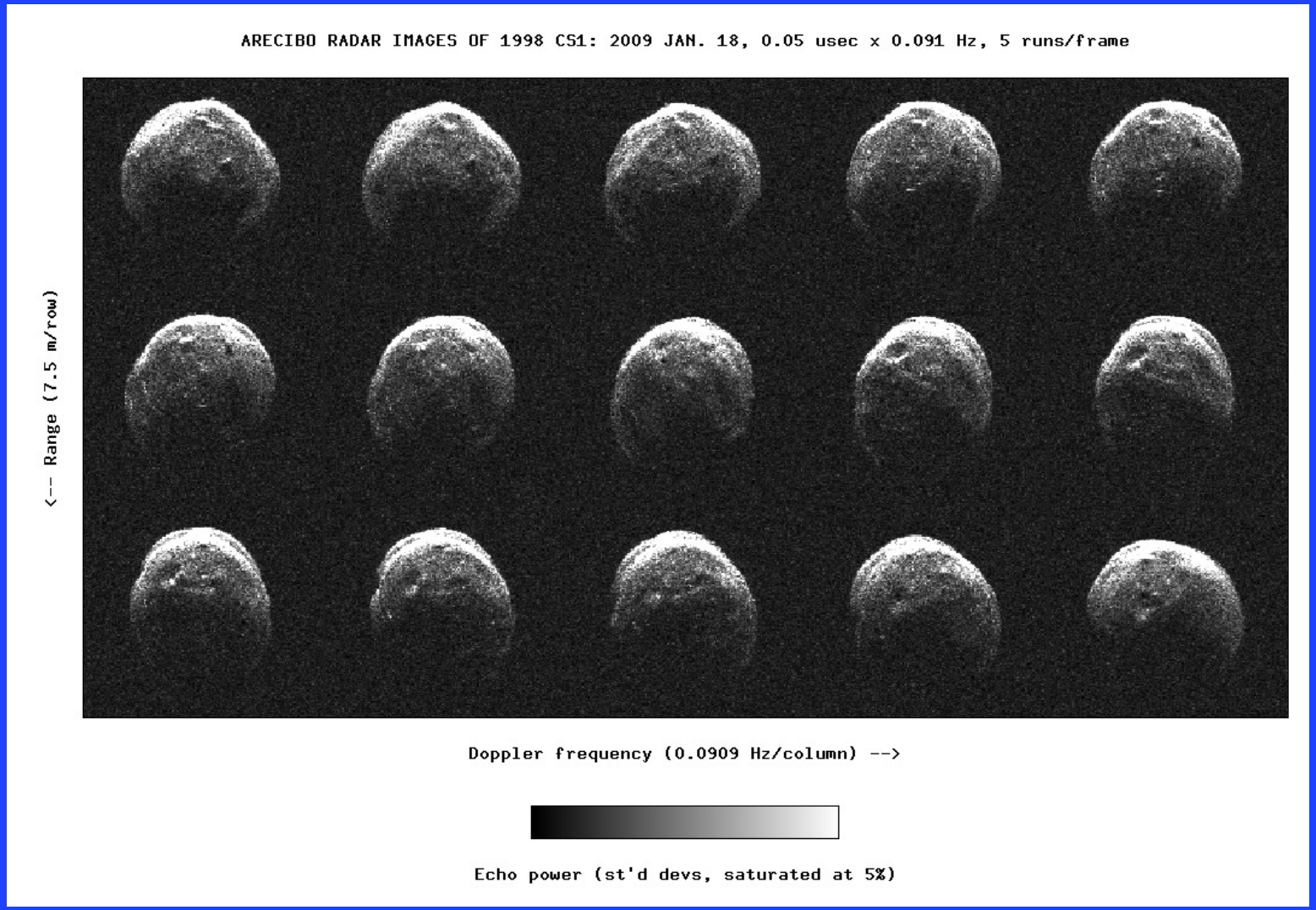


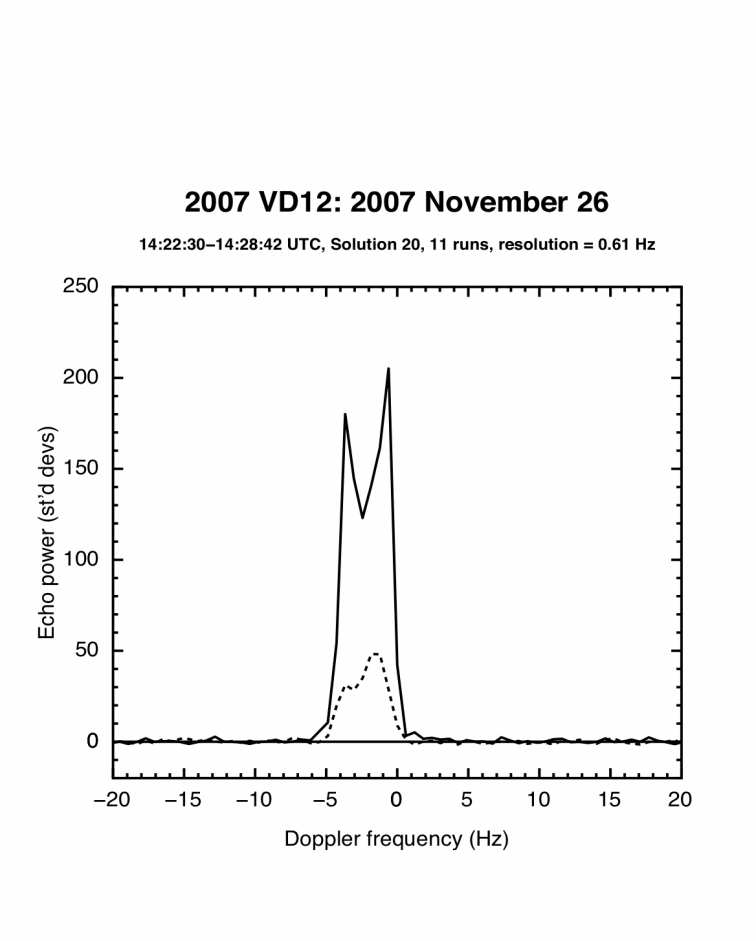
図3 イトカワの +90 度面

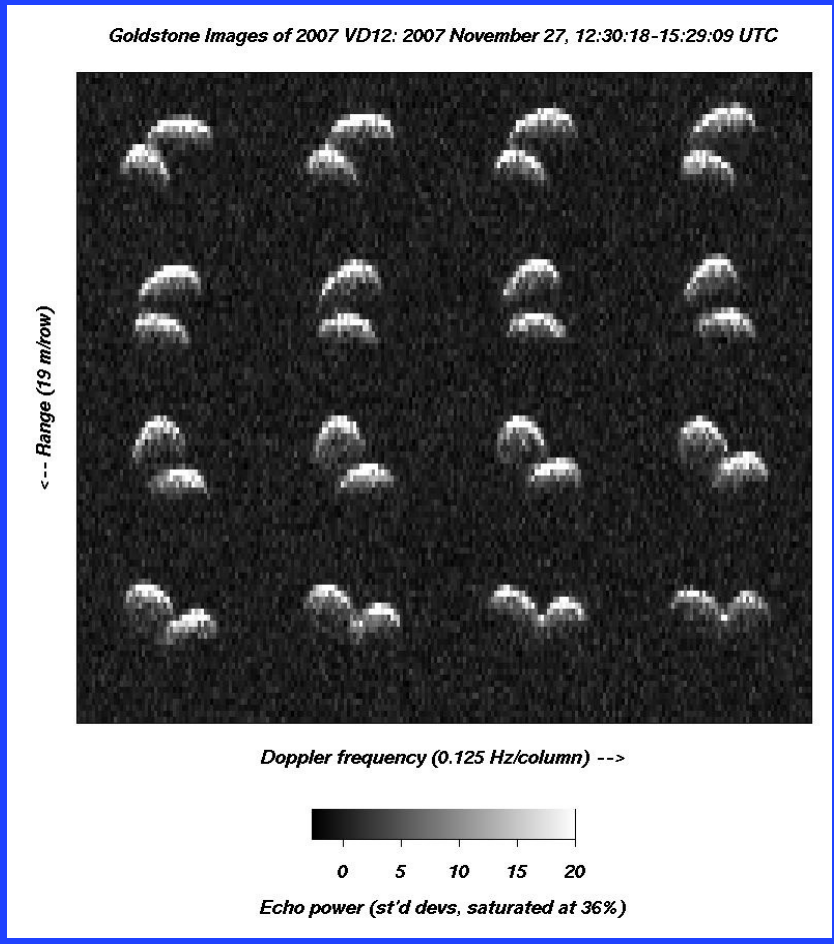
1998 CS1
Arecibo: January 18, 2009



Courtesy L. Benner

2007 VD12
Goldstone, November 2007





Courtesy L. Benner

Composition and mineralogy:

We can approach our knowledge of this through different means:

- Remote sensing of mineralogy from telescopic or spacecraft observations of spectral reflectance

- “Ground truth” (usually somewhat contaminated) samples present in meteorite samples (!!)

- Spacecraft elemental compositional experiments (γ-ray, x-ray neutron spectrometers)

Spectral reflectance gives us spectra and photometry by which we class asteroids, including the NEAs

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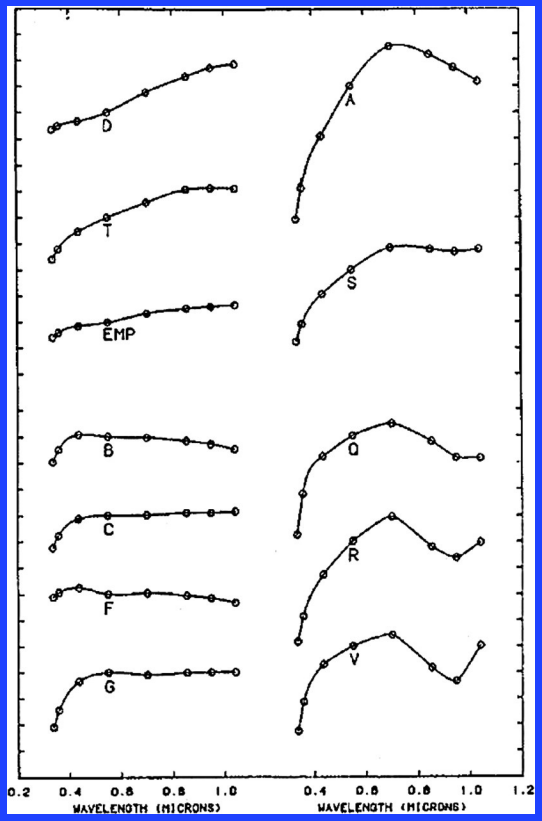
SOFIA can greatly benefit remote sensing, especially those objects near the Sun

Tholen Asteroid Classes



Population of NEAs - largely S-class (and types similar to S-class) asteroids:

Quality of data varies, and because of many spectra being obtained during discovery apparitions of the NEA, it is difficult to confirm/improve the spectra

The reflectance spectra have been used to address one of the most vexing problems in asteroid science: why are spectral properties of the ordinary chondrites,the most common meteorite type, not well represented in spectra of the asteroid population?

And, concurrently, why is the spectrum of S-class asteroids, the dominant type of asteroid in the inner edge of the main belt (heliocentric distances of 2.2 - 2.6 AU) - presumably the source of most of the NEAs - not seen in spectra of terrestrial meteorite collection?

Potential solution:

The “space weathering” mechanism operating on the lunar surface by creation of Fe^0 from solar wind interaction with the surface or micrometeoroid bombardment has also affected the general S-class asteroid population:

Effect?

Redden spectra

Reduce depth of absorption features

NEAs being a younger, transient population should show unweathered, - or less weathered - spectra, closer to or matching the ordinary chondrite spectra.

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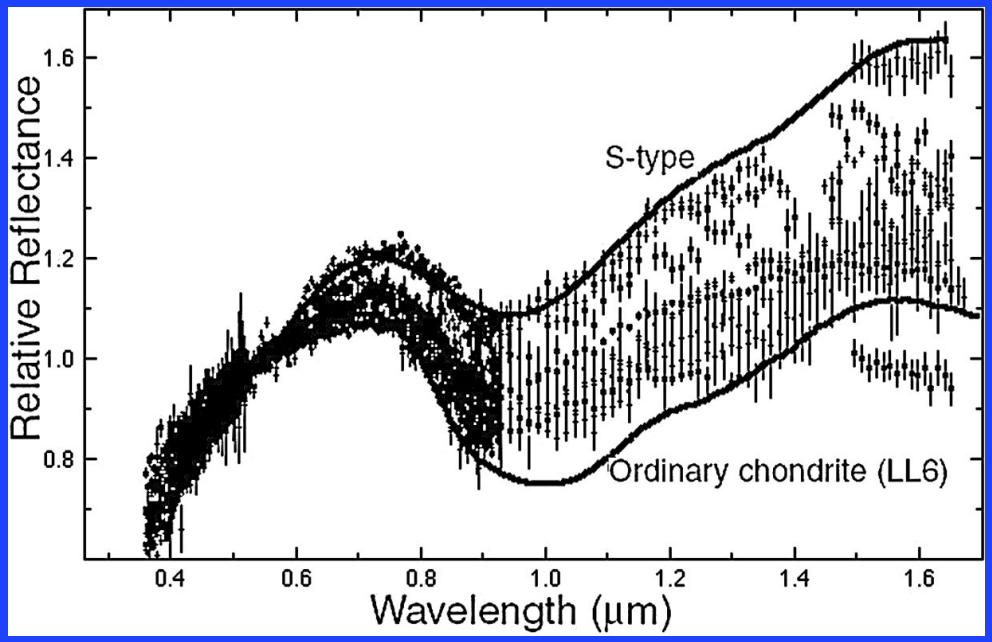
Unknown NEA population inside 1 AU can be characterized by SOFIA

NEAs show gradation between reflectance spectra of S-class asteroids and ordinary chondrites (but be careful…)



Spectra from Binzel in Chapman (2004)

Two Reasons to be Interested in Near-Earth Asteroids:

I. Science:

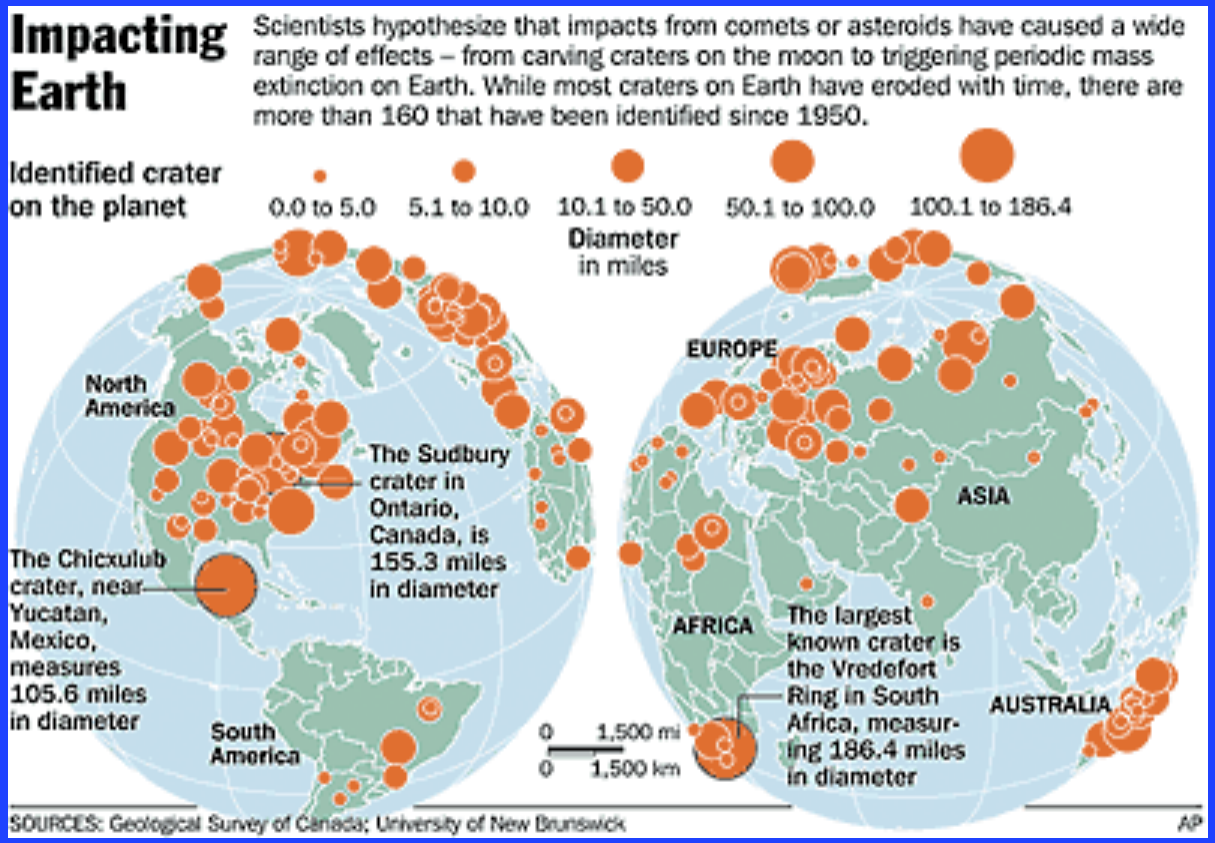
Asteroids are likely bodies in the Solar System forming in different locations than the Earth, and serve as windows into early Solar System (planetary?) formation processes

II. Planetary Protection:

NEAs constitute the primary source of objects that could impact the Earth, causing major destruction

TUNGUSKA EVENT
1908

NEO IMPACTS PAST



How Do Asteroids Get from Near-Earth Space to the Earth?

Pass through resonance “keyholes” - small areas where - if an NEA passes through this small space, the Earth’s gravitational pull can perturb the NEA to intersect the Earth on a *future* approach

Cannot distinguish the changes in orbit with optical or radar tracking; proposed tagging of target asteroids such as Apophis

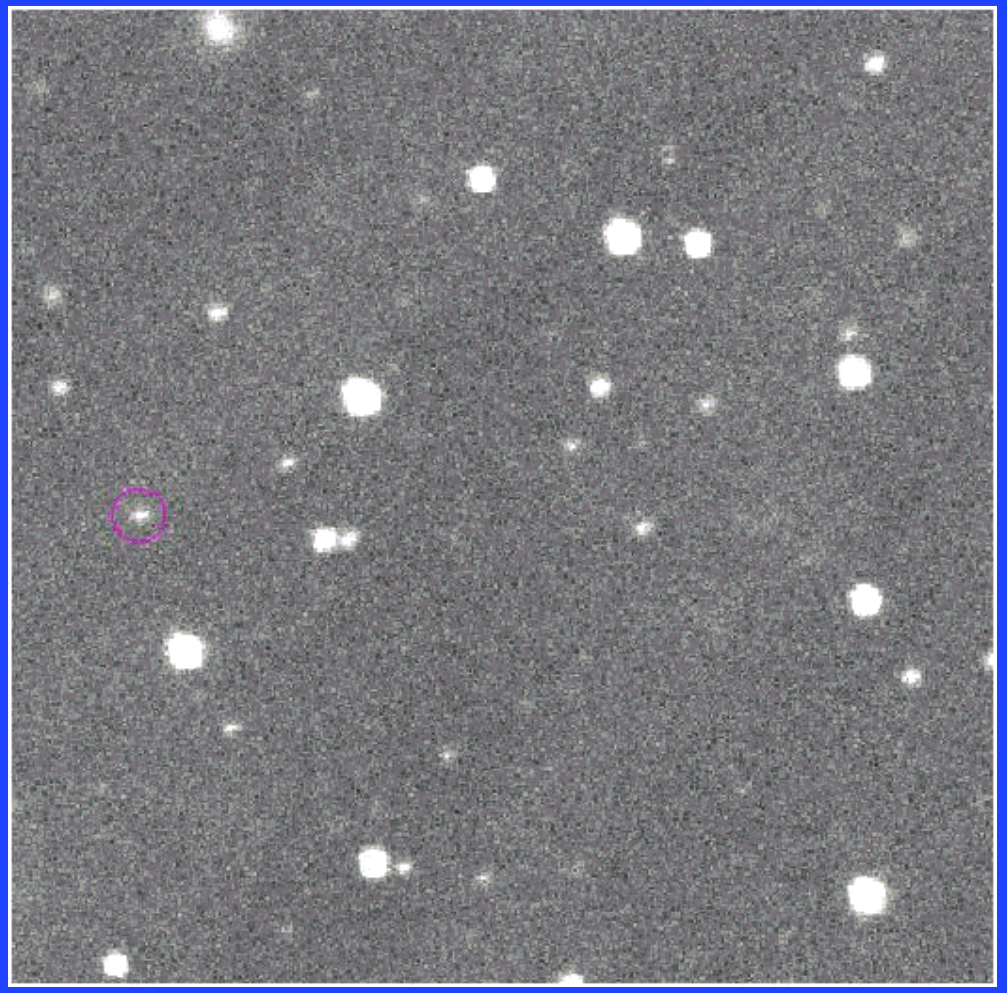
Case Study:

Imminent impactor 2008 TC_3

Discovered by Catalina Sky Survey Mt Lemmon Survey Telescope (1.5m) at 0640 UT on Oct 6, 2008.

~19 M_v

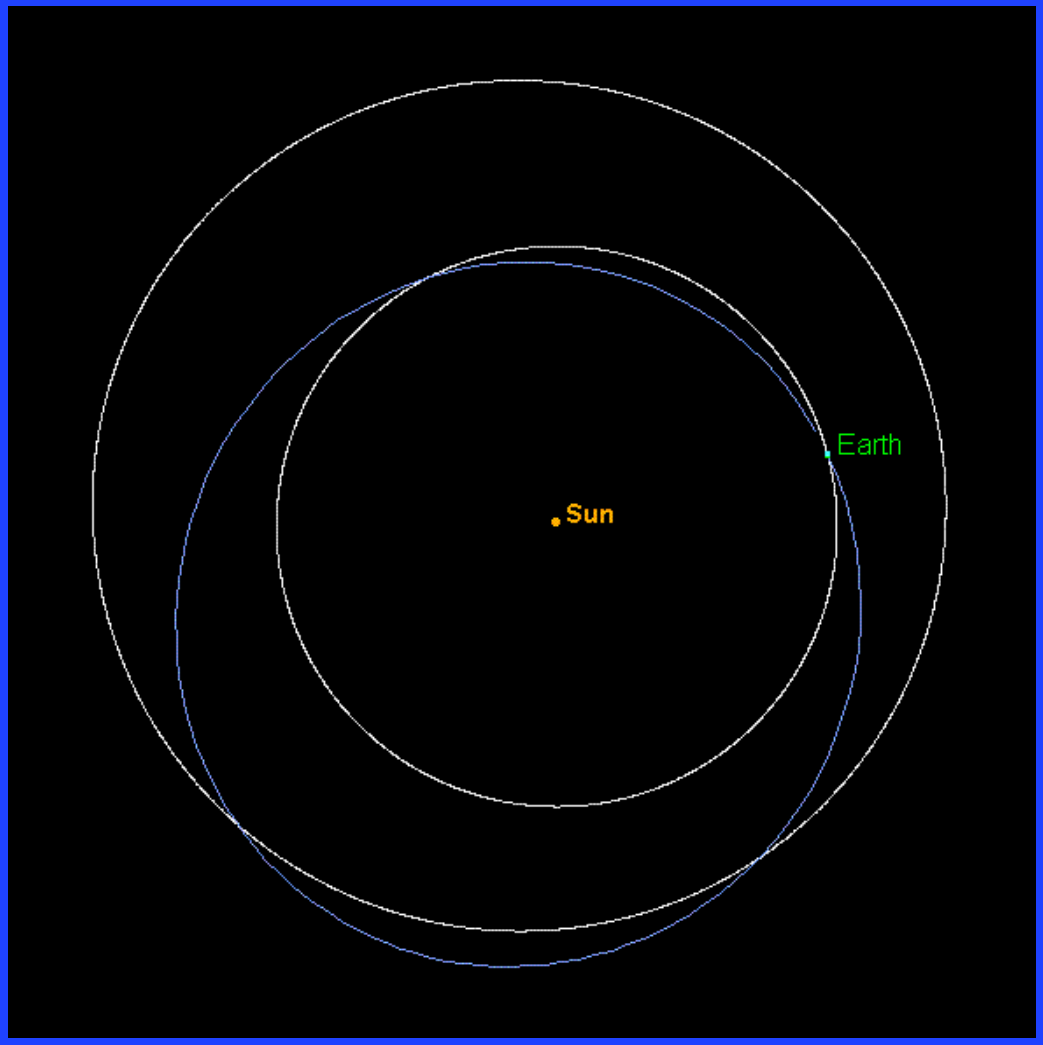
T - 19 hr to impact



Four discovery images of 2008 TC_3, spaced by 10 m

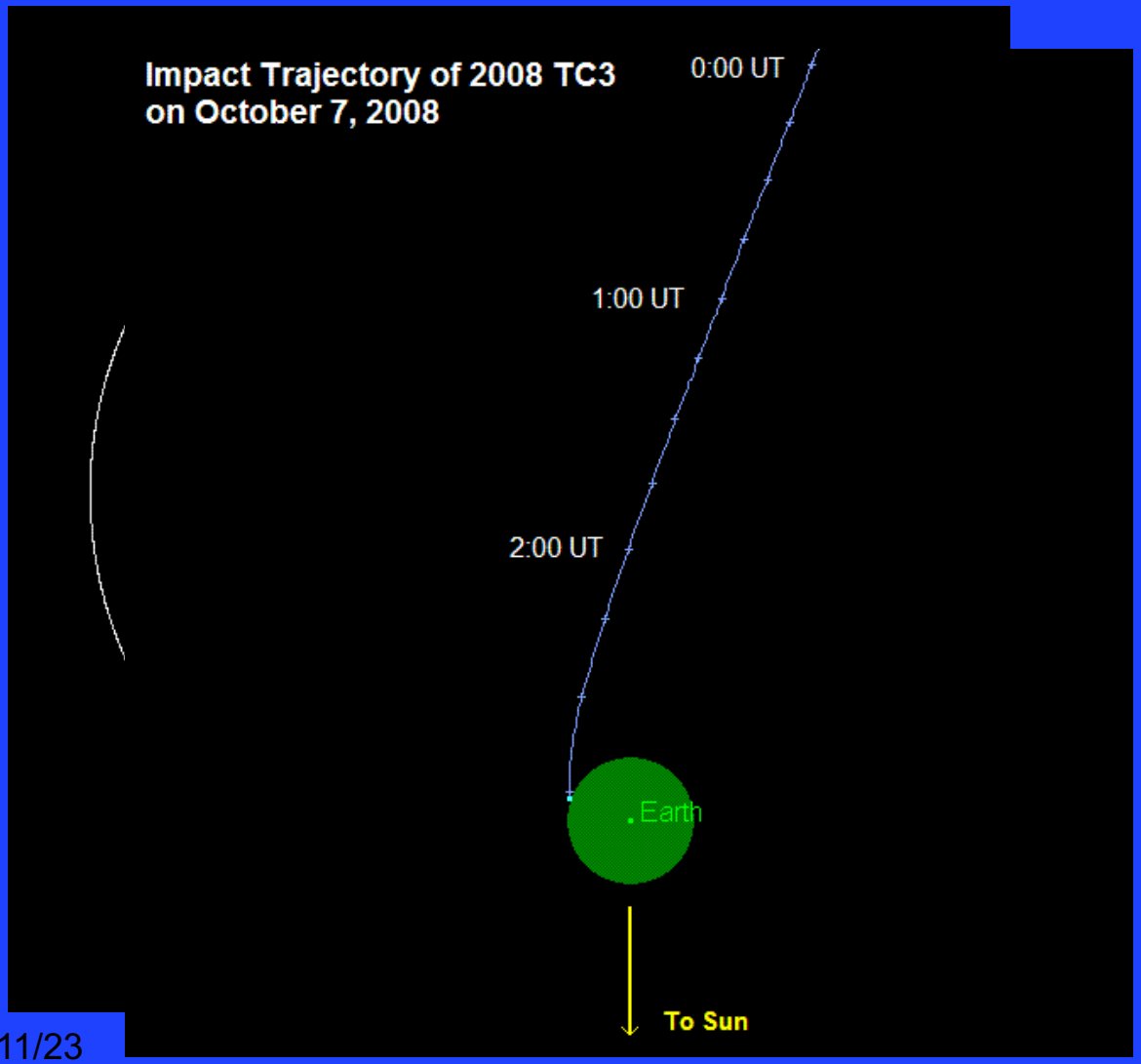
Courtesy of Catalina Sky Survey/University of Arizona/NASA

The Short Life of 2008 TC_3



Initial MPC orbit determination finds object will impact Earth within 24 hrs. MPC alerts JPL NEO Program Office and HQ NASA

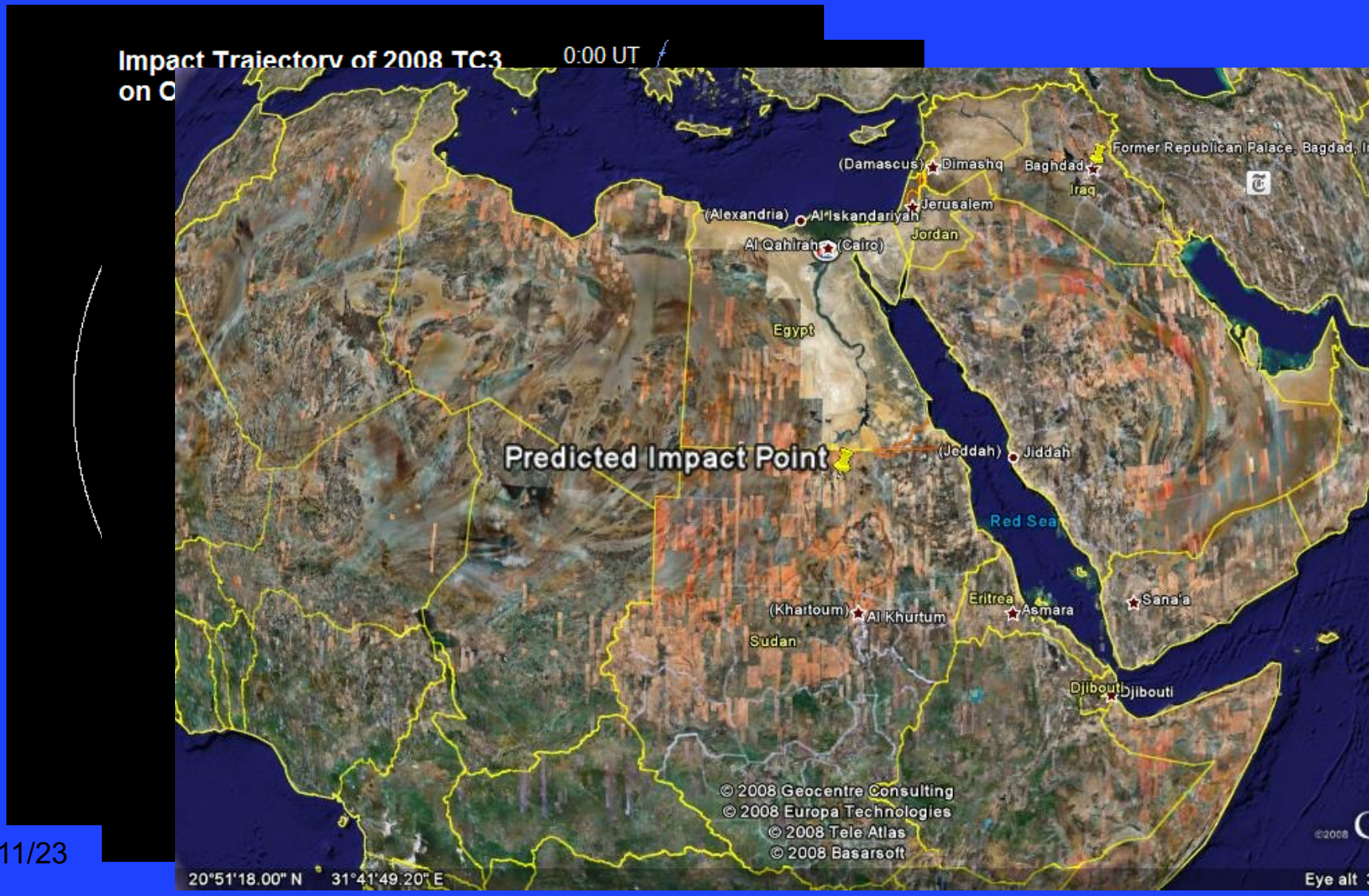
The Short Life of 2008 TC_3



JPL SENTRY run predicts impact at 0245 on 7 Oct, 2008 over northern Sudan

Community responds with 570 observations from 27 observers

The Short Life of 2008 TC_3



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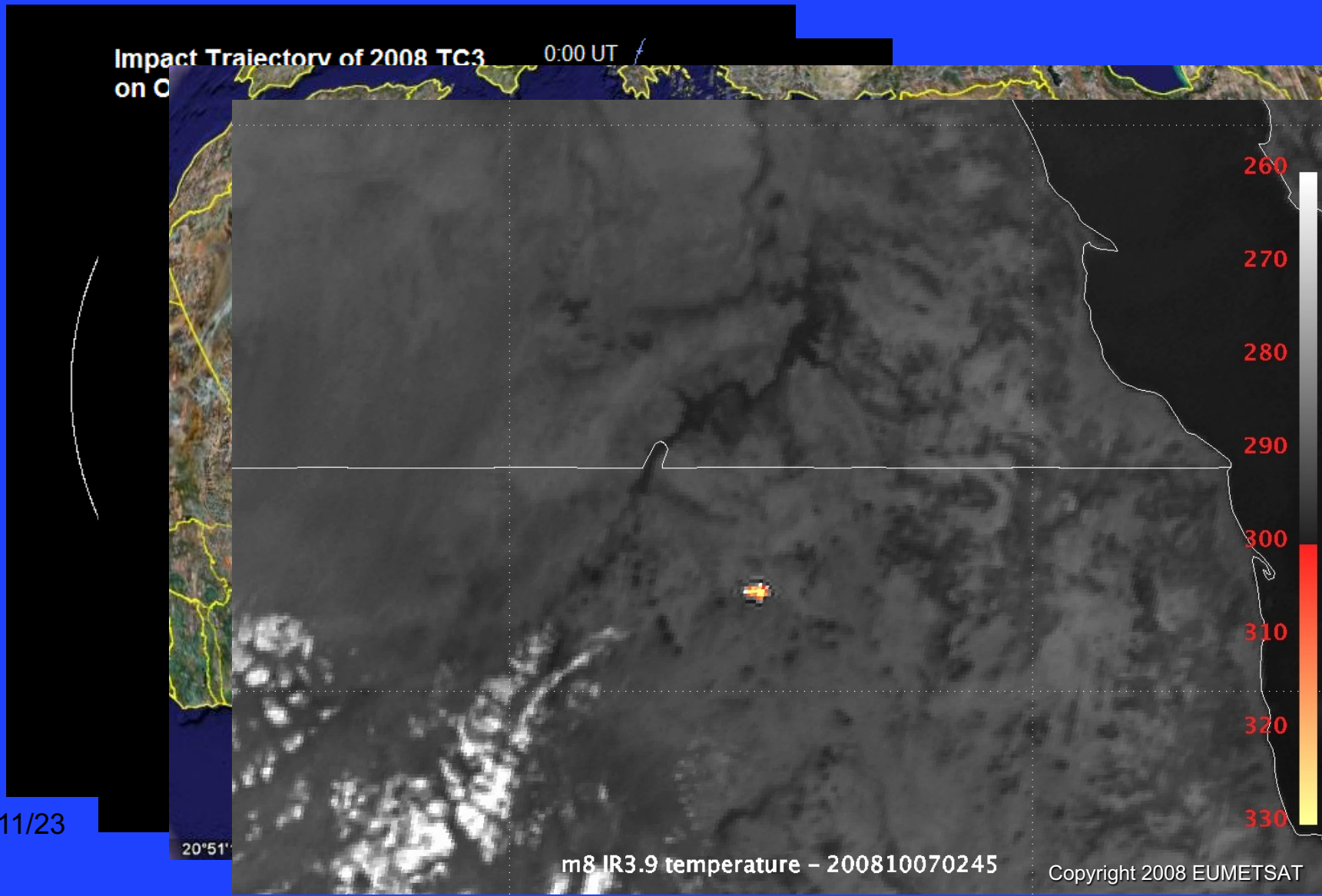
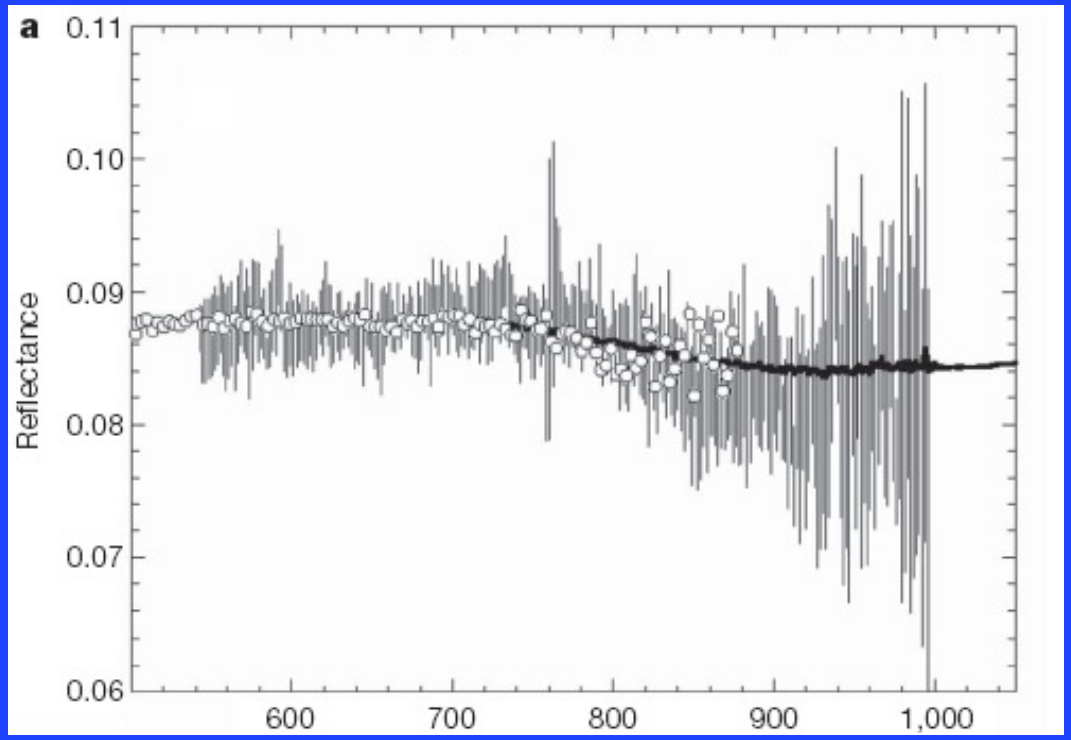


TC_3 spectrum:



From Jenniskens et al., 2009: TC_3 spectrum acquired with 4.2-m Herschell telescope for 6 min; solar analogue 16 Cyg B, compared to spectrum of collected meteorite. Each line represents std dev of 10 spectral points

11/19: Target marker released onto surface
Itokawa descends and stays for 1/2-hr visit