Whizzing past Earth:
properties of Near Earth Asteroids

Francesca E. DeMeo, MIT

ESAC May 12, 2011

Outline

- What is a near-Earth asteroid?
- Why do we study them?
- Space weathering and surface freshening
- Super close Earth encounters

What is an asteroid?

Figure credit: JAXA

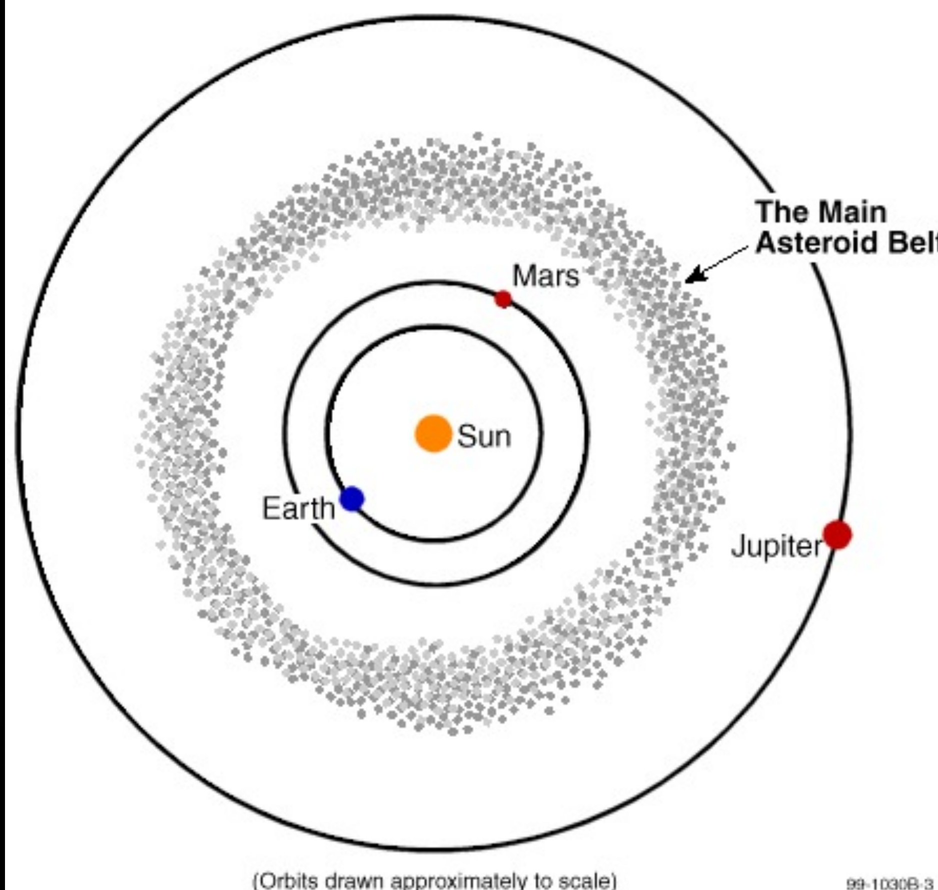
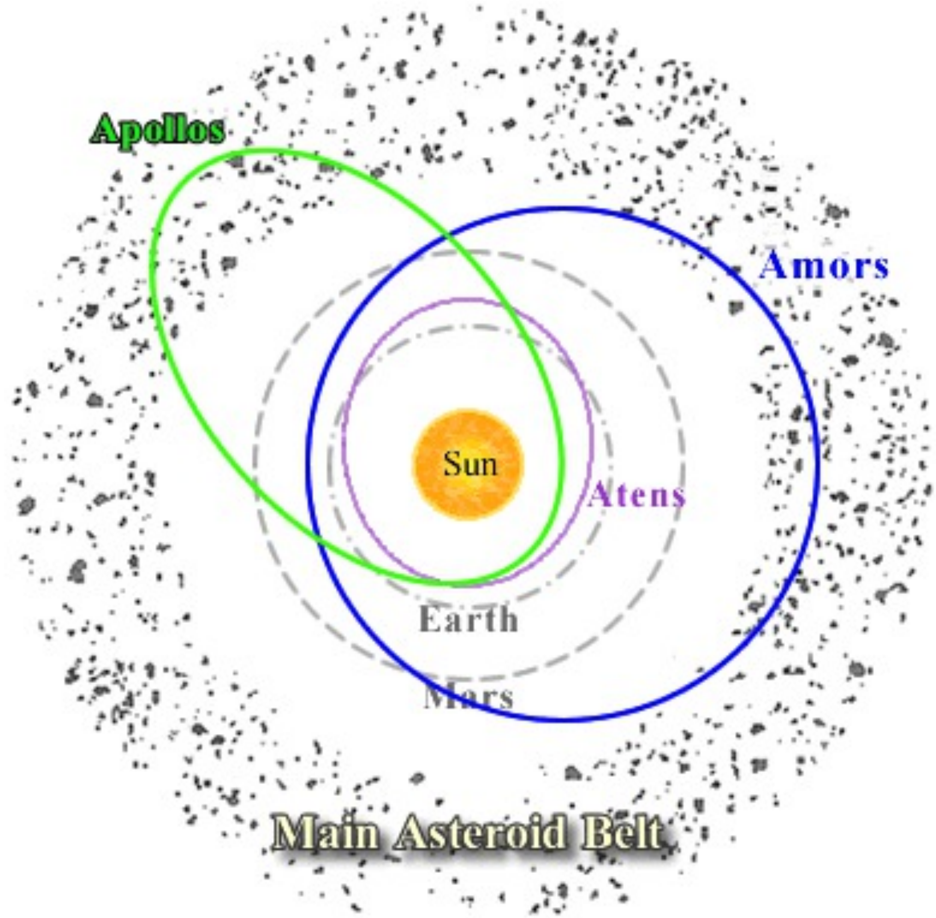


Figure from www.daviddarling.info

What is a near-Earth asteroid?

Figure credit: JAXA



Why study them?

- What are the planets made out of?
- How did the solar system form?
- How has the solar system evolved?
- What is the structure of the solar system?
- What if one hits Earth?

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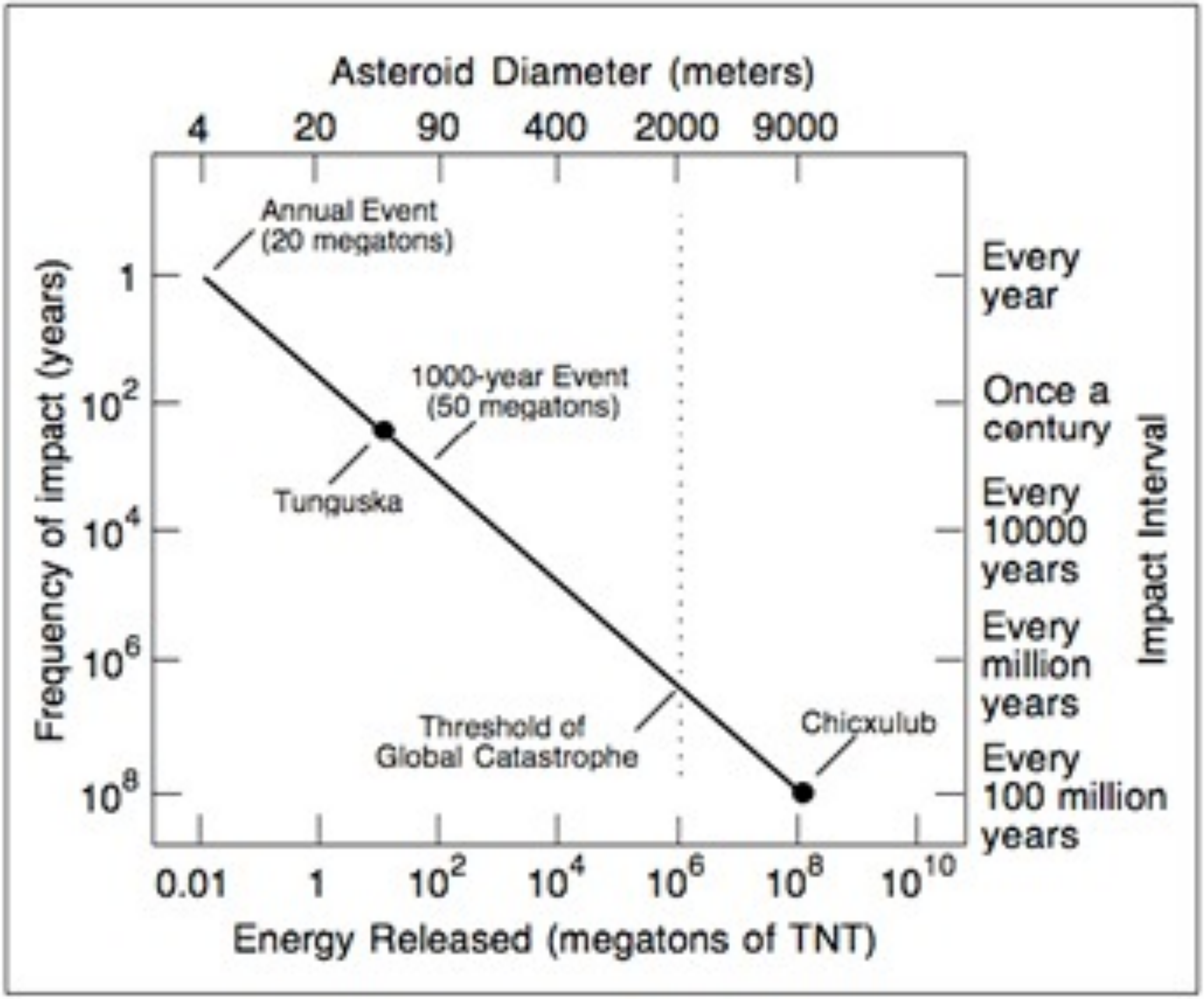
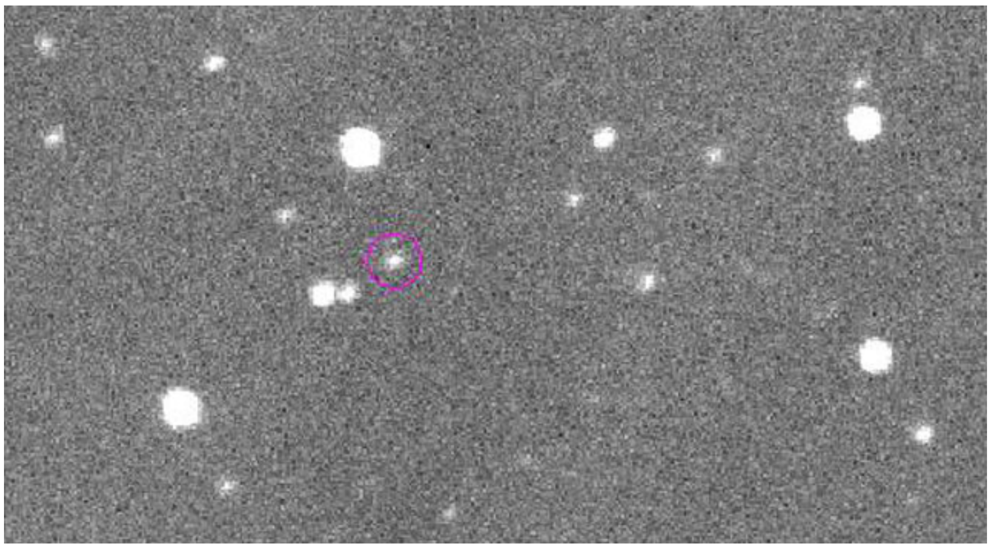
Fig: mi9.com

Impact Frequency



Catch a shooting star: 2008 TC3

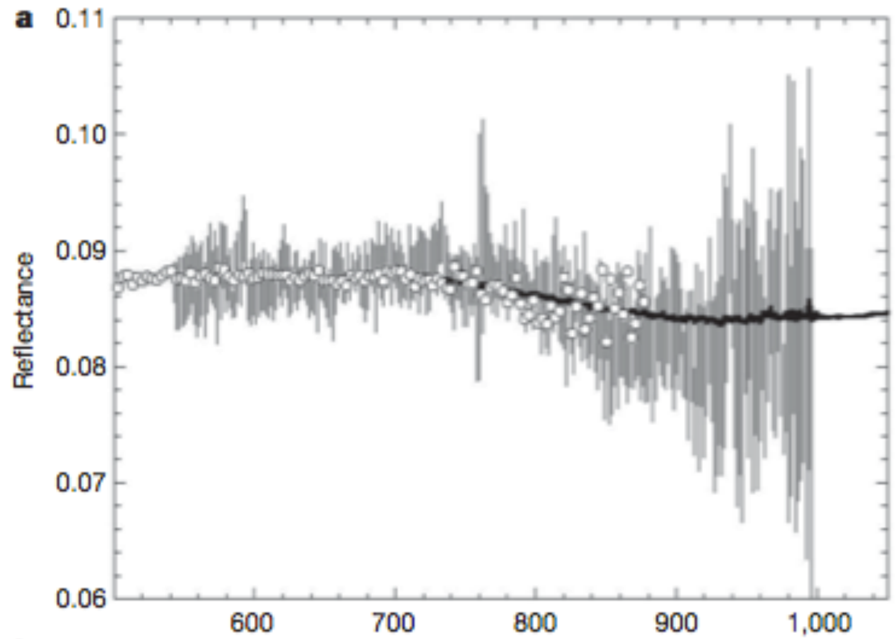


Discovered on October 6, 2008
(20 hrs before impact)
2-5 meter diameter
Image Credit: NASA JPL

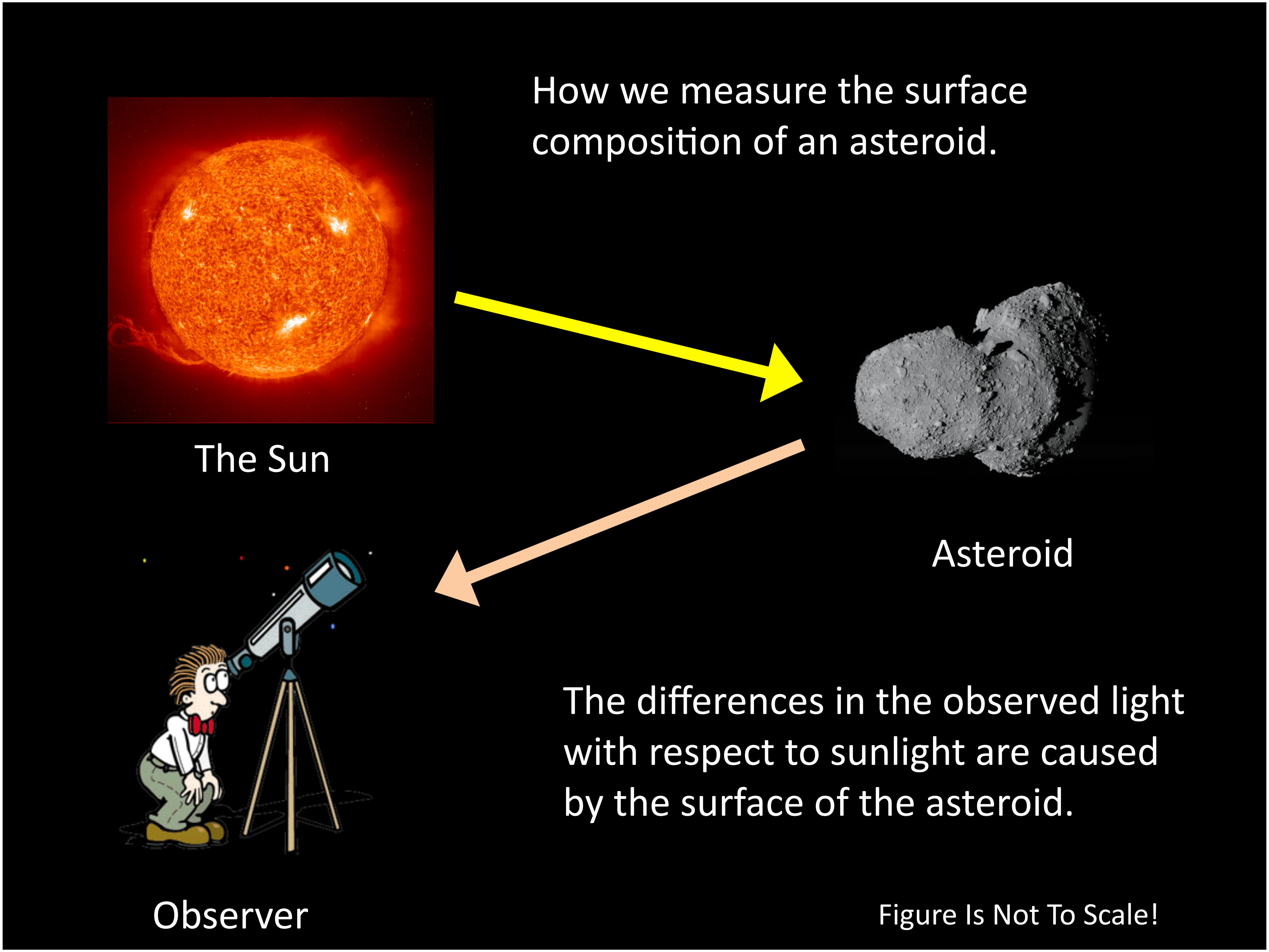
It enters the sky on October 7, 2008
creating a fireball
Image Credit: Mahir, Shaddad, Jenniskens

Catch a shooting star: 2008 TC3

Meteorites were recovered in the Nubian Desert in Sudan
Image Credit: Jenniskens



Comparison of the asteroid v. meteorite spectrum
Jenniskens et al. 2009


How we measure the surface composition of an asteroid.
The Sun
Asteroid
Observer
The differences in the observed light with respect to sunlight are caused by the surface of the asteroid.
Figure Is Not To Scale!

Reflected Light Depends On:

- Grain size
- Phase angle
- Temperature
- Composition
- Weathering

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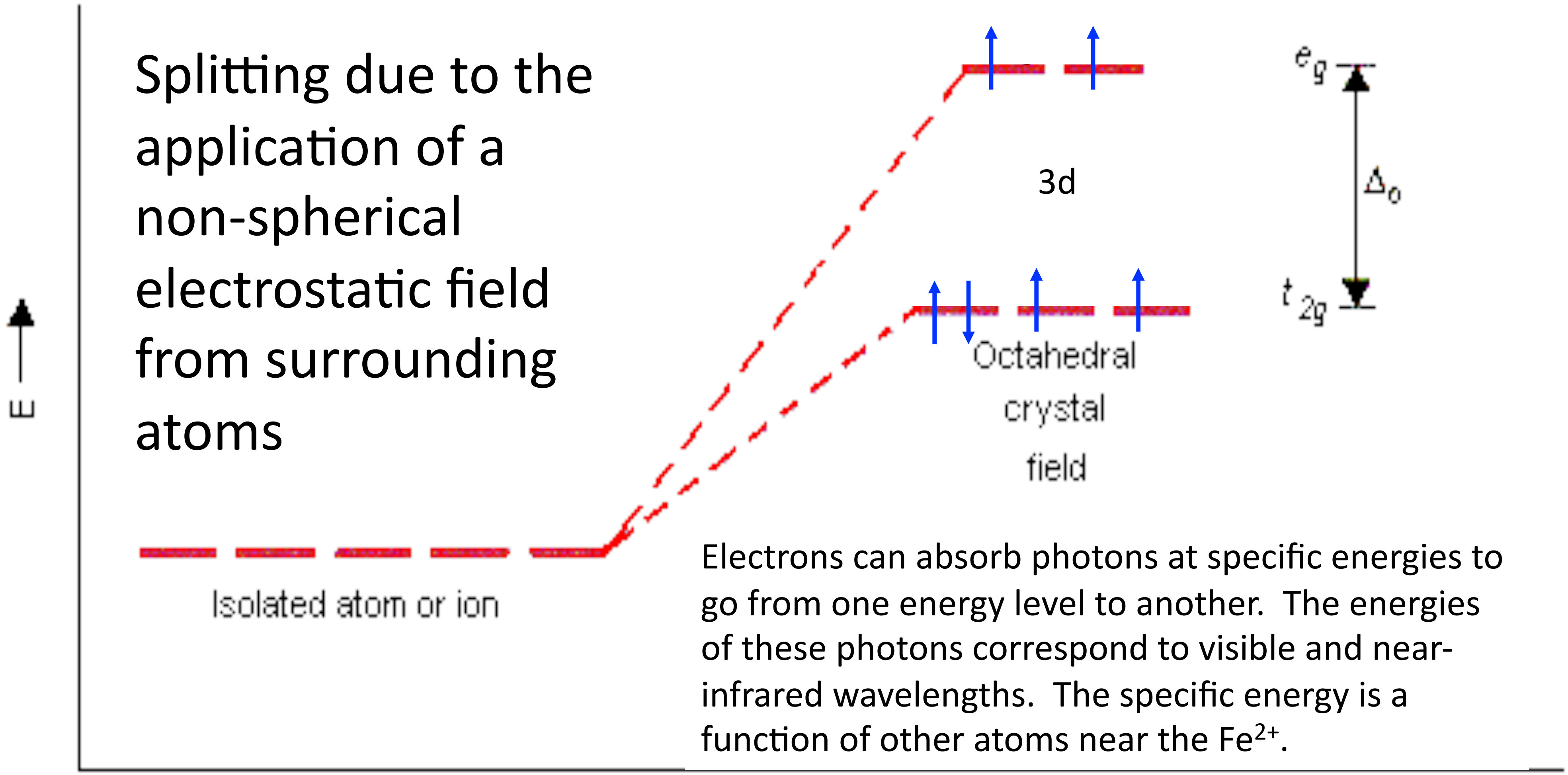
Absorption features due to the presence of Fe^{2+}

Splitting due to the application of a non-spherical electrostatic field from surrounding atoms

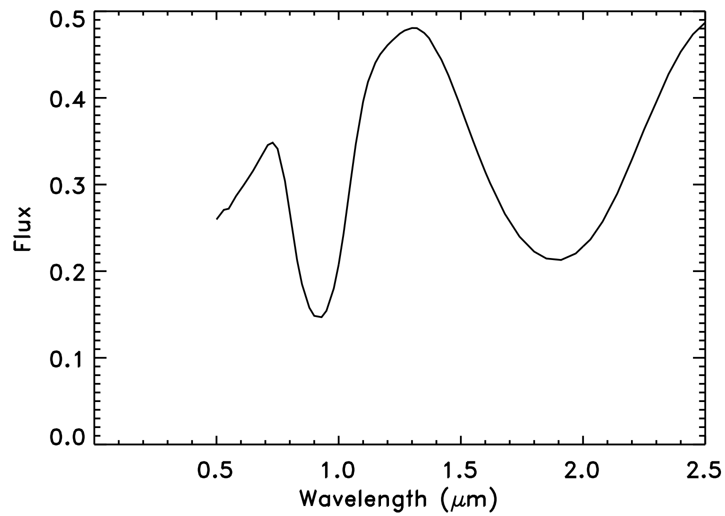


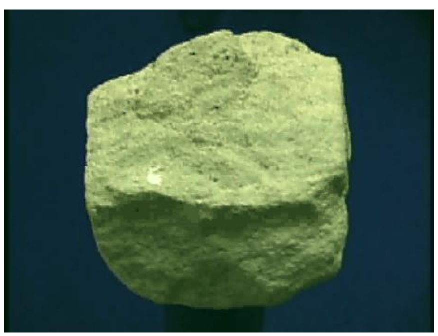
Electrons can absorb photons at specific energies to go from one energy level to another. The energies of these photons correspond to visible and near-infrared wavelengths. The specific energy is a function of other atoms near the Fe^{2+}.

Slide Credit: T. Burbine

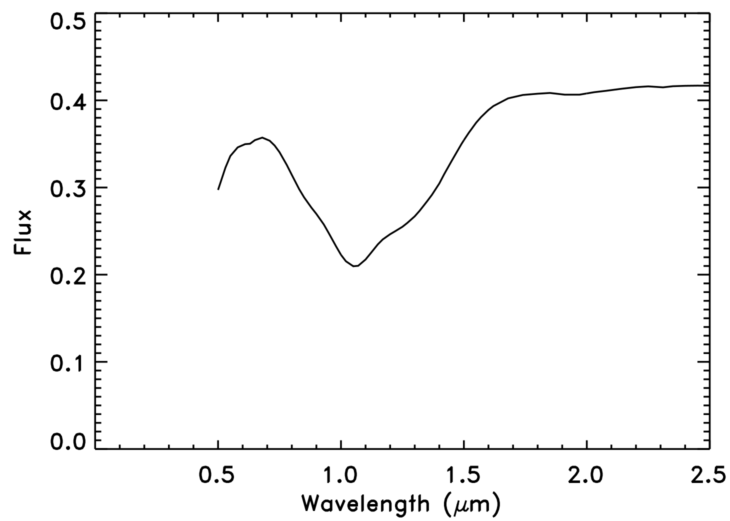
Mineral Absorption

Pyroxene
$(Mg,Fe)_2Si_2O_6$

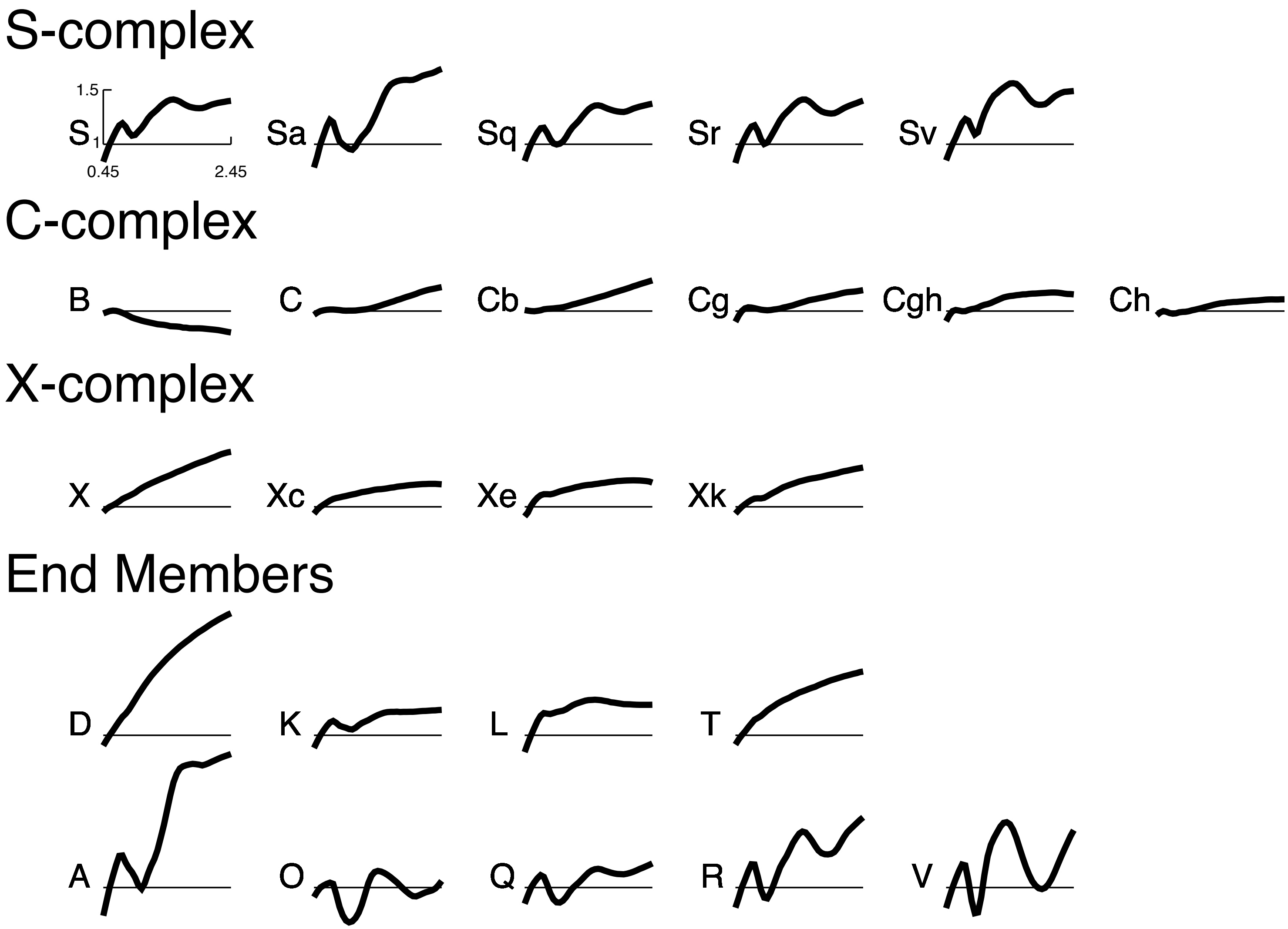




Olivine
$(Mg,Fe)_2SiO_4$



Bus-DeMeo Taxonomy Key



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

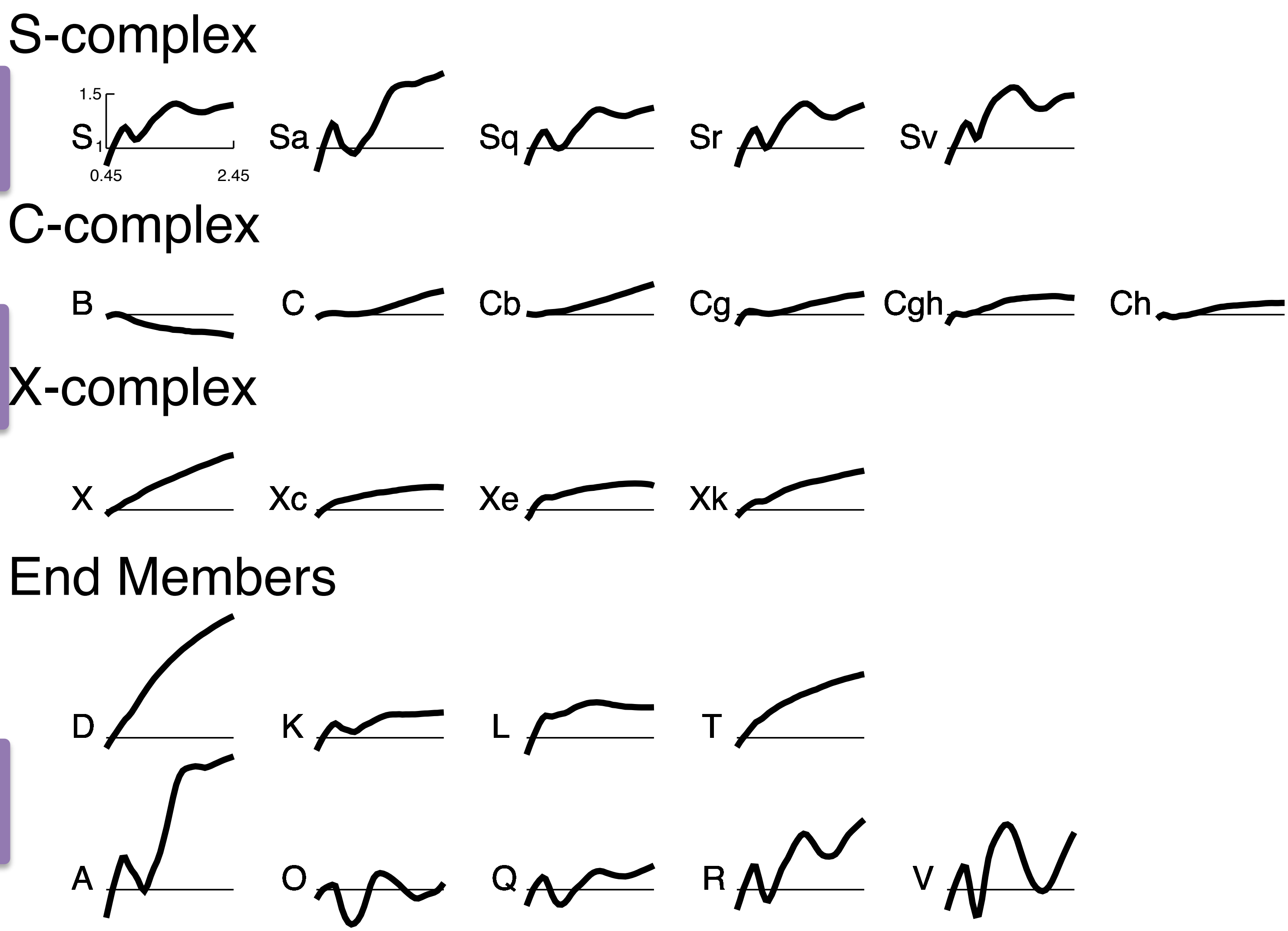
DeMeo et al. 2009

Bus-DeMeo Taxonomy Key

Silicates

Carbonaceous

Unique



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DeMeo et al. 2009

Reflected Light Depends On:

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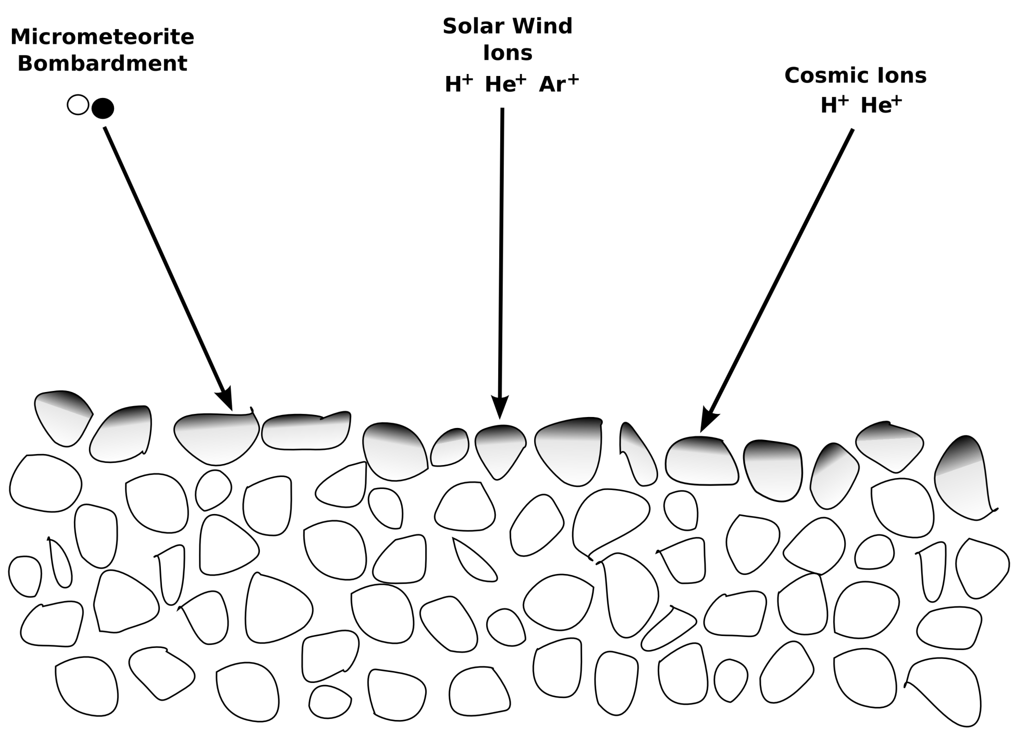
Space Weathering



Surfaces of asteroids are constantly bombarded by high energy particles which chemically alter the top few microns of the surface.

Space Weathering

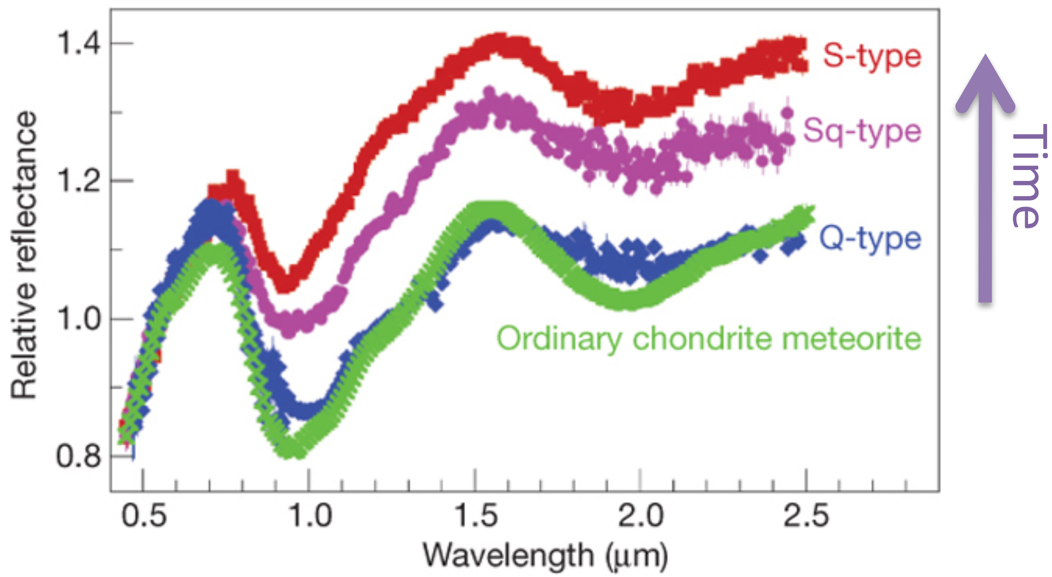


Fig from Binzel et al. 2010

Space weathering reddens the spectrum over ~1 million years.

Space Weathering

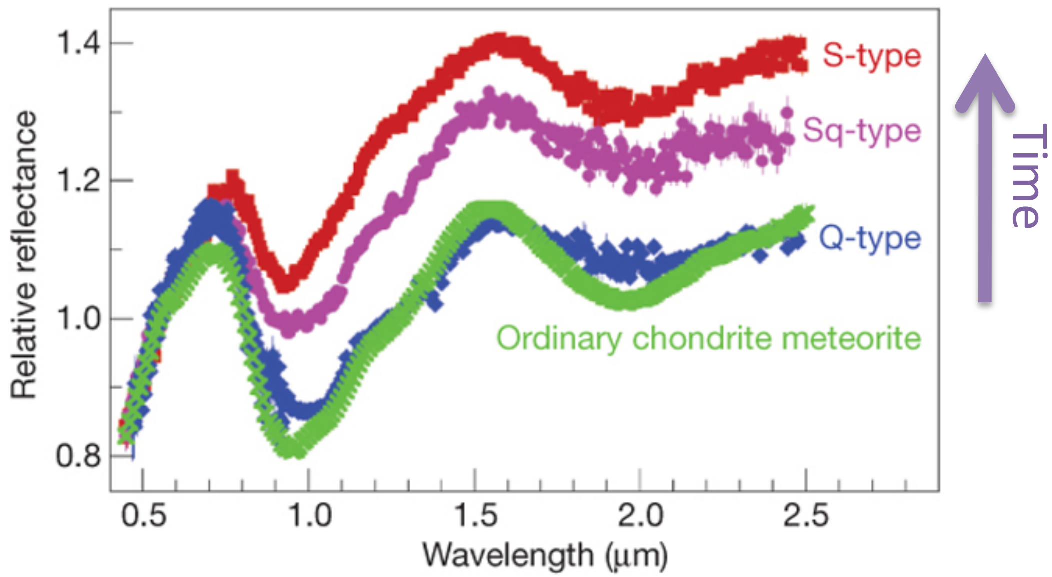


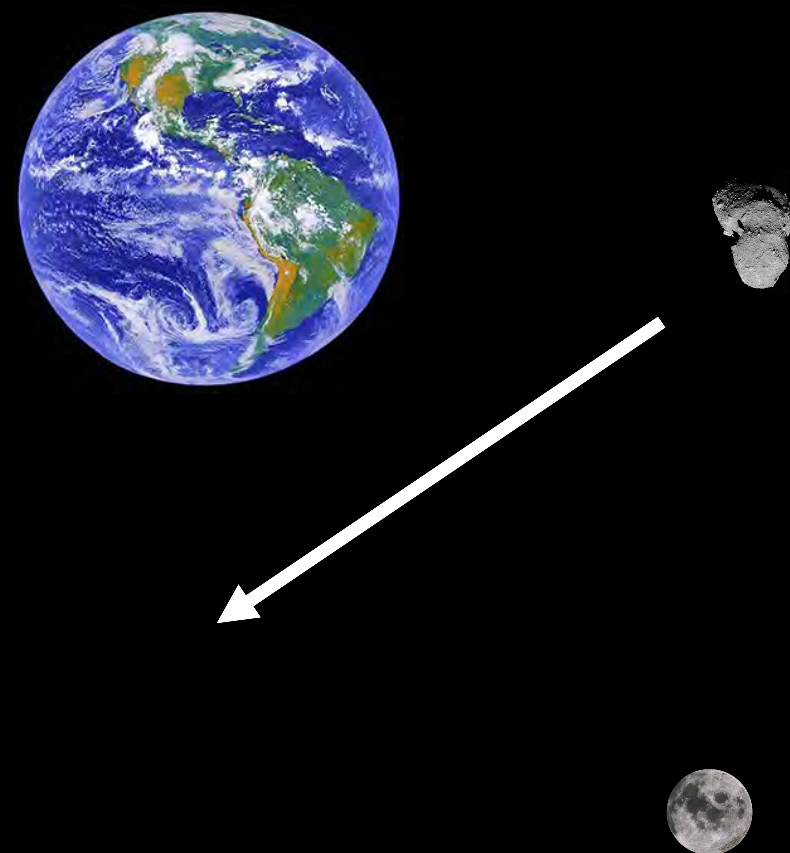
Fig from Binzel et al. 2010

Space weathering reddens the spectrum over ~1 million years.

How can a weathered surface become fresh again?

How to freshen a surface

- Planetary Encounters
- Collisions
- YORP Spin-up
- Resonances
- Magnetic Field



Tidal forces from close approach
cause seismic shaking

How to freshen a surface

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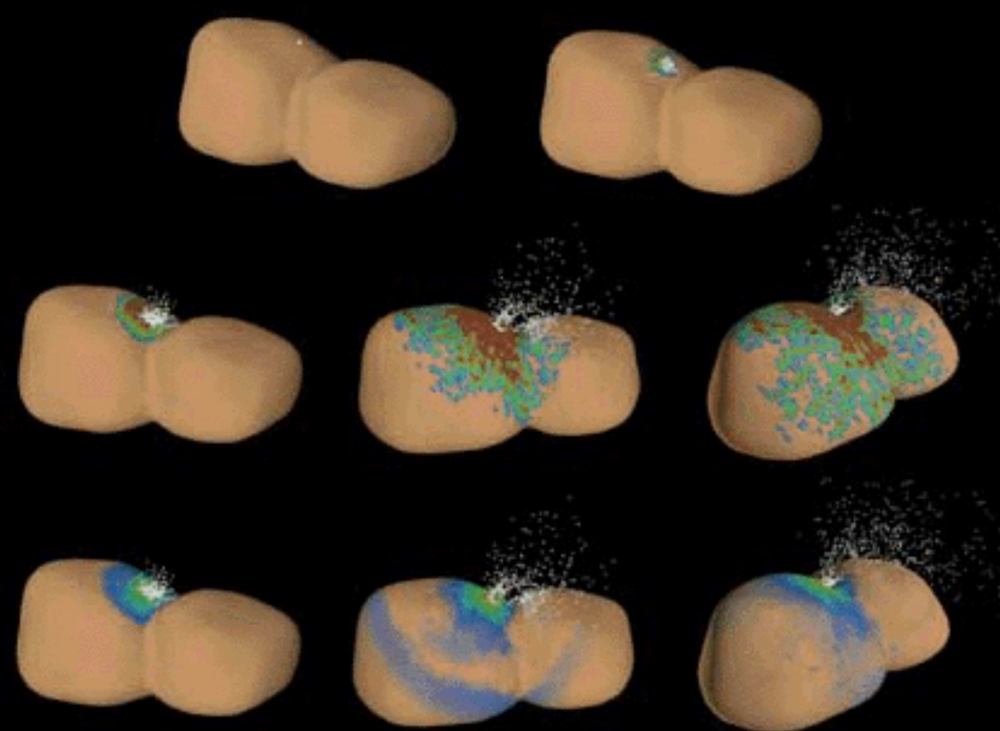

Image: UCSC/E. Asphaug

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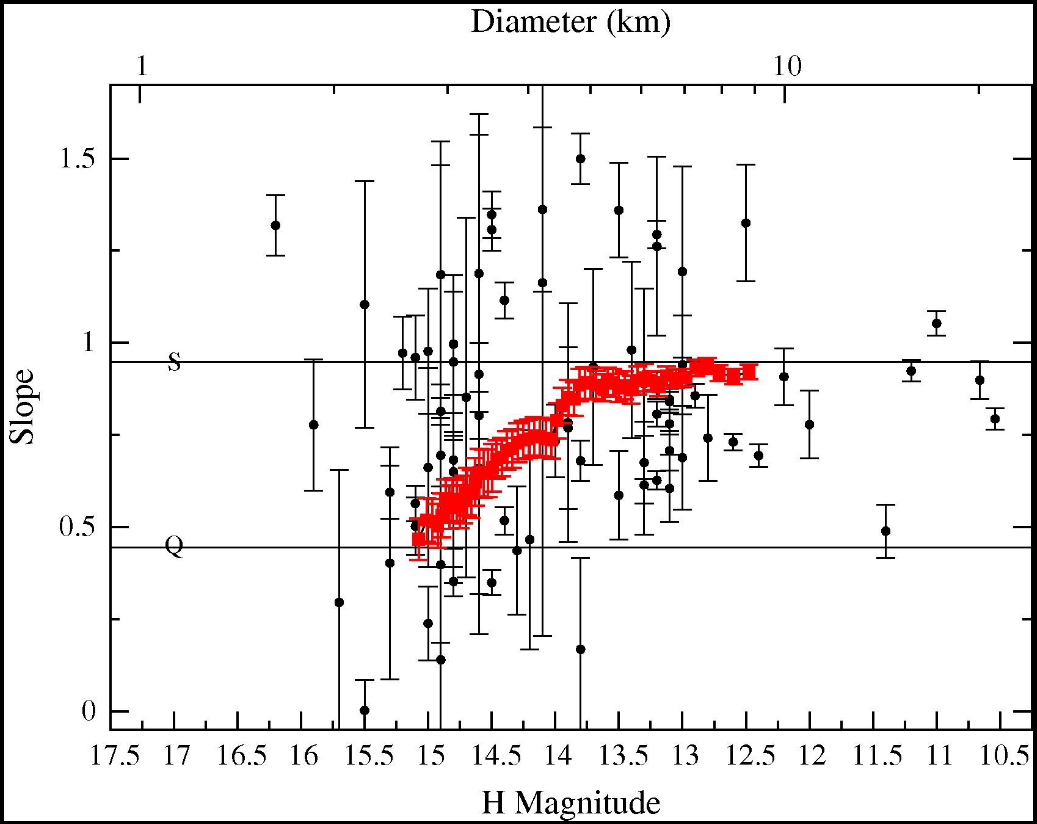

Thomas et al. 2011

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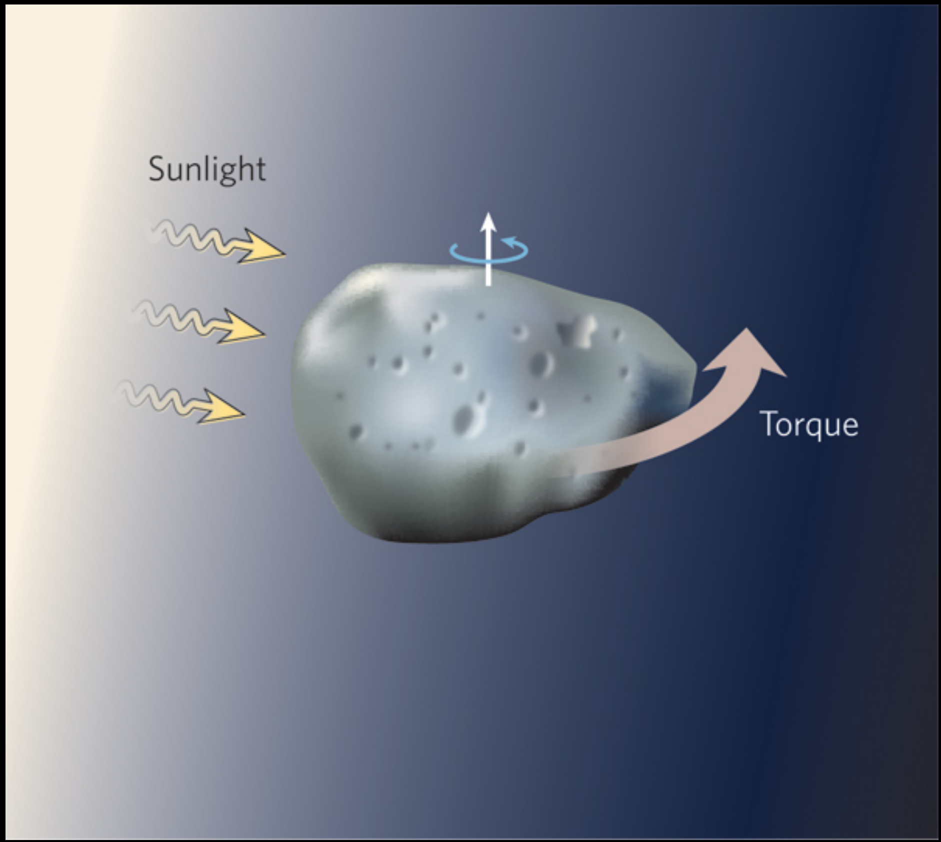

Bottke 2007

How to freshen a surface

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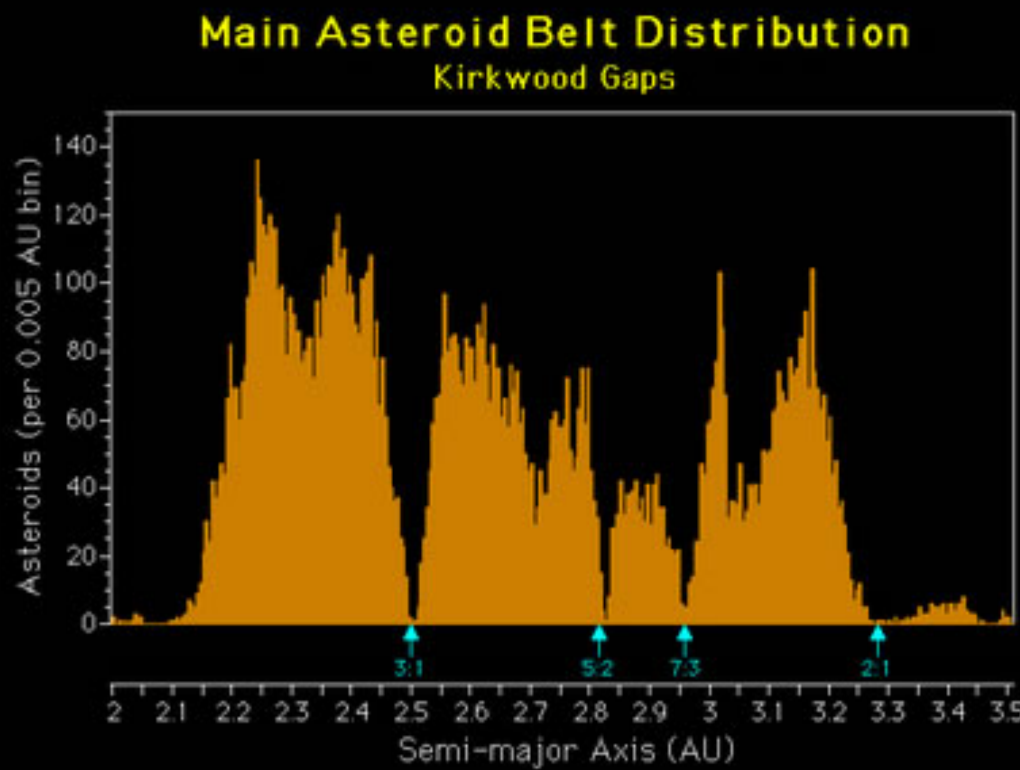

Credit: NASA

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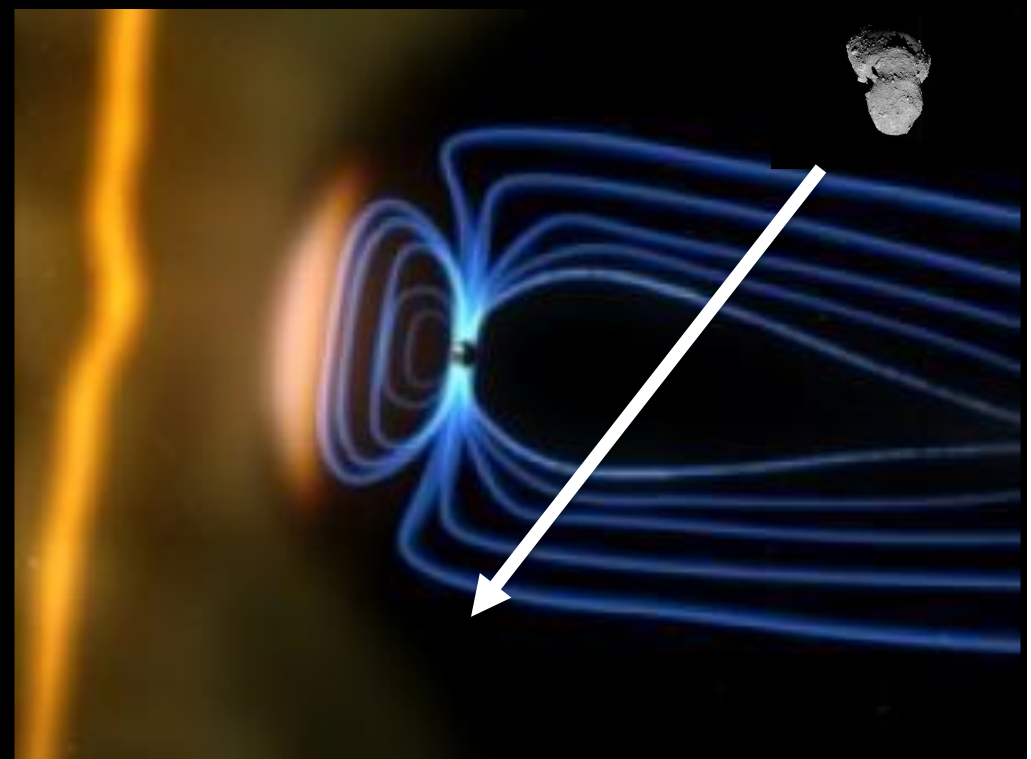

Electrostatic levitation of surface particles when passing through Earth's magnetic field

Magnetosphere Image: NASA

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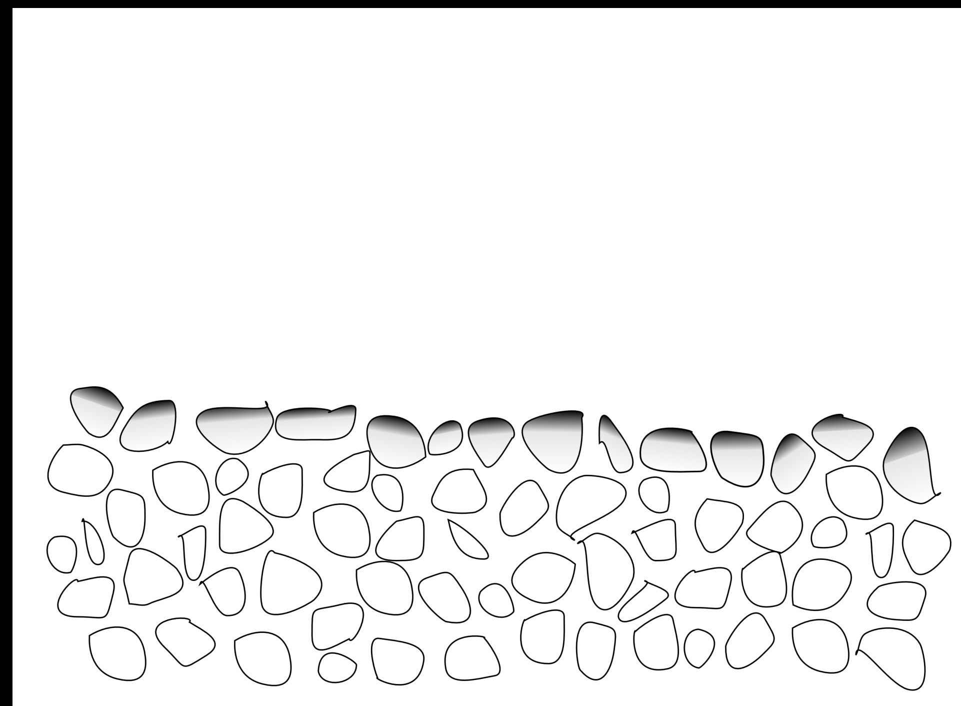

Electrostatic levitation of surface particles when passing through Earth's magnetic field

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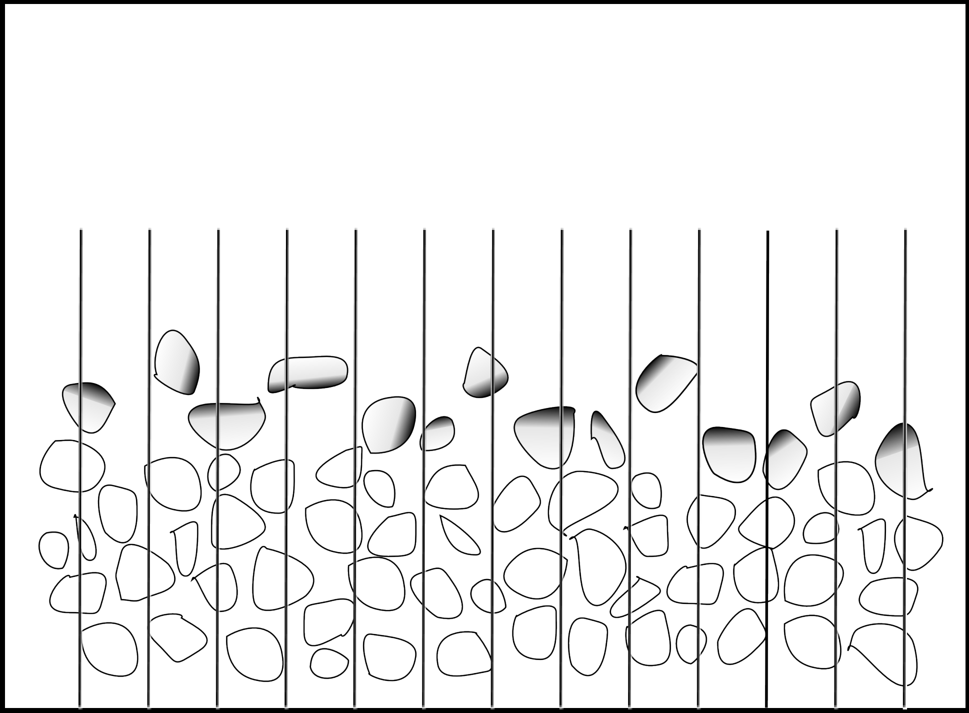
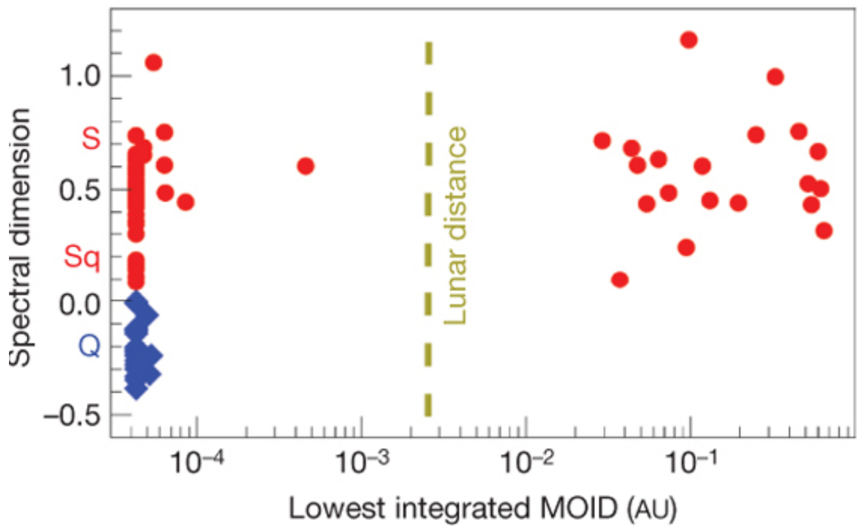
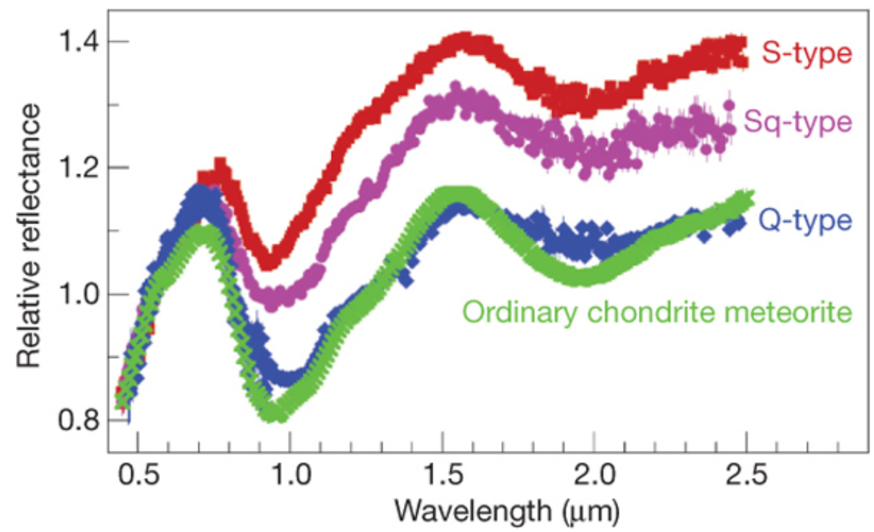
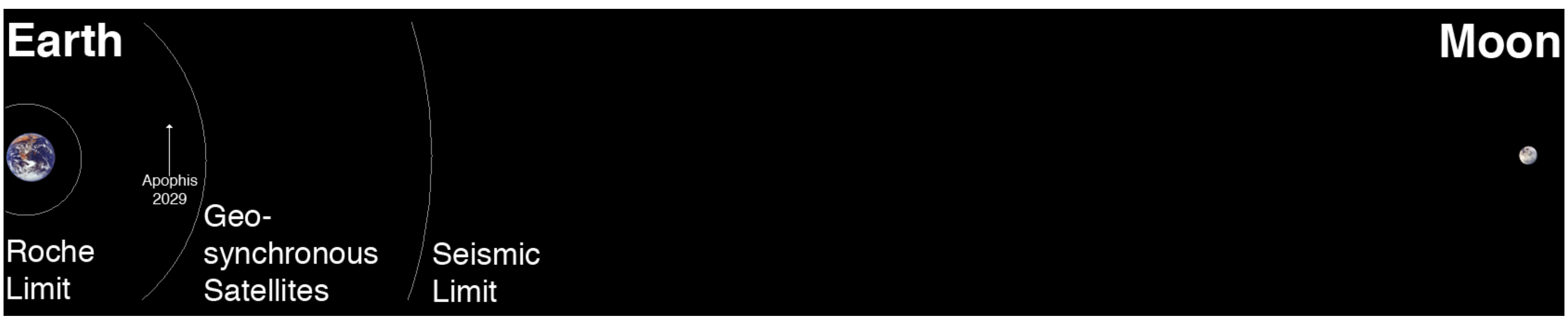


Electrostatic levitation of surface particles when passing through Earth's magnetic field

Q-types experienced close encounters with Earth



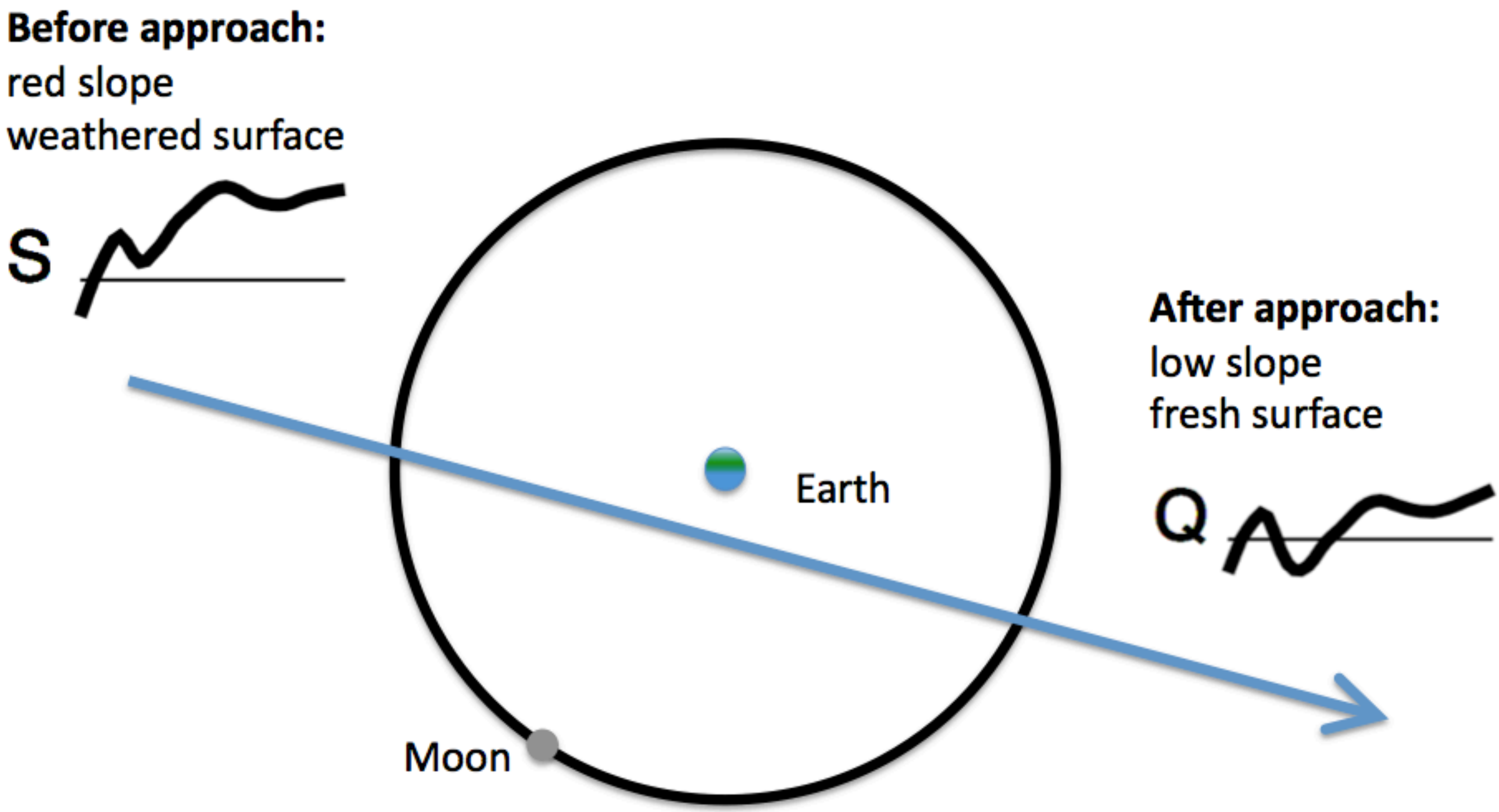




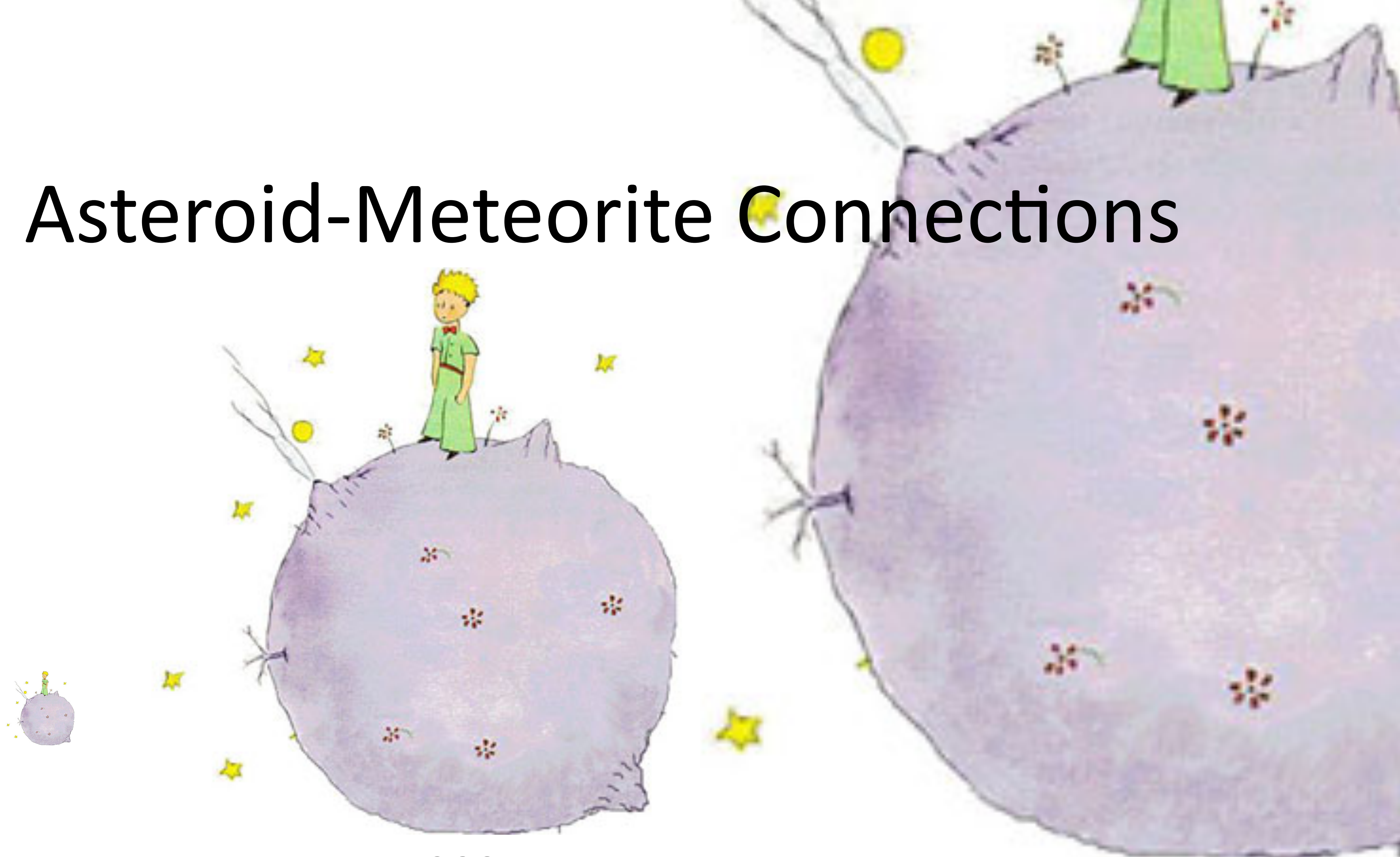
Seismic Limit:
16 Earth Radii

Binzel et al. 2010

Goal: Observe Spectral Change



Asteroid-Meteorite Connections



Fortunately, these very rarely pass within the seismic limit.

Asteroid-Meteorite Connections

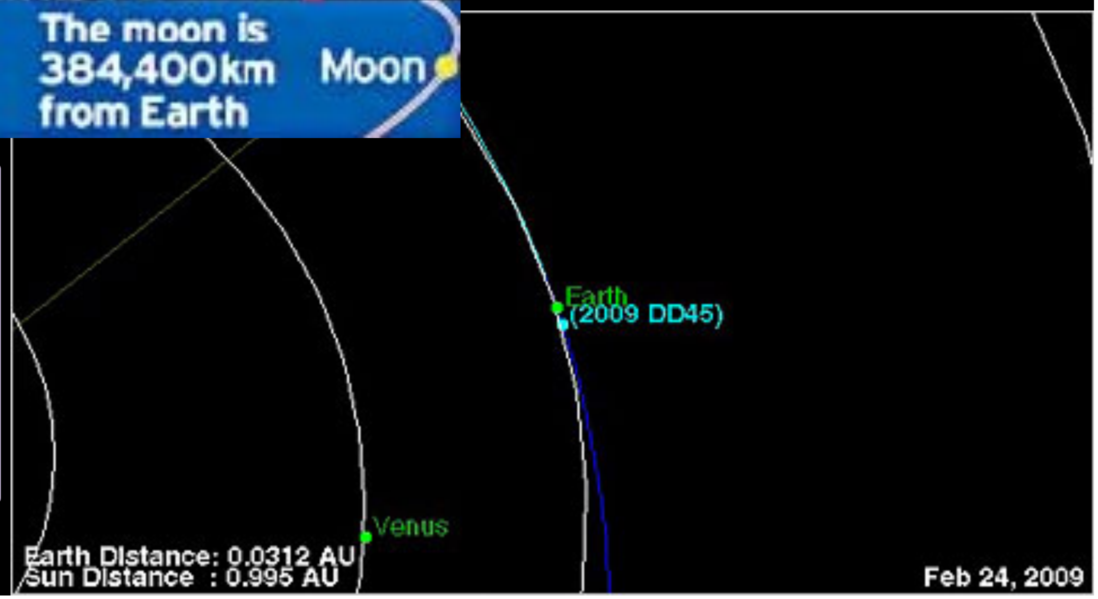
20 m

Can only observe when they pass close to Earth.

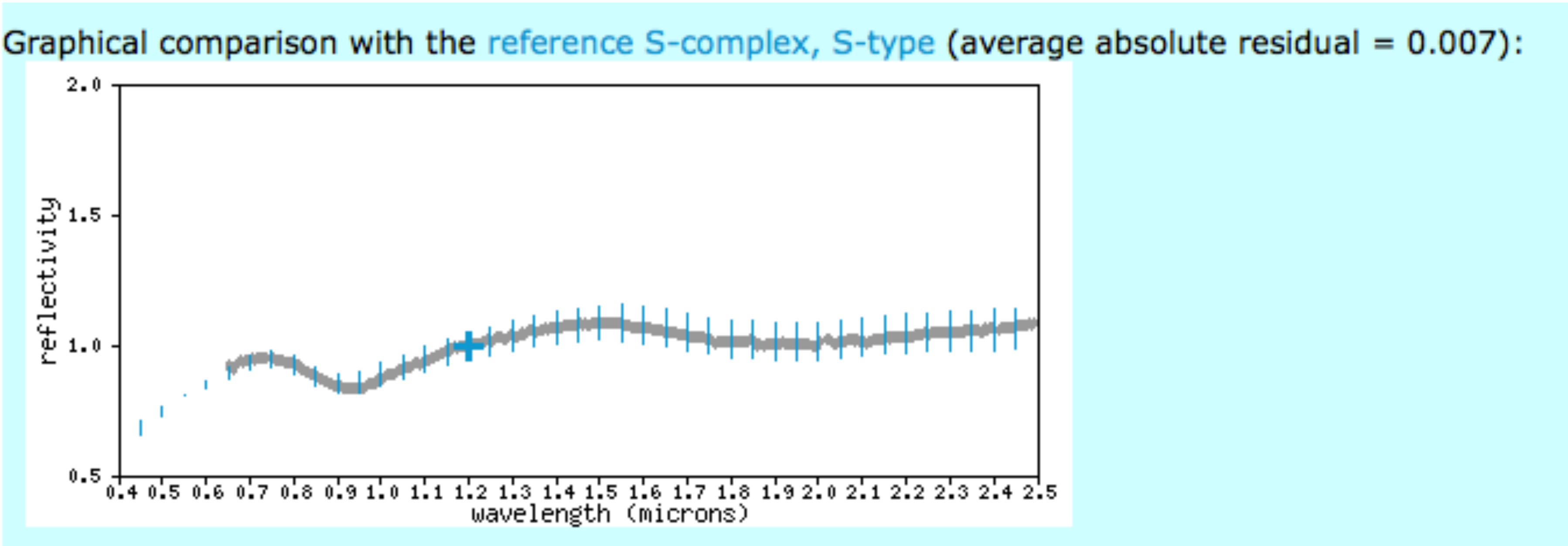
Observing Close Encounters

Figure left: The Sidney Morning Herald
Figure below: NASA

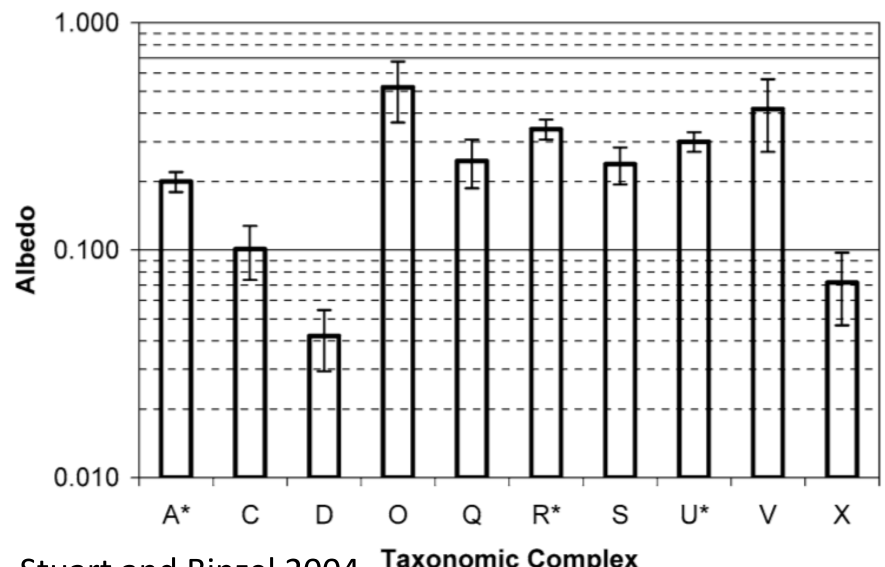
Observed: March 2, 2009
Closest Dist: 61,000 km (0.000482 AU)
Speed: 26”/sec
Brightness change: 7 magnitude increase in 1.5 days



2009 DD45



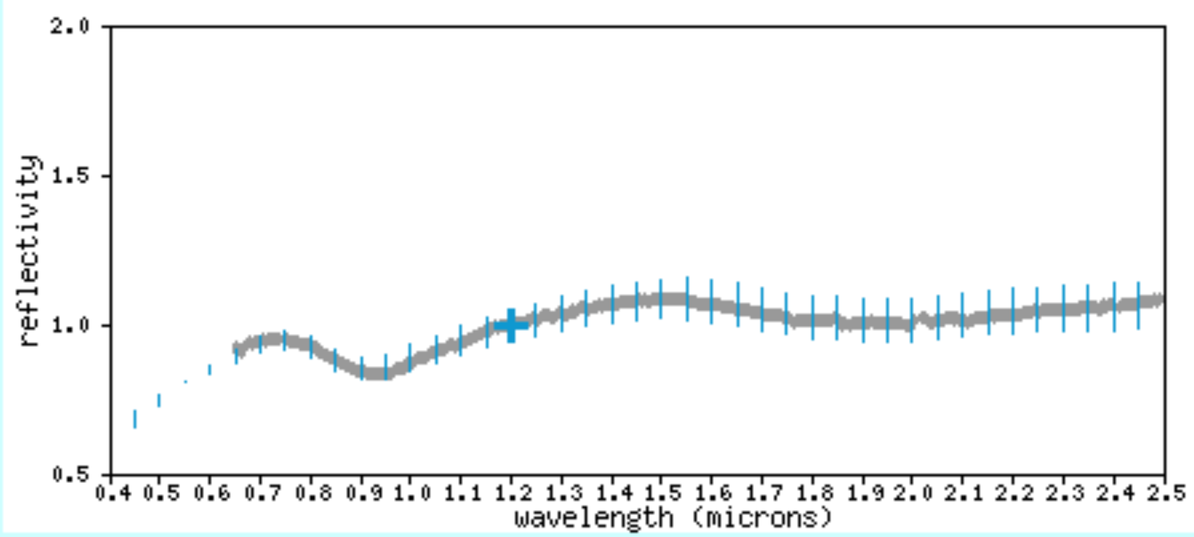
- Classified as S-type
- Est. albedo: 0.36
- Est. size: 19 ± 4 meters



Stuart and Binzel 2004

2009 DD45

Graphical comparison with the reference S-complex, S-type (average absolute residual = 0.007):



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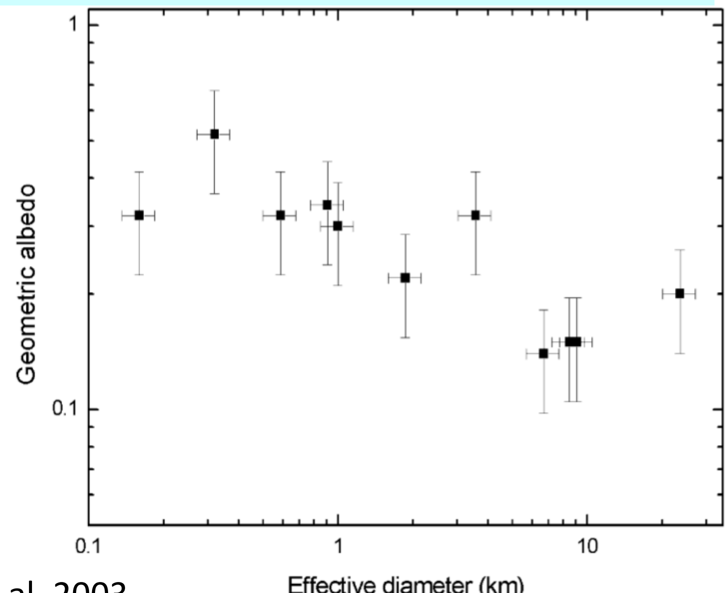
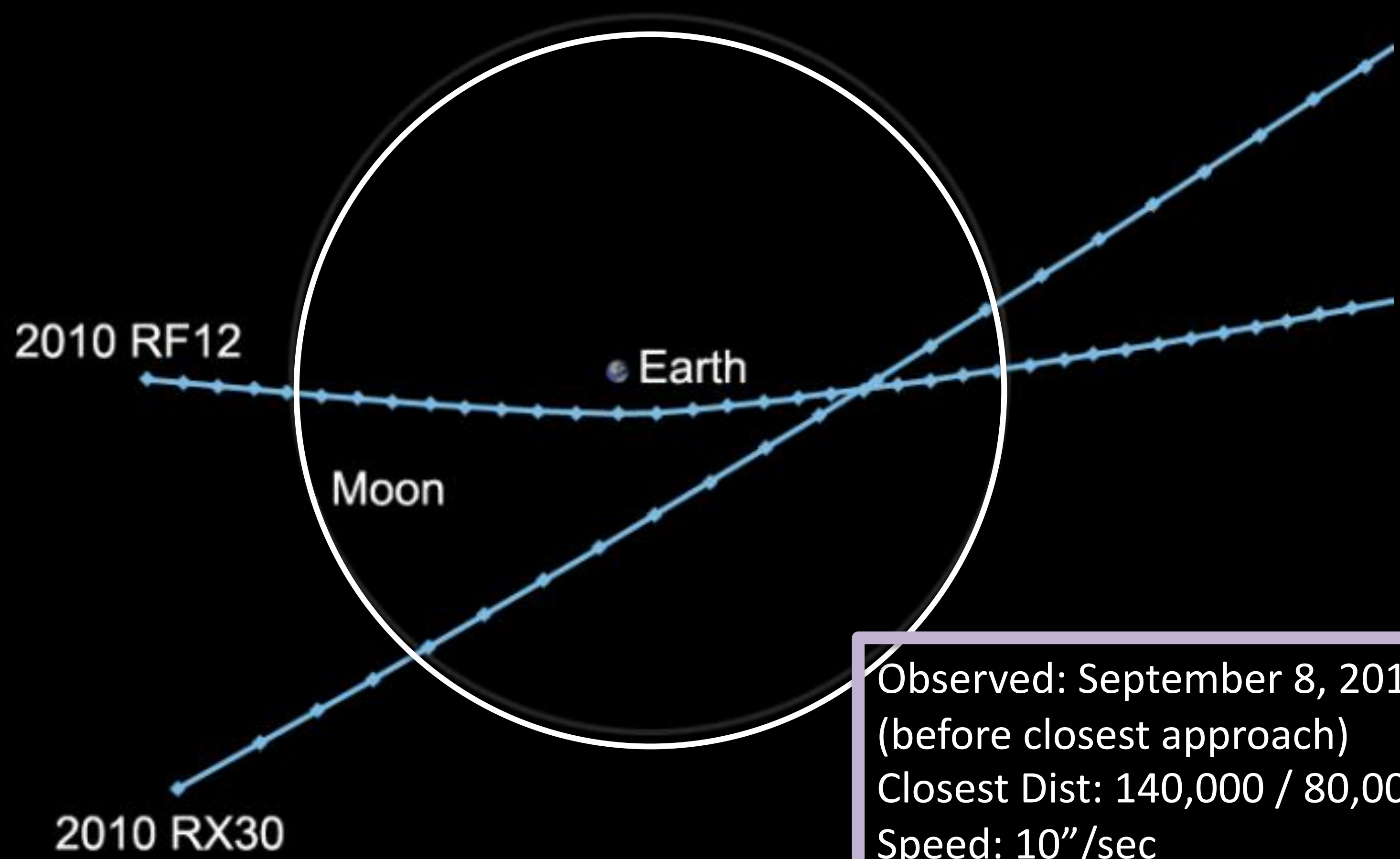


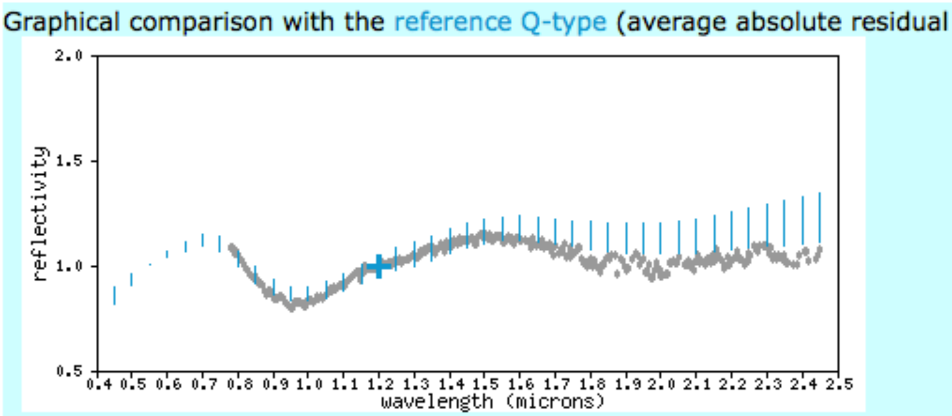
Delbo et al. 2003

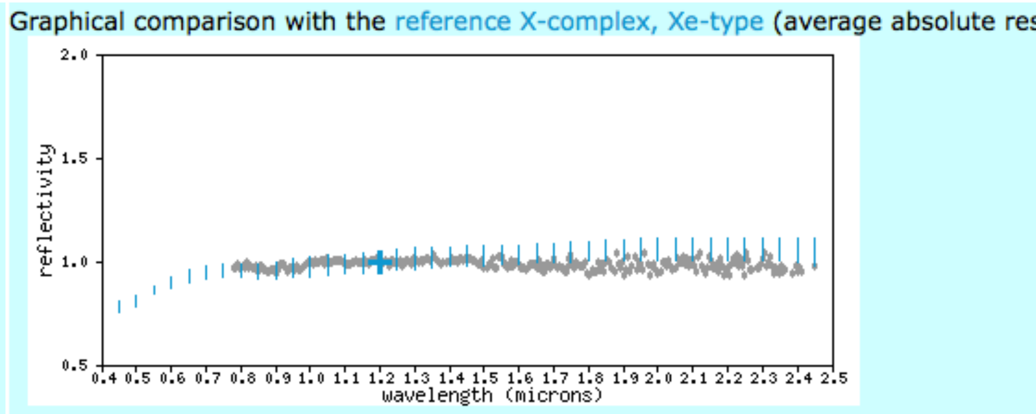
2010 RF12 and 2010 RX30



Observed: September 8, 2010
(before closest approach)
Closest Dist: 140,000 / 80,000 km
Speed: 10”/sec
Brightness change: 2 magnitude
increase in 1.5 days

2010 RF12 and 2010 RX30

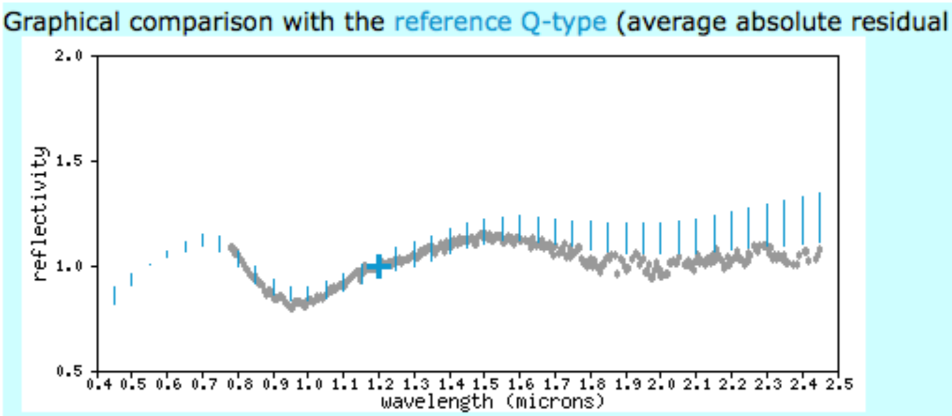


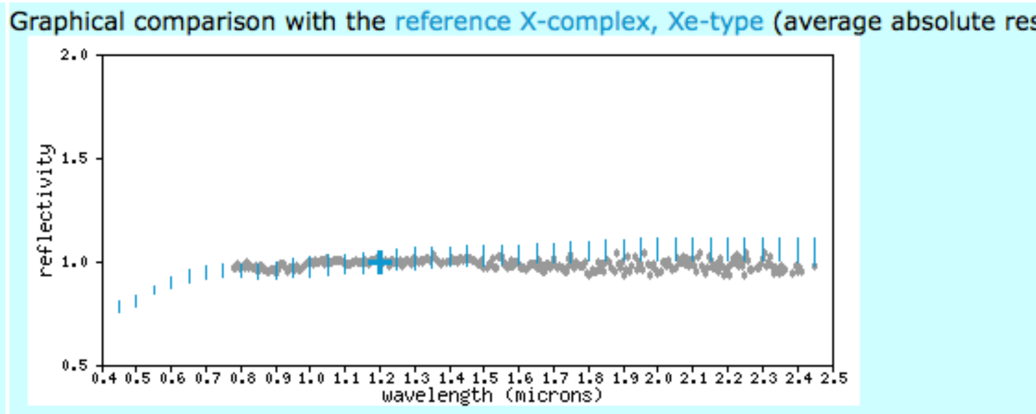


- Classified as Q-type
- Est. albedo: 0.30
- Est. size: 9 ± 2 meters

- Classified as X-complex
- Est. albedo: 0.25 ± 0.1
- Est. size: 6 ± 2 meters

2010 RF12 and 2010 RX30





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Already experienced a close encounter?

- Classified as X-complex
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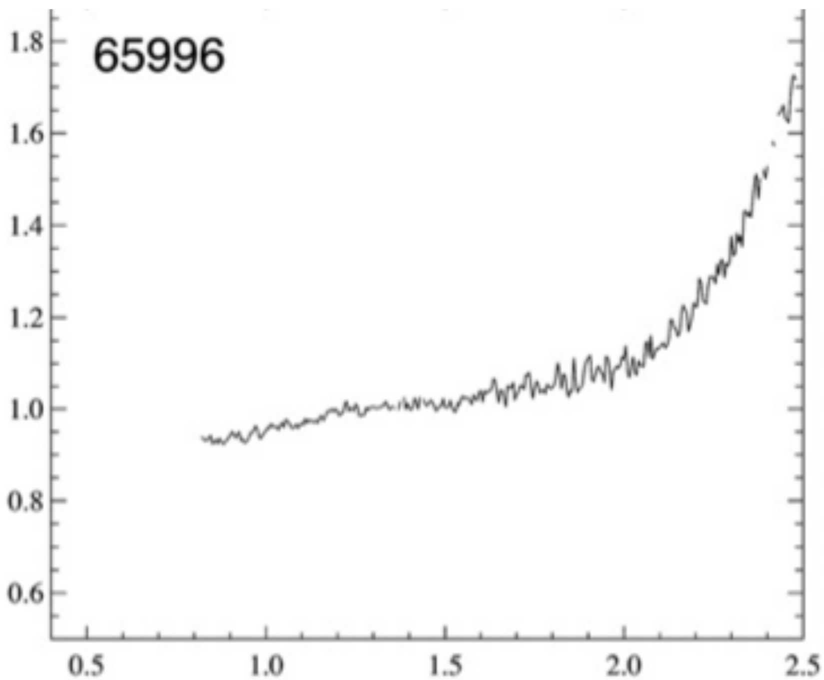
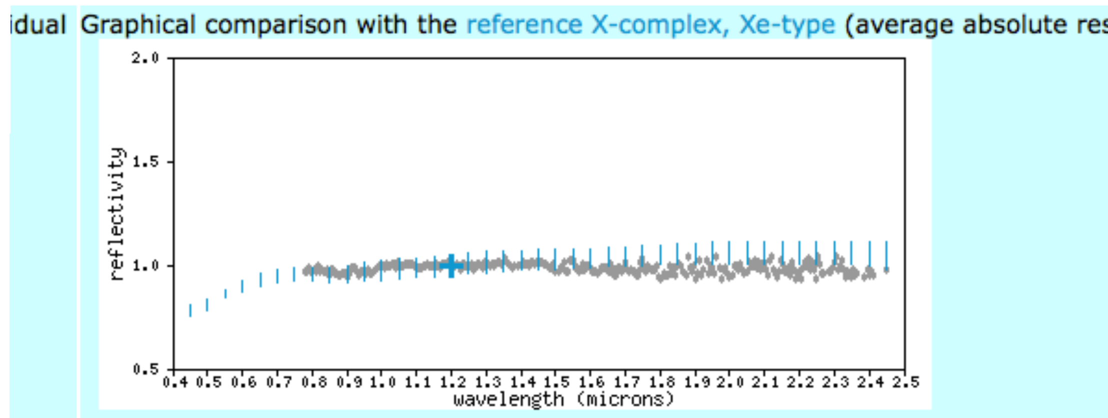
- Est. size: 6 ± 2 meters

2010 RF12 and 2010 RX30



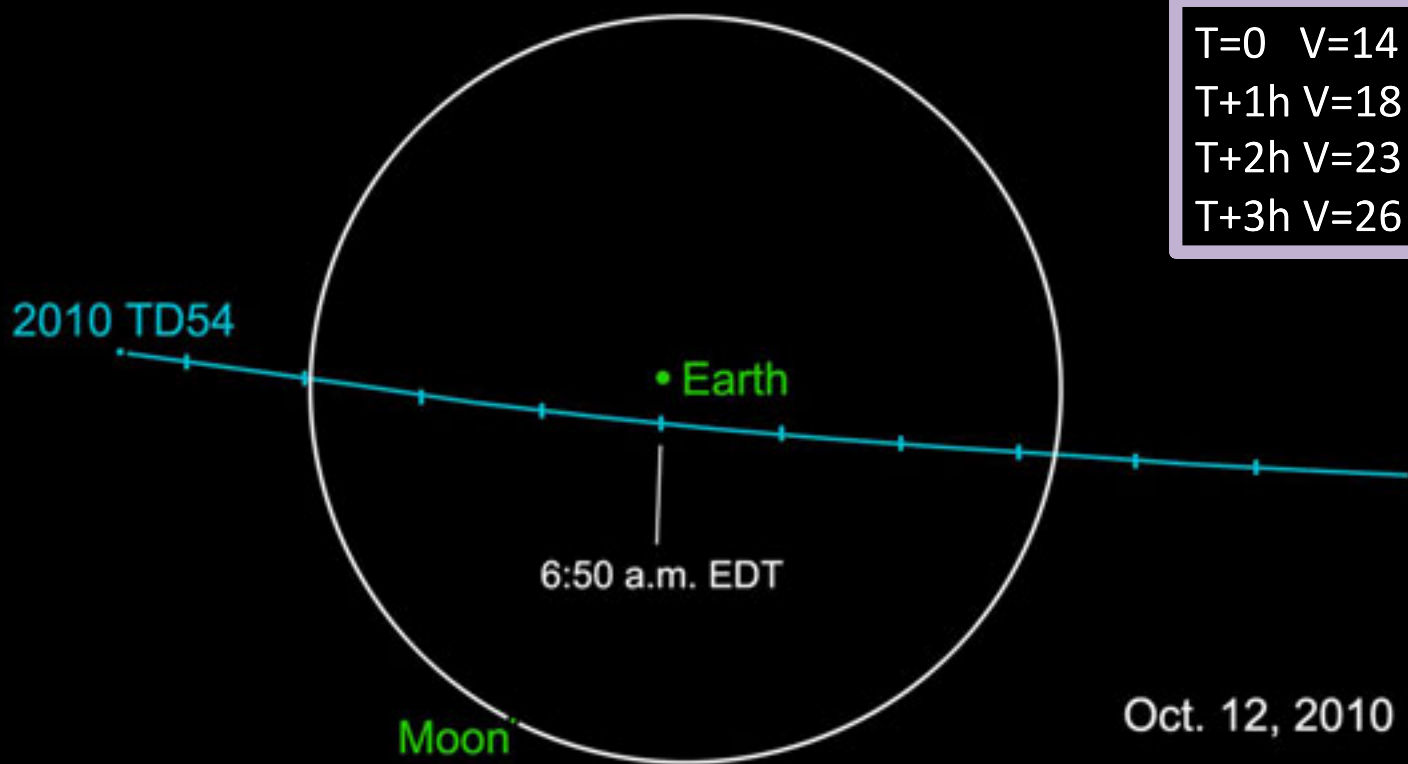
Example of a thermal tail of a low albedo object from DeMeo and Binzel 2008



- Classified as X-complex
- Est. albedo: 0.25 ± 0.1
- Est. size: 6 ± 2 meters

Albedo constrained by lack of thermal tail

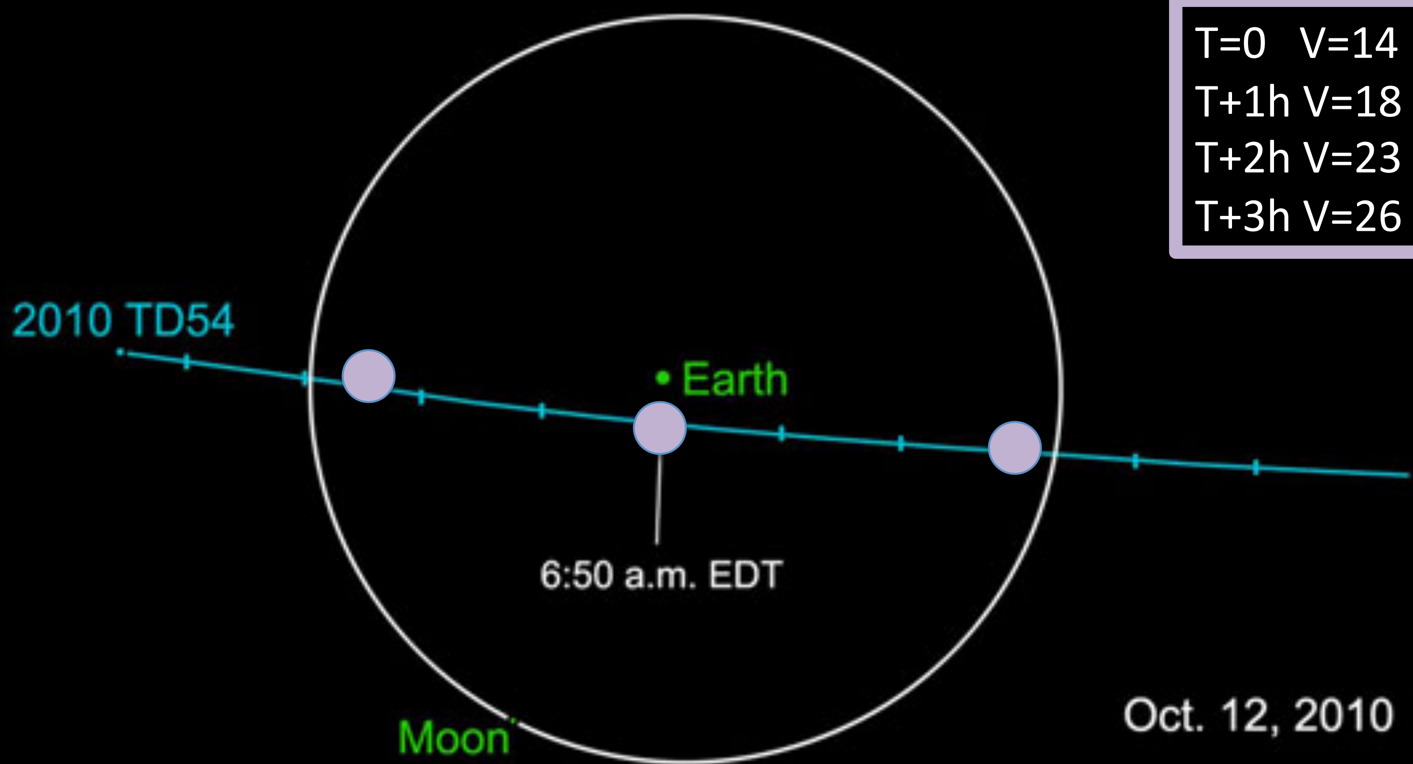
2010 TD5



T=0 V=14
T+1h V=18
T+2h V=23
T+3h V=26

Max Motion > 60”/sec!!

2010 TD5



T=0 V=14
T+1h V=18
T+2h V=23
T+3h V=26

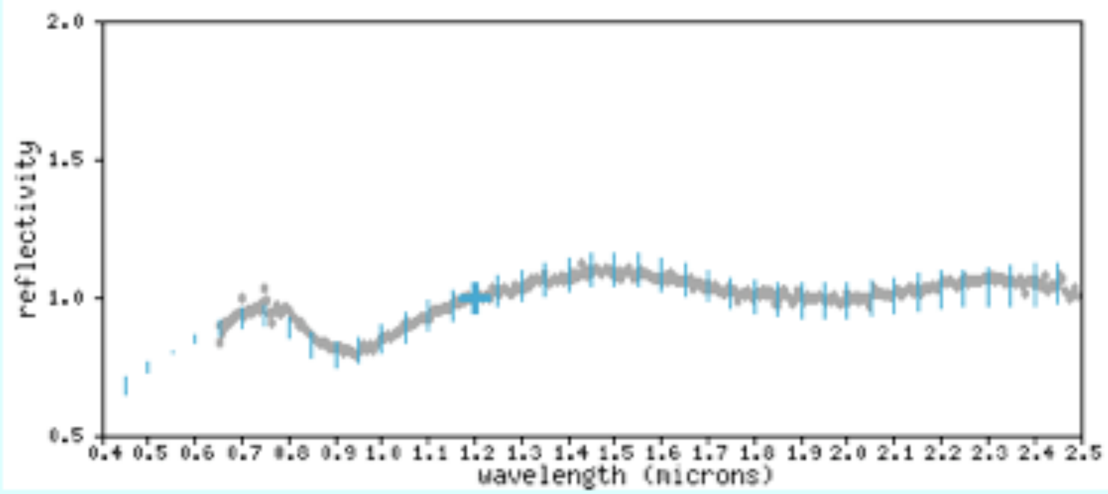
Max Motion > 60”/sec!!

2010 TD54 Timeline

- T-72 hours: Discovery by Catalina.
- T-56 hours: Tim Spahr notifies our team of possibility.
- T-40 hours: Minor Planet Electronic Circular issued.
- T-38 hours: Interrupt on IRTF requested.
- T-32 hours: Arrangements completed and approved.
- T-7 hours: Observations begin at IRTF.
- T=0: Closest approach.

2010 TD54

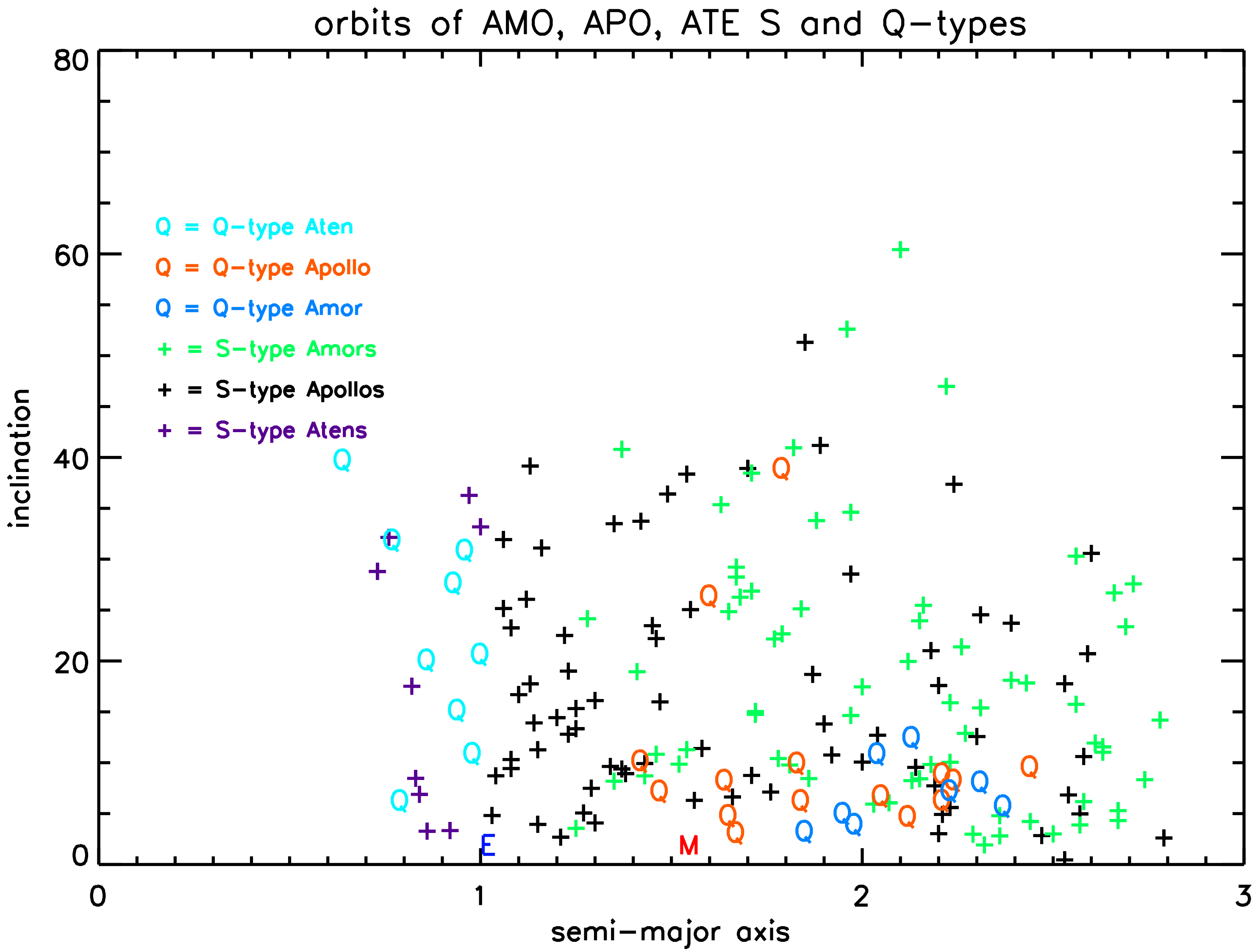
Graphical comparison with the reference S-complex, Sr-type (average absolute residual = 0.009):



- Closest Distance: 45,000 km
- Classified as: S- complex
- Est. albedo: 0.25
- Est. size: 5 ± 2 m

Object was moving too fast at and just after closest approach to record spectrum.

What are the Q-type orbits?



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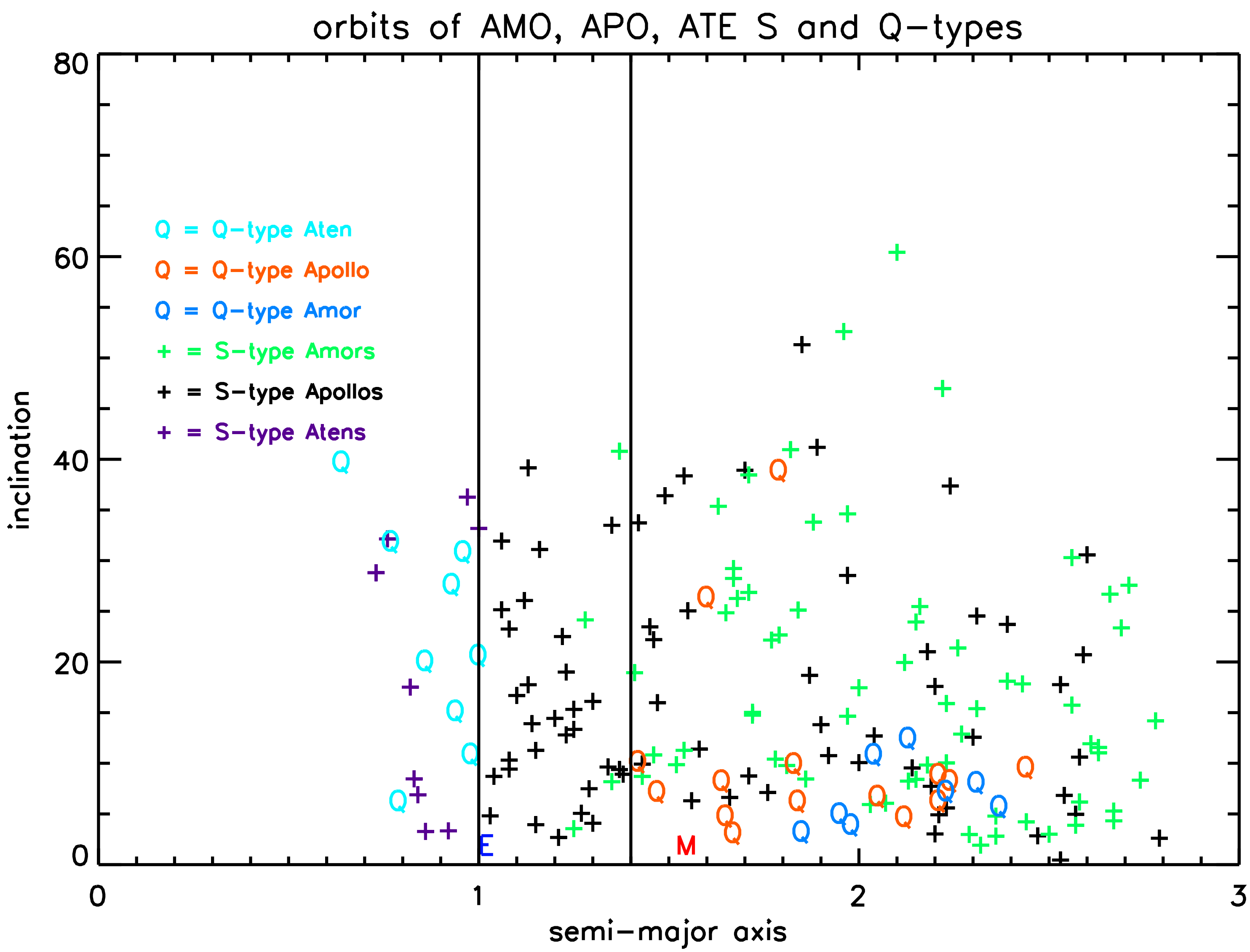

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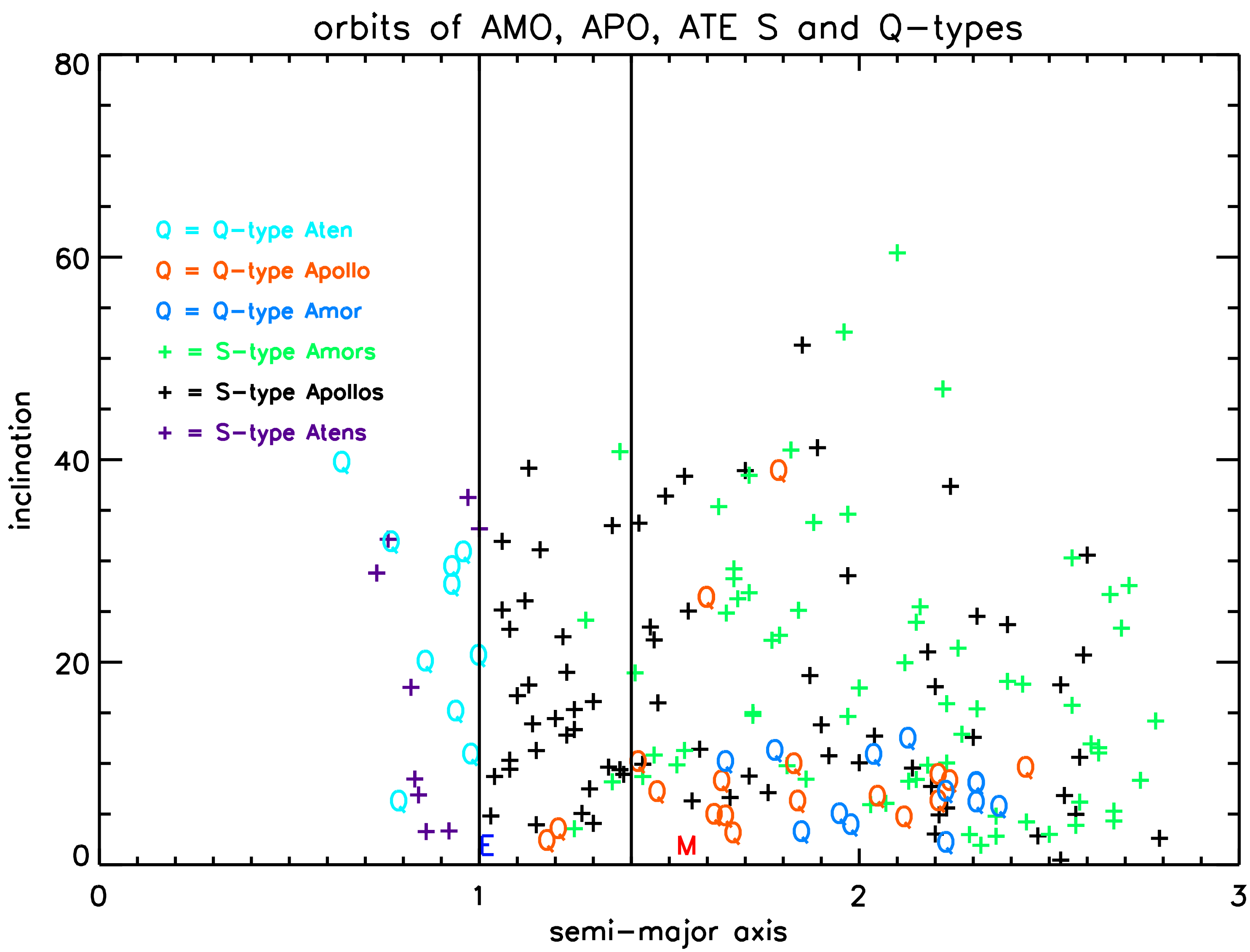
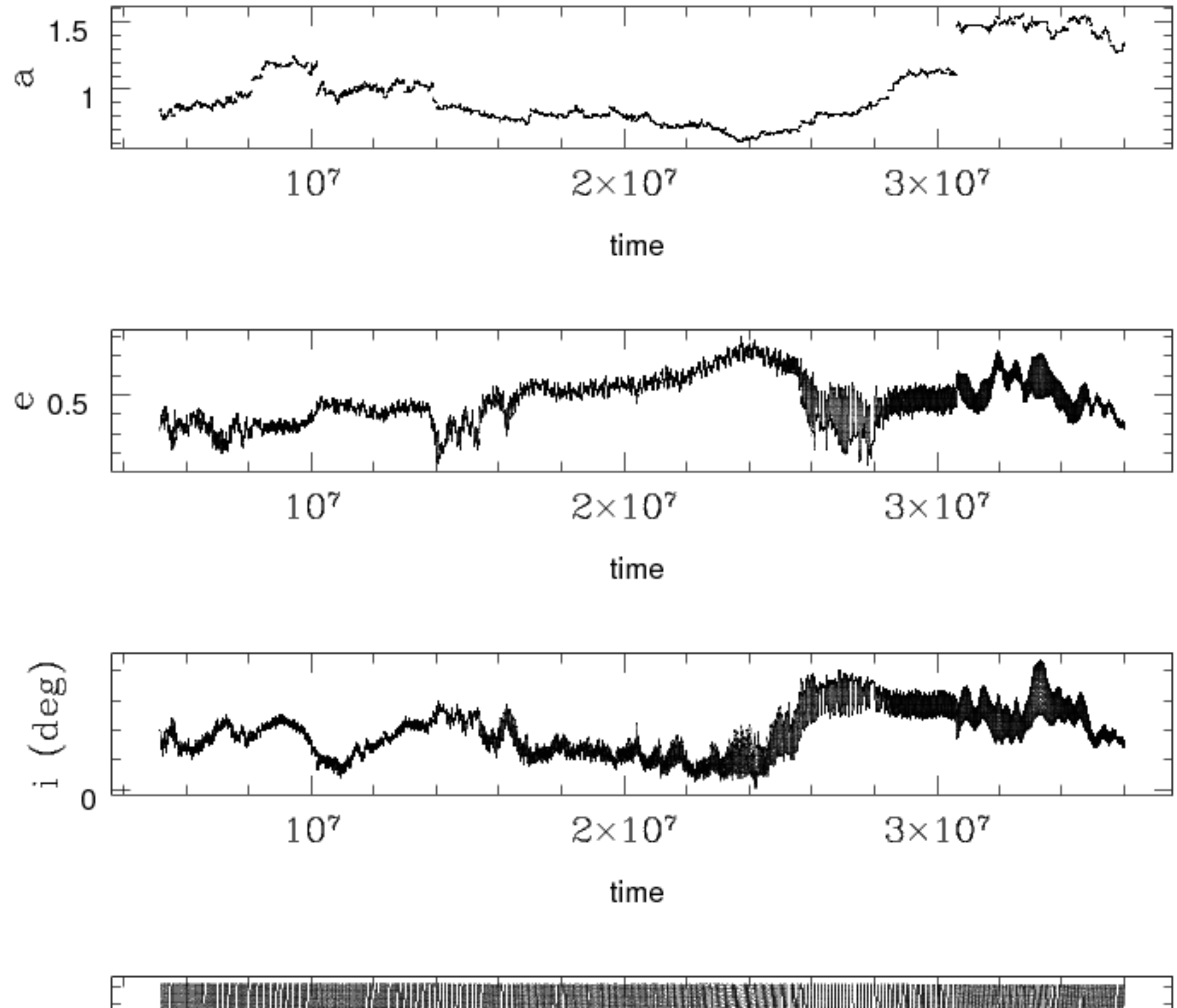


Orbital change after encounter



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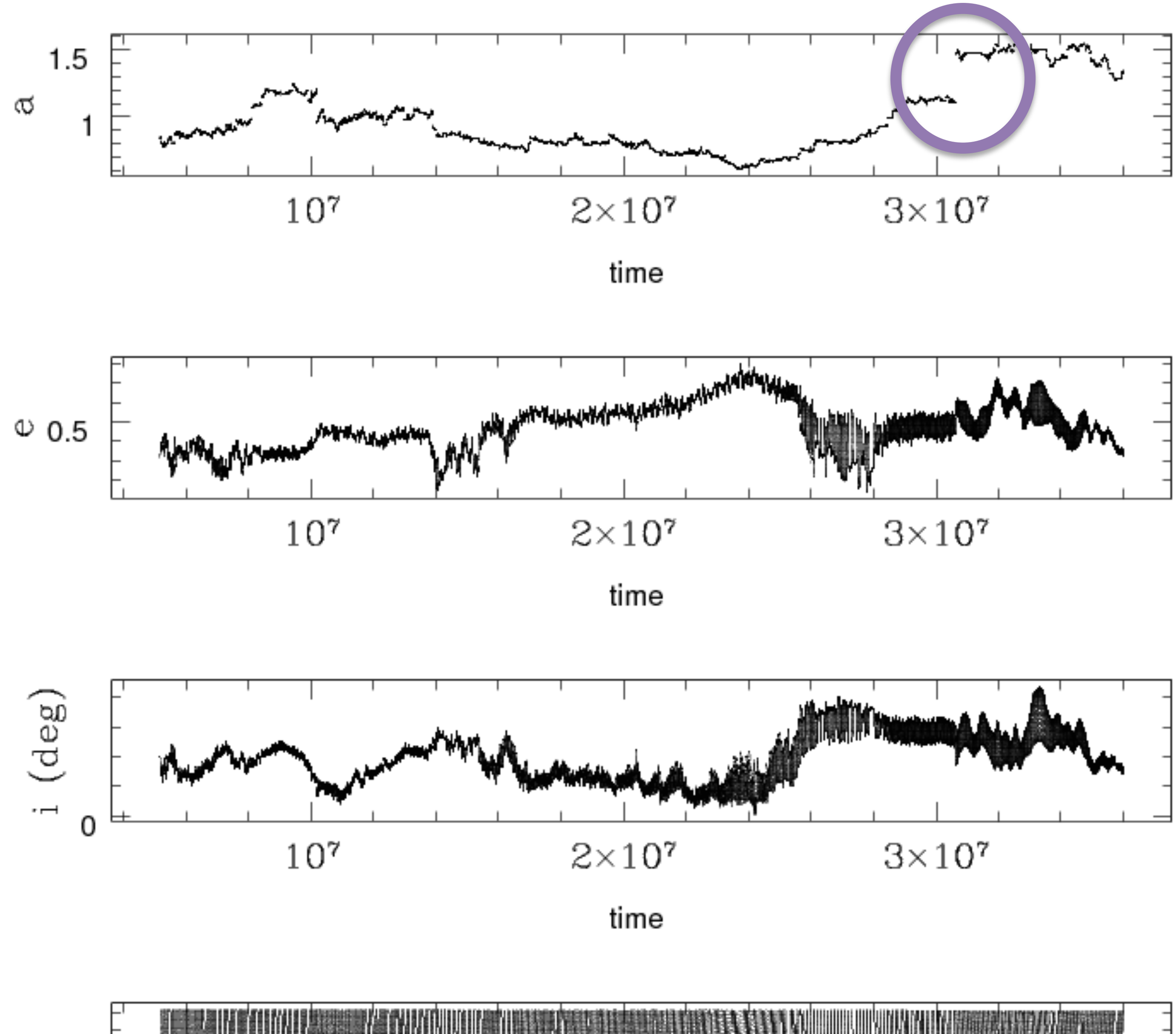

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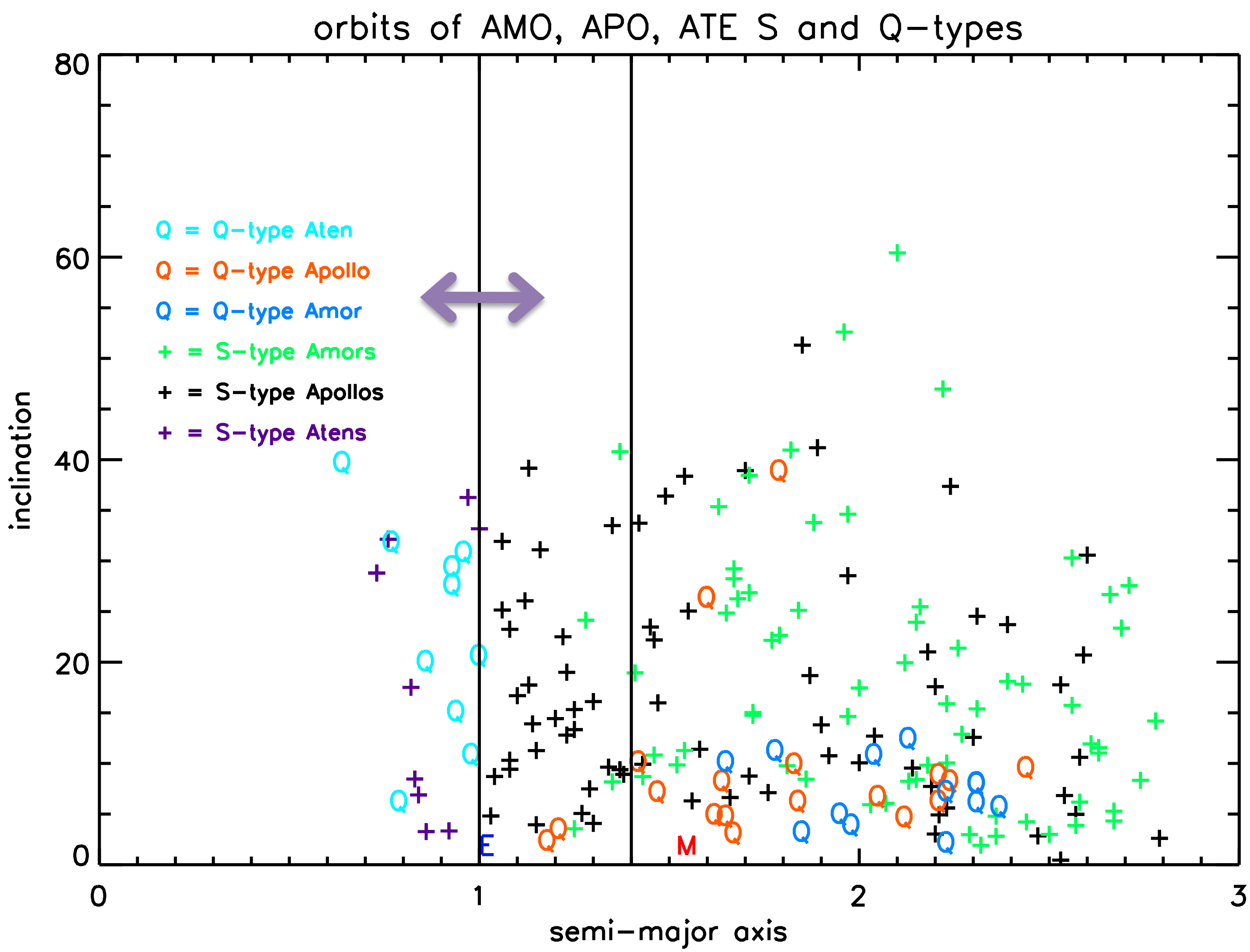
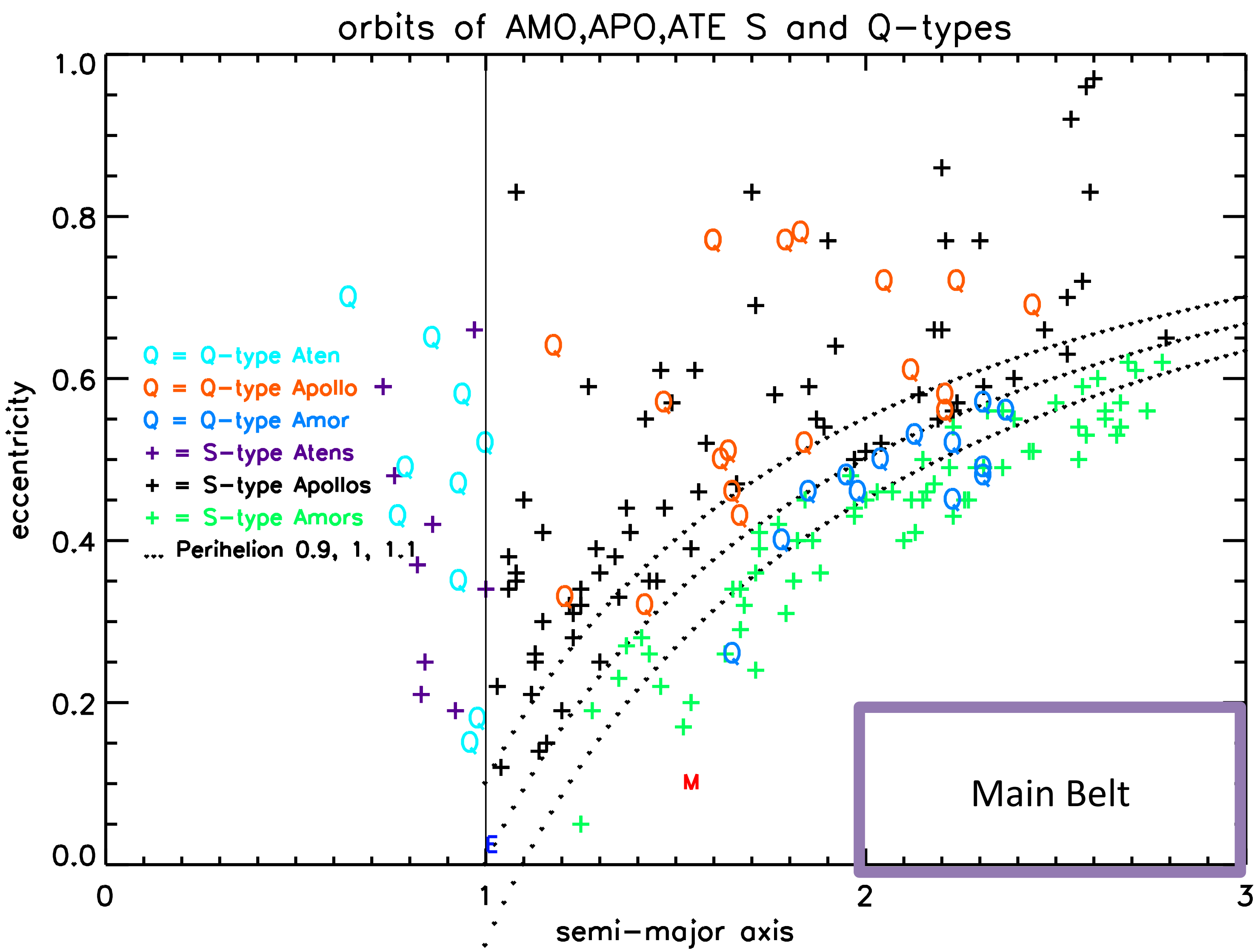


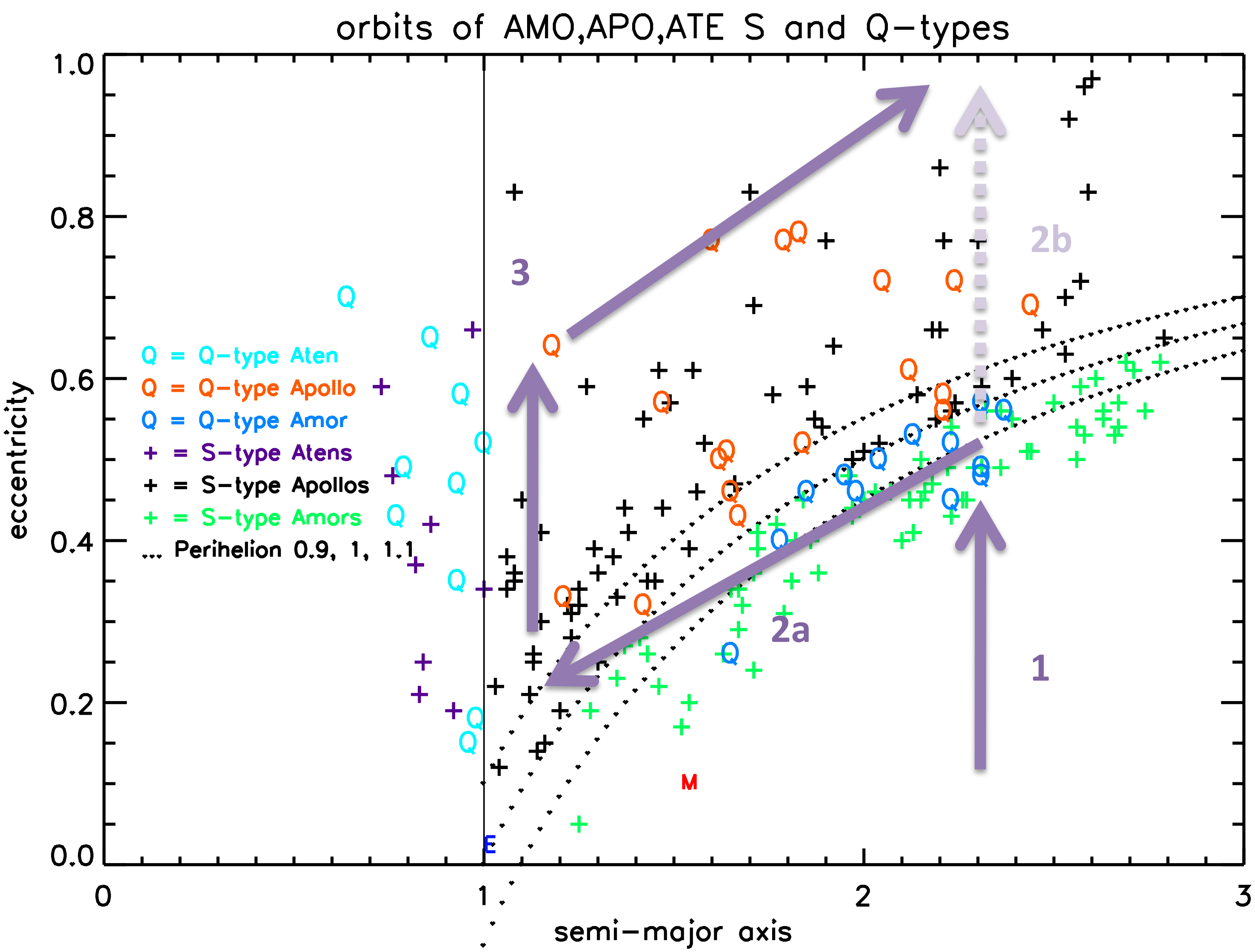
Lifetime of an NEO

- 1. Eccentricity increase bumps perihelion into NEO space
- 2a. Eccentricity increased until it collides with Sun or is ejected by Jupiter (lifetime < 1My)
- 2b. Planetary encounters cause semi-major axis to migrate inward (lifetime ~10s My)
- 3. Collision with a planet, or sun, or ejection as eccentricity increases

Lifetime of an NEO



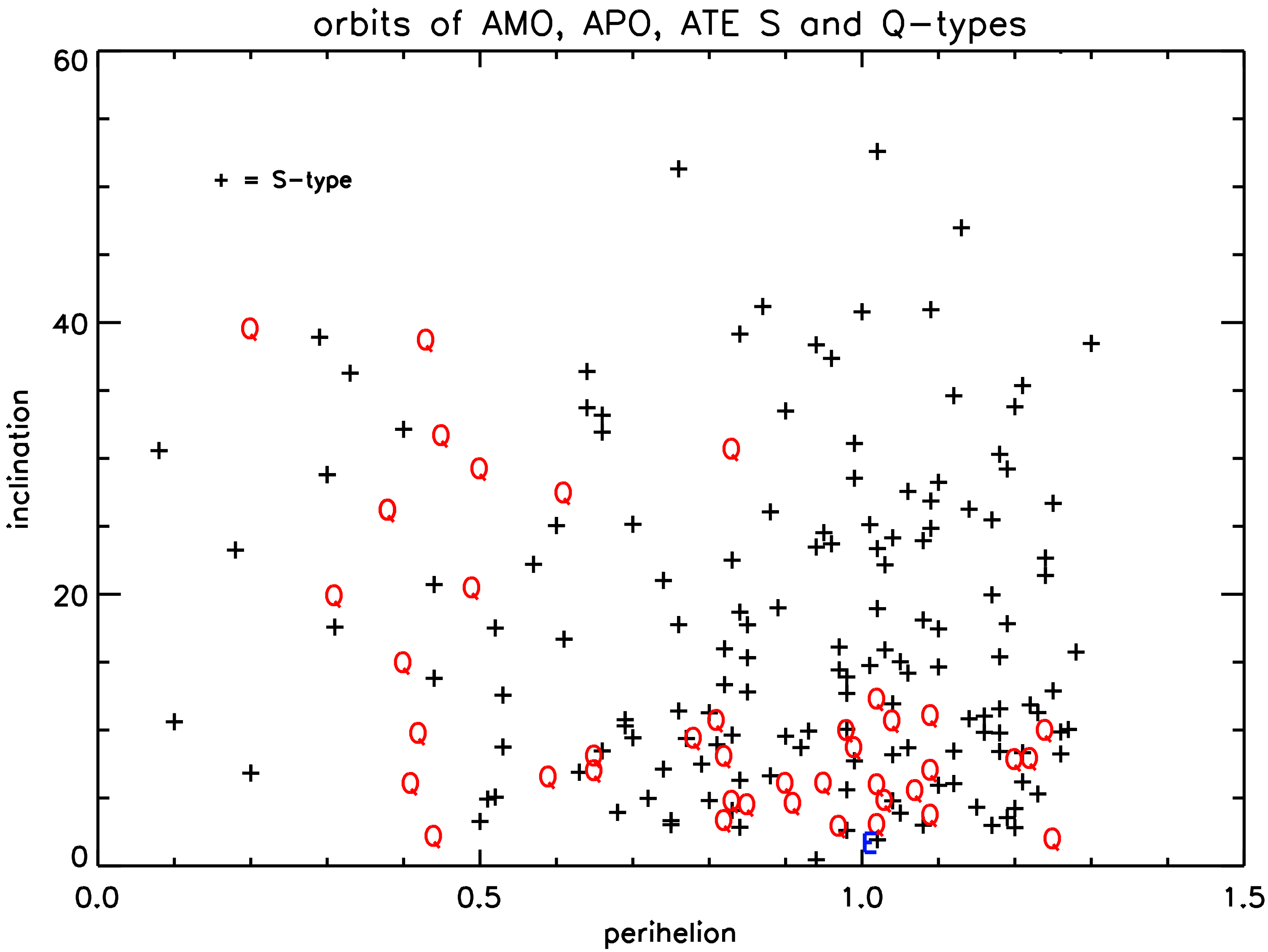
Lifetime of an NEO



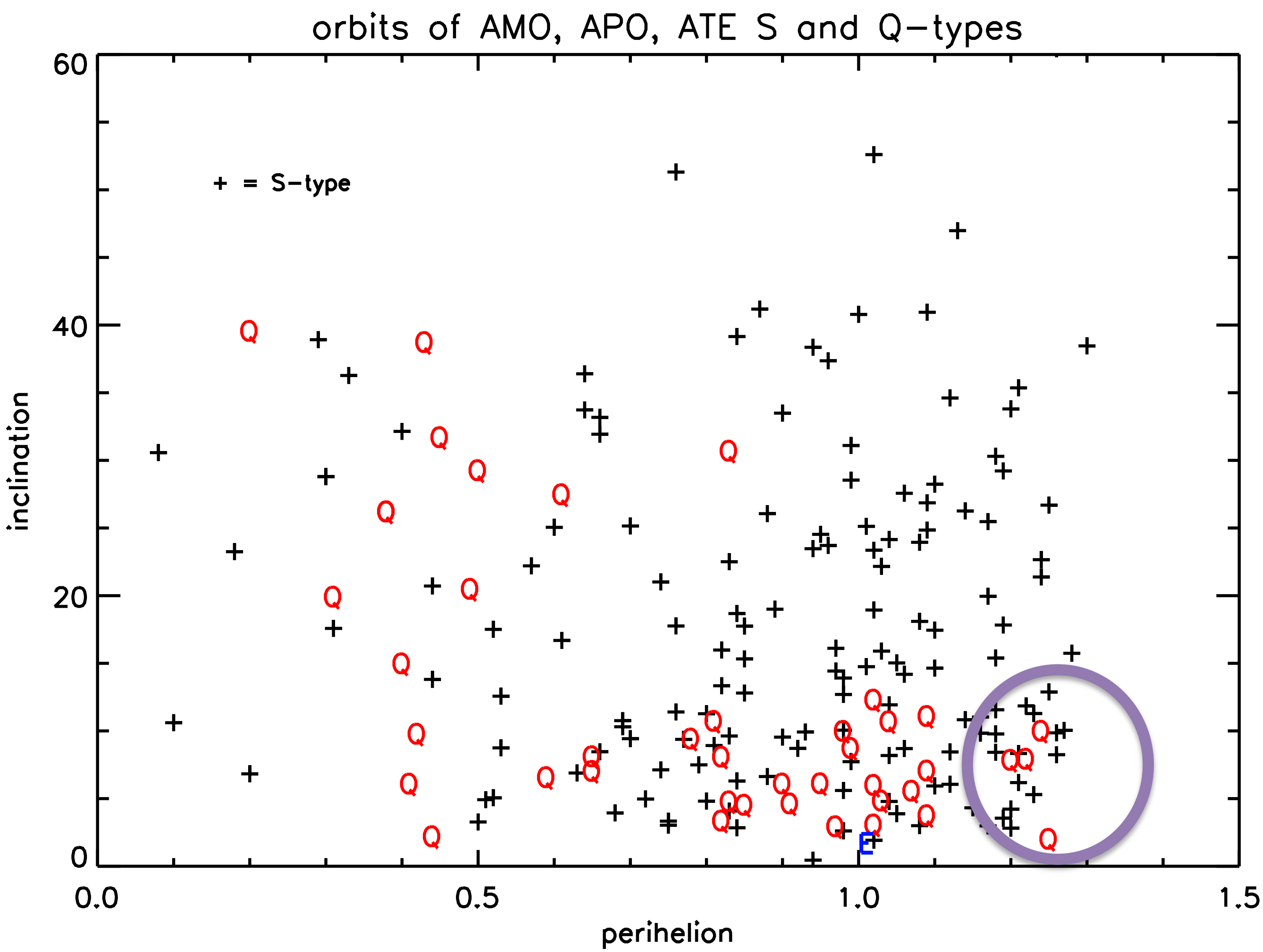
Scenarios

- Frequent Encounters: NEOs constantly have close encounters and are freshened soon after entering
- Infrequent Encounters: Freshening occurs only for evolved orbits where a=1 and then migrate back outward

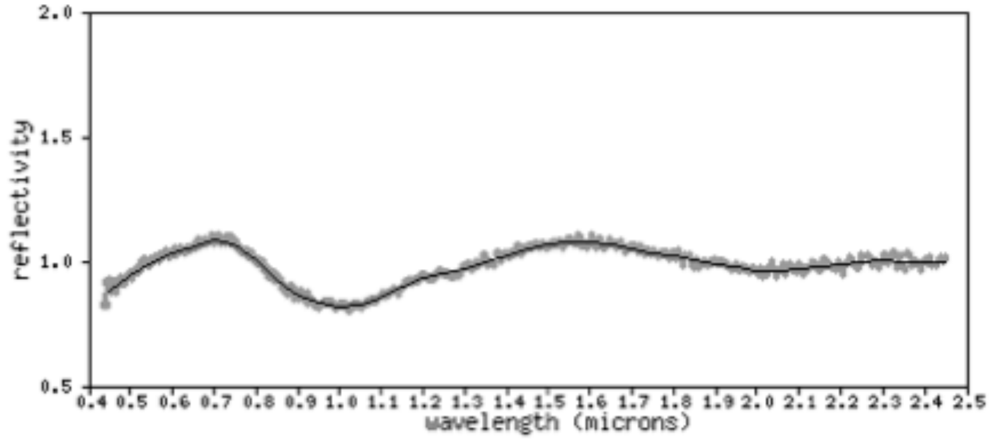
Q-type Perihelia



Q-type Perihelia



Data from `a007336.sp93.txt`
Smoothed model normalized to unit reflectance at 0.55 micron.
Smoothing scale parameter [(read more)]: 1.00

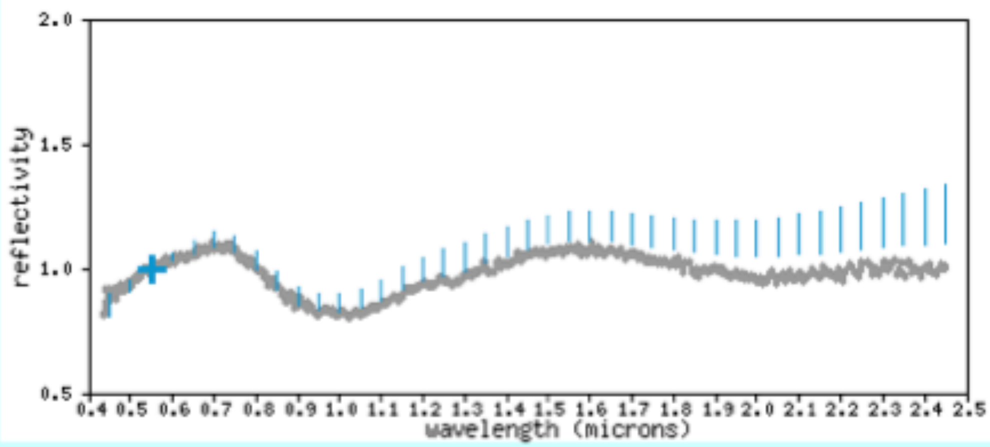


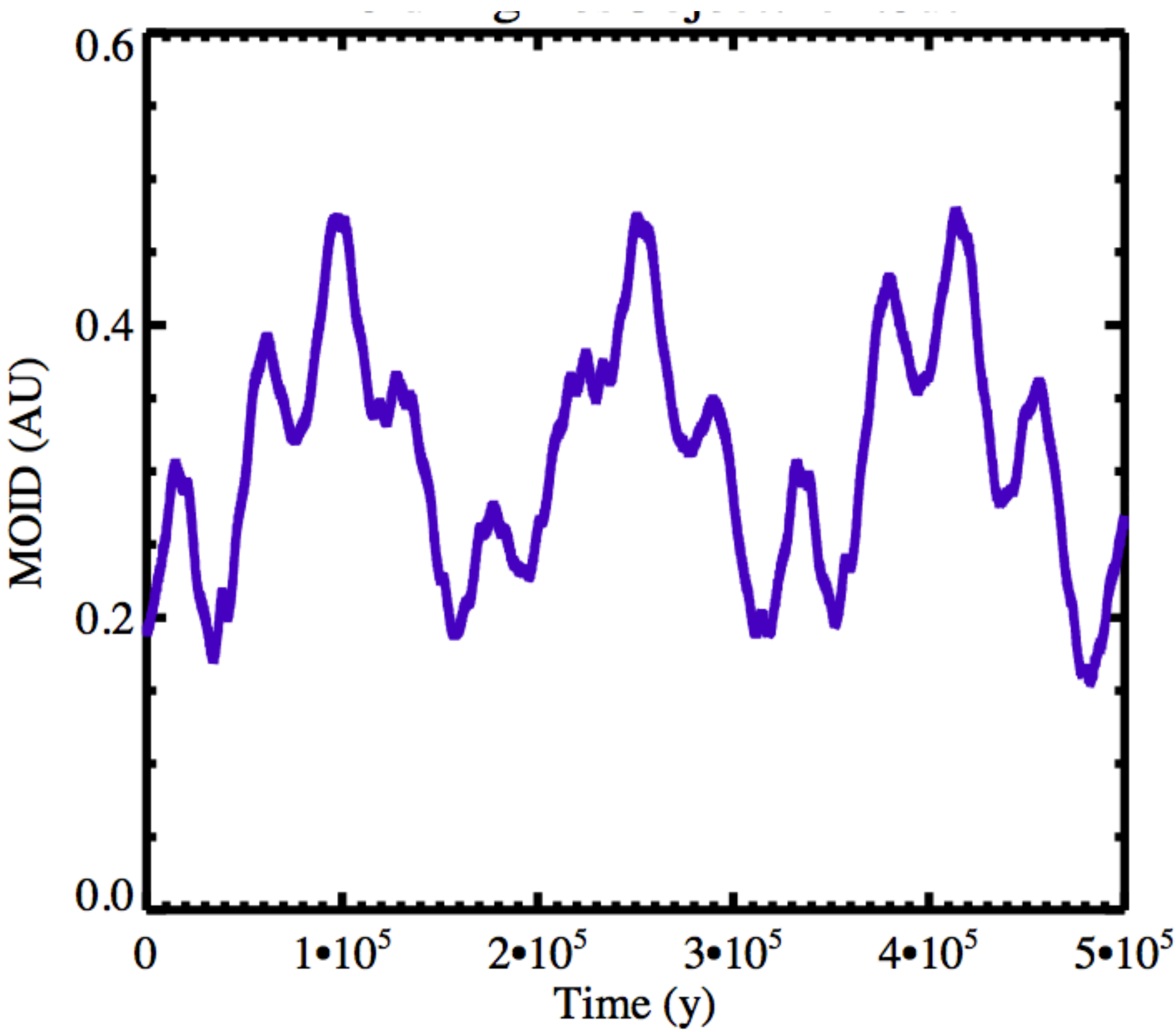
Classification result: Q-type

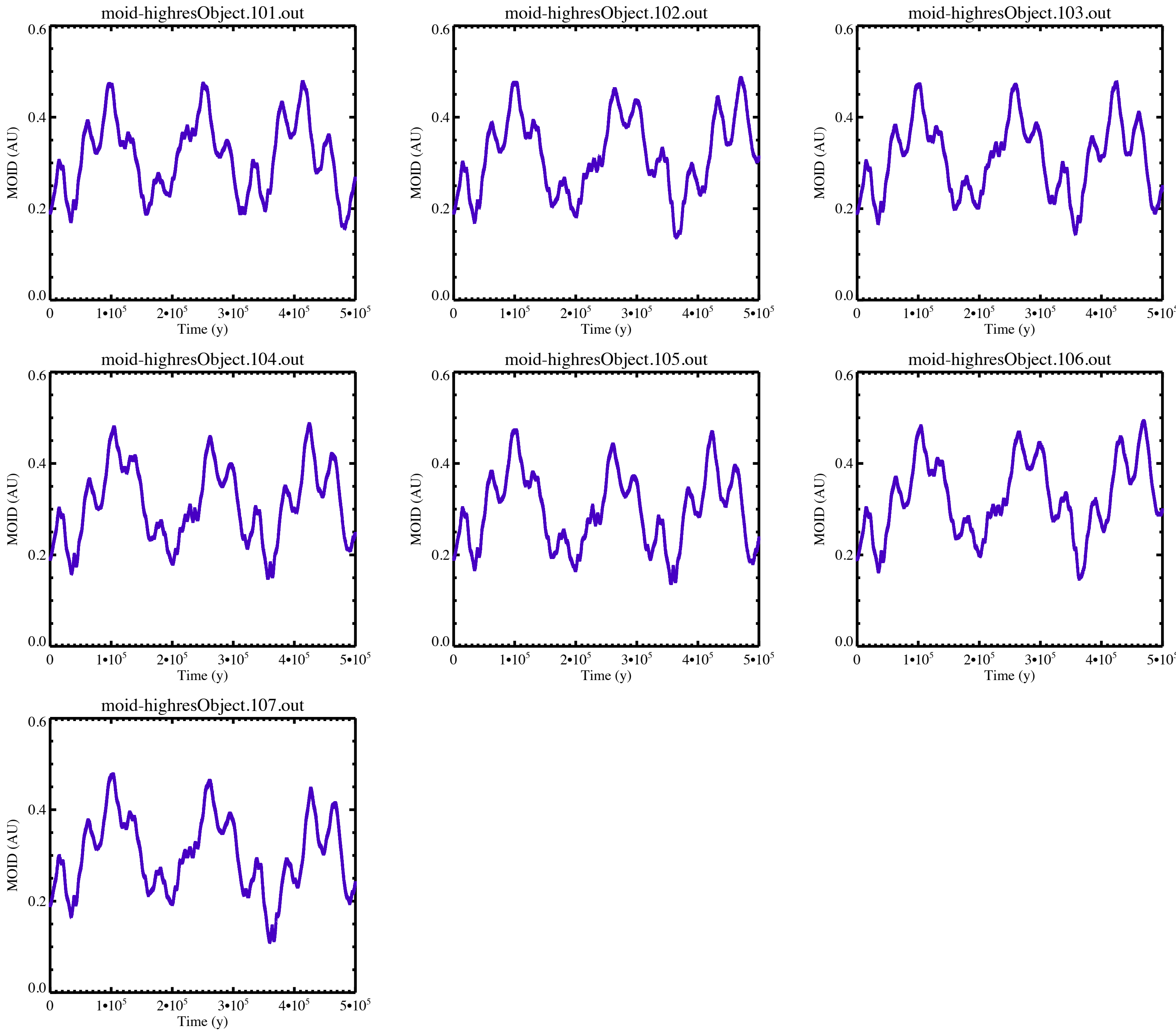
slope: 0.0281   PC1': −0.6170   PC2': 0.2372   PC3': 0.1675   PC4': 0.0029   PC!

Q-type: Distinct 1-micron absorption feature with evidence of another
with varying depths between objects.

Graphical comparison with the reference Q-type (average absolute resi




0.6
0.4
0.2
0.0
MOID (AU)
0
1•10^5
2•10^5
3•10^5
4•10^5
5•10^5
Time (y)


moid-highresObject.101.out
moid-highresObject.102.out
moid-highresObject.103.out
moid-highresObject.104.out
moid-highresObject.105.out
moid-highresObject.106.out
moid-highresObject.107.out
MOID (AU)
Time (y)
0.0
0.2
0.4
0.6
0
1•10^5
2•10^5
3•10^5
4•10^5
5•10^5

Conclusions

- Earth encounters: are the primary expected mechanism to freshen a surface

- Timing: We seek to determine when in an NEO's lifetime this occurs

- Bimodal: Two potential orbital distributions of Q-types may indicate two freshening mechanisms

- High MOID: New MOID calculations of high-q Q-types show that Earth encounters are not the only mechanism (collisions or Mars encounters)