

Today

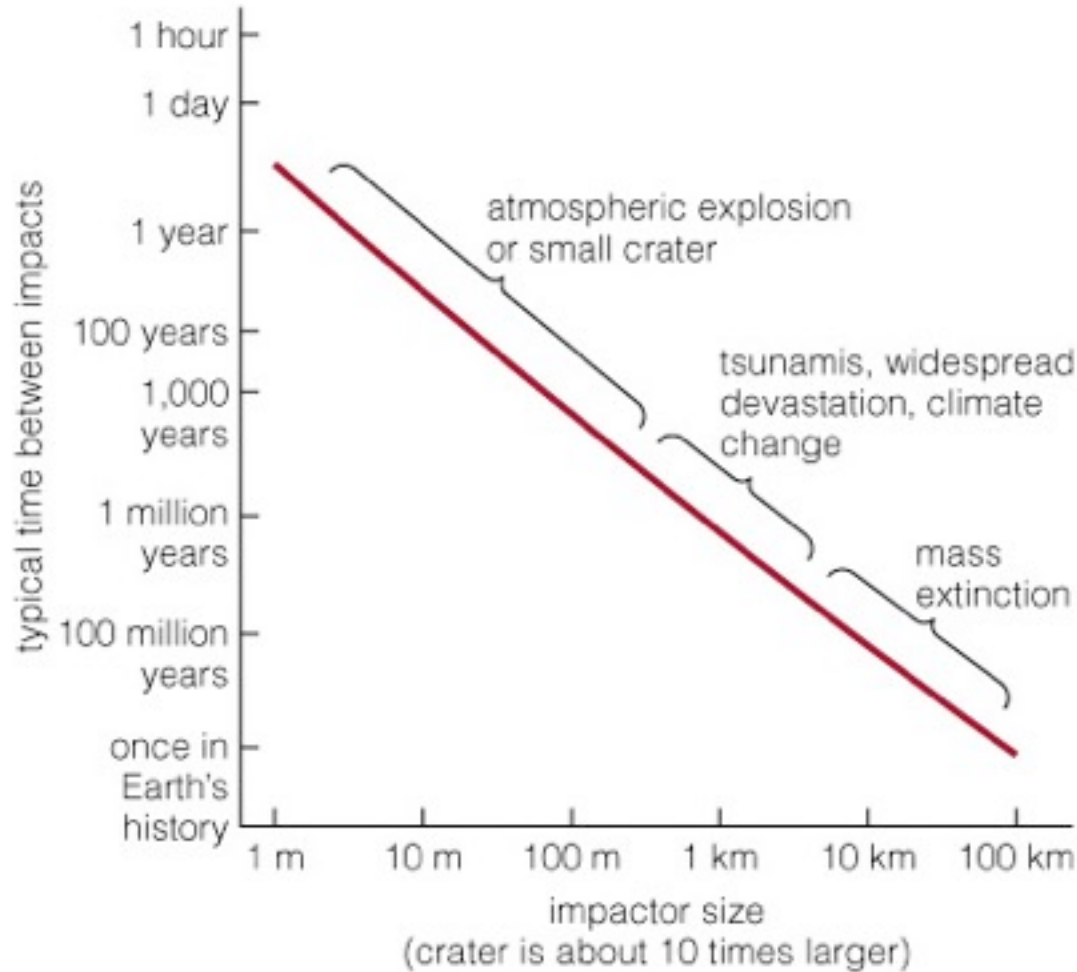
- The Little Things
 - Comets
 - Impacts - when asteroids or comets strike



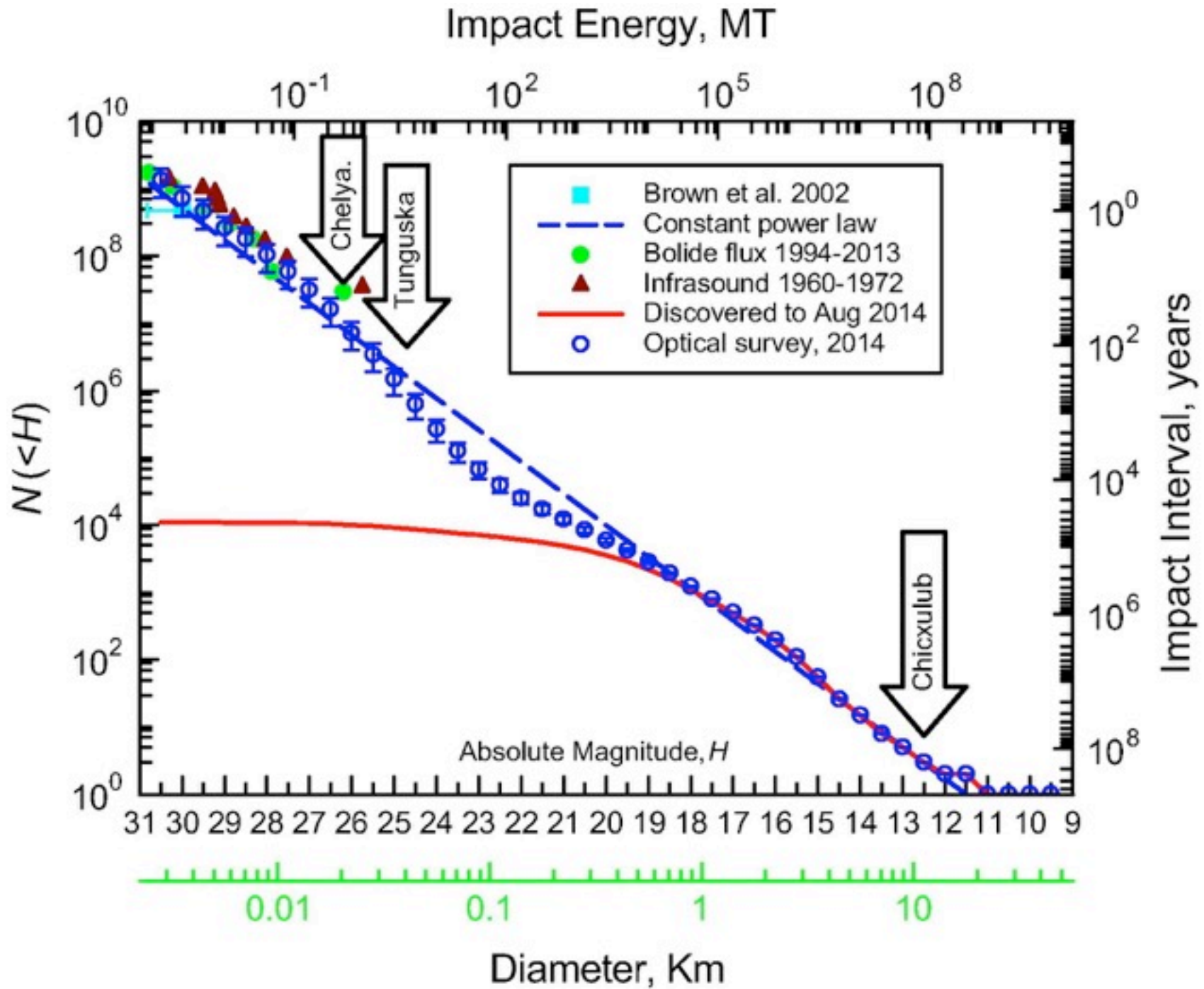


Meteor Crater, Arizona: 50,000 years ago (50 meter object)

Frequency of Impacts



- Small impacts happen almost daily. – meteors!
- Impacts large enough to cause mass extinctions are many millions of years apart.

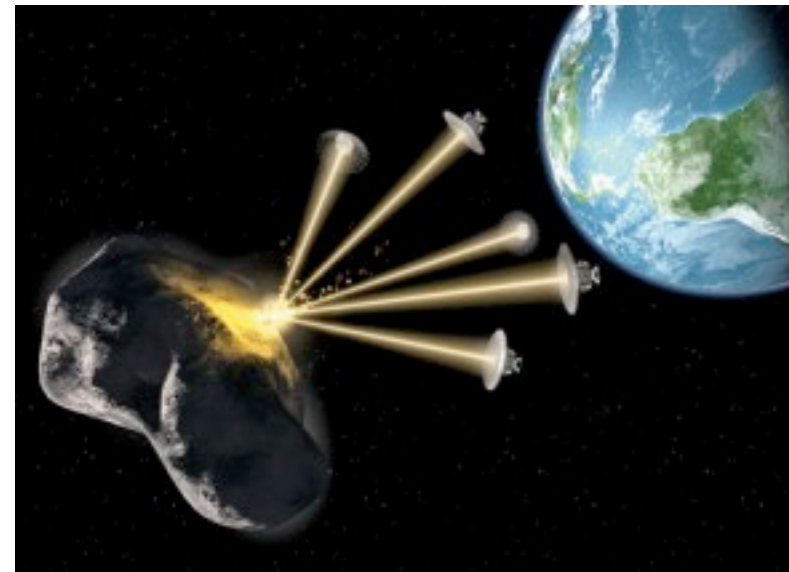


Asteroid Deflection

- Deflection is challenging; the more advance warning the better.
- Breaking a big asteroid into a bunch of little asteroids does not really help.
- Best chance is to nudge the orbit a bit.



gravity
tug

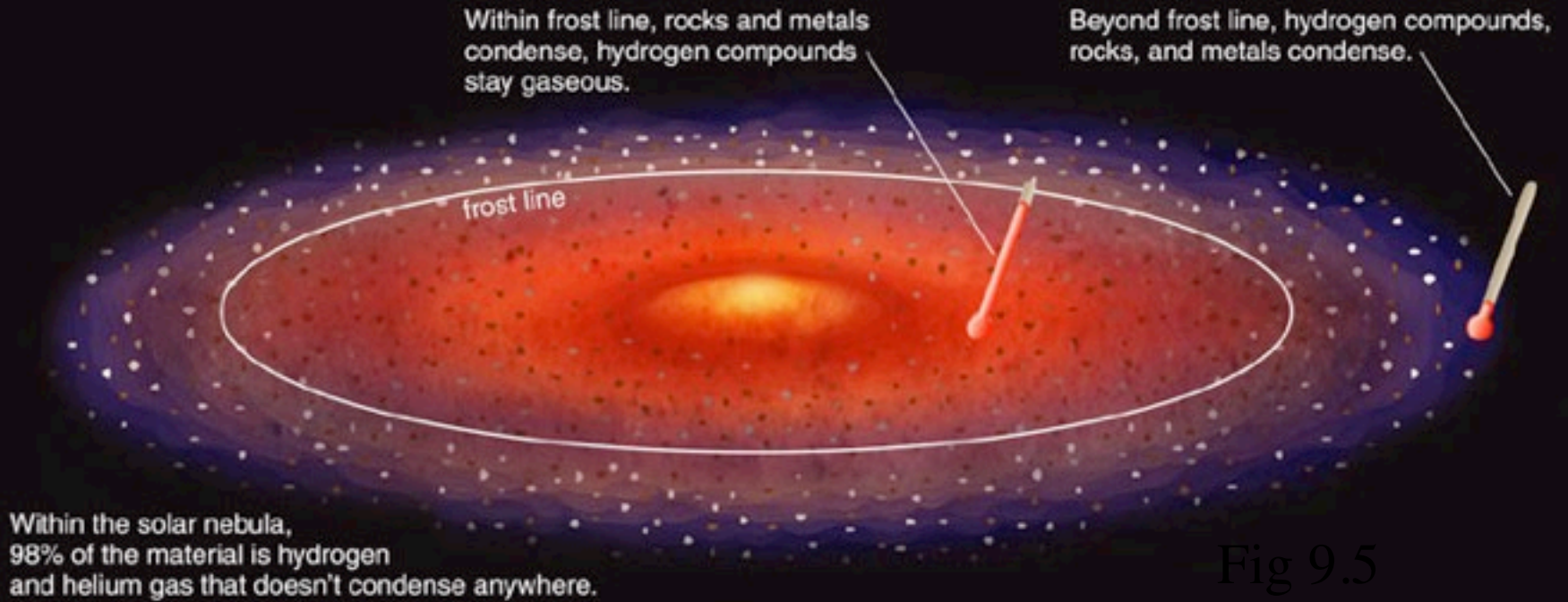


solar sublimation

Comets



a Comet Hyakutake.



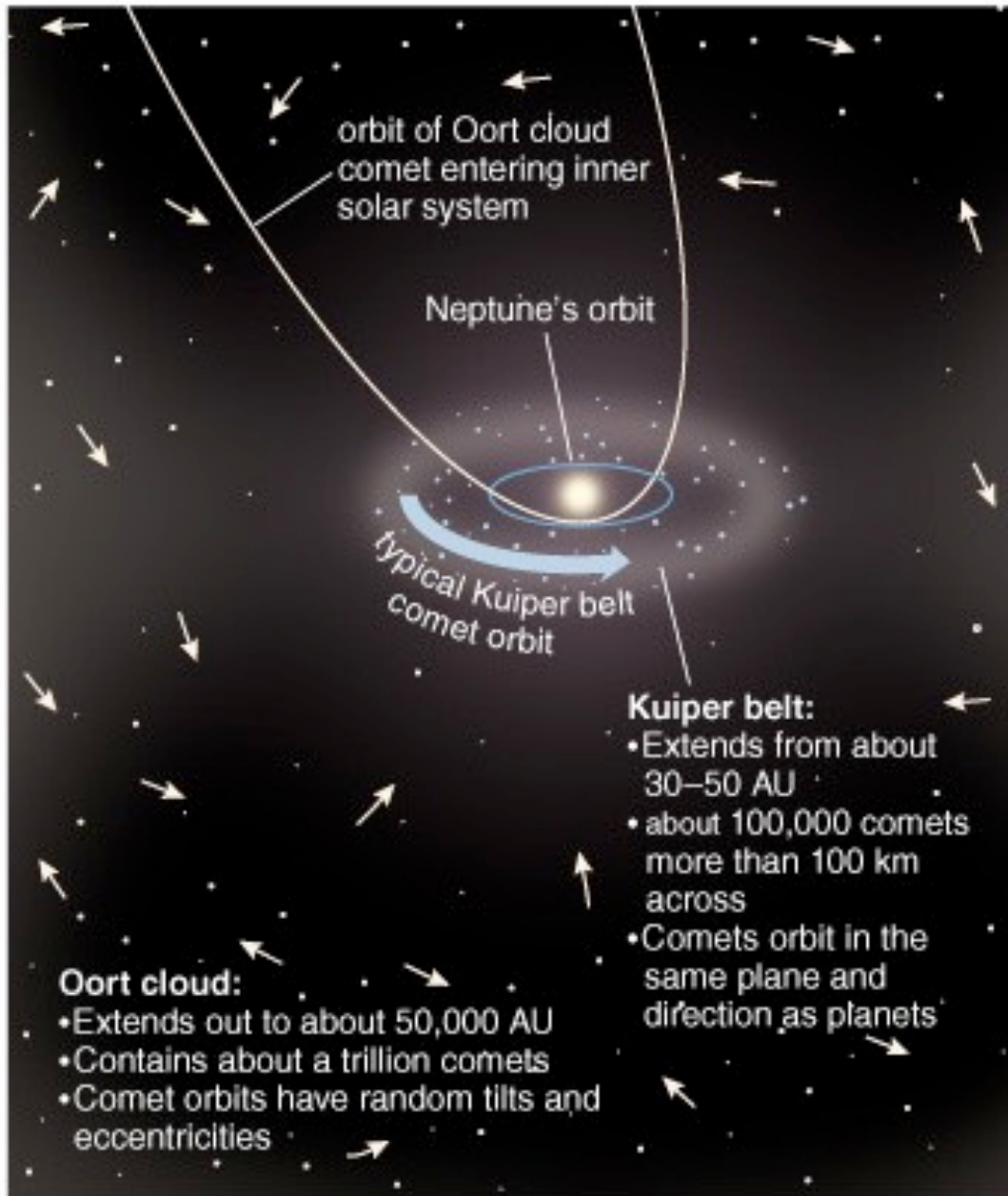
FROST LINE at about 3.5 AU

Inside the *frost line*: Too hot for hydrogen compounds to form ices
- only get rocky asteroids and planets

Outside the *frost line*: Cold enough for ices to form
- get icy moons and comets
- ice is a major component of their total mass

Comet Facts

- Formed beyond the frost line, comets are icy counterparts to asteroids.
- Nucleus of comet is a "dirty snowball."
 - soft serve ice with a hard coating of tar and dust
- Most comets do not have tails.
- Most comets remain perpetually frozen in the outer solar system.
- Only comets that enter the inner solar system grow tails.
 - i.e., the “apparition” of a comet is its brief-lived summer season while it is near the sun
- Most comets on highly elliptical orbits
 - often highly inclined (out of ecliptic plane)



Only a tiny number of comets enter the inner solar system; most stay far from the Sun.

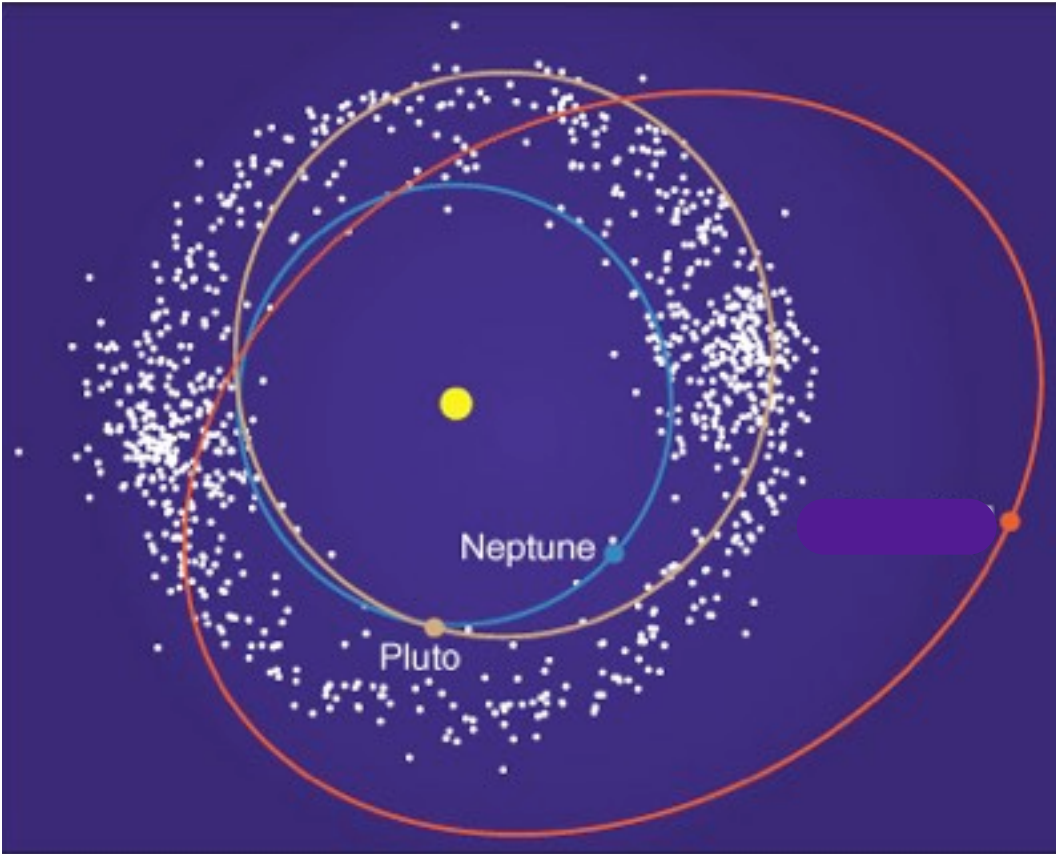
Oort cloud:

On random orbits extending to about 50,000 AU.

Kuiper belt:

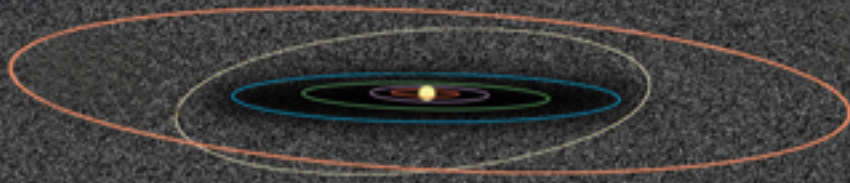
On orderly orbits (mostly in ecliptic plane) from 30–50 AU. Sort of an outer comet belt.

Kuiper Belt

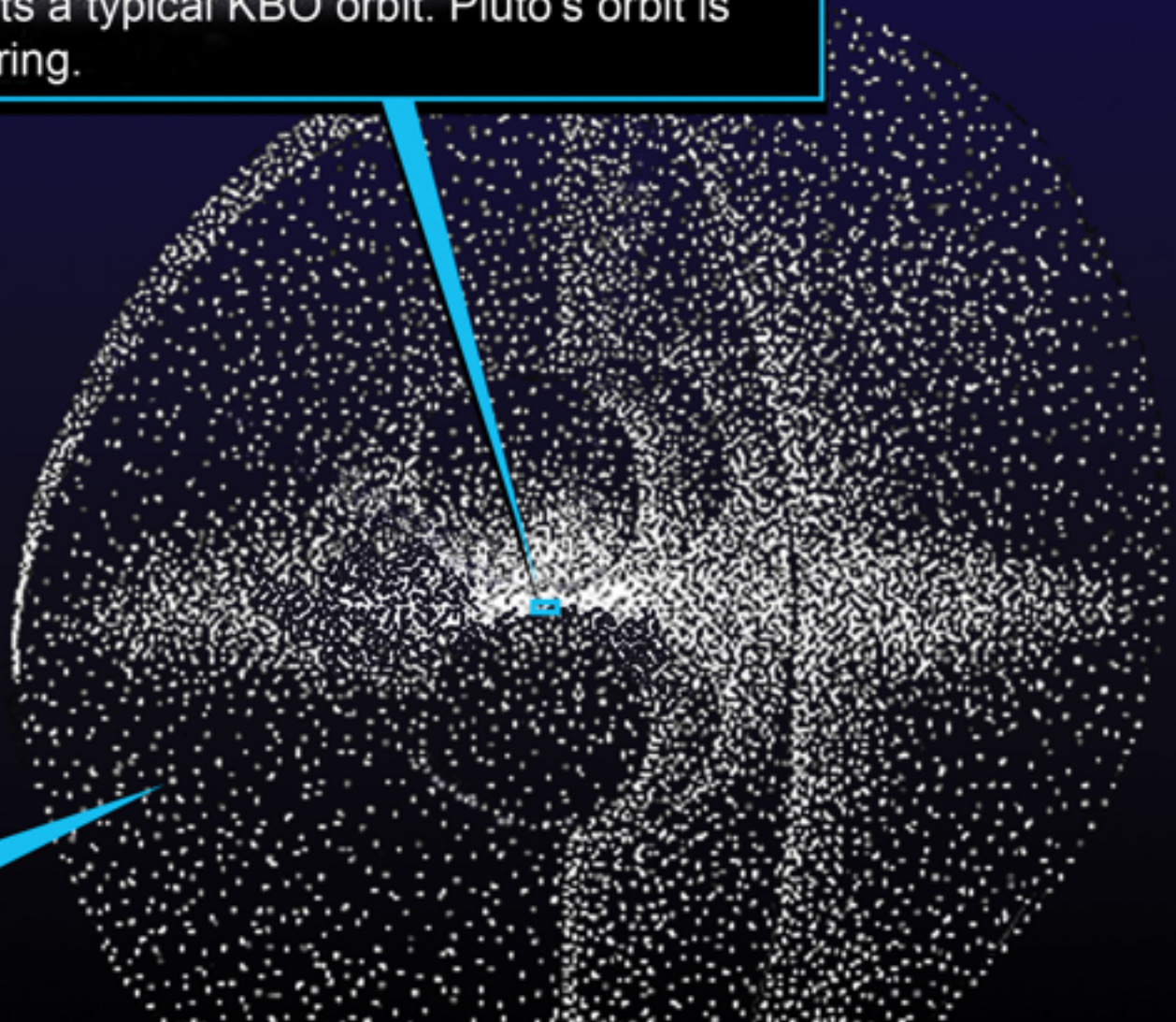


- disk of objects beyond the orbit of Neptune
- Like more distant, icy version of asteroid belt
- Many small objects; some large ones (like Pluto)

Kuiper Belt



The orange track represents a typical KBO orbit. Pluto's orbit is represented by the yellow ring.



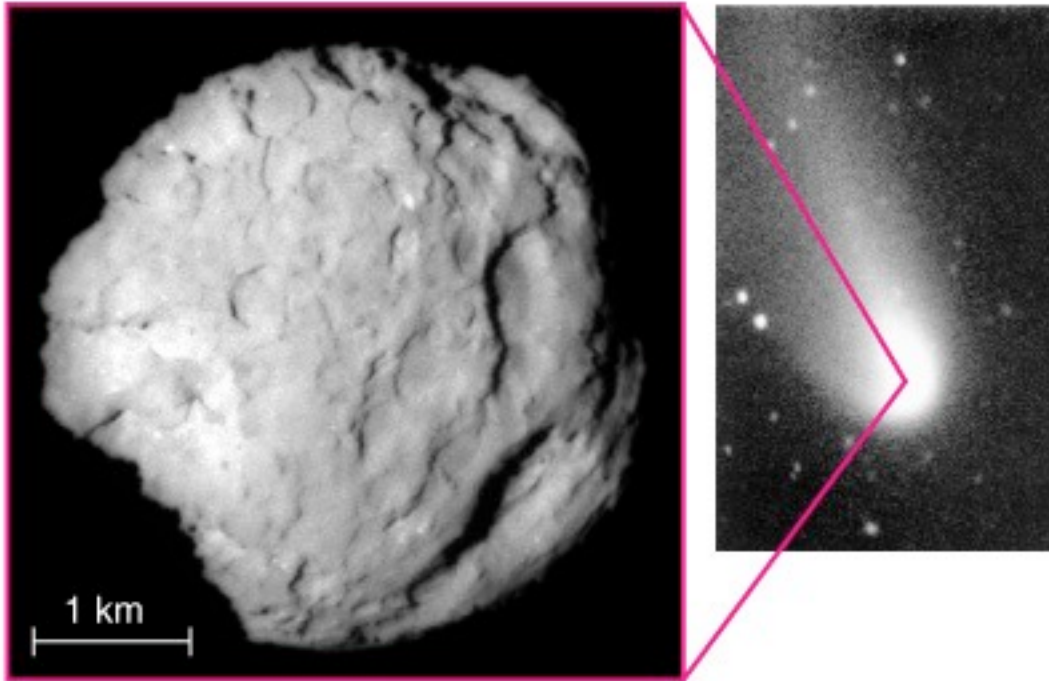
Oort Cloud

How did they get there?

- Kuiper belt comets formed in the Kuiper belt: flat plane, aligned with the plane of planetary orbits, orbiting in the same direction as the planets
- Oort cloud comets were once closer to the Sun, but they were kicked out there by gravitational interactions with jovian planets: spherical distribution, orbits in any direction

**Jupiter & Neptune -
the great scatterers of the
inner and outer Solar System:
those objects not absorbed by
planets are ejected by them.**

Nucleus of Comet



- A “dirty snowball” -
- a combination of rock, ice, and carbon-rich “tar”
- thought to be primitive material unaltered since the formation of the SS

- Source of material for comet’s tail -
- Tail only appears when comet nears the sun: ices are heated into vapor, forming coma and tail.

© 2006 Pearson Education, Inc., publishing as Addison Wesley

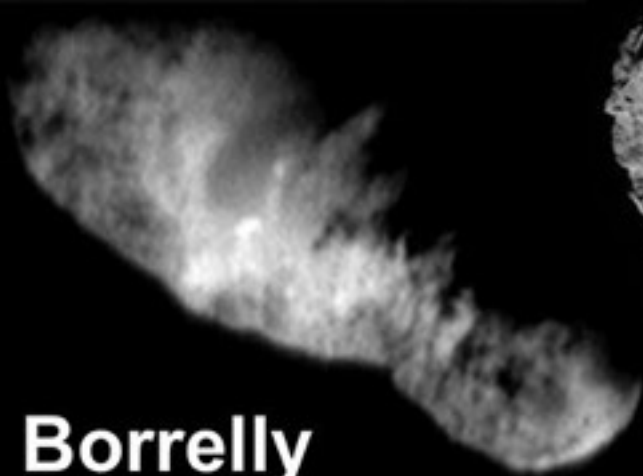
Wild 2



Halley



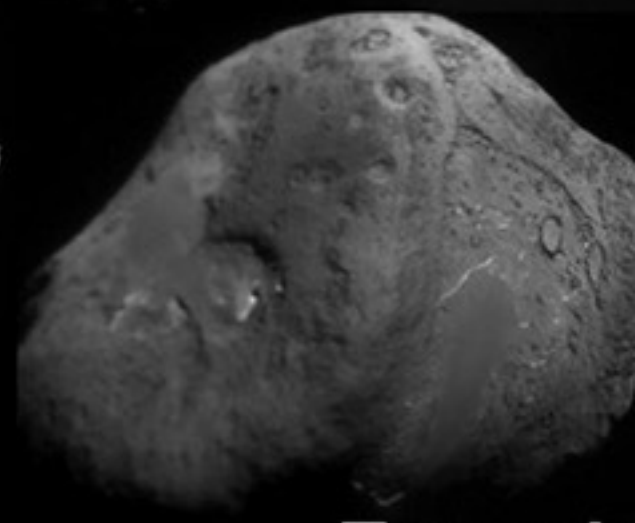
Hartley 2



Borrelly



Churyumov-Gerasimenko



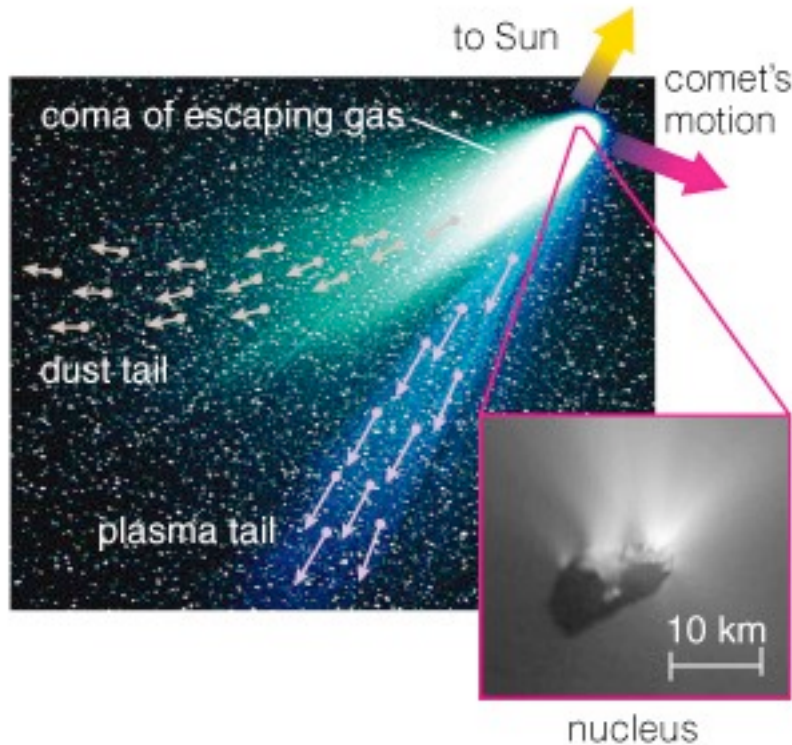
Tempel 1

Anatomy of a Comet

- Nucleus: actual object

- Coma is a temporary atmosphere that comes from heated nucleus.

- Tail always points away from the sun
 - Plasma tail is gas escaping from coma, pushed by solar wind.
 - Dust tail is pushed by photons.

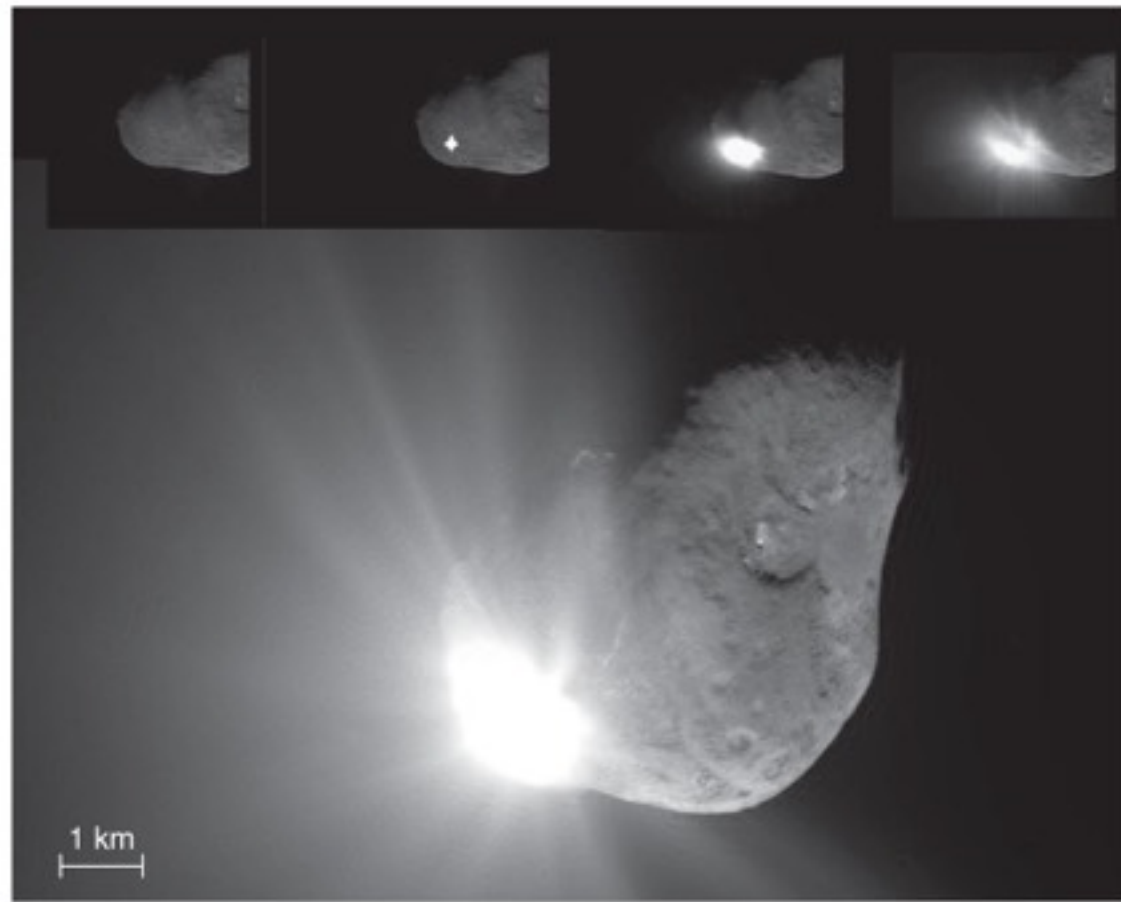


dry ice video

- Larger debris follow comet's orbit; source of meteoroids.

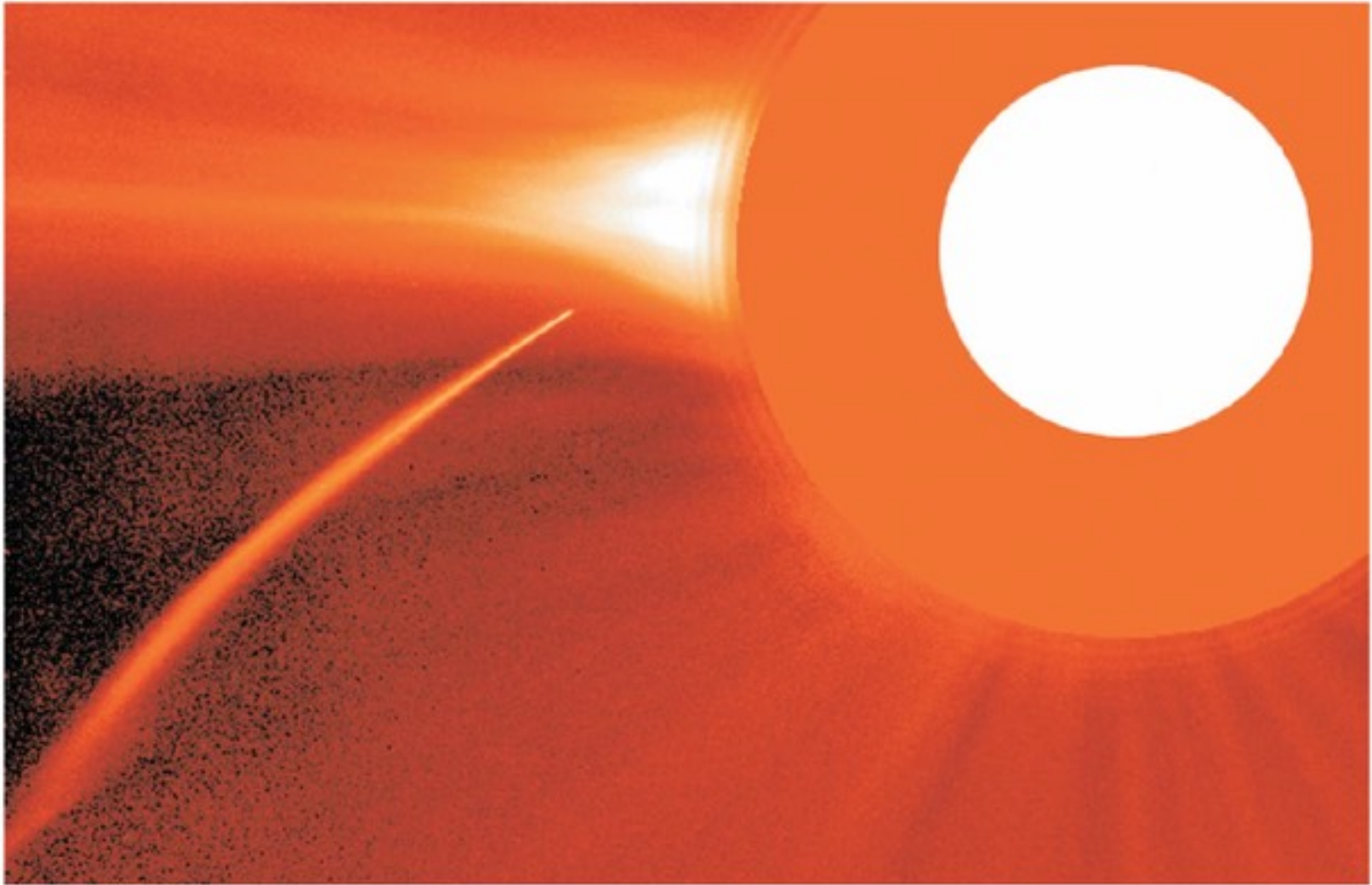
Deep Impact

- Mission to study nucleus of Comet Tempel 1
- Projectile hit surface on July 4, 2005
- Lots of ices (as expected) but also a lot of tarry hydrocarbon materials



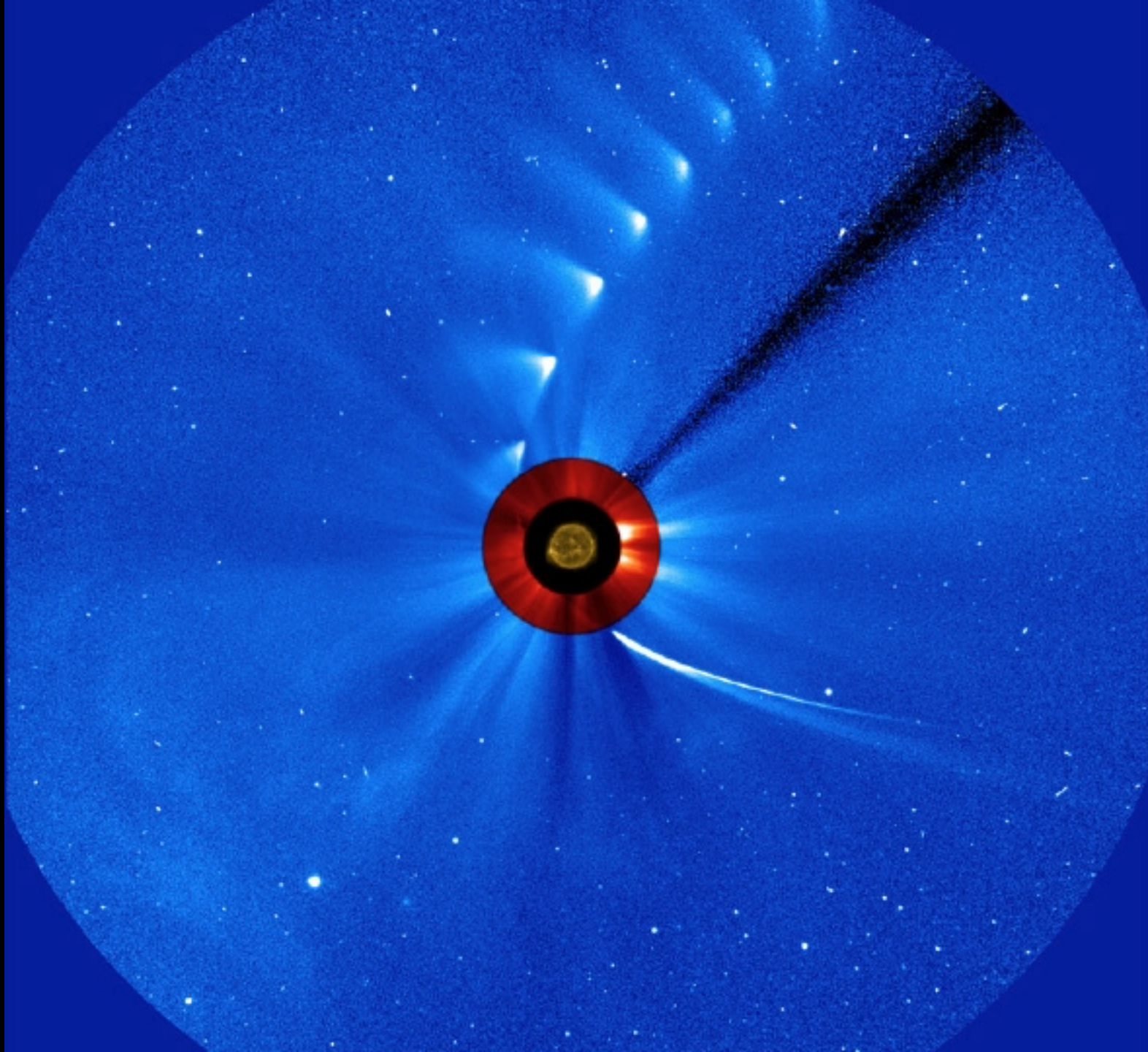
Interactive Figure 

Sun-Grazing Comet

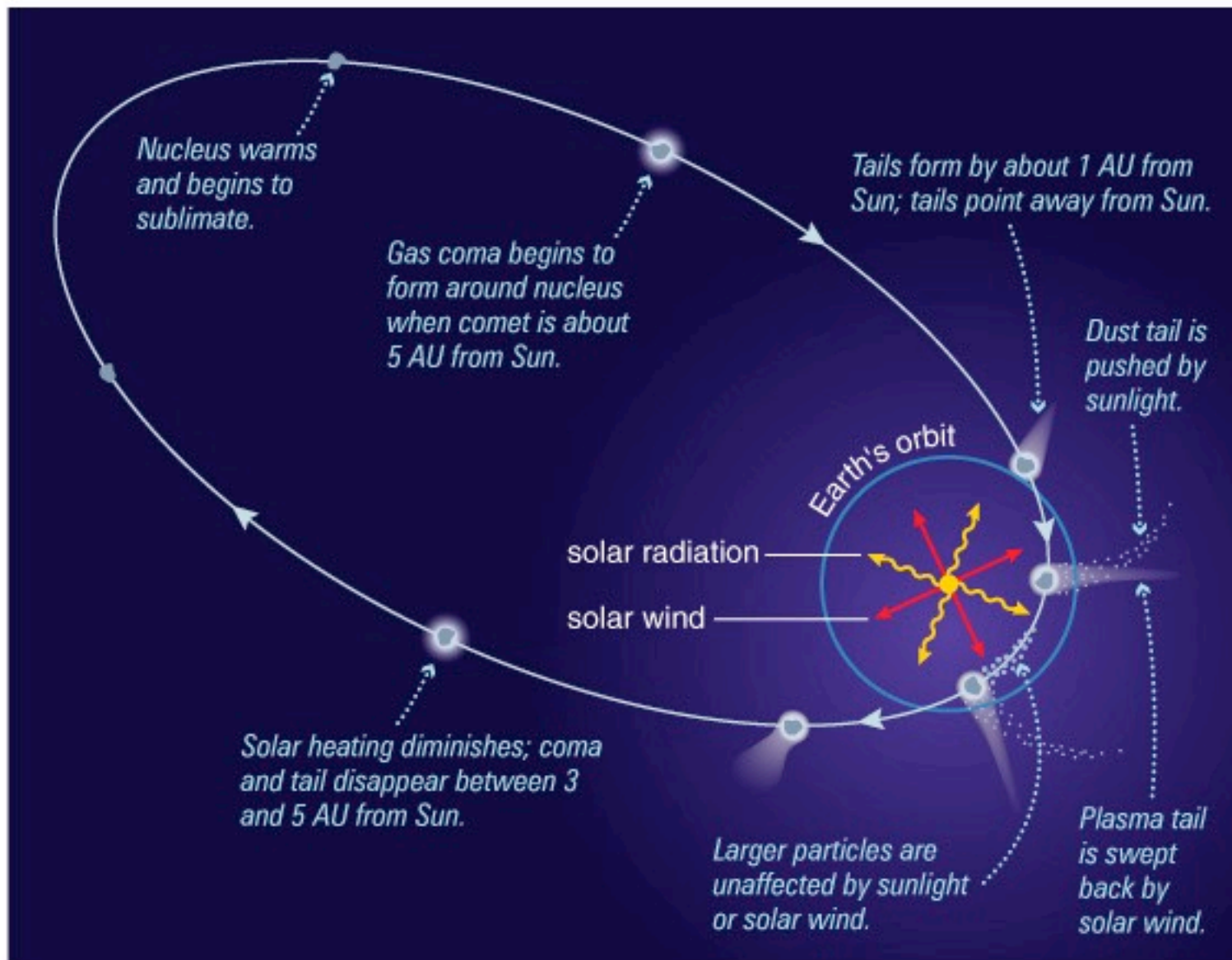


<https://www.youtube.com/watch?v=QJmZlA50DpM>

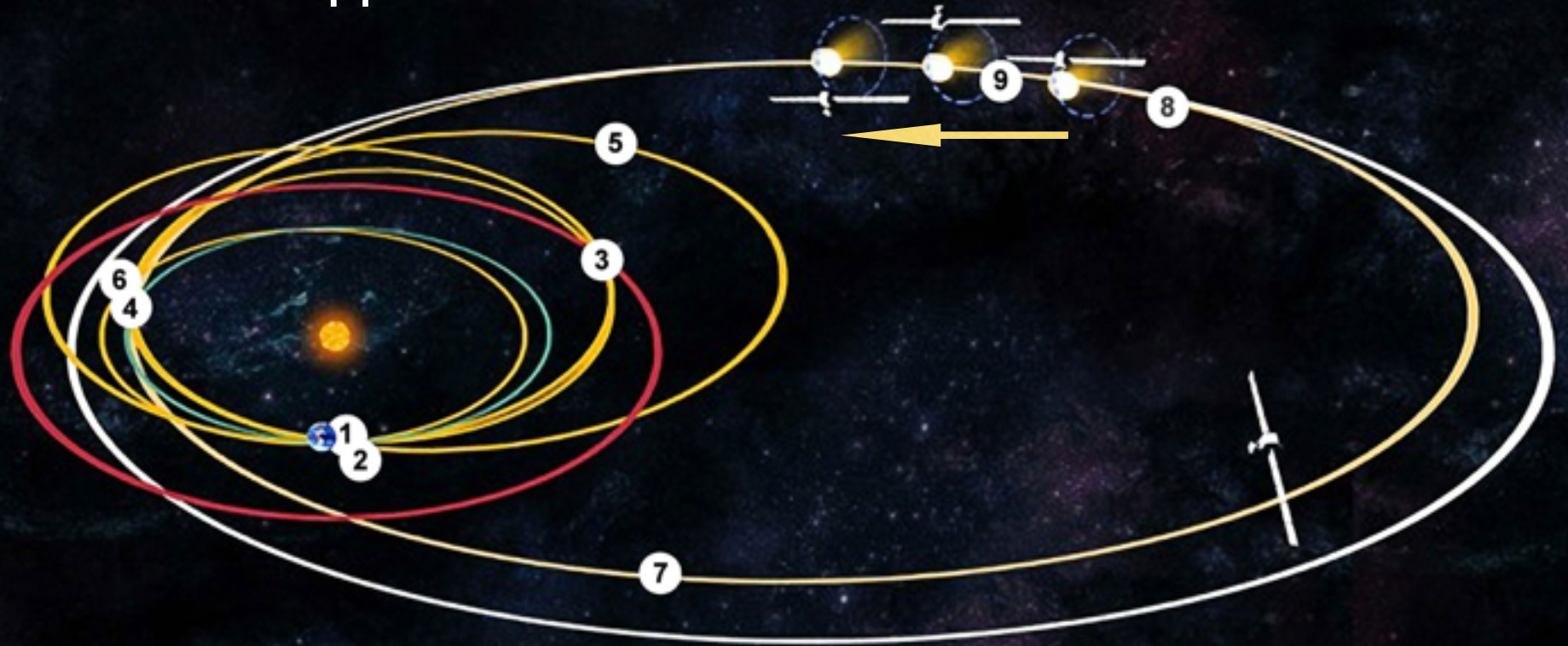
Time-lapse of a sun grazing comet evaporating



Growth of Tail



ESA Rosetta mission - launched in 2004; arrived in 2014 as Comet 67P approached the sun



1. Launch, March 2, 2004

2. First Earth flyby, March 3, 2005

3. Mars flyby, February 26, 2007

4. Second Earth flyby, November 14, 2007

5. Asteroid Steins flyby

6. Third Earth flyby, November 11, 2009

7. Asteroid Lutetia flyby

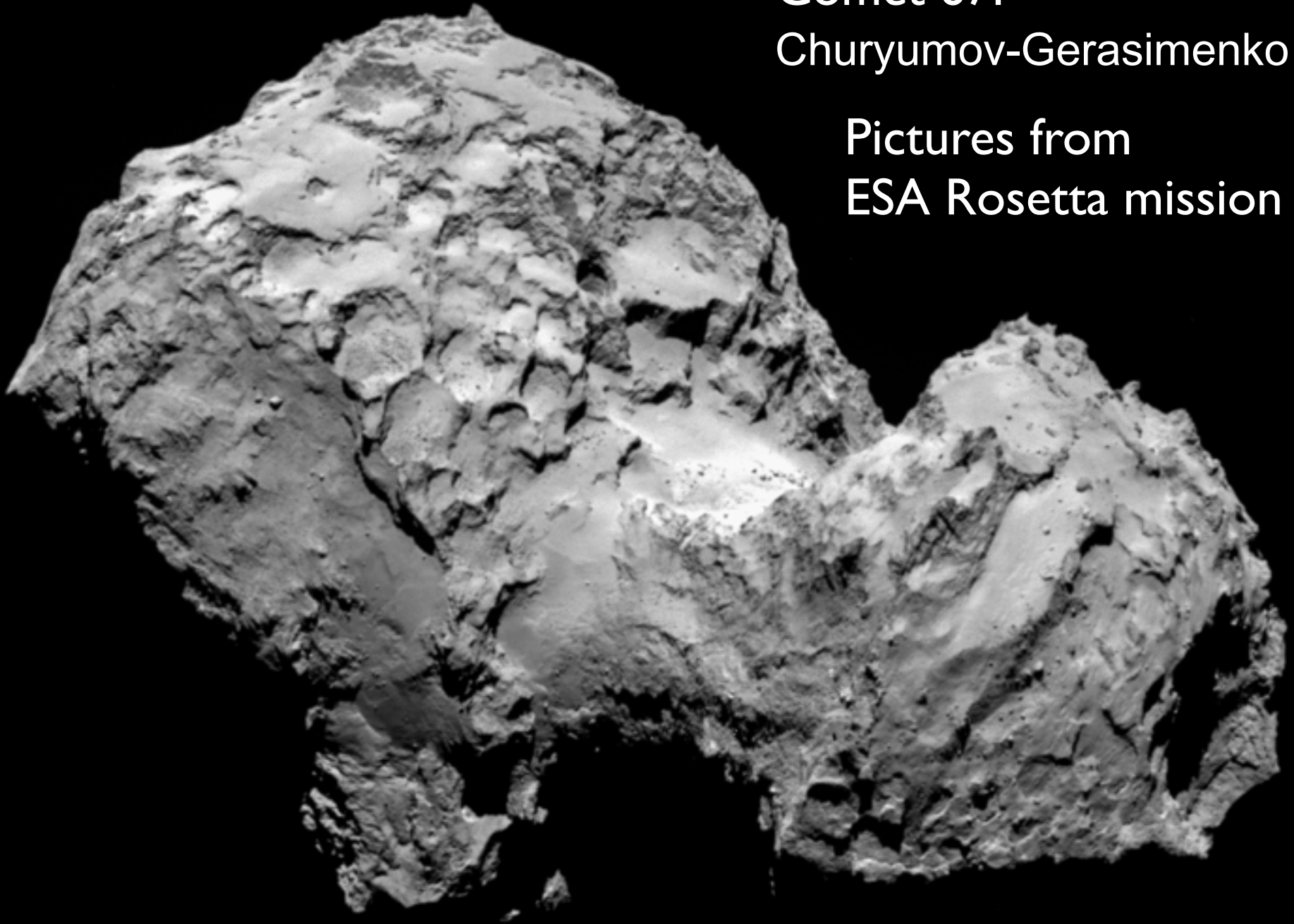
8. Arriving at the comet in 2014

9. Rosetta observes comet 67P/Churyumov-Gerasimenko

● Mars' Orbit ● Earth's Orbit ● Rosetta's Orbit ● Comet's Orbit

Comet 67P
Churyumov-Gerasimenko

Pictures from
ESA Rosetta mission



Comet 67P
4,100 m

Mount Fuji
3,776 m

Mount Olympus
2,917 m

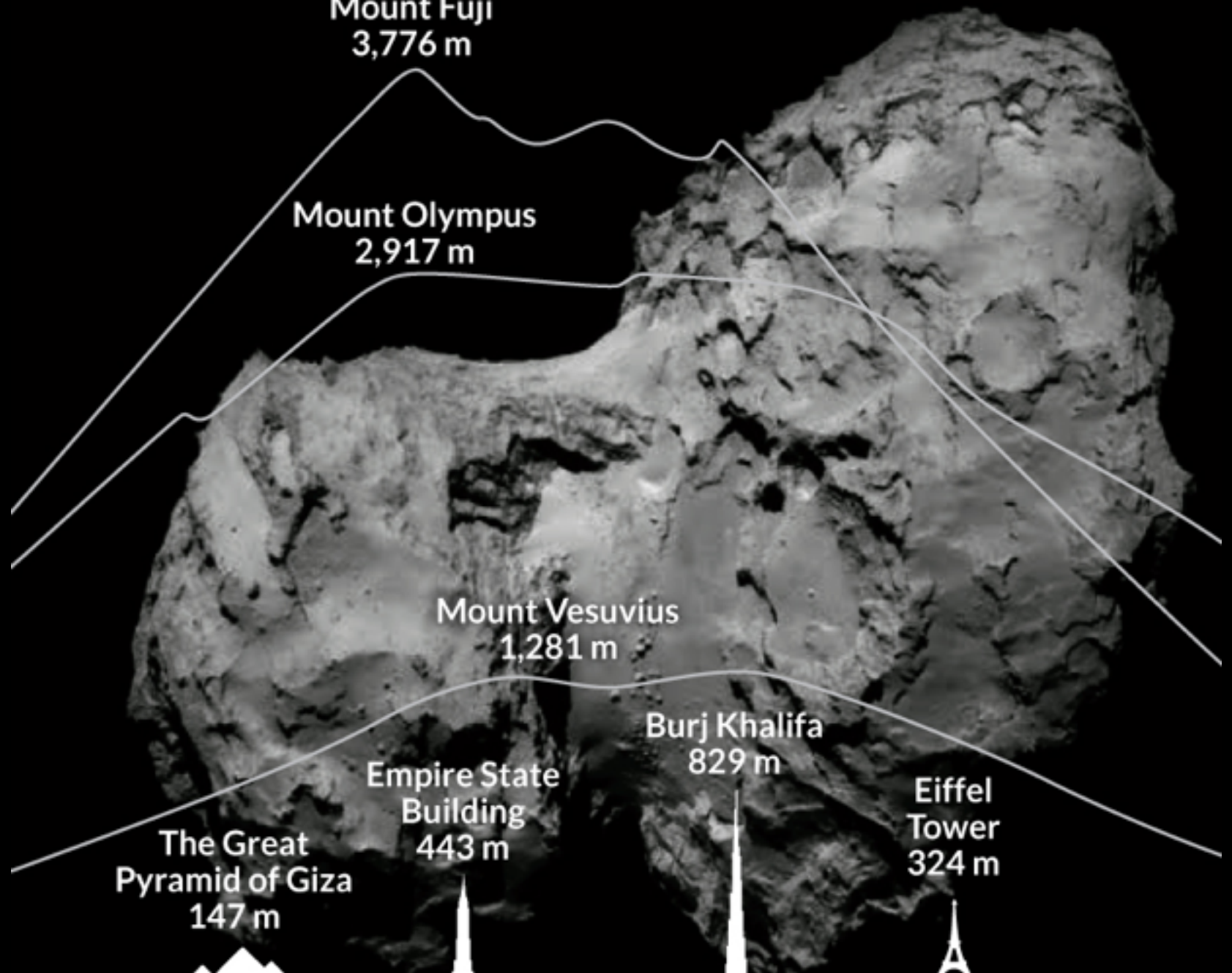
Mount Vesuvius
1,281 m

Burj Khalifa
829 m

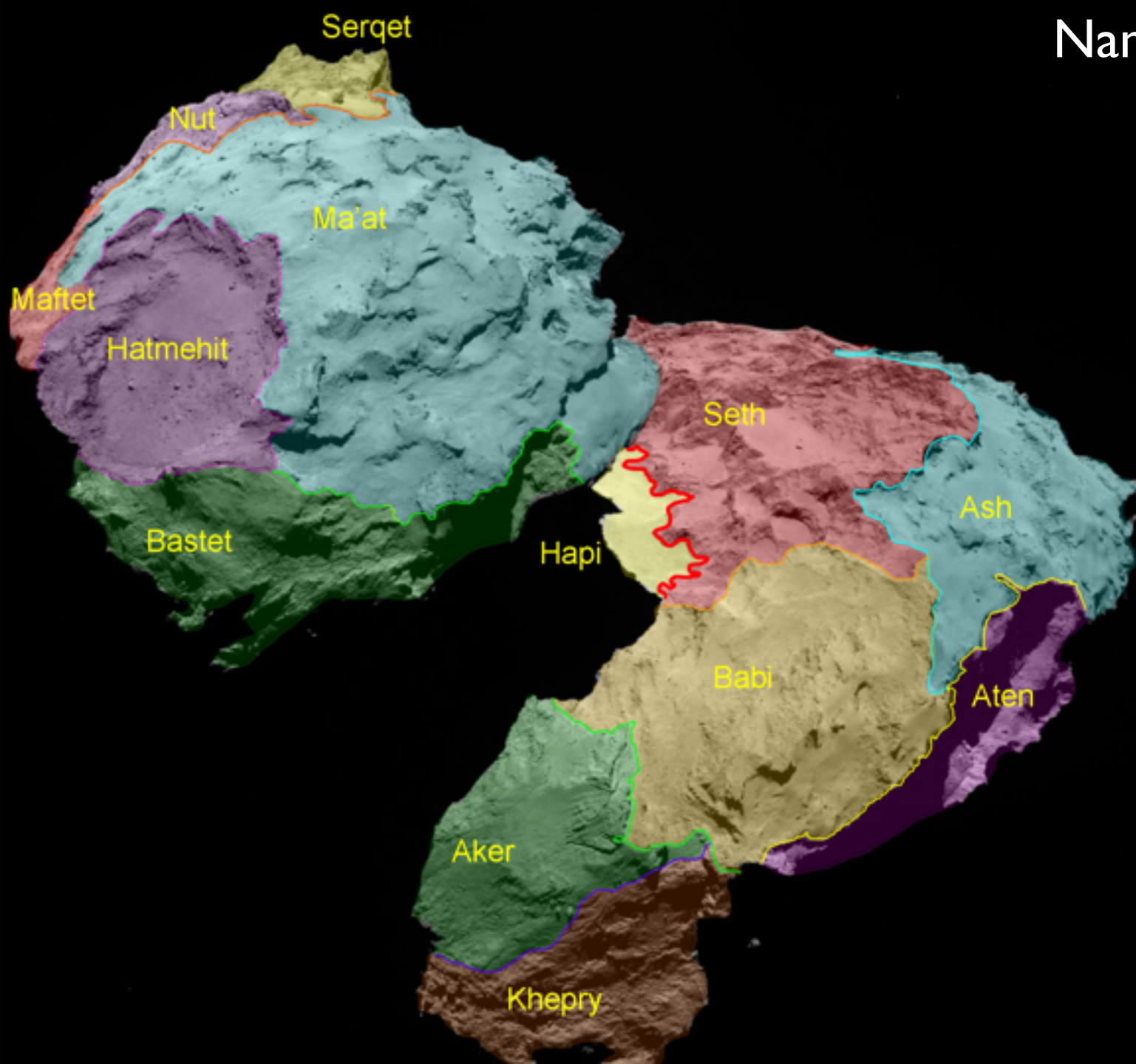
Empire State
Building
443 m

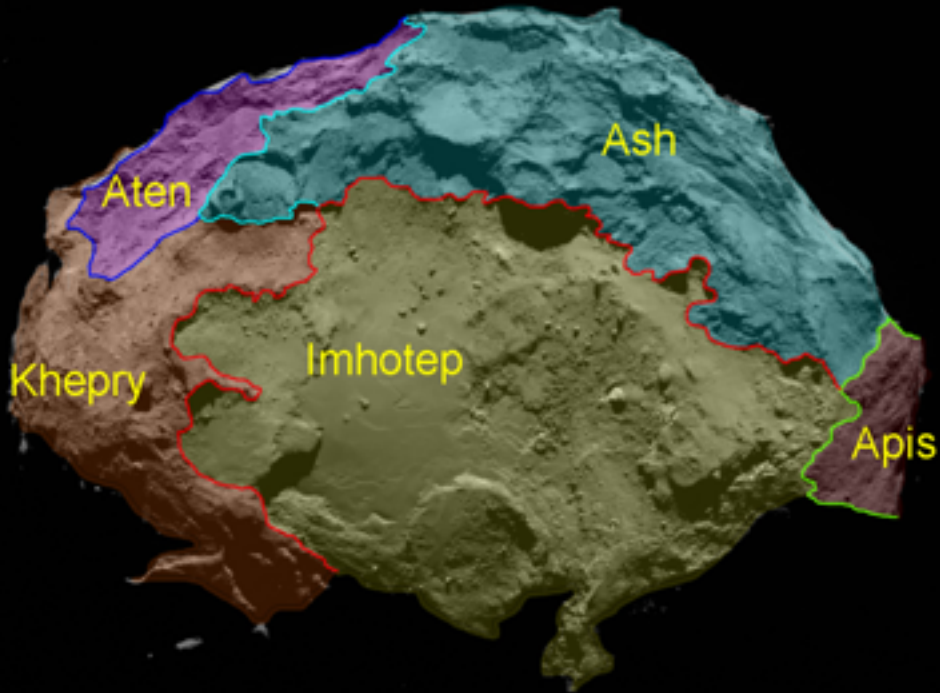
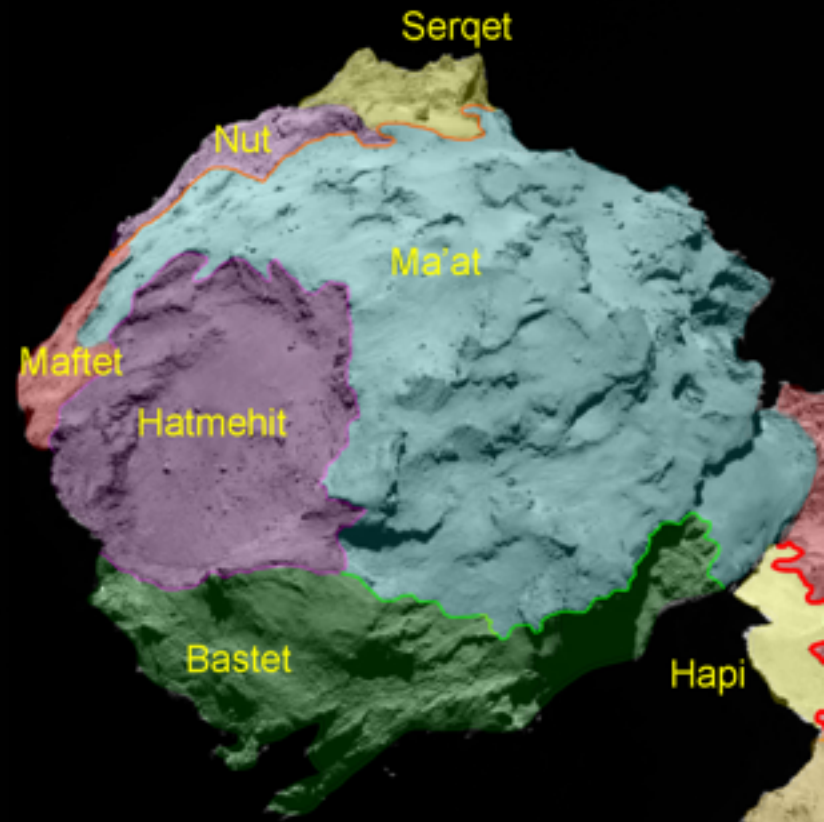
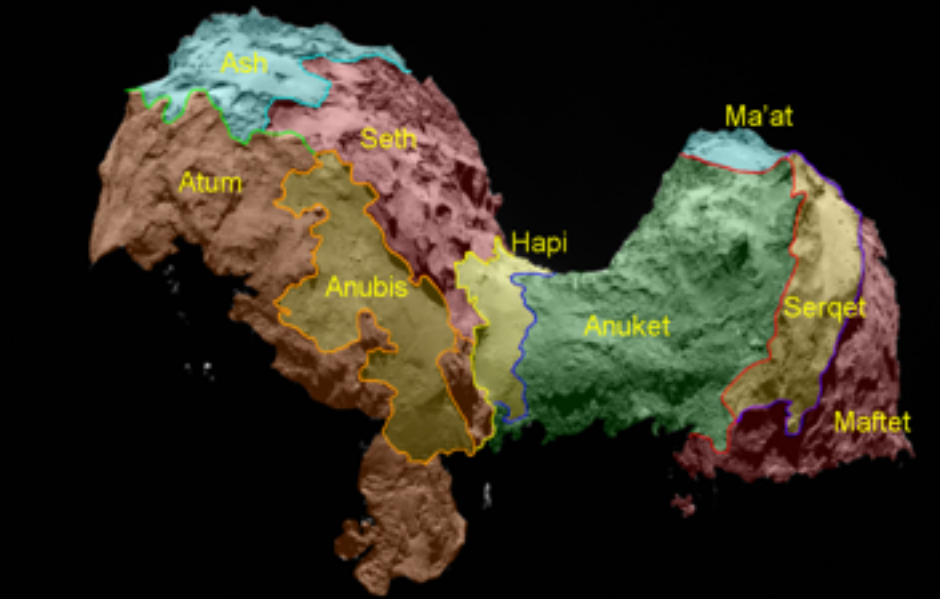
Eiffel
Tower
324 m

The Great
Pyramid of Giza
147 m



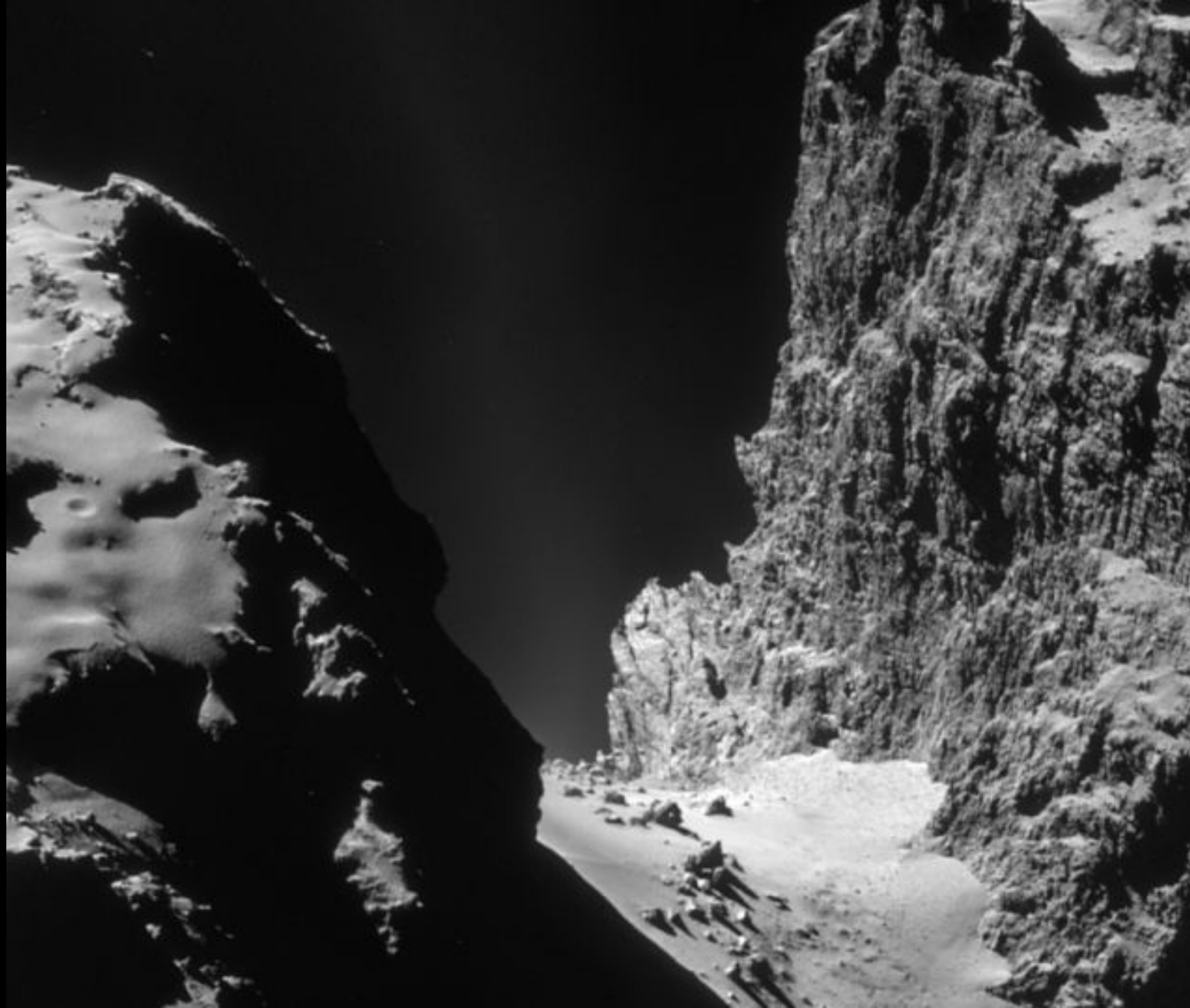
Named regions





Named regions

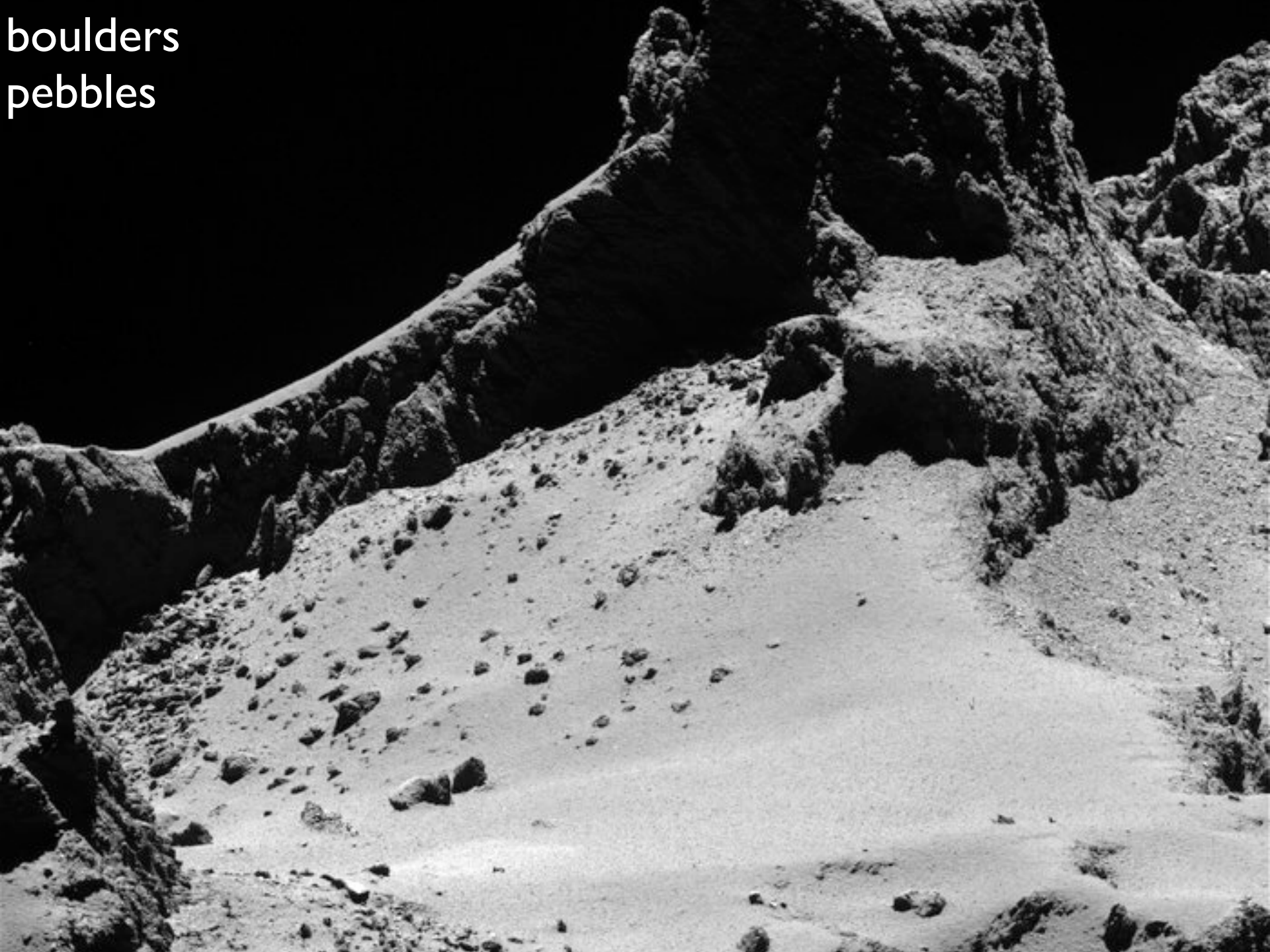
cliffs



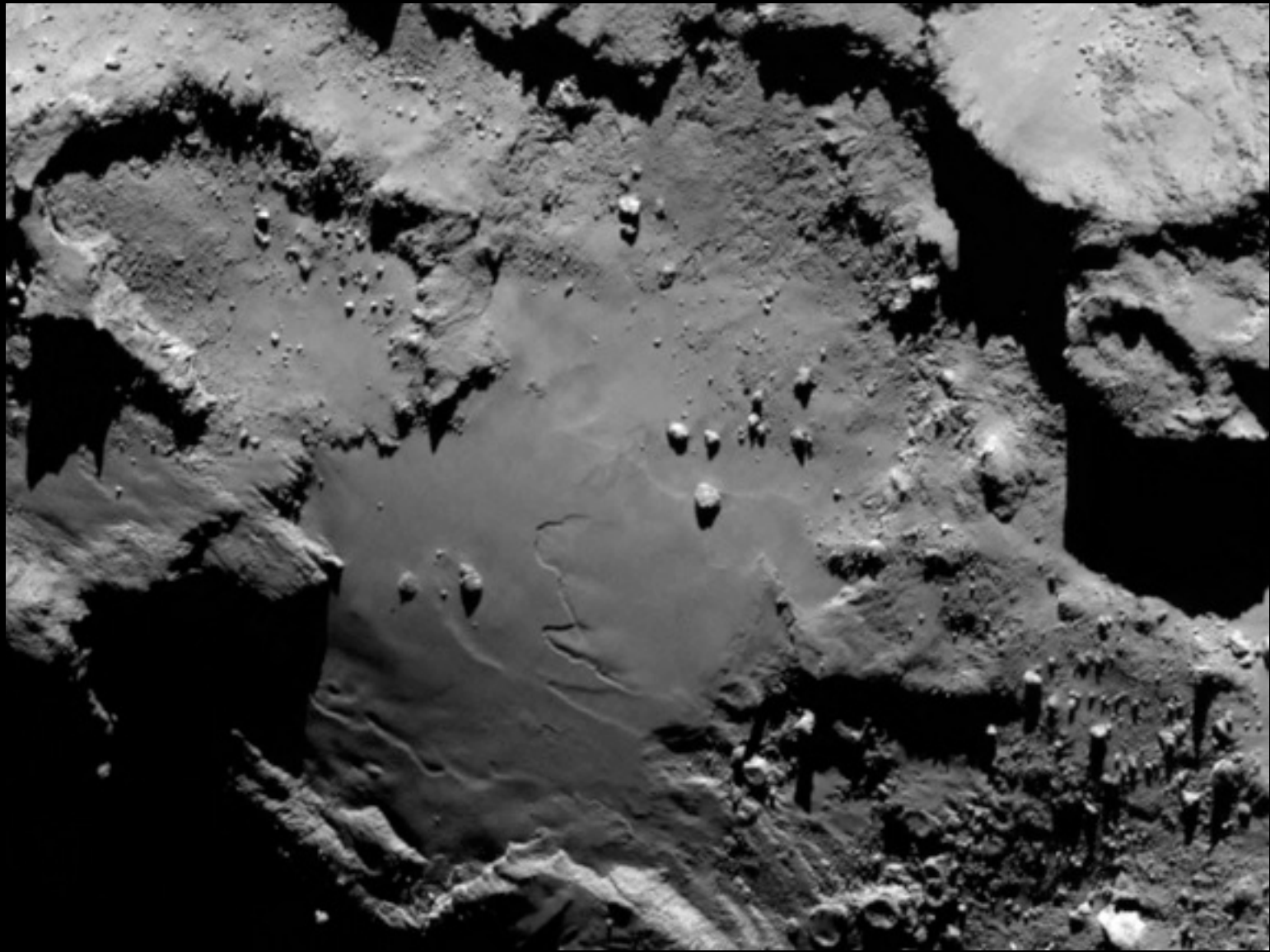
outcrops



boulders
pebbles



sand



“goosebumps” & sinkholes



ROSINA has detected many molecules:

Water (H_2O)

Carbon monoxide (CO)

Carbon dioxide (CO_2)

Ammonia (NH_3)

Methane (CH_4)

Methanol (CH_3OH)

Formaldehyde (CH_2O)

Hydrogen sulphide (H_2S)

Hydrogen cyanide (HCN)

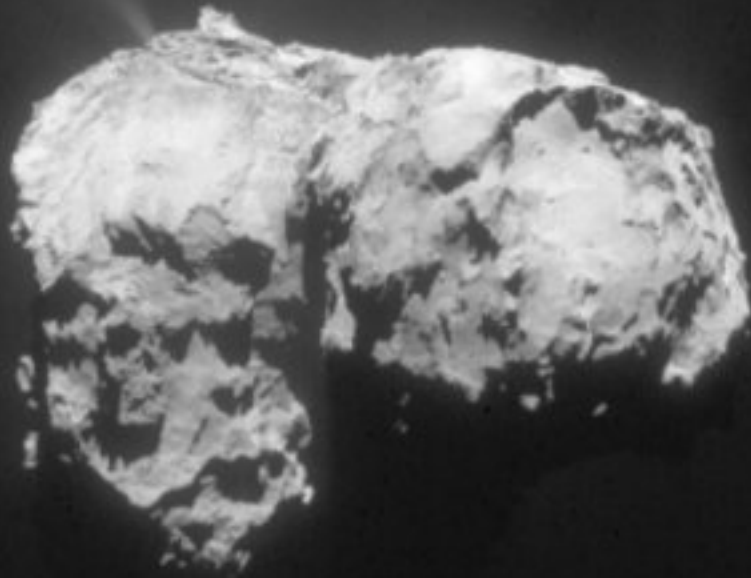
Sulphur dioxide (SO_2)

Carbon disulphide (CS_2)

Comet 67P

Became moderately
active as it passed the
sun (perihelion Nov. 2015)

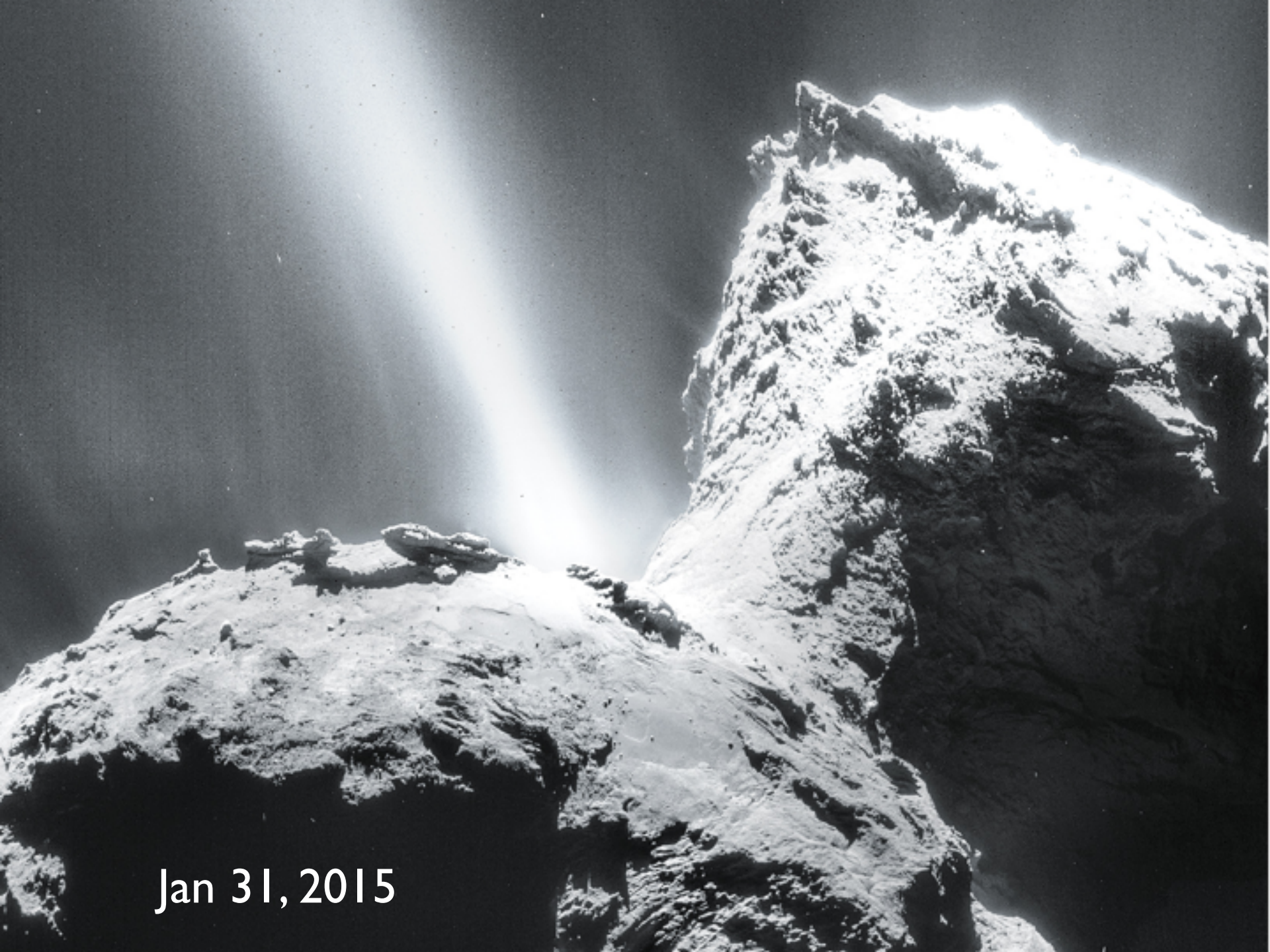




Nov 13, 2014

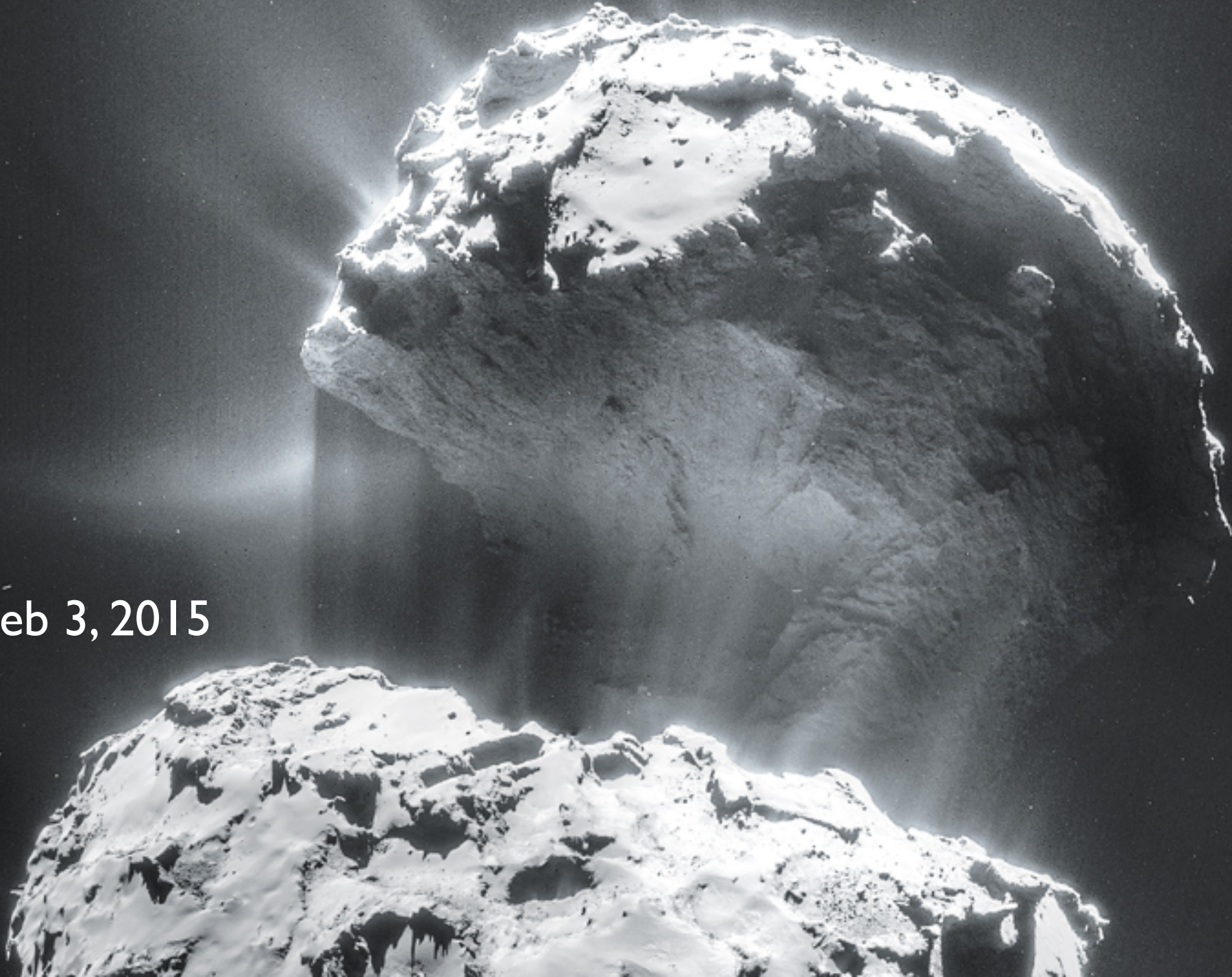


Nov 22, 2014

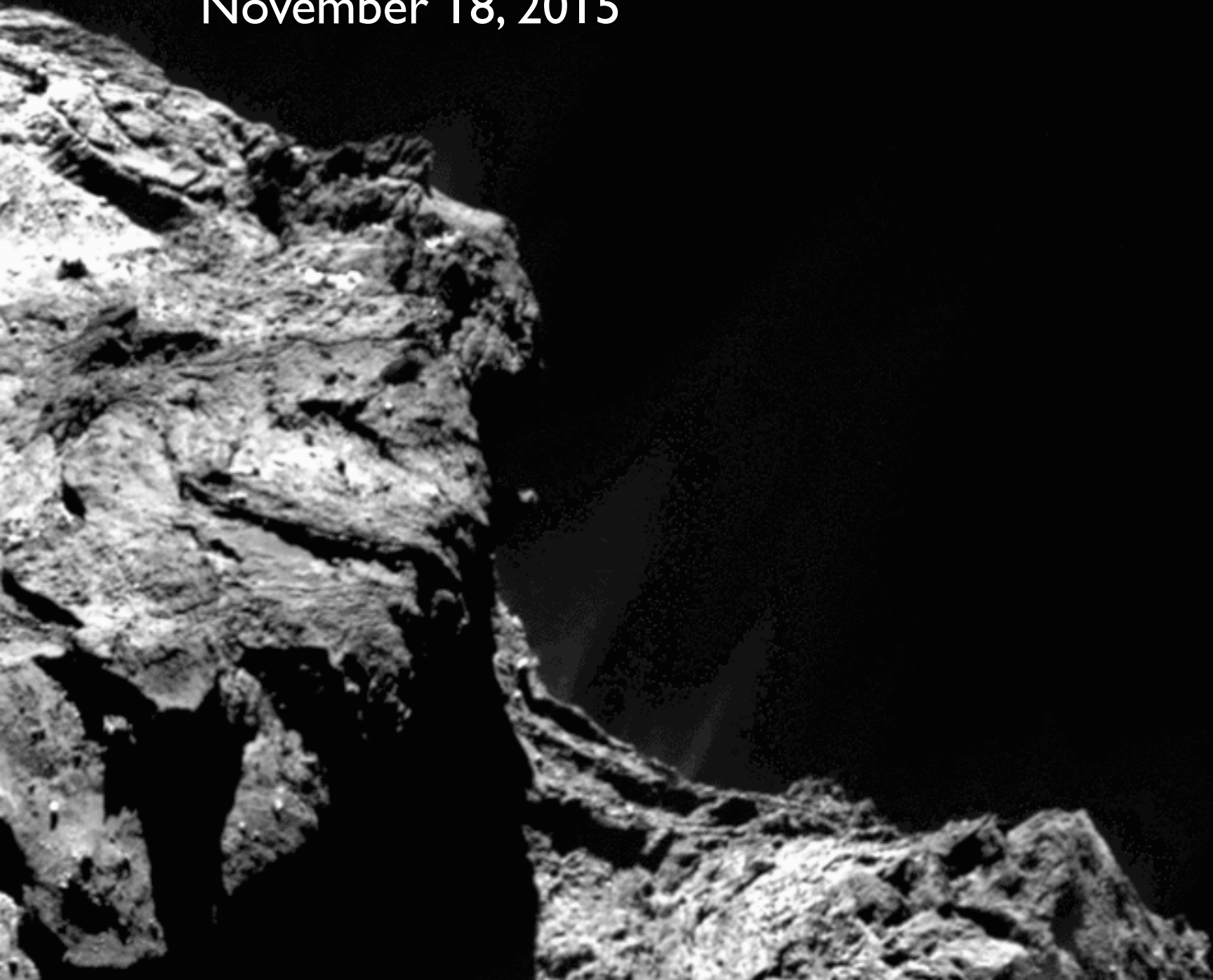


Jan 31, 2015

Feb 3, 2015

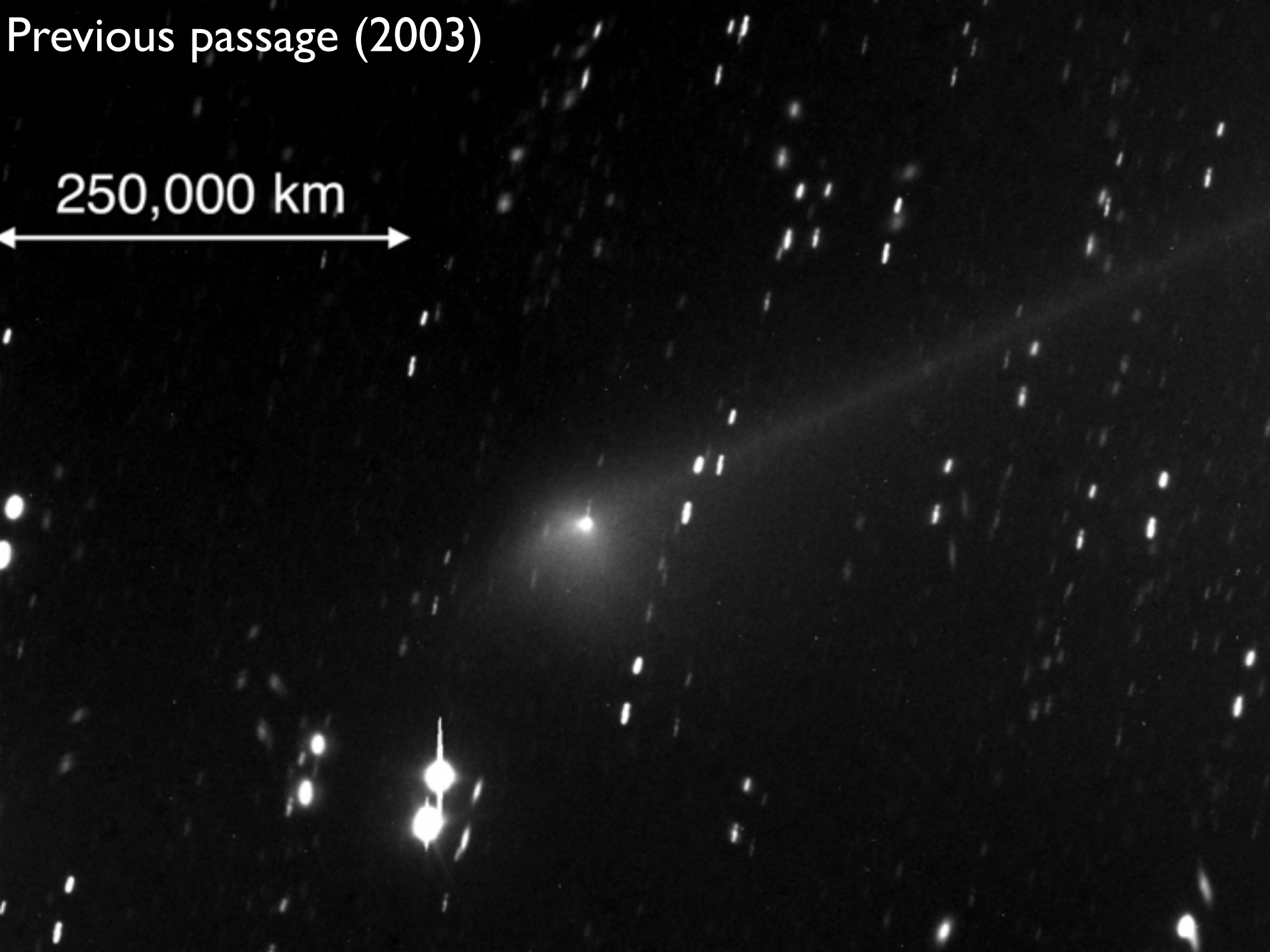


November 18, 2015

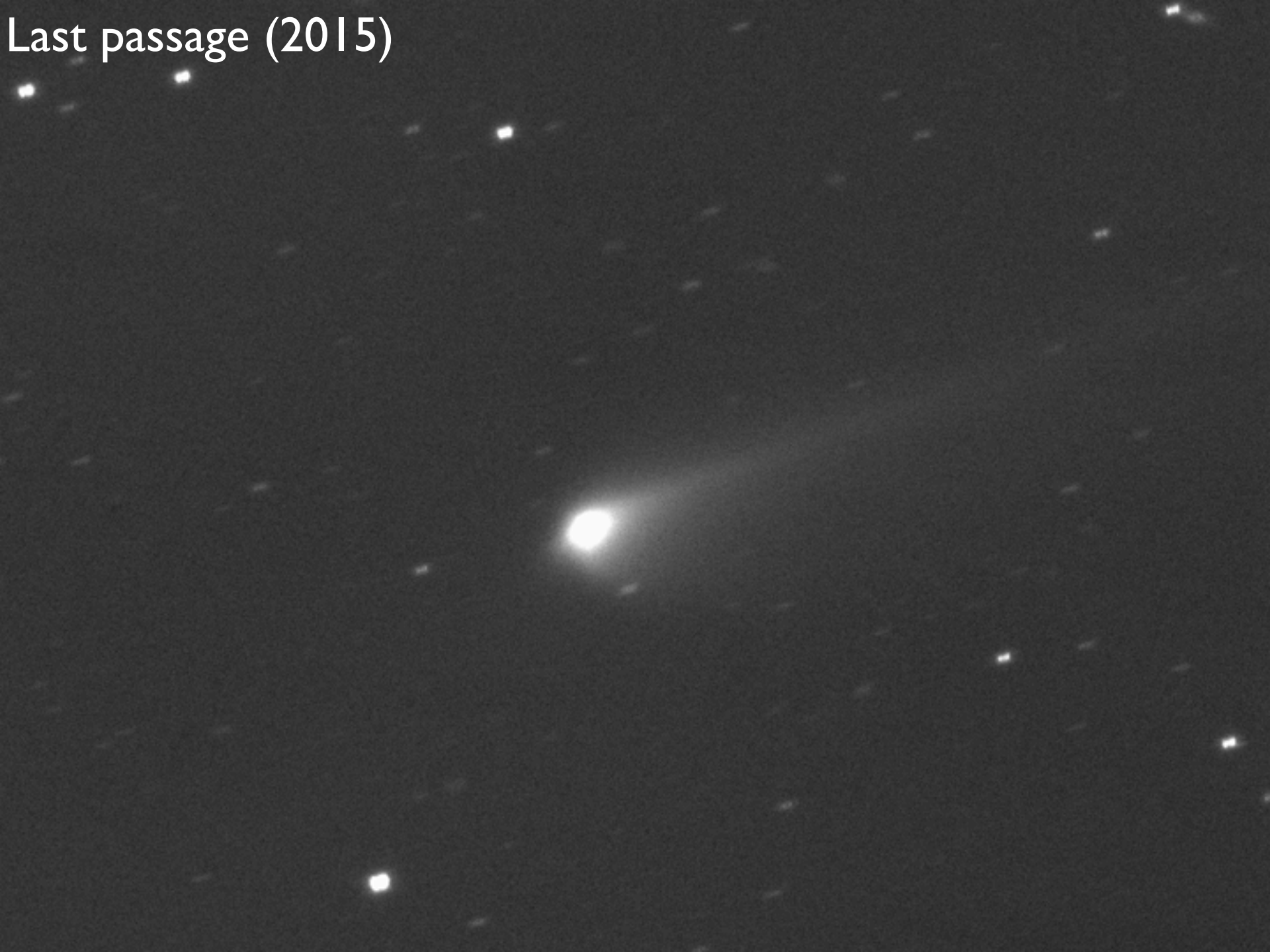


Previous passage (2003)

250,000 km



Last passage (2015)



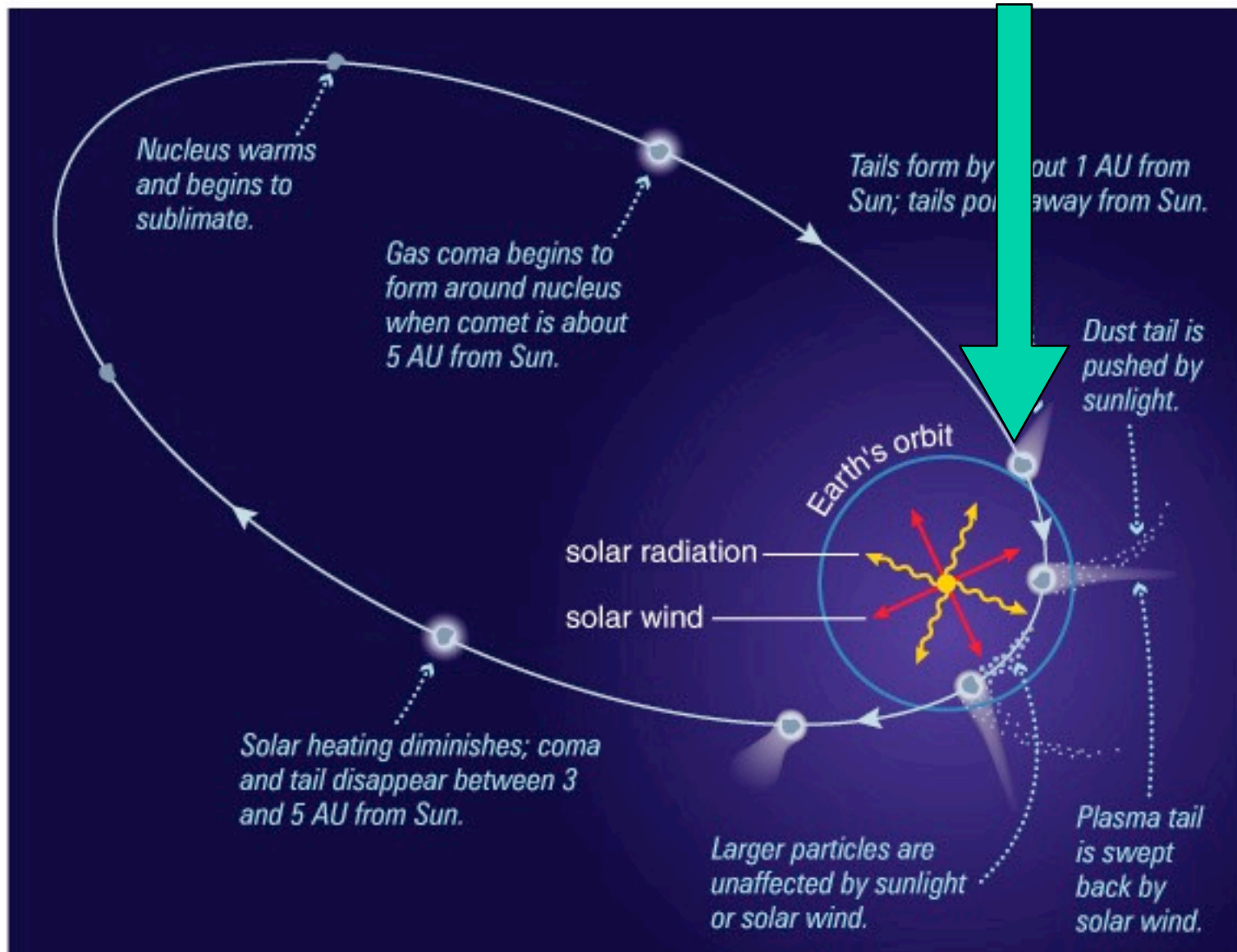
Comet debris: meteoroids



Comets eject small particles (**meteoroids**) that follow the comet around in its orbit and cause meteor showers when Earth crosses the comet's orbit.

Annual meteor showers

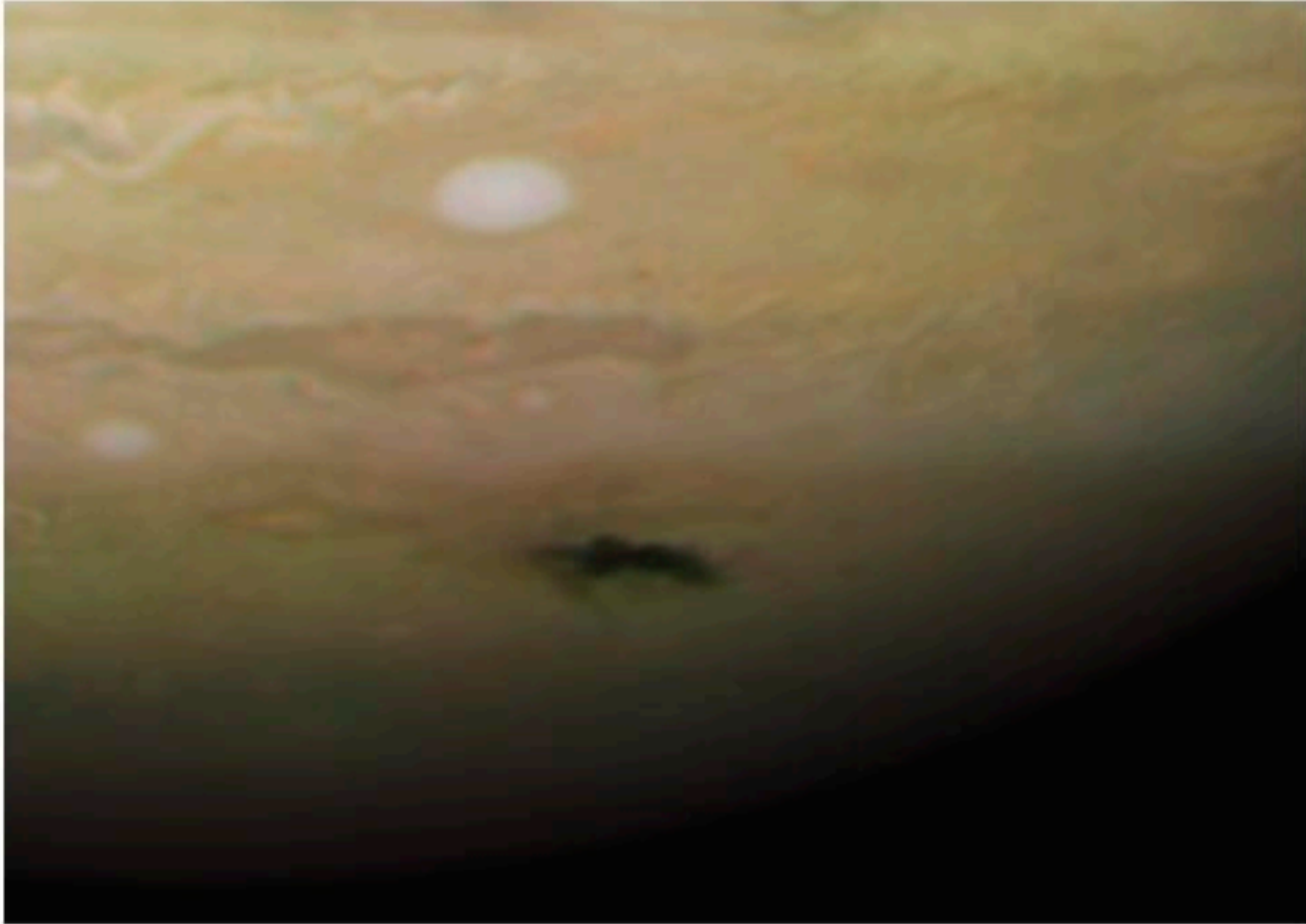
Happen when Earth's orbit intersects a comet's orbit strewn with meteoroids

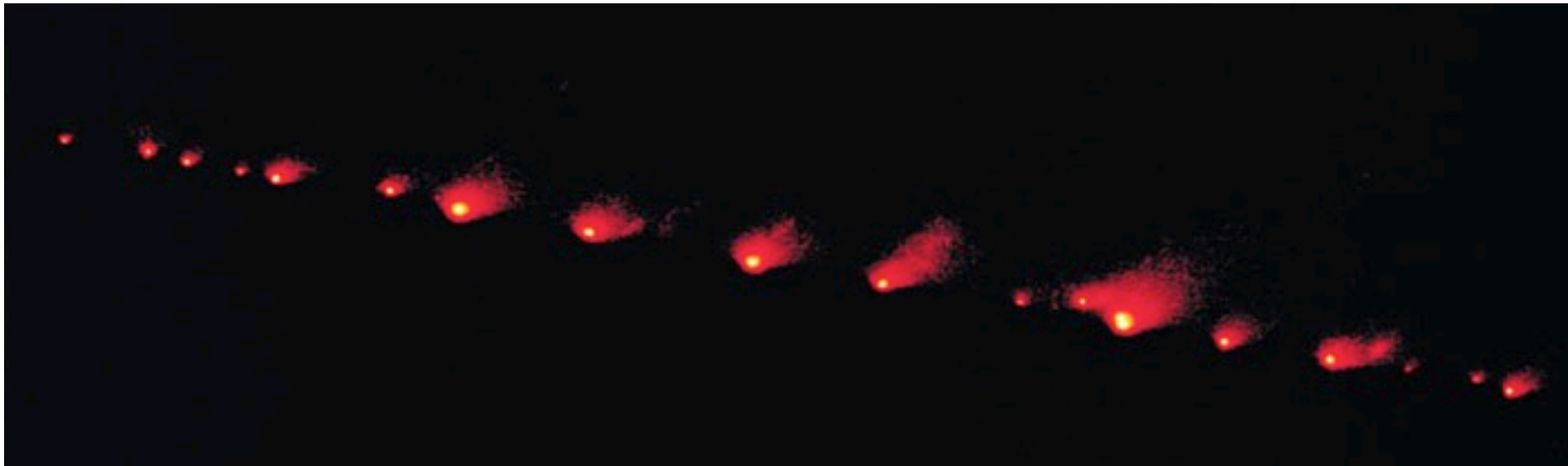


Big meteor
shower:
Comet 67P
compared
to Boston



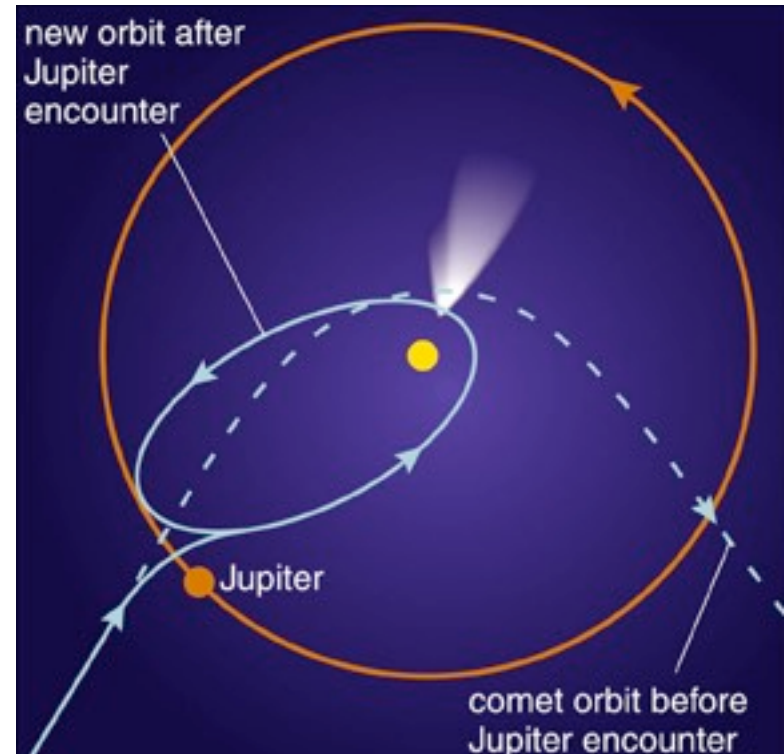
Have we ever witnessed a major impact?

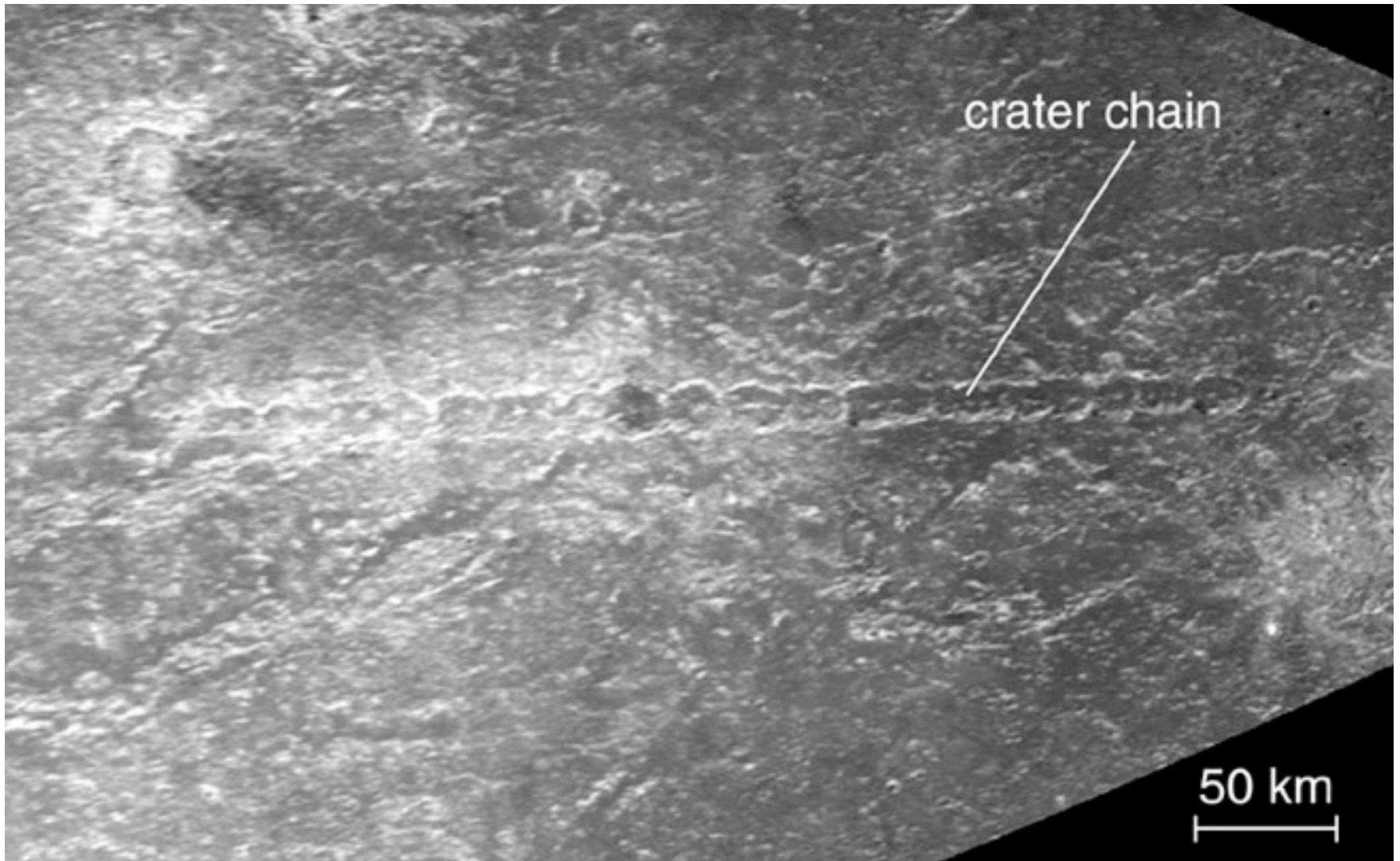




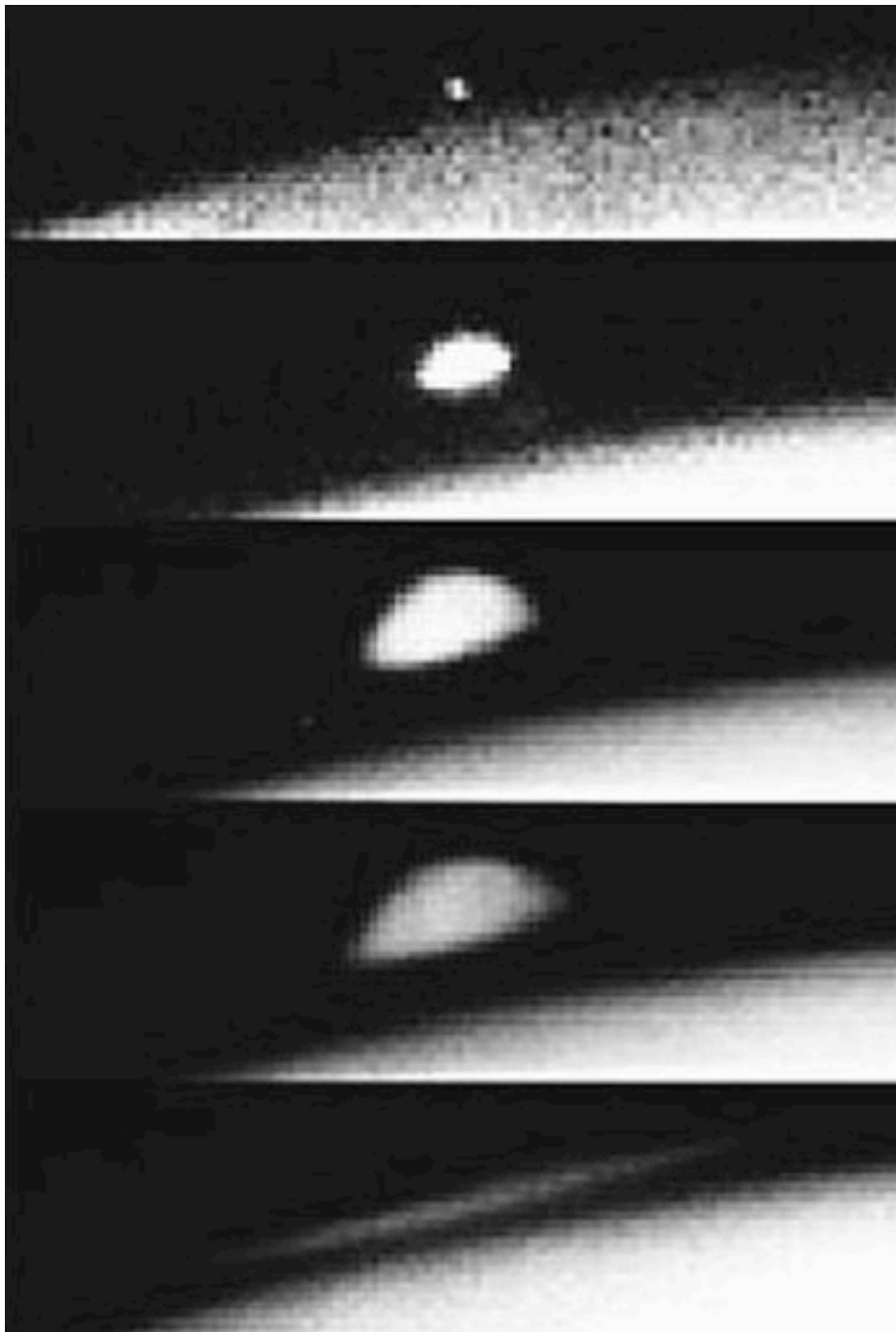
Comet SL9 caused a string of violent impacts on Jupiter in 1994, reminding us that catastrophic collisions still happen.

Tidal forces tore it apart during a previous encounter with Jupiter.





This crater chain on Callisto probably came from another comet that tidal forces tore to pieces.

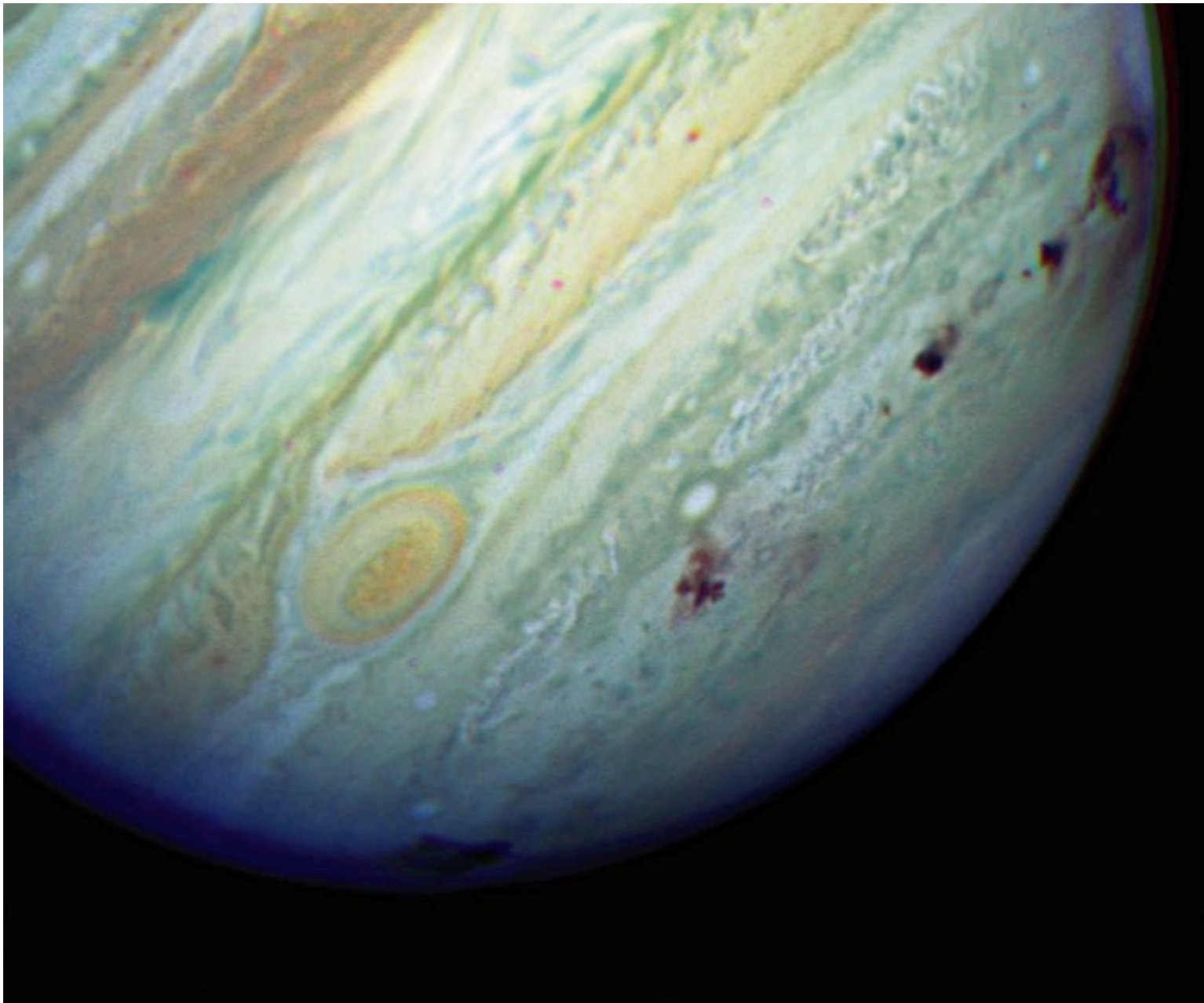


Impact plume
from a fragment
of comet SL9
rises high above
Jupiter's surface

See movies in
`/Users/ssm/Documents/Courses/
UMd/misc_movies/cometSL9`



Impact sites in infrared light



Several impact sites