Today

- more gravity & orbits
- Tides

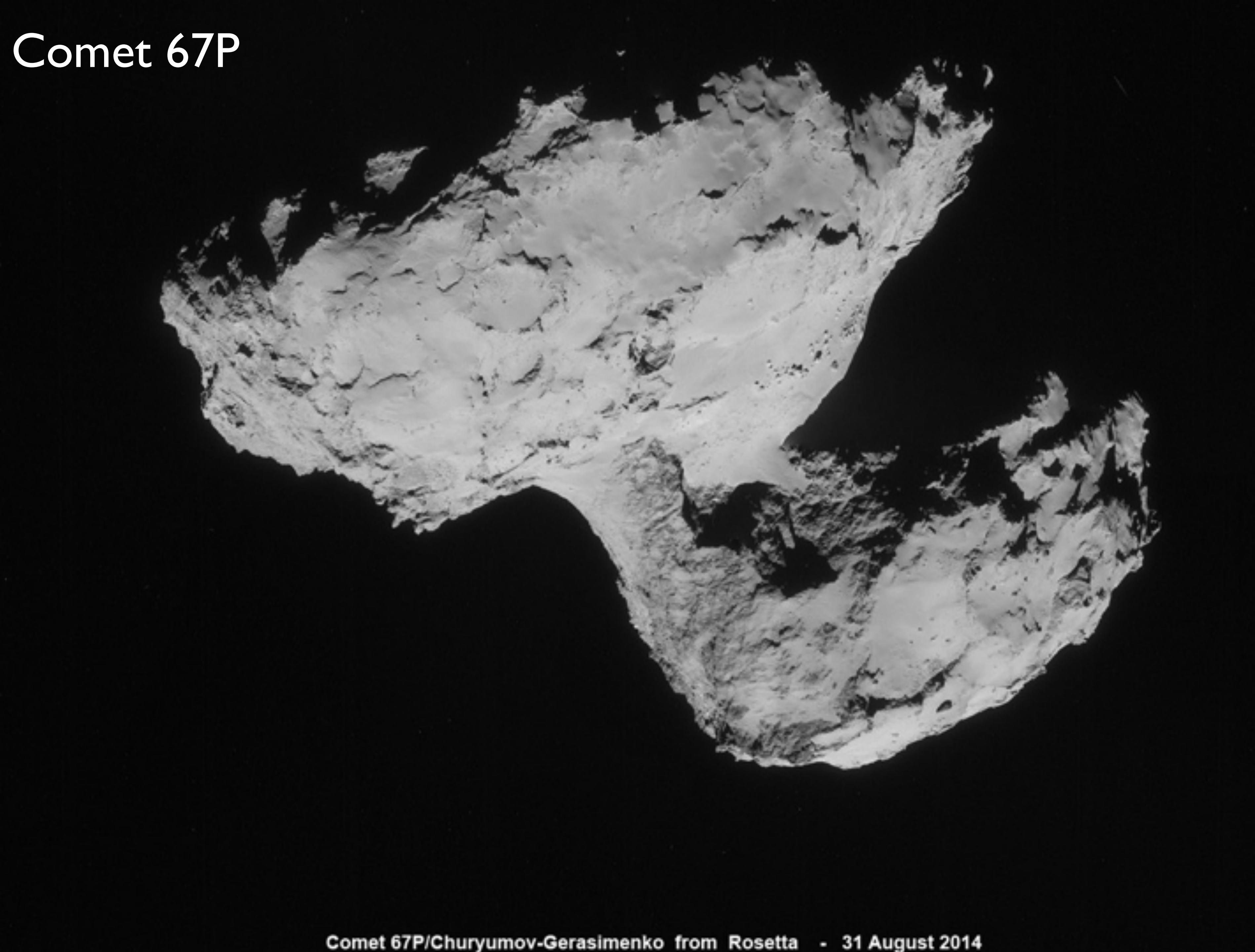
Events

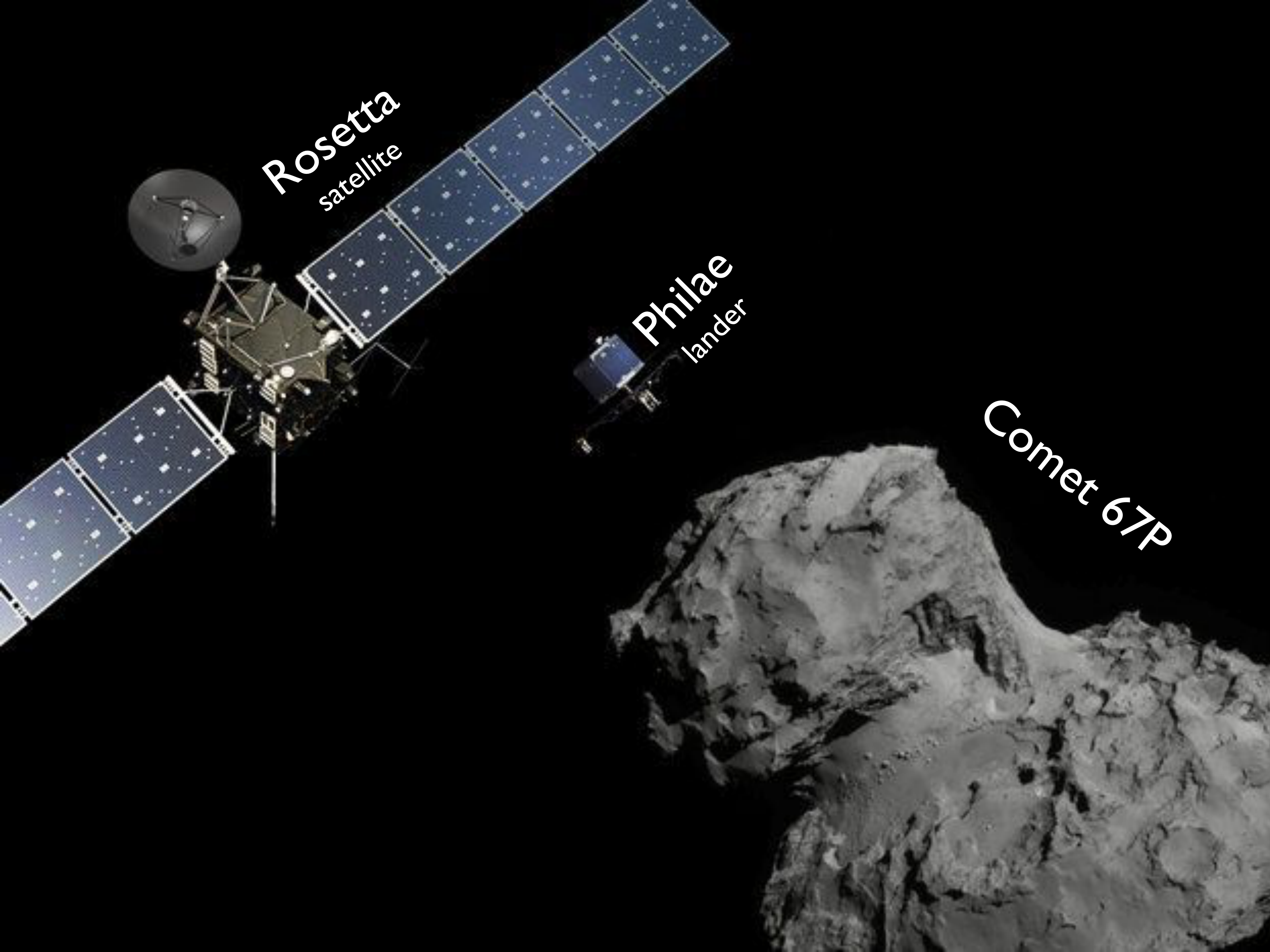
- Homework Due Next time; Exam reiview (Sept. 27)
- Exam I on Sept. 29 (one week)

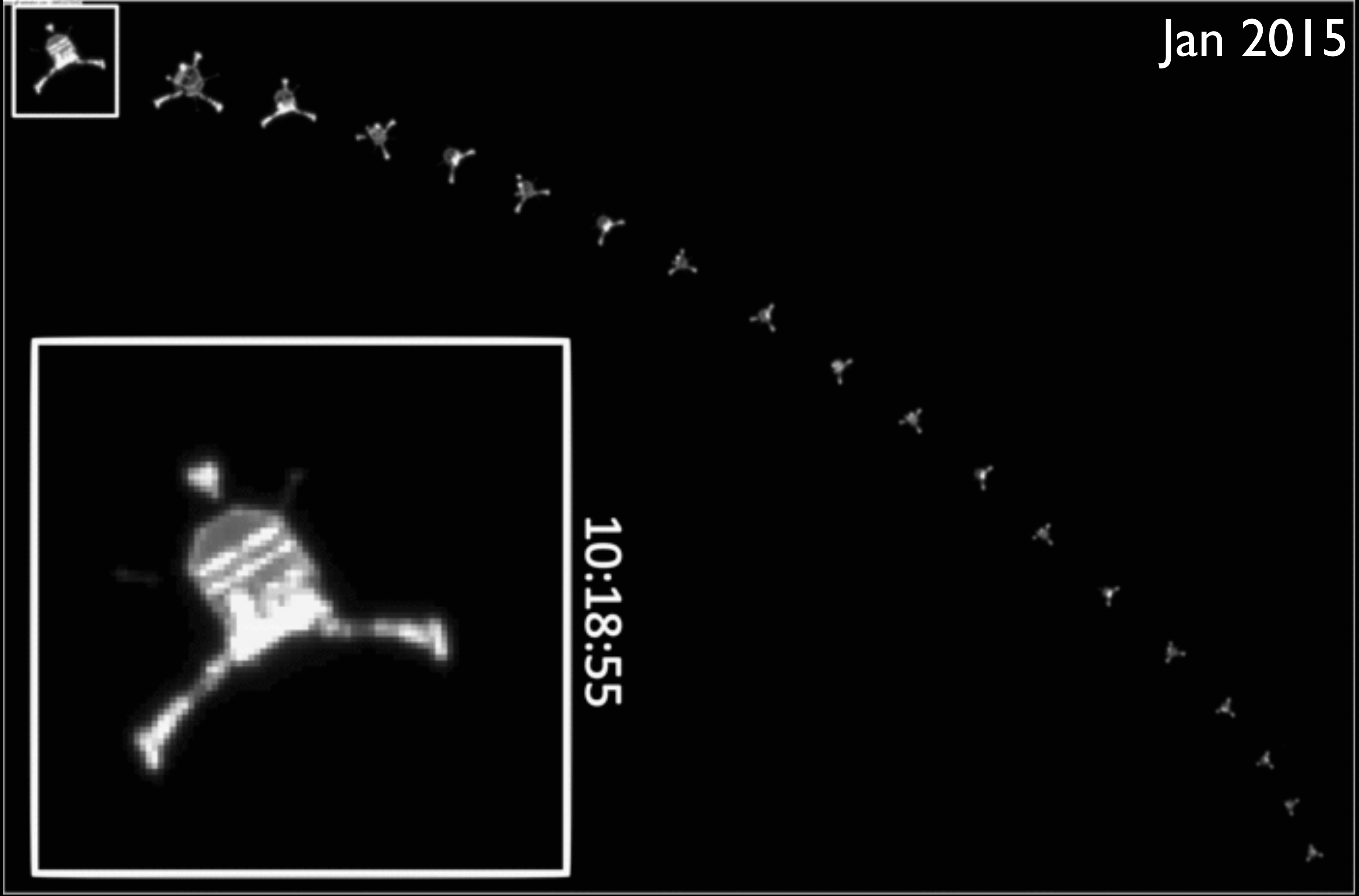
Notable

- Fall equinox (Sept. 22 - today, at 10:21AM)
- Rosetta mission end Sept. 30

Comet 67P


Comet 67P/Churyumov-Gerasimenko from Rosetta - 31 August 2014

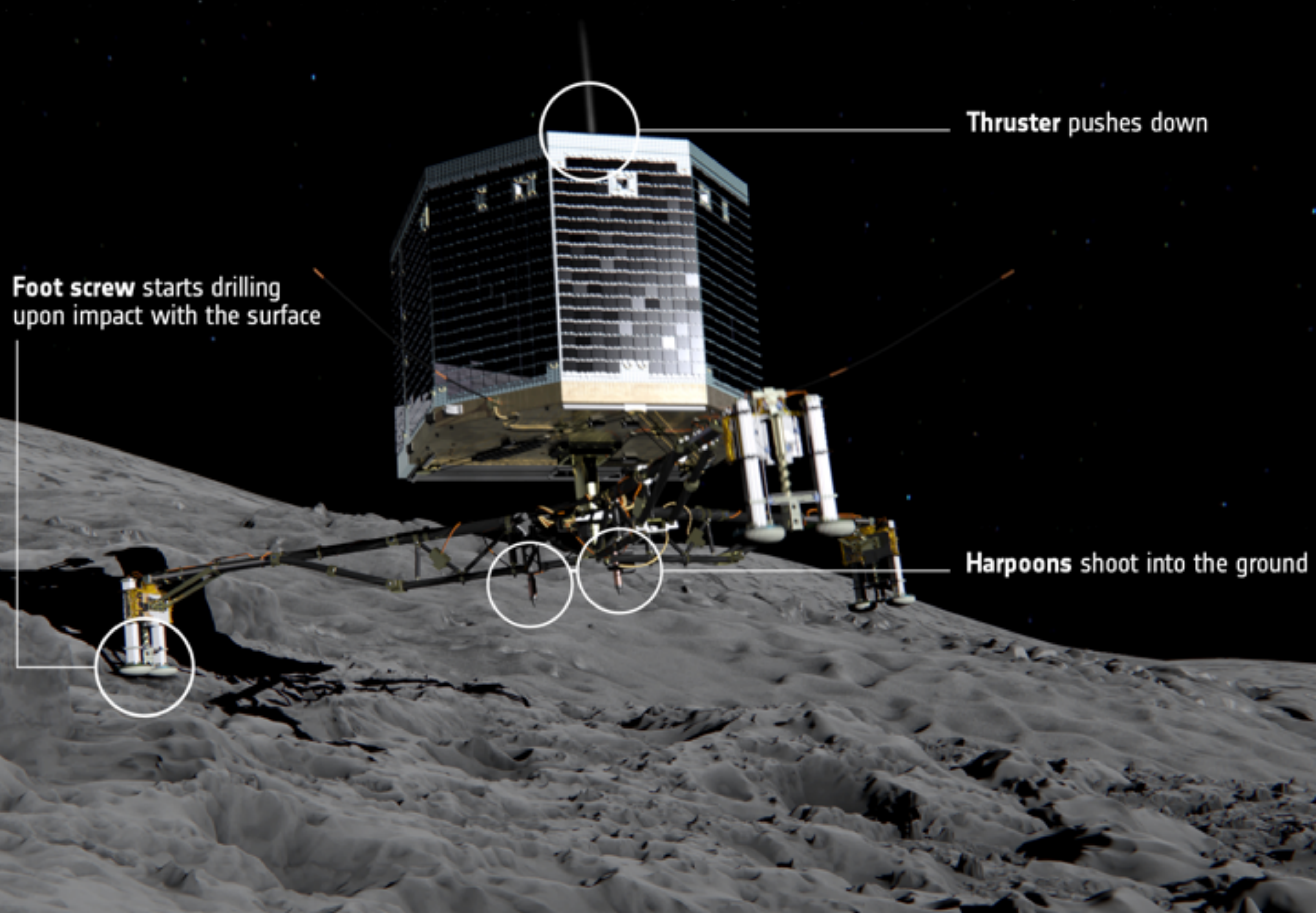

Rosetta
satellite
Philae
lander
Comet 67P

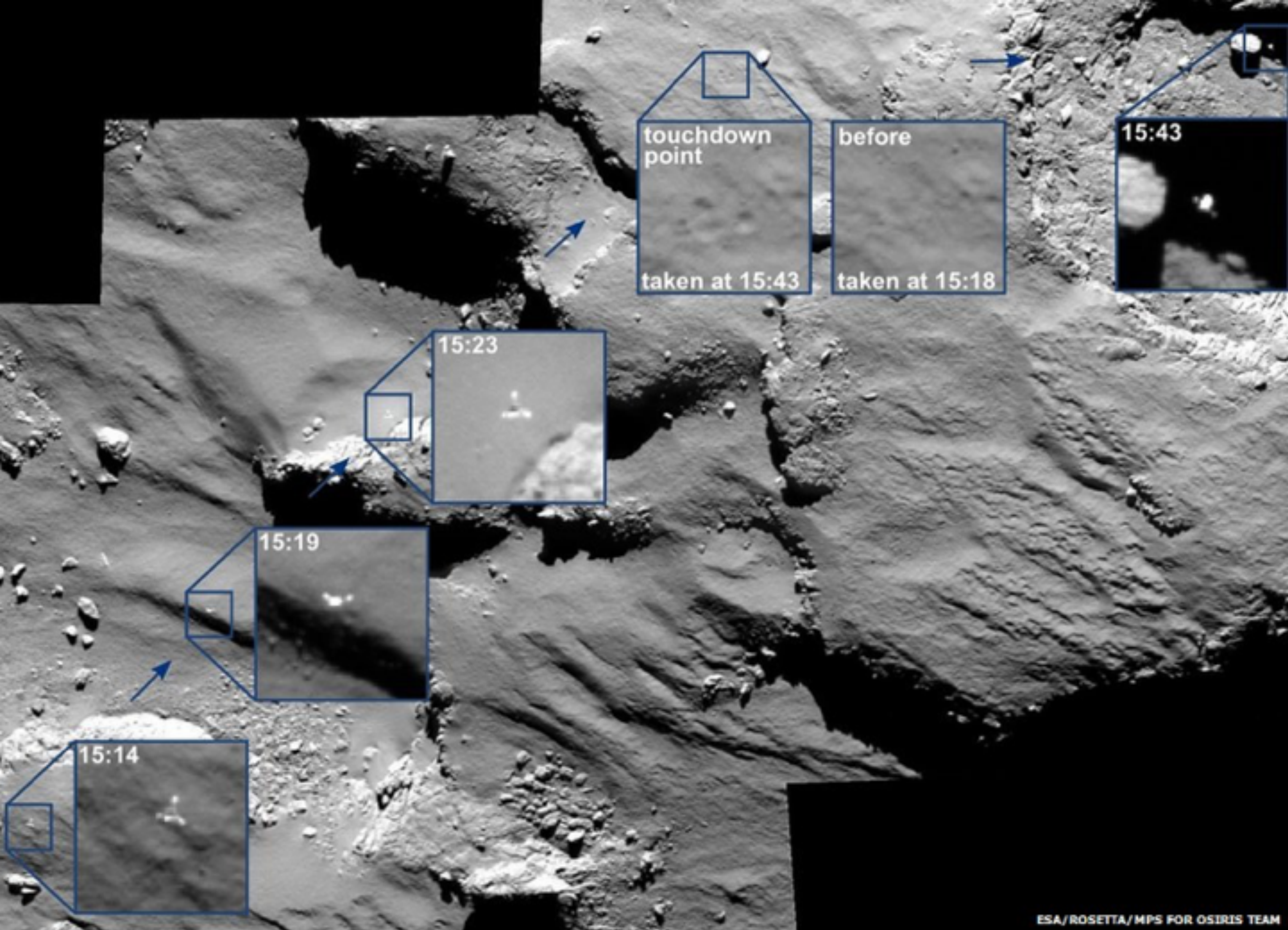


Jan 2015

http://www.esa.int/spaceinimages/Images/2015/01/Philae_descends_to_the_comet

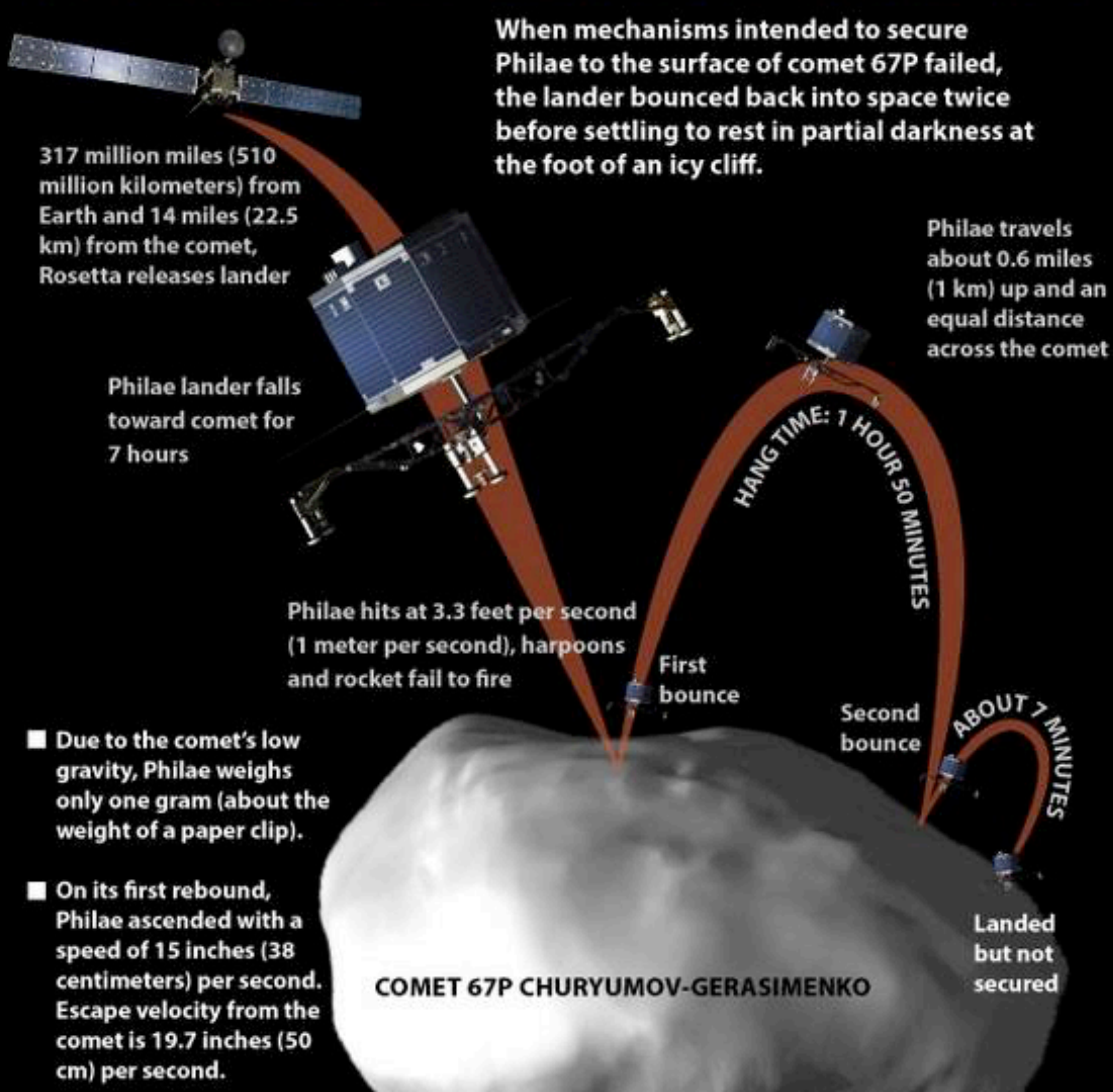
A thruster, harpoon, & screws planned to hold Philae down

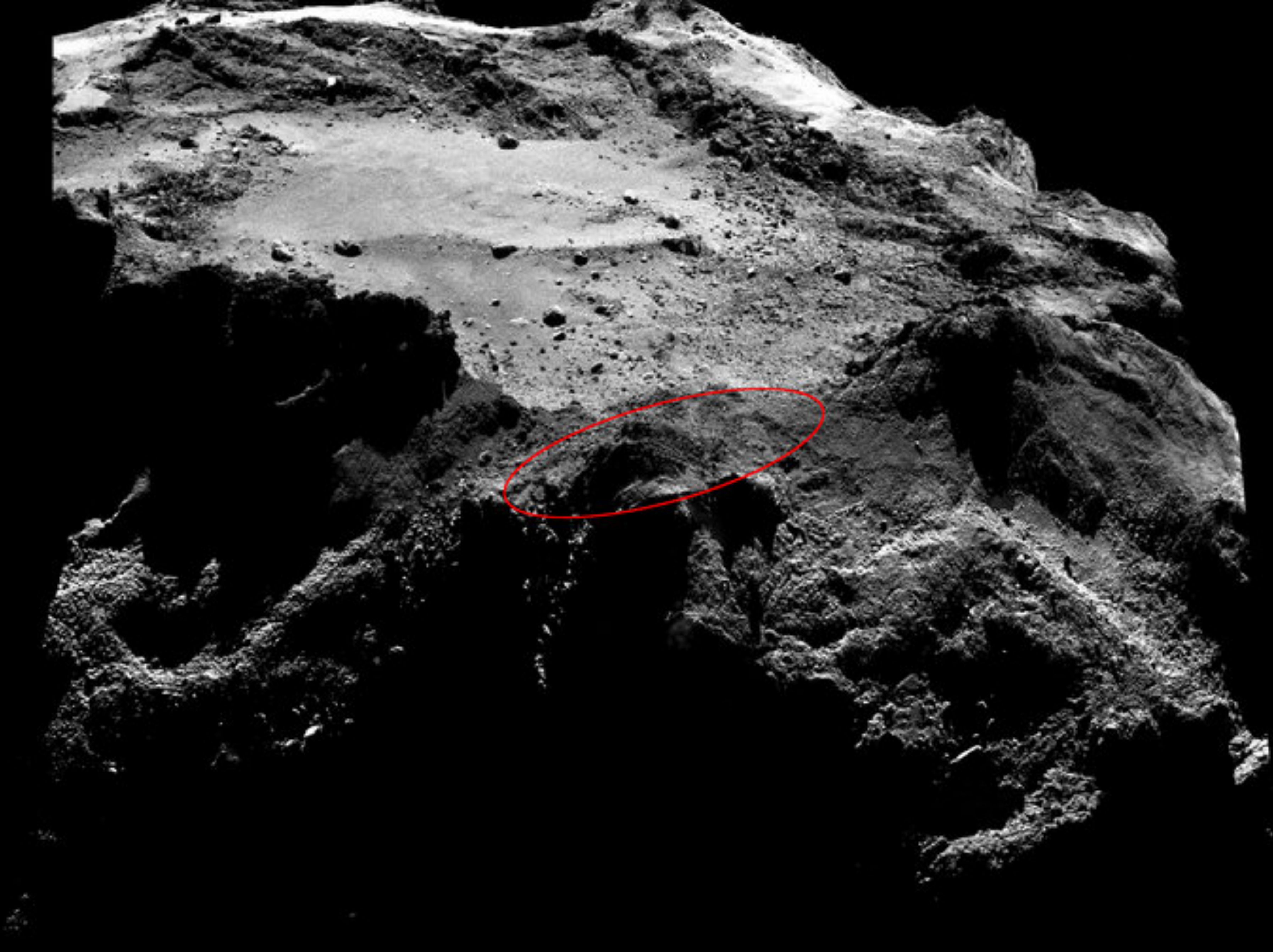




touchdown point
taken at 15:43
before
taken at 15:18
15:43
15:23
15:19
15:14
ESA/ROSETTA/MPS FOR OSIRIS TEAM

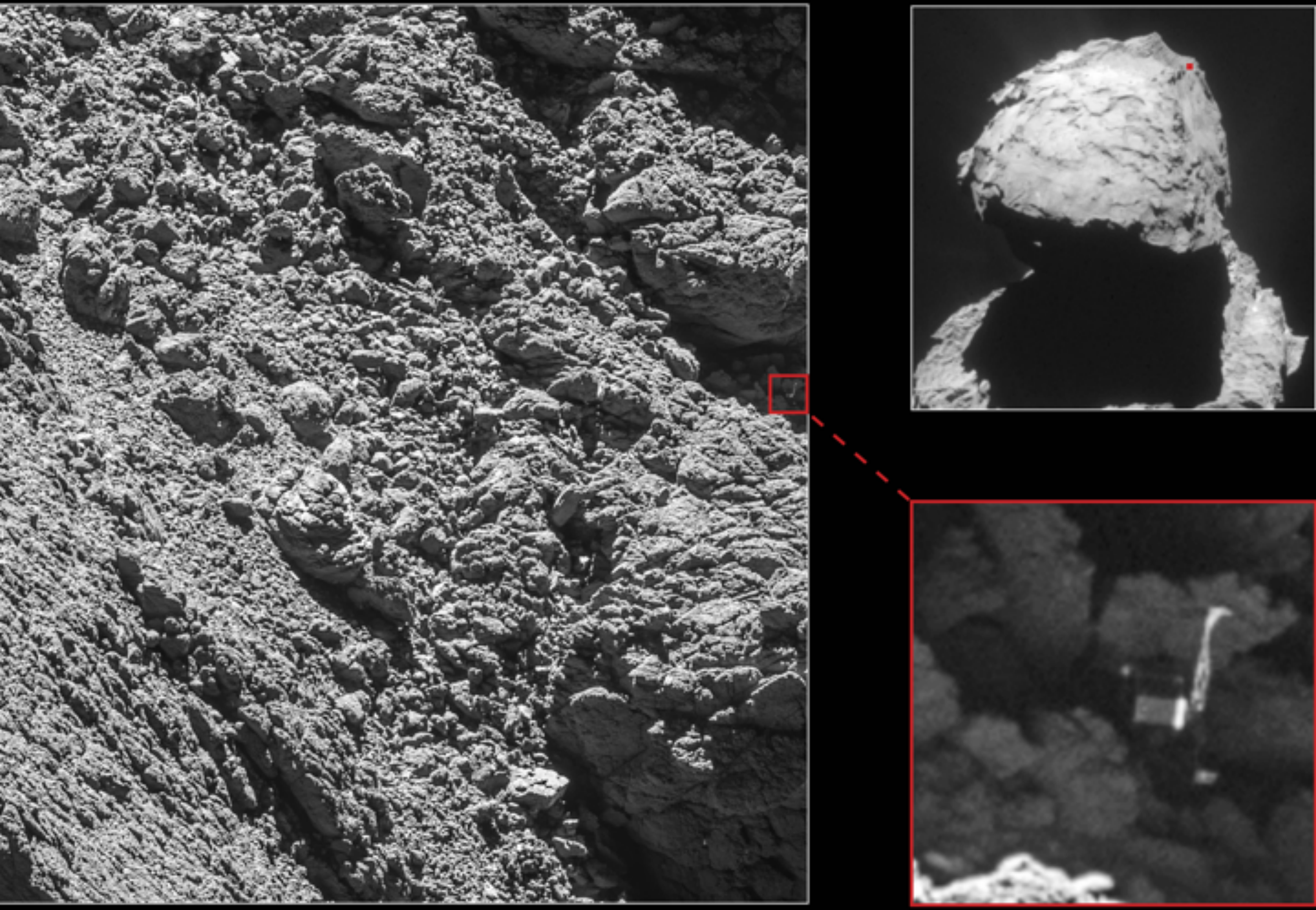
Philae bounced twice

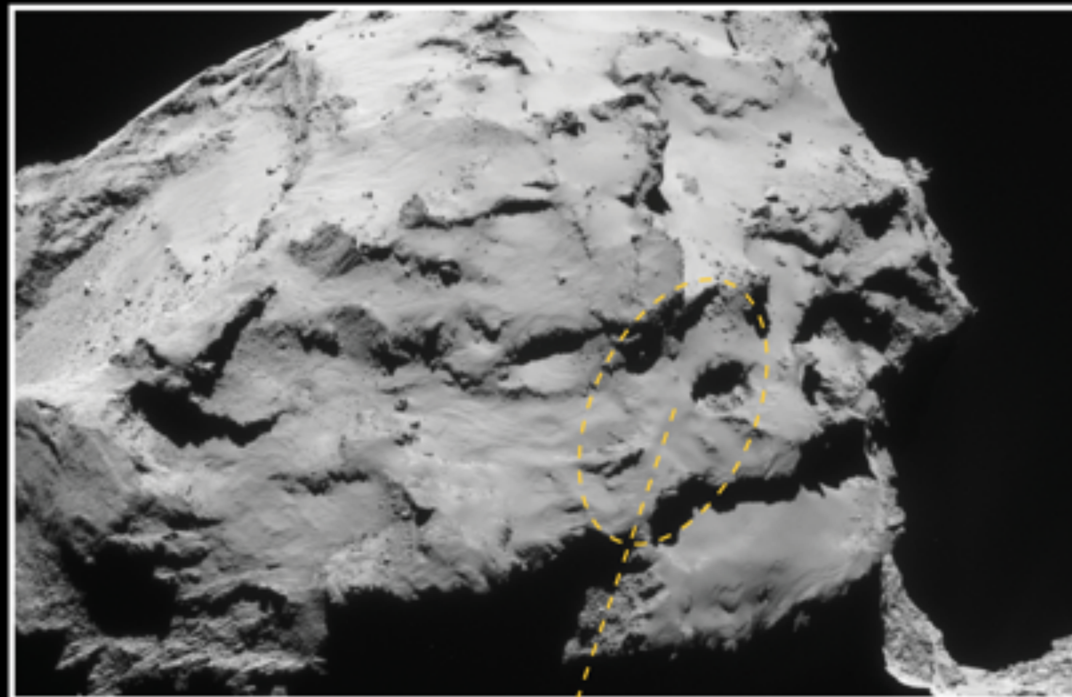




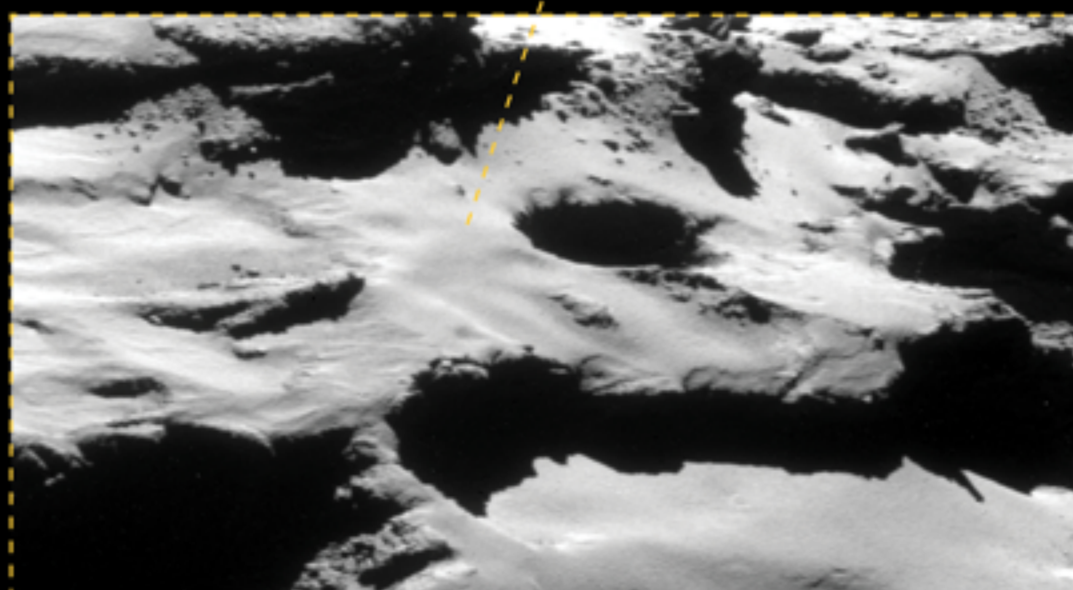
Picture taken by Philae

Philae found 2 September 2016 as the orbiter came within 2.7 km of the surface





Rosetta will end its mission with a controlled impact in the Ma’at region, on the small lobe of Comet 67P



Kepler's Third Law

$$P^2 = a^3$$

Newton's version of Kepler's Third Law

$$P^2 = \frac{4\pi^2}{G}\frac{a^3}{M}$$

p = orbital period

a = average orbital distance (between centers)

M = (M_1 + M_2) = sum of object masses

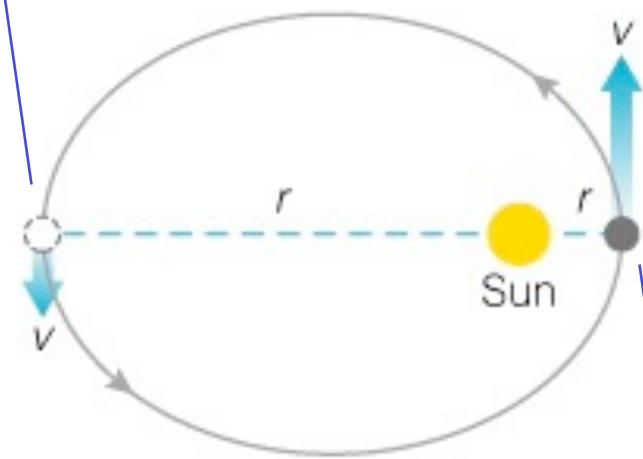
(basically the mass of the sun)

Orbits of the Moons of Jupiter

Moon	P (days)	a (km)	a^3/P^2 (solar masses)
Io	1.8	4×10^5	0.001
Europa	3.6	7×10^5	0.001
Ganymede	7.2	1×10^6	0.001
Callisto	16.7	2×10^6	0.001

How do gravity and energy together allow us to understand orbits?

More gravitational energy;
Less kinetic energy



Less gravitational energy;
More kinetic energy

Total orbital energy stays constant.

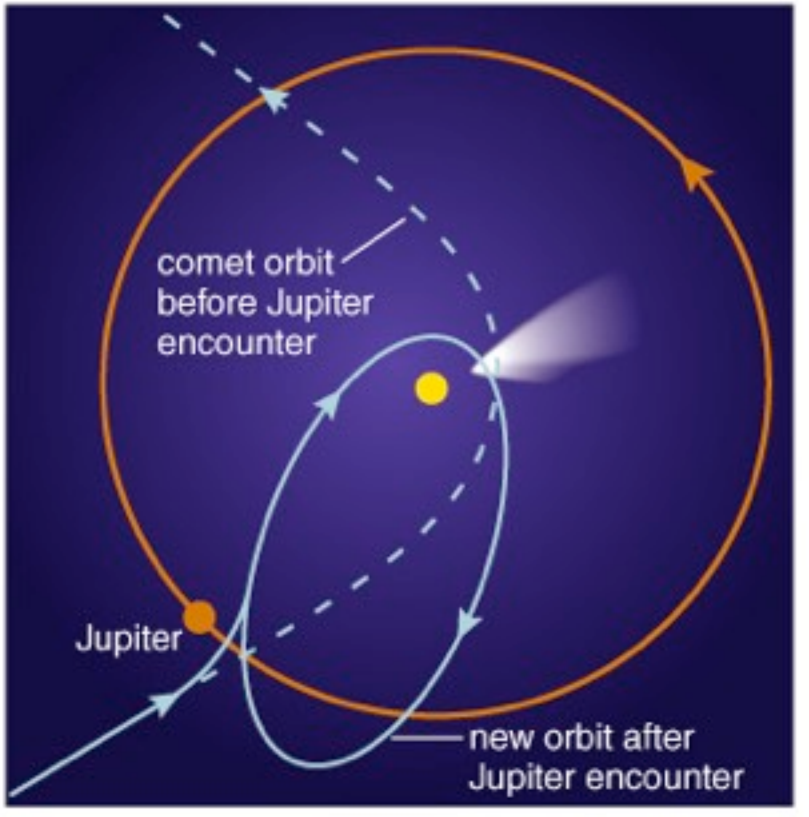
- Total orbital energy (gravitational + kinetic) stays constant if there is no external force.
- Orbits cannot change spontaneously.

Changing an Orbit

⇒ So what can make an object gain or lose orbital energy?

- Friction or atmospheric drag
- A gravitational encounter
- The thrust of a rocket

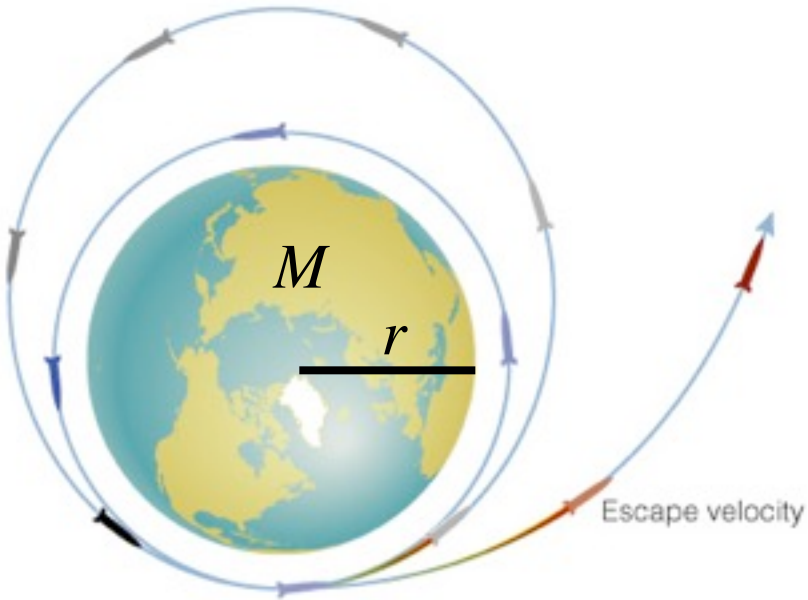
i.e., some external force



movie: Messenger orbit

https://www.youtube.com/watch?v=GXEuQtpreXE

Escape Velocity



- If an object gains enough orbital energy, it may escape (change from a bound to unbound orbit).
- **Escape velocity** from Earth ≈ 11 km/s from sea level (about 40,000 km/hr).

PLAY 04_02 canon ball 04_EscapeVEarth

Circular & Escape velocity

Circular velocity: $$v_{circ} = \sqrt{\frac{GM}{r}}$$

Escape velocity: $$v_{esc} = \sqrt{\frac{2GM}{r}} = \sqrt{2}v_{circ}$$

Examples:

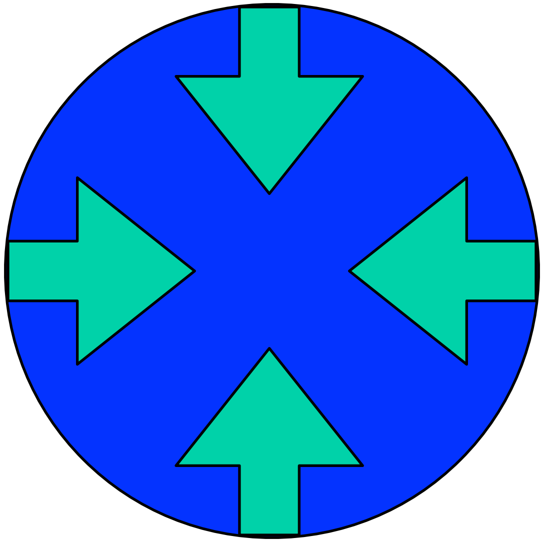
Object	circular speed at surface	escape speed from surface
Earth	7.8 km/s	11 km/s
Sun	436 km/s	617 km/s
Moon	1.7 km/s	2.4 km/s

What have we learned?

- What determines the strength of gravity?
  - Directly proportional to the *product* of the masses ($M \times m$)
  - *Inversely* proportional to the *square* of the separation
- How does Newton's law of gravity allow us to extend Kepler's laws?
  - Applies to other objects, not just planets
  - Includes unbound orbit shapes: parabola, hyperbola as well as bound ellipse
  - Can be used to measure mass of orbiting systems

Why are stars and planets spherical?

- Gravity pulls - it is an attractive force
- IF self-gravity is the most important force holding an object together, it must be spherical.



Example: Earth

- Diameter of Earth: 12,756 km
- Mt. Everest: 8.848 km above sea level
- Mariana Trench: 10.934 km below
- Maximum variation: 19.782 km

$$\frac{\text{maximum variation}}{\text{diameter}} = \frac{19.782}{12,756}$$

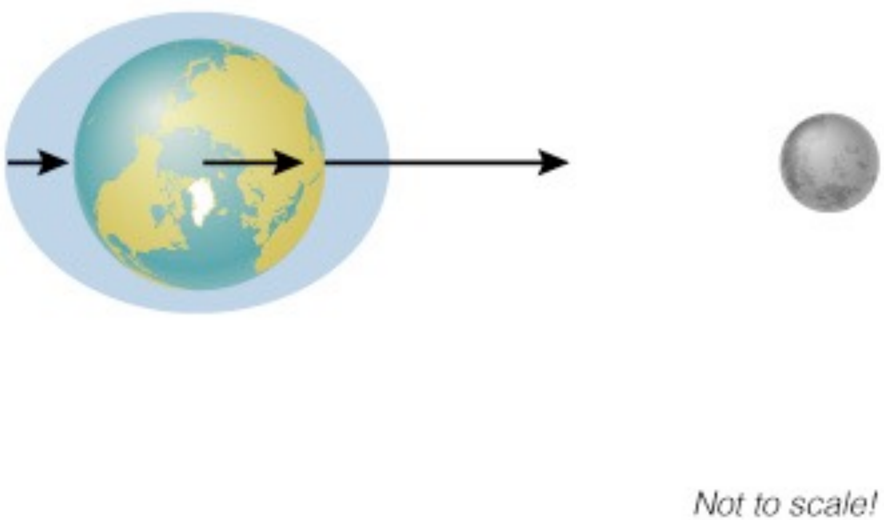
$$= 0.0015$$

- a very smooth sphere!

- Gravity makes individual objects round
  - about 100 km in diameter is where objects start to become dominated by self-gravity
    - planets round
    - asteroids still lumpy

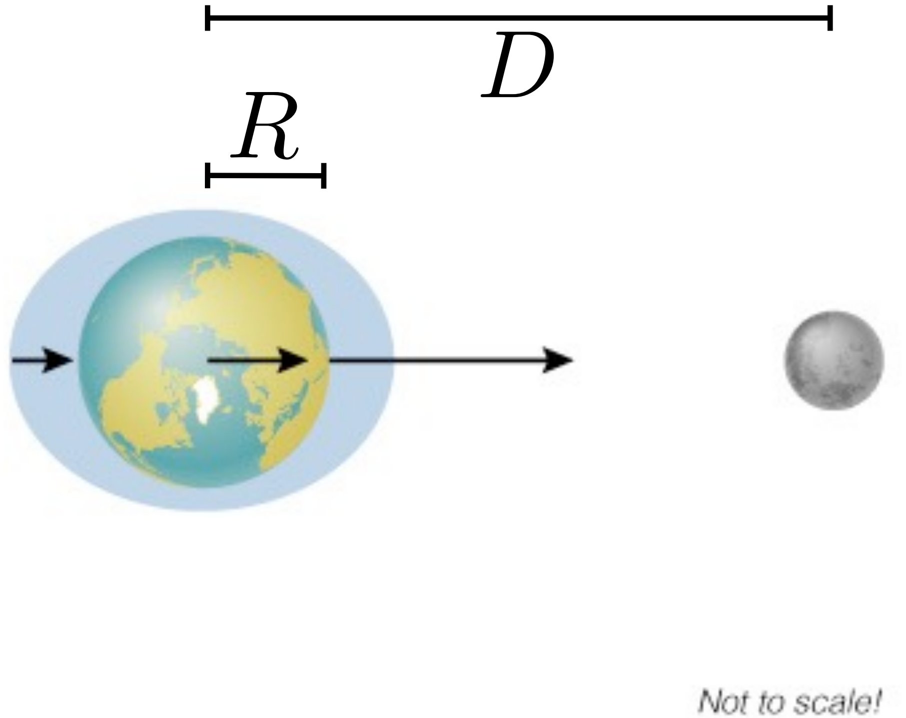
This holds for individual objects.
What about multiple objects?

Tides



Tides are the result of differential gravity

- The Moon’s gravity pulls harder on near side of Earth than on far side (inverse square law).
- The difference in the Moon’s gravitational pull stretches Earth.



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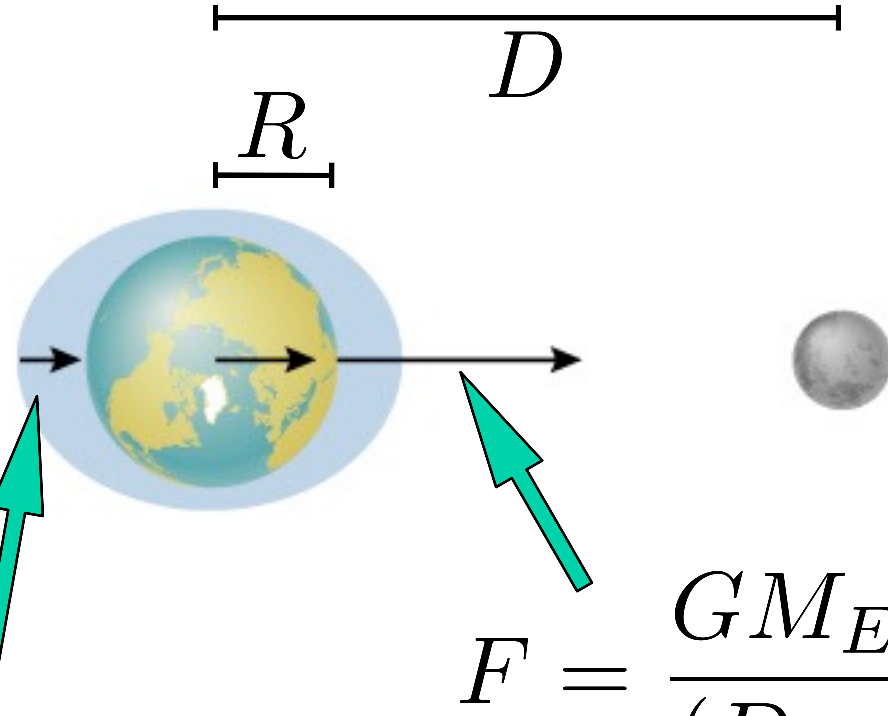


$$F = \frac{GM_E M_m}{(D-R)^2}$$

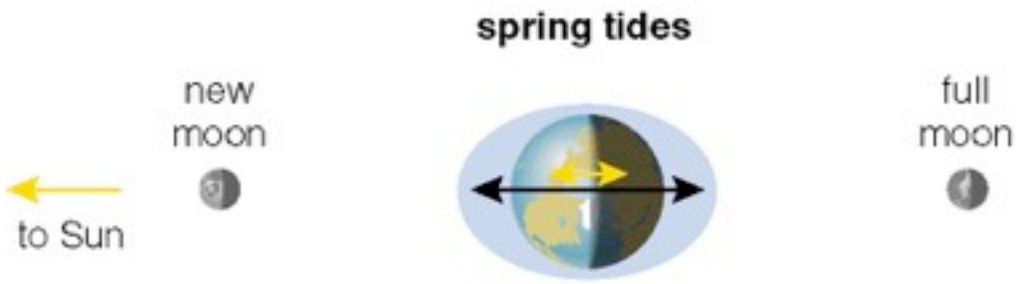
$$F = \frac{GM_E M_m}{(D+R)^2}$$

$$D = 384,400 \text{ km}$$

$$R = 6,378 \text{ km}$$

So the gravitational attraction towards the moon is about 7% stronger on the near side of the Earth than on the far side.

2 Tides a day

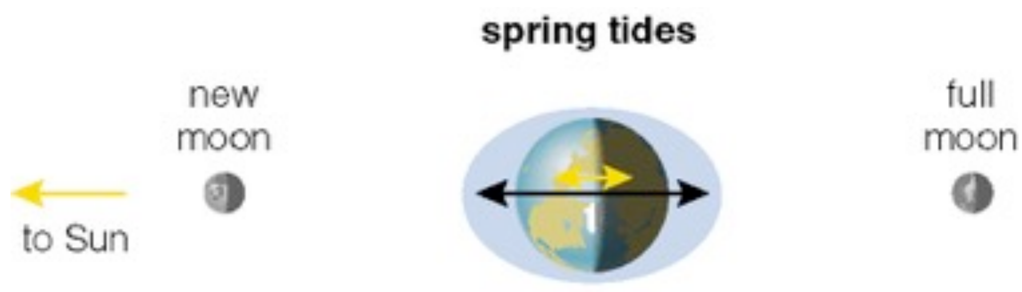


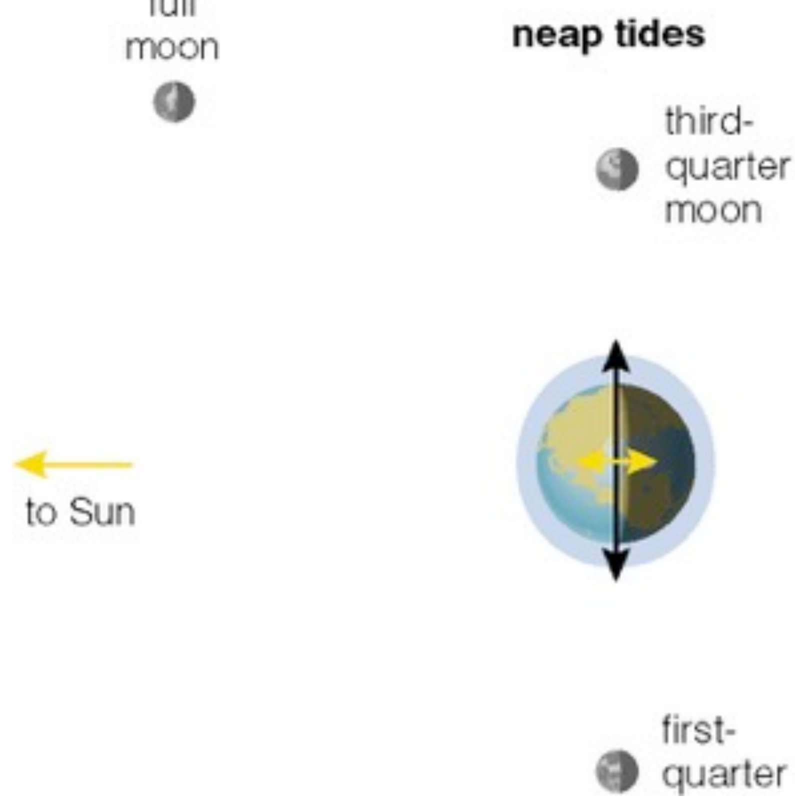
The combined force of the sun and moon causes the ideal gravitational surface to be slightly non-spherical.

Consequently, Earth's oceans to fill a slightly oblate spheroid.

The Earth spins under this spheroid, so we have two pairs of low & high tides a day.

Tides and Phases



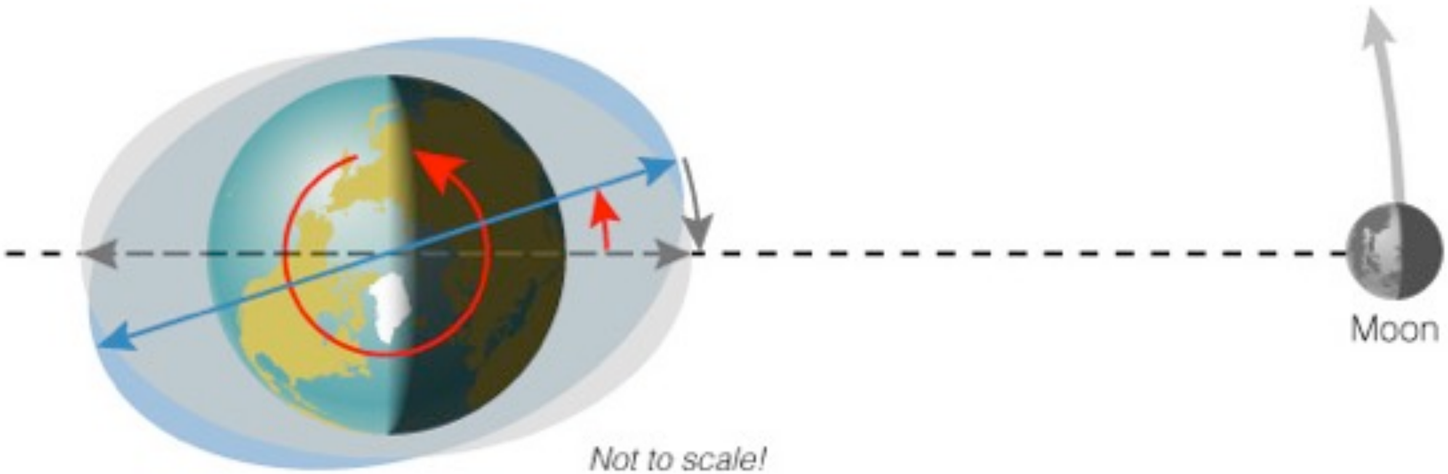


Size of tides depends on the phase of the Moon.

Spring tides are stronger than neap tides because the sun and moon team up at new & full moon.

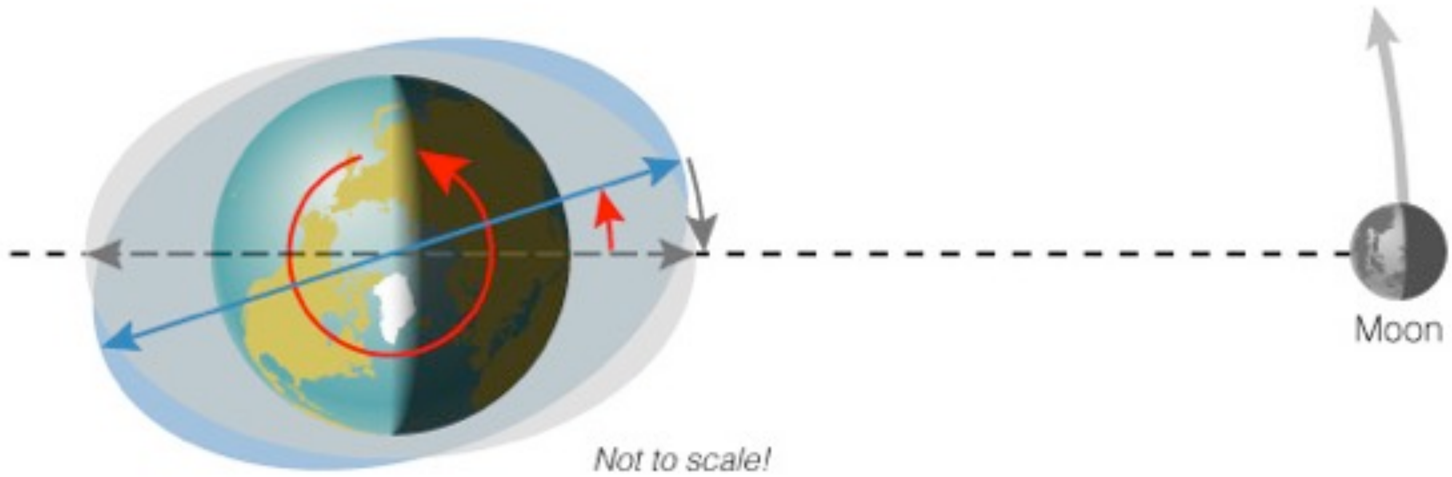
PLAY 04_03 Tides

Tidal Friction



- The spin of the Earth drags the tidal bulge of the ocean ahead of the ideal oblate spheroid, which is aligned with the moon.
- The gravity of the moon pulls back on the leading, near side bulge more strongly than it pulls forward the far side bulge.
- The net result is **tidal friction**, which results in a gradual braking of the spin of the Earth.

Tidal Friction



- Tidal friction gradually slows Earth rotation
  - Moon gradually drifts farther from Earth (3.8 centimeters per year)
  - conservation of angular momentum

The length of Earth's day increases 2 milliseconds per century

- Moon once spun faster; tidal friction caused it to "lock" in synchronous rotation
  - orbit period:spin period = 1:1

Summary of Tides

- Gravitationally bound objects are spherical
  - e.g., planets, stars
- Tides are caused by the differential gravity of the sun and moon
  - Spring tides are cause when the sun and moon are aligned; neap tides when they are perpendicular.
- Tidal friction gradually changes
  - the orbit of the moon and the spin of the earth