Department of Physics and Astronomy

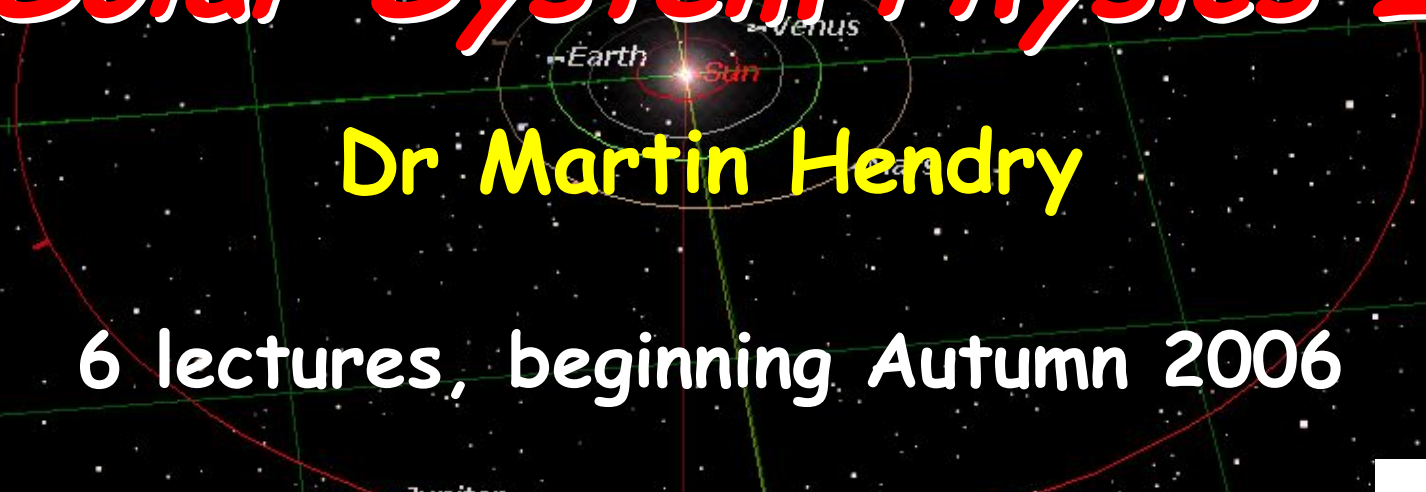
Astronomy 1X

Session 2006-07

Solar System Physics I

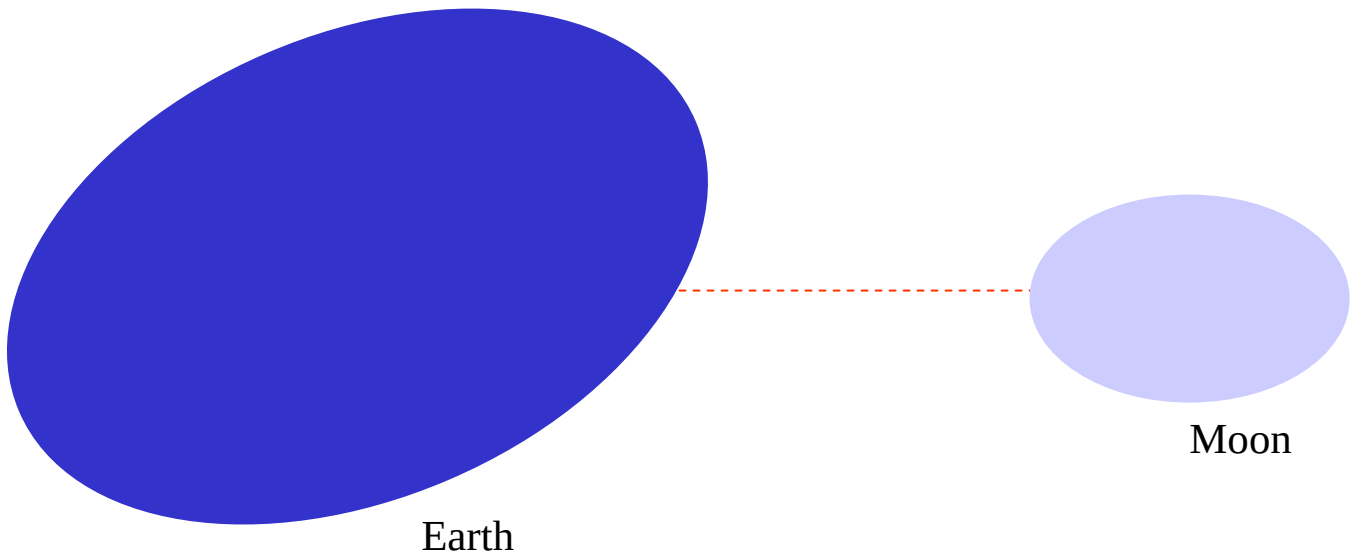
Dr Martin Hendry

6 lectures, beginning Autumn 2006

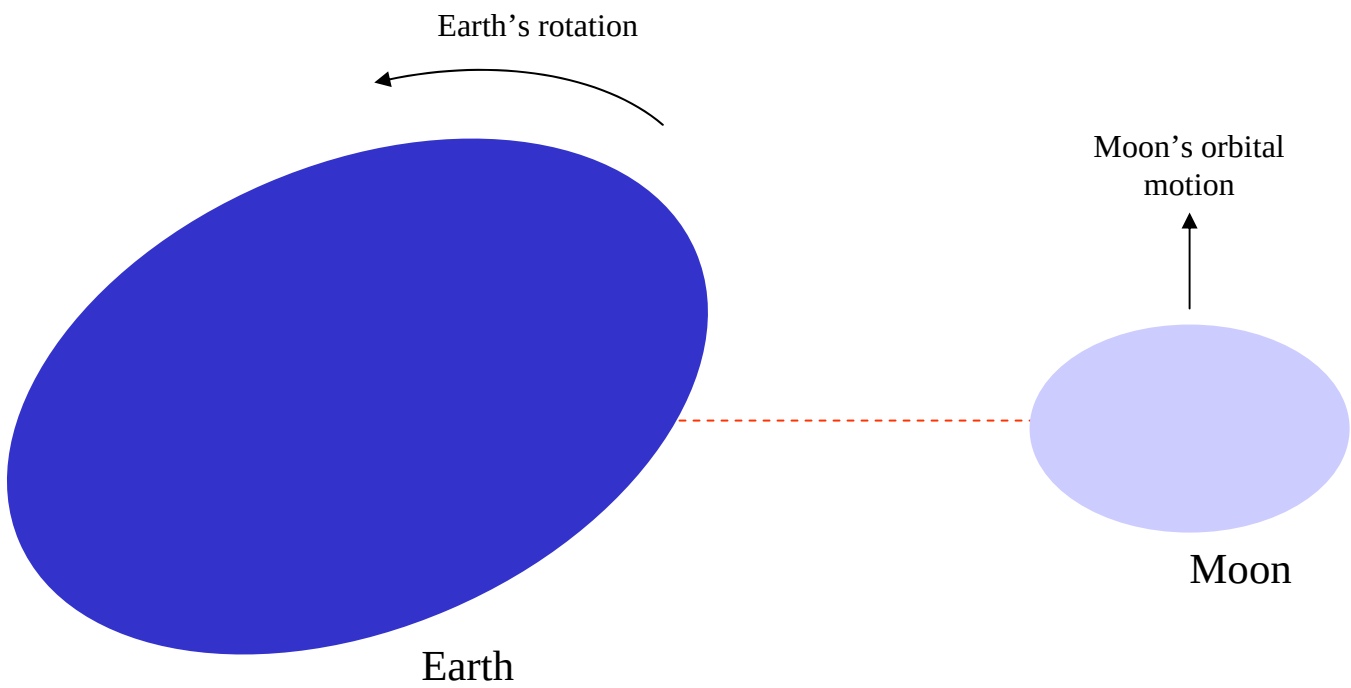


Lecture 6

Even if there were no tidal force on the Earth from the Sun, the Earth's tidal bulge would **not** lie along the Earth-Moon axis. This is because of the Earth's rotation.

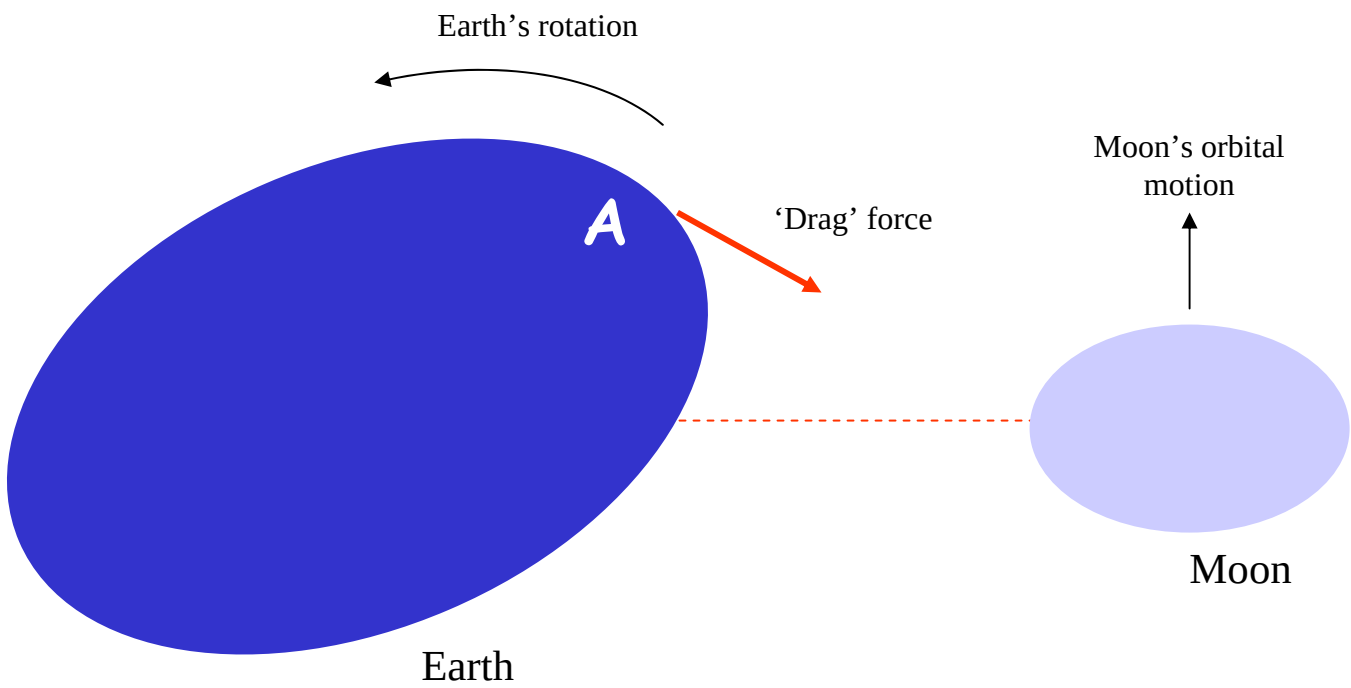


The Earth's rotation carries the tidal bulge ahead of the Earth-Moon axis. (The Earth's crust and oceans cannot instantaneously redstribute themselves along the Earth-Moon axis due to friction)



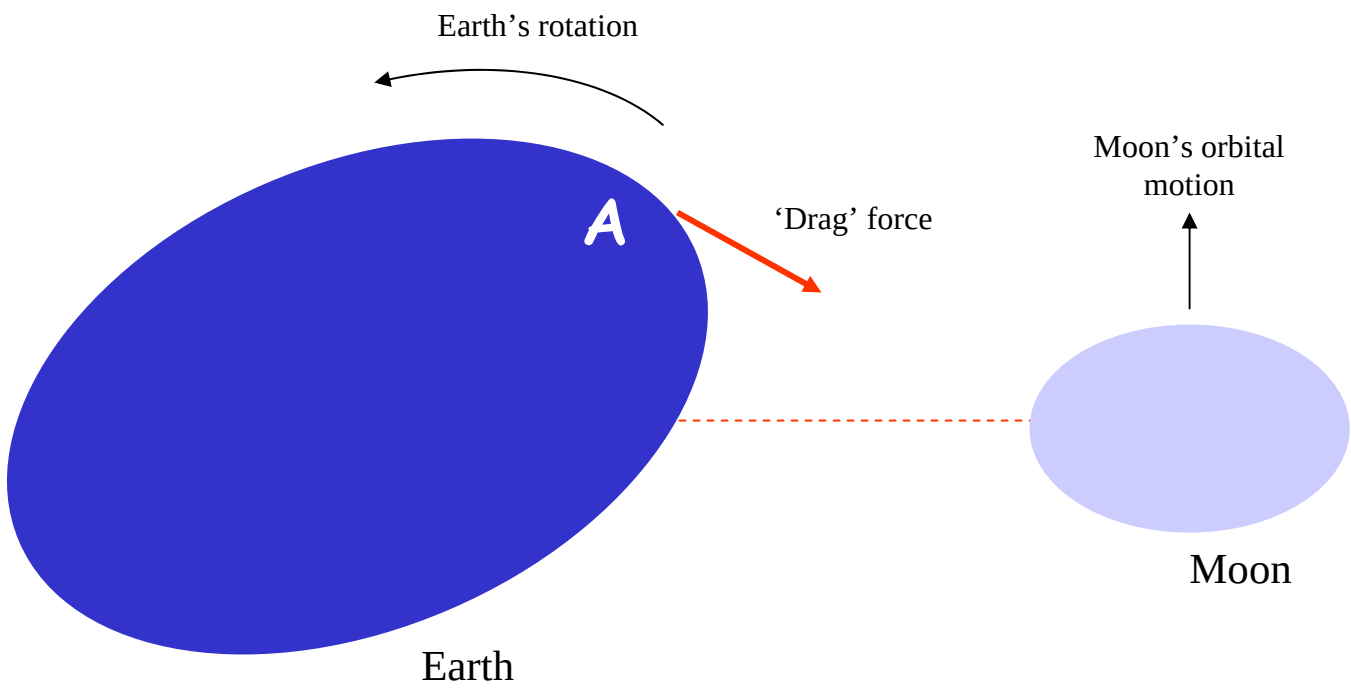
The Moon exerts a drag force on the tidal bulge at A, which slows down the Earth's rotation.

The length of the Earth's day is increasing by 0.0016 sec per century.



At the same time, bulge A is pulling the Moon forward, speeding it up and causing the Moon to spiral outwards. **This follows from the conservation of angular momentum.**

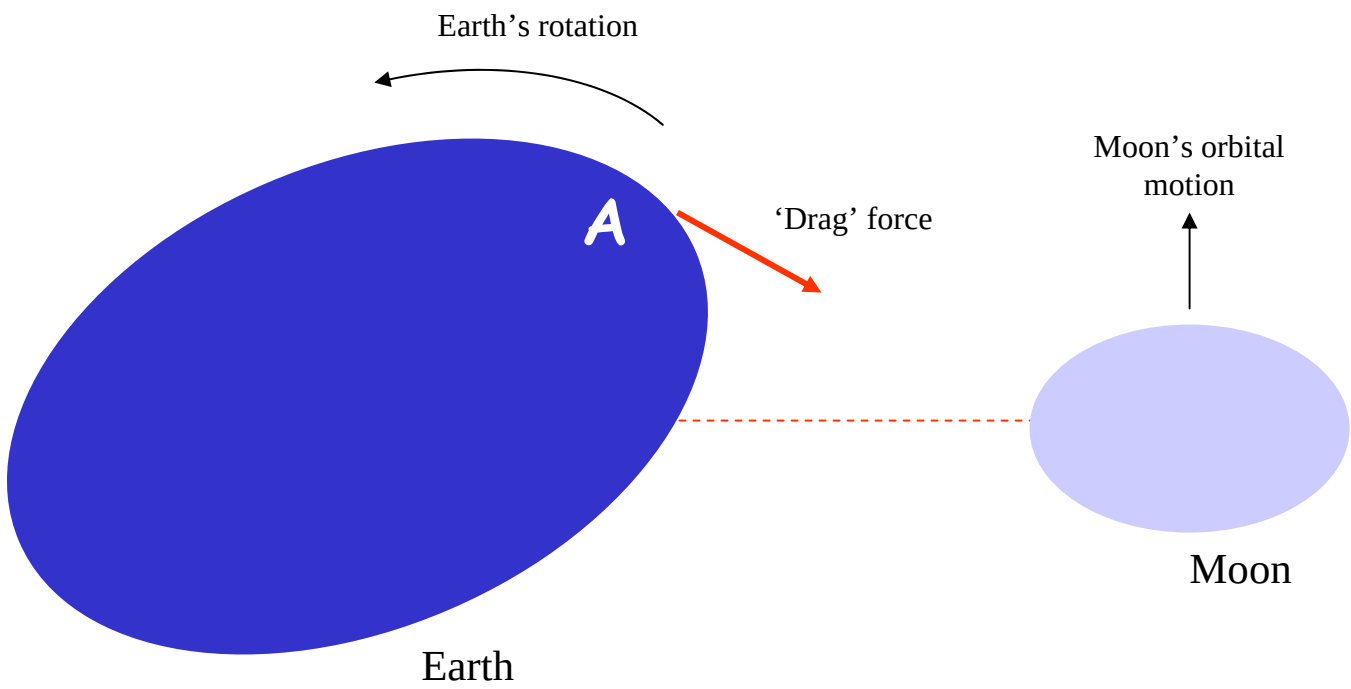
The Moon's semi-major axis is increasing by about 3cm per year.

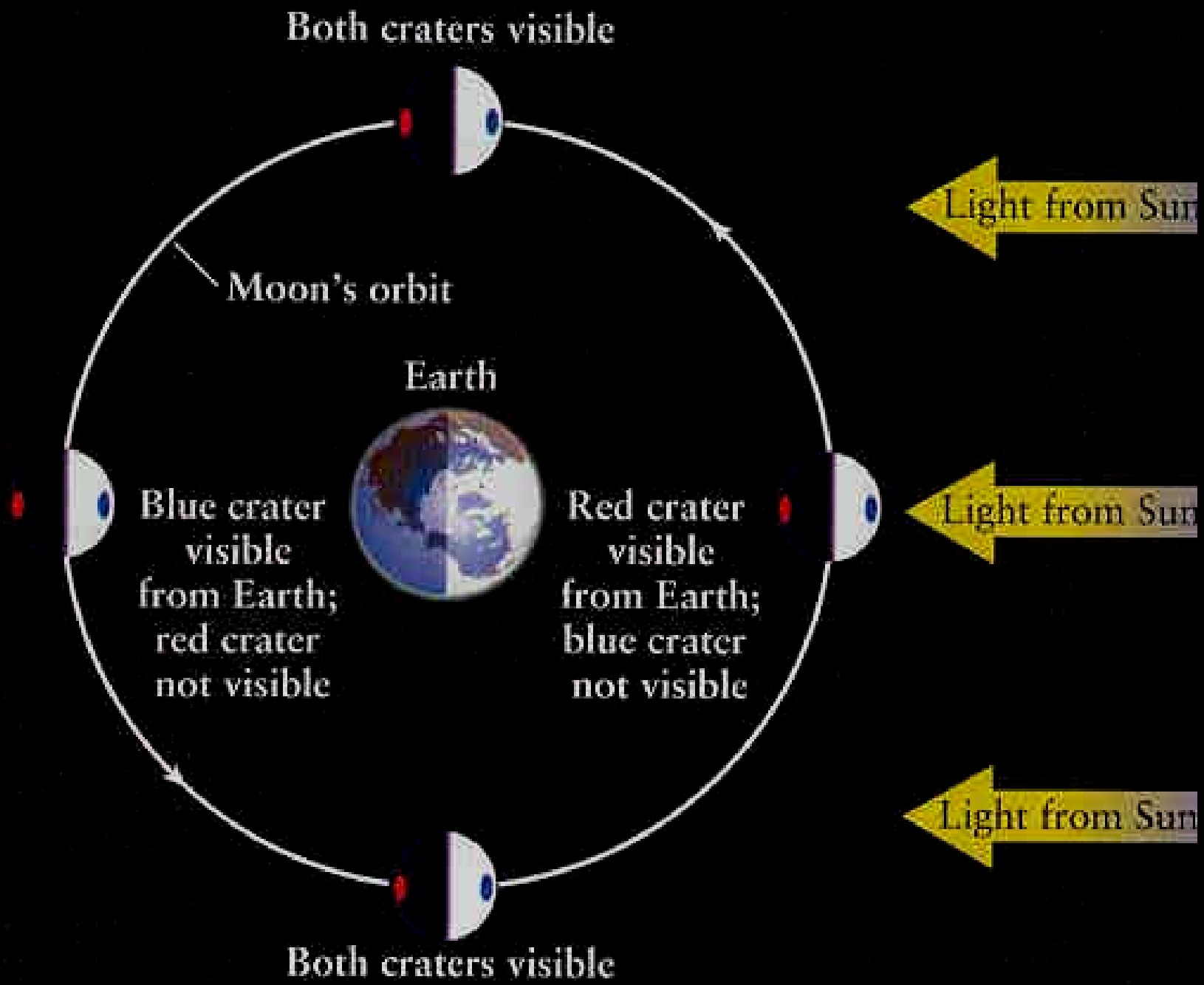


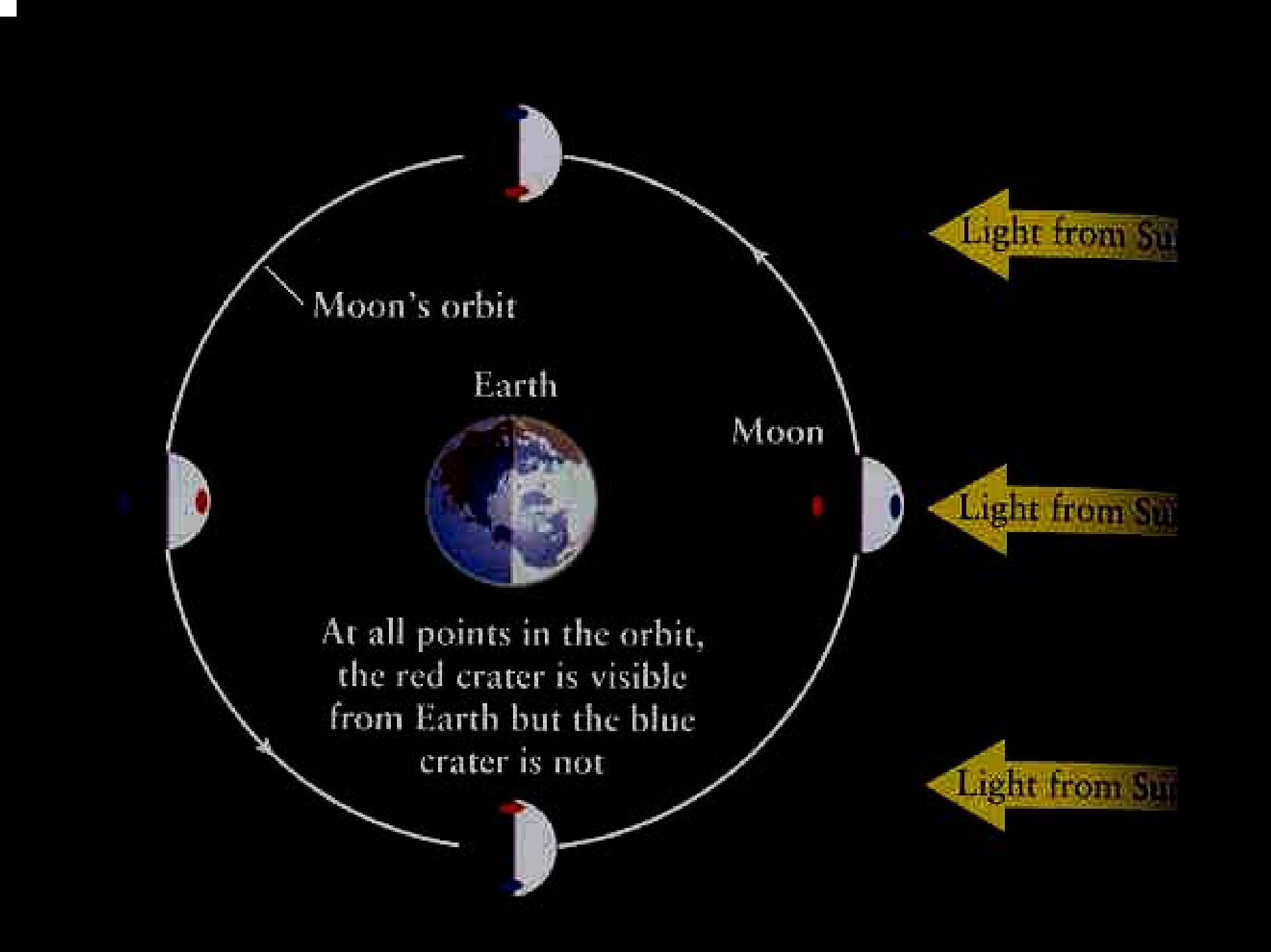
- Given sufficient time, the Earth's rotation period would slow down until it equals the Moon's orbital period – so that the same face of the Earth would face the Moon at all times. We call this synchronous rotation

  (This will happen when the Earth's "day" is 47 days long)

  In the case of the Moon, synchronous rotation has *already happened !!!*




Both craters visible
Light from Sun
Moon's orbit
Earth
Blue crater visible from Earth; red crater not visible
Red crater visible from Earth; blue crater not visible
Light from Sun
Light from Sun
Both craters visible


Moon's orbit
Earth
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Light from Sun
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At all points in the orbit, the red crater is visible from Earth but the blue crater is not

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- Tidal locking has occurred much more rapidly for the Moon than for the Earth because the Moon is much smaller, and the Earth produces larger tidal deformations on the Moon than vice versa.

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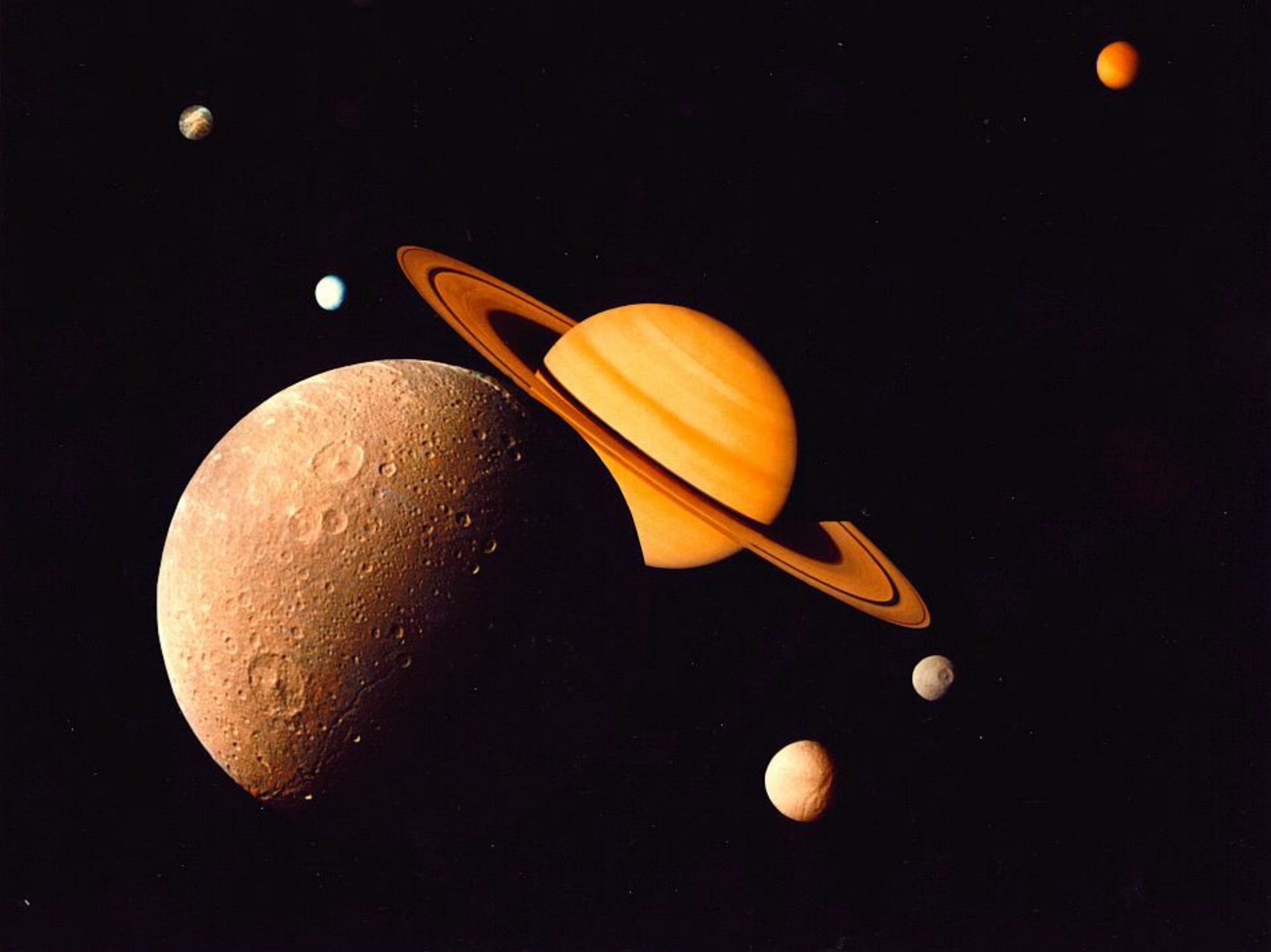
- The Moon is not exactly 'tidally locked': over about 30 years, 59% of its surface is visible from the Earth. This is because of a wobble known as *Libration* – which is caused by the gravitational perturbations of the Sun (and other planets) on the Earth-Moon system, and the fact that the Moon's orbit is slightly eccentric.

- Many of the satellites in Solar System are in synchronous rotation, e.g.:-

Mars:	Phobos and Deimos
Jupiter:	Galilean moons + Amalthea
Saturn:	All major moons, except Phoebe + Hyperion
Neptune:	Triton
Pluto:	Charon

The moons of Jupiter



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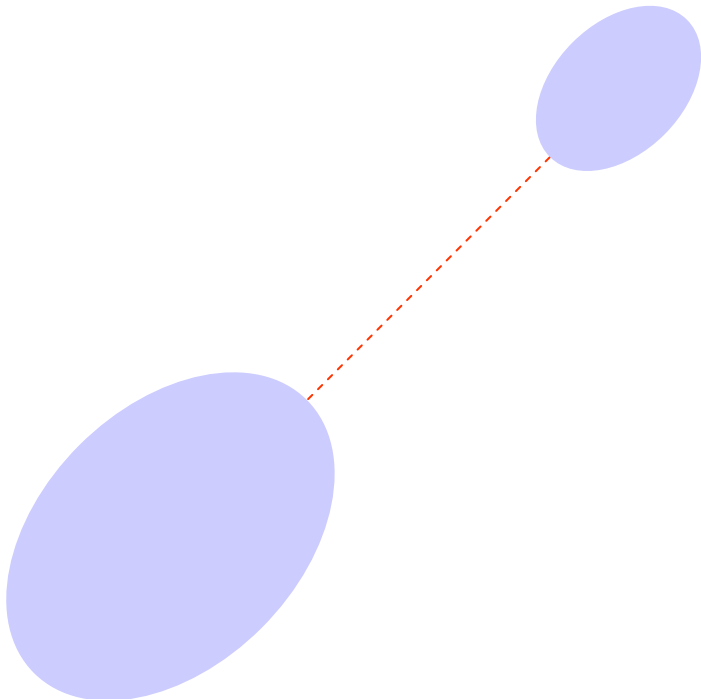
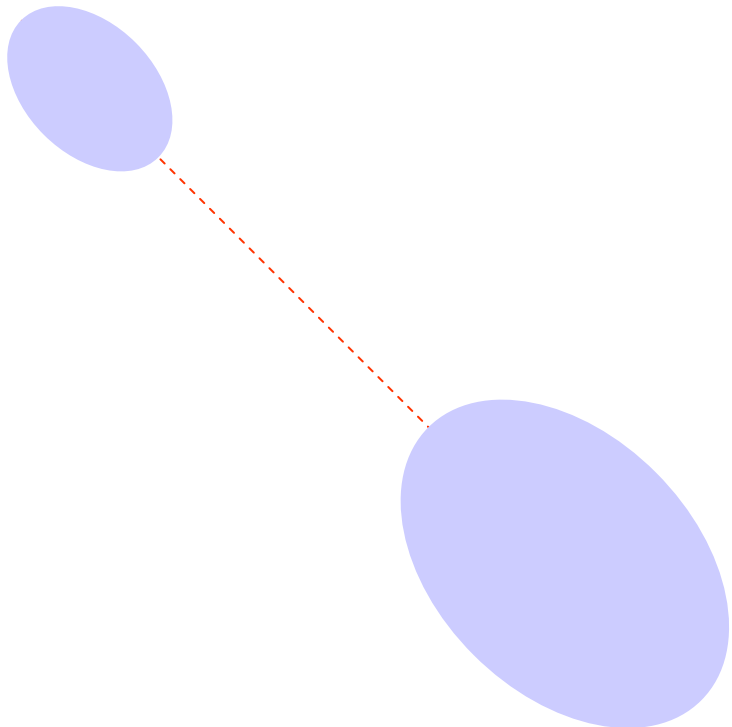
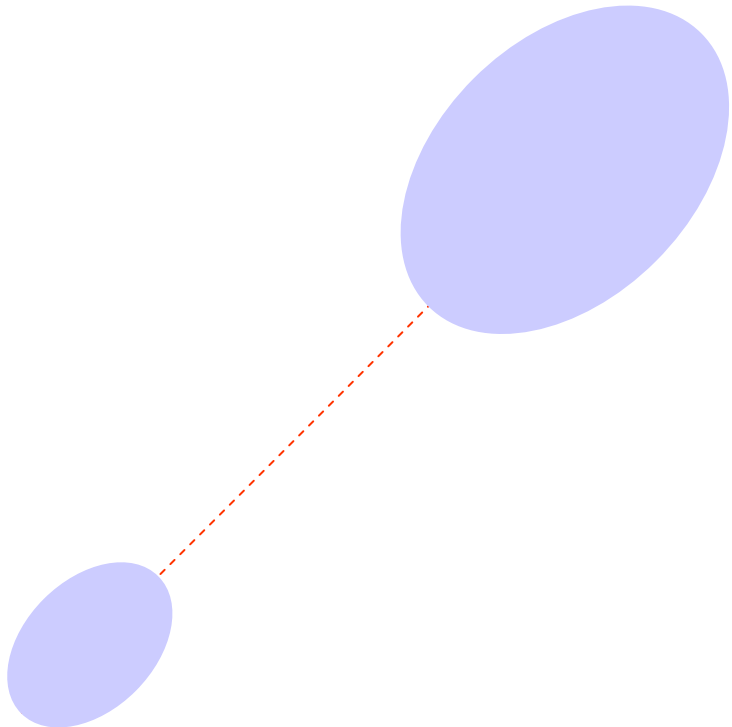
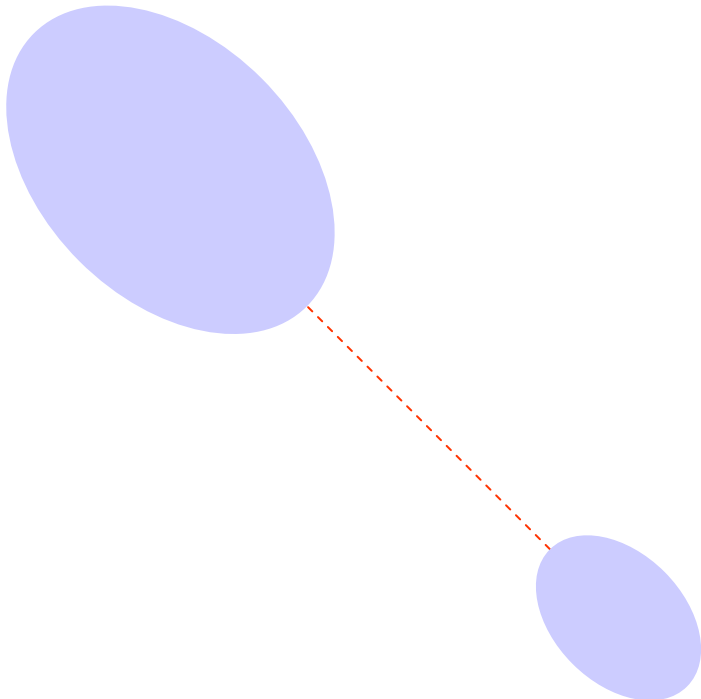
- Pluto and Charon are in mutual synchronous rotation: i.e. the same face of Charon is always turned towards the same face of Pluto









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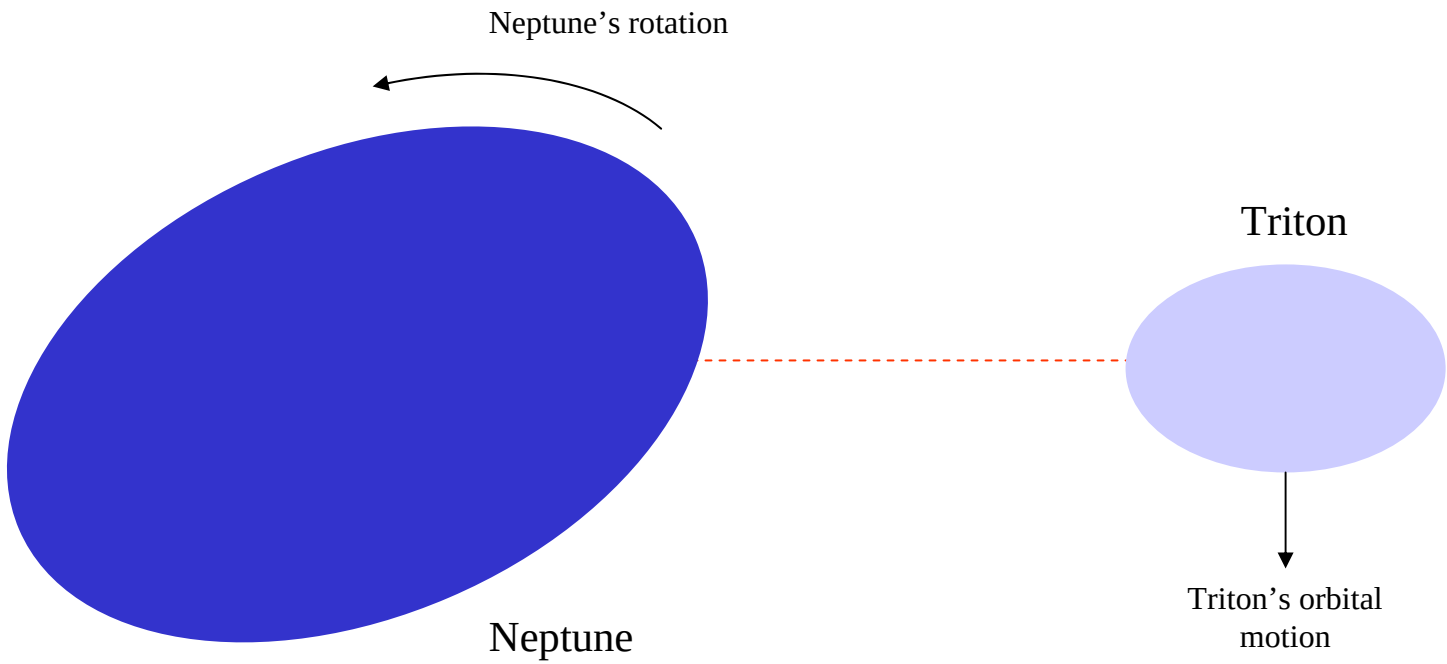
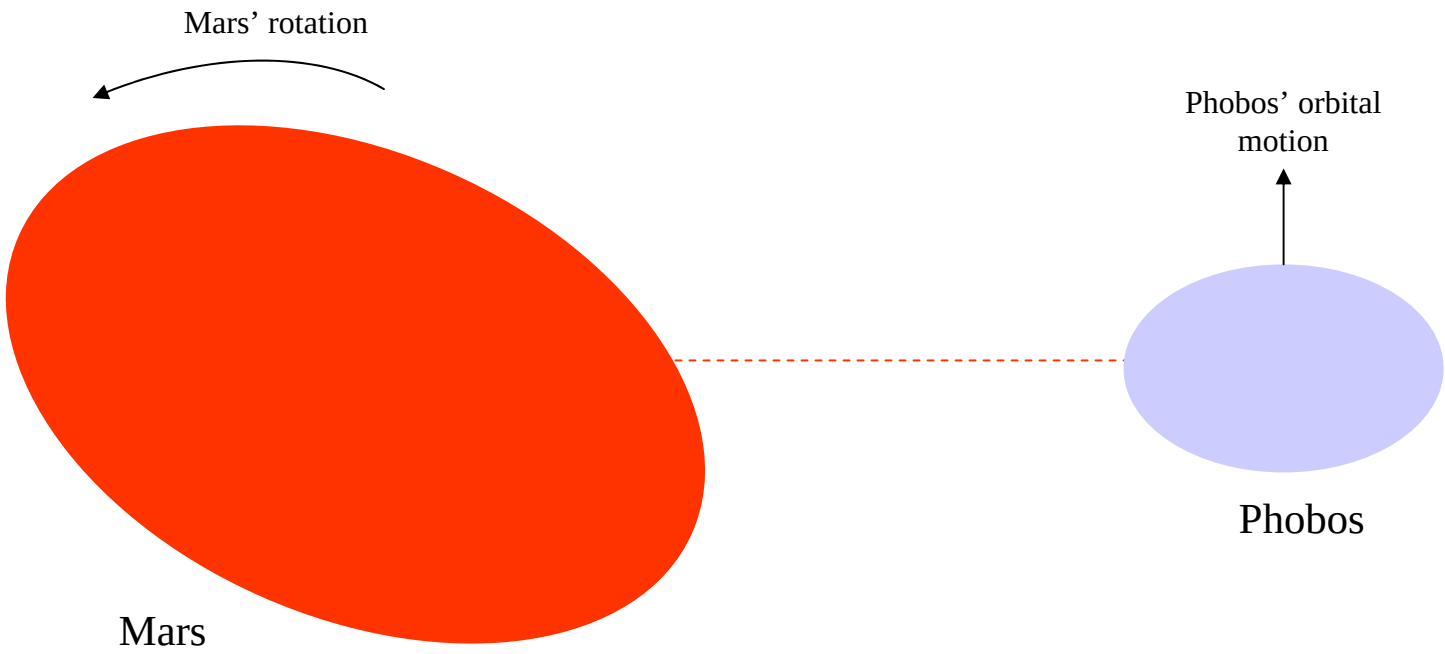
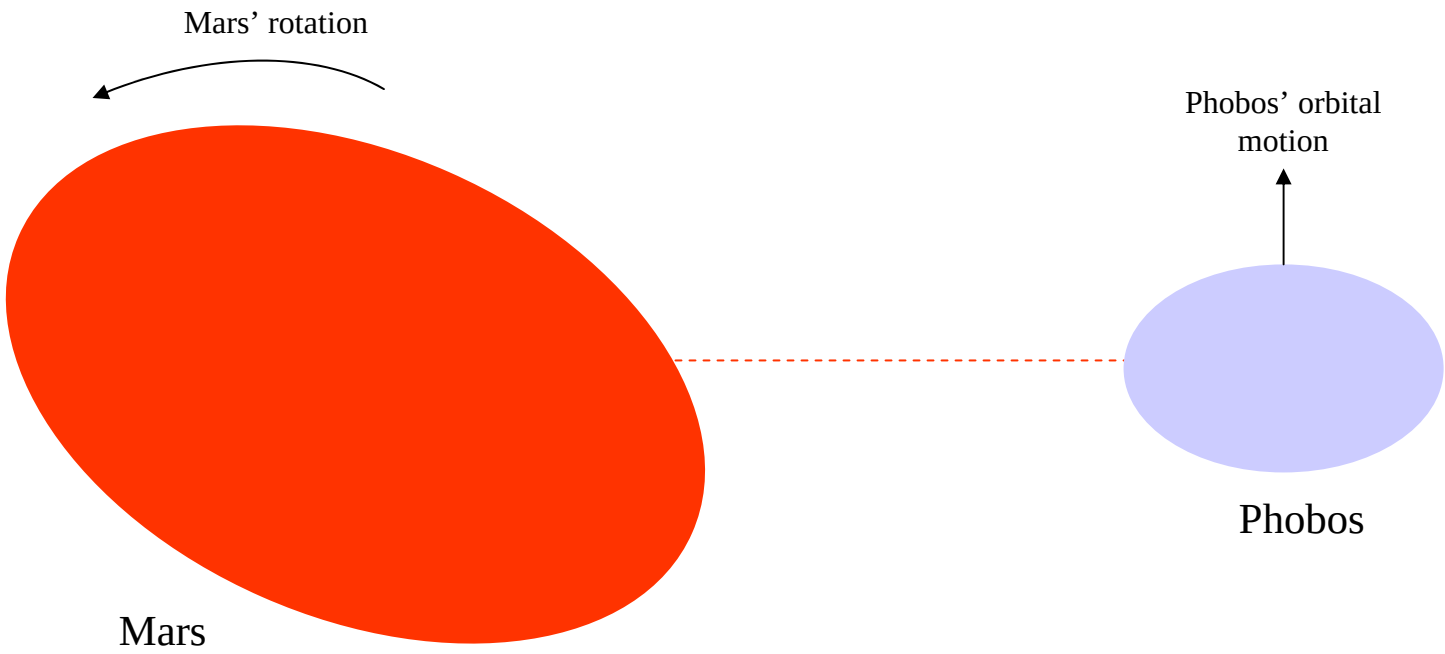
- Triton is in synchronous rotation, but is orbiting Neptune on a *retrograde* orbit (i.e. in the opposite direction to Neptune's rotation).



In this case Neptune's tidal bulge acts to *slow down* Triton. The moon is spiralling toward Neptune (although it will take billions of years before it reaches the Roche stability limit)



- Phobos is orbiting in the same direction as Mars, but is so close to the planet that its orbital period is less than 1 Martian day. Hence, Phobos is 'outrunning' Mars' tidal bulge, which lags behind. The effect of the bulge is, then, to slow down the moon, causing it to spiral inward.



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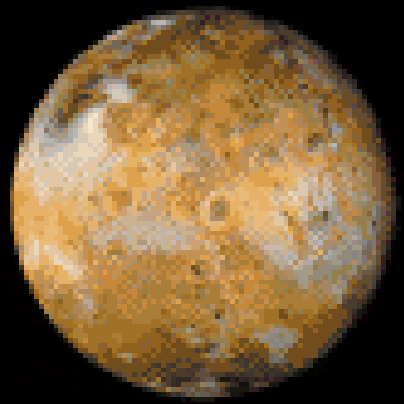
  Phobos would hit Mars in about 50 million years if it stayed intact, but it will reach its Roche stability limit and break apart before then.

Tidal forces have a major influence on the Galilean Moons

Name	Diameter (m)	Semi-major axis (m)	Orbital Period (days)	Mass (kg)
Io	3.642×10^{6}	4.216×10^{8}	1.769	8.932×10^{22}
Europa	3.120×10^{6}	6.709×10^{8}	3.551	4.791×10^{22}
Ganymede	5.268×10^{6}	1.070×10^{9}	7.155	1.482×10^{23}
Callisto	4.800×10^{6}	1.883×10^{9}	16.689	1.077×10^{23}
The Moon	3.476×10^{6}	3.844×10^{8}	27.322	7.349×10^{22}
Mercury	4.880×10^{6}	—	—	3.302×10^{23}

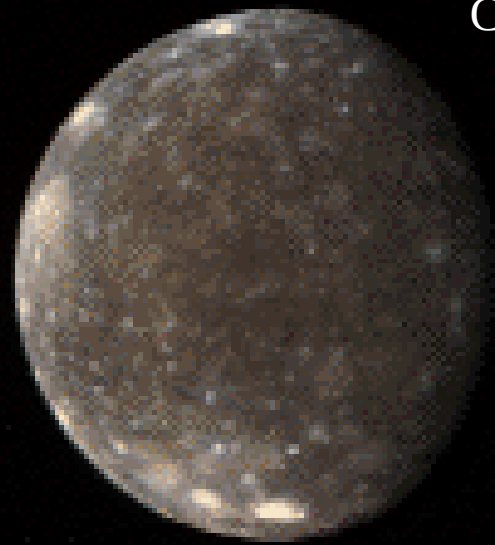
Io



Europa

Ganymede

Callisto



Tidal forces have a major influence on the Galilean Moons

- The orbital periods of Io, Europa and Ganymede are almost exactly in the ratio **1:2:4**. This leads to resonant effects :-

- The orbit of Io is perturbed by Europa and Callisto, because the moons regularly line up on one side of Jupiter. The gravitational pull of the outer moons is enough to produce a small eccentricity in the orbit of Io. This causes the tidal bulges of Io to 'wobble' (same effect as the Moon's libration) which produces large amount of frictional heating.

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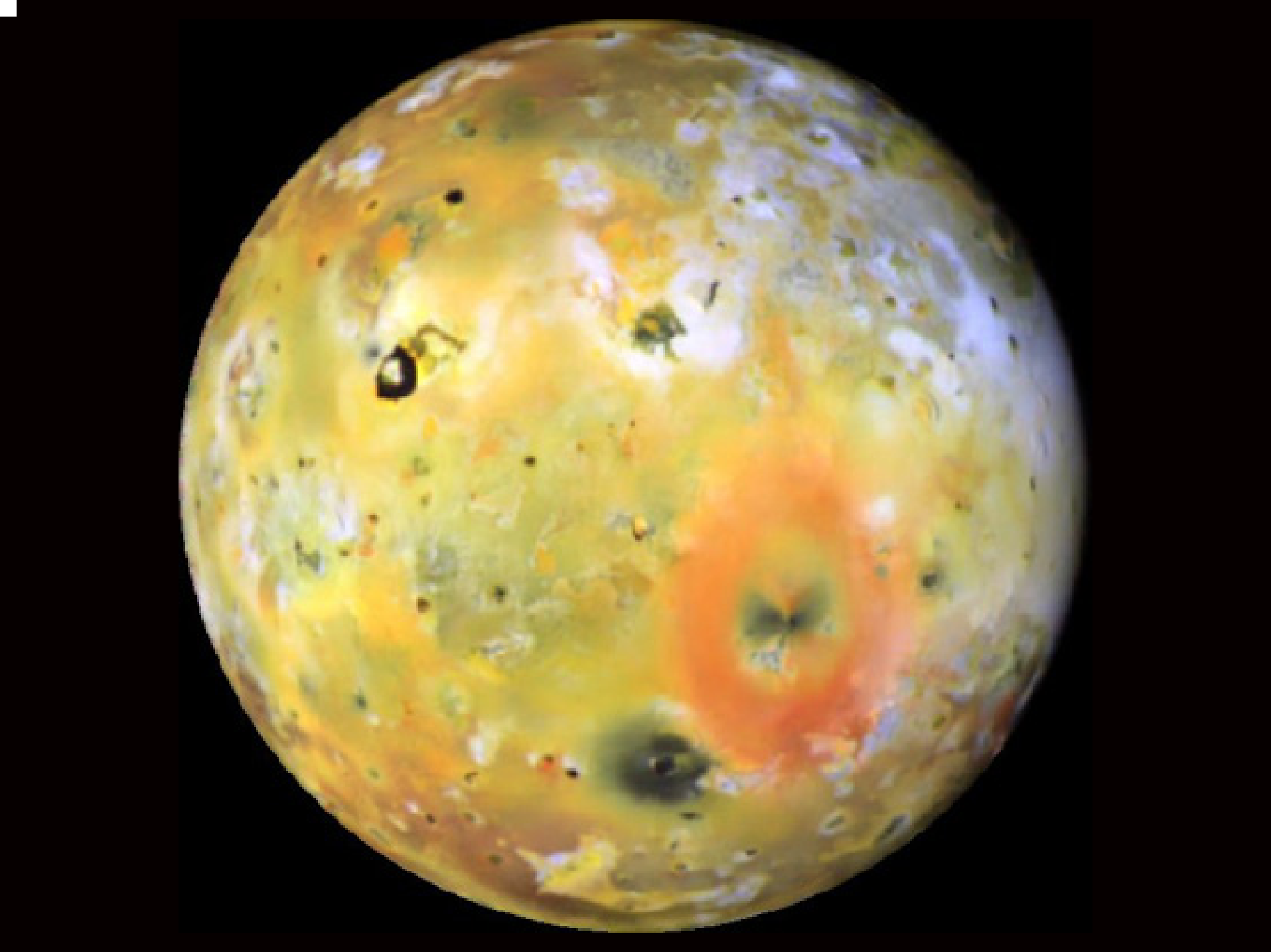
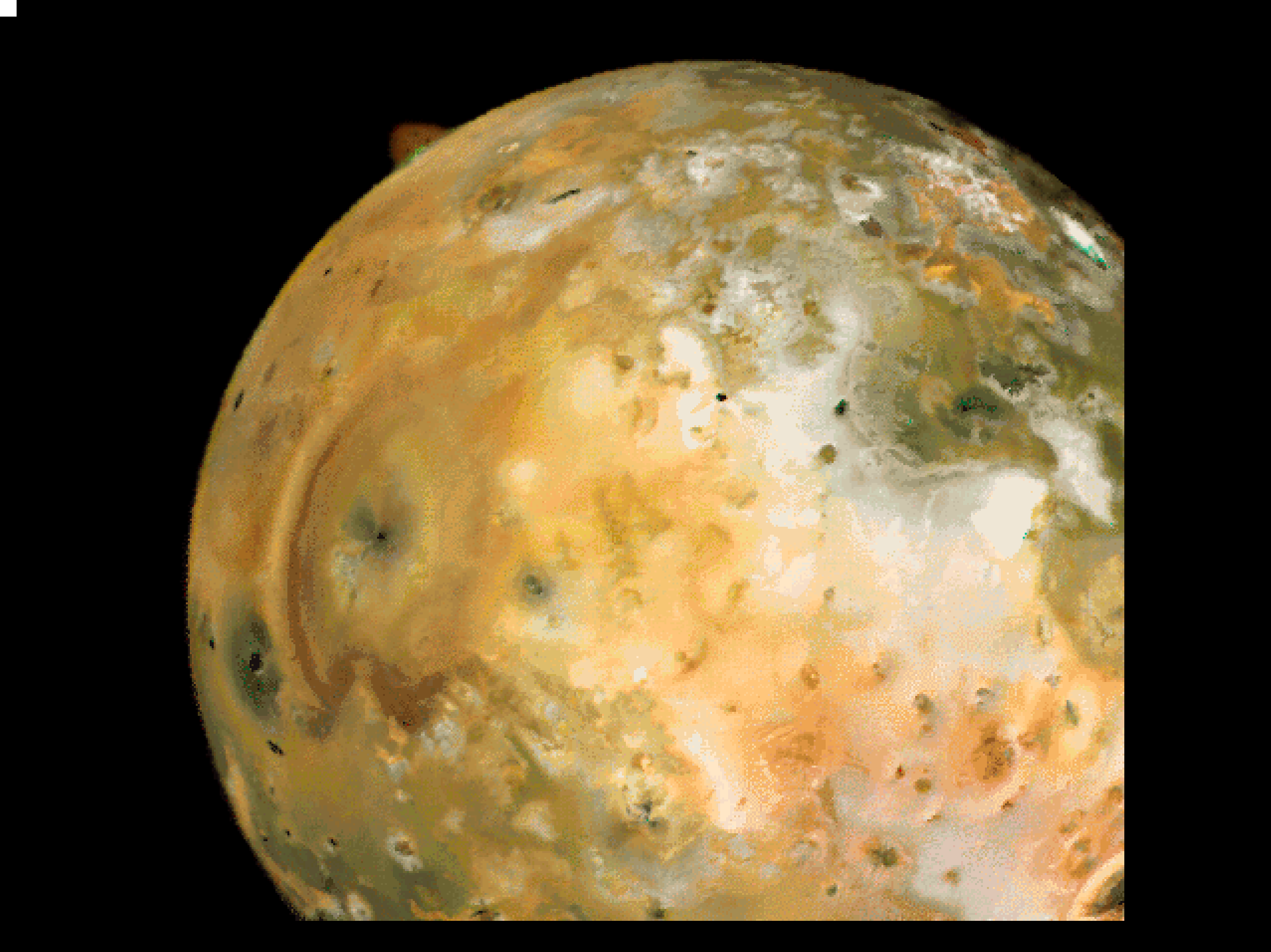
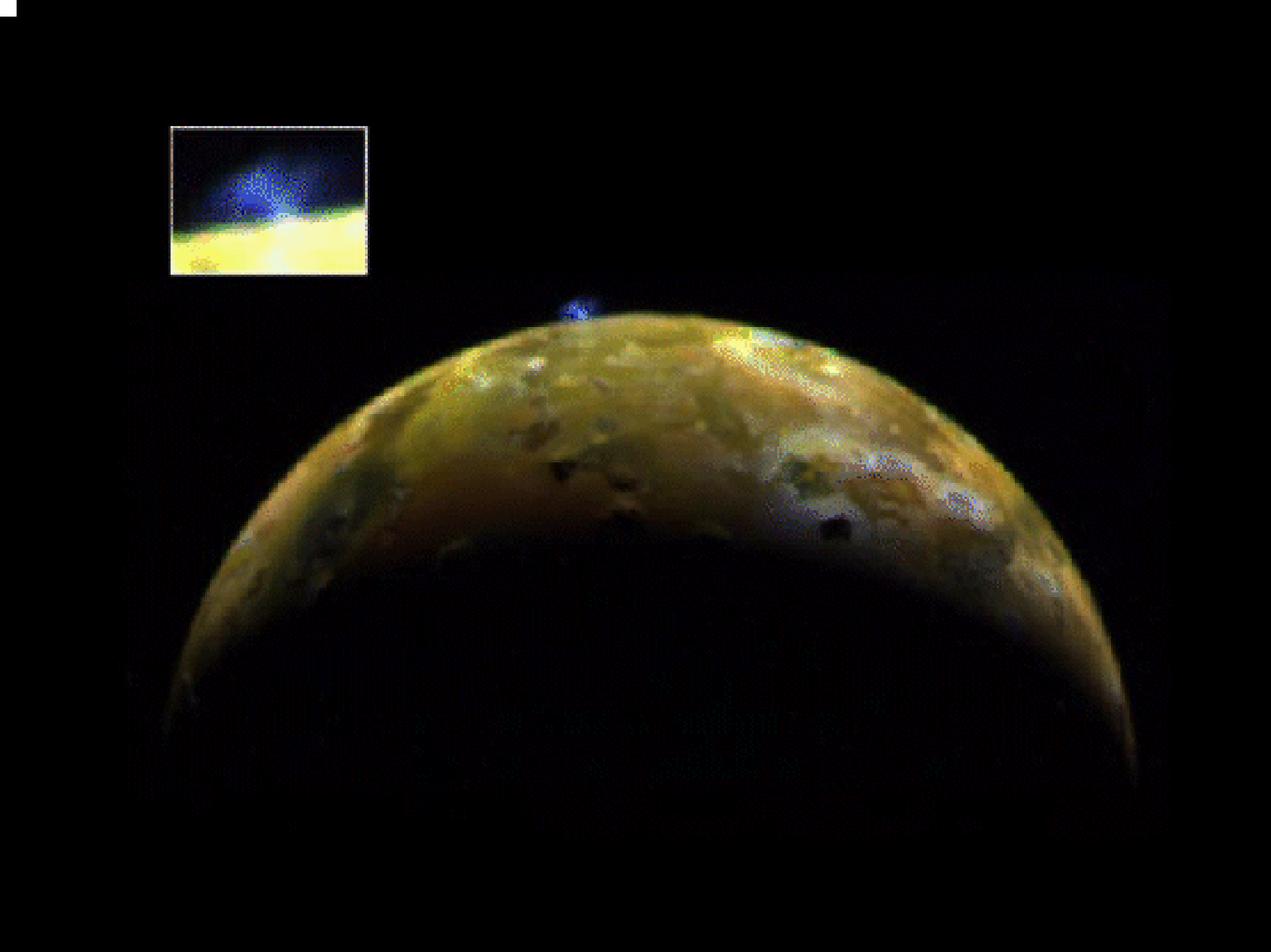
- The surface of Io is almost totally molten, yellowish-orange in colour due to sulphur from its continually erupting volcanoes.

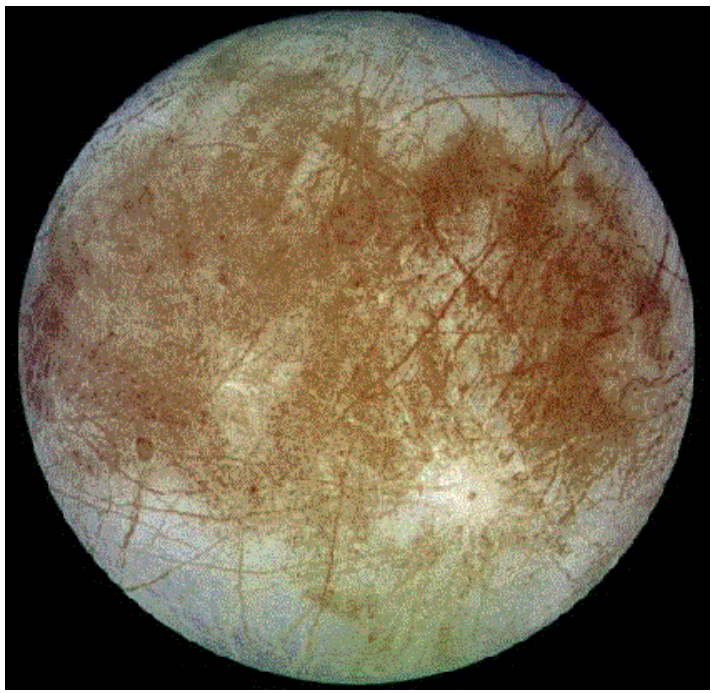


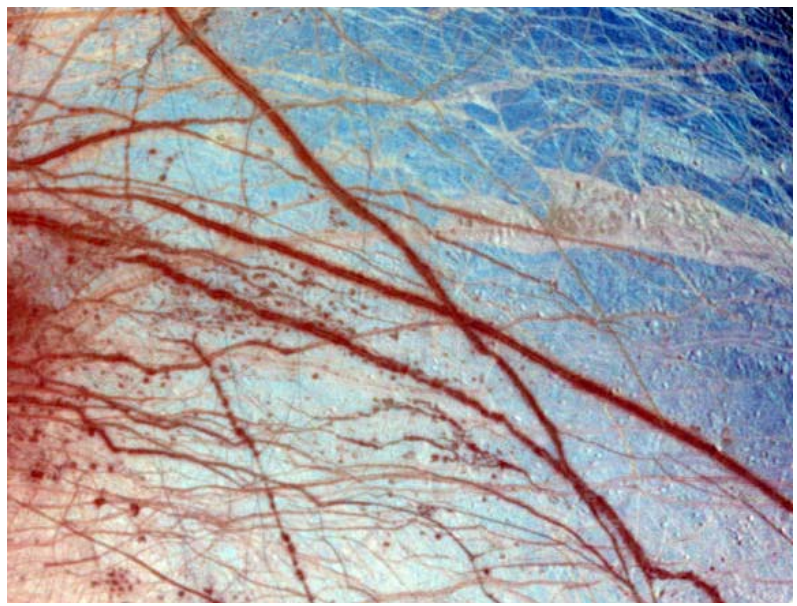


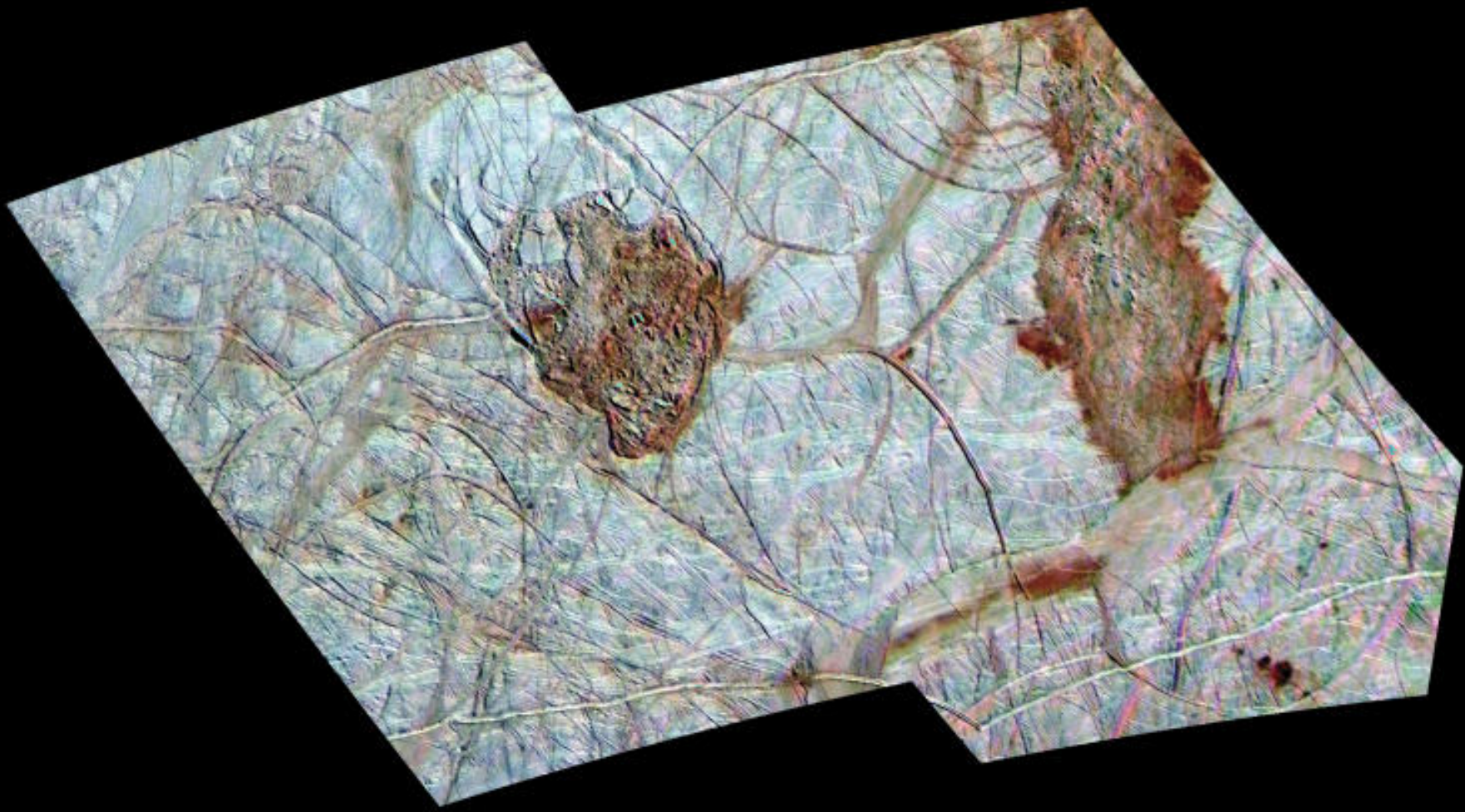


Tidal forces have a major influence on the Galilean Moons

- Tidal friction effects on Europa are much weaker than on Io, but still produce striking results. The icy crust of the moon is covered in 'cracks' due to tidal stresses, and beneath the crust it is believed that frictional heating results in a thin **ocean layer**



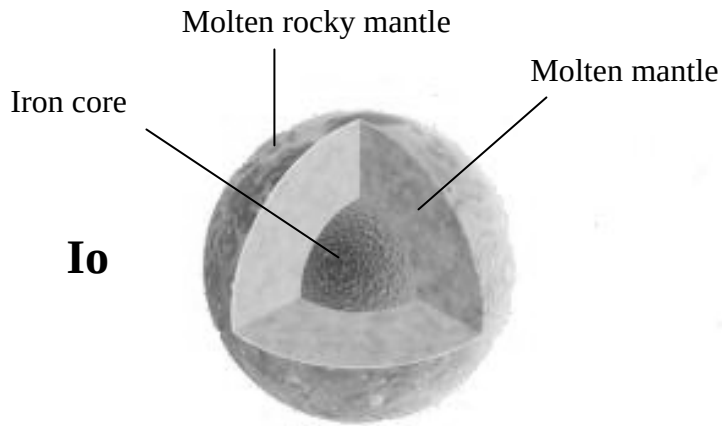


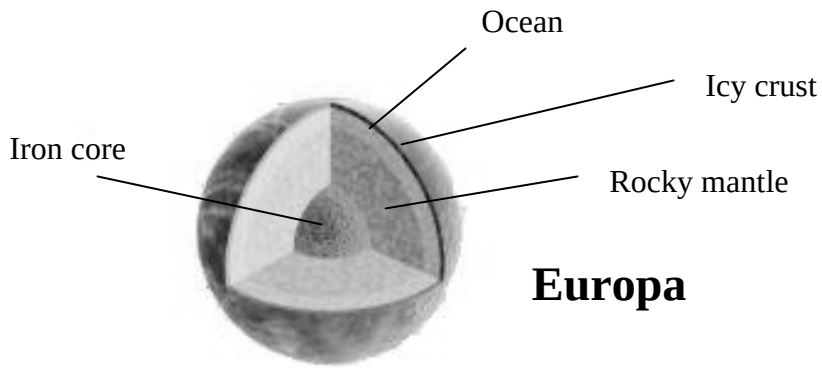


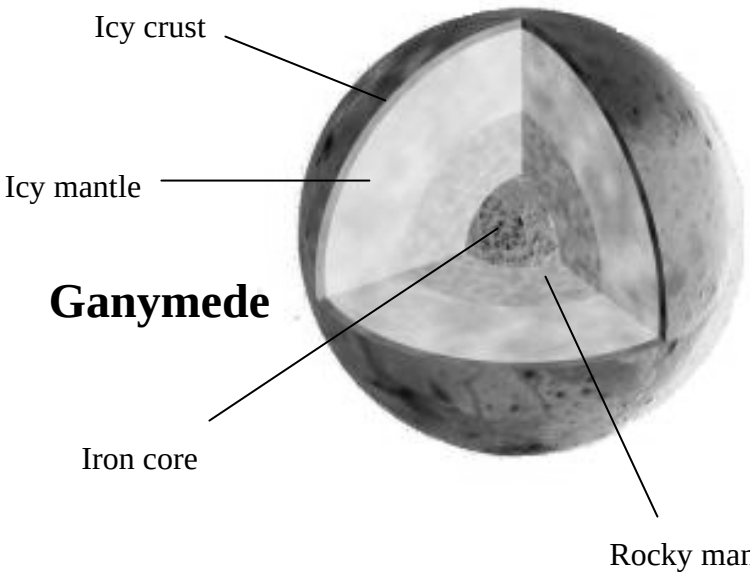
Inside Europa

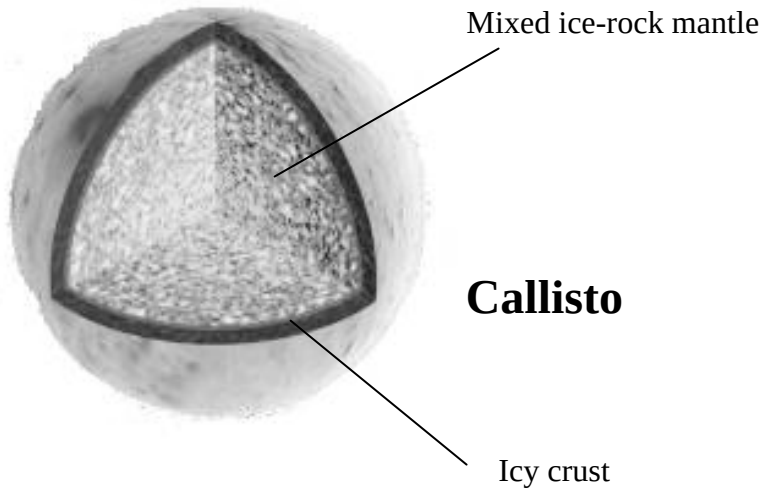
Could there be life?…..

Interior structure of the Galilean Moons









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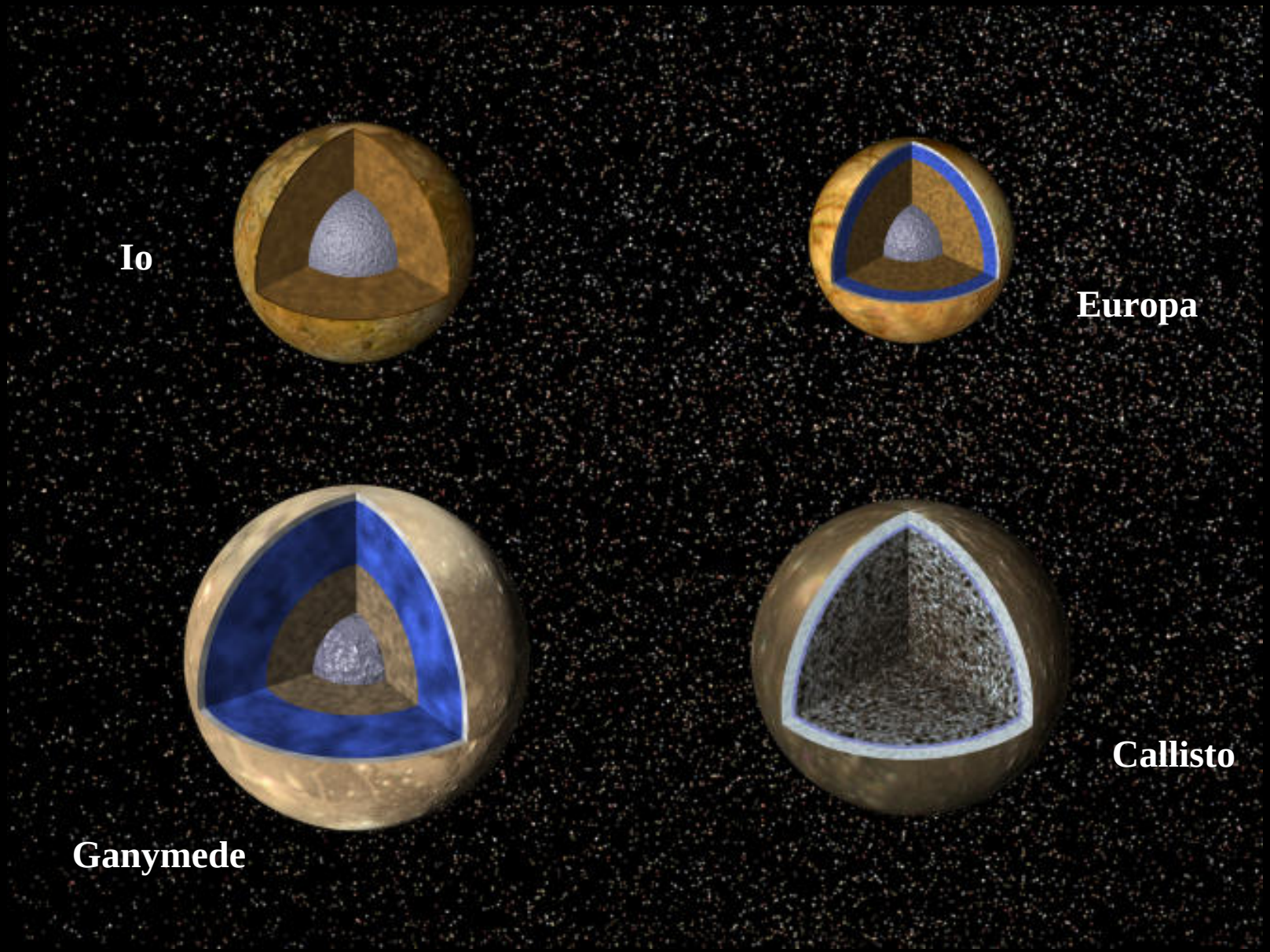
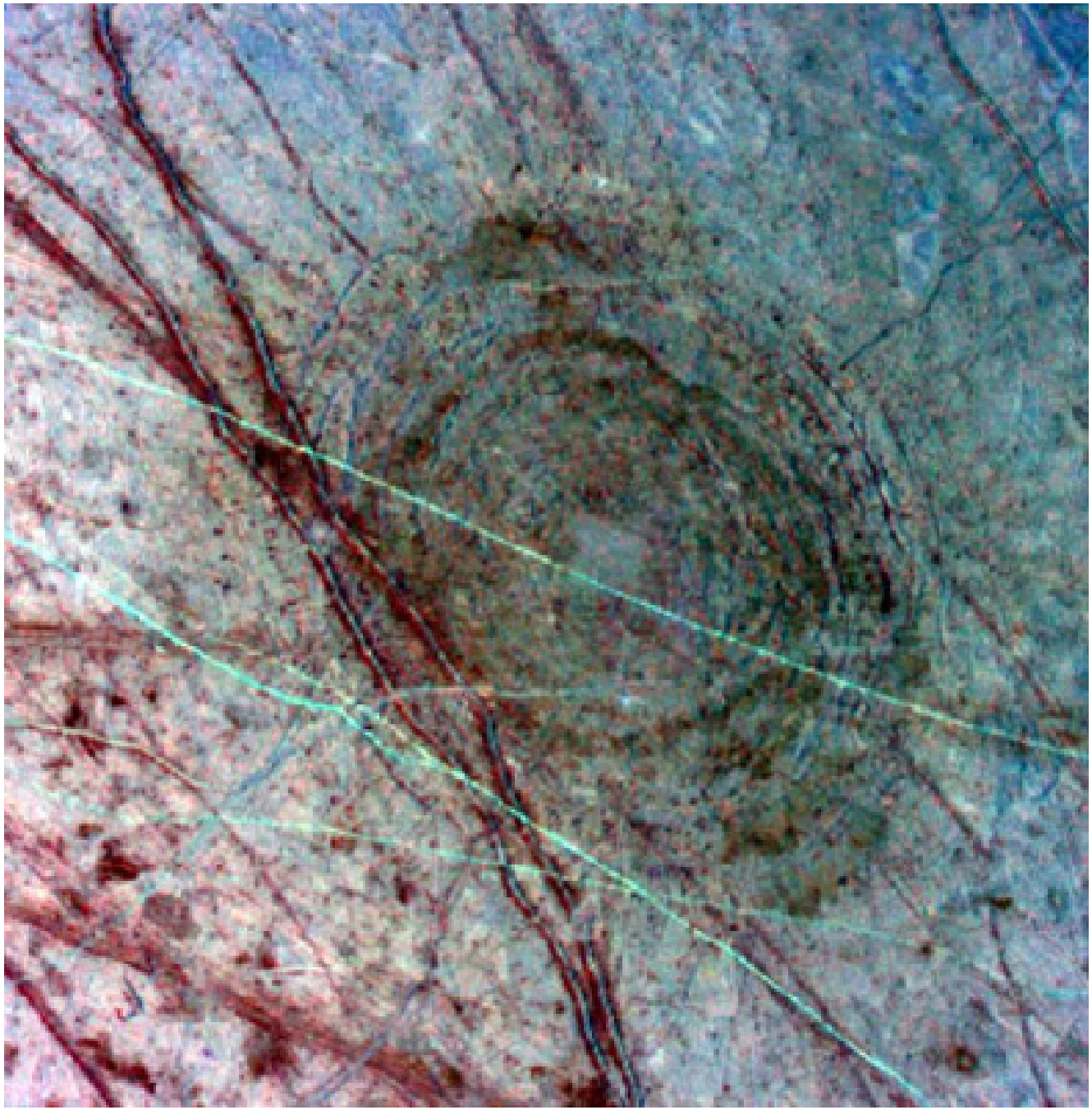


Structure of the Galilean Moons

- The mean density of the moons decreases with distance from Jupiter
- The fraction of ice which the moons contain increases with distance from Jupiter.
- This is because the heat from 'proto-Jupiter' prevented ice grains from surviving too close to the planet. Thus, Io and Europa are mainly rock; Ganymede and Callisto are a mixture of rock and ice.
- The **surface** of the Moons also reflects the history of their formation:

Io:	surface continually renewed by volcanic activity. No impact craters
Europa:	surface young (< 100 million years), regularly 'refreshed' – hardly any impact craters



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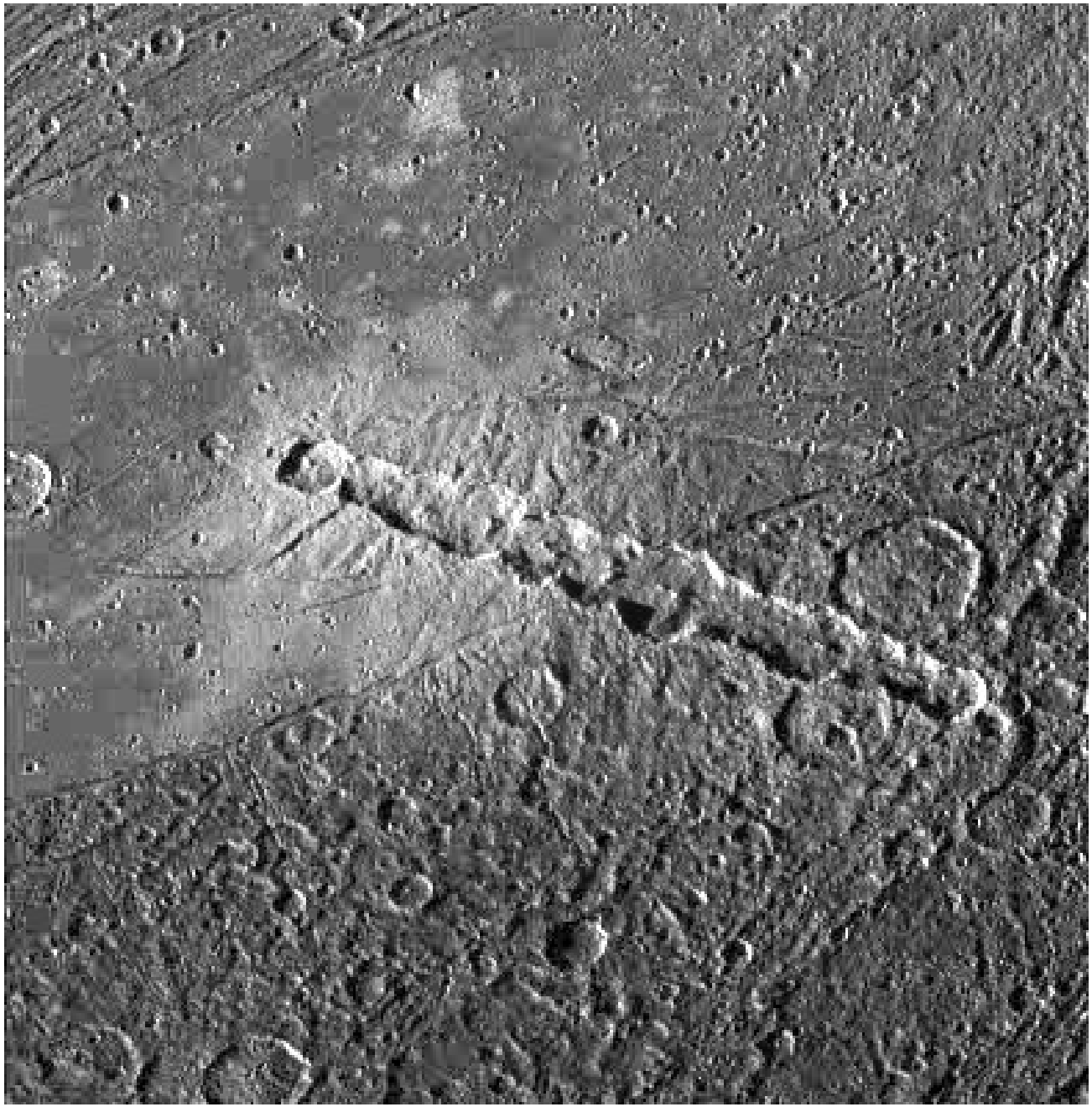

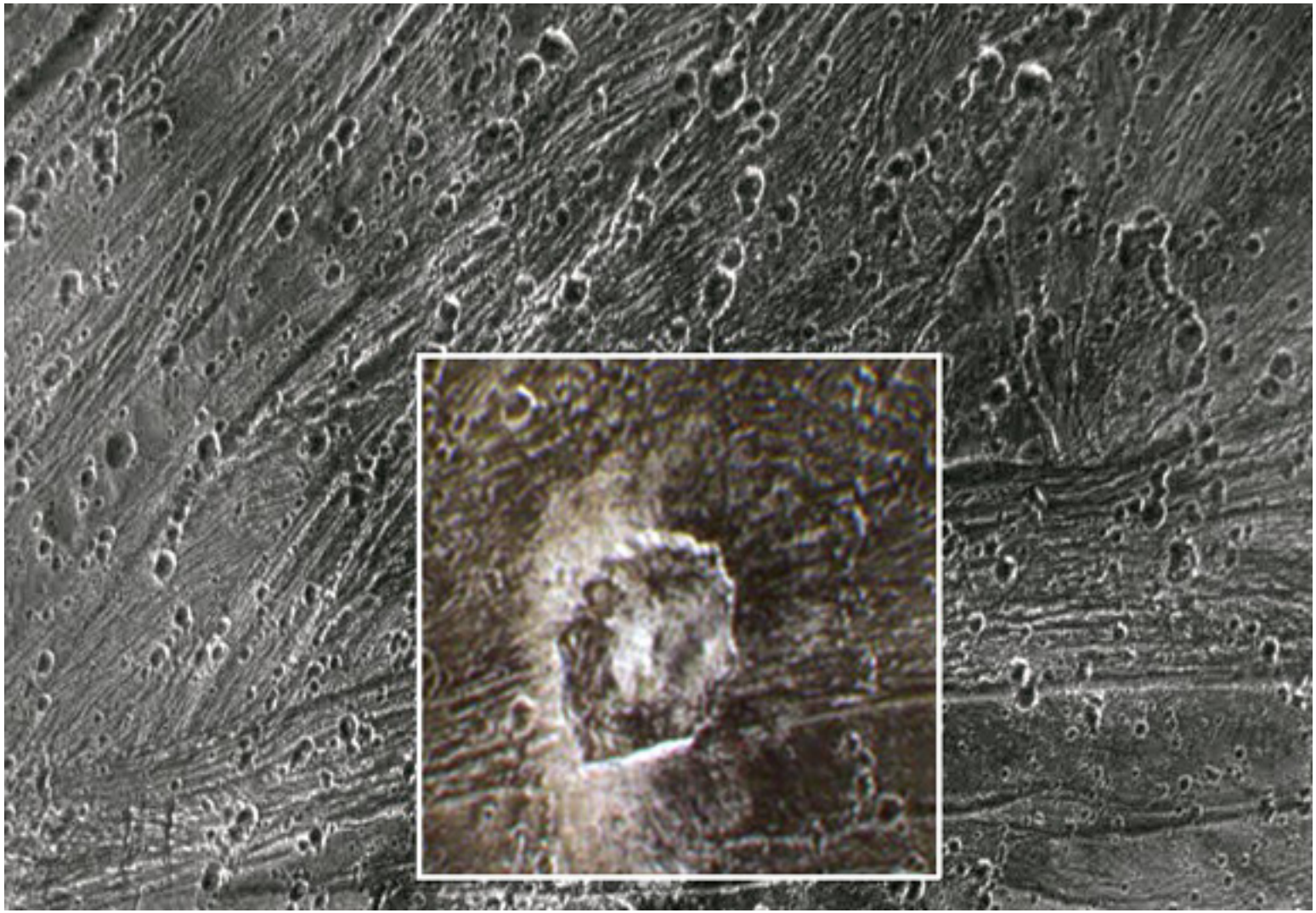

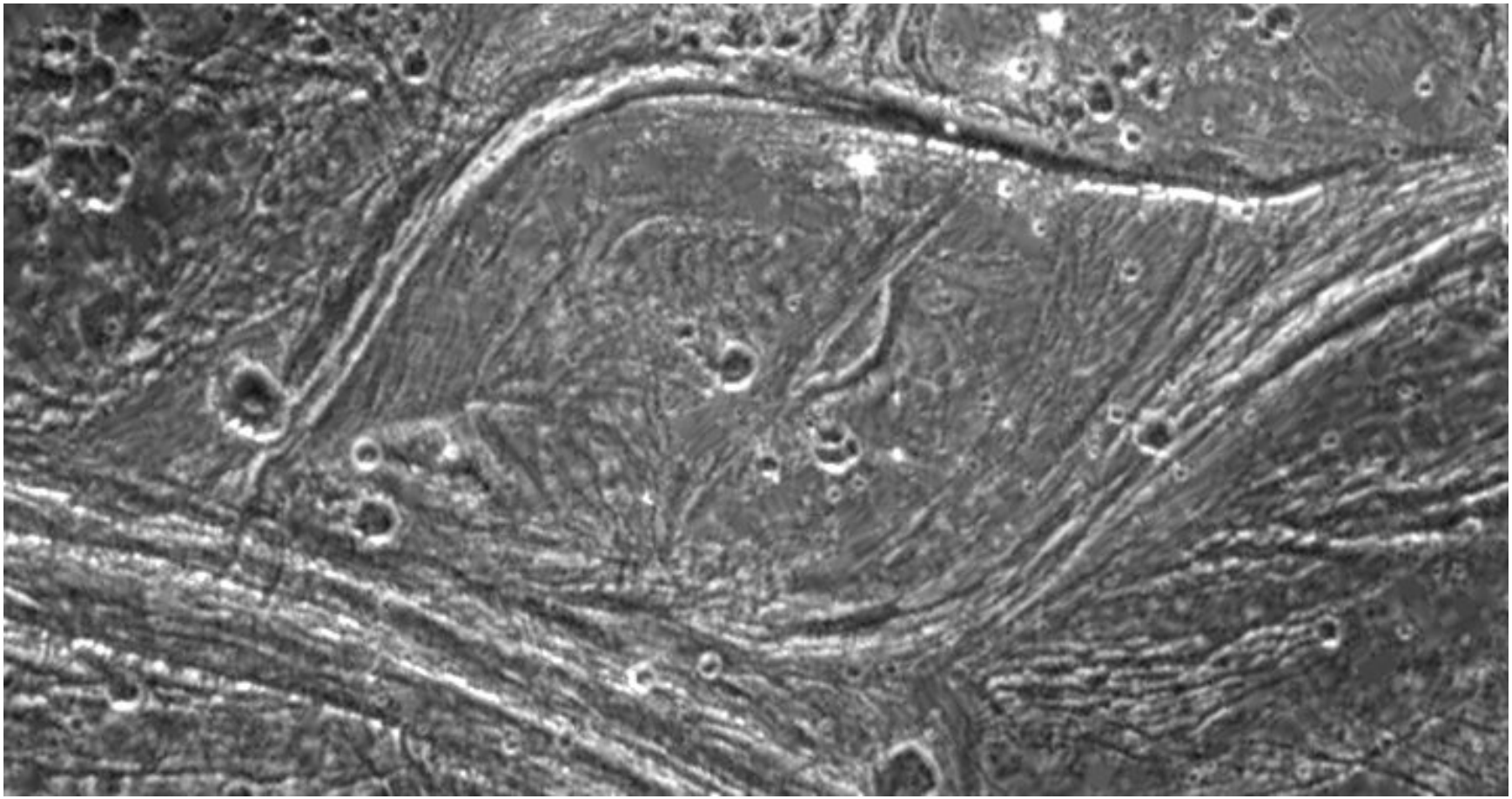

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Callisto:	Cooled even earlier. Extensive impact cratering.