Tidal locking

We always see the same face of the Moon. This means: period of orbit = period of spin

Why?

The tidal bulge in the solid Moon elongates it slightly (2-3 km) along an axis pointing to Earth.

If orbit period is faster than the spin period, tidal bulge would have to move around surface of Moon, creating friction, which slows the Moon’s spin down until tidal bulge no longer migrates around.
Jupiter’s Galilean satellites are easily seen with Earth-based telescopes

- The four Galilean satellites orbit Jupiter in the plane of its equator
- All are in semi-synchronous rotation
- The orbital periods of the three innermost Galilean satellites, Io, Europa, and Ganymede, are in the ratio 1:2:4
Note: Jupiter is shown to the same scale as the distances of the satellites from Jupiter. Compared to this scale, the images of the satellites themselves have been enlarged 74×.
Data from spacecraft reveal the unique properties of the Galilean satellites

The two innermost Galilean satellites, Io and Europa, have roughly the same size and density as our Moon.

They are composed principally of rocky material.

The two outermost Galilean satellites, Ganymede and Callisto, are roughly the size of Mercury.

Lower in density than either the Moon or Mercury, they are made of roughly equal parts ice and rock.

<table>
<thead>
<tr>
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<th>The Galilean Satellites Compared with the Moon, Mercury, and Mars</th>
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<tbody>
<tr>
<td></td>
<td>Average distance from Jupiter (km)</td>
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<tr>
<td>Io</td>
<td>421,600</td>
</tr>
<tr>
<td>Europa</td>
<td>670,900</td>
</tr>
<tr>
<td>Ganymede</td>
<td>1,070,000</td>
</tr>
<tr>
<td>Callisto</td>
<td>1,883,000</td>
</tr>
<tr>
<td>Moon</td>
<td>—</td>
</tr>
<tr>
<td>Mercury</td>
<td>—</td>
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<tr>
<td>Mars</td>
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- They are composed principally of rocky material.
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- Lower in density than either the Moon or Mercury, they are made of roughly equal parts ice and rock.
The Galilean satellites probably formed in a similar fashion to our solar system but on a smaller scale.

**Diagram:**
- **Protosun**
- **Proto-Jupiter**

**Text:**
In the inner parts of both the solar and Jovian nebulae, only rocky grains survive...

...while in the outer reaches of these nebulae, ice and rocky grains survive.
Io is covered with colorful sulfur compounds ejected from active volcanoes.

Areas not observed by the Voyager spacecraft.
Worlds of Fire and Ice:

Io

- Io has over 400 active volcanoes, some of which have produces plumes up to ~300 miles above the surface.
- From the surface of Io, Jupiter would subtend an arc of 19.5°, making Jupiter appear 39 times the apparent diameter of our Moon.
- Orbits Jupiter in 1.8 days.
- Surface level varies ~100 meters twice an orbit due to tidal forces.
- Average temperature is 110 K, but volcanic activity can cause surface temperatures to reach 700 K.
Volcanic activity requires a heat source – on Earth it is internal. Io is a small body. Should be cold and geologically dead by now. What is source of heat?

First, Io and Europa are in a "resonance orbit":

Day 0
Europa  Io  Jupiter

Day 1.77
Europa  Io  Jupiter

Day 3.55
Europa  Io  Jupiter

The periodic pull on Io by Europa makes Io's orbit elliptical.
• Tidal bulge always points to Jupiter. So the angle of the bulge changes faster when Io is closer to Jupiter.
• But Io rotates on its axis at a constant rate.
• So bulge moves back and forth across surface => stresses => heat => volcanoes
Jupiter Magnetic Field

- Io co-rotates with ionized radiation that is trapped in Jupiter’s strong magnetic field.

- A fatal dose of radiation is at 1000 rad. Io receives 3600 rad/day.
Europa is covered with a smooth layer of ice that may cover a worldwide ocean

- Surface is smooth and bright, consisting of water ice crisscrossed by long, linear fractures. Surface ~65 millions years old.
- Like Earth, Europa is thought to have an iron core, a rocky mantle and an ocean of salty water beneath its ice crust.
- Like Io, Europa is tidally locked in a 3.5 day orbit. But due to Ganymede, Europa experiences tidal heating.
- In 2013, NASA announced that Europa might be actively venting plumes of water into space. Providing evidence that the moon is geologically active in the present day.
- Has a weak induced magnetic field. Receives 540 rad/day.
• Other indications of water are a worldwide network of long cracks and ice rafts that indicate a subsurface layer of liquid water or soft ice.
• The “chaos terrain” is of particular interest because it is a place where geologic activity has disrupted the otherwise smooth surface.

Reddish material is of unknown composition, named “chaos terrain”
Smooth ice plains with a network of fractures

Linear ridges (dark colors are caused by minerals in the ice)
Galileo spacecraft observed distortions of Jupiter’s magnetic field.

Distortion is in reaction to Jupiter’s Magnetic field.

As charged particles move through magnetic fields, they induce their own fields.

If enough salt water is present on Europa, this could explain this.
• Tidally locked like Io and Europa, but appears not to have internal heating.

• 7.1 day orbital period and mean surface temperature 110 K.

• Ganymede might have a stack of several ocean layers separated by different phases of ice, with the lowest liquid layer adjacent to the rocky mantle.

• Tidal heating in the past may explain the liquid oceans and tectonic activities.
Two types of terrain are found on the icy surface of Ganymede:

- areas of dark, ancient, heavily cratered surface
- regions of heavily grooved, lighter-colored, younger terrain
• Strong magnetic field lines indicate a liquid iron core.
• Induced magnetic field lines indicate salty oceans.
• This suggests a composition of about equal parts rocky material and mostly water-ices and an internal structure that is fully differentiated like Earth.
• Receives about 8 rad/day due to the strong magnetic field and large distance from Jupiter.
Callisto has a heavily cratered crust of water ice.

The surface shows little sign of geologic activity, because there was never any significant tidal heating of Callisto.

However, some unknown processes have erased the smallest craters and blanketed the surface with a dark, dusty substance.

Magnetic field data seem to suggest that Callisto has a shallow subsurface ocean.
Jupiter has dozens of small satellites that have different origins

- As of early 2004, Jupiter had a total of 63 known satellites
- In addition to the Galilean satellites, Jupiter has four small inner satellites that lie inside Io’s orbit
- Like the Galilean satellites, these orbit in the plane of Jupiter’s equator
- The remaining satellites are small and move in much larger orbits that are noticeably inclined to the plane of Jupiter’s equator
- Many of these orbit in the direction opposite to Jupiter’s rotation
Deep Space Earth

- Saturn’s largest moon, Titan, is the only moon to have an atmosphere. Mainly composed of Nitrogen with minor components of methane and ethane clouds.
- The climate (94 K) includes wind and rain and is dominated by seasonal weather patterns as on Earth. “Geologically Young”
- Is protected from radiation by Saturn’s magnetic field.
- Titan is mostly a desert, but does support hydrocarbon lakes near the poles.
The Surface of Titan

Titan’s rocks are water ice!

Seas of methane or ethane
Living on Titan

- Most hospitable extraterrestrial world within our solar system for human colonization.
- Evidence also indicates the presence of liquid water and ammonia under the surface, which are delivered to the surface by volcanic activity.
- Water can easily be used to generate breathable oxygen and nitrogen is ideal to add buffer gas partial pressure to breathable air.
- Nitrogen, methane and ammonia can all be used to produce fertilizer for growing food.
- Wind power can be viable because of earth-like weather.
(a) Mimas
(diameter 392 km)

(b) Enceladus
(diameter 500 km)

(c) Tethys
(diameter 1060 km)

(d) Dione
(diameter 1120 km)

(e) Rhea
(diameter 1530 km)

(f) Iapetus
(diameter 1460 km)
Enceladus: South Polar Geyser
Cassini/Huygens Mission
Enceladus is contributing to a very faint, tenuous ring, called the E Ring, to Saturn’s rings.
Uranus’s Five largest Moons

- Uranus has five major moons: Miranda, Ariel, Umbriel, Titania, and Oberon.
- The masses of the moons range from $6.7 \times 10^{19}$ kg (Miranda) to $3.5 \times 10^{21}$ kg (Titania). (moon’s mass $7.5 \times 10^{22}$ kg.
- Relatively smooth surfaces suggest resonant orbits and tidal heating.
- Because of Uranus’s tilt, the sun moves in a circle through out the day.
The Sun's path in the sky in the daytime of this moon of Uranus during its summer. We're located near this moon's equator looking north.
Neptune largest moon: Triton
Neptune largest moon: Triton

- In retrograde orbit and similar composition to other Kuiper belt object.
  - Dwarf planet captured by Neptune’s gravity
- Young surface implies past geological activity.
- Frozen nitrogen “maria” deposited from cryo-volcanism.
- Neptune’s lack of moons may be due to Triton’s retrograde orbit
A view from Triton