So Many Moons!

Small moons (< 300km)
- Not spherical
- Probably failed planetesimals which were captured

Medium/Large moons (> 300km)
- All spherical
- Formed like planets out of the ‘mini nebulae’ surrounding jovian planets

Where are all the craters?!?!?!

Jovian satellites break the rules for terrestrial geology!

Reasons?
- Tidal Heating: A new heat source!
- Their different composition makes a difference together with the larger masses of their host planets
Towards understanding tidal heating: Orbital Resonances

Observing Jupiter’s moons

I=Io  E=Europa  G=Ganymede  C=Callisto

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Observing Jupiter’s moons

• Two (or more) objects orbiting a larger object can arrange themselves such that one’s period is twice, three times (etc.) the other’s; this is known as an orbital resonance.

• When the objects re-align, they nudge and pull each other’s orbits and change the orbital shape (circles become slight ellipses.)
So the orbits are elliptical, so what?

Let’s think about **TIDES**

The Moon's gravity stretches the Earth, causing two tidal bulges

Tides stretch every moon and every planet - a small but important amount

Tides + Elliptical Orbit = ??

- Orbit disturbed by the orbital resonance
- Tides distort Io's shape
- Io is being flexed continually during its orbit
  - This heats the interior
  - Known as **TIDAL HEATING**

Not to scale! The real tidal bulge raises the oceans by only a few meters

Not to scale! The real tidal bulge raises the Moon's surface by a few kilometers
Zooming in on Jupiter and Io

- Jupiter and Io from Hubble
  - Io is ~2000 miles across

Io

- Io against Jupiter, from Galileo

Volcanoes erupt frequently on Io.
- Sulfur in the lava accounts for yellow color
- Surface ice vaporizes and jets away
- Evidence of tectonics & impact cratering is easily covered.

The material leaving Io can even

Jupiter Aurora
NASA and J. Clarke (University of Michigan) • STScI-PRC09-38
The Galilean Satellites

Galileo, 1610

Galileo, 1995-2003

Europa:
Is it hiding a subsurface ocean?

Europa Zoom

- Few craters
- Many fractures

Europa Zoom
Ice Leads

Europa

Europa’s ridges

• Fractured surface tells a tale of tectonics and tidal heating
• Possible magnetic field adds to clues
• Jupiter Icy Moon Explorer (JUICE) targeted for 2022 launch

Clicker Question

What makes Jupiter’s moon, Europa, so special?

A. It is the only moon with a thick atmosphere
B. It is the most volcanically active body in the solar system
C. It is the largest of all moons in the solar system.
D. Its ice covered surface could be covering a liquid ocean
E. It is the only large moon that is not round.
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Europa has only ice while Io has many volcanoes. Tidal heating on Europa is weaker than on Io mainly because...

A. Europa is smaller than Io
B. Europa is farther from Jupiter
C. Europa is not in an orbital resonance
D. Tidal heating is not important if liquid water is present
E. None of the above: tidal heating is greater on Europa
Terrestrial Planet Geology
• Radioactivity heats interior
  - Drives volcanism & tectonics

Jovian Moon Geology
• Tidal heating can cause active geological activity (Io, Europa)
  - Moons on elliptical orbits around massive planets.
• Icy materials melt & deform easier than rock
  - Geological activity likely, even for smaller objects

We’ve talked about the Terrestrial Planets and the Jovian Planets - What about planets around other systems?

NEXT: EXOPLANETS

• Planets around other stars.....

Why is it so difficult to detect planets around other stars?
**Planet Detection**

- **Direct:** Pictures or spectra of the planets themselves

- **Indirect:** Measurements of stellar properties revealing the effects of orbiting planets

**Size/Brightness Difference**

- Like being in NY and trying to see a marble (Jupiter) or ball point pen tip (Earth) 15 meters from a grapefruit in Alaska
  - Remember the Model Solar System

- Now light that grapefruit on fire so you can see it all the way from Boulder!
  - A Sun-like star is about a billion times brighter than the sunlight reflected from its planets

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**Clicker Question**

At what wavelength would it be easiest to see the planet’s emitted light compared to the star?

A. X-rays  
B. Ultraviolet  
C. Visible  
D. Infrared  
E. Radio

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**Clicker Question**

At what wavelength would it be easiest to see the planet’s emitted light compared to the star?

A. X-rays  
B. Ultraviolet  
C. Visible  
D. Infrared  
E. Radio
• Planet is always fainter than the star, but at infrared wavelengths the relative brightness is the closest
  • e.g. Jupiter is only 10,000 times fainter at IR

**How can we detect planets around other stars?**

- What about indirect detection?
  - Detecting the planet by detecting its interaction with things around it.
- What properties of the planet could affect the star?

**Even in the infrared, direct detection is still VERY hard**

Only a few planets have been detected by this method.

**Detections due to MASS of planet**
- Astrometric Technique
- Doppler Technique

**Detections due to SIZE of planet**
- Transit Technique