AST 105
Intro Astronomy
The Solar System

MIDTERM III next Thursday, 11/19
(covering lectures 17--22)
The Galilean Moons

Galileo, 1610

Io
Europa
Ganymede
Callisto

Galileo, 1995-2003
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

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Medium and Large Moons of the Jovian Planets

- Jupiter
  - Io
  - Europa
  - Ganymede
  - Callisto
- Saturn
  - Mimas
  - Enceladus
  - Tethys
  - Dione
  - Rhea
  - Titan
  - Iapetus
- Uranus
  - Miranda
  - Ariel
  - Umbriel
  - Titania
  - Oberon
- Neptune
  - Triton
  - Nereid

Other objects for comparison

- Mercury
- Moon
- Pluto 3,000 km
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
Observing Jupiter's moons

I=Io     E=Europa     G=Ganymede     C=Callisto
Observing Jupiter's moons

I=Io, E=Europa, G=Ganymede, C=Callisto
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I=Io   E=Europa   G=Ganymede   C=Callisto
Observing Jupiter's moons

C = Callisto
E = Europa
G = Ganymede
I = Io
Observing Jupiter's moons

I=Io  E=Europa  G=Ganymede  C=Callisto
Observing Jupiter's moons
Orbital Resonances

• 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. Not to scale! The real tidal bulge raises the oceans by only a few meters.
Tides stretch every moon and every planet - a small but important amount.

Not to scale! The real tidal bulge raises the Moon’s surface by a few kilometers.
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
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 be seen affecting Jupiter's aurora!
The Galilean Satellites

Galileo, 1610

Galileo, 1995-2003
Europa:
Is it hiding a subsurface ocean?
Europa
Zoom

- Few craters
- Many fractures
Europa Zoom
Iceberg Field
Europa Zoom
Europa

• 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
Europa’s ridges
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
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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 - but 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 NY
  - A Sun-like star is about a billion times brighter than the sunlight reflected from its planets
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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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
Even in the infrared, direct detection is still VERY hard

Only a few planets have been detected by this method
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?
Detections due to MASS of planet
• Astrometric Technique
• Doppler Technique

Detections due to SIZE of planet
• Transit Technique
Astrometric Technique

- Can detect planets by measuring the change in a star’s position on the sky.

- Tiny motions are very difficult to measure.
  - 1 arcsecond ~ width of a human hair from about 30 feet away.

0.0005 arcsecond = angular radius of Sun from 30 light-years
Doppler Technique

• We need a reminder about light
Doppler Shift

• First let’s think about sound
  - Sound moving towards you sounds like a higher pitch
  - Sound moving away from you sounds like a lower pitch
Doppler Shift

Moving towards: Light appears shifted to higher frequency blueshifted

Moving away: Light appears shifted to lower frequency redshifted
Doppler shift of spectral lines

• Usually involves measuring the gas in a lab (on Earth)

• Then, measure redshift or blueshift of the astronomical object to get the velocity towards or away from you.

Which object is moving away the fastest?

Laboratory spectrum
Lines at rest wavelengths.
Think of the freeway at night!

- The red lights are going away from you
- The blue lights are coming towards you