Physics 112
Star Systems

Lecture 15
The Jovian System

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Fall 2015
Jupiter

“Poets say science takes away from the beauty of the stars – mere gobs of gas atoms. Nothing is "mere."

…

For far more marvelous is the truth than any artists of the past imagined!

Why do the poets of the present not speak of it?

What men are poets who can speak of Jupiter if he were like a man, but if he is an immense spinning sphere of methane and ammonia must be silent?”

Richard Feynman
Jupiter

Mass: $1.9 \times 10^{27}$ kg
Diameter: 142,984 km
Density: 1.326 gm/cm$^3$

5.2 AU from the Sun
Rotation: 9.925 hours
Revolution: 11.86 years

“Surface” gravity: 24.79 m/s$^2$
“Surface” Temp: -186° F

Atmospheric Composition:
86% H$_2$
13% Helium
0.1% Methane
0.1% Water vapor
0.02% Ammonia
Jupiter

Jupiter is a **GAS GIANT**

It is over 300 times more massive than the Earth.

It is mostly Hydrogen gas.

The **Great Red Spot** is a storm that has been raging since Galileo first looked at Jupiter through the telescope.
Comparison of Planetary Sizes

http://www.rense.com/general72/size.htm
Comparison of Planetary Interiors

Jupiter

Saturn

Uranus

Neptune

Earth

Cross-section Key:
- Lower mantle
- Outer core
- Hydrogen (H₂)
- Metallic hydrogen (H)
- Rock core
- Inner core (solid)

http://wapi.isu.edu/Geo_Pgt/Mod11_Jupiter/mod11.htm
Jupiter’s Interior

- Depth 100 km
  - Temperature 300 K
  - Pressure 10 atm

- Depth 20,000 km
  - Temperature 11,000 K
  - Pressure $3 \times 10^6$ atm

- Depth 60,000 km
  - Temperature 25,000 K
  - Pressure $12 \times 10^6$ atm

- Depth 70,000 km
  - Temperature 40,000 K
  - Pressure $50 \times 10^6$ atm

Molecular hydrogen

Metallic hydrogen
Jupiter’s Banding Structure
Jupiter Winds

As on the Earth, the convective motion in conjunction with the Coriolis Force gives Jupiter’s atmosphere a banded structure.

However, Earth is heated by the Sun.

But Jupiter’s winds are heated mainly from within.
Jupiter’s Band Colors
Voyager Approaches Jupiter
Voyager Approaches Jupiter
Jupiter’s Atmosphere
Jupiter’s Atmosphere
The Great Red Spot

The Great Red Spot is a storm that has been raging for over 400 years!

Is it a Low Pressure System?

Or a High Pressure System.
Jupiter’s Atmosphere
Comet Shoemaker-Levy was orbiting Jupiter for over 50 years when it broke into pieces due to tidal forces in on July 8, 1992. The pieces were up to 2km across.

It was discovered on March 23, 1993.

And impacted Jupiter over several days from July 16 – 22, 1994 at a speed of 37 miles/second!!!
The comet broke into more pieces from 1993 to 1994.
Cometary Impact

Visible light

Infrared
16 Days after Cometary Impact

Infrared
Magnetic Fields and Auroras
Planetary Magnetic Fields
Earth’s Magnetic Field

Close to the Earth, the Earth’s magnetic field looks like that from a bar magnet.

Further from the Earth, the winds of electrically charged particles moving at 200 km/sec “blow” the field back forming a magnetotail.
The Effect of Charged Particles

Electrically charged particles from the Sun (electrons, protons, and Helium nuclei) can become trapped by the magnetic field.

They spiral in along the field lines to the poles.

The regions where they are trapped are called the Van Allen Radiation Belts.
Auroras

When the Solar Winds are strong, these particles can collide with atoms in the Earth’s upper atmosphere. These collisions excite the air atoms resulting in the emission of light.

We call these lights:
Aurora Borealis (Northern Lights)

Aurora Australis (Southern Lights)
Auroras

An Aurora on Earth. Photo taken from the ISS
An Aurora on Earth. Photo taken from the Space Shuttle
Auroras

An Aurora on Earth. Photo taken from the Space Shuttle
Auroras

An Aurora from the surface of Earth
Auroras

An Aurora from the surface of Earth
Jupiter’s Magnetic Field

Jupiter has a HUGE magnetic field.

The electrically charged particles of the Solar Wind “blow’ back Jupiter’s field, which reaches all the way to Saturn!!!
Auroras on Jupiter

These are images of an aurora on Jupiter taken by the Hubble Space Telescope.
Auroras on Jupiter

Jupiter Aurora
NASA and J. Clarke (University of Michigan) • STScI-PRC00-38
## Jupiter’s Moons

|   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
Galilean Satellites

Io               Europa            Ganymede            Callisto
A Sense of Scale
A Sense of Scale
Moons of the Solar System Scaled to Earth's Moon

Earth: Moon (Moon), Phobos, Deimos
Mars: Asteroid Ida, Dactyl, Io (Jupiter)
Jupiter: Io, Europa, Ganymede, Callisto
Saturn: Mimas, Enceladus, Tethys, Dione, Rhea, Titan, Hyperion, Iapetus, Phoebe
Uranus: Puck, Miranda, Ariel, Umbriel, Titania, Oberon, Nereid
Neptune: Triton, Charon
Pluto: Charon

Earth
More Moons

Thebe
25 miles in diameter

Amalthea
25 miles in diameter

Metis
25 miles in diameter
Jupiter’s Rings
Innermost Moons and Rings

- Gossamer Rings
- Main Ring
- Halo
- Amalthea
- Adrastea
- Metis
- Thebe
Jupiter’s System

Schematic of Jupiter’s Outer Satellites
University of Hawai‘i, Institute for Astronomy

44 New satellite orbits are shown in red

Retrograde satellites

Prograde satellites

Callisto’s orbit

5 million km
Orbits of Jupiter’s Moons
The Galilean moons are tidal locked to Jupiter so that the same side faces Jupiter at all times.

Ganymede’s Orbital Period is twice Europa’s. Europa’s Orbital Period is twice Io’s.

These tidal forces from the other moons heats up Io so that the whole moon is volcanic!
Galilean Satellites

Io               Europa             Ganymede               Callisto
Sua Serenità,

Gallen Galilei, Filosofo, Senza delle sue 6. 

Questa è una copia della sua lettera:

Gallen Galilei, Filosofo, Senza delle sue 6.

Questa è una copia della sua lettera:
Jupiter and Moons from a Telescope
Jupiter and Moons from a Telescope

Movement of Galilean Satellites for 9.5 hours

Naoyuki Kurita
http://www.ne.jp/asahi/stellar/scenes/moon_e/galileo2.htm
Jupiter’s Moon Motions

Many skymaps of Jupiter’s Moons look like this.

Note that the inner moons orbit faster according to Kepler’s Third Law

Io
Europa
Ganymede
Calisto

http://www.nightskyobserver.com(bitmap/jupinfo.gif)
Mass: $8.93 \times 10^{22}$ kg
Diameter: 3640 km
Density: $3.528 \text{ gm/cm}^3$

Rotation: Synchronous
Revolution: 1.769 days

Surface gravity: 1.8 m/s²
Surface Temp: -225° F

Atmospheric Composition:
90% Sulfur Dioxide (SO$_2$)
Trace: Salt (NaCl)

Surface temperatures near the volcanoes are the hottest in the solar system reaching 1800 K (1527 C)
Io’s Mantle is Molten

Io seems to be most similar to the terrestrial planets when it comes to its composition.

It has an iron core with a radius of at least 900 km.

The rest is molten silicates with a thin solid highly volcanic crust.
Jupiter and Io
Io Naming Conventions

Volcanoes and Eruptive Centers are named after Volcano Gods, and Blacksmiths in Mythology.

Volcanic Crater Chains are named after Sun Gods.

Lava Flows are named after Fire and Thunder Gods.

Mesas, Plateaus, and other features are named after Fire Gods or locations associated with the Nymph Io in Greek Mythology.
Zal Patera is a volcanic caldera.

The mountains surrounding the caldera are known as Zal Montes. There is a 5 km high range to the south and a 2 km high plateau to the west. They can tell their heights by knowing the position of the Sun and the lengths of the shadows.
Euboea Montes on Io

Euboea Montes is the second highest range on Io at 13.4 kilometers.

Boösaule Montes is the highest at About 18 km.

Io Mountain Database
http://planetologia.elte.hu/io/

Io Maps
http://www.solarviews.com/cap/jup/ioqloc.htm

(Image courtesy of Paul Schenk.)
Tvashtar Catena

Tvashtar Catena is a volcano discovered by the Galileo Mission.
Hot Lava from Tvashtar
Io — Tvashtar Catena

I25 (26 Nov 1999)
+ C21 low-resolution color
+ fire fountain sketch

I27 (22 Feb 2000)
visible wavelength data
+ IR data of active lava flow

50 km
Tvashtar Erupts on Io
Tvashtar Again
More Volcanoes

- New eruptive center
- 500-km high plume from new eruptive center

- Tvashtar
- Dazhbog
Volcano with Lava on Io
Volcanoes and their Deposits

Pillan Patera

Pele

Fresh deposit
Io’s Plasma Torus

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Io’s Constant Auroral Glow

The image on the left was taken when Io was in Jupiter’s shadow.
Galilean Satellites

Io               Europa             Ganymede               Callisto
Europa

Mass: $4.8 \times 10^{22}$ kg
Diameter: 1560 km
Density: 3.014 gm/cm$^3$

Rotation: Synchronous
Revolution: 3.55 days

Surface gravity: 1.3 m/s$^2$
Surface Temp: -274° F

Atmospheric Composition:
100% Oxygen

Features on Europa are named after Greek, Celtic, and Irish Mythology. Linae are named after the mythology of Cadmus and Europa and European Megalithic Stone Rows.
Pwyll Crater

Pwyll Crater is relatively new crater about 15 miles across. Its white icy ejecta sprays for hundreds of miles. Reddish-brown material has filled the crater floor.
Europa

The surface is composed of water ice, and is cracked. The composition of the reddish-brown material is unknown.
Europa’s Cracked Icy Crust

This shows rafts and ridges probably due to frozen ice floating on an ocean.
Antarctic Ice Shelf on Earth

Ward Hunt Ice Shelf breaking up in Antarctica
On Earth volcanic activity under the ice can create ice volcanoes or fumaroles where the steam freezes forming giant towers. Could similar features exist on Europa? Probably not fumaroles, but perhaps ice water volcanoes!
Ice Volcanoes along Lake Superior

Ice water volcanoes form on Earth. These volcanoes are formed along Lake Superior where water waves flowing under the ice burst through forming vents and building volcanoes.

http://www.geo.mtu.edu/volcanoes/ice/
Ice Volcanoes Erupting

Michael Dolan and Paul Kimberly at Michigan Tech

http://www.geo.mtu.edu/volcanoes/ice/
Europa
Europa
Europa Dark Spot
Ridges

Close-up images of the linea reveal that they are ridges averaging about 1 km in height.

A spectacular view awaits on the surface!
This rough mixed up terrain is thought to be formed from icebergs frozen in a frozen sea.
Lenticulae (Freckles)

This image shows pits filled with reddish-brown material. This may be from warm ice bubbling up through the frozen surface. If so, the water underneath may be reddish-brown in color.
Europa’s Interior

- Metallic Core
- Ice Covering
- Rocky Interior
- Liquid Ocean Under Ice
- H₂O Layer
Like Io, Europa also has a plasma torus.
Galilean Satellites

Io               Europa             Ganymede               Callisto
Ganymede

Mass: $1.48 \times 10^{23}$ kg
Diameter: 5260 km
Density: 1.92 gm/cm$^3$

Rotation: Synchronous
Revolution: 7.15 days

Surface gravity: 1.43 m/s$^2$
Surface Temp: -263° F

Atmospheric Composition: 100% Oxygen

Features on Ganymede are named after Egyptian, Mesopotamian, and other ancient Middle Eastern myths
Ganymede is the largest moon in the solar system.

It is the only moon with a magnetosphere. It also has an induced magnetic moment indicating that its interior is electrically conductive.

It has a salt water subsurface ocean that is 60 miles deep under 95 miles of icy crust. It has more water than Earth!
Ganymede is characterized by dark and light terrain. The dark terrain is ancient and is heavily cratered. The light terrain is cratered as well, but less so. This indicates that it is younger.
Dark and Light Terrain

Note how the dark terrain (left) is heavily cratered. The light terrain is grooved and less cratered. Its age is unknown.

The dark terrain is estimated to be 4 billion years old (the age of our Moon’s highlands). The grooved features are due to tectonic activity extension and compression of the icy crust.
Galileo Regio

Galileo Regio is the circular dark region.

This was the site of an ancient impact.

It is dark material and heavily cratered.
Galileo Regio

This is a 3D reconstruction of Galileo Regio.
(Ignore the Blue Sky)
Chain Crater on Ganymede

This is a chain crater formed from an object that broke up before impact, much like Comet Shoemaker-Levy

How does the age of this impact compare to the other features in this image?
Callisto

Mass: $1.08 \times 10^{23}$ kg  
Diameter: 4820 km  
Density: $1.83 \text{ gm/cm}^3$

Rotation: Synchronous  
Revolution: 16.7 days

Surface gravity: 1.23 m/s$^2$  
Surface Temp: $-244$° F

Atmospheric Composition:  
100% Carbon Dioxide

Features on Calisto are named after Norse mythology.

Craters are the dominant feature on Callisto
Callisto is a Cratered World

Callisto is a colorful cratered world. Here craters dominate as there is little tectonic activity.

For this reason, Callisto was first thought to be simple and uninteresting.

Now we find new mysteries. Perhaps stranger than any of the other moons.
Callisto has an icy crust, a salty subsurface ocean, and a rocky interior with little or no iron core.
Clearly Heavily Cratered Old Surface
Callisto Features

The Asgard Region of Callisto is the site of an ancient impact basin. Notice the concentric ridges forming a bullseye pattern.

More recent craters have white icy ejecta.

Again, there is evidence of water ice below the surface.
Valhalla is another enormous impact basin.
This and other unusual crater chains on Callisto formed by the impact of tidally disrupted comets. This chain is ~620 kilometers long, with craters up to 40 kilometers across (scale bar is 100 km long). Gipul Catena is located near the north pole of Callisto. Several similar crater chains have also been identified on Ganymede.
Callisto Crater Chain Close Up
This is Callisto at several different scales. Clearly the moon is heavily cratered. But do you notice anything unusual?
Lack of Small Craters!

There is a conspicuous lack of small craters! Why? Where did they go?

Ganymede has 5 times the number of small craters than Callisto.
What else do you notice?
There is dark material on the surface that is not present on the mountain tops.

Or is it light material on the mountain tops?
Dark Material coats the surface of the moon.

But not at high altitudes!

What is it?

Could it have something to do with the fact that there are no small craters?