Lecture #29: Neptune

• Neptune
  – General properties
  – Atmosphere
  – Interior
  – Origin and evolution
• Readings: Chapters 7.1 (Neptune) and 11.1

The Main Point

Neptune, the second planet discovered by telescope, is a mid-sized Jovian planet made mostly of hydrogen, helium, and methane and possessing a strong internal heat source.

The Jovian Planets

Basic Properties of Neptune

• Average Distance from Sun: 4.5 billion km ($a=30.1$ AU)
• Orbital period: 165 years; eccentricity: 0.01
• Period of Spin around axis: ~16 hours
• Tilt of Neptune's spin axis: 29° (seasons)
• Mass: $1.0 \times 10^{26}$ kg = 17 $M_E$; Radius: 24,750 km = 3.9 $R_E$
• Density = 1.6 $g/cm^3$ (mostly "rocky/icy")
• No "surface" like the terrestrial planets: clouds/haze visible
• Gravity = 11.6 m/sec$^2$ (1.18 times Earth's)
• Cloud-top temperature: 60 K (-213°C) [same as Uranus!]
• Atmosphere: Mostly H, He, CH$_4$
• Moons: 8 presently known
• Neptune has a set of thin, dark rings
**Discovery**

- Neptune was discovered by telescope in 1846
  - Galileo saw Neptune in 1613, but thought it was a star!
- Neptune's existence was predicted based on mathematical studies of small perturbations in the orbits of Uranus, Saturn, and Jupiter
  - Mathematicians John C. Adams and Urbain Jean Joseph Le Verrier independently predicted Neptune's position
  - Johann Gottfried Galle and Heinrich Louis d'Arrest found the planet independently at different telescopes
- Lots of nasty business about who got the credit!

**A Triumph of Newtonian physics!**

> "Monsieur, the planet of which you indicated the position really exists."  
> Galle to Le Verrier on 25 Sept., 1846

> "I thank you for the alacrity with which you applied my instructions. We are thereby, thanks to you, definitely in possession of a new world."  
> Le Verrier's reply

**Observations of Neptune**

- Neptune's disk is only about 2 arcsec diameter
  - You need a telescope to see Neptune
  - Even then, it's challenging to see any details
- Neptune appears slightly blue through telescopes
- More detail can be seen in higher resolution HST images, or using telescopes in the infrared
- Features in Neptune's atmosphere can be seen
  - More subtle than those on Jupiter or Saturn
  - But much more visible than those on Uranus

**Space Missions**

- Only one encounter: Voyager 2

<table>
<thead>
<tr>
<th>Mission</th>
<th>Date</th>
<th>Goals and Results</th>
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<tbody>
<tr>
<td>Voyager 2</td>
<td>1989</td>
<td>Flyby; high resolution imaging and other studies</td>
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Future Mission: Neptune/Triton Orbiter  
Launch: 2035
Features in Neptune’s Atmosphere
• Zones & belts stronger than Uranus’
• Smaller clouds, storms apparent
• Clouds, storms changed during the past decade

Atmospheric Composition
• Determined by spectroscopy from telescopes and spacecraft
• Observed (upper) composition very “solar”

<table>
<thead>
<tr>
<th>Name</th>
<th>Symbol</th>
<th>% Volume</th>
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<tbody>
<tr>
<td>Hydrogen</td>
<td>H\textsubscript{2}</td>
<td>65</td>
</tr>
<tr>
<td>Helium</td>
<td>He</td>
<td>13</td>
</tr>
<tr>
<td>Methane</td>
<td>CH\textsubscript{4}</td>
<td>0.1 to 1%</td>
</tr>
<tr>
<td>Water</td>
<td>H\textsubscript{2}O</td>
<td>??</td>
</tr>
<tr>
<td>Carbon Monoxide</td>
<td>CO</td>
<td>\sim 1 \times 10^{-6}</td>
</tr>
<tr>
<td>C\textsubscript{2}H\textsubscript{6}</td>
<td>1.5 \times 10^{-6}</td>
<td></td>
</tr>
<tr>
<td>C\textsubscript{2}H\textsubscript{2}</td>
<td>6 \times 10^{-8}</td>
<td></td>
</tr>
<tr>
<td>HCN</td>
<td>\sim 1 \times 10^{-9}</td>
<td></td>
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</table>

• The ratio of H\textsubscript{2}/He in Neptune’s atmosphere is close to the Sun’s
• Much more He than Jupiter & Saturn, but comparable CH\textsubscript{4}
• Neptune’s atmosphere differs from Uranus’; different internal heating/mixing?

Atmospheric Structure
Like Uranus, clouds and hazes of methane gas give Neptune its distinctive blueish color.

Neptune’s Interior
• Slightly higher density, higher Helium abundance, and lower internal pressures & temperatures argue that Uranus and Neptune have very different interior structures than Jupiter and Saturn
• “Ice” and “rock” are much larger fractions of Uranus and Neptune

Remember:
• “Rock” means silicate minerals like in the terrestrial planets
• “Ice” here means volatiles like CH\textsubscript{4}, NH\textsubscript{3}, H\textsubscript{2}O

Neptune rotation 1996 HST Images

“Great Dark Spot” 1989 Voyager Images
Internal vs. External Heat Sources

- What is Neptune's energy balance?
- For Neptune: Outgoing = $3 \times$ Incoming
- Neptune generates its own internal heat!
  - Primordial heat of formation?
  - More radioactive "rocky" materials?
  - But why is Uranus so different?
- May explain the greater variety and variability of clouds compared to Uranus

Neptune has a strong magnetic field

- Like Uranus, Neptune has no metallic H in its interior...why does it have a field?
- Same theory: Field is generated in the core by high pressure ionization of ices/rock (making them conductive)

Satellites of Neptune

- 1 large satellite, Triton
  - Also discovered in 1846
  - Similar size as Earth's Moon
  - But orbits *backwards* compared to Neptune's spin...!
  - Has an *atmosphere* and *active geysers* on the surface!
- 1 mid-size satellite, Nereid
  - Nereid has a very eccentric orbit ($e=0.75$)
- 6 smaller moons discovered by Voyager 2
- 5 irregular outer satellites

More details: Lecture 30

Neptune’s irregular moons

- Halimede, Sao, Laomedeia, and Neso discovered in 2002 at Cerro Tololo
- Psamathe discovered in 2003 at Mauna Kea

Artists' conception of three irregular moons of Neptune

Cerro Tololo is a complex of astronomical observatories located 70 km east of La Serena, Chile.


These extremely faint moons with diameters of 30 to 50 kmrs were presumably captured by Neptune. Two of the five irregular moons of Neptune have prograde and three have retrograde orbits.
A time-lapse movie of Neptune…
…assembled from combining NASA Hubble Space Telescope images taken over a 15-hour period. The animation has four sections:

- Neptune and its largest satellite Triton, which is about as large as our moon.
- Colors enhanced to better show the subtle detail of clouds in Neptune's atmosphere.
- Spectral region of light changed from the visible to special methane bands in the near infrared.
- Traces the satellite orbits.

Rings!
- Neptune has rings
  - 4 main rings
  - 3 narrow, 1 diffuse
  - all very dark
- Discovered from Earth by star occultations
- Once thought to be "arcs" not complete rings
- But Voyager images showed them to be full rings, with "clumps"
- Made of organics+ices?

Summary
- Neptune was "discovered" mathematically
- Neptune is a gas giant planet with a thick H, He, and CH4 atmosphere
- Neptune's atmosphere has clouds and other features that change rapidly like Jupiter's or Saturn's
  - Neptune generates its own internal heat
- Neptune's interior consists mostly of "icy" and "rocky" materials at high pressure and temperature
  - Strong & offset magnetic field like Uranus
- Neptune has 13 known satellites and a ring system...