

Optional Observing Tonight

with CeeCee Bishop (TA)

8 pm: Meet in Small Hall lobby.

8:15 pm: Go to roof for telescope observations.

→ Moon, Jupiter, Saturn, nebula (?)

9 pm: End of observing.

Today's Topics

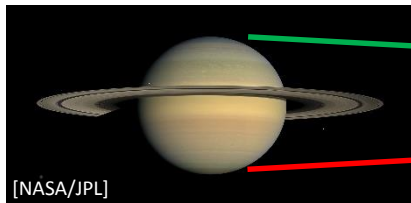
Monday, October 2, 2019 (Week 5, lecture 14) – Chapter 7.

1. Space Probes
2. Structure of the Solar System
3. Density

Angular Resolution and Size

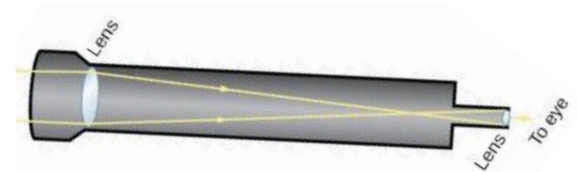
Angular resolution (or resolving power) θ_{min}

The minimum angle that a telescope can see, i.e. it's the “angular pixel” size.



celestial object

θ_{object}



telescope

Imaging Detail

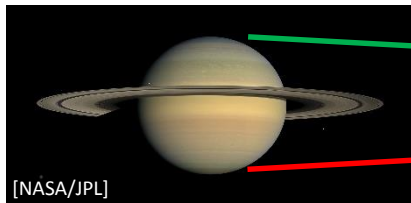
What ultimately matters is the number of angular pixels that you can get for your image:

$$\text{number of angular pixels} = \frac{\theta_{object}}{\theta_{min}}$$

Angular Resolution and Size

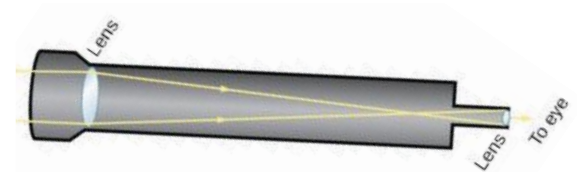
Angular resolution (or resolving power) θ_{min}

The minimum angle that a telescope can see, i.e. it's the “angular pixel” size.



celestial object

θ_{object}



telescope

Imaging Detail

What ultimately matters is the number of angular pixels that you can get for your image:

$$\text{number of angular pixels} = \frac{\theta_{object}}{\theta_{min}}$$

Telescopes maximize the number of pixels by minimizing θ_{min} .

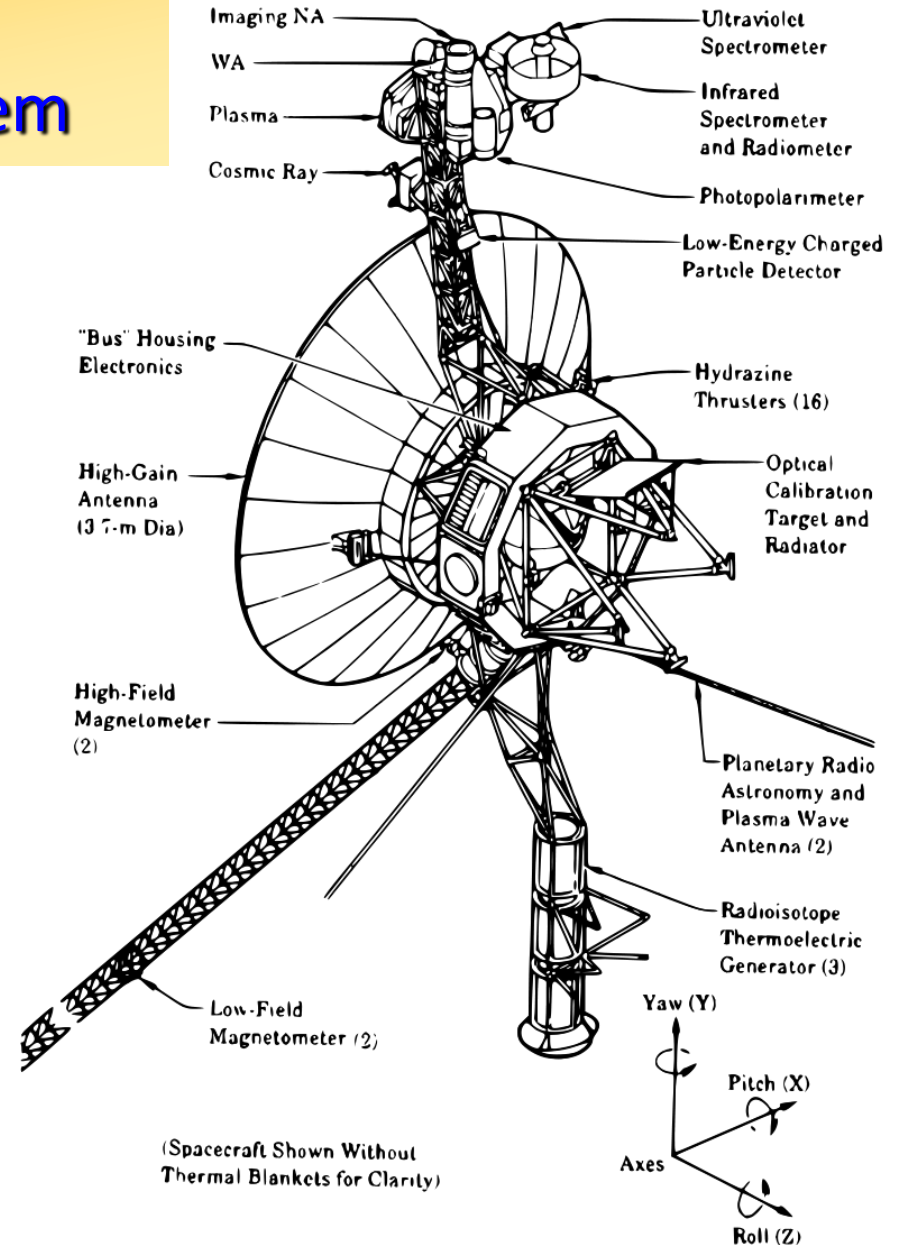
Space probes maximize the number of pixels by maximizing θ_{object} .

→ i.e. They get closer to the celestial object.

Space Probes

for exploring the Solar System

Voyager Spacecraft: basic structure



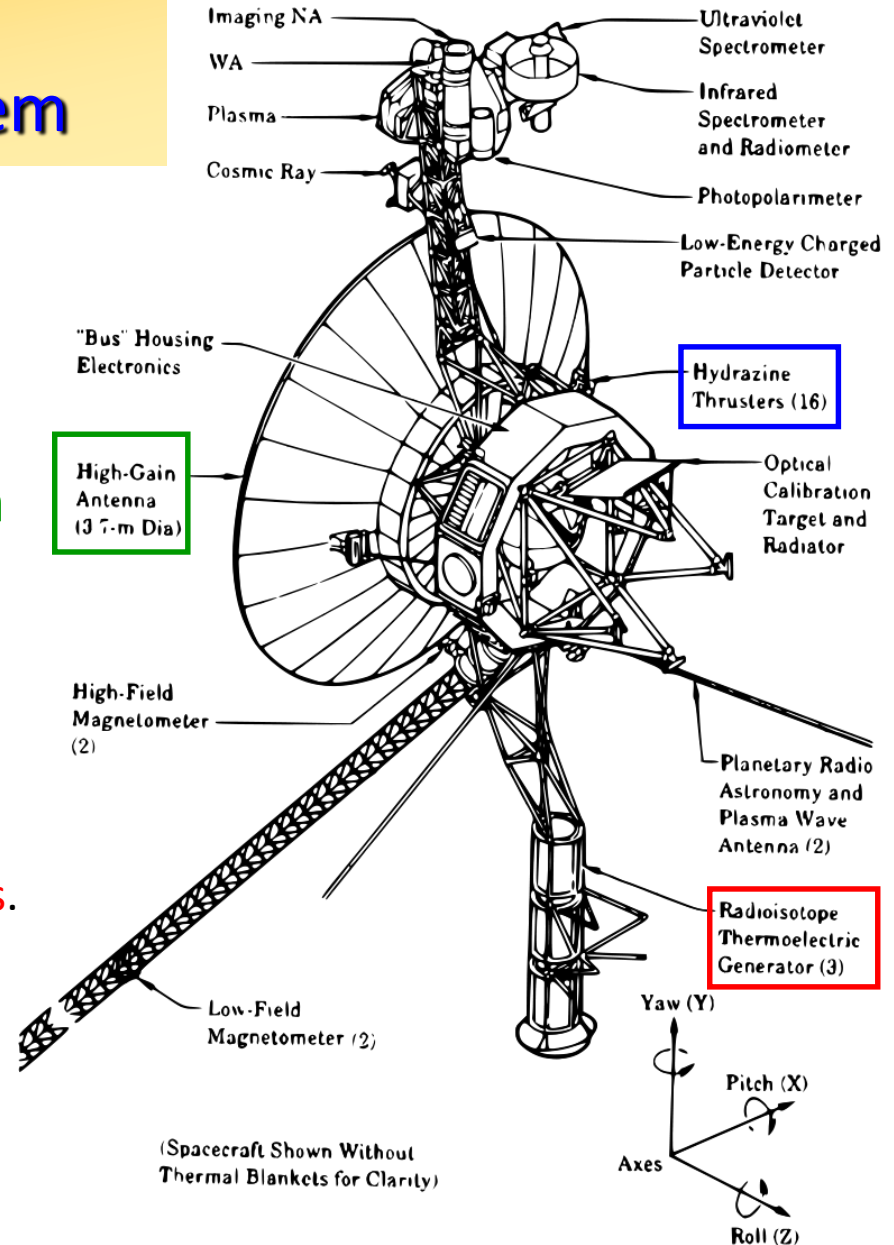
Space Probes

for exploring the Solar System

Basic Structure of an Interplanetary Space Probe

- ❑ Communications antenna / dish
 - receive commands.
 - transmit data.
- ❑ Computer
 - Control all spacecraft parts.
- ❑ Power source
 - Plutonium (thermoelectric), solar cells.
- ❑ Thrusters
 - Rockets for motion control.
- ❑ Science sensors
 - cameras, magnetometers, particle detectors, etc .

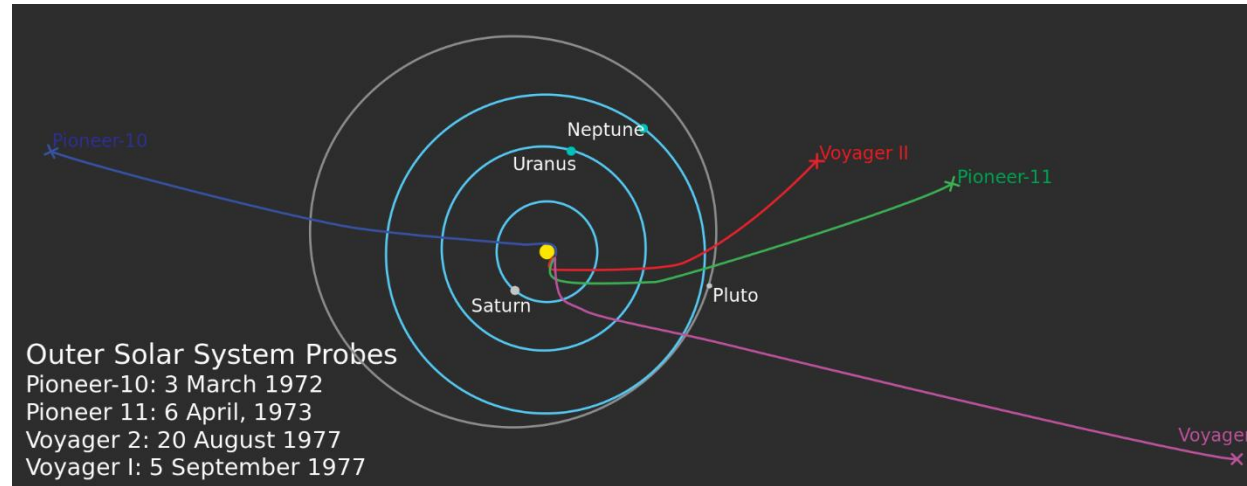
Voyager Spacecraft: basic structure



Voyager 1 & Voyager 2

Explored the gas giant planets:

- Jupiter
- Saturn
- Uranus (V2)
- Neptune (V2)



[By 7Train at the English Wikipedia, CC BY-SA 3.0]

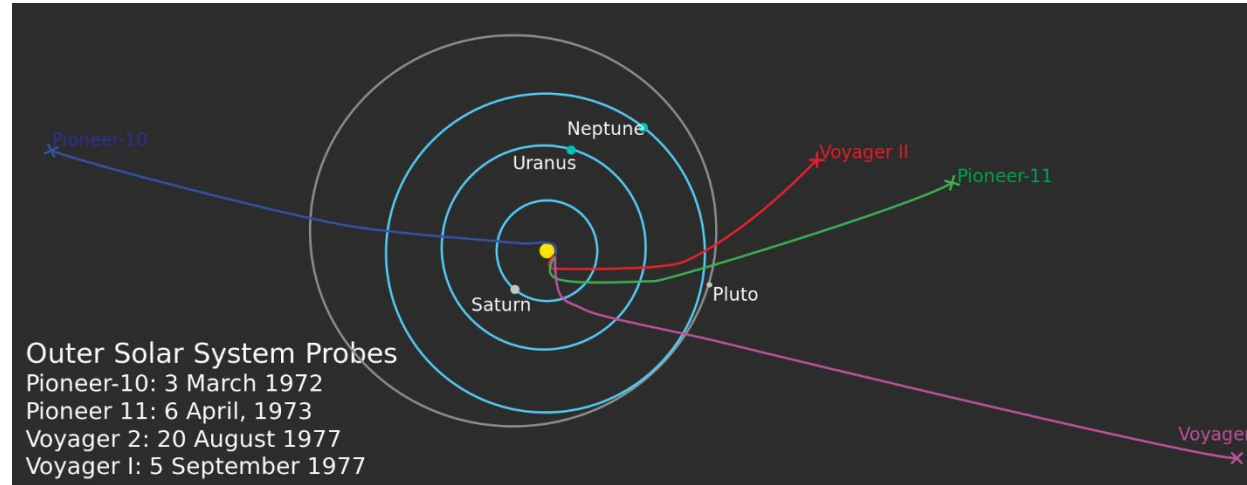
Main Instruments

Cameras, magnetometers, IR & UV spectrometers, low-energy particle detector, cosmic ray detector, etc.

Voyager 1 & Voyager 2

Explored the gas giant planets:

- Jupiter
- Saturn
- Uranus (V2)
- Neptune (V2)



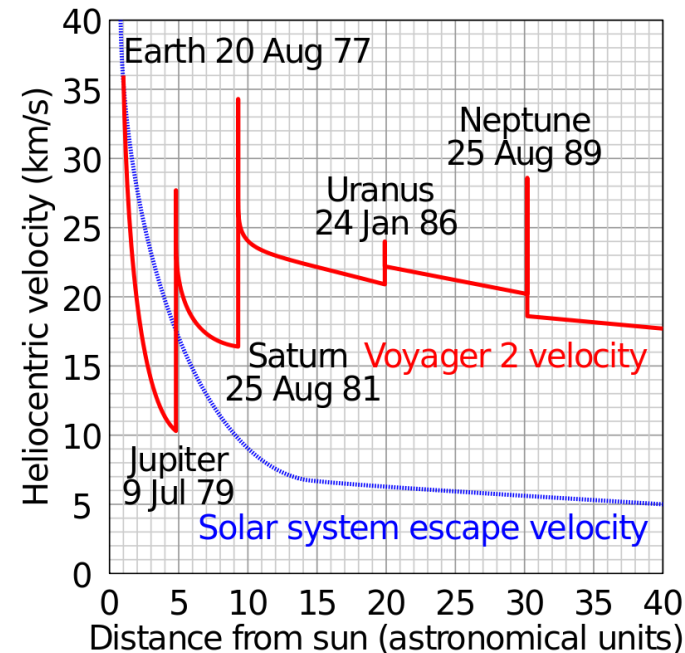
[By 7Train at the English Wikipedia, CC BY-SA 3.0]

Main Instruments

Cameras, magnetometers, IR & UV spectrometers, low-energy particle detector, cosmic ray detector, etc.

Key facts

- USA, launched in 1977, cost ~ \$ 850 million USD.
- Voyager 1 was the first probe to leave the Solar System and enter interstellar space (2012).
- Used gravity assist from planets to increase speed.



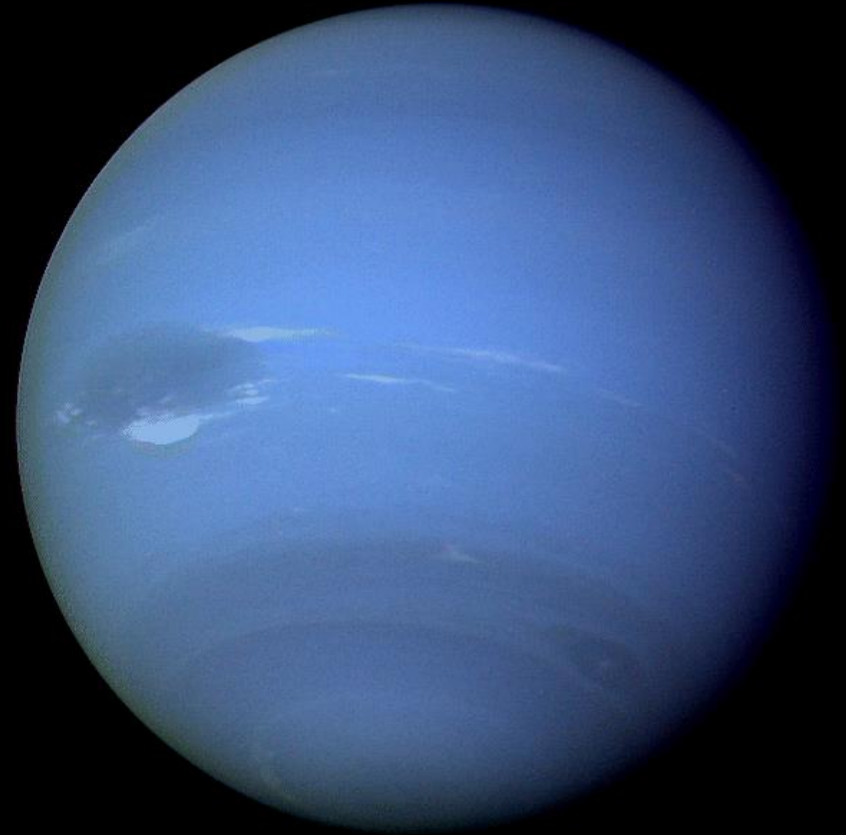
[By Cmglee - Own work, CC BY-SA 3.0]

Voyager 2: Uranus & Neptune



[NASA, JPL]

Uranus -- photo by Voyager 2 (1986)



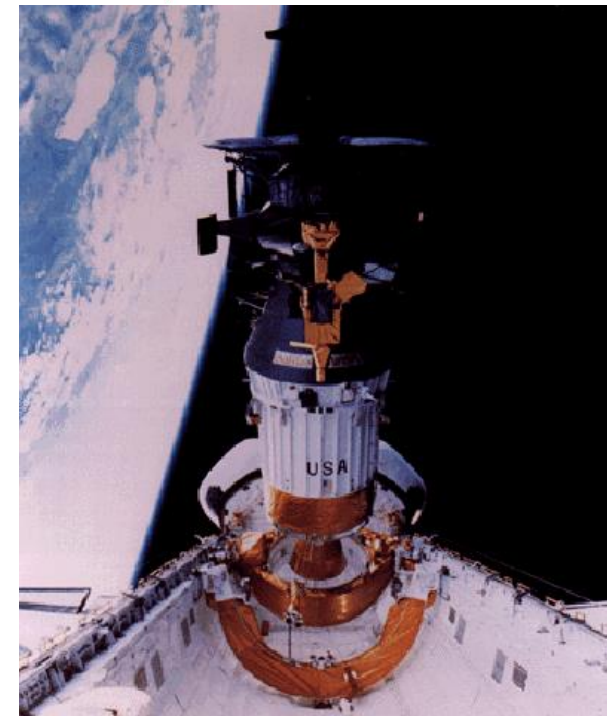
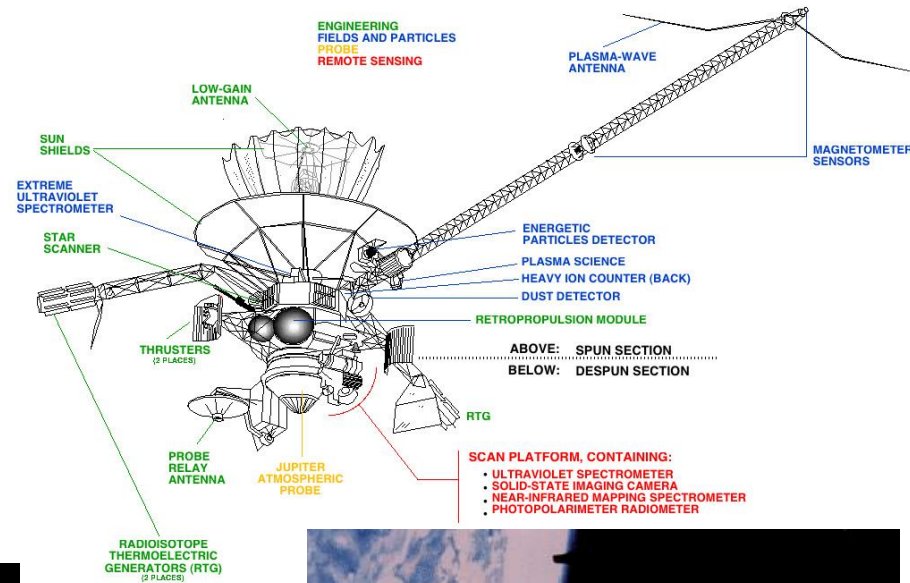
[NASA, JPL]

Neptune -- photo by Voyager 2 (1989)

Galileo Probe: Jupiter

Key Facts

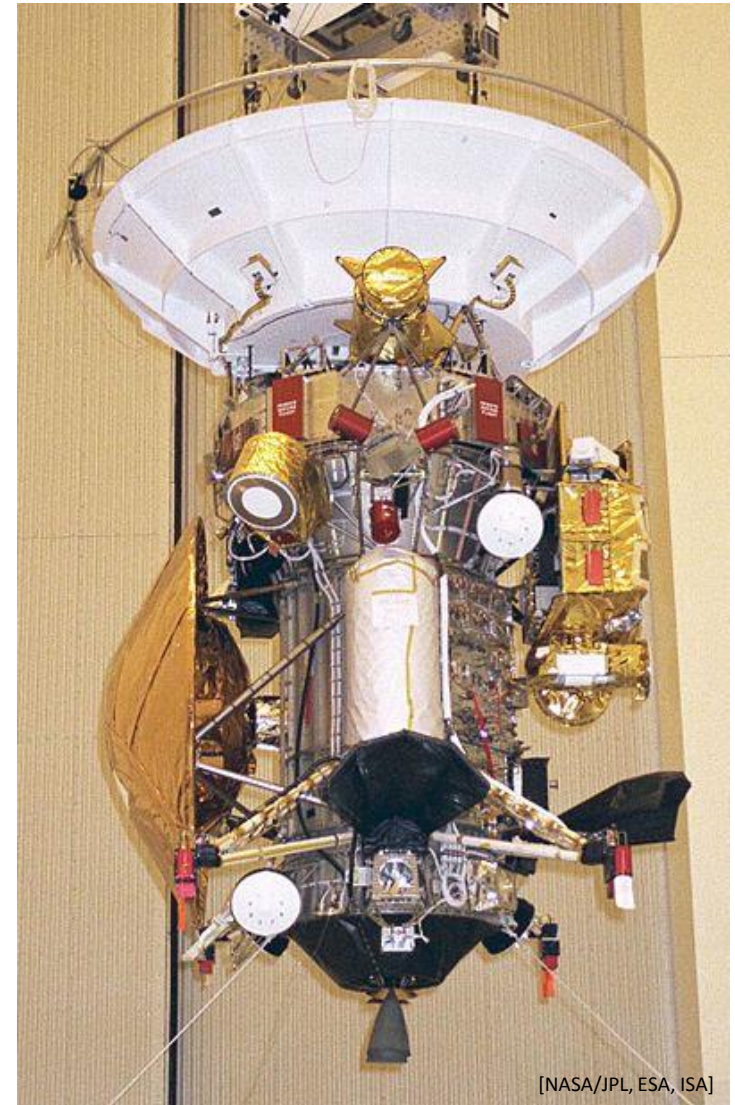
- Launched 1989 (NASA + UK, FR, CA, SW).
- Arrived at Jupiter in 1995.
- 34 orbits & atmospheric probe.
- Studied Jupiter and main moons:
 - Io, Ganymede, Callisto, and Europa.
- Mission end in 2003 (atmospheric entry).



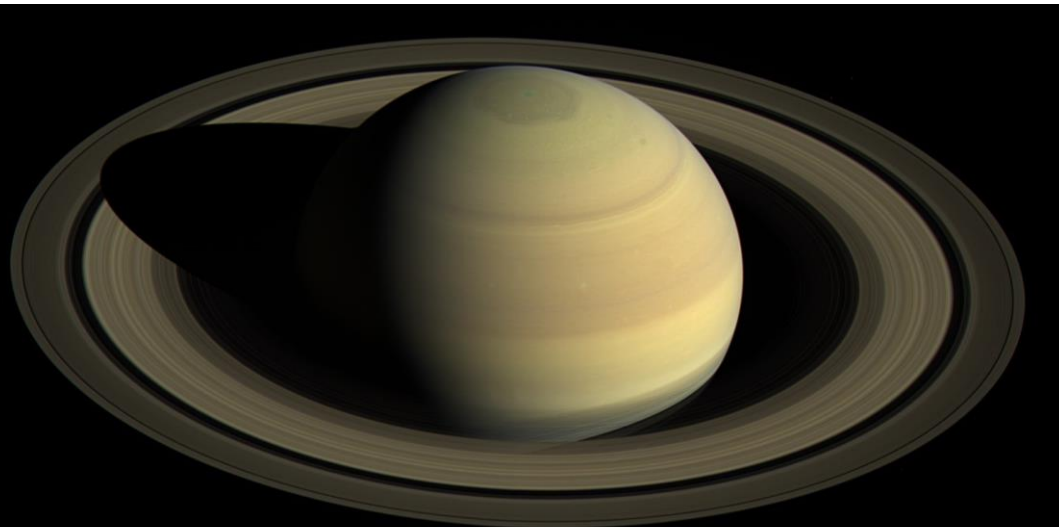
Cassini-Huygens Probe: Saturn

Key Facts

- Launched in 1997, NASA + ESA, ISA.
- Arrived at Saturn in 2004.
- Studied Saturn, rings, and moons.
 - Lander probe on Titan (largest moon).
- Mission end in 2017 (atmospheric entry).



[NASA/JPL, ESA, ISA]



Saturn by Cassini, 2016.

[NASA/JPL]

New Horizons: Pluto

Key Facts

- Launched in 2006, NASA + Johns Hopkins APL.
- Fly-by of Pluto in 2015.
- Studied Pluto and five moons.
- Studying Kuiper Belt objects, e.g. Ultima-Thule.
- Mission is on-going.



[NASA]

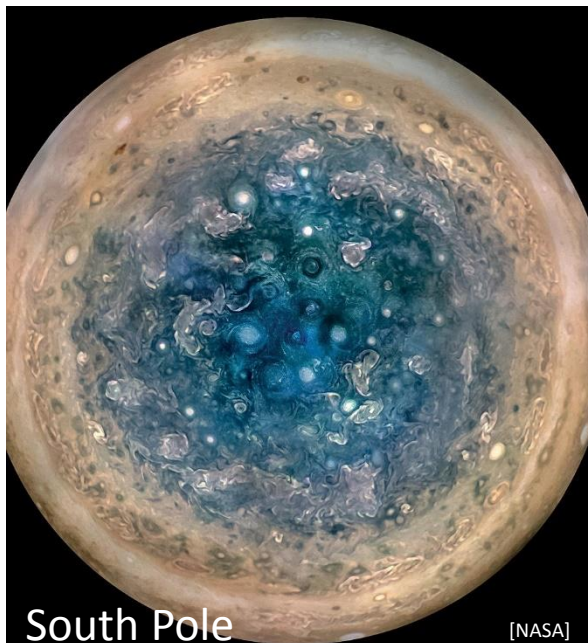
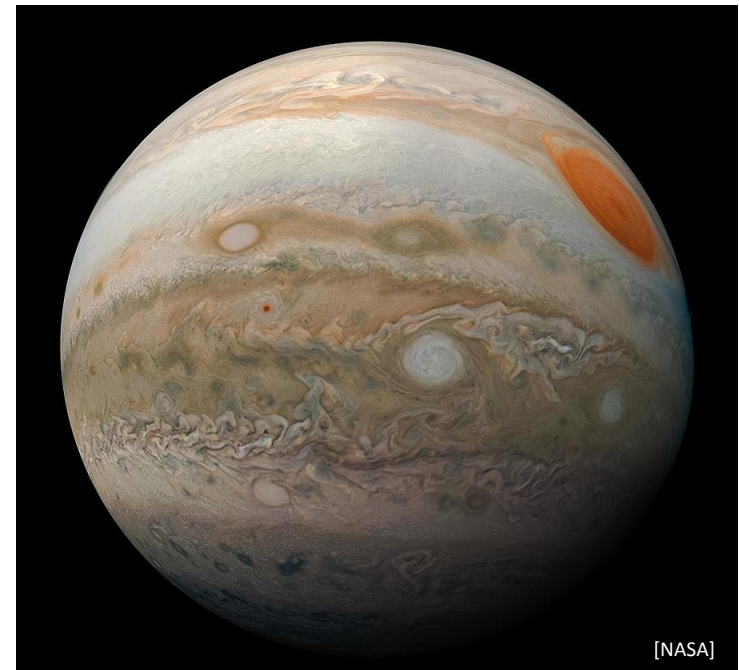


[NASA]

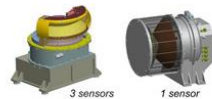
Juno: Jupiter again

Key Facts

- Launched in 2011, NASA/JPL.
- Arrival at Jupiter in 2016.
- Studying **polar** regions, precision **gravity** map, precision **magnetic** map, frame dragging test (general relativity), chemical composition, atmosphere.
- Mission is on-going (end: 2021).

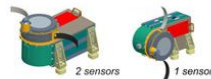


Jovian Auroral Distributions Experiment (JADE)



JADE will measure the distribution of electrons and the velocity distribution and composition of ions.

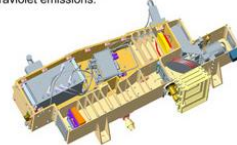
Jupiter Energetic-particle Detector Instrument (JEDI)



JEDI is a suite of detectors that will measure the energy and angular distribution of charged particles.

Ultraviolet Spectrograph (UVS)

UVS is an imaging spectrograph that is sensitive to ultraviolet emissions.



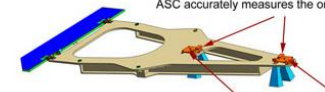
Gravity Science (GS)

The Juno Gravity Science Investigation will probe the mass properties of Jupiter by using the communication subsystem to perform Doppler tracking.

Magnetometer (MAG)

Advanced Stellar Compass (ASC)

ASC accurately measures the orientation of the magnetometers.

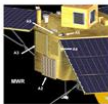


Fluxgate Magnetometer (FGM)

The two fluxgate sensors will measure the magnitude and direction of the magnetic field in Jupiter's environment.

Microwave Radiometer (MWR)

MWR is designed to sound deep into the atmosphere and measure thermal emission over a range of altitudes.



Plasma Waves Instrument (Waves)

Waves will measure plasma waves and radio waves in Jupiter's magnetosphere.



Jovian Infrared Auroral Mapper (JIRAM)



JIRAM will acquire infrared images and spectra of Jupiter. JIRAM is located on the aft/bottom deck.

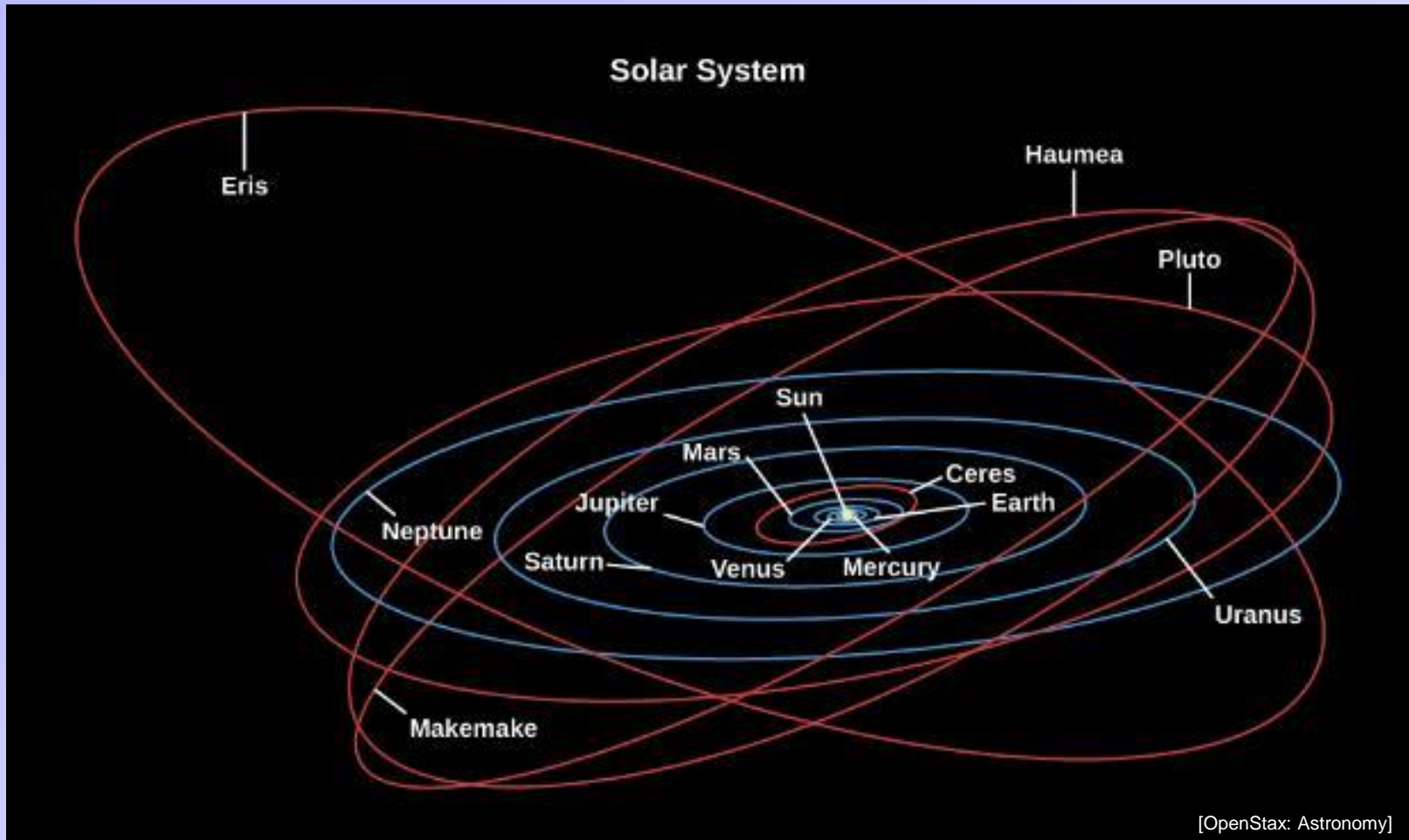
JunoCam



JunoCam will provide visible-color images of the Jovian cloud tops.

[NASA]

Structure of Solar System



- Planets orbit in the **same plane** (more or less), but outer dwarf planets do not.
- **Orbit direction is the same** for all planets, and matches Sun's rotation direction.
- Inner planets: rocky; outer planets: "gaseous" ... icy/less rocky.

Density of Planets

Name	Distance from Sun (AU) ^[2]	Revolution Period (y)	Diameter (km)	Mass (10 ²³ kg)	Density (g/cm ³) ^[3]
Mercury	0.39	0.24	4,878	3.3	5.4
Venus	0.72	0.62	12,120	48.7	5.2
Earth	1.00	1.00	12,756	59.8	5.5
Mars	1.52	1.88	6,787	6.4	3.9
Jupiter	5.20	11.86	142,984	18,991	1.3
Saturn	9.54	29.46	120,536	5686	0.7
Uranus	19.18	84.07	51,118	866	1.3
Neptune	30.06	164.82	49,660	1030	1.6

Density of Planets

measurements
or Kepler's 3rd Law

observations

telescope
measurements



?



Name	Distance from Sun (AU) ^[2]	Revolution Period (y)	Diameter (km)	Mass (10 ²³ kg)	Density (g/cm ³) ^[3]
Mercury	0.39	0.24	4,878	3.3	5.4
Venus	0.72	0.62	12,120	48.7	5.2
Earth	1.00	1.00	12,756	59.8	5.5
Mars	1.52	1.88	6,787	6.4	3.9
Jupiter	5.20	11.86	142,984	18,991	1.3
Saturn	9.54	29.46	120,536	5686	0.7
Uranus	19.18	84.07	51,118	866	1.3
Neptune	30.06	164.82	49,660	1030	1.6

Density of Planets

measurements
or Kepler's 3rd Law

observations

telescope
measurements

Newton's version
of Kepler's 3rd Law
using moons/satellites



Name	Distance from Sun (AU) ^[2]	Revolution Period (y)	Diameter (km)	Mass (10 ²³ kg)	Density (g/cm ³) ^[3]
Mercury	0.39	0.24	4,878	3.3	5.4
Venus	0.72	0.62	12,120	48.7	5.2
Earth	1.00	1.00	12,756	59.8	5.5
Mars	1.52	1.88	6,787	6.4	3.9
Jupiter	5.20	11.86	142,984	18,991	1.3
Saturn	9.54	29.46	120,536	5686	0.7
Uranus	19.18	84.07	51,118	866	1.3
Neptune	30.06	164.82	49,660	1030	1.6

Density of Planets

measurements or Kepler's 3rd Law observations telescope measurements Newton's version of Kepler's 3rd Law using moons/satellites **Calculation**

Name	Distance from Sun (AU) ^[2]	Revolution Period (y)	Diameter (km)	Mass (10 ²³ kg)	Density (g/cm ³) ^[3]
Mercury	0.39	0.24	4,878	3.3	5.4
Venus	0.72	0.62	12,120	48.7	5.2
Earth	1.00	1.00	12,756	59.8	5.5
Mars	1.52	1.88	6,787	6.4	3.9
Jupiter	5.20	11.86	142,984	18,991	1.3
Saturn	9.54	29.46	120,536	5686	0.7
Uranus	19.18	84.07	51,118	866	1.3
Neptune	30.06	164.82	49,660	1030	1.6

Density of Planets

Density of water = 1 g/cm³
note: ml = cm³

measurements
 or Kepler's 3rd Law

observations

telescope
 measurements

Newton's version
 of Kepler's 3rd Law
 using moons/satellites

Calculation

Name	Distance from Sun (AU) ^[2]	Revolution Period (y)	Diameter (km)	Mass (10 ²³ kg)	Density (g/cm ³) ^[3]
Mercury	0.39	0.24	4,878	3.3	5.4
Venus	0.72	0.62	12,120	48.7	5.2
Earth	1.00	1.00	12,756	59.8	5.5
Mars	1.52	1.88	6,787	6.4	3.9
Jupiter	5.20	11.86	142,984	18,991	1.3
Saturn	9.54	29.46	120,536	5686	0.7
Uranus	19.18	84.07	51,118	866	1.3
Neptune	30.06	164.82	49,660	1030	1.6

rocky

icy

Planet Density

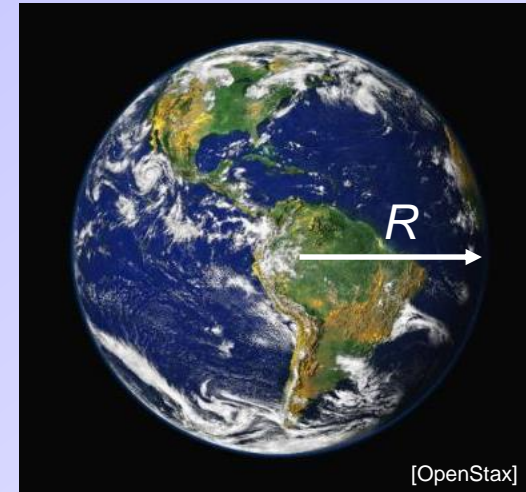
Q: How do you calculate density ?

Answer:

$$\text{Density} = \rho = \frac{\text{Mass}}{\text{Volume}} = \frac{\text{Mass of Planet}}{\text{Volume of Planet}}$$

$$\text{Volume of a Sphere} = V_{\text{sphere}} = \frac{4}{3}\pi R^3$$

with $R = \text{radius of sphere/planet}$



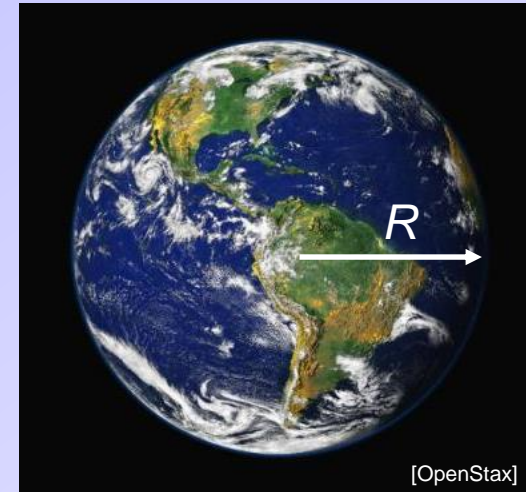
Planet Density

Q: How do you calculate density ?

Answer:

$$\text{Density} = \rho = \frac{\text{Mass}}{\text{Volume}} = \frac{\text{Mass of Planet}}{\text{Volume of Planet}}$$

$$\text{Volume of a Sphere} = V_{\text{sphere}} = \frac{4}{3}\pi R^3$$



with $R = \text{radius of sphere/planet}$

Densities of planetary materials

water/ice $\text{H}_2\text{O} = 1 \text{ g/cm}^3$

liquid hydrogen = 0.07 g/cm^3

liquid helium = 0.1 g/cm^3

liquid nitrogen = 0.8 g/cm^3

liquid methane = 0.4 g/cm^3

solid $\text{CO}_2 = 1.6 \text{ g/cm}^3$

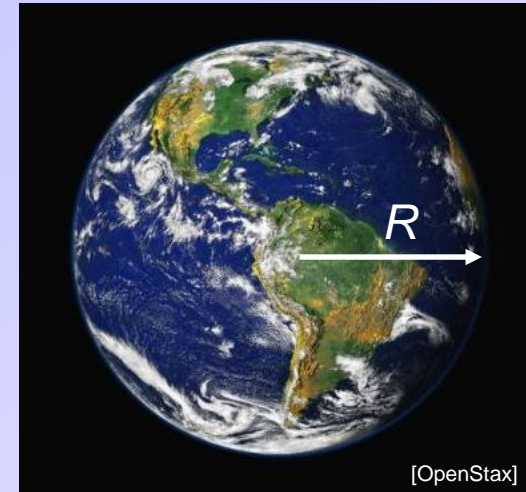
Planet Density

Q: How do you calculate density ?

Answer:

$$\text{Density} = \rho = \frac{\text{Mass}}{\text{Volume}} = \frac{\text{Mass of Planet}}{\text{Volume of Planet}}$$

$$\text{Volume of a Sphere} = V_{\text{sphere}} = \frac{4}{3}\pi R^3$$



with $R = \text{radius of sphere/planet}$

Densities of planetary materials

water/ice $\text{H}_2\text{O} = 1 \text{ g/cm}^3$

liquid hydrogen = 0.07 g/cm^3

liquid helium = 0.1 g/cm^3

liquid nitrogen = 0.8 g/cm^3

liquid methane = 0.4 g/cm^3

solid $\text{CO}_2 = 1.6 \text{ g/cm}^3$

limestone ~ 2.6 g/cm^3

granite ~ 2.7 g/cm^3

basalt ~ 3.0 g/cm^3

iron ~ 9 g/cm^3

nickel ~ 9 g/cm^3

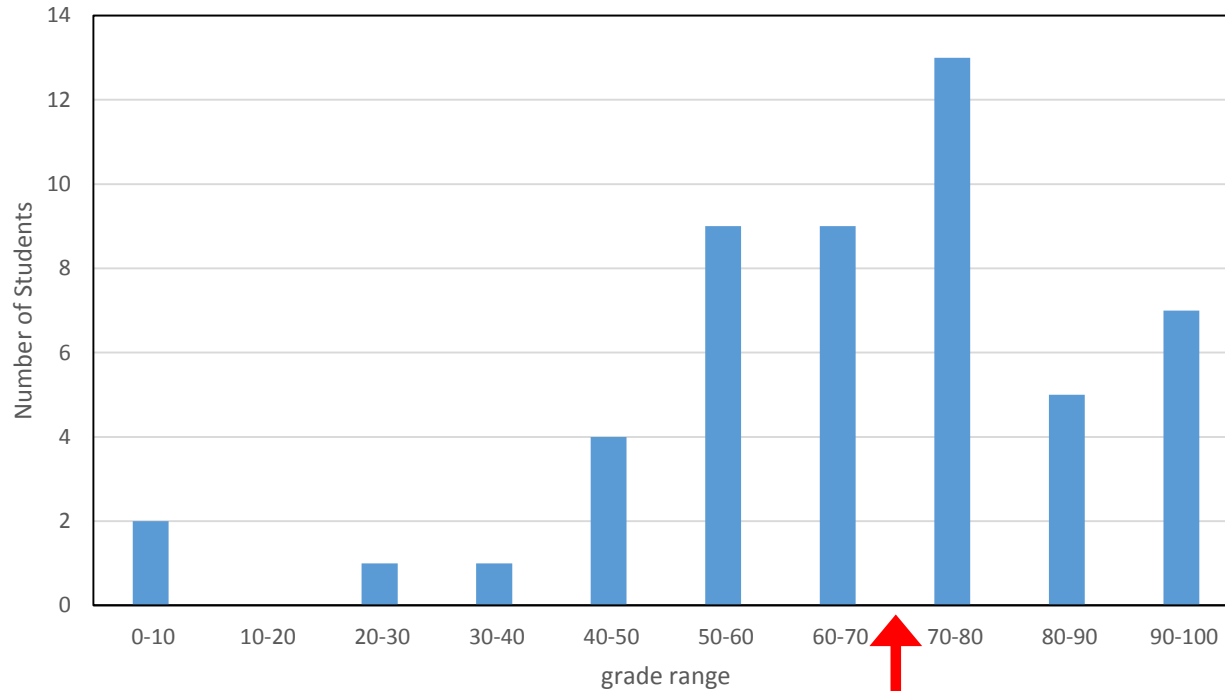
uranium ~ 19 g/cm^3

iridium ~ 22.7 g/cm^3

rock

Midterm Test #1

Midterm #1: Histogram of Grades



Average = 70

Median = 71

High Score = 98.5