# 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

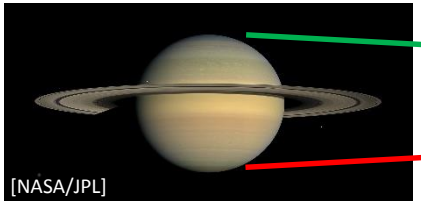
Monday, October 2, 2019 (Week 5, lecture 14) – Chapter 7.

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

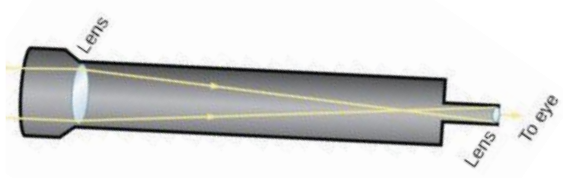
# Angular Resolution and Size

**Angular resolution** (or resolving power) $\boldsymbol{\theta_{min}}$

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




$\theta_{object}$




celestial object

telescope

**Imaging Detail**

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

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

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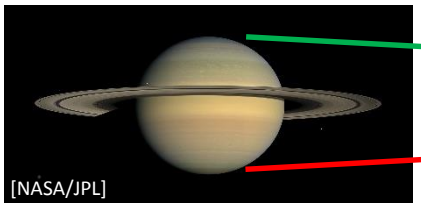
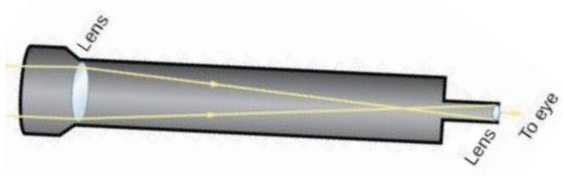



$\theta_{object}$




celestial object

telescope

**Imaging Detail**

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

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

**Telescopes** maximize the number of pixels by minimizing $\theta_{min}$.

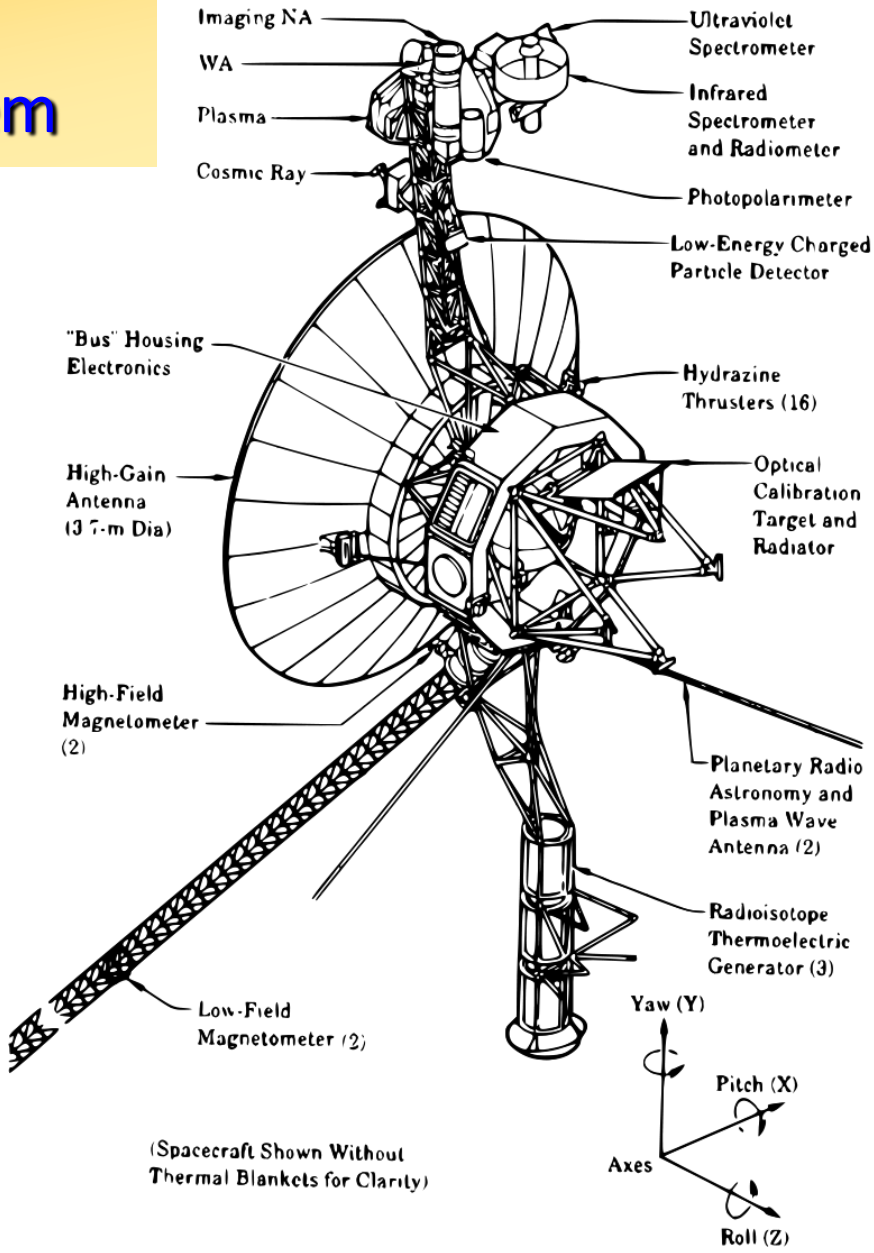
**Space probes** maximize the number of pixels by maximizing $\theta_{object}$.

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

# Space Probes

## for exploring the Solar System

**Voyager Spacecraft:** basic structure




[Wikipedia: NASA derivative work: Camilo Sanchez (talk)]

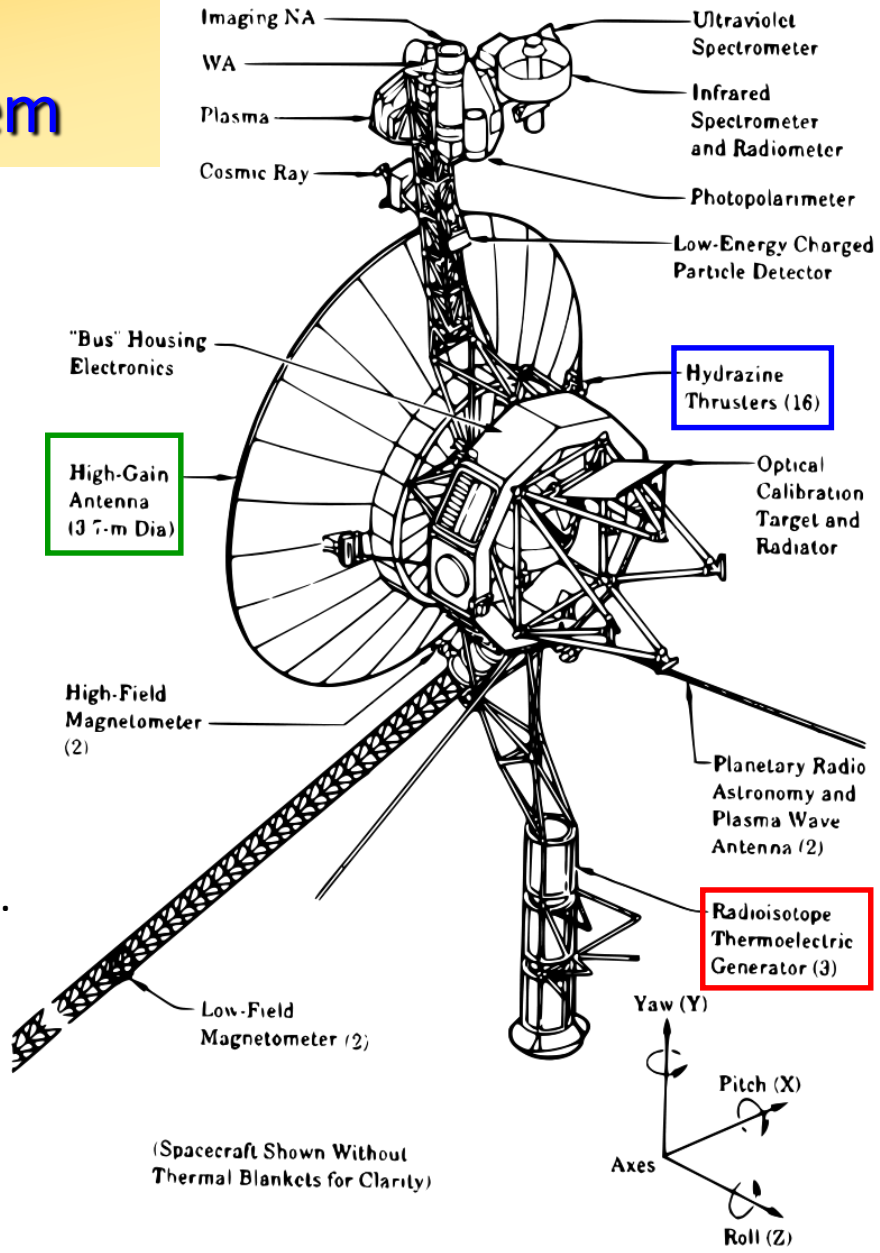
# Space Probes

## 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

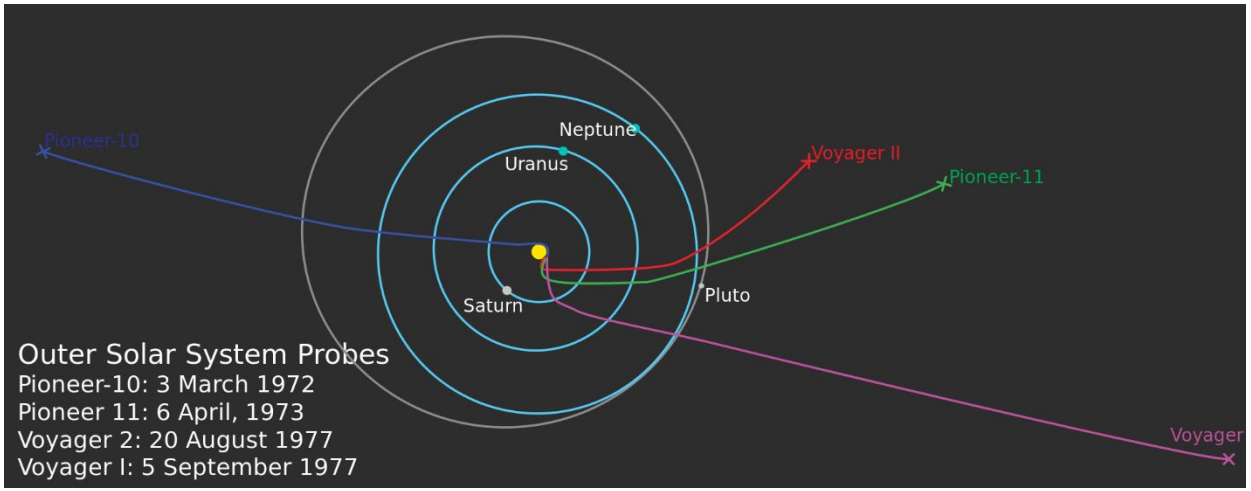



[Wikipedia: NASA derivative work: Camilo Sanchez (talk)]

# Voyager 1 & Voyager 2

Explored the gas giant planets:

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






## Main Instruments

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

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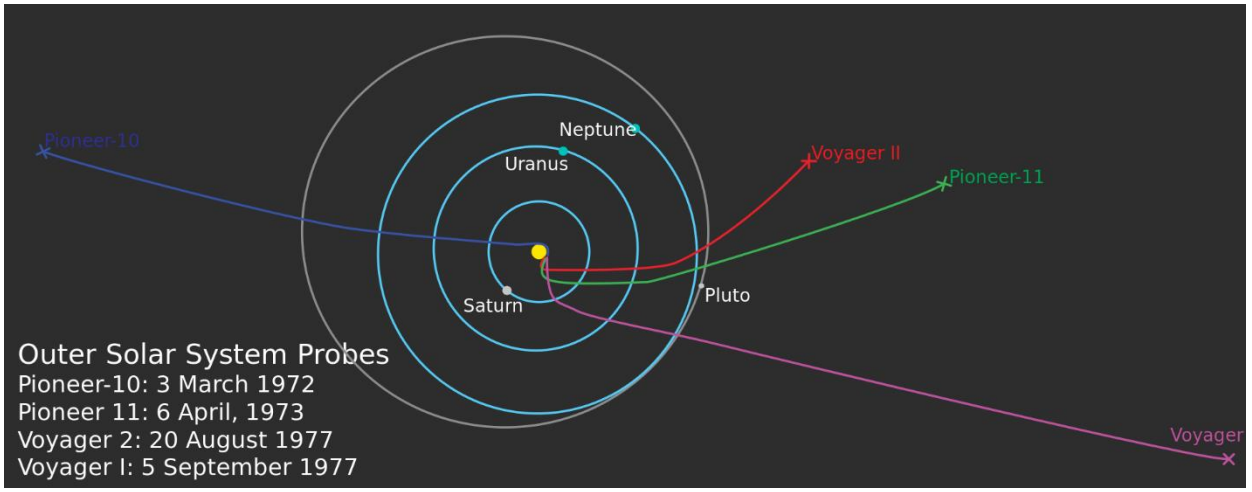


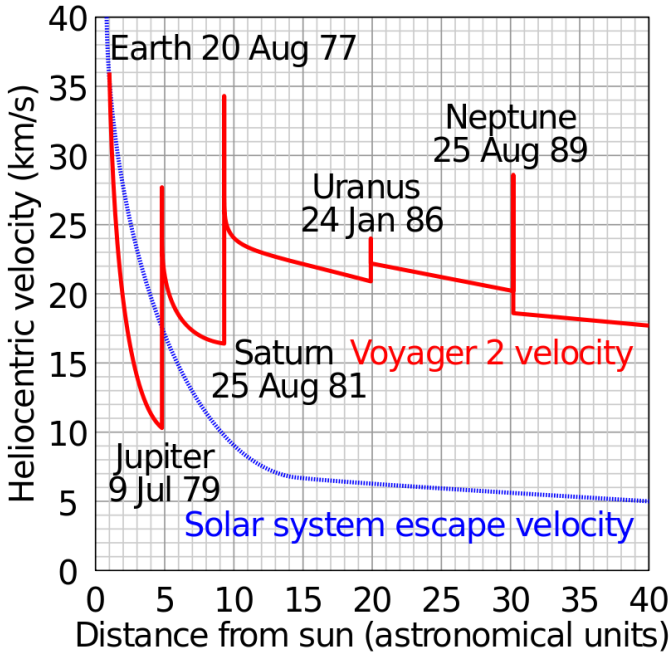

[By 7Train at the English Wikipedia, CC BY-SA 3.0]

## Main Instruments

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

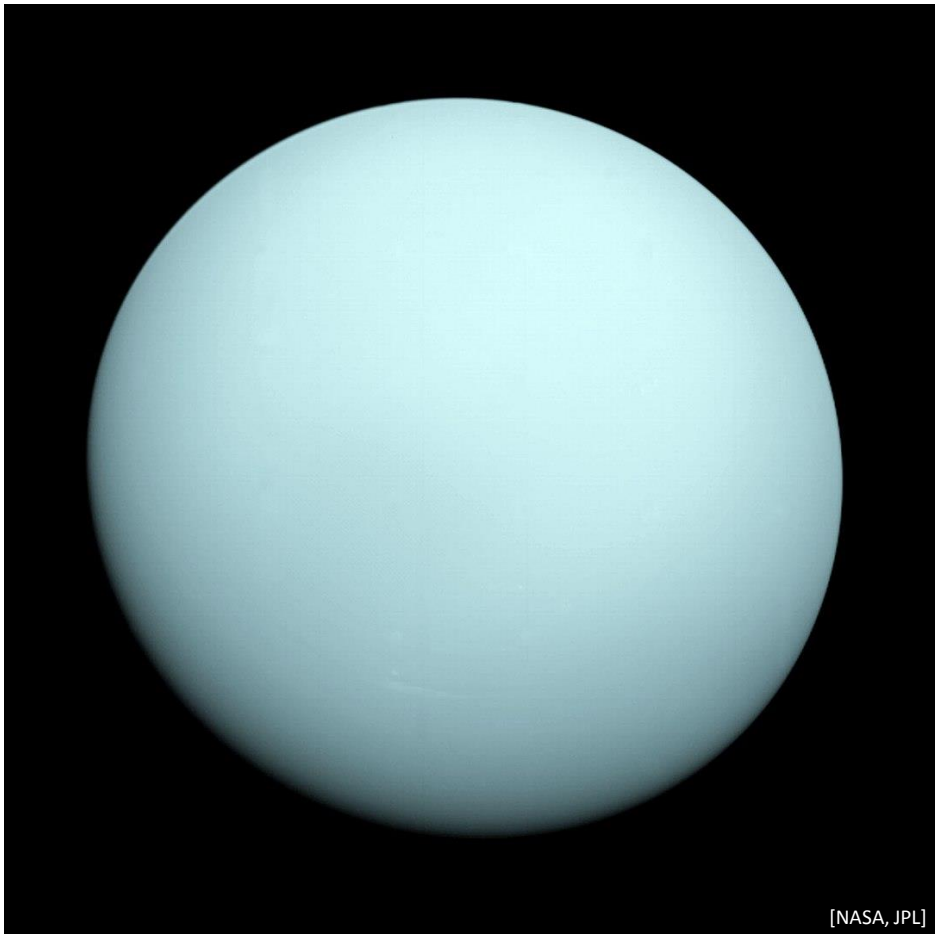
## Key facts

- 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.

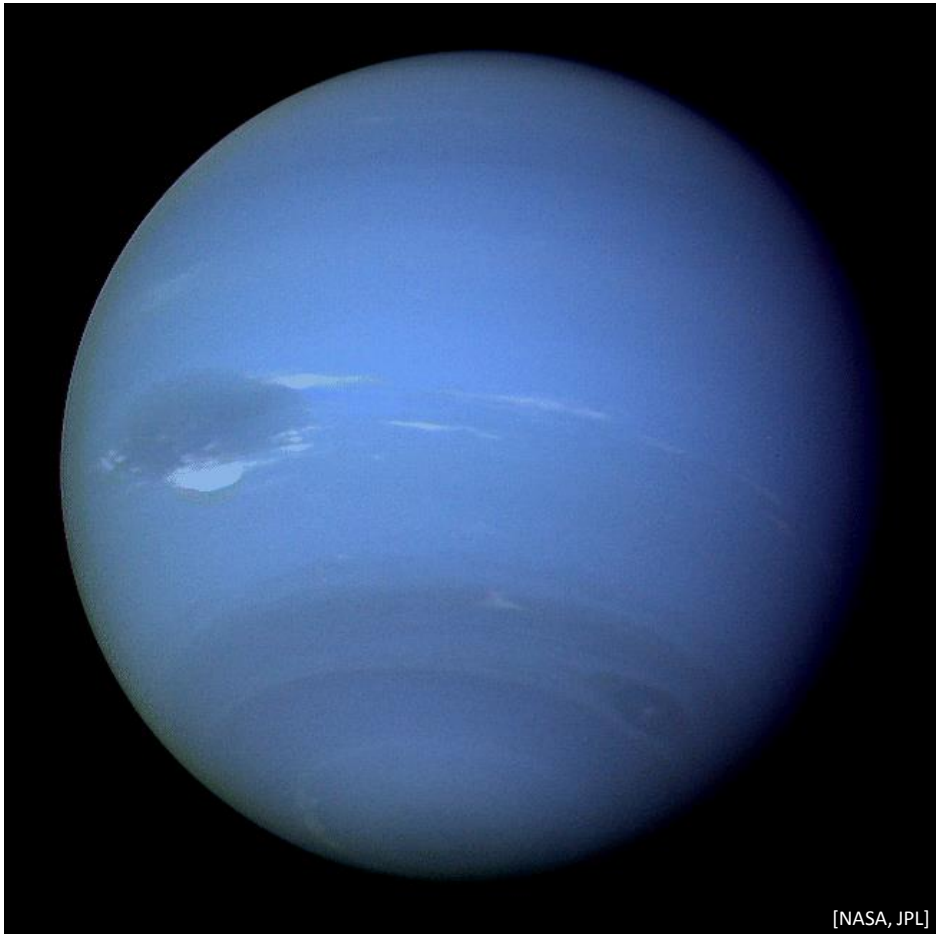



[By Cmglee - Own work, CC BY-SA 3.0]

# Voyager 2: Uranus & Neptune




Uranus -- photo by Voyager 2 (1986)

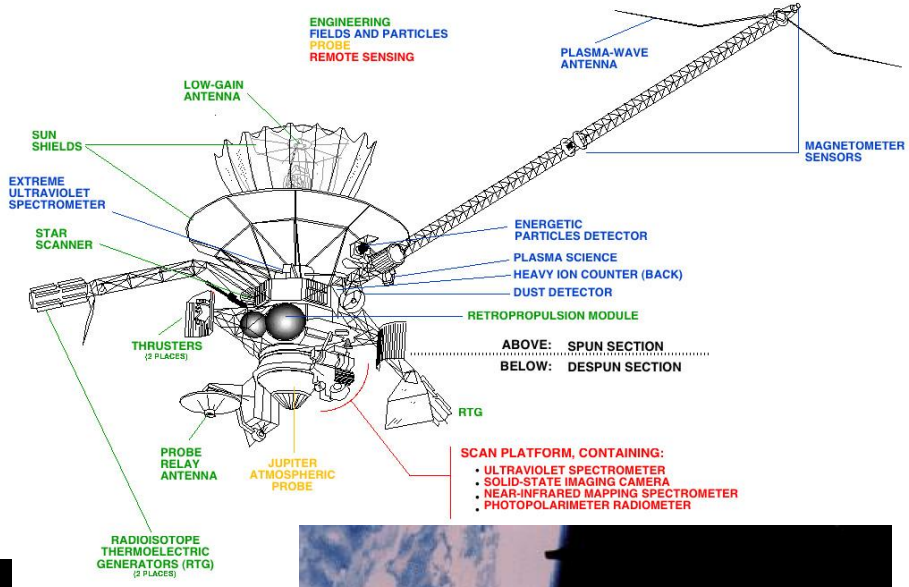



Neptune -- photo by Voyager 2 (1989)

# 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).



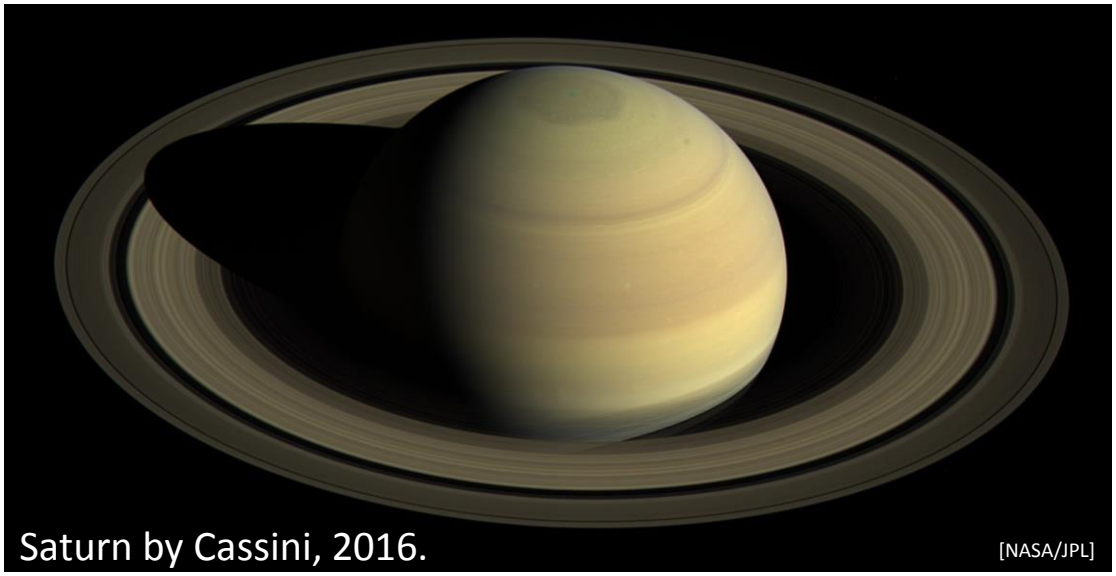


Europa by Galileo spacecraft [NASA/JPL]

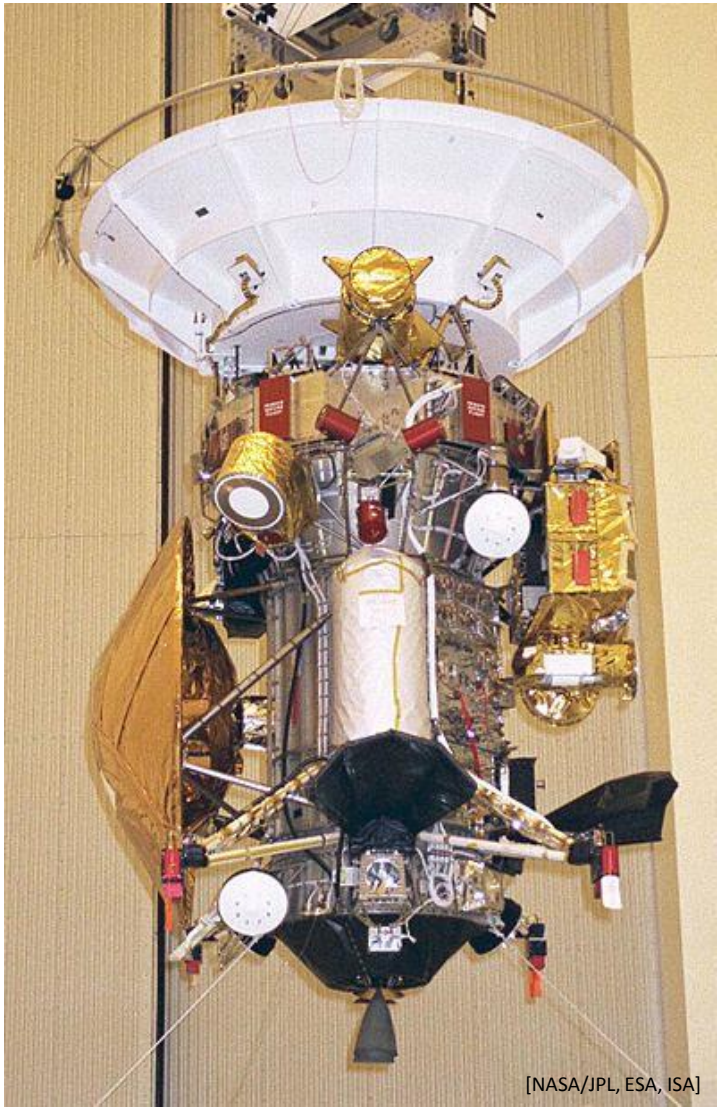
# Cassini-Huygens Probe: Saturn

**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).



Saturn by Cassini, 2016. [NASA/JPL]



[NASA/JPL, ESA, ISA]

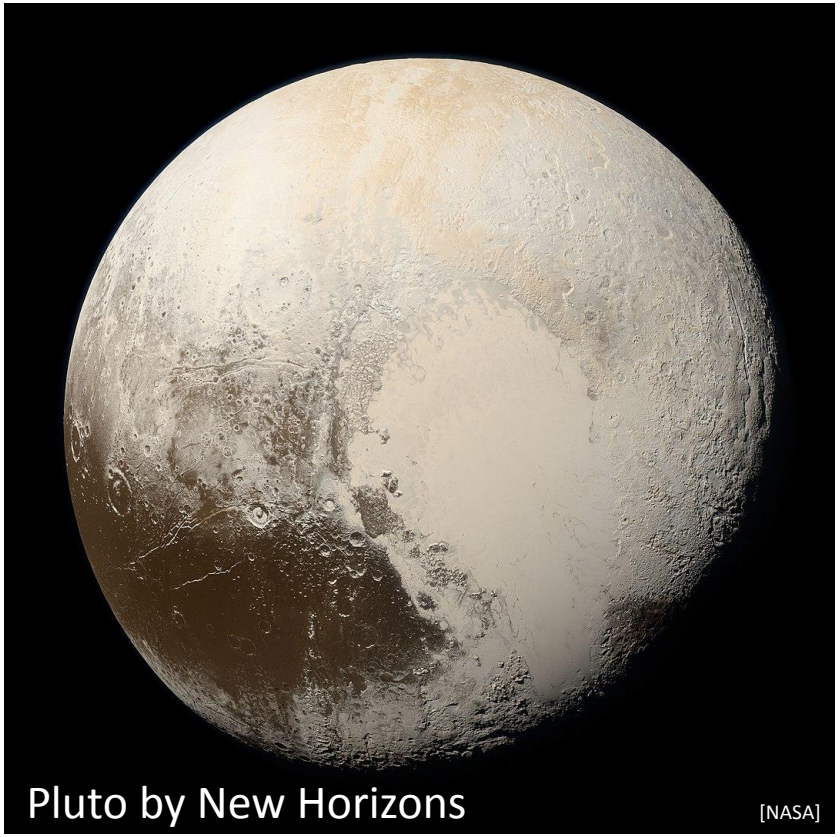
# New Horizons: Pluto

**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.

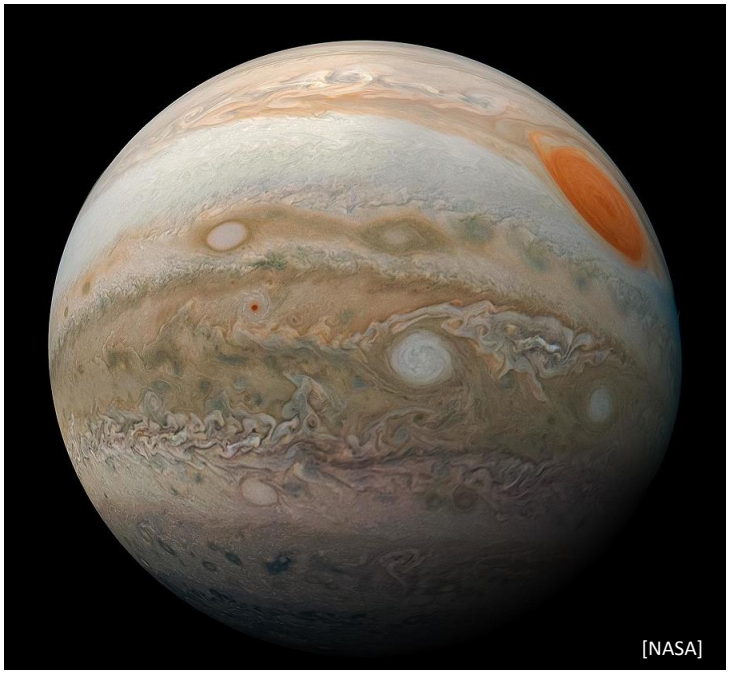

[NASA]

[NASA]



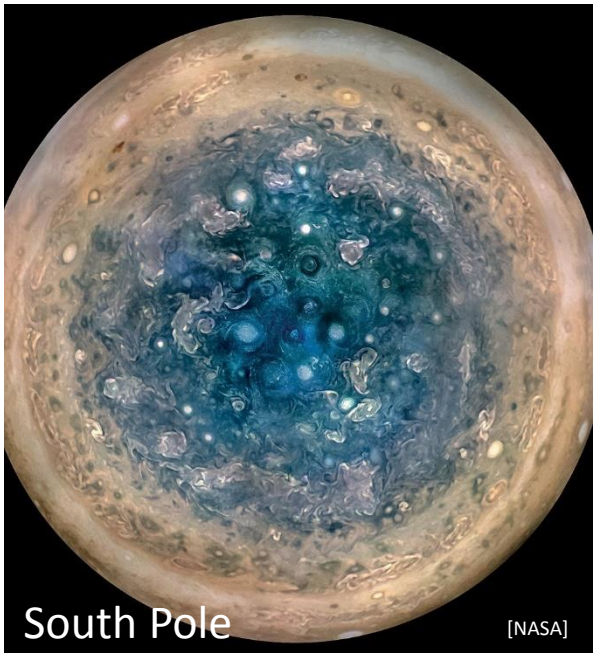

[NASA]

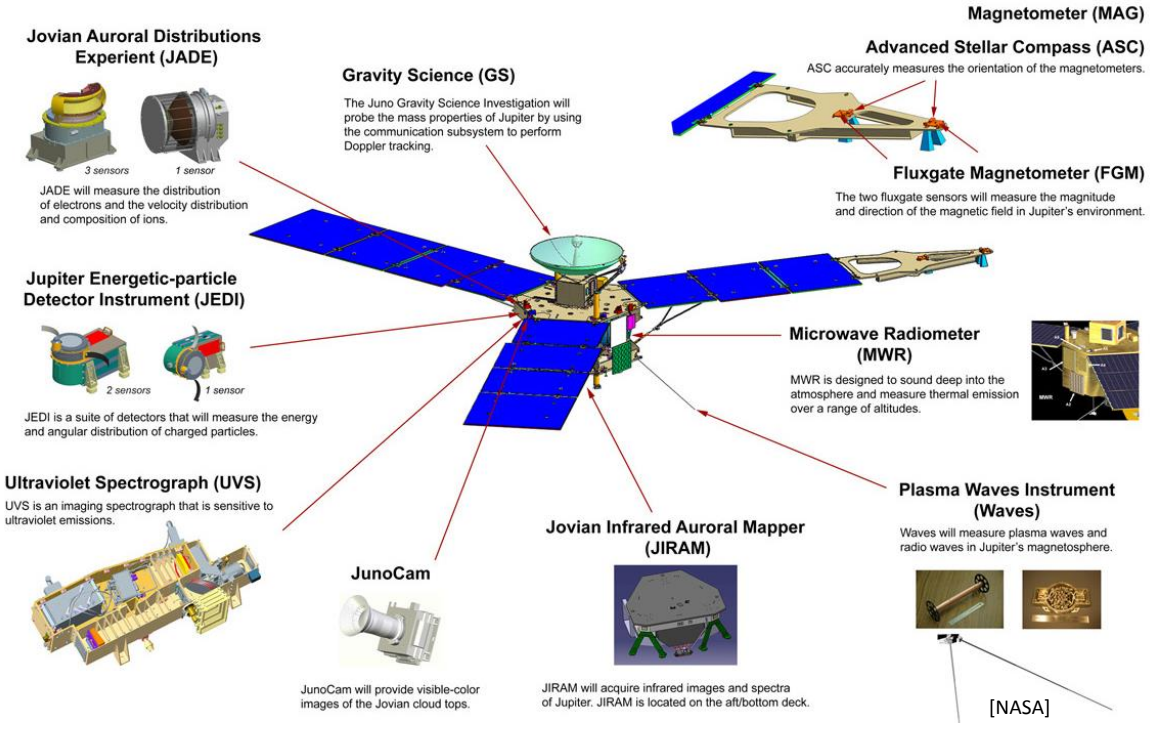
# Juno: Jupiter again


[NASA]

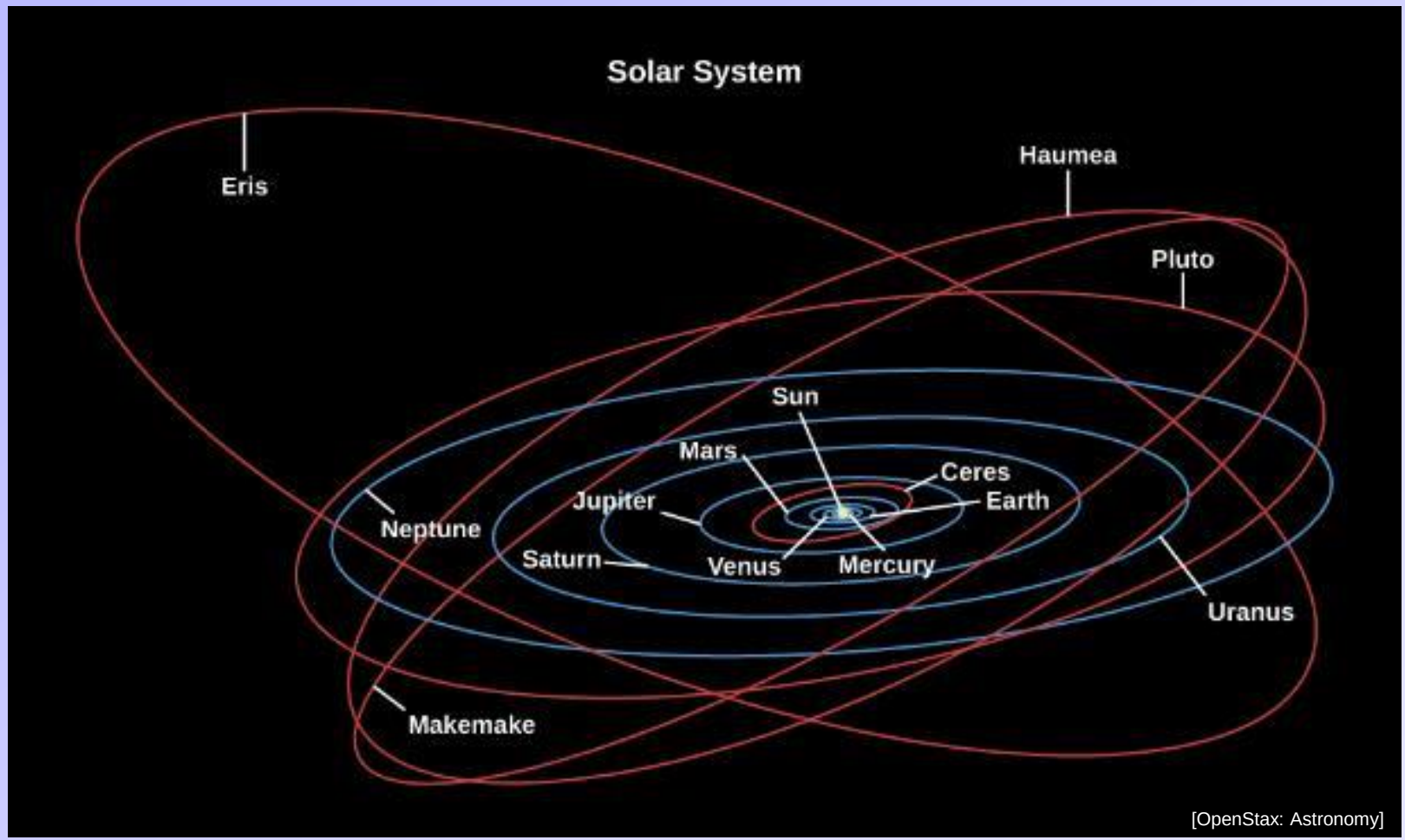
**Key Facts**

- 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).


South Pole [NASA]



# Structure of Solar System




- Planets orbit in the **same plane** (more or less), bit 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 |

[OpenStax: Astronomy]

# Density of Planets

telescope measurements

?

measurements or Kepler's 3rd Law

observations

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

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**Calculation**

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[OpenStax: Astronomy]

# Density of Planets

Density of water = 1 g/cm$^3$

*note: ml = cm$^3$*

measurements or Kepler's 3rd Law

observations

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

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| Earth | 1.00 | 1.00 | 12,756 | 59.8 | 5.5 | rocky |
| 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 | icy |
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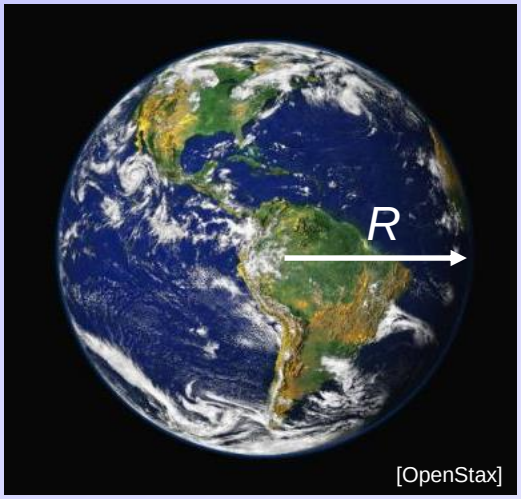
[OpenStax: Astronomy]

# Planet Density

**Q: How do you calculate density ?**




**Answer:**

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

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

with $R = radius\ of\ sphere/planet$

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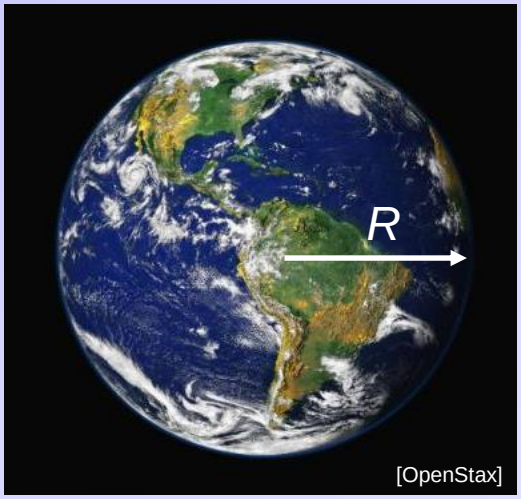


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## Densities of planetary materials

water/ice $H_2O$ = 1 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$^3$

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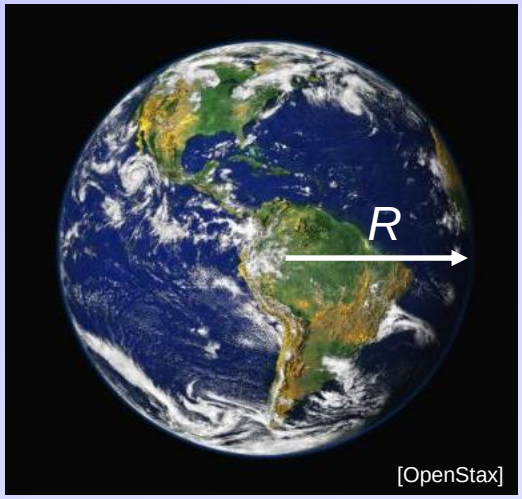


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solid $CO_2$ = 1.6 g/cm$^3$

limestone ~ 2.6 g/cm$^3$

granite ~ 2.7 g/cm$^3$

basalt ~ 3.0 g/cm$^3$

rock

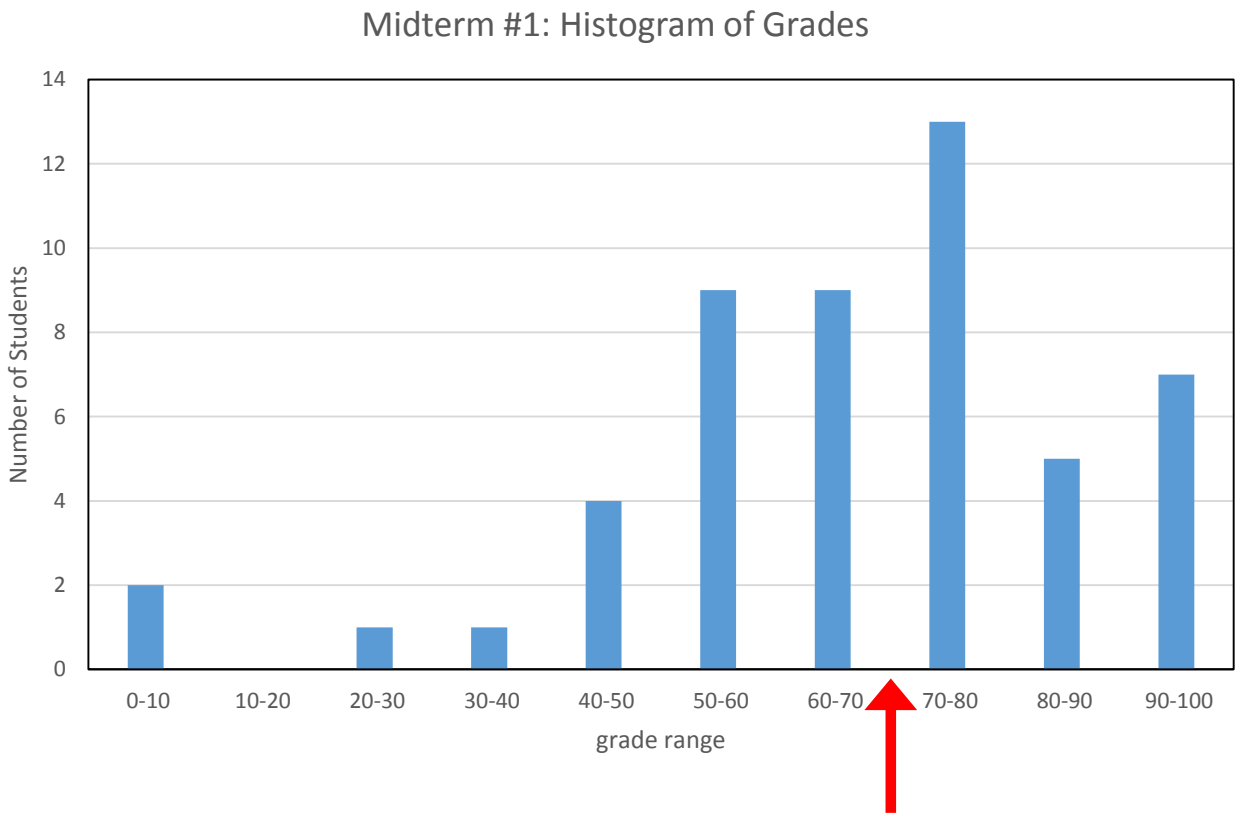
iron ~ 9 g/cm$^3$

nickel ~ 9 g/cm$^3$

uranium ~ 19 g/cm$^3$

iridium ~ 22.7 g/cm$^3$

# Midterm Test #1




Average = 70

Median = 71

High Score = 98.5