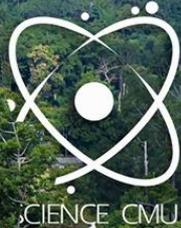


Solar System, Kepler Laws, and Application to Exoplanet

Dr. Suwicha Wannawichian & Team,
Chiang Mai University



SCIENCE CMU

Class Materials

1. Go to the workshop website
On 'overview page'



2. Go to the Materials session, on the same 'overview' page, and look for 'SW lecture Materials' at the bottom.

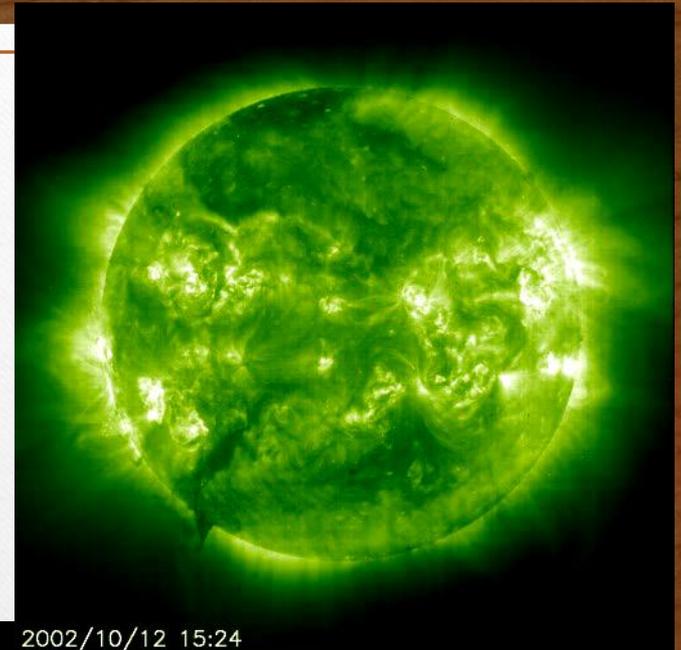
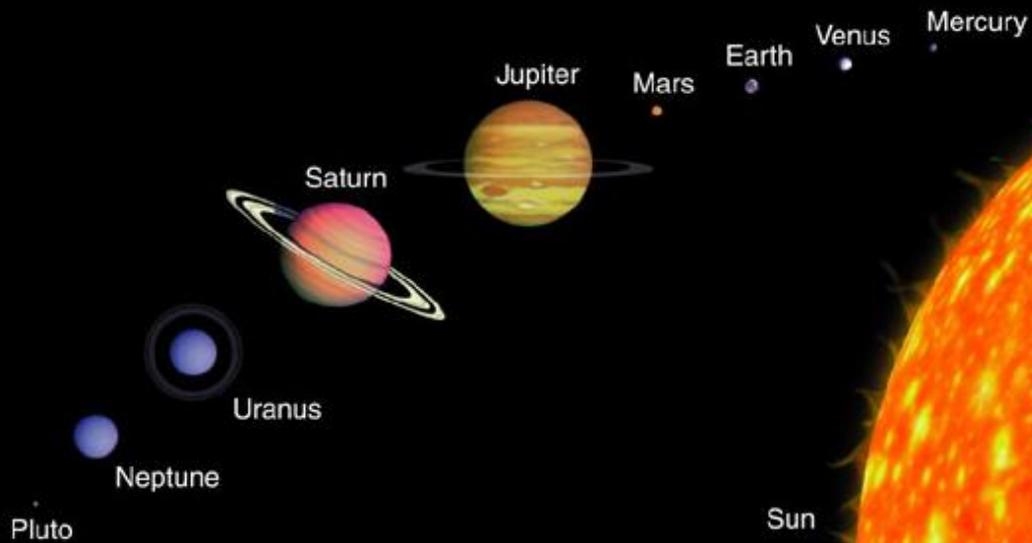
Starts 23 Sep 2022, 08:00
Ends 25 Sep 2022, 12:00
Asia/Ho_Chi_Minh

Dong A University

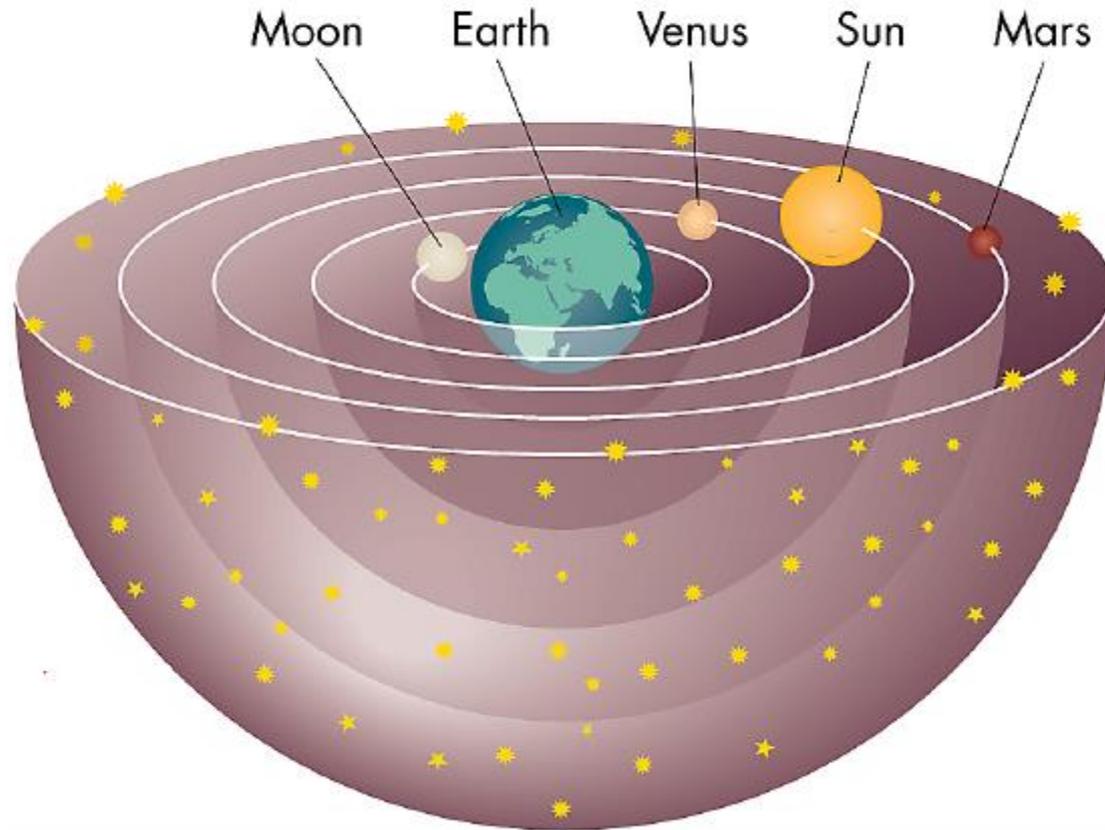
SW Lecture Materials
Lecture sw1 Solar System.pdf
SW-Lecture and Hands on plan.pdf

Solar System

2002/10/12 15:24



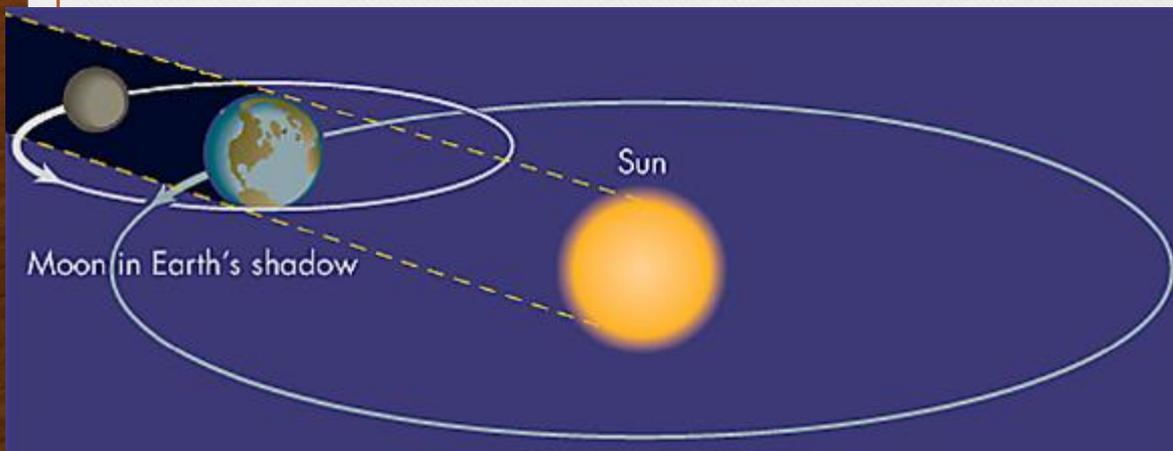
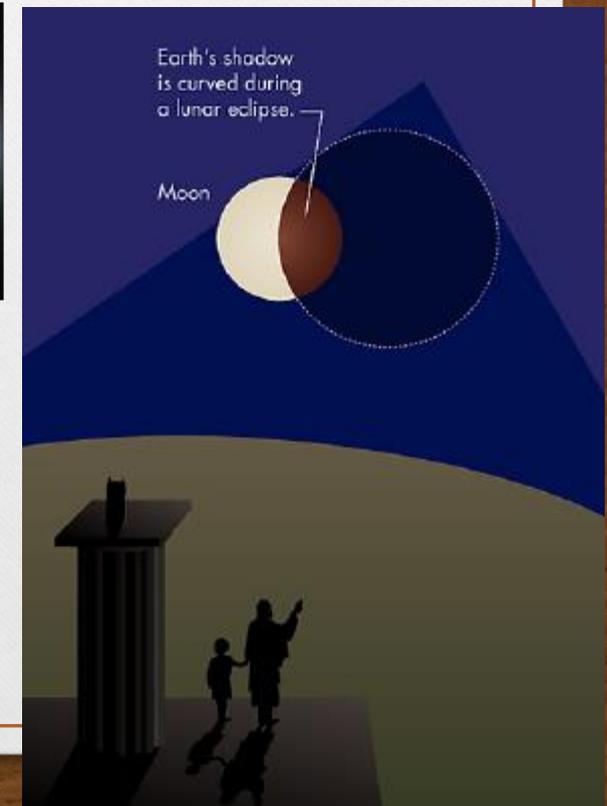
Geocentric model by Eudoxus (400-347 BC)



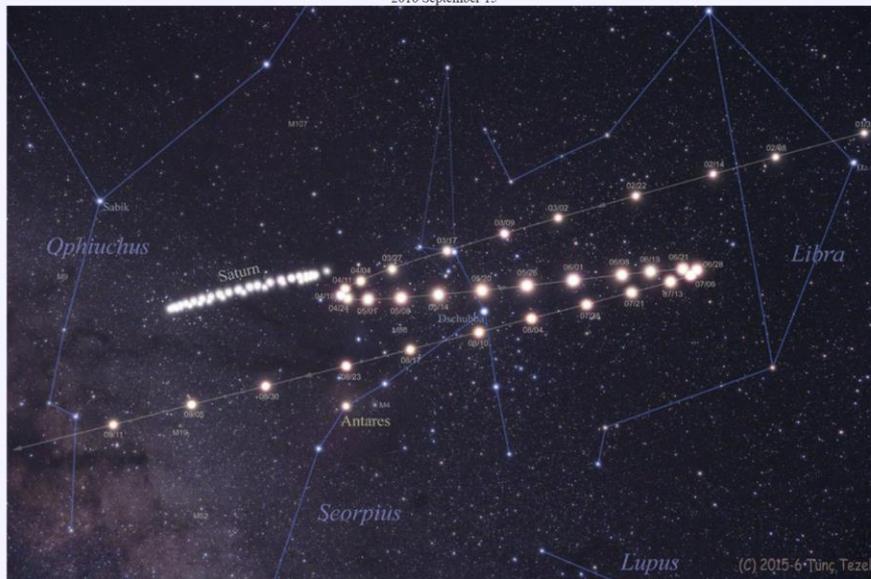
Origin believe about our solar system

We long knew that the earth is round (560-480 BC)

With the trigonometry theorem, Aristotle had shown that Earth is round by looking at the Earth's shadow on the Moon during the lunar eclipse.



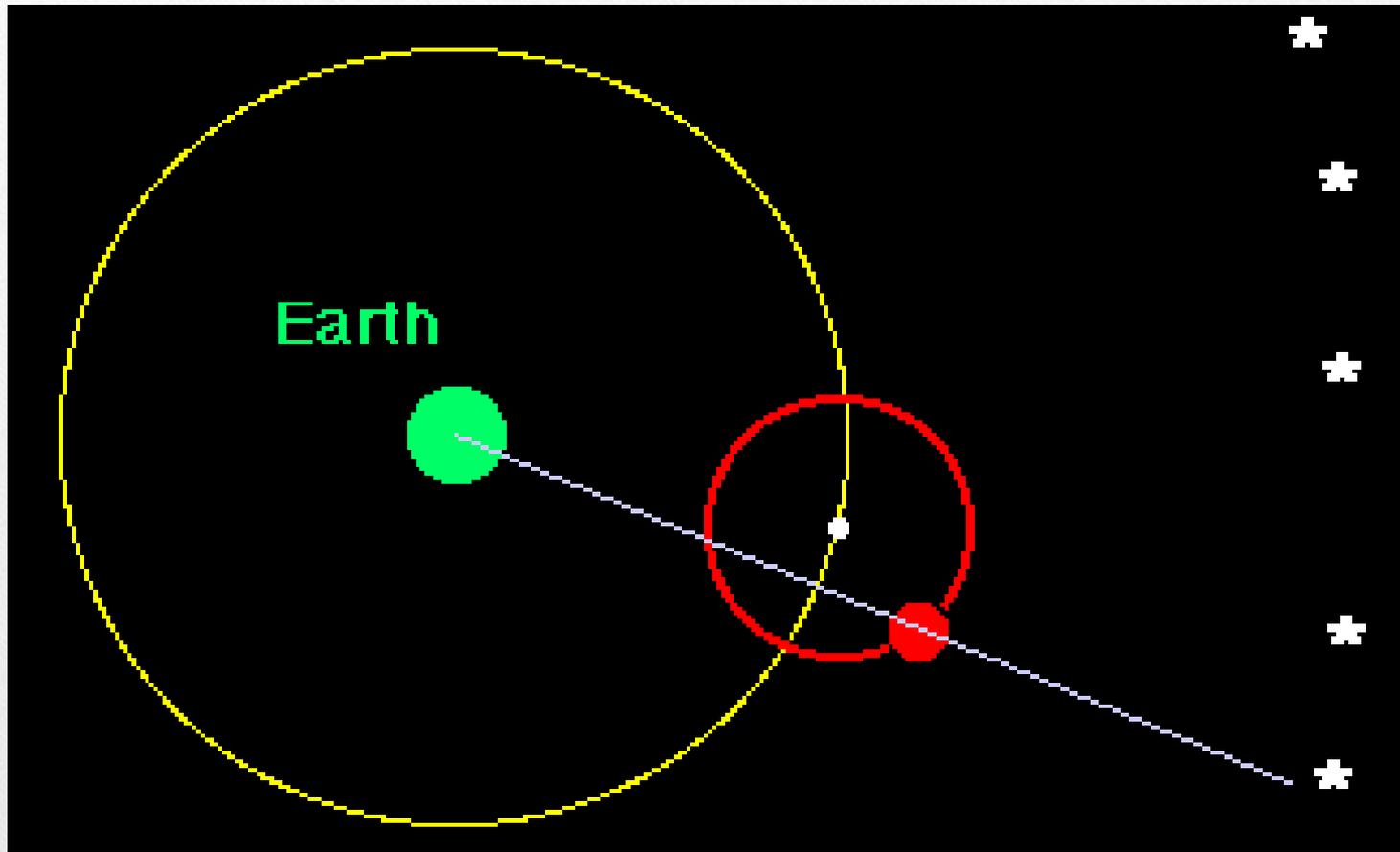
Change of belief: Retrograde motion



<https://starwalk.space/>

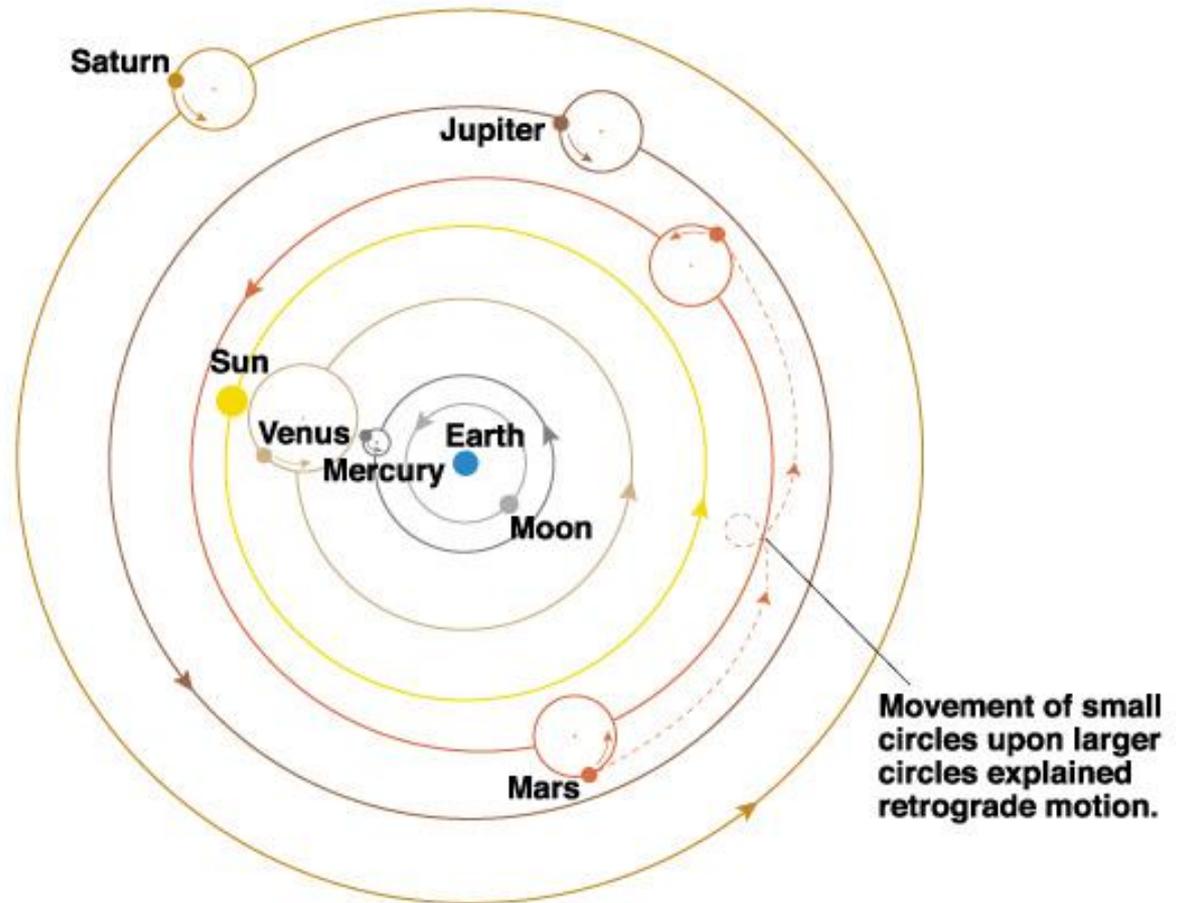
Retrograde Mars and Saturn
Image Credit & Copyright: Tunç Tezel

Early explanation: Epicycle



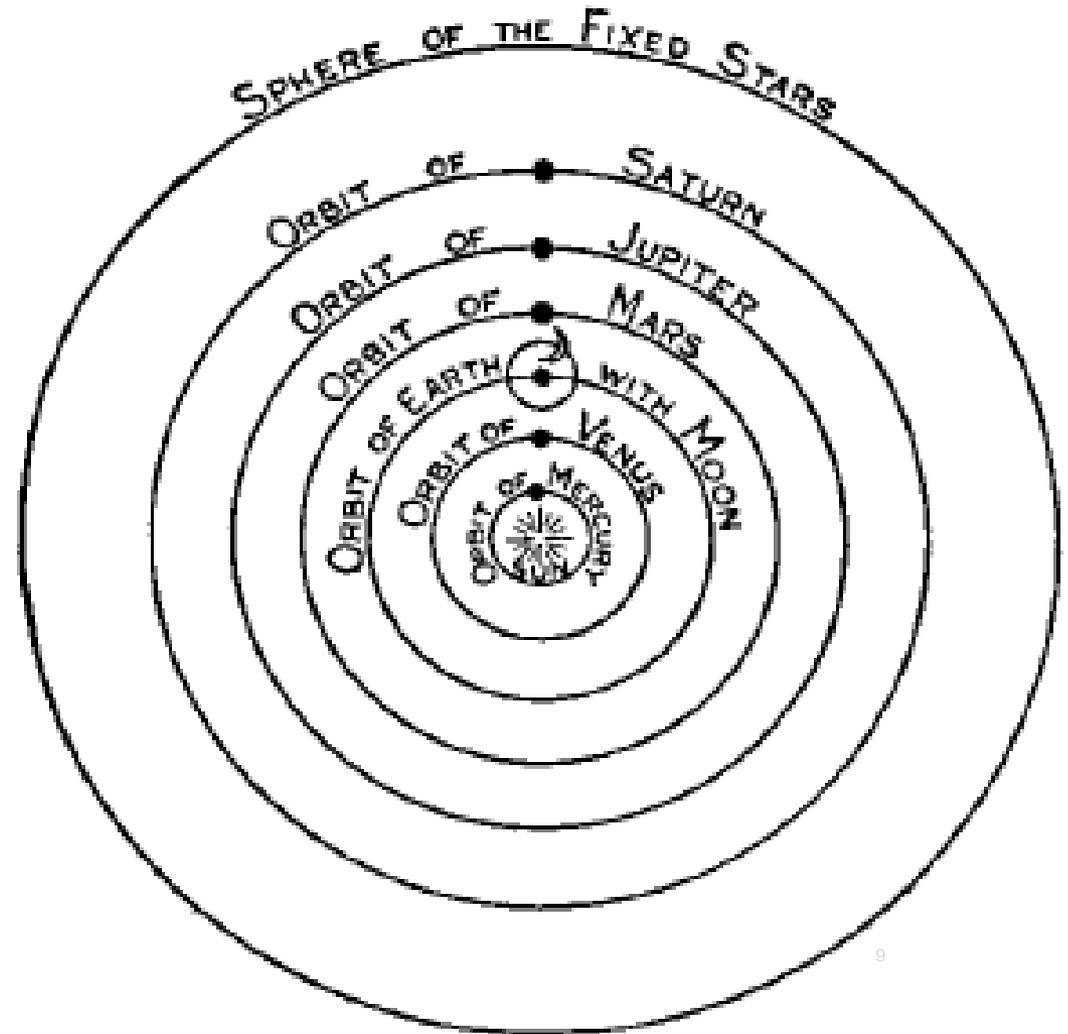
Ptolemy (~150AD)

Predicted celestial
sphere and
planetary positions



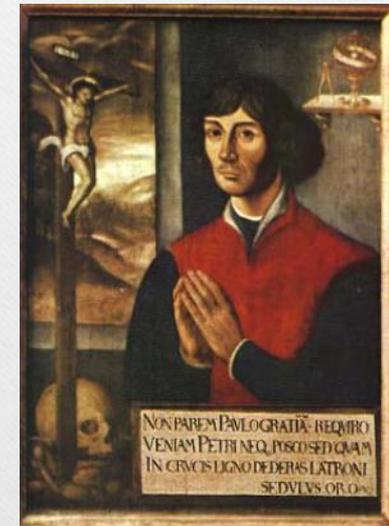
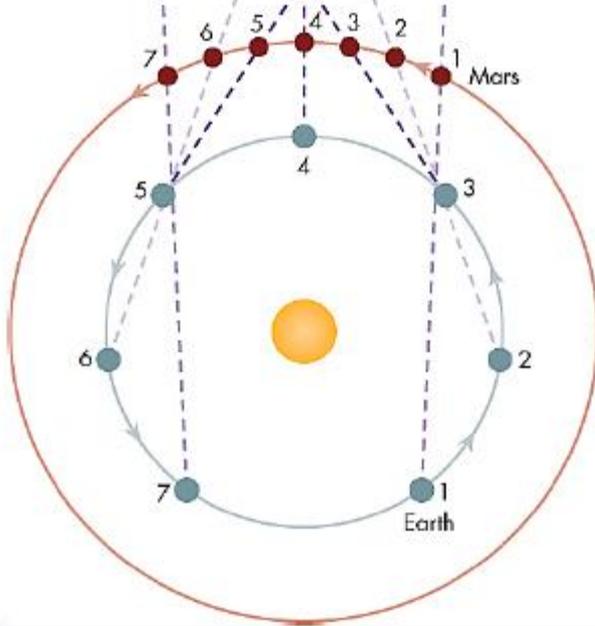
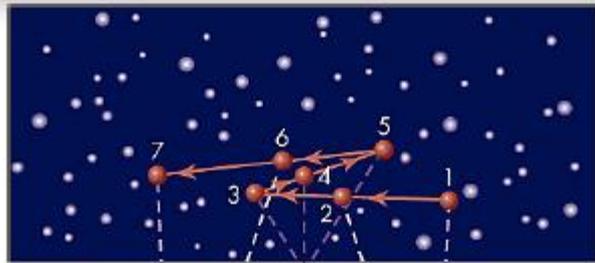
Copernicus Model

Renaissance Era
(14th-16th century)



His version of explanation: Retrograde Motion

Retrograde motion is only the view from the observer. Everything is about “perspective”



Nicolaus Copernicus
(1473-1543)

Sun-centered Theory

NICOLAI
COPERNICITO-
RINENSIS DE REVOLVTIONI-
bus orbium coelestium,
Libri VI.

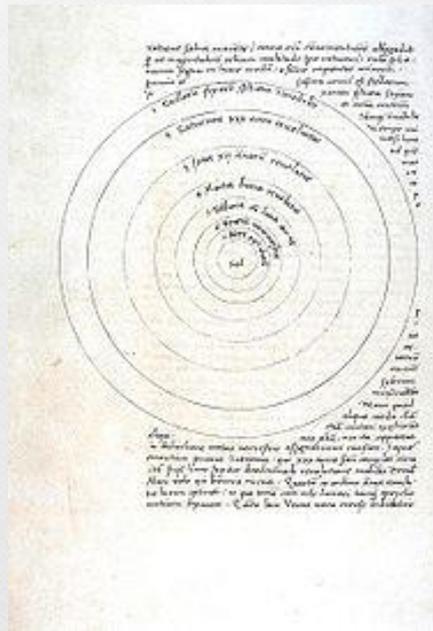
IN QUIBUS STELLARVM ET PL-
NARVM ET ERRATICARVM MOTVS, EX VET-
ERIS atq; recentibus obseruationibus, reseruit hic autor.
(Praeterea tabulas expeditas facientemq; addidit, ex quib-
us eisdem motus ad quoduis tempus Martis
instans frigidiorum facillime calcula-
re poterit.)

STYLVS DE LIBRIS REVOLVTIONVM NICOLAI
Copernici Natusse prima per M. Georgium Ioschi-
mann Rheinicum ad D. Ioh. Schoe-
rum scripta.



Com Gratia & Privilegio Caes. Maiest.
BASILEAE, IN OFFICINA
HENRICI PETRINI.

De revolutionibus orbium coelestium (On the Revolutions of the Heavenly Spheres)

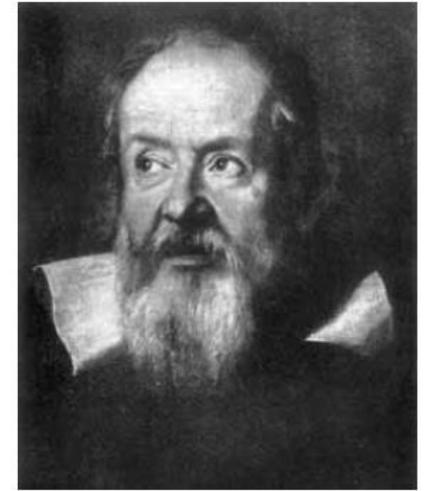


A book was written by
Nicolaus Copernicus. He was
afraid to publish it, until the
last day of his life.

One more brave astronomer.....

Galileo Galilei

Even though he is not the one who INVENTED the telescope, he used it systematically and brought many new discoveries.

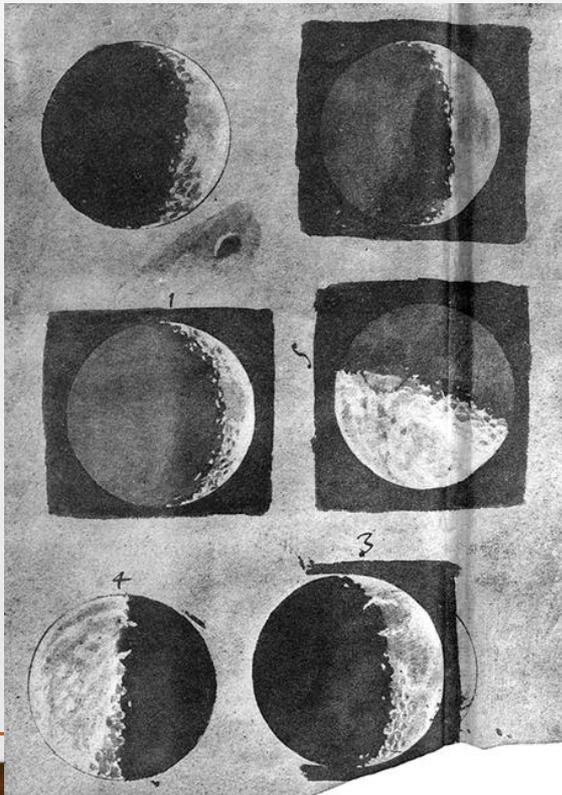


Galileo Galilei (1564 –1642)



Galileo's Astronomy

- Discovers Jupiter's Moons
- Discovers Sun Spots
- Discovers Solar rotation



On the third, at the seventh hour, the stars were arranged in this sequence. The eastern one was 1 minute, 30 seconds from Jupiter; the closest western one 2 minutes; and the other western one was

East * ○ * * West

10 minutes removed from this one. They were absolutely on the same straight line and of equal magnitude.

On the fourth, at the second hour, there were four stars around Jupiter, two to the east and two to the west, and arranged precisely

East * * ○ * * West

on a straight line, as in the adjoining figure. The easternmost was distant 3 minutes from the next one, while this one was 40 seconds from Jupiter; Jupiter was 4 minutes from the nearest western one, and this one 6 minutes from the westernmost one. Their magnitudes were nearly equal; the one closest to Jupiter appeared a little smaller than the rest. But at the seventh hour the eastern stars were only 30 seconds apart. Jupiter was 2 minutes from the nearer eastern

East ** ○ * * West

one, while he was 4 minutes from the next western one, and this one was 3 minutes from the westernmost one. They were all equal and extended on the same straight line along the ecliptic.

On the fifth, the sky was cloudy.

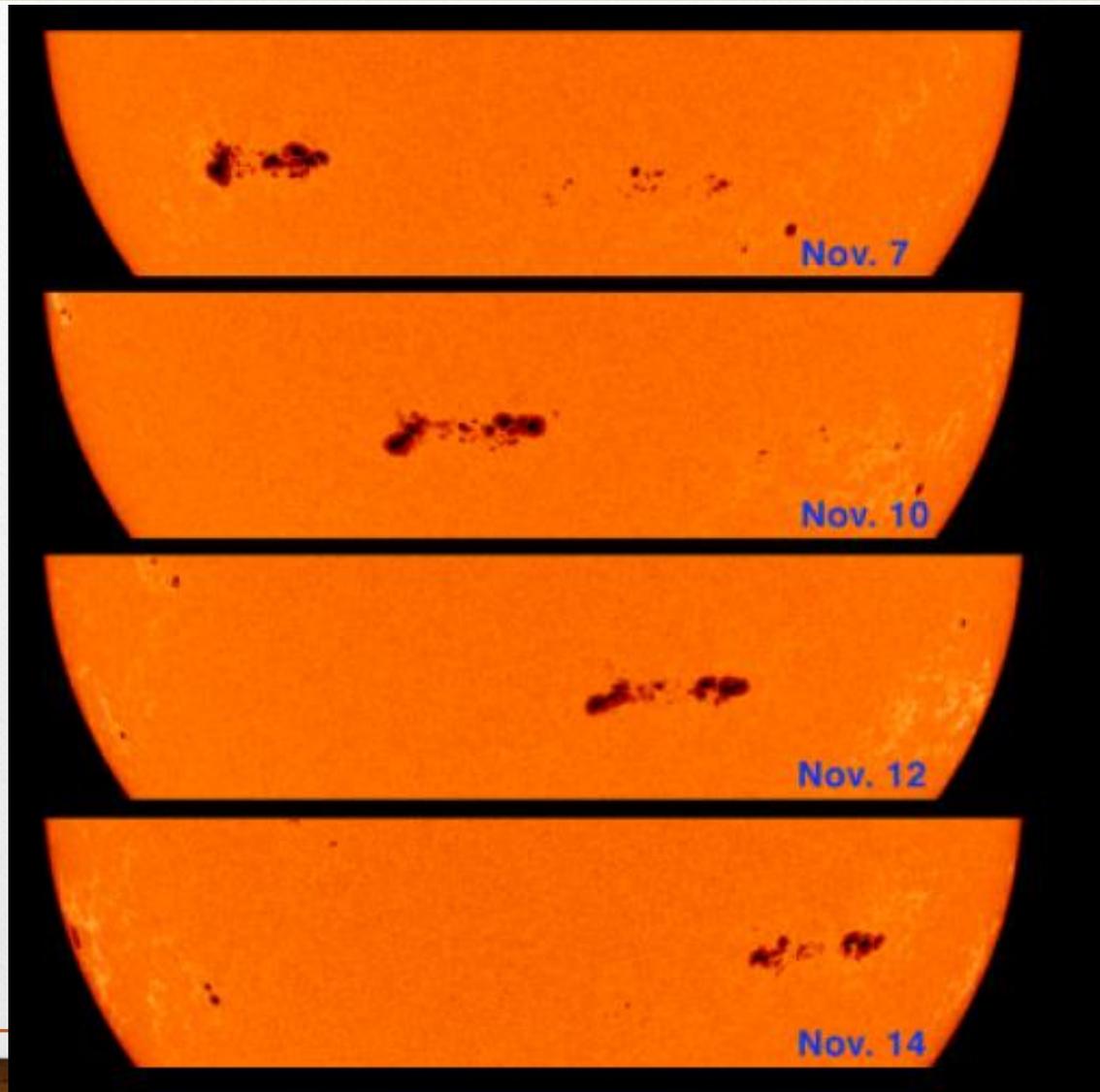
On the sixth, only two stars appeared flanking Jupiter, as is seen

East * ○ * West

in the adjoining figure. The eastern one was 2 minutes and the western one 3 minutes from Jupiter. They were on the same straight line with Jupiter and equal in magnitude.

On the seventh, two stars stood near Jupiter, both to the east, arranged in this manner.

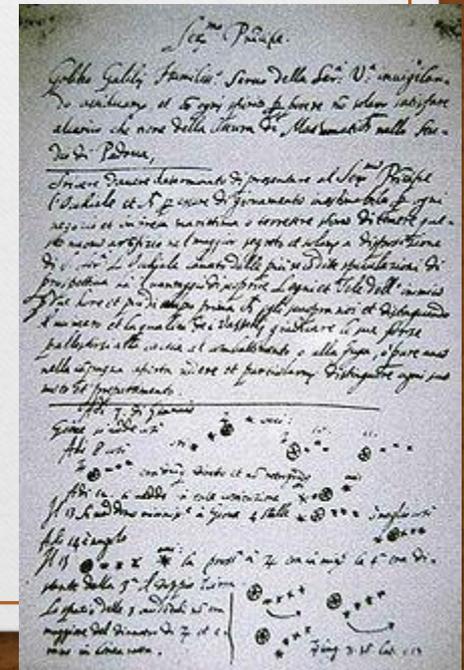
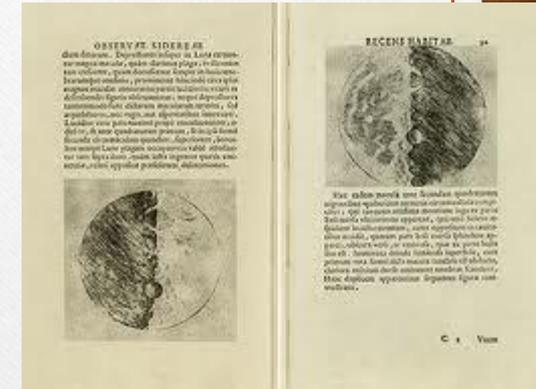
What Galileo saw....



From the discoveries of Jupiter's four moons and the Sunspots (causing his eyes to nearly blinded!!)

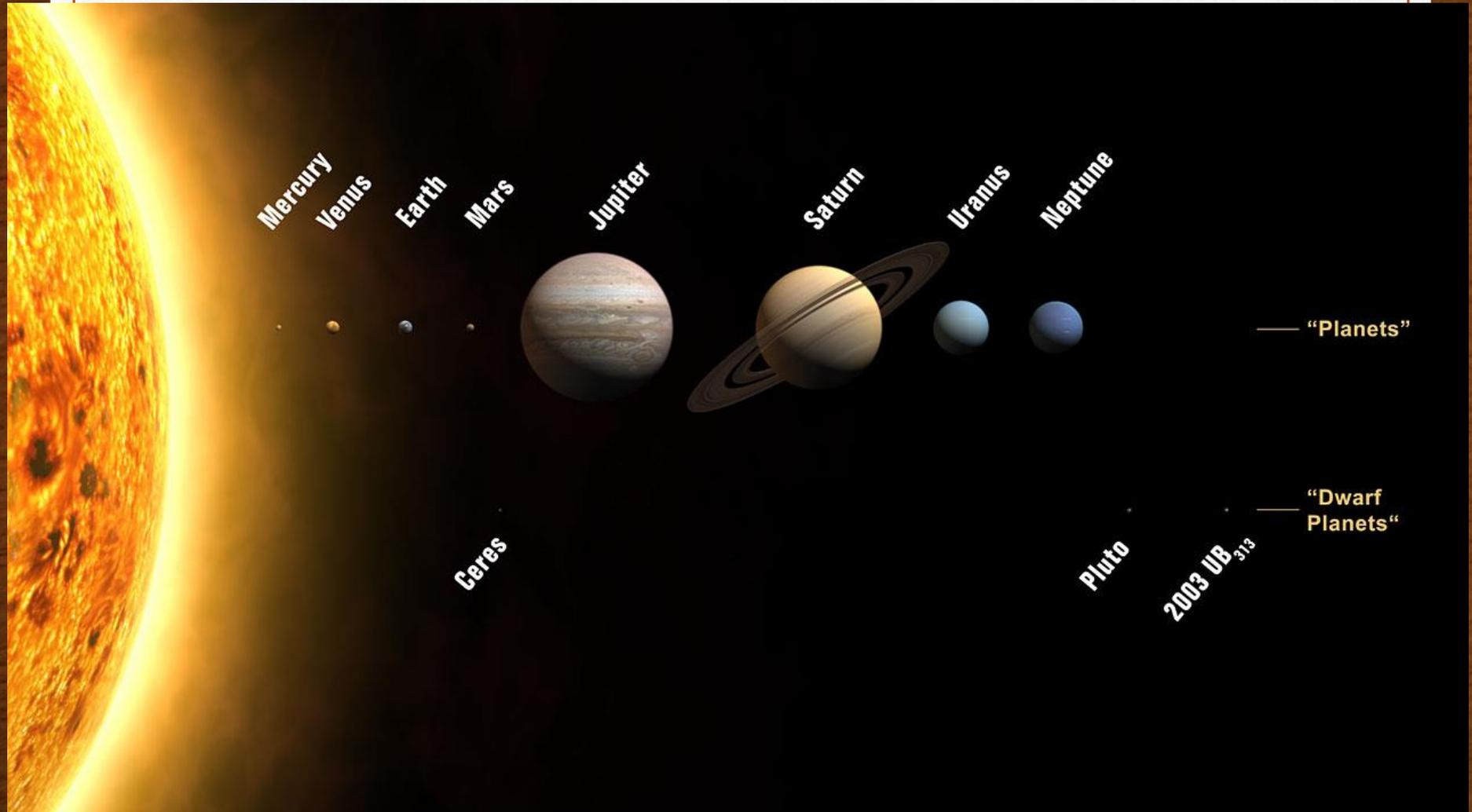


Galileo did not wait until his last day on Earth to let every know what he thinks!! He proposed that, indeed, the Sun is at the center of our solar system, and it is Earth that orbits around the Sun!!!!



This violation of the old belief caused him a lot of problems!!

Our Solar System



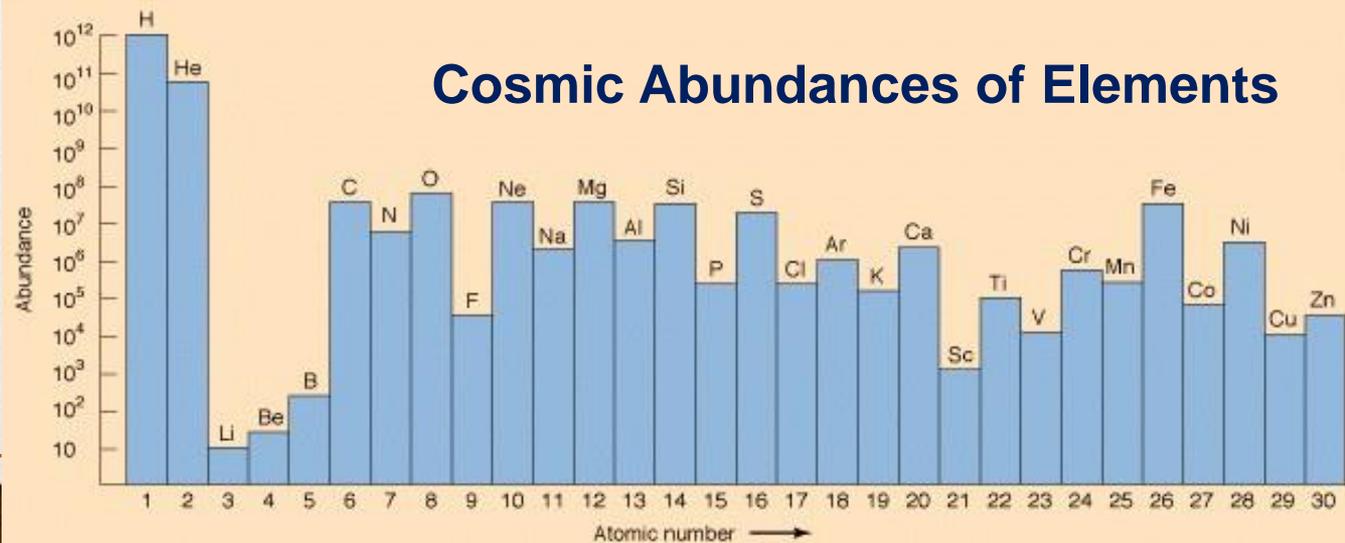
Planetary Position

Planets	Average orbital distance (AU)
Mercury	0.39
Venus	0.72
Earth	1.00
Mars	1.52
Ceres	2.77
Jupiter	5.20
Saturn	9.54
Uranus	19.2
Neptune	30.06
Pluto	39.44

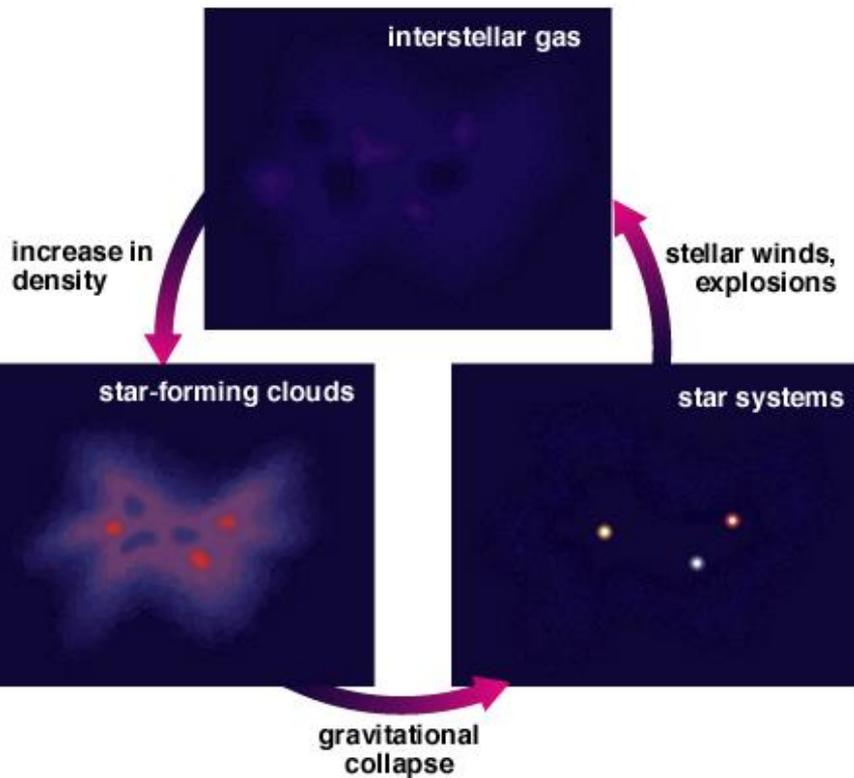
Birthplace of Solar Systems: Gas nebula



Copyright © Addison Wesley

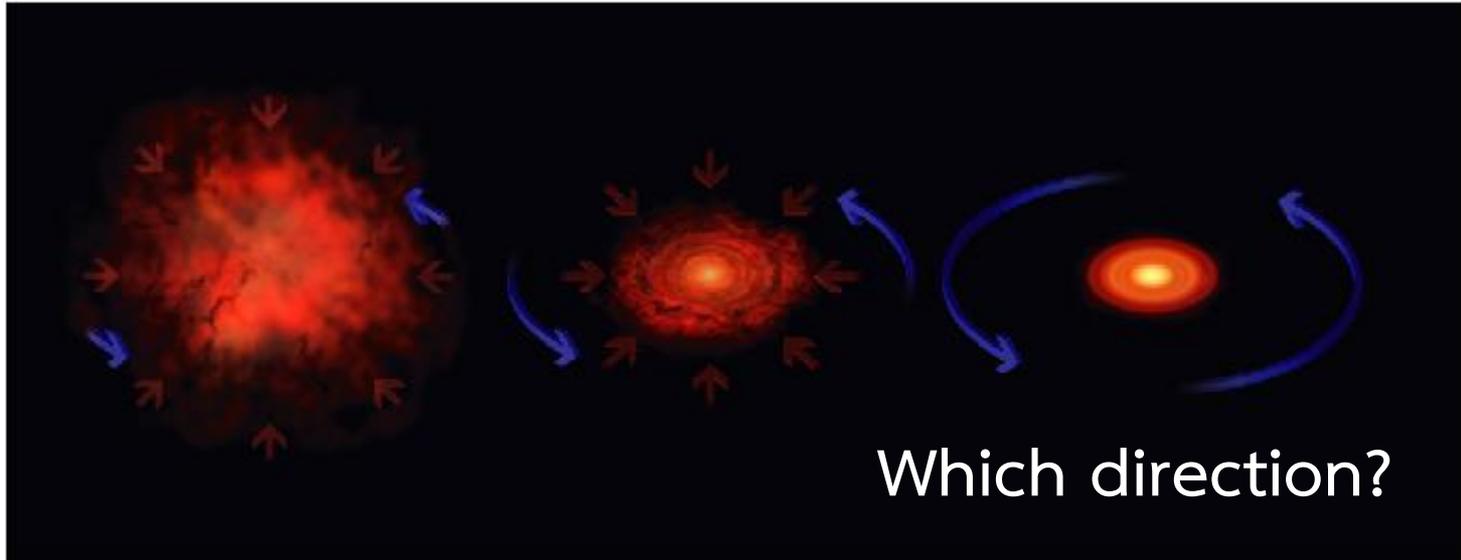


Nebular Theory of Solar System Formation



1. Gas particle gravitationally gathering -> cloud of swirling gas (Nebula or interstellar gas)
2. Gravitational collapse to a disk
3. Condensation and accretion
4. Clearing the dust out of the nebula

Step 1: Collapse of the Nebula



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Conserved quantity during collapse:
“Angular momentum”

Effects of Gravitational collapse:

1. Rotate faster
2. Hotter

Materials in the Solar Nebula

Materials in the Solar Nebula				
	Metals	Rocks	Hydrogen Compounds	Light Gases
Examples	 iron, nickel, aluminum	 silicates	 water (H ₂ O) methane (CH ₄) ammonia (NH ₃)	 hydrogen, helium
Typical Condensation Temperature	1,000– 1,600 K	500– 1,300 K	<150 K	(do not condense in nebula)
Relative Abundance (by mass)	▪ (0.2%)	▪ (0.4%)	▪ (1.4%)	 (98%)

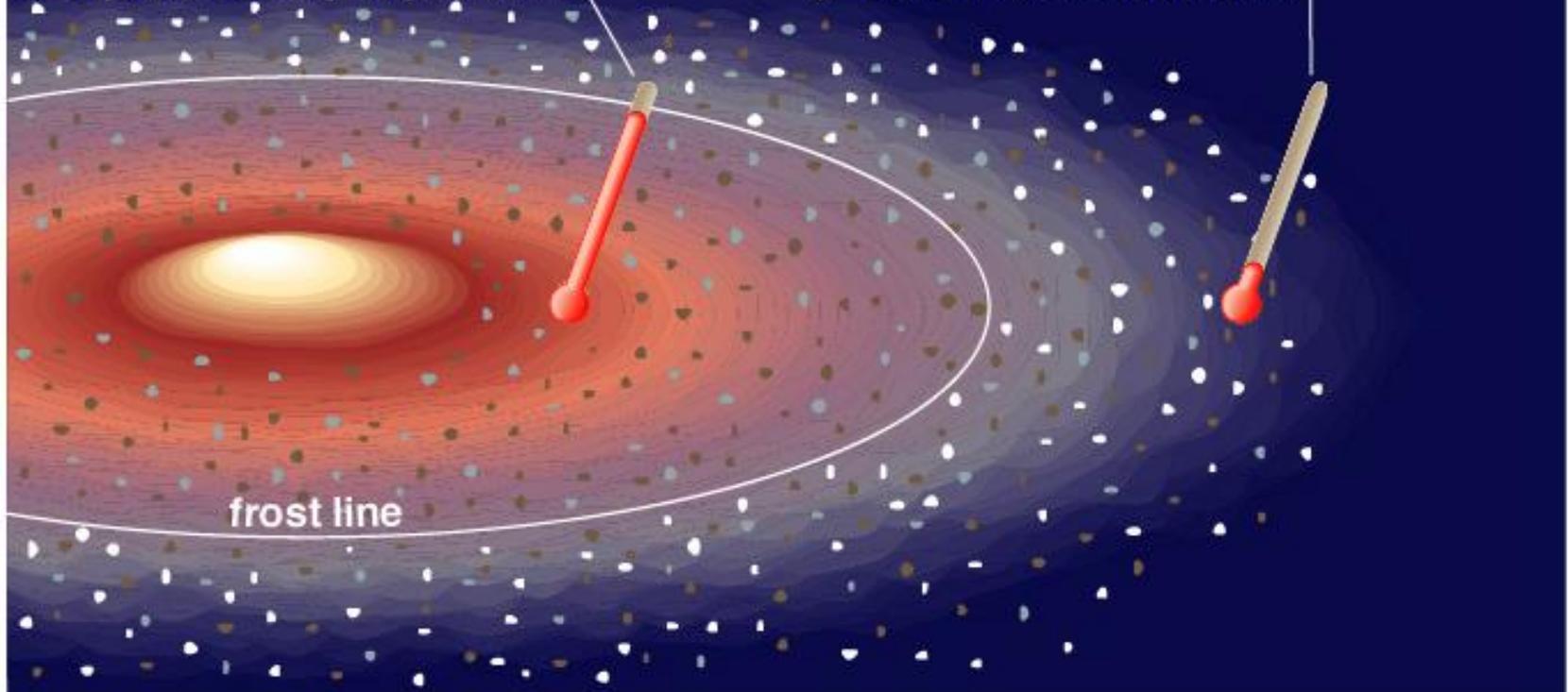
Task 1

At the beginning of the nebular collapsing, WHY did only solid rock and metal form near the sun, instead of the gaseous materials?

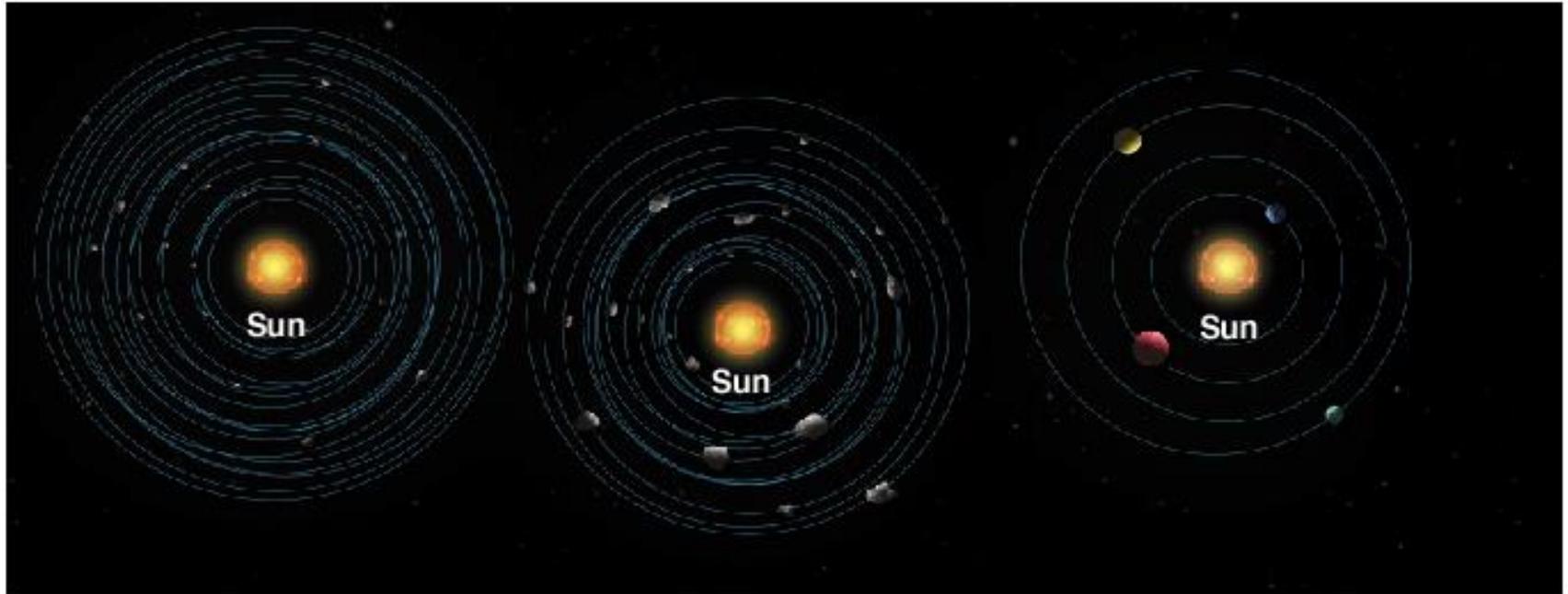
Nebular Theory Step 2: Condensation

Rocks and metals condense, hydrogen compounds stay vaporized.

Hydrogen compounds, rocks, and metals condense.



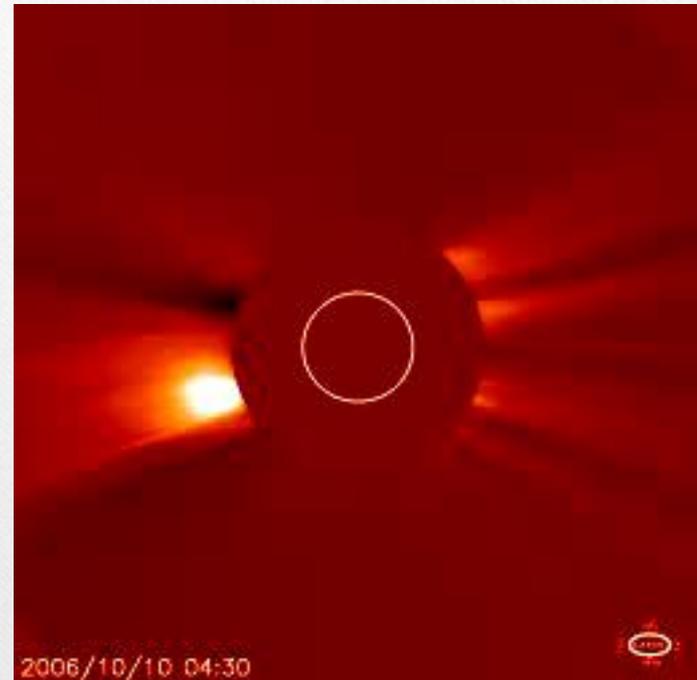
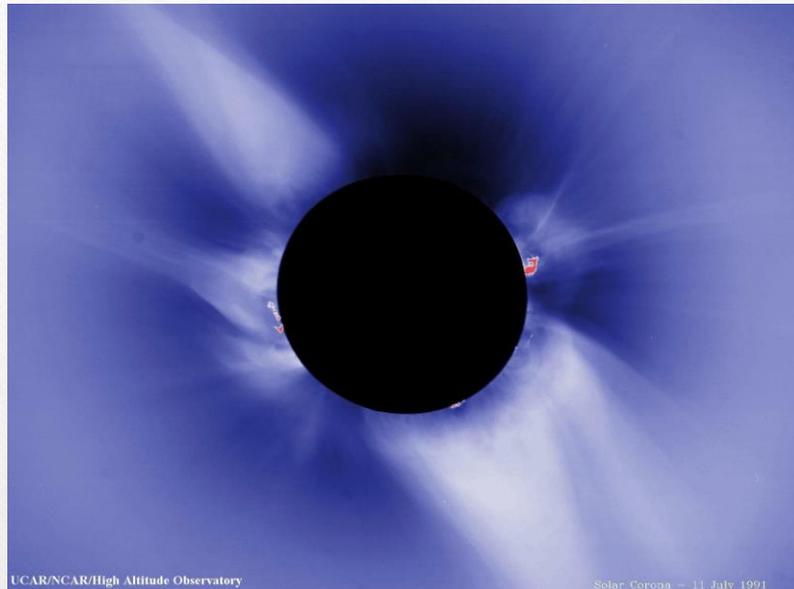
Nebular Theory Step 3: Accretion



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Gravitational pull helps the objects to become bigger and denser.

Nebular Theory Step 4: Clearing away the Nebula



High speed solar wind (400-2000 km/s) released from newly formed star clears away the left over nebular gas and dusk from the solar system.

Time out to Think Question

Which features of the Solar system are not explained by the Nebular Theory?

1. All planets and satellites orbit near the ecliptic
2. Terrestrial planets form close to the Sun
3. Gas giants form far from the sun
4. Some planets revolve clockwise
5. All planets orbit counterclockwise
6. Terrestrial planets are denser than Jovian planets

Exceptions to the Rules

- Why do some moons orbit opposite their planet's rotation?
- Why rotation axes of some planets are tilted?
- Why do some planets rotate more quickly than others?
- Why Earth is the only terrestrial planet with a large Moon?

Exceptions to the Rules

How does the nebular theory deal with exceptions?

IMPACTS

- In the early solar system, there were many more leftover planetesimals than today.
- They collided with the planets & moons during the first few 10^8 years.
- The **heavy bombardment** period.

Exceptions to the Rules

Close encounters with and impacts by planetesimals could explain:

- **Why do some moons orbit opposite their planet's rotation**
 - captured moons (e.g. Triton, the largest moon of Neptune)
- **Why rotation axes of some planets are tilted**
 - impacts “knock them over” (extreme example: Uranus)
- **Why do some planets rotate more quickly than others**
 - impacts “spin them up”
- **Why Earth is the only terrestrial planet with a large Moon**
 - giant impact

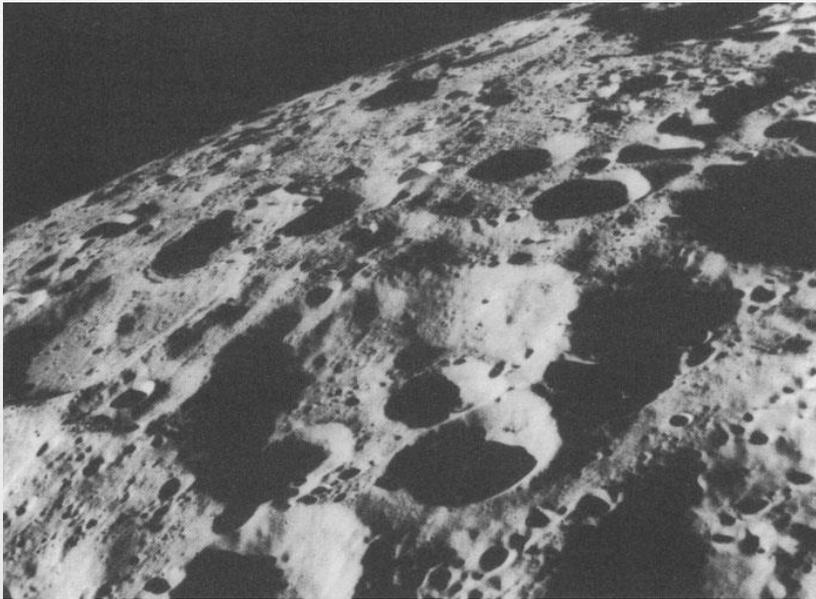
Formation of the Moon (Giant Impact Theory)

- The Earth was struck by a Mars-sized planetesimal
- Part of Earth's mantle was ejected
- This coalesced into the Moon.
 - it orbits in same direction as Earth rotates
 - lower density than Earth
 - Earth was “spun up”



Lunar Highlands

The lighter-colored, heavily cratered highlands **cover roughly 84% of the Moon's surface** and tend to dominate the far side terrain. The rocks which make up the highland surface are **similar to the types of rocks which make up the Earth's crust and mantle.**



Lunar sample 60025 is a large sample of coarse-grained catacaustic anorthosite

<https://www.lpi.usra.edu>

Captured Satellites can orbit clockwise



(a) Phobos



(b) Deimos

Our solar system today



Now I am just
a dwarf planet



The three criteria of the IAU for a full-sized planet are:

1. It is in orbit around the Sun.
2. It has sufficient mass to assume hydrostatic equilibrium (a nearly round shape).
3. It has “cleared the neighborhood” around its orbit.



The International
Astronomical Union (IAU)

NASA's New Horizons spacecraft captured a color view of Pluto on July 14, 2015.

Why Pluto cannot join the planet family.....

The International Astronomical Union (IAU) downgraded the status of Pluto to that of a dwarf planet because Pluto meets all the criteria except one—it **“has not cleared its neighboring region of other objects.”**

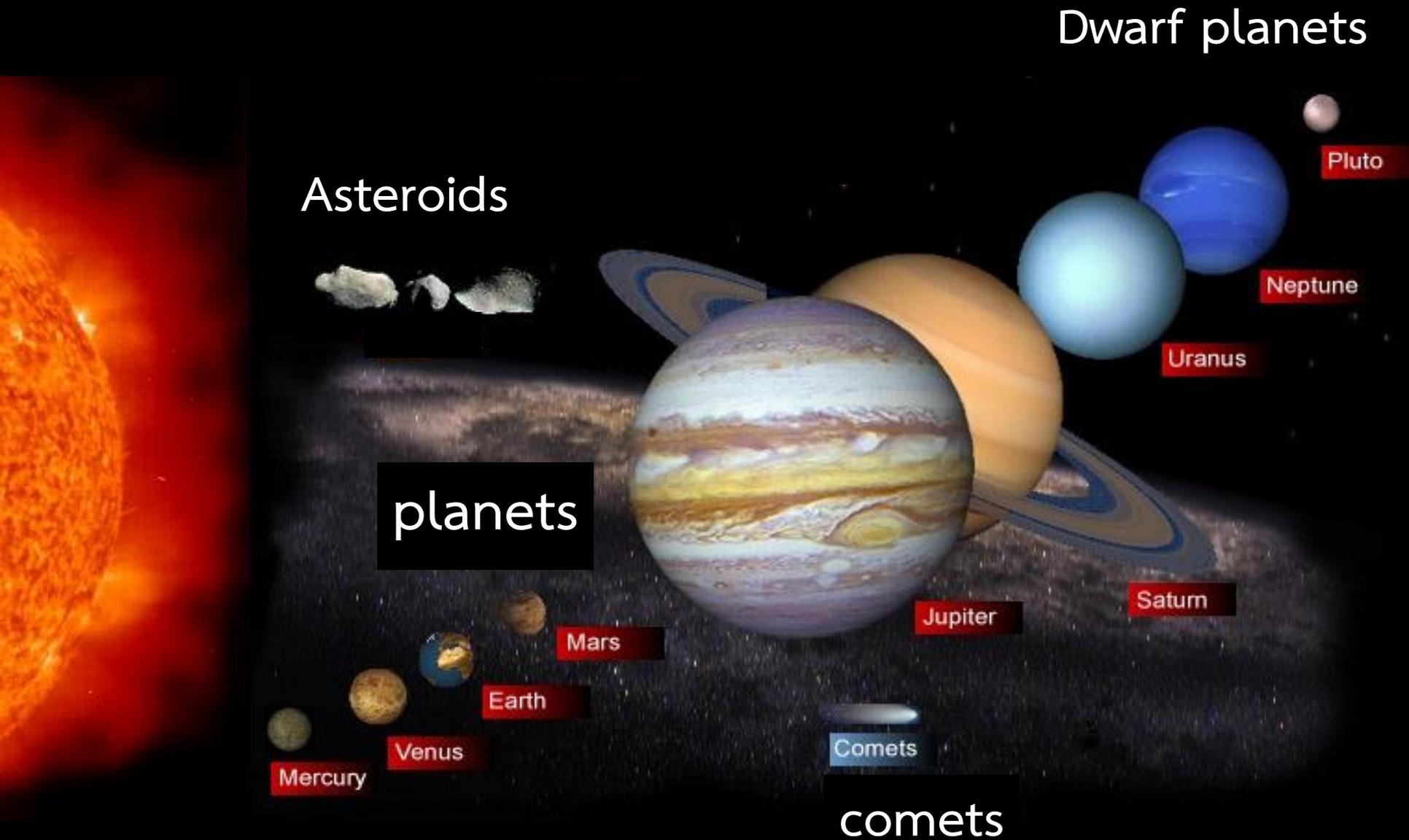
Accident Neighbor?

Pluto and its moon, Charon, shown here at the same scale, have strikingly **different surfaces.**

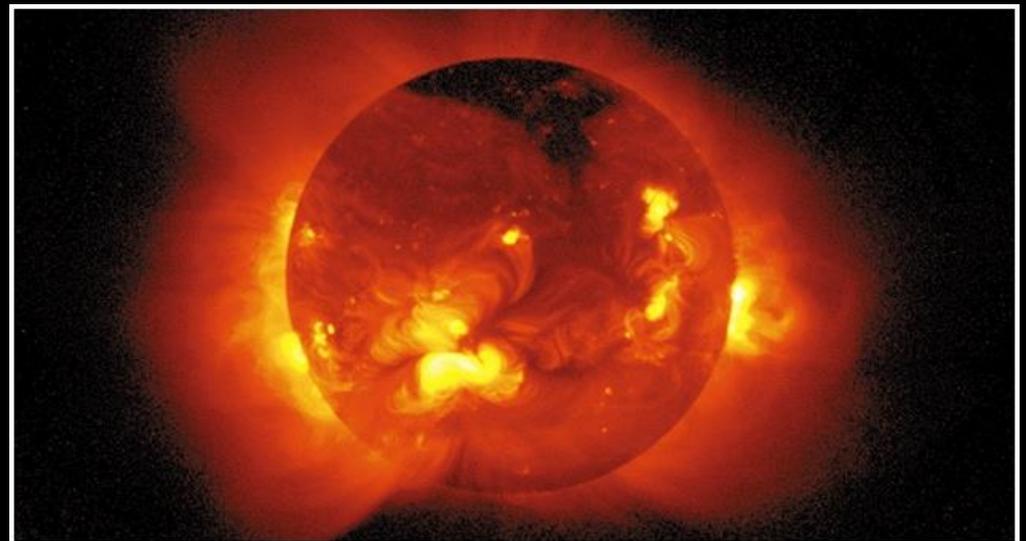
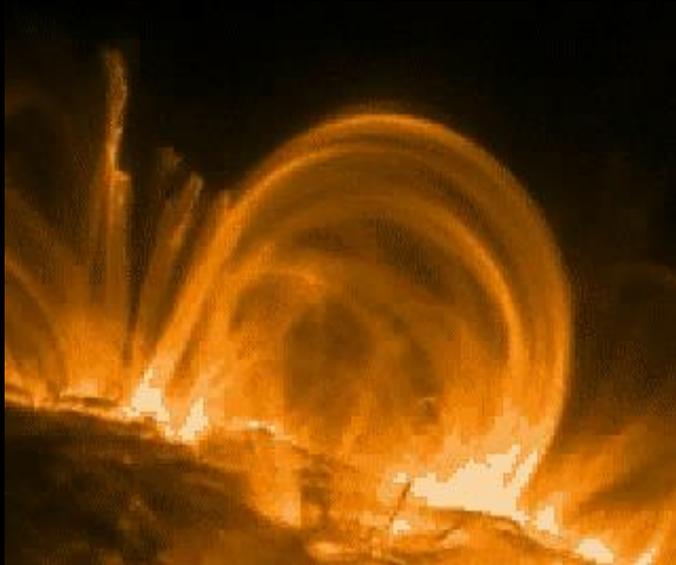
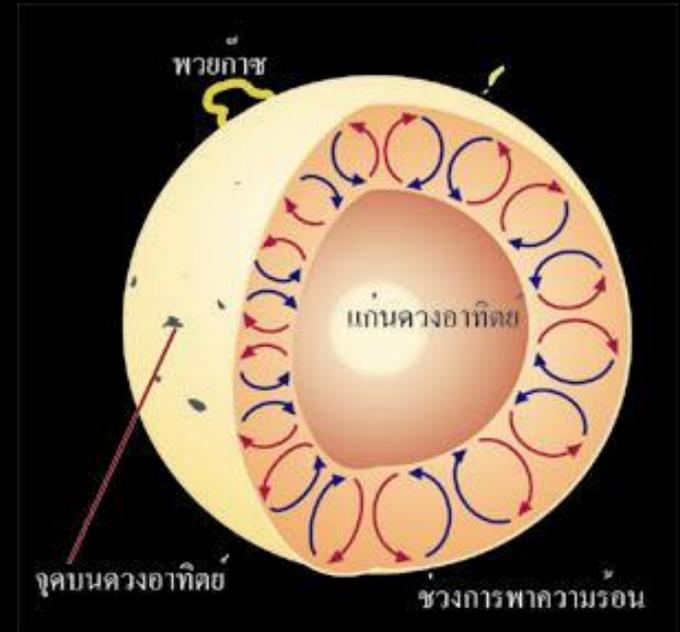
NASA / JHU-APL / SWRI

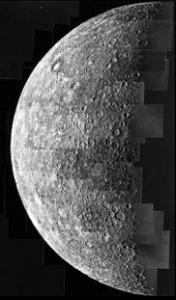


The members of our solar system



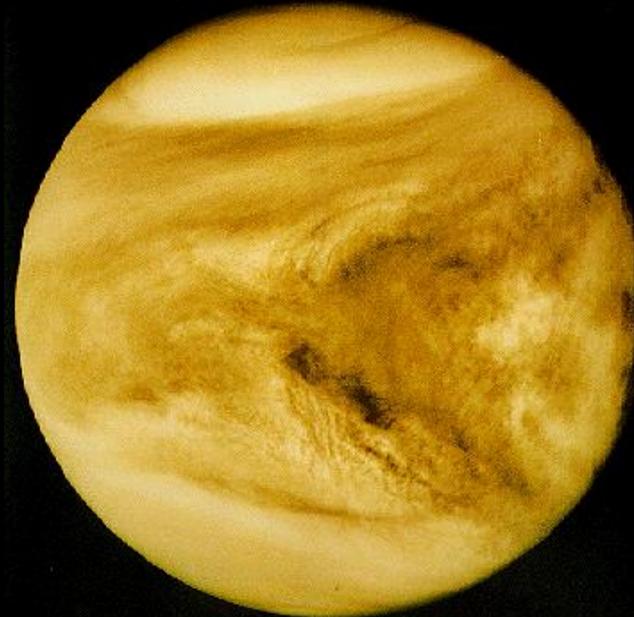
The Sun





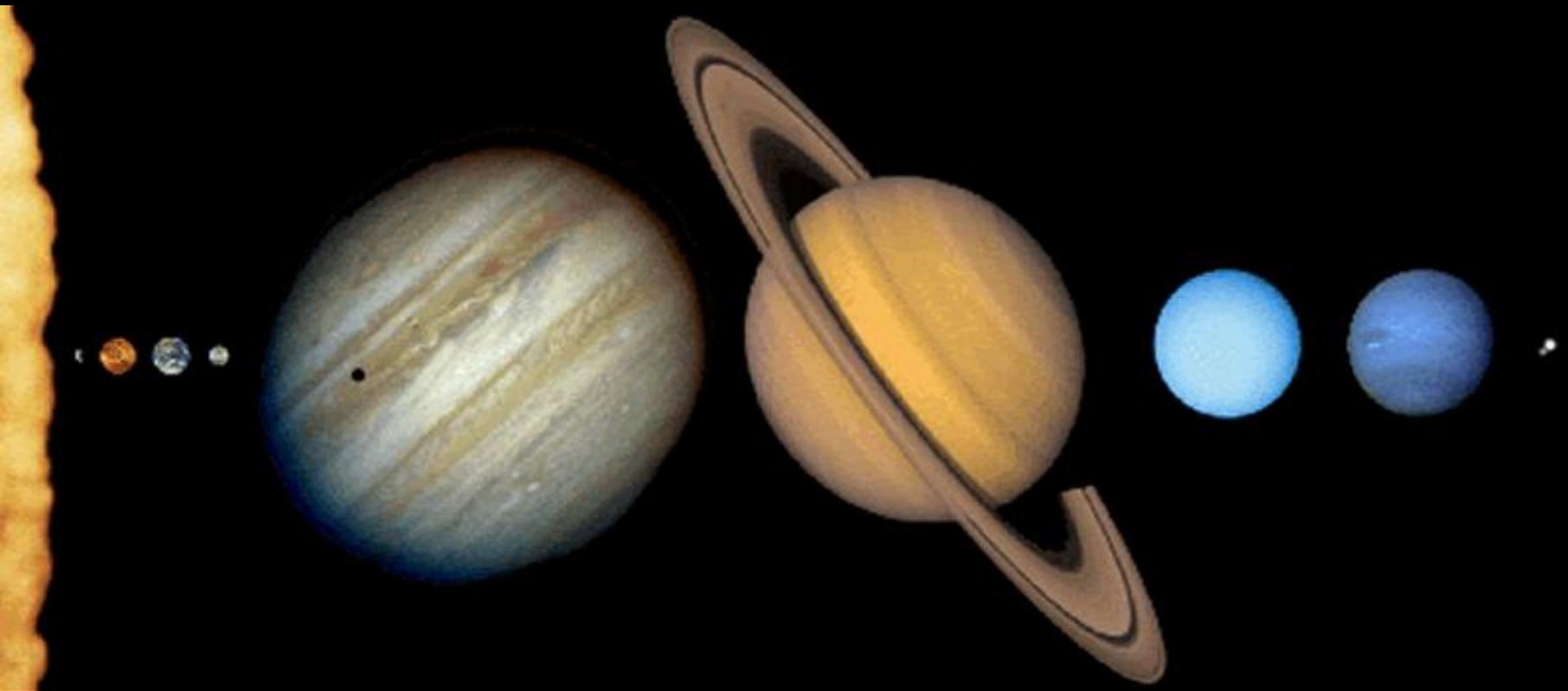
Inner Planets

(AKA Terrestrial planets or Earth-like)

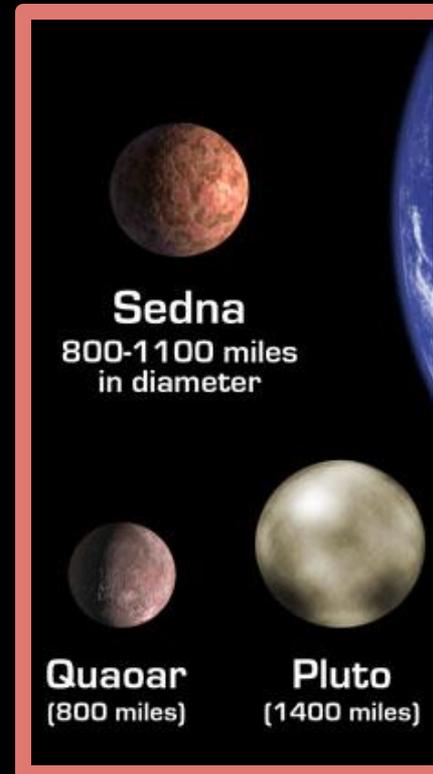
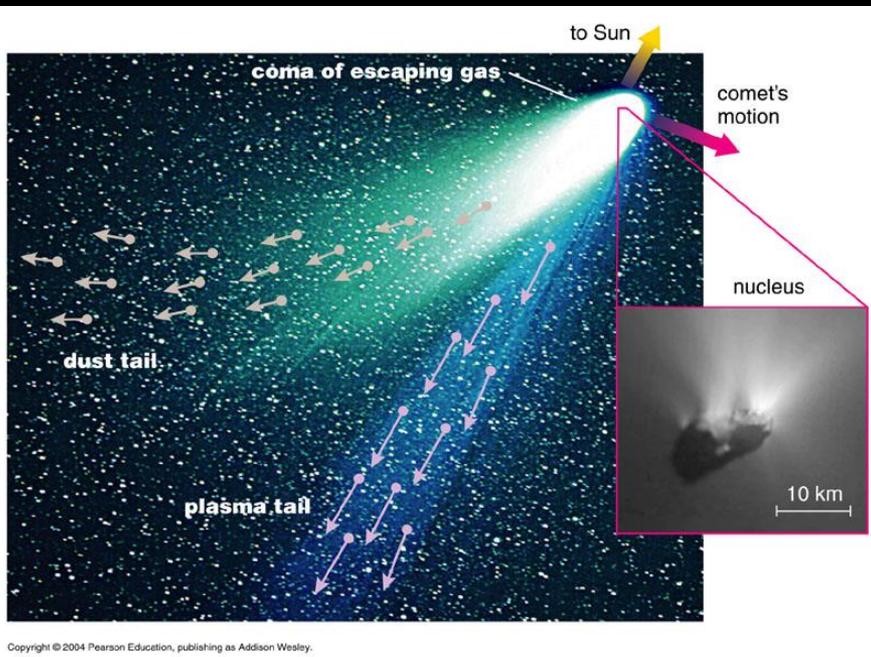
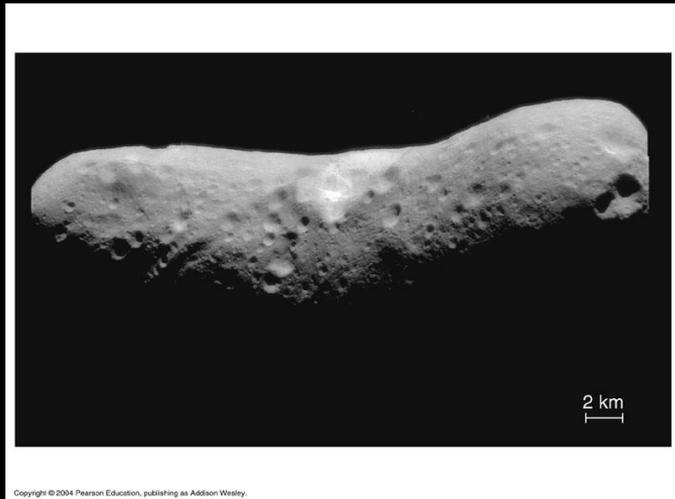


Outer Planets

(AKA Jovian Planets or Jupiter-Like)



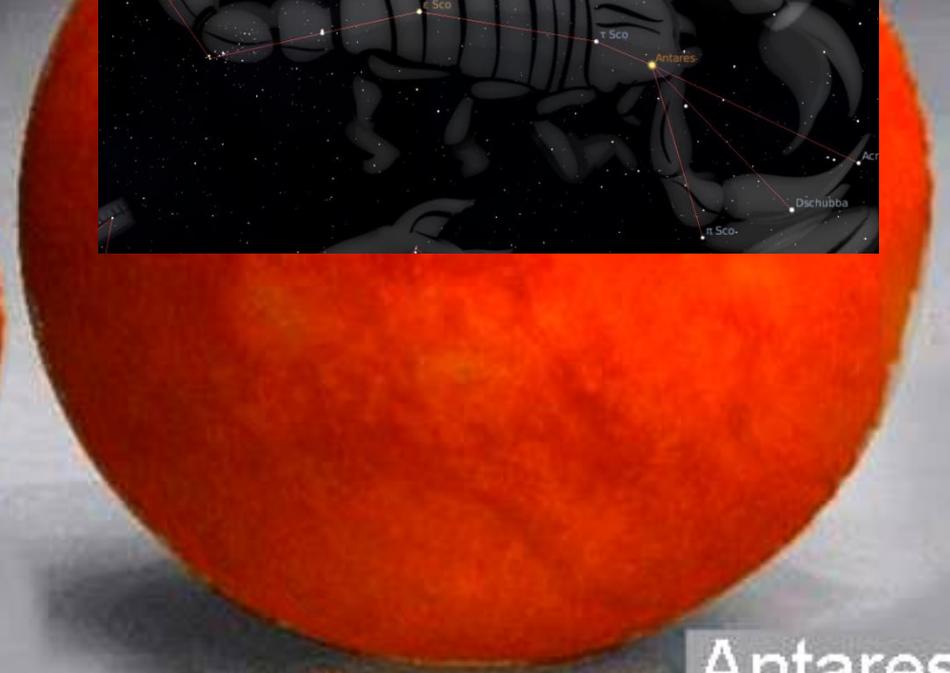
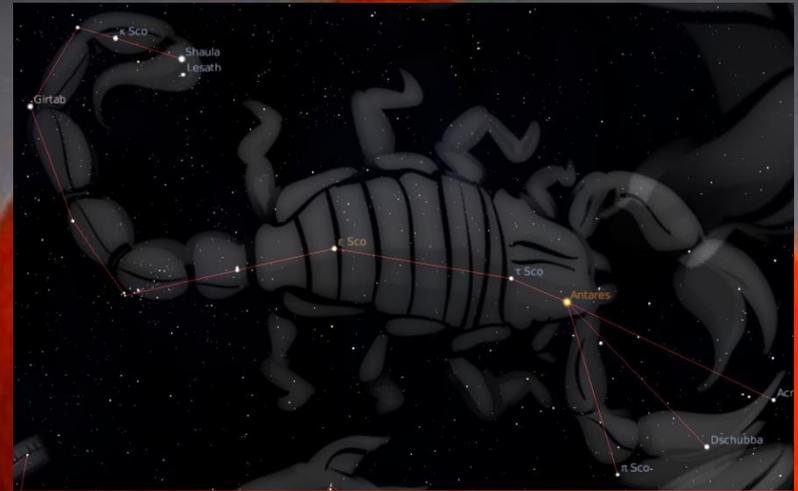
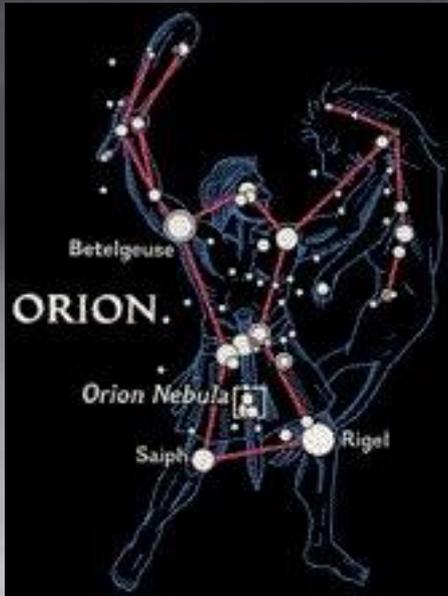
Other objects in our solar system



Moon
(2100 miles)

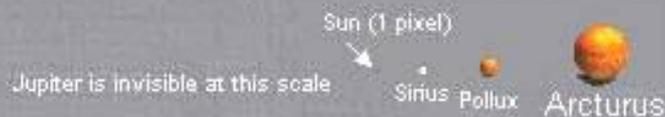
Earth
(8000 miles)

Our Sun in comparison with other stars



Betelgeuse

Antares

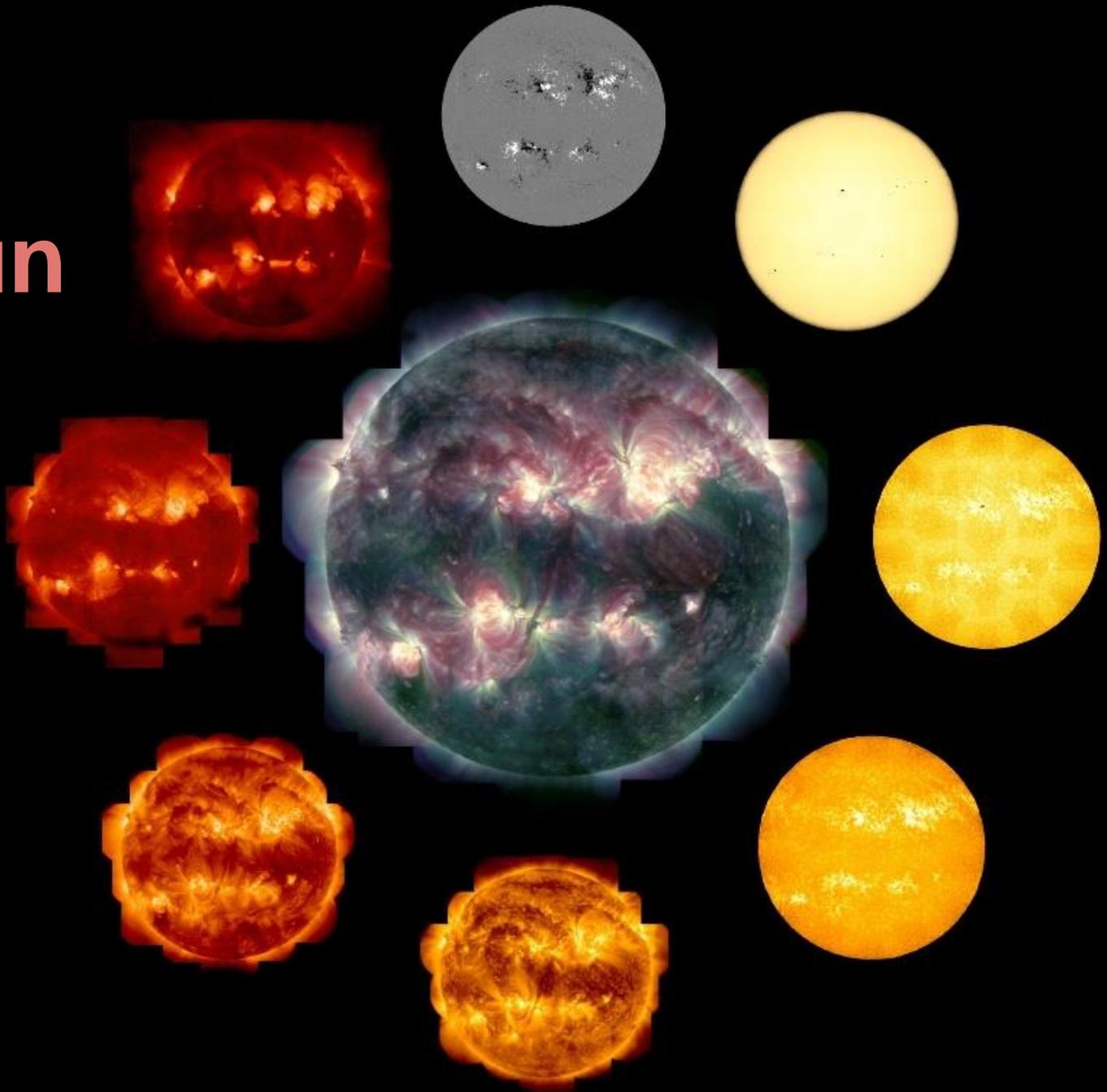


Rigel

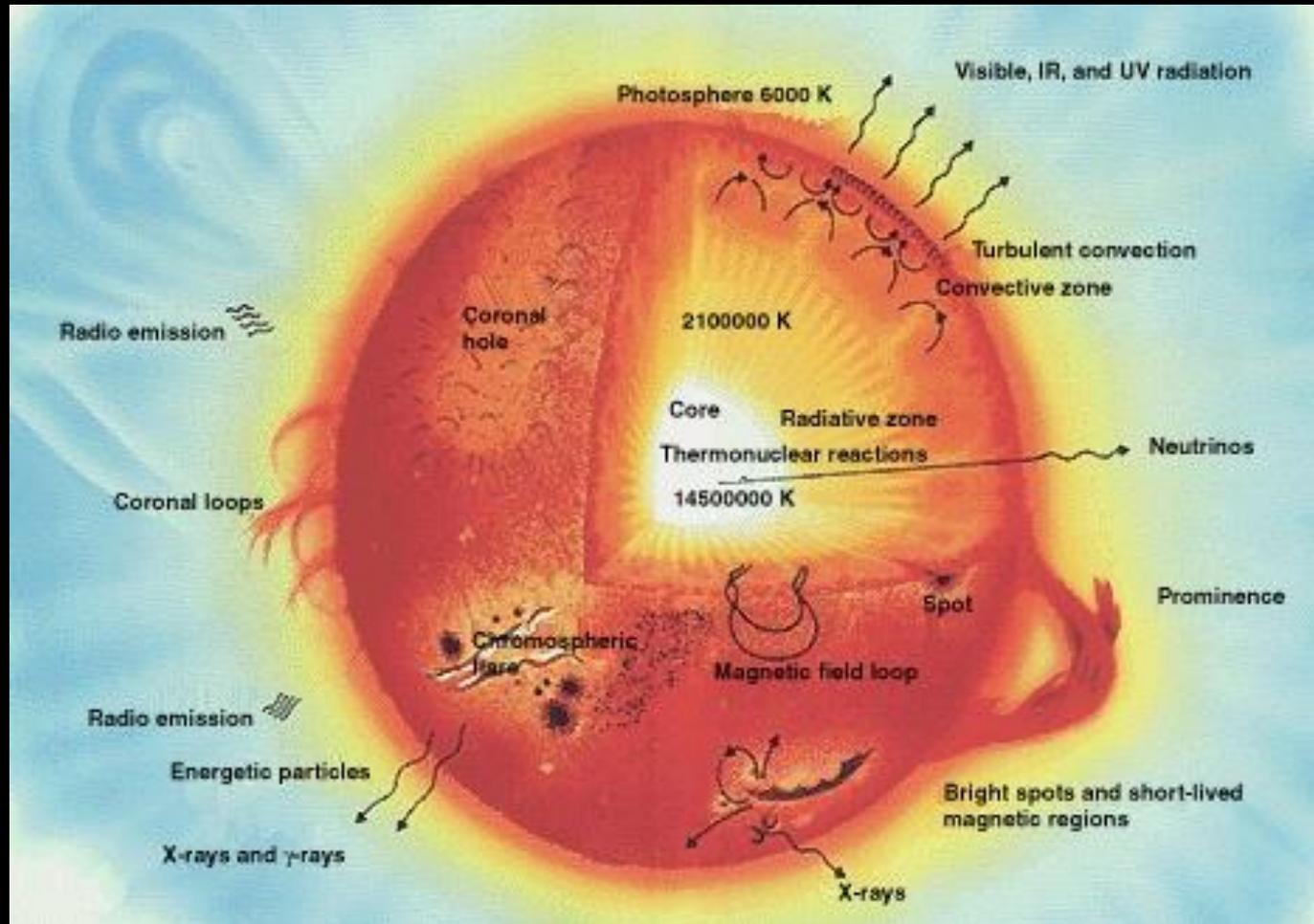
Aldebaran

The Sun

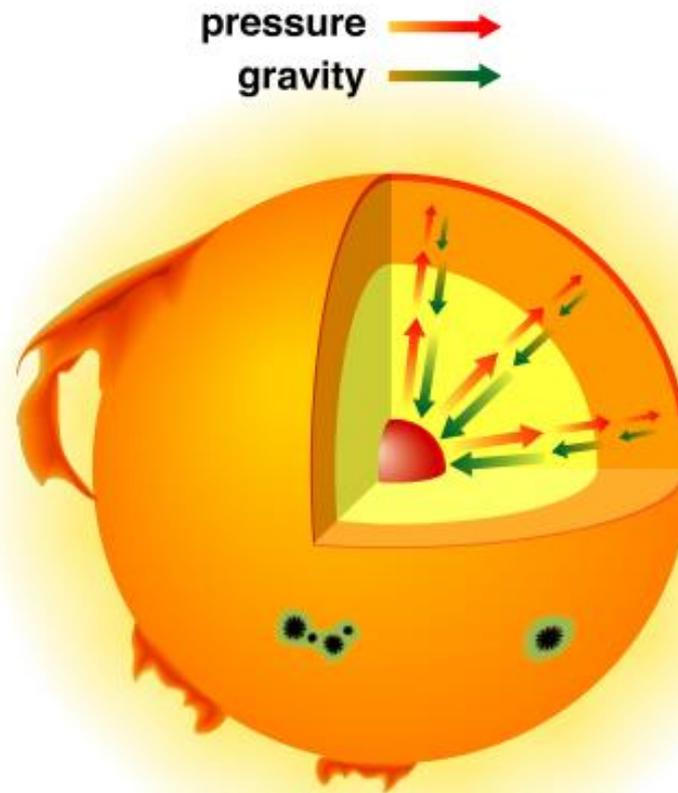
Views at many
wavelengths



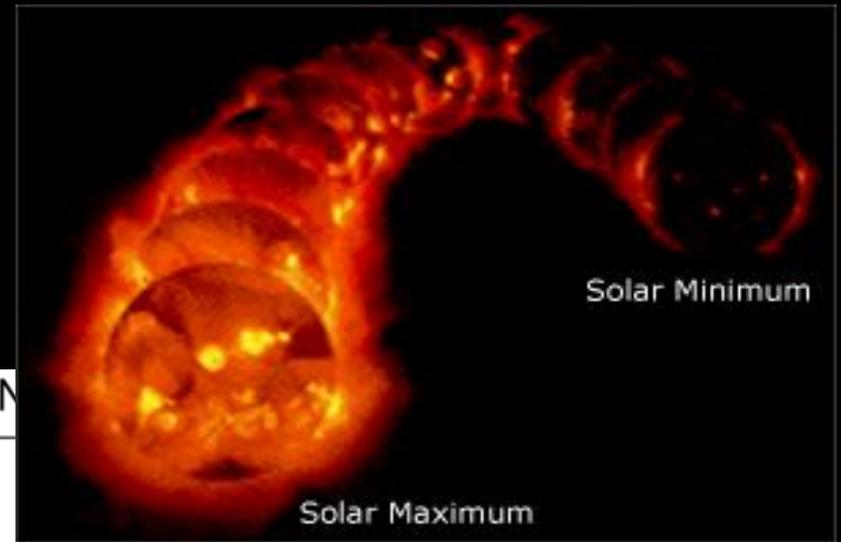
The Sun structure



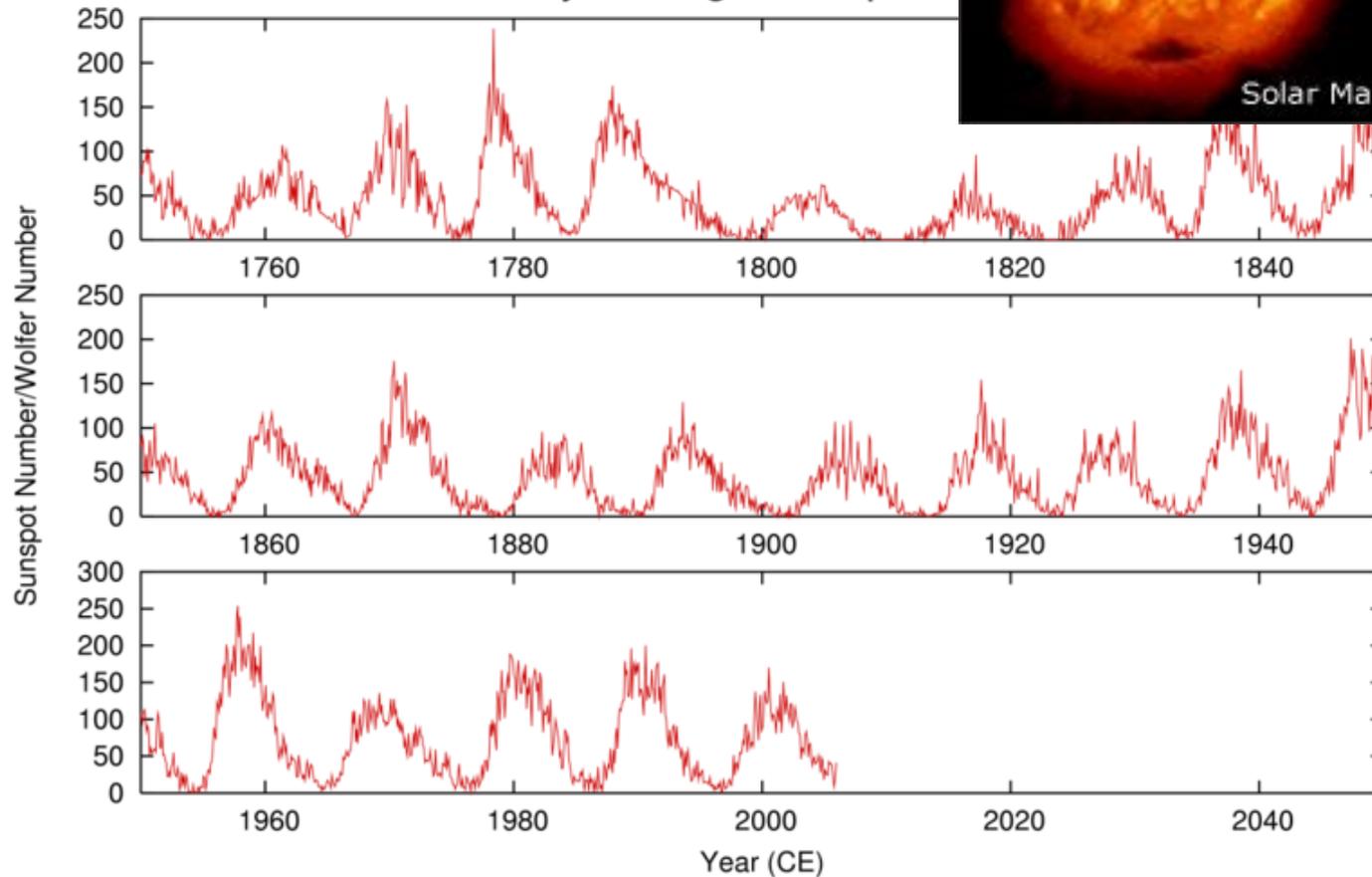
Sun is a gas sphere held up by pressure



Solar Cycle

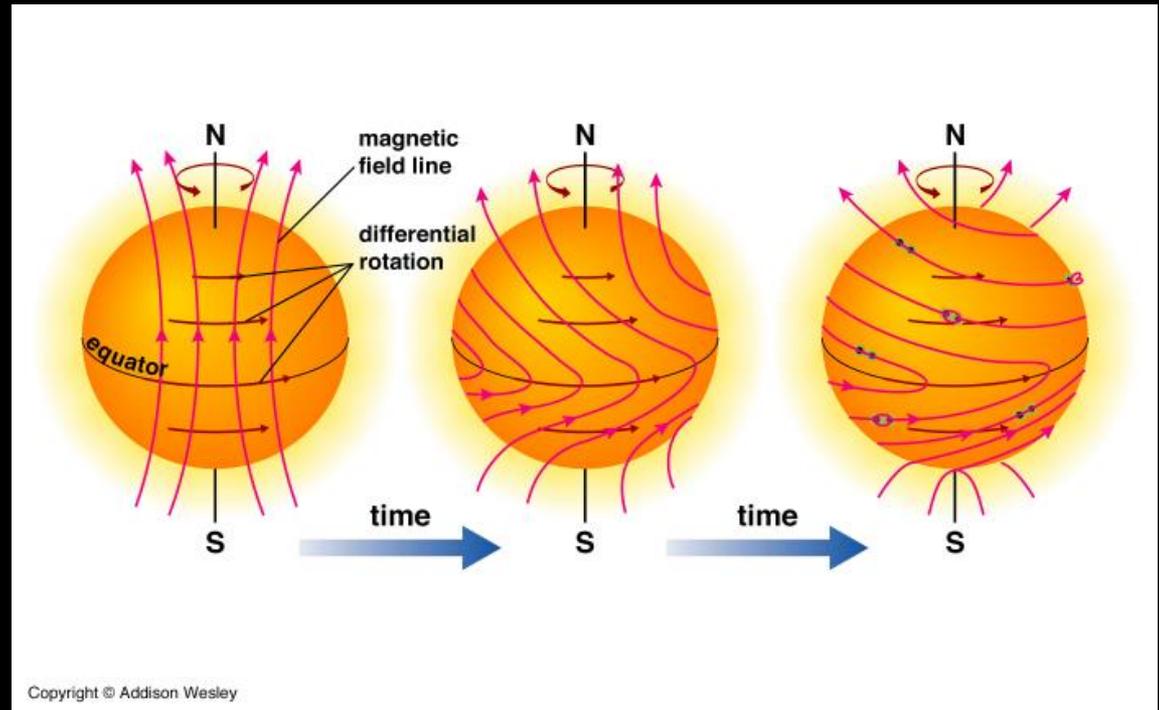


Monthly average Sunspot Number

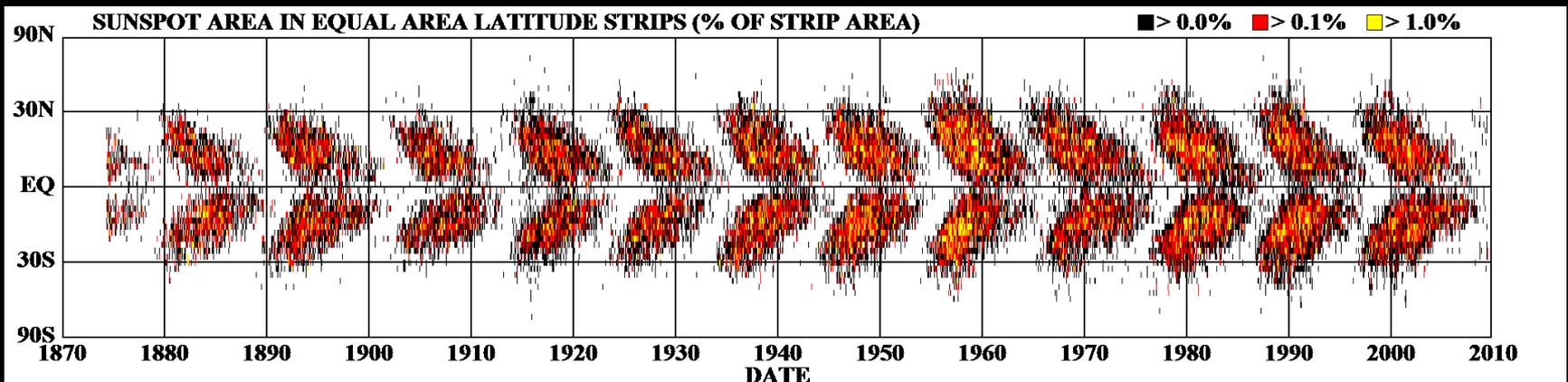


Solar Cycle related to magnetic twisting

Differential Rotation of the Sun Twists the Magnetic Field Lines

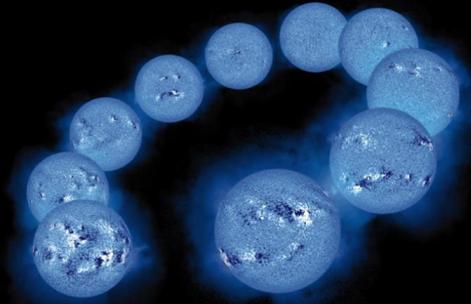


Butterfly Diagram

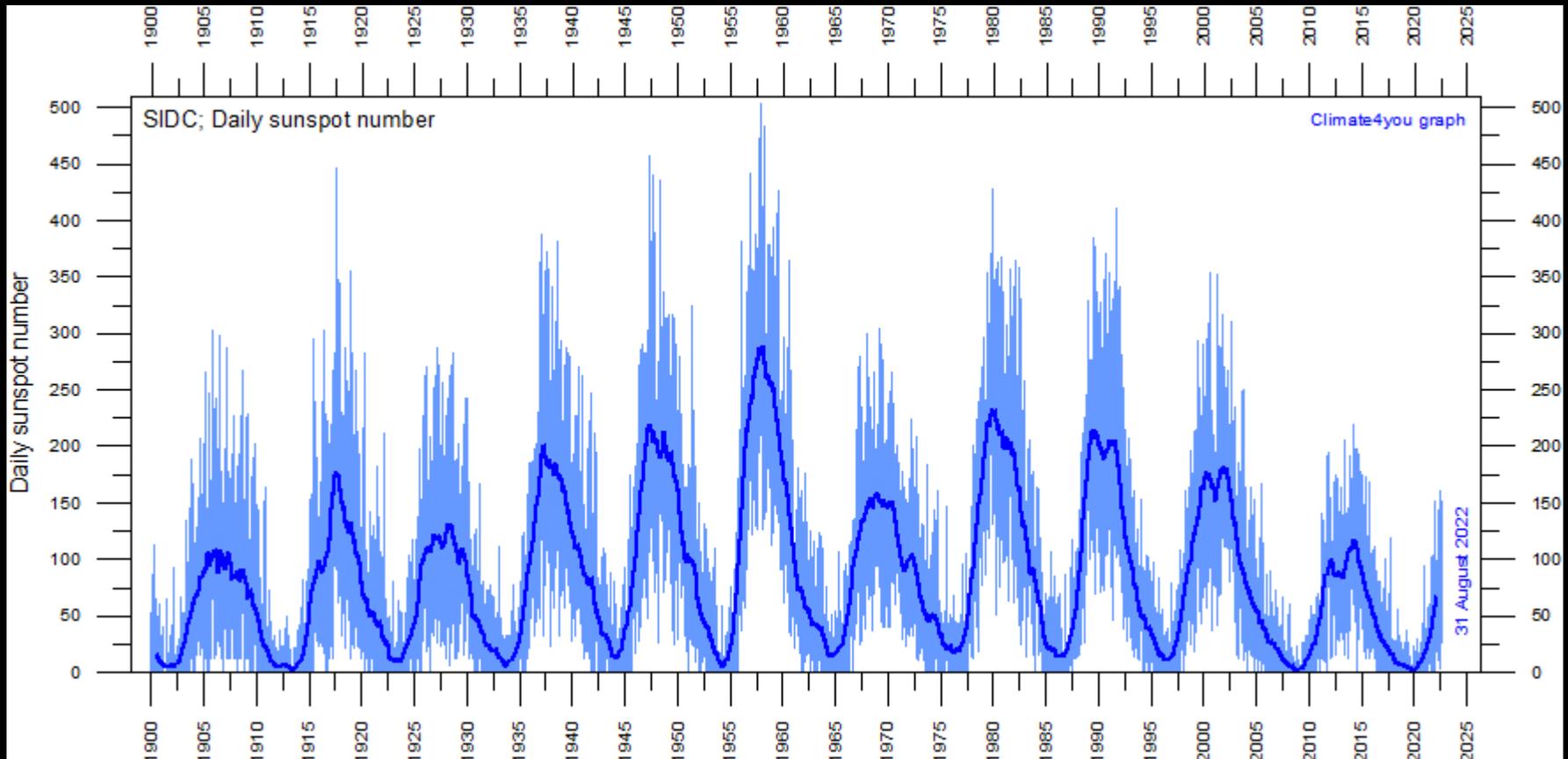


Solar Cycle

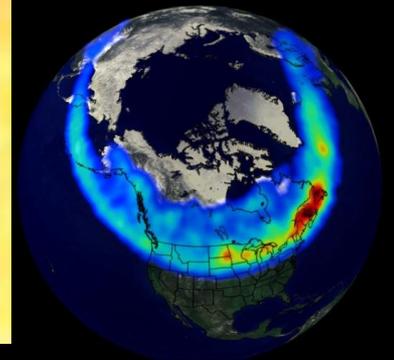
The sun was found to be active approximately every 11 years, for example in 1989 and in 2014. The sun is **EXPECTED** to be active again approximately in 2025.



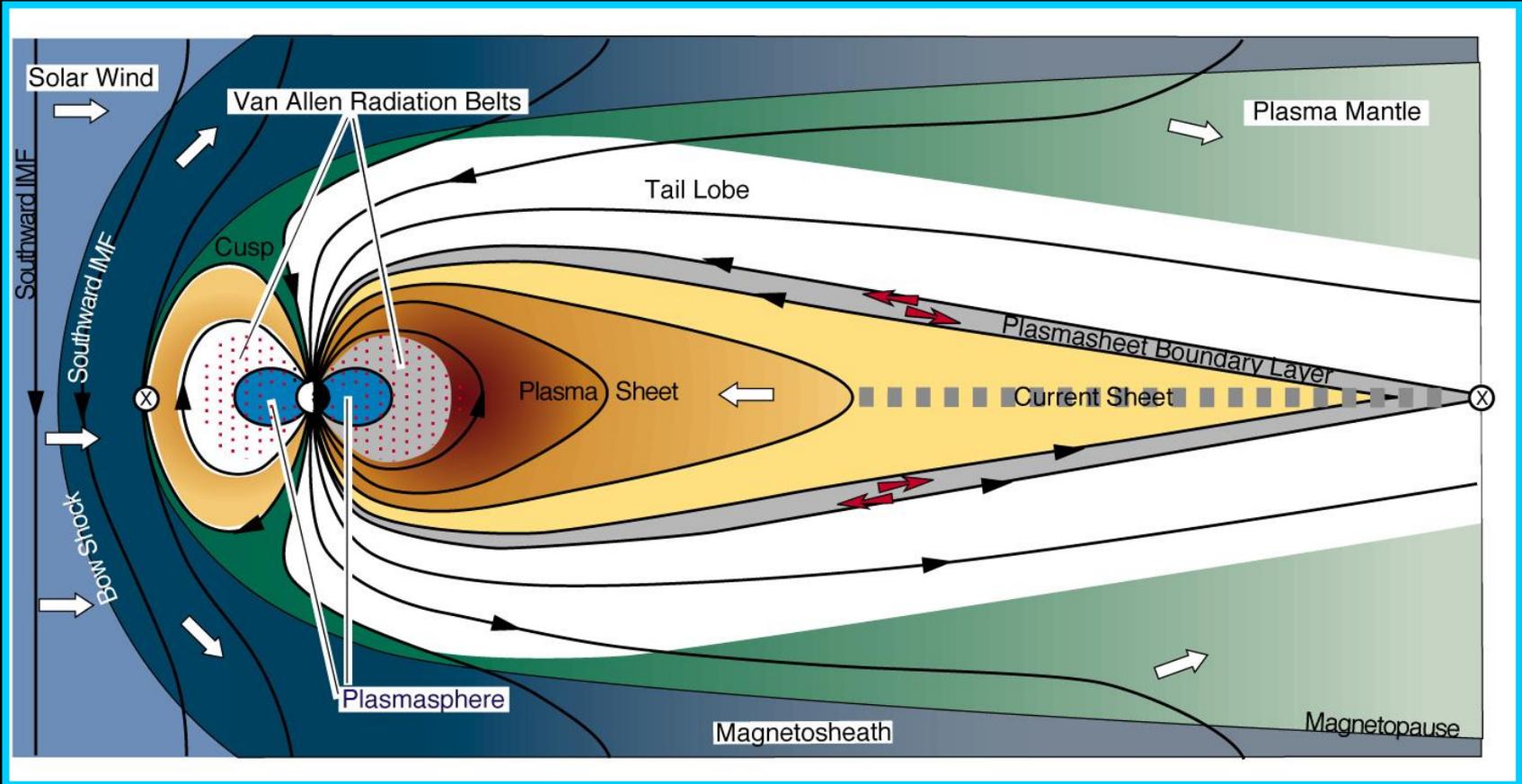
Credit: National Solar Observatory



Solar wind and Earth's magnetic field

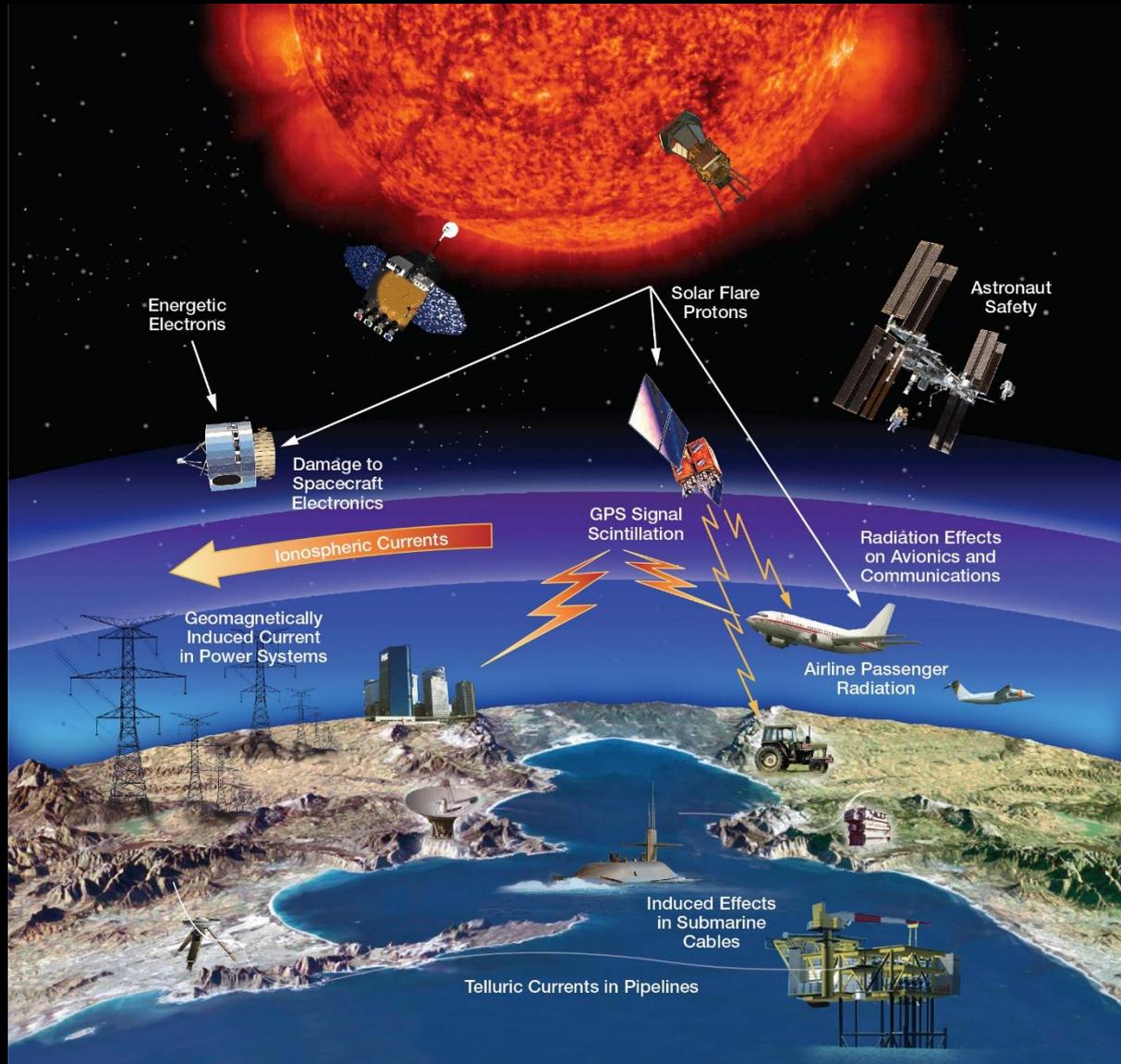


Earth's magnetosphere (Hill and Dessler, 1991)



We are safe (mostly) from the solar wind and cosmic rays because of Earth magnetosphere's and atmosphere

Space Weather Impacts



Space Weather Impact: ground electronics

Geomagnetic field fluctuations drive geomagnetically induced currents (GIC) that can be a hazard to long conductor systems on the ground.

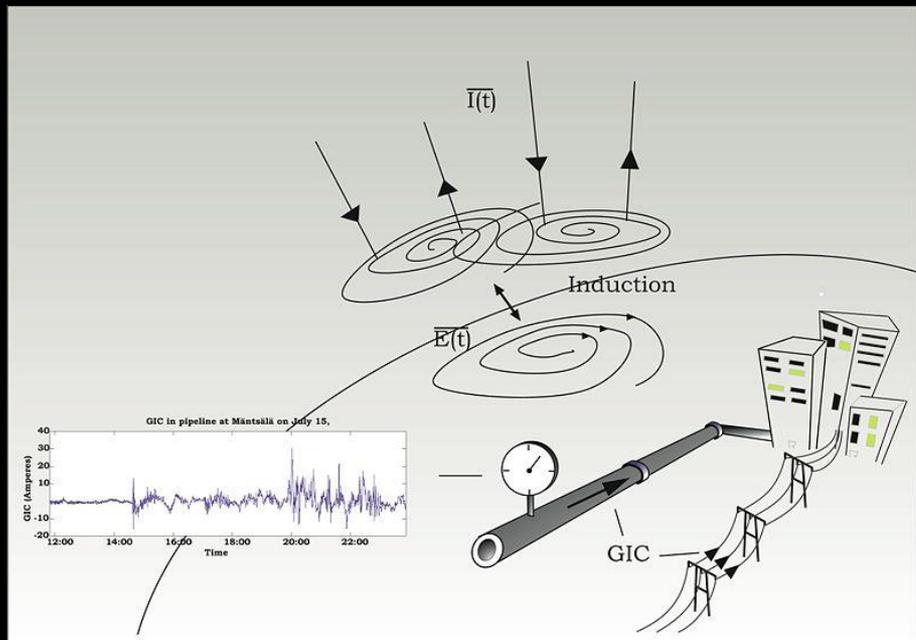


Illustration of mechanism for generating GIC

Transformer damage in South Africa



Credit: Gaunt and Coetzee (2007)