Introduction to Astronomy and Astrophysics I

Lecture 2

Yogesh Wadadekar

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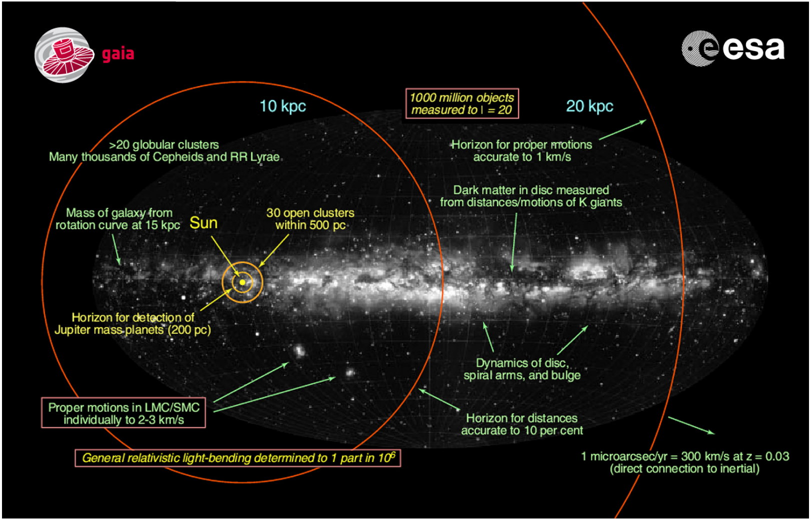
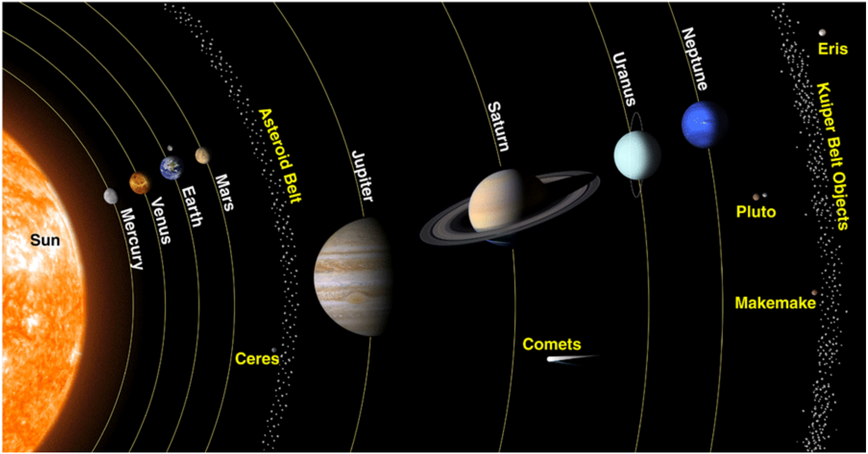
Gaia


gaia
esa
10 kpc
1000 million objects
measured to I = 20
20 kpc
>20 globular clusters
Many thousands of Cepheids and RR Lyrae
Horizon for proper motions
accurate to 1 km/s
Dark matter in disc measured
from distances/motions of K giants
Mass of galaxy from
rotation curve at 15 kpc
Sun
30 open clusters
within 500 pc
Horizon for detection of
Jupiter mass planets (200 pc)
Dynamics of disc,
spiral arms, and bulge
Proper motions in LMC/SMC
individually to 2-3 km/s
Horizon for distances
accurate to 10 per cent
General relativistic light-bending determined to 1 part in 10^6
1 microarcsec/yr = 300 km/s at z = 0.03
(direct connection to inertial)

The Solar System



Credit: Universe Today

Introduction to the Solar System

- The Solar System: our cosmic neighborhood
- Composed of the Sun, planets, moons, asteroids, comets, and dust
- Formed approximately 4.6 billion years ago How do we know this?
- Gravitationally bound system
- Extends from the Sun to the outer edges of the Oort Cloud
- Divided into inner and outer regions

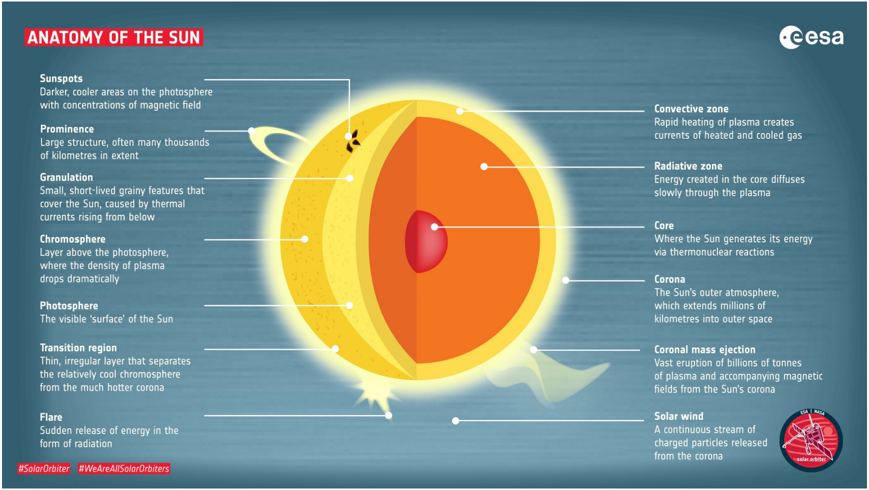
The Sun

- Central star of our Solar System
- Accounts for 99.86% of the system's mass
- Main-sequence star (G-type)
- Fusion reactor: converts hydrogen to helium, 4 million tons of mass is lost every second

Some solar properties

- Diameter: 1.4 million km (109 times Earth's diameter)
- Surface temperature: 5,800 K
- Core temperature: 15 million K
- Drives the Solar System's dynamics and energy

Anatomy of the Sun



Resolving the “coronal heating” problem

- Wave heating: Magnetohydrodynamic (MHD) waves, particularly Alfvén waves, propagate from the lower layers of the Sun’s atmosphere These waves carry energy and dissipate in the corona, heating it.
- Magnetic reconnection: The Sun’s magnetic field lines can become tangled and then snap back into place. This process, called magnetic reconnection, releases significant energy. Nanoflares, small but frequent reconnection events, may contribute to consistent heating
- Alfvén wave turbulence: As Alfvén waves propagate, they can become turbulent. This turbulence can cascade to smaller scales where the energy is more easily dissipated as heat.

The exact combination and relative importance of these mechanisms is still an active area of research using Parker Solar Probe, Aditya L1, Solar Orbiter.

Aditya L1 Payloads

- Visible Emission Line Coronagraph (VELC): For studying the solar corona and origin of CMEs
- Solar Ultraviolet Imaging Telescope (SUIT): For imaging the photosphere and chromosphere
- Aditya Solar Wind Particle Experiment (ASPEX): For studying solar wind properties
- Plasma Analyser Package for Aditya (PAPA): For solar wind ion analysis
- Solar Low Energy X-ray Spectrometer (SoLEXS): For studying solar flares
- High Energy L1 Orbiting X-ray Spectrometer (HEL1OS): For studying solar flares in higher energy X-rays
- Magnetometer: For measuring interplanetary magnetic field

Why heating is more efficient in the corona?

- The corona is much less dense than the chromosphere. Lower density means that the same amount of energy input heats the corona more effectively
- The magnetic field dominates the plasma dynamics in the corona, making magnetic heating mechanisms more efficient

Inner Planets

- Also known as terrestrial or rocky planets
- Include Mercury, Venus, Earth, and Mars
- Characterized by:
  - Solid, rocky surfaces
  - Relatively small sizes
  - Few or no moons
  - No ring systems

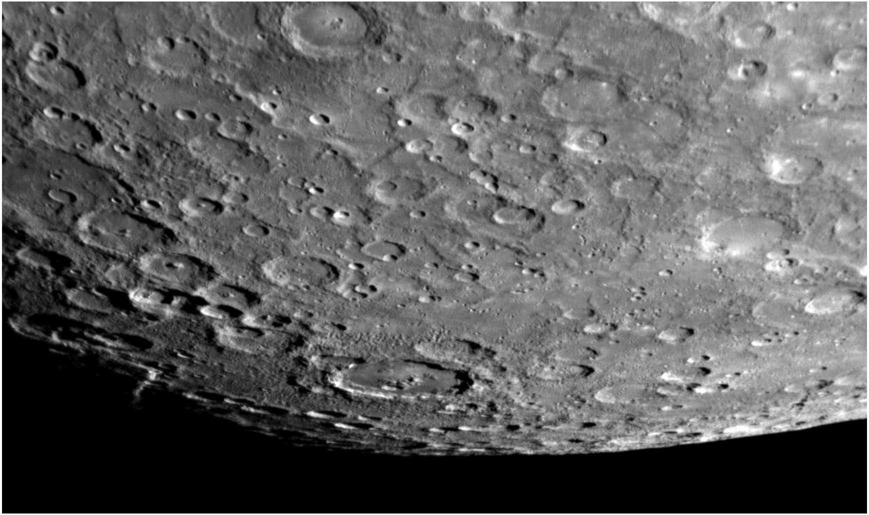
Inner Planets Comparison

Credit: Wikipedia

Mercury

- Smallest planet in the Solar System
- Closest to the Sun
- No atmosphere, extreme temperature variations
- Heavily cratered surface
- Unexpected magnetic field

Mercury Surface

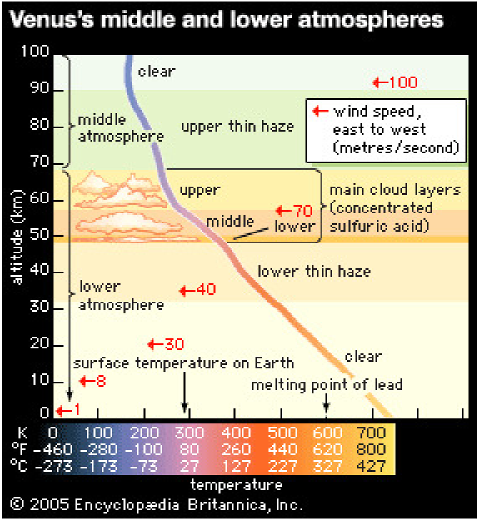


Credit: NASA

Venus

- Similar in size to Earth
- Thick atmosphere of CO_2
- Extreme greenhouse effect
- Surface temperature: 462 ℃
- Retrograde rotation - 243 days to turn on its axis and 224.7 days to orbit the Sun

Venus Atmosphere



Albedo

is the fraction of light reflected by a planet. It is 76% for Venus, 30% for Earth and 7% for the Moon.

Earth

- Third planet from the Sun
- Only known planet with life
- 71% of surface covered by water
- **Nitrogen-oxygen** atmosphere
- Active geology and weather systems

Earth from Space

Credit: Encyl. Britannica

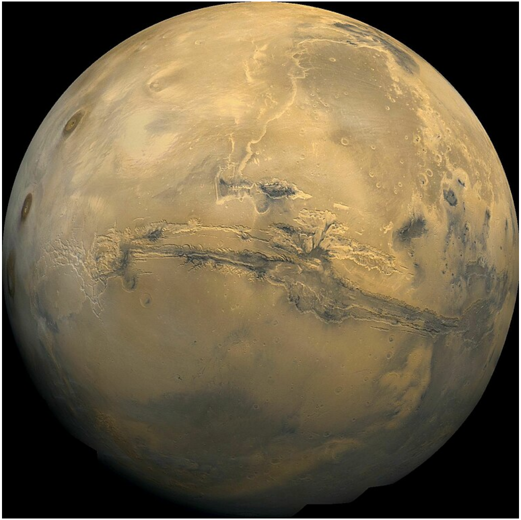
Earth's Moon

- Largest moon relative to its planet's size in the Solar System
- Synchronous rotation with Earth
- Influences Earth's tides and stabilizes its axial tilt
- Formation likely due to giant impact early in Earth's history

Mars

- Fourth planet from the Sun
- Known as the "Red Planet"
- Thin atmosphere, mostly CO_2
- Evidence of past water activity
- Two small, irregular moons: Phobos and Deimos

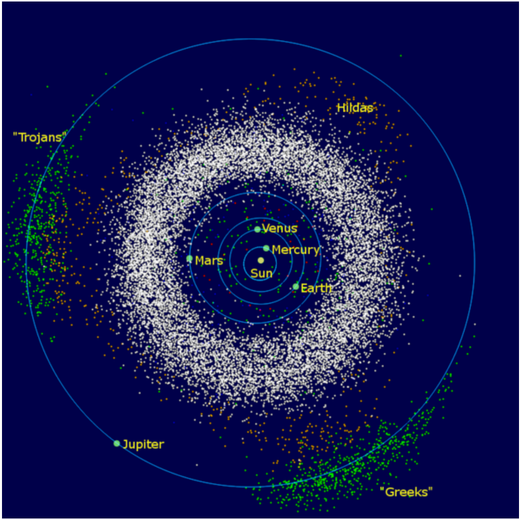
Mars Surface Features



Asteroid Belt

- Region between Mars and Jupiter
- Contains millions of asteroids
- Ranges from dust-sized to dwarf planet Ceres (940 km diameter)
- Likely remnants from the Solar System's formation
- Source of most meteorites on Earth

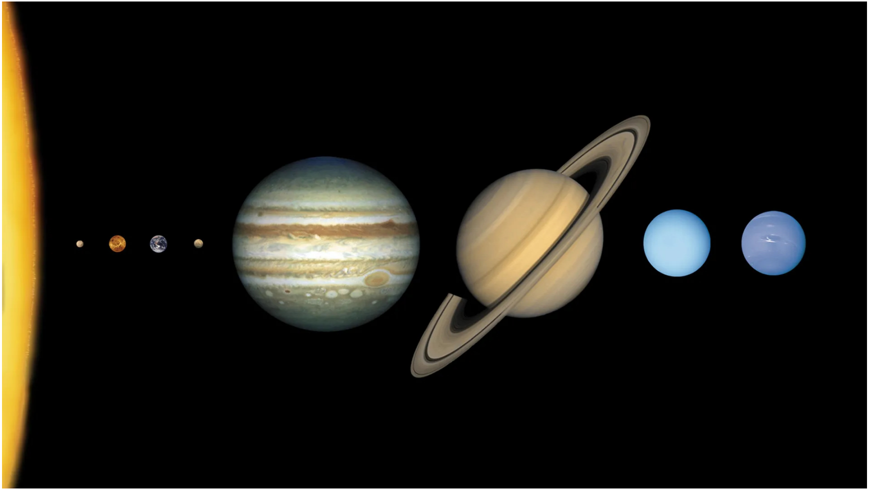
Asteroid Belt



Outer Planets

- Also known as gas giants or Jovian planets
- Include Jupiter, Saturn, Uranus, and Neptune
- Characterized by:
  - Large size and mass
  - Primarily composed of hydrogen and helium
  - Numerous moons and ring systems
  - No solid surface (except possibly rocky/icy cores)

Outer Planets Comparison



Jupiter

- Largest planet in the Solar System
- Mass 2.5 times that of all other planets combined
- Great Red Spot: a giant storm raging for centuries
- Powerful magnetic field
- At least 79 known moons

Jupiter and its Moons

Credit: NASA

Brown Dwarf

- Jupiter: largest planet in our Solar System, Mass: 317.8 Earth masses
- Brown dwarfs: objects between planets and stars, Minimum mass: $\sim$ 75 Jupiter masses ($\sim$ 0.013 solar masses)
- Jupiter's mass: much below the brown dwarf threshold
- Key difference: nuclear fusion
  - Brown dwarfs can fuse deuterium
  - Jupiter cannot initiate any nuclear fusion

Question

Jupiter radiates more energy than it receives from the Sun. How is this possible?

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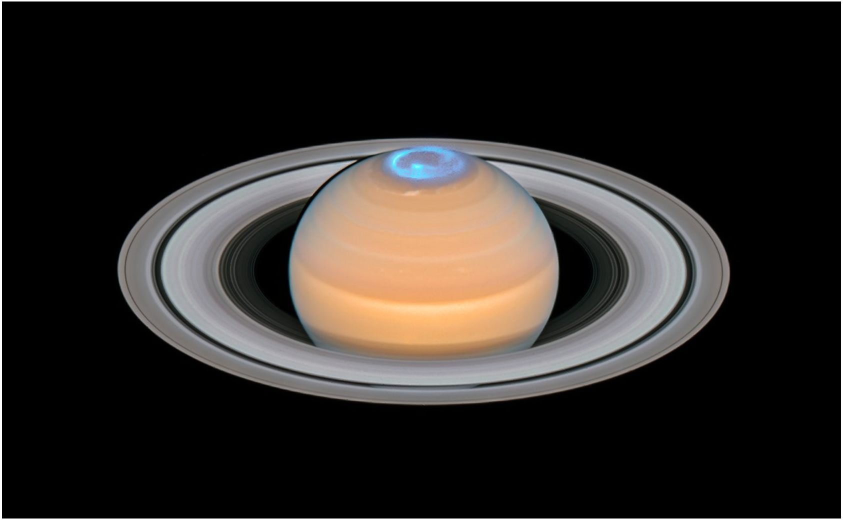
Jupiter radiates more energy than it receives from the Sun. How is this possible?

Jupiter emits almost twice as much energy as it receives from the sun due to its internal heat source, which is powered by its slow gravitational collapse. Astronomers estimate that Jupiter is shrinking by almost 2 centimeters per year. Jupiter's internal structure is believed to consist of an outer mantle of fluid metallic hydrogen and a denser inner core. As helium rain falls from the top of the metallic hydrogen layer towards the center of the planet, it generates kinetic energy.

Saturn

- Second-largest planet
- Known for its extensive ring system
- Lowest density of any planet (less than water)
- At least 82 known moons, including Titan

Saturn’s Rings and Aurorae

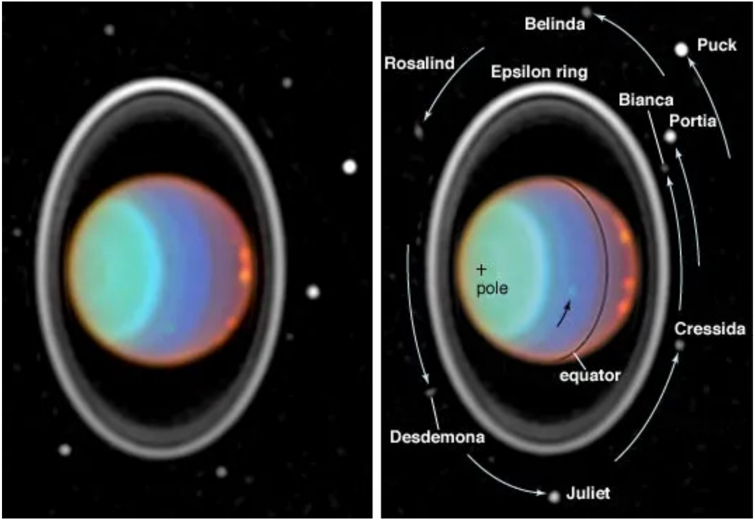


Credit: ESA

Uranus

- Third-largest planet in the Solar System
- Ice giant: primarily composed of ices (water, ammonia, methane)
- Tilted axis of rotation (97.77°): unique seasonal changes
- Faint ring system
- 27 known moons, named after Shakespearean characters

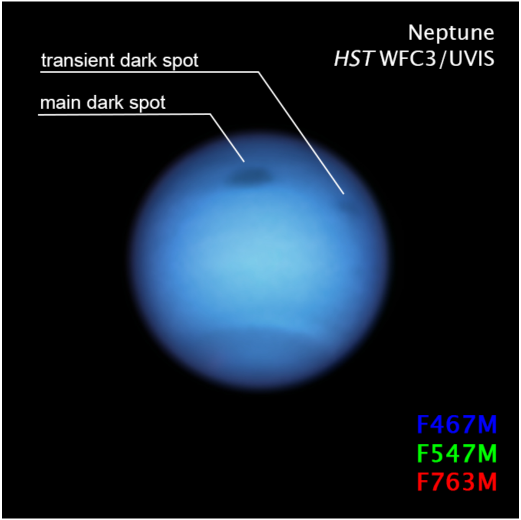
Uranus and Its Moons



Neptune

- Outermost known planet in the Solar System
- Another ice giant, similar composition to Uranus
- Discovered through mathematical predictions
- Great Dark Spot: large storm system
- Strongest winds in the Solar System (up to 2,100 km/h)
- 14 known moons, largest being Triton

Neptune


Neptune
HST WFC3 / UVIS
transient dark spot
main dark spot
F467M
F547M
F763M

Dwarf Planets

- New category created in 2006
- Orbit the Sun and have sufficient mass for gravity to make them nearly spherical
- Have not cleared their orbital neighborhood
- Five recognized: Pluto, Eris, Haumea, Makemake, and Ceres

Pluto

- Formerly classified as the ninth planet
- Highly eccentric and inclined orbit
- Smaller than Earth's moon
- Has five known moons, largest being Charon
- Visited by New Horizons spacecraft in 2015

Pluto and Charon