Lecture 3: Measurements and Mysteries

Overview

In this lecture, we explore the foundational tools and challenges of measuring astronomical distances, understand the structure of the solar system, and learn how methods like parallax, spectroscopy, and transits enable us to probe our cosmic neighborhood and beyond.

The Challenge of Measurement

- Astronomy is largely observational; direct experimentation is limited.
- Most of the universe is inaccessible; the furthest human-made object (Voyager 2) is just one light day away.
- Nearest star (Proxima Centauri): 4.2 light years away.

From the Moon to the Cosmos

- We first measured the **distance to the Moon** using basic geometry and Earth-based tools.
- From Earth-Moon to **Earth-Sun** (Astronomical Unit, or AU = 93 million miles = 8.3 light minutes).
- Built up a **cosmic distance ladder**:
- Earth measurements (feet, meters).
- Moon.
- Sun and inner planets (via transits and radar).
- Outer planets (radar).
- Nearby stars (parallax).
- Distant stars and galaxies (brightness/luminosity).

Parallax

- Parallax: measuring angular shift of nearby stars as Earth orbits the Sun.
- Baseline = 1 AU.
- 1 arcsecond of parallax = **1 parsec** = 3.26 light years.
- Closest star has a parallax <1 arcsecond.
- Tools: telescopes, Gaia satellite (accuracy to micro-arcsecond level, measures a billion stars).

Inverse Square Law & Luminosity

- **Luminosity (L)** = energy emitted per second (e.g., Sun = ~10^{26} watts).
- **Flux (F)** = energy received per square meter.
- Flux diminishes as $1/d^2$.
- If L is known and F is measured, distance can be calculated.

Telescopic Innovations

- With better tech, we reach farther: radio/radar astronomy, photometry, spectroscopy.
- Example: radar to Venus; measuring time delay to calculate distance.

The Solar System

- Composed of:
- Sun (99.8% of solar system mass).
- 8 planets (Mercury to Neptune).
- Dwarf planets (Pluto, Eris, Makemake).
- Minor bodies: asteroids, comets, meteoroids.

- **Planetary criteria**:
- Orbits the Sun.
- Spherical shape.
- Clears its orbital neighborhood.
- Pluto fails #3; now classified as a **dwarf planet**.

Eclipses and Syzygy

- **Syzygy**: alignment of three celestial bodies.
- Solar eclipse: Moon blocks Sun.
- Lunar eclipse: Earth blocks Sunlight to Moon.
- Only Earth has perfect total solar eclipses.
- Syzygies are rare but crucial for measurement.

Tides and Tidal Locking

- Tides caused by Moon's gravitational pull (and to a lesser extent, Sun).
- Moon is tidally locked: one side always faces Earth.
- Mercury is also locked to the Sun.

Discovering Exoplanets

Two Main Methods:

1. **Doppler (Radial Velocity)**:
2. Measures wobble in star’s spectrum due to orbiting planet.
3. Determines mass and orbital period.
4. **Transit Method**:
5. Planet crosses star's face, dims its light.
6. Light dip reveals size; combined with radial velocity gives **density**.

7. Transits also allow for **atmosphere analysis** using **spectroscopy**.
8. Light filters through atmosphere during transit.
9. Can detect biosignatures or technological signs (e.g., Freon).

Habitability Considerations

- Magnetic field crucial for shielding life.
- Earth has protective magnetosphere.
- Jupiter acts as cosmic shield, deflecting comets.
- Future focus: detecting signs of **intelligent life** through atmospheric composition and anomalies.

Summary

- Astronomy builds on indirect measurements: parallax, inverse square law, spectroscopy.
- A cosmic distance ladder helps us move from Earth to the observable edge of the universe.
- Exoplanets are found using light and motion—no direct travel required.
- The Moon, eclipses, tides, and orbits reveal the precision and beauty of our cosmic mechanics.