

Lecture 4: The Life of Stars

Last lecture, we explored the structure of our solar system. Now we turn to the true protagonists of cosmic evolution: **stars**.

What is a Star?

A **star** is a giant ball of gas undergoing **nuclear fusion**, primarily converting **hydrogen** into **helium** at its core. The Sun, our local star, is just one among an estimated **100 billion** in the Milky Way galaxy, and there are likely 100 billion galaxies in the observable universe.

Nuclear Fusion

- **Core fusion** happens in the central 15% of the star's volume.
- The dominant fusion process in stars like the Sun is the **proton-proton chain**:
- Two **protons** fuse to form **deuterium** (one proton, one neutron).
- Deuterium fuses with another proton to create **helium-3**.
- Two helium-3 nuclei fuse to create **helium-4**, releasing energy.

This process releases **energy** because of mass conversion: $E = mc^2$. The amount of mass lost in each reaction is tiny but, multiplied by the number of reactions in the Sun, becomes vast.

Energy Output

- Fusion of 1 kg of hydrogen yields **620 trillion joules**, millions of times more than chemical combustion.
- The Sun outputs the energy equivalent of millions of nuclear bombs **every second**.

- Its fuel supply is sufficient for a **10-billion-year** lifespan.
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Stellar Lifespan

How Do We Know the Sun's Age?

- The Sun formed from remnants of a **Population II** star that underwent a **supernova**.
- **Radioactive dating** of elements like uranium and lead in **meteorites** and **zircons** tells us the age of the solar system: **4.5 billion years**.
- The Sun is **middle-aged**.

Life Cycle of Stars

1. **Protostar**: gravity pulls gas together.
 2. **Main sequence**: hydrogen fusion balances gravity.
 3. **Red giant** (for low-mass stars) or **supergiant** (for high-mass stars).
 4. Final stages:
 5. Low-mass stars: become **white dwarfs**.
 6. High-mass stars: undergo **core-collapse supernova**, leaving behind **neutron stars** or **black holes**.
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You Are Made of Stars

Elements heavier than helium—**carbon, oxygen, iron**—were produced in ancient stars and **spread by supernovae**. This is why Carl Sagan said:

"We are made of star stuff."

Classifying Stars

Stars are classified via:

Hertzsprung-Russell (H-R) Diagram

- Main sequence: stars fusing hydrogen to helium.
- Giants: cooler, larger stars.
- White dwarfs: hot, dense remnants of low-mass stars.

Spectroscopy

- Reveals chemical composition, temperature, and **radial velocity**.
 - Used in Doppler shift calculations.
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Motions and Orbits

- Planets orbit stars; stars orbit galaxy centers.
- The Earth orbits the Sun at **~30 km/s**.
- The Sun orbits the Milky Way center at **~220 km/s**.

Proper Motion

- **Barnard's Star** has the highest known proper motion: shifts by 1 degree every 350 years.
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Kepler and Newton

Kepler's Laws

1. Planets move in **elliptical orbits**.
2. Equal areas swept out in equal times.
3. $T^2 \propto r^3$ (orbital period squared proportional to radius cubed).

Newton's Universal Law of Gravitation

- Gravity explains Kepler's laws.
 - Distant planets move slower in their orbits.
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Stellar Dynamics in the Galaxy

- The Sun takes hundreds of millions of years to orbit the Milky Way center.
 - All stars experience motion: **radial (toward/away)** and **tangential**.
 - These motions combine to give the star's **proper motion**.
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Observational Tools

- **Doppler Shift**: measures motion via frequency change.
 - **Parallax**: measures distance via geometric triangulation.
 - **Luminosity & Flux**: measures intrinsic and observed brightness.
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Final Concepts

- **Globular clusters**: tight, spherical groups of ~1 million stars orbiting the galaxy.
- These structures helped prove we are **not** the center of the galaxy.

In the next lecture, we explore how stars aggregate into galaxies and uncover the mysterious dark matter that governs large-scale cosmic structure.

Stay curious.