Galaxies and Gravity

Welcome back. We've already covered so much — from our home planet to the outer reaches of the solar system. But in the grand scale of things, our journey so far has barely scratched the surface. The entire solar system is just a drop in the cosmic ocean compared to what's out there.

What is a Galaxy?

A **galaxy** is a vast, gravitationally bound collection of stars, planets, gas, and dust. Our home galaxy, the **Milky Way**, contains over 100 billion stars. We're located about two-thirds of the way out in its disk.

- The word "galaxy" comes from the Greek *galaktos*, meaning "milk."
- The Milky Way appears as a luminous band in the night sky.
- Galaxies vary in size and structure, but most follow gravitational dynamics.

If we could take a cosmic selfie from a million light-years away, the Milky Way would appear as a beautiful spiral disk, with arms curling outward from a central bulge.

The Components of a Galaxy

- **Stars and planets**
- **Gas and dust**
- **Globular clusters** – spherical collections of stars
- **Dark matter** – mysterious, invisible matter
- **A central black hole** – in our case, *Sagittarius A**

The Role of Gravity

Gravity is the fundamental force that binds galaxies. Though the weakest of the four fundamental forces, gravity acts over vast distances:

- Keeps planets orbiting stars
- Keeps stars orbiting the galactic center
- Governs galaxy formation and structure

Newtonian Motion and Gravity

Sir Isaac Newton's three laws of motion and his *law of universal gravitation* help us understand the behavior of celestial bodies:

1. **Inertia** – Objects remain in motion unless acted upon
2. **F = ma** – Force equals mass times acceleration
3. **Action and Reaction** – Every force has an equal and opposite force

Newton also showed:

- Gravity follows an **inverse square law**: $F = G\frac{m_1 m_2}{r^2}$
- All objects fall at the same rate regardless of mass
- You can **calculate the mass** of a star or galaxy by measuring orbital velocities and radii

Einstein's Contribution

Einstein later refined our understanding of gravity by introducing the idea of **spacetime curvature** in *General Relativity*:

- Gravity is not a force, but a curvature of space and time
- This becomes crucial in extreme environments (e.g., near black holes)

Mapping the Milky Way

Early Views

- **Aristotle**: Believed the Milky Way was in Earth's atmosphere
- **William and Caroline Herschel**: Made the first map of the Milky Way in 1785
- Incorrectly placed the Sun at the center due to **dust obscuration**

Galactic Structure

- **Disk** – contains most stars and gas
- **Bulge** – dense central region
- **Halo** – sparse, spherical shell with **globular clusters**
- **Satellite galaxies** – orbiting dwarf galaxies (e.g., the Magellanic Clouds)

The 1920 Great Debate

A major turning point in astronomy occurred in 1920 between:

- **Harlow Shapley** – Argued the Milky Way was the entire universe
- **Heber Curtis** – Argued that spiral nebulae (like Andromeda) were other galaxies

This debate set the stage for a **new cosmological model**. Eventually, Edwin Hubble would show that Andromeda is far outside the Milky Way, confirming Curtis's view.

Standard Candles and Distance

To measure distances in space, astronomers use:

- **Radar** (for nearby planets)
- **Parallax** (for nearby stars)
- **Standard candles** (like Cepheid variables and supernovae)

These allow us to map the structure and size of the galaxy and identify the dynamics of orbiting stars and clusters.

Galactic Rotation and Dark Matter

When we measure the **orbital speed** of stars far from the galactic center, they move faster than expected. This led to the conclusion that:

- The **visible mass** (stars, planets, gas) is **not enough** to account for the motion
- There must be **dark matter**, an invisible component making up most of the galaxy's mass

Gravity as a Cosmic Scale

Using orbital velocity and radius, we can determine mass:

$$M = \frac{v^2 r}{G}$$

This is how we "weigh" galaxies and stars.

Final Thoughts

We've come to understand that:

- The Milky Way is one of **hundreds of billions of galaxies**
- Our Sun is just **one star** in this vast system
- **Gravity and dark matter** govern galactic dynamics
- **Globular clusters** orbit the galaxy and help us understand its structure

In the next lecture, we'll discuss how globular clusters helped astronomers measure distances and uncover the true size—and mystery—of our galaxy. The realization that the matter we're made of is only a **small fraction** of the universe changed everything.

Thank you.