Formation and evolution of the galaxy

4.3 The structure of the galaxy

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4.3.1 Galaxy formation scenario

- Atomic Galactic Cloud: A large gas cloud within the Milky Way Galaxy, composed primarily of neutral hydrogen atoms. It is part of the Milky Way's interstellar medium and is the raw material for star formation. It also contains small amounts of helium and other elements.
- Proper motion: The apparent movement of a star across the celestial sphere, measured in arc seconds per year.
- Orbital motion: The movement of a celestial body or object in an orbit around another body due to forces such as gravity. e.g., the Earth revolving around the Sun.

4.3.1 Galaxy formation scenario

- Orbital eccentricity: Orbital eccentricity is a numerical value that indicates the shape of an orbit and indicates how much the orbit deviates from a circle. Eccentricity (e) quantitatively indicates the elliptical state of the orbit. e=0 is a perfectly circular orbit
- UV Excess: The phenomenon in which celestial bodies such as stars and galaxies emit more ultraviolet (UV) radiation than would be expected. This is measured primarily in UV wavelengths (approximately 100-400 nm).
- Momentum: A physical quantity that expresses the momentum of an object in rotational or orbital motion, and depends on the object's mass, velocity, and distance from the axis of rotation or the center of the orbit.

4.3.1 Galaxy formation scenario

- Rotational motion: The motion of an object rotating around a fixed axis or point. e.g., the rotation of the Earth.
- Circular motion: A specific type of rotational or orbital motion in which an object moves in a circular path with a constant radius (r) around a fixed center point. When the magnitude of the velocity is constant, it is called uniform circular motion, but the velocity may also change.
- ELS theory: A hypothesis about the formation of the Milky Way. It is hypothesized that the Milky Way was formed by the rapid gravitational collapse of a giant atomic gas cloud. During the collapse, the gas cloud rotated and flattened, forming a disk and halo.

4.3.1 Galaxy formation scenario

- Horizontal branch stars: Horizontal branch stars are low-mass stars that have passed the red giant stage and are at the stage where the fusion of helium into elements heavier than hydrogen begins at their centers.
- Dwarf galaxies: Dwarf galaxies are galaxies that are much smaller than larger galaxies. They have a high proportion of dark matter and low metallicity.
- SZ hypothesis: A hypothesis about the formation process of the Milky Way. It opposes the ELS hypothesis. It posits that the Milky Way was formed by repeated gravitational convergence and mergers of small gas clouds and star clusters that existed in the early universe, and that halos and globular clusters have different origins and dynamics.

4.3.3 Traces of dwarf galaxy accretion

- Sagittarius Dwarf Galaxy: A satellite galaxy of the Milky Way, it is a type of dwarf galaxy located in the Galactic halo and is currently being destroyed. It is located approximately 20 kiloparsecs from the Galactic Center.
- Galactic tidal forces: Non-uniform forces on objects in the galaxy due to different strengths of gravity on different parts of the object.
- Gravitational interaction: A physical phenomenon in which objects with mass are attracted to each other by the force of gravity, and is important for the movement and evolution of galaxies, stars, gas clouds, etc.

4.3.3 Traces of dwarf galaxy accretion

- Disk cluster: A star cluster located within the disk of the Milky Way, primarily an open cluster. It is a collection of relatively young stars.
- Halo clusters: These are star clusters that exist in the halo of the Milky Way and have different characteristics from disk clusters and bulge clusters. They are made up of very old stars and have strong gravitational interactions.
- Bulge clusters: These are star clusters that exist in the bulge of the Milky Way. They are mainly globular clusters and have different characteristics from disk clusters and halo clusters. They are collections of very old stars.

4.3.4 A new scenario for the formation of the Milky Way

- Energy dissipation of interstellar gas: The phenomenon in which the kinetic energy, thermal energy, etc. of interstellar gas in the Galaxy is lost through various physical processes.
- CDM cosmology: The current standard cosmological model that explains the formation and evolution of structure in the universe, and in particular assumes that dark matter behaves as cold dark matter. This model has been successful in explaining the formation of large-scale structure in the universe and observational data on the cosmic microwave background radiation.

4.3.4 A new scenario for the formation of the Milky Way

- Redshift: The phenomenon in which the wavelength of light reaching Earth from distant celestial bodies becomes longer (shifted toward the red side) due to the expansion of the universe and its relative motion. This is an important observational indicator for understanding the structure and evolution of the universe.
- Metal-poor stars: Stars whose chemical composition contains significantly less heavy elements than the Sun. These stars are often old stars that were born in the early stages of the formation of the galaxy or the universe.

4.3.1 Galaxy formation scenario

The later the star, the more it orbits the center. The gas continues to contract, and its speed increases. Stars that are closer to the center have a higher metallicity.

As the galaxy grows, gravity becomes stronger, there are satellite galaxies orbiting, and the stellar stream cannot be maintained.

ELS theory	**SZ theory**
Stars in the halo all have large orbital eccentricities	Halo formation occurs over billions of years, resulting in variations in the age of galaxies.
The more metallic stars born in later generations, the more circular their orbits become.	If star clusters are formed by frequent infall of dwarf galaxies from the outer galaxy, the metallicity of the clusters will be spatially uniform.
Metal-poor stars have no near-circular orbits	The halo formed slowly through the chaotic merging of many dwarf galaxies.

4.3.2 Galaxy formation scenario

- Current observational technology and stellar data suggest that the ELS hypothesis proposed in 1962 is partly correct. It cannot be said that the ELS was formed through continuous free-fall contraction from the halo to the disk.
- Because…
- Halo stars have orbits with a wide range of eccentricities, from low to high, and no significant correlation was found between orbital eccentricity and metallicity.
- Gas is not infinite. It can be supplied from a nearby filament.

Discussion of this chapter

- When the ELS theory and SZ theory were proposed in the 1960s, observational technology was less advanced than it is today, and there was probably little understanding of the concept of cold dark matter.
- Rather, the main cause is incomplete data samples!
- The ELS theory states that "all stars in the halo have large orbital eccentricities," and the SZ theory states that "the metallicity of star clusters is spatially uniform." These are laws (patterns) discovered using the observational technology of the time, but modern observational technology produces samples that fall outside the patterns in terms of orbital motion, rotation, and classification.
- Is density fluctuation also the cause of the non-uniformity?
- Density fluctuations only have an effect in the early universe, so they don't have much of an effect here.

- At the time, observational technology was insufficient, and only nearby bright stars could be seen, leading to inconsistencies in the theory. In particular, it cannot be said that cold dark matter is the cause.
- The results may change when fainter stars that have not been observed before, or outer stars with low metallicity far from the center, become visible.
- Therefore, rather than being caused by cold dark matter, it can be said that the cause is a bias in the observation sample.