Lecture 11: ISM, IMF and Galaxy Evolution Notes

Course: Introduction to Astronomy and Astrophysics I

August-September 2024

1 Interstellar Medium (ISM) Physics

1.1 Ionization in the ISM

The ionization state of gas in the ISM is determined by several processes:

- Photoionization by UV radiation from stars

- Cosmic ray ionization

- Collisional ionization in hot gas

The Saha equation describes ionization equilibrium in Local Thermodynamic Equilibrium (LTE):

$$\frac{n_{i+1}n_e}{n_i} = \frac{2g_{i+1}}{g_i}\left(\frac{2\pi m_e kT}{h^2}\right)^{3/2}e^{-\chi_i/kT}$$

Key implications of the Saha equation:

- Ionization increases with temperature

- Ionization decreases with increasing electron density

- Different elements ionize at different temperatures

1.2 Equilibrium Conditions

Three main types of equilibrium in the ISM:

- Thermal Equilibrium: $\Gamma_{\text{heating}} = \Lambda_{\text{cooling}}$

- Pressure Equilibrium: Total pressure remains constant

- Ionization Equilibrium: Ionization rate equals recombination rate

2   Initial Mass Function (IMF)

The IMF describes the mass distribution of newly formed stars: $\xi(M) = c\,M^{-(1+x)}$
Common IMF formulations:

- Salpeter IMF: Single power law with x = 1.35

- Scalo IMF: Multiple power law segments

- Miller-Scalo IMF: Four-segment power law

3   Galaxy Morphology and Evolution

3.1   Barred Galaxies

Key characteristics:

- About 50% of disk galaxies (including Milky Way) have central bars

- Bars can contain up to 1/3 of total galaxy light

- Bars rotate with pattern speed but are not density waves

- Gas loses angular momentum through bar-induced shocks

3.2   Galaxy Mergers

Types of mergers:

- Major mergers: Similar mass galaxies

- Minor mergers: Mass ratio > 3:1

- Wet mergers: Gas-rich galaxies

- Dry mergers: Gas-poor galaxies

3.3   Dynamical Friction

Important process in galaxy evolution that causes massive objects to sink toward the center of galaxy clusters. Explains:

- Most massive galaxies located near cluster centers

- Merging of supermassive black holes during galaxy mergers

- Evolution of satellite galaxies like Magellanic Clouds

4 Large Scale Structure Surveys

Historical progression of galaxy surveys:
   Imaging Surveys:

- 1970: Lick Survey (1M galaxies)

- 1990: APM (2M)

- 1995: DPOSS (50M)

- 2005: SDSS (200M)

- Post-2023: LSST (2000M expected)

Redshift Surveys:

- 1985: CfA (2,500 galaxies)

- 1995: CfA2 (20,000)

- 1996: LCRS (23,000)

- 2003: 2dF (250,000)

- 2005: SDSS (800,000)

- 2017: SDSS DR14 (2.5M)

5 Further Reading

- Binney & Merrifield (1998) "Galactic Astronomy" - Detailed discussion of Malmquist bias (pp. 111-115)

- Salpeter (1955) ApJ, 121, 161 - Original IMF paper

- Miller & Scalo (1979) ApJS, 41, 513 - Alternative IMF formulation

- For galaxy mergers: Toomre & Toomre (1972) ApJ, 178, 623

- For large scale structure: Peebles (1980) "The Large-Scale Structure of the Universe"

Useful online resources:

- SDSS website: `http://www.sdss.org`

- Galaxy Zoo project: `http://www.galaxyzoo.org`