Lecture 14: Galaxy Scaling Relations, Dark Matter, and AGN

Course: Introduction to Astronomy and Astrophysics I

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1 Galaxy Scaling Relations

1.1 Overview

Important correlations exist between global galaxy parameters:

- Luminosity
- Size
- Surface Brightness
- Rotation Velocity

These scaling relations are important because they:

- Reveal internal properties of galaxies
- Must arise naturally in galaxy formation theories
- Provide constraints on galaxy evolution models

1.2 Tully-Fisher Relation

For disk galaxies:

- Relates luminosity to rotation velocity: $L \propto V_{\rm max}^{\alpha}$
- $\alpha \approx 3 - 4$
- Scatter decreases at longer wavelengths
- Important distance indicator
- Links dark halo properties (Vmax) with integrated star formation (luminosity)

1.3 Faber-Jackson Relation

For elliptical galaxies:

- Relates luminosity to velocity dispersion
- Similar to Tully-Fisher but for pressure-supported systems
- Shows more scatter than Tully-Fisher

1.4 Kormendy Relation

Relates effective radius to surface brightness:

- $R \propto I^{-0.8}$
- Suggests formation through combination of:
  - Dissipationless merging ($R \propto I^{-1}$)
  - Dissipative collapse ($R \propto I^{-0.5}$)

2 Dark Matter

2.1 Universal Dark Matter Profile

NFW (Navarro, Frenk & White) profile:

$$\rho(r) = \frac{\rho_0}{(r/r_s)(1 + r/r_s)^2}$$

where:

- ρ_0 = characteristic density
- r_s = scale radius

2.2 Types of Dark Matter

2.2.1 Hot Dark Matter (HDM)

- Relativistic particles (e.g., low-mass neutrinos)
- Erases small-scale density fluctuations
- Top-down structure formation

2.2.2 Cold Dark Matter (CDM)

- Non-relativistic particles
- Preserves small-scale fluctuations
- Bottom-up structure formation
- Better match to observations

2.3 Dark Matter Candidates

- Massive neutrinos (known to exist)
- WIMPs (Weakly Interacting Massive Particles)
- Axions (from quantum chromodynamics)

3 Active Galactic Nuclei (AGN)

3.1 Key Characteristics

- Powered by accretion onto supermassive black holes
- Emission from hot accretion disk and sometimes relativistic jets
- About 10% of massive galaxies are AGN
- Strong blue continuum and emission lines in optical spectra

3.2 AGN Types

- Seyfert 1 galaxies
- Seyfert 2 galaxies
- Quasars/QSOs
- Blazars and BL Lacs
- Radio galaxies
- Type 2 QSOs

3.3 AGN Unification Model

Different AGN types explained by:

- Viewing angle differences
- Presence/absence of obscuring torus
- Jet power and orientation

4 Further Reading

Key references:

- Tully & Fisher (1977) A&A, 54, 661 - Original TF relation
- Faber & Jackson (1976) ApJ, 204, 668 - FJ relation
- Kormendy (1977) ApJ, 218, 333 - Kormendy relation
- Navarro, Frenk & White (1997) ApJ, 490, 493 - NFW profile
- Urry & Padovani (1995) PASP, 107, 803 - AGN unification

Additional resources:

- SDSS AGN catalog: `http://www.sdss.org/dr16/spectro/catalogs/#qso`
- NASA AGN fact sheet: `https://imagine.gsfc.nasa.gov/science/objects/active_galaxies1.html`
- Dark matter review: `https://pdg.lbl.gov/2023/reviews/rpp2022-rev-dark-matter.pdf`