Lecture 9 Notes: Black Holes and ISM

Notes based on lectures by Yogesh Wadadekar

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1 Black Holes

1.1 Fundamental Concepts

Black holes are regions of spacetime where gravity is so strong that nothing, not even light, can escape. They are key predictions of Einstein's General Theory of Relativity. The main properties of black holes include:

- An event horizon - the boundary beyond which nothing can escape
- A singularity (theoretical) at the center
- Detection through:
  - Effects on surrounding matter
  - Gravitational waves
  - Gravitational lensing

1.2 Types of Black Holes

Based on mass, black holes are classified as:

- Stellar-mass black holes ($5 - 50 M_\odot$)
  - Formed from collapse of massive stars ($> 20 - 25 M_\odot$)
- Supermassive black holes ($10^6 - 10^{10} M_\odot$)
  - Found at galactic centers
  - Formation mechanism still debated
- Intermediate-mass black holes ($10^2 - 10^5 M_\odot$)
  - Evidence still emerging

1.3 Key Properties

The Schwarzschild radius (event horizon for non-rotating black hole) is given by:

$$R_s = \frac{2GM}{c^2}$$

According to the No-hair theorem, black holes are characterized by only three parameters:

- Mass (M)
- Angular momentum (J)
- Electric charge (Q) (usually negligible in astrophysical contexts)

1.4 Black Hole Observations

Major observational evidence comes from:

- X-ray binaries showing accretion processes
- Gravitational wave events (like GW150914)
- Event Horizon Telescope imaging (M87* black hole)
- Effects on surrounding stars and gas

2 The Interstellar Medium (ISM)

2.1 Components

The ISM consists of:

- Gas (ionized, atomic, and molecular)
- Dust (¡ 1 micron sized particles)
- Cosmic rays
- Magnetic fields
- Dark matter

2.2 Mass Distribution

- About 10% of total galactic mass is in baryons
- Of the baryonic matter, about 10% is in the ISM
- The ISM occupies ¿99.9999% of the Universe's volume

2.3 Energy Content

The ISM contains various forms of energy:

- Thermal energy: $u = (3/2)nkT$
- Bulk kinetic energy: $(1/2)\rho v^2$
- Cosmic ray energy
- Magnetic energy: $B^2/8\pi$
- Electromagnetic energy

3 Further Reading

- Shapiro, S. L., & Teukolsky, S. A. "Black Holes, White Dwarfs and Neutron Stars: The Physics of Compact Objects" (Wiley)
- Rees, M. J. "Black Holes in the Universe" Scientific American (1998)
- Event Horizon Telescope papers in ApJ Letters (2019)
- Draine, B. T. "Physics of the Interstellar and Intergalactic Medium" (Princeton)
- Spitzer, L. "Physical Processes in the Interstellar Medium" (Wiley)

4 Advanced Topics for Further Study

- Kerr metric and frame dragging effects
- Penrose process for energy extraction
- Information paradox and Hawking radiation
- Role of ISM in galaxy evolution
- Molecular cloud collapse and star formation
- Cosmic ray acceleration mechanisms