Lecture 7 Notes: Variable Stars and Compact Objects

Summary Notes

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1 Classical Cepheid Variables

1.1 Basic Characteristics

- F and G type pulsating giants and supergiants
- Variation up to approximately one magnitude
- Periods: Few days to over 100 days
- Important standard candles for distance measurement

1.2 The Instability Strip

- Specific region in HR diagram where stars become unstable
- Pulsation mechanism:
  - He III (doubly ionized helium) drives pulsations
  - Temperature-dependent opacity changes
  - Cyclical process of expansion and contraction

1.3 Types of Cepheids

Classical Cepheids	Type II Cepheids
Population I stars	Population II stars
4-20 $M_\odot$	$\sim M_\odot$
More luminous (up to $10^5 L_\odot$)	Less luminous
Prototype: δ Cep	Types: BL Her, W Vir, RV Tau

2 Period-Luminosity Relationship

2.1 Historical Impact

- Key to cosmic distance measurements
- Hubble's initial error due to confusion between Classical and Type II Cepheids
- Led to factor of 10 error in distance measurements

2.2 Modern Applications

- Gaia DR3: Over 15,000 Cepheids identified
- HST uses Cepheids to measure distances up to 100 Mpc
- Critical rung in cosmic distance ladder

3 Other Variable Stars

3.1 General Properties

- Period-density relationship: $P\rho^{1/2} = constant$
- Various types occupy different regions of HR diagram
- Different pulsation mechanisms and timescales

3.2 Wolf-Rayet Stars

- Very massive stars
- Strong stellar winds ($\sim 10^{-5} M_\odot$ yr^{-1})
- Significant mass loss affects stellar evolution

4 Gravitational Potential Energy

4.1 Solar Energy Source

- Gravitational potential energy of Sun: $\sim 10^{41}$ Joules
- Kelvin-Helmholtz timescale: $\sim 10^7$ years
- Historical significance: Showed nuclear fusion needed as energy source

5 Introduction to Compact Objects

5.1 Definition and Types

- Extremely dense stellar remnants
- Three main types:
  - White Dwarfs
  - Neutron Stars
  - Black Holes
- Fourth possibility: Quark stars (theoretical)

5.2 Post-Main Sequence Evolution

- Low/Intermediate-mass stars ($M < 8M_\odot$):
  - Red Giant phase
  - Helium flash (for $M < 2M_\odot$)
  - AGB phase
  - End as White Dwarfs
- High-mass stars ($M > 8M_\odot$):
  - Red Supergiant phase
  - Heavy element fusion
  - Supernova explosion
  - End as Neutron Stars or Black Holes

6 White Dwarfs

6.1 Formation and Structure

- End state for low/intermediate-mass stars
- Formation process:
  1. Red Giant phase
  2. Planetary Nebula ejection
  3. Hot, dense core remains
- Supported by electron degeneracy pressure
- No active fusion reactions

6.2 Physical Properties

- Typical mass: 0.6 $M_\odot$
- Radius: Similar to Earth
- Composition varies: C/O, He, ONeMg
- Density: $\sim 10^6$ g/cm^3
- Maximum mass: Chandrasekhar limit (1.44 $M_\odot$)

7 Key Equations and Relationships

- Light echo geometry: Paraboloid surface
- Period-density relationship for pulsating stars
- Mass-radius relationship for white dwarfs: $R \propto M^{-1/3}$
- Gravitational potential energy of a sphere: $(3/5)GM^2/R$