Introduction to Astronomy and Astrophysics I
Lecture 7

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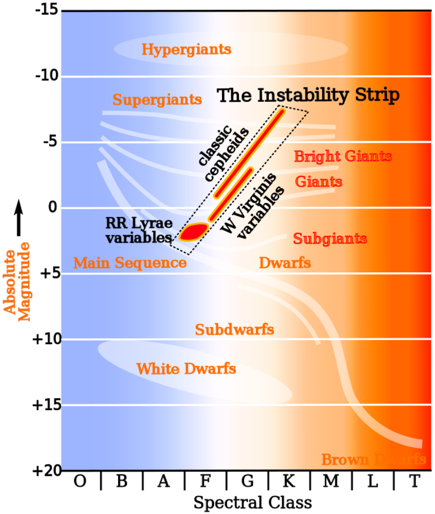
Aug-Sep 2024

Classical cepheids

The classical Cepheids are highly luminous F and G type pulsating giants and supergiants that vary periodically up to roughly a magnitude. Periods range from a few days to over 100 days.

The instability strip



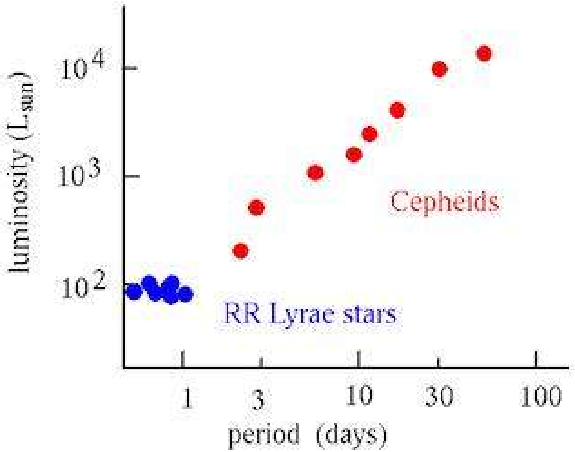
Why do pulsations occur?

Stars in the *instability strip* pulsate due to He III (doubly ionized helium). In normal A-F-G stars He is neutral in the stellar photosphere. Deeper below the photosphere, at about 25,000–30,000K, begins the He II layer (first He ionization). Second ionization (He III) starts at about 35,000–50,000K.

When the star contracts, the density and temperature of the He II layer increases. He II starts to transform into He III (second ionization). This causes the opacity of the star to increase and the energy flux from the interior of the star is effectively absorbed. The temperature of the star rises and it begins to expand. After expansion, He III begins to recombine into He II and the opacity of the star drops. This lowers the surface temperature of the star. The outer layers contract and the cycle starts anew.

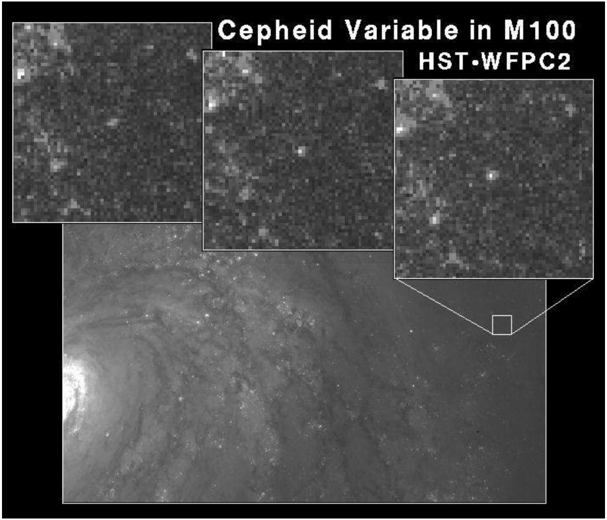
Both temperature and luminosity of the star changes.

Cepheid variables



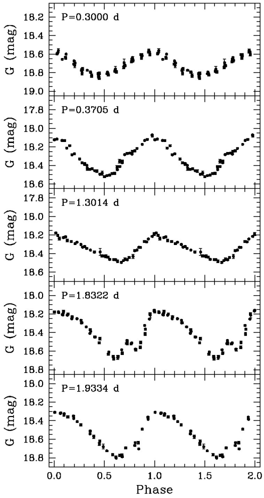
Before Gaia 800 Cepheids were known in our galaxy. Gaia DR3 has 15,000 Cepheids and the number will increase in future Gaia DRs.

Measure the Universe with Cepheid variables



The Hubble Space Telescope has identified classical Cepheids in NGC 4603, which is 100 million light years distant.

Cepheid light curves



Two types of Cepheids

Classical	Type II
Prototype: δ Cep	BL Her, W Vir, RV Tau
Pop I	Pop II
4-20 $M_\odot$	$\sim M_\odot$
More luminous upto $10^5 L_\odot$	much less luminous

Because of this, Hubble measured his constant incorrectly by a factor of 10.

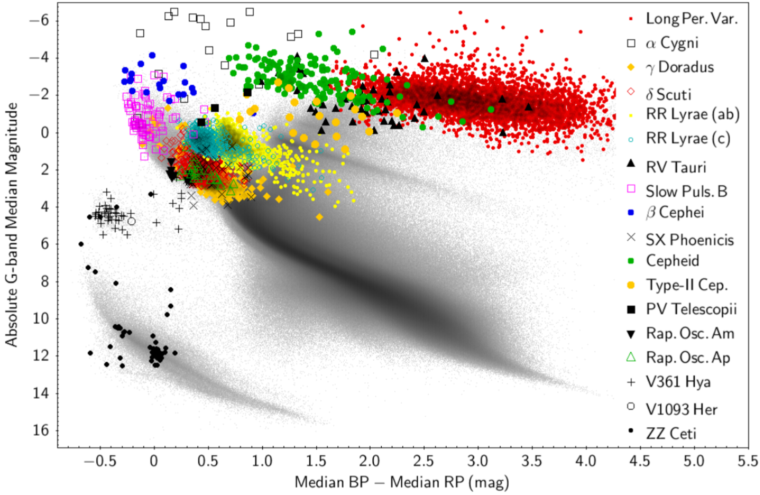
Mid term exam

proposed for 10-11 am on Wed. 4 September. 25% weightage. Short answer questions based on the first 6 lectures. Closed notes, closed book. **Please bring a scientific calculator**

For pulsating variables of most kinds

$P\rho^{1/2} =$constant
Equation of State

Pulsating variables HRD



Wolf-Rayet stars

Very massive. Drive a very strong stellar wind as much as $10^{-5} M_\odot$ yr^{-1}. Must be taken into account in stellar evolution.

Gravitational potential energy of a sphere:

$(3/5)GM^2/R \sim 10^{41}$ Joules for the Sun

How long will the sun radiate if if uses it's gravitational potential energy as its source of energy and keeps contracting and shining at it's current luminosity throughout?

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10^7 years

The Kelvin-Helmholtz timescale.

When the biologists were right and the physicist (Kelvin!) was wrong!

Light echo - V838 Monocerotis - Irregular Variable

Show video What is the locus of the surface traced by the light echo?
Hint: it is not a sphere

Compact Objects in Astronomy

- Definition: Extremely dense stellar remnants
- Three main types:
  - White Dwarfs
  - Neutron Stars
  - Black Holes
- There is a fourth possibility. What is it?
- Represent the final stages of stellar evolution
- Key to understanding fundamental physics and cosmology

Why are neutron stars not present on the HR diagram?

Post-Main Sequence Evolution

- Low/Intermediate-mass stars ($M < 8M_\odot$):
  - Red Giant phase
  - Helium flash (for $M < 2M_\odot$)
  - Asymptotic Giant Branch (AGB)
  - Planetary Nebula formation
- High-mass stars ($M > 8M_\odot$):
  - Red Supergiant phase
  - Fusion of heavier elements up to iron
  - Type II Supernova explosion

Stellar Death and Compact Remnants

- Final state depends on initial stellar mass:
  - $M < 8M_{\odot}$: White Dwarf
  - $8M_{\odot} < M < 20M_{\odot}$: Neutron Star
  - $M > 20M_{\odot}$: Black Hole
- Ejection of outer layers enriches interstellar medium

White Dwarfs: Formation and Structure

- End state for low/intermediate-mass stars
- Formation process:
  1. Red Giant phase
  2. Ejection of outer layers (Planetary Nebula)
  3. Exposed hot, dense core becomes a White Dwarf
- Supported by electron degeneracy pressure
- No active fusion reactions
- Composition varies: C/O (most common), He, ONeMg

White Dwarf Structure

- Typical mass: 0.6 $M_\odot$
- Typical radius: $\sim$ Earth's radius
- Layers:
  - Core: C/O or ONeMg
  - He layer
  - Thin H atmosphere (if present)
- Extremely high density:
  $\rho \sim 10^6$ g/cm^3

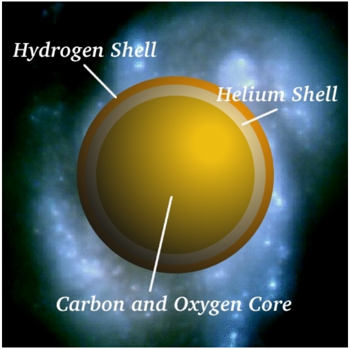

Image: Schematic of CO White Dwarf internal structure

White Dwarf Properties

- Mass-Radius Relationship:
  - $R \propto M^{-1/3}$
  - More massive = smaller radius
- Chandrasekhar Limit:
  - Maximum mass for a stable White Dwarf
  - $M_{Ch} \approx 1.44 M_{\odot}$
- Cooling over time: $L \propto t^{-7/5}$

White Dwarfs: Observations and Detection

- Spectral classification:
  - DA: H atmosphere
  - DB: He atmosphere
  - DC: Continuous spectrum (cool WDs)
  - Some Other types: DO, DZ, DQ
- Detection methods:
  - Proper motion surveys
  - UV excess in galaxies
  - Companion to main sequence stars e.g. Sirius B