Evolutionary Status of Epsilon Aurigae

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September 3, 2010

Outline

Why we care about evolutionary state

- Where the star was, what it did there
- Where the star will be going, what it will do
- Testing Nuclear Theory
- The Astrophysical Laboratory
- We are made of stardust

HR Diagram

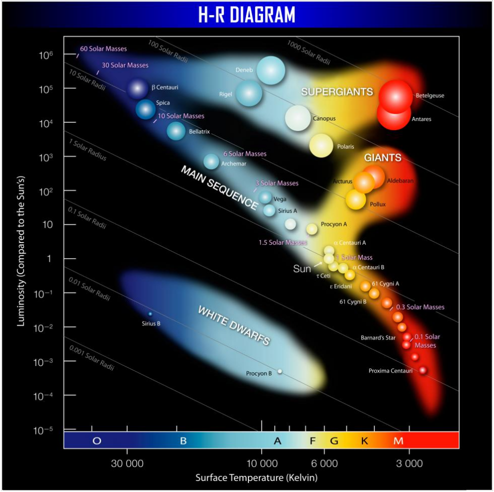
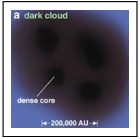


Image Courtesy of the Museum of Flight

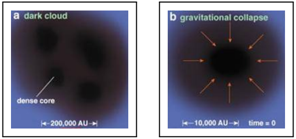
Single Star Formation



Images Courtesy of SSC IR Compendium

1. Cloud of gas and dust

Single Star Formation



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2. Gravitational collapse

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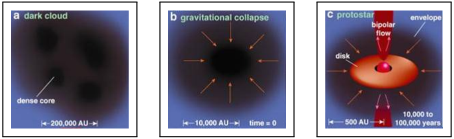

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3. Conservation of angular momentum and collisions cause disk to form.

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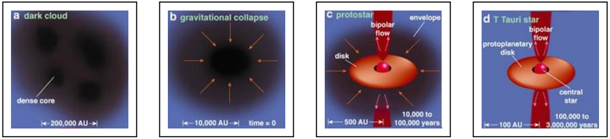

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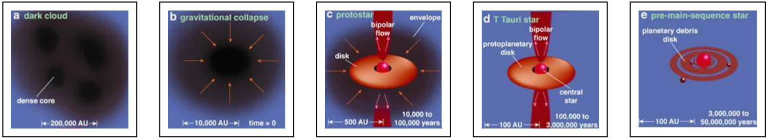

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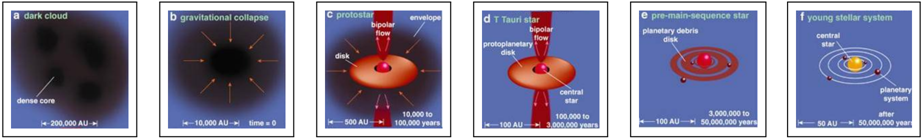

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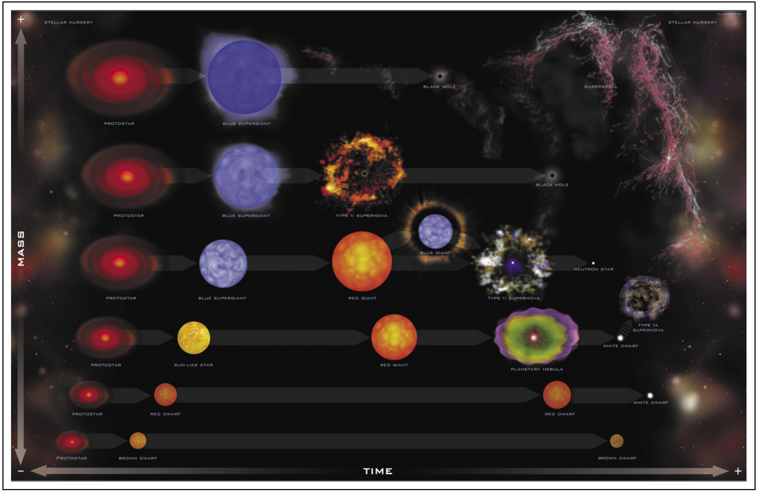
6. Star ignites hydrogen in its core.

Mass Dictates Evolution*



Images Courtesy of CHANDRA EPO

* Composition changes evolution too, but it's a far second compared to mass.

Substellar objects

Brown Dwarf Gliese 229B

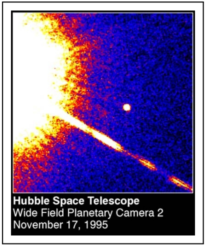
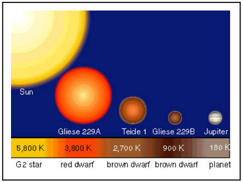


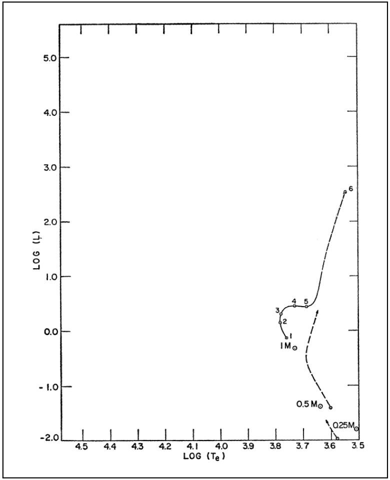
Image Courtesy of HST Gallery, PRC95-45 STSCI OPO



American Scientist/Linda Huff

- No Hydrogen Fusion
- Powered by gravitational collapse, Deuterium (^2H or ^2D) burning
- Masses below 0.085 $M_\odot$ (75 $M_{♃}$)
- $T_{eff} \approx 900\ K$
- Sometimes Show Stellar-like activity

Low-mass Stellar Evolution



Evolutionary Tracks, adapted from Iben (1967)

- M $< 0.3\ M_\odot$ remains on MS for more than τ_{Hubble}

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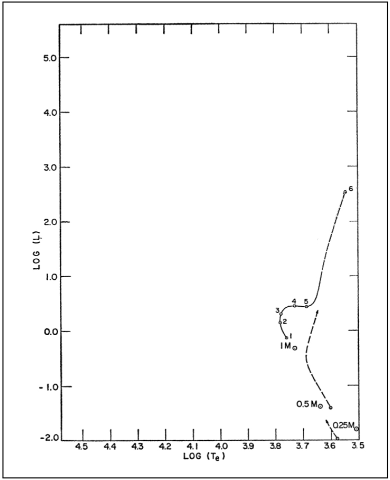

Evolutionary Tracks, adapted from Iben (1967)

- M $< 0.3\ M_\odot$ remains on MS for more than τ_{Hubble}
- M $> 0.3\ M_\odot$ H in core exhausted, climbs up RGB
- H burning in shell, star swells. He ash falls on core
- He core becomes degenerate
- M $< 0.4\ M_\odot$ core degeneracy never lifted, becomes He white dwarf

Intermediate Mass Stars

- $0.4 < \mathrm{M} < 6\text{-}10\ M_\odot$ Degeneracy is lifted (He flash)

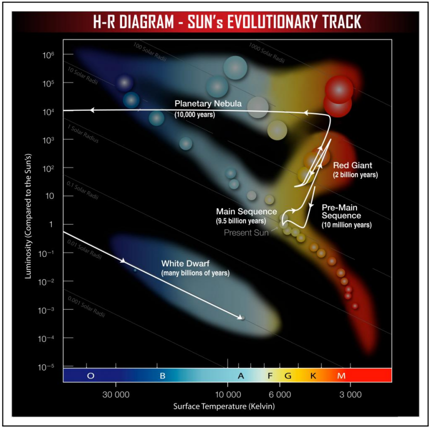

Image Courtesy of the Museum of Flight

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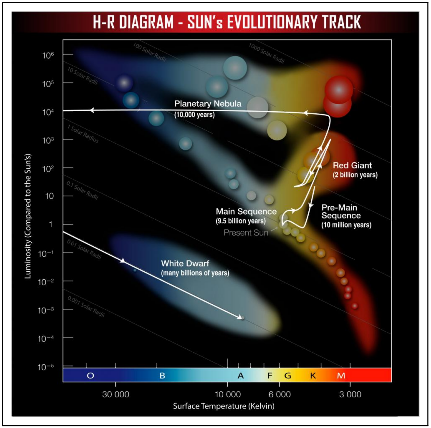

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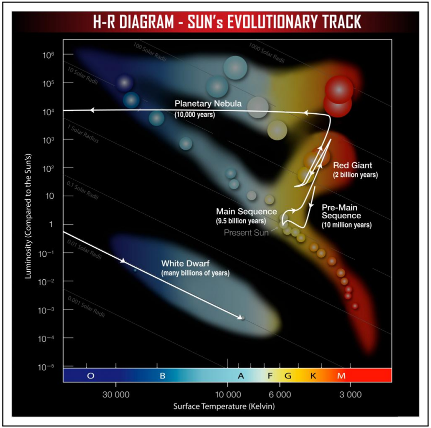

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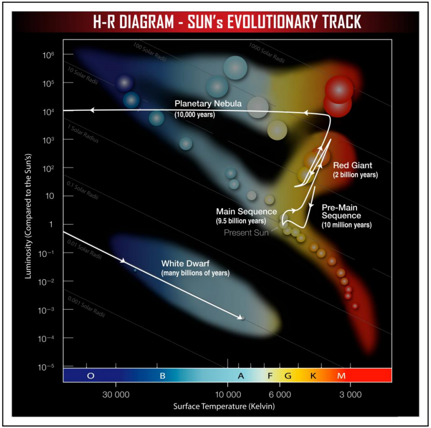

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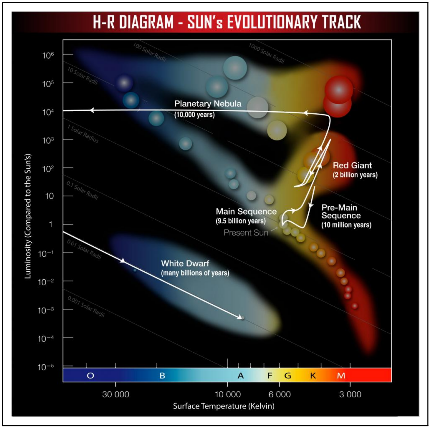

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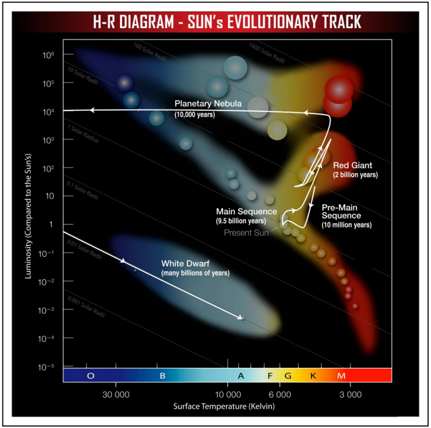

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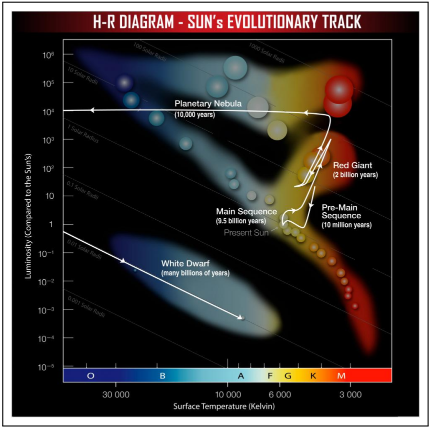

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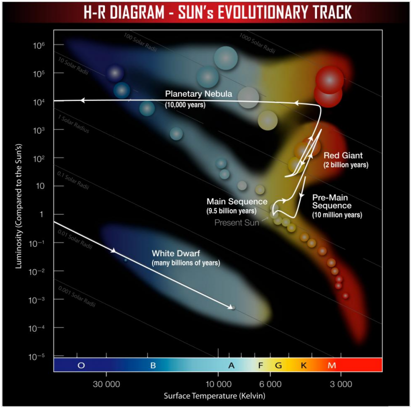
- Evolves into planetary nebulae whose core becomes a WD



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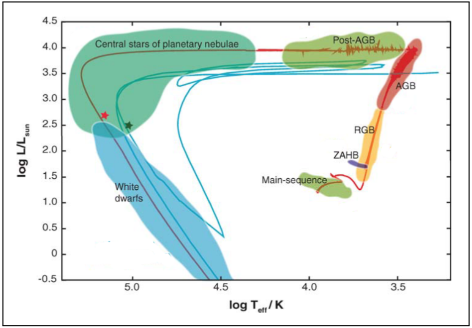
Intermediate-Mass Phase: Post-AGB

- Low to intermediate initial mass (1 - 8 $M_\odot$) transitioning between AGB and PN
- Not very well understood
- Fairly short lived ($10^2 - 10^3$ yr)
- Often shrouded in dust with silicate or carbonate features in the IR
- Look like Supergiant in many respects
- Detailed Spectral Analysis needed, will reveal s-process elements
- Several Unstable Pulsation Modes
- Good AAVSO Observing opportunity



Evolution of a $2M_\odot$ star (Herwig, 2005)

Massive Stars

- M $> 10\ M_{\odot}$

Massive Stars

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- Burn Nuclear Fuel Quickly
- HR Diagram Becomes Mostly Useless
  Envelope cannot respond fast enough.

Dominant fuel	T_c	Duration	Important products
Carbon	5×10^8 K	10^3–10^4 yr	Ne, Na
Neon	8×10^8 K	10^2–10^3 yr	Mg, some O
Oxygen	1×10^9 K	< 1 yr	Si, some S, etc.
Silicon	3×10^9 K	days	^{56}Ni

Stellar Timescales (Hansen, 2004)

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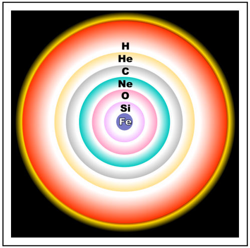
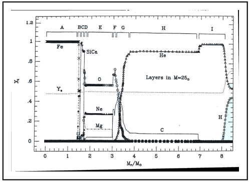


Layering in Highly Evolved Stars (Wikimedia Commons)



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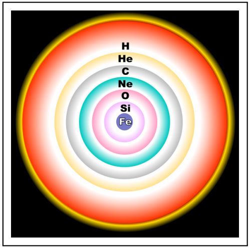

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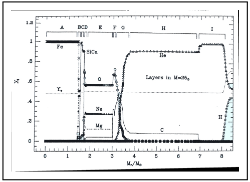

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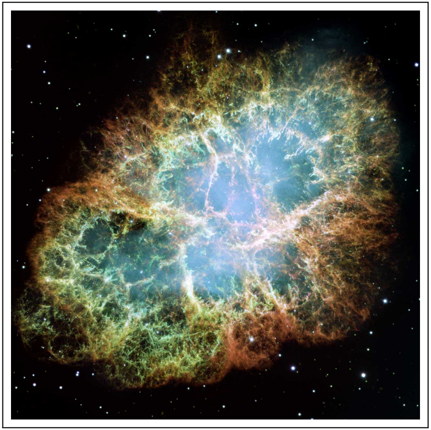

Image Credit: Hester (2005) via. HST

Binary Star Evolution

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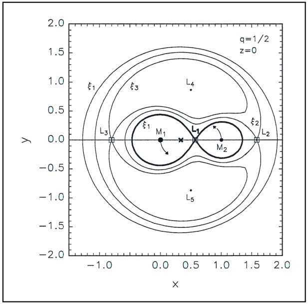

Roche Lobes (Hansen, 2004)

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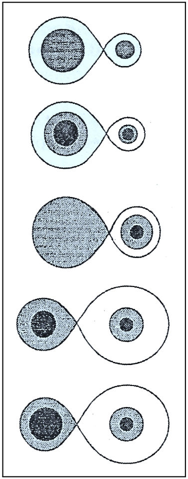
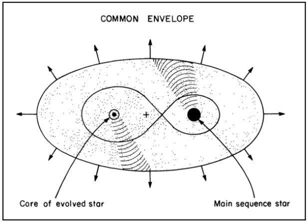


Roche Lobe Overflow
(Hansen, 2004)

- Roche Lobes
- Roche Lobe overflow, mass transfer

Binary Star Evolution



Common Envelope (Iben, 1991)

- Roche Lobes
- Roche Lobe overflow, mass transfer
- Common Envelope Phase

Other Stellar Evolution Concerns

Single Stars:

- Stellar Composition
- Rotation
- Mixing/Convection

Binary Stars:

- Non-spherical cores
- Tidal Interactions (including Tidal Heating)

ϵ Aur on the HR diagram

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ϵ Aurigae F-star Stats:

- Temperature: 7750 K
- Radius: 135 $R_\odot$
- Luminosity: $> 10^4$

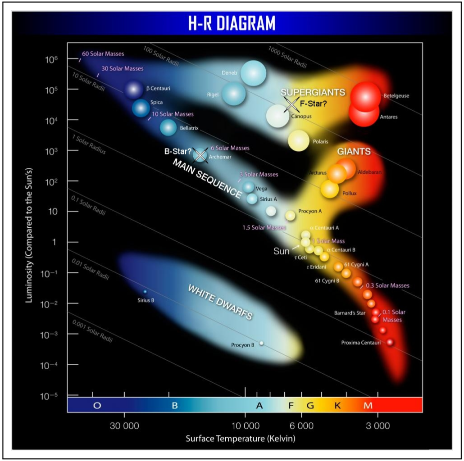

Image Courtesy of the Museum of Flight

The Evolutionary Status of eps Aur

Summarizing Webbink's 1985 Review of the Evolutionary State:

- High-Mass: Massive star in the post-main sequence star burning Helium in a shell
- Low-Mass: Star is contracting towards white dwarf (post-AGB)

F-star Stats

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Appears to support the low-mass, post-AGB model

Problems with this interpretation

Problems:

- post-AGB stars often have:
  - Circumbinary disks
  - Period/temperature changes (your observations help here)
  - Molecular and/or crystalline emission lines
- Spectral analysis shows oddities, could be non-LTE?

Remaining Work

- Need a modern spectroscopic analysis
- Look for changing Period and Temperature in/from historical and CS observational data

Acknowledgements

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- William Hershel Womble Estate