The Upper Main Sequence

O stars
OBN and OBC stars
Wolf-Rayet stars

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Oh! O-stars

Zeta-Puppis

- Massive, bright, hot, bluest, shortest lifetime (3-6 Myr)
- Rarest main sequence stars (1 in 32,000)
- 30,000-60,000K
- 20-100 Msun
- ~15 Rsun

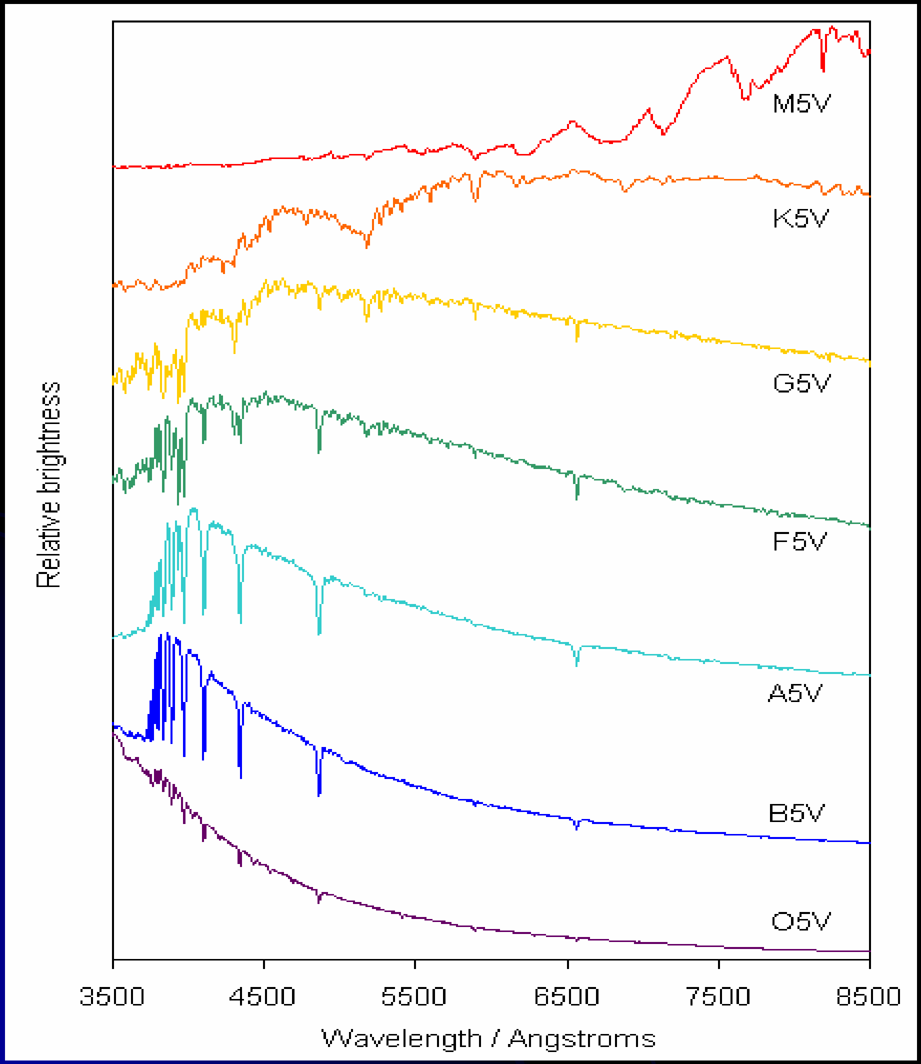
Other O characteristics

- O dwarfs don't have much mass loss, but O supergiants lose mass at a rate of

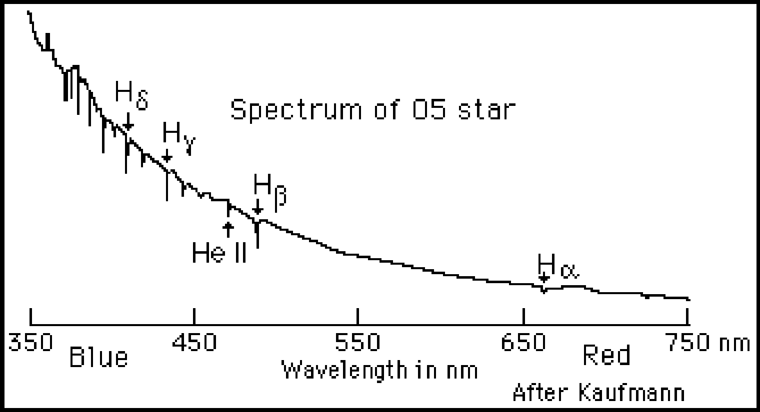
  M' α L^(1.7)

  Up to 10^-5 Msun per year!
- Ionize surrounding interstellar medium leading to emission nebulae (they define MW spiral arms)
- Can rotate very fast

O spectral lines



- Weak hydrogen lines, weak atomic helium
- Strong He II lines (only main sequence hot enough for the 24eV to ionize)
- Also, lines of Si IV, O III, N III and CIII

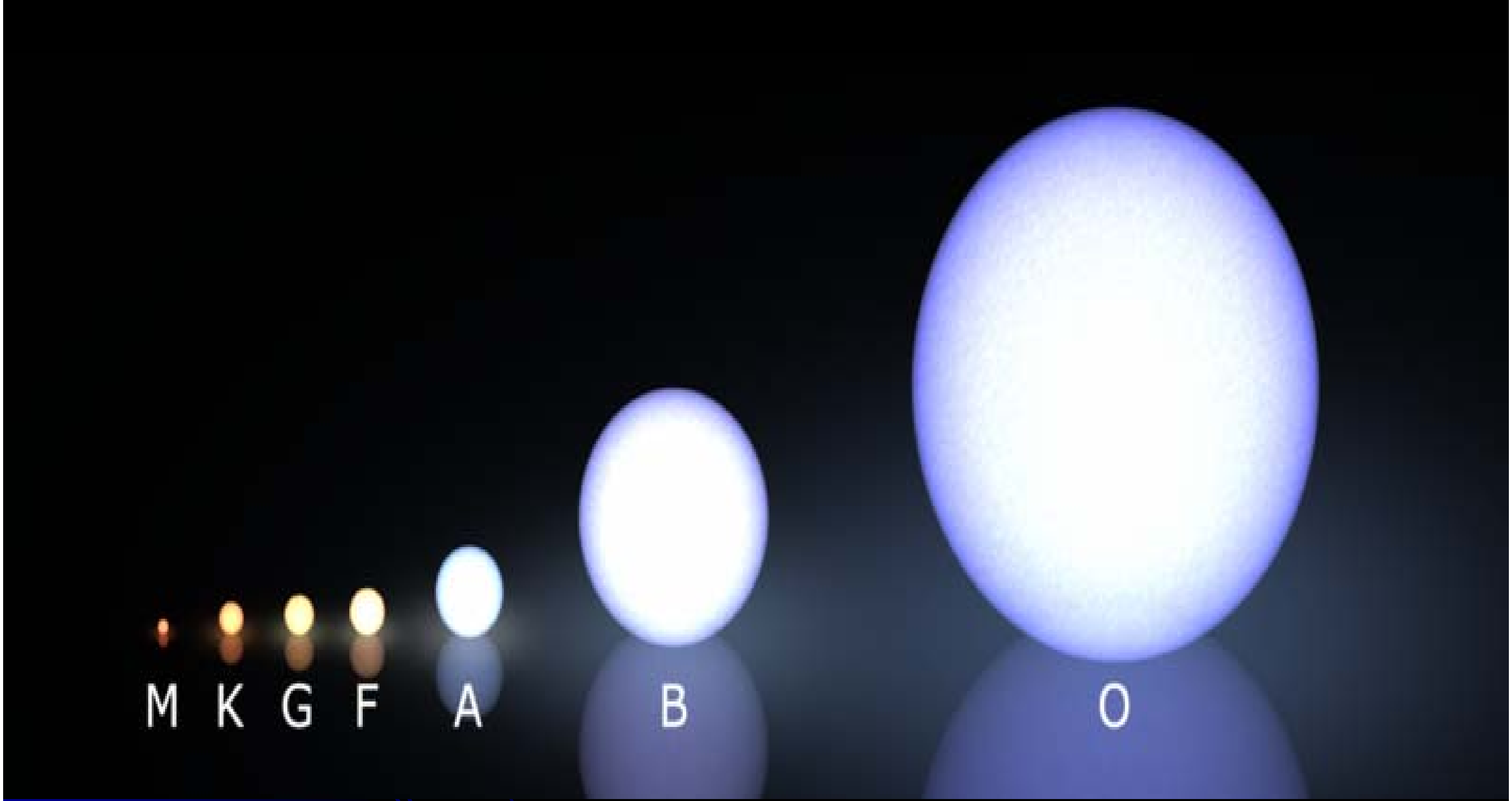


O subclasses

Oe	prominent H lines
Oef	early type o-stars with double lines in He II
Of	peculiar O stars with N III and He II lines, variable spectra, are extreme Population I stars

- Anything earlier than 05 are Of

Oh! Be…



OB stars

Some OB stars have Carbon and Nitrogen anomalies (too much!)→ OBC & OBN stars.

But why?

Meridional mixing

Mass Transfer in Binary Systems

Atmospheric structural differences

Nonuniform initial abundances

Mass loss (10^-7 – 10^-5 Msun/year)

OBN stars

- OBN stars come from mass loss in OB stars
- Say the CN cycle converts C→N in the inner 60% of a star over 15% of its main sequence lifetime
- If 40% of the remaining mass can be removed in the final 85% of the lifetime, then it’s a nitrogen rich star
- It’s ok to lose this much mass and still be OB, but if it loses much more, then its luminosity will be too low
- Often present in young clusters

OBC stars

- OBC stars are more difficult to “make” than OBN stars.
- Mass transfer in a binary can only lead to OBC by stripping part of the carbon-oxygen core of the primary.
- Carbon enhancement most likely from supernovae. Early forming massive stars could go supernova and enrich nearby protostars.
- Mass loss an unlikely cause

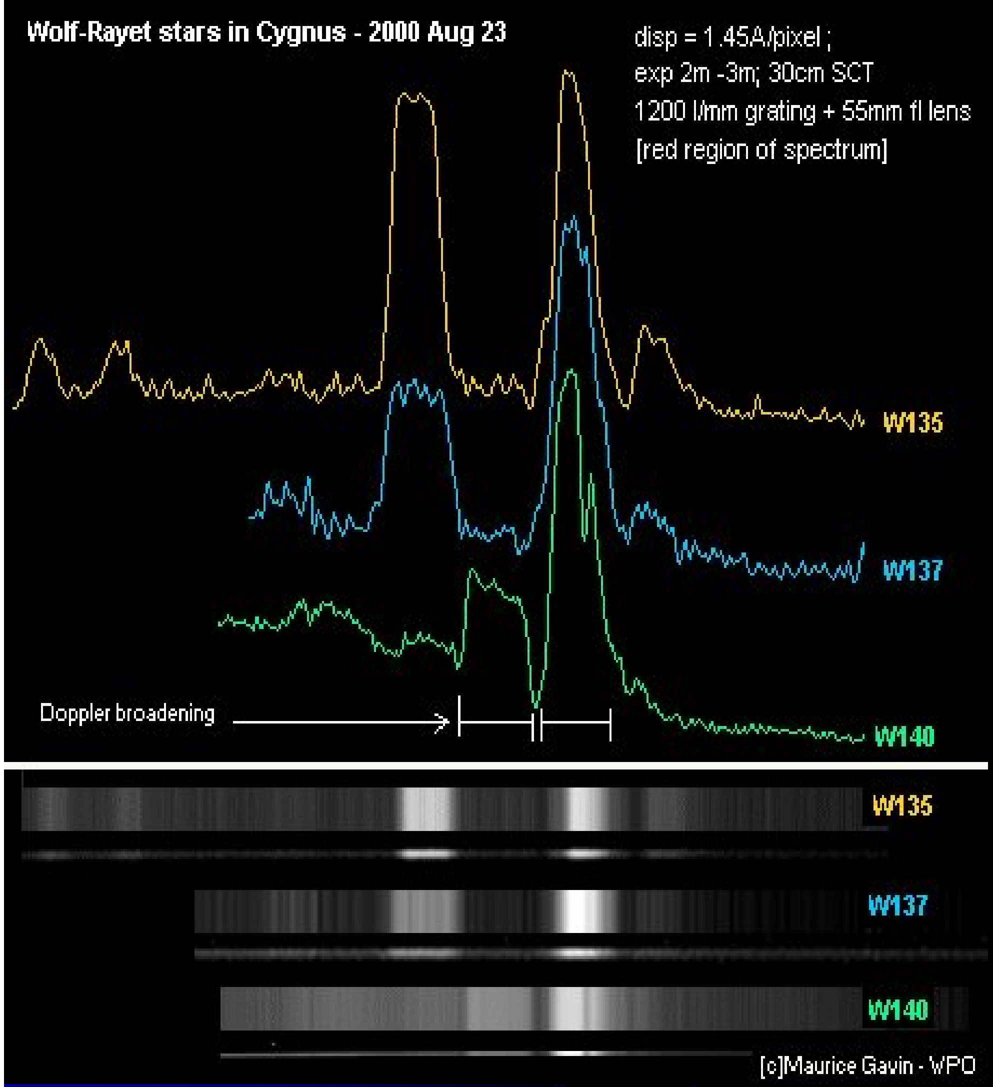
OBNC characteristics

- 50%-100% of sampled OBN stars found in short-period binary systems, ~0% of OBC stars found similarly→ possibly kinematically distinct groups?
- Found in OB associations (20+) and smaller OB subgroups (4-10 stars) from molecular clouds (OMC1). A small group of a few OB stars forms, they evolve and ionize gas. The HII region pushes a shock wave into the molecular cloud and compresses gas to start gravitational collapse for a new group of OB stars. They spread out in evolutionary sequence.

Wolf-Rayet stars

- Discovered by Charles Wolf and George Rayet at the Paris Observatory in 1867
- O stars with strong and wide emission lines (few nm) and few absorption lines
- M*> 20 Msun
- T~10^5 K+
- R~1-15 Rsun
- Luminous (abs mag between -4.5 to -6.5)
- Hot stellar core surrounded by dense, rapidly expanding stellar wind/envelope expanding at ~2000km/s
- KE released over lifetime is comparable to that in a SNe explosion

Spectroscopy of WR


Wolf-Rayet stars in Cygnus - 2000 Aug 23

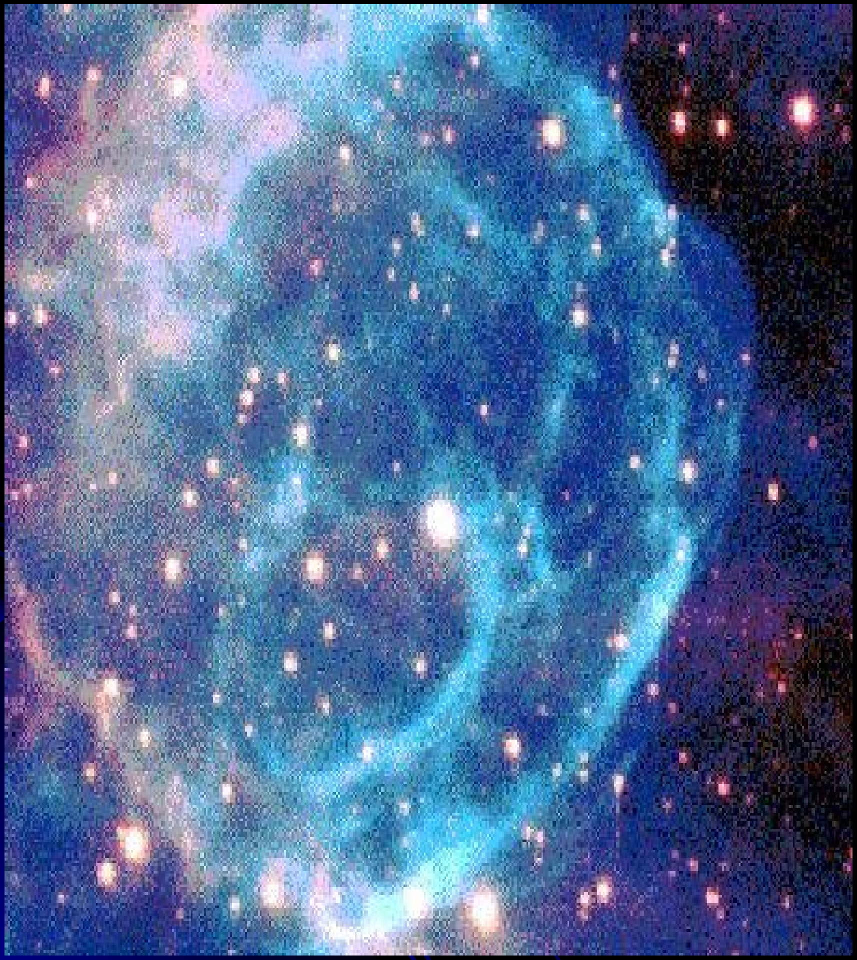
[c]Maurice Gavin - WPO

Must use the EPM, escape probability method with ‘core-halo’ approach.

Define the emission line region with a ‘representative’ radius,

Use bound-bound and bound-free mechanisms to compute transition source functions and line strengths, this leads to Ne and Te

Not there yet..



- Now, we have Ne and Te.
- Solve simultaneous equations of statistical equilibrium and line and continuum transfer throughout stellar wind
- Assume spherical geometry, monotonic velocity law, and homogeneity
- Also must adopt a characteristic core Teff, Mass loss rate, wind terminal velocity, core R, chemical composition
- Use radiative equilibrium/grey LTE approximation
- SOLVED

WR Subclasses

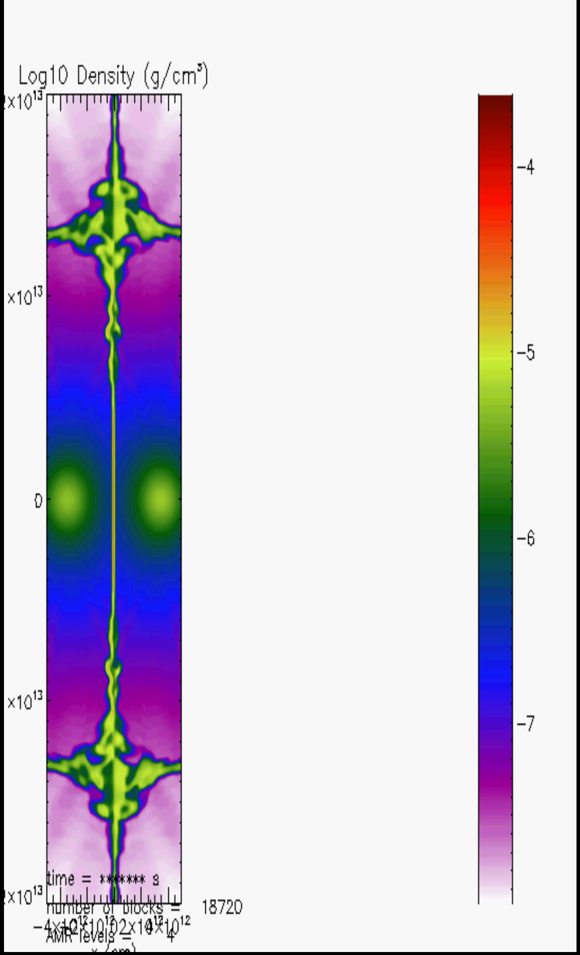
WN	emission lines in He and N ions
WC	emission lines in He, C, O
WO	emission lines in OVI, He, C

WR galactic (~200 stars) and LMC/SMC (~100 total stars) catalogs available.

All have high mass loss rates (10^-5/10^-4 Msun/yr! 10^9 times the solar wind!) making normal atmosphere modeling impossible

Where do WR stars come from?

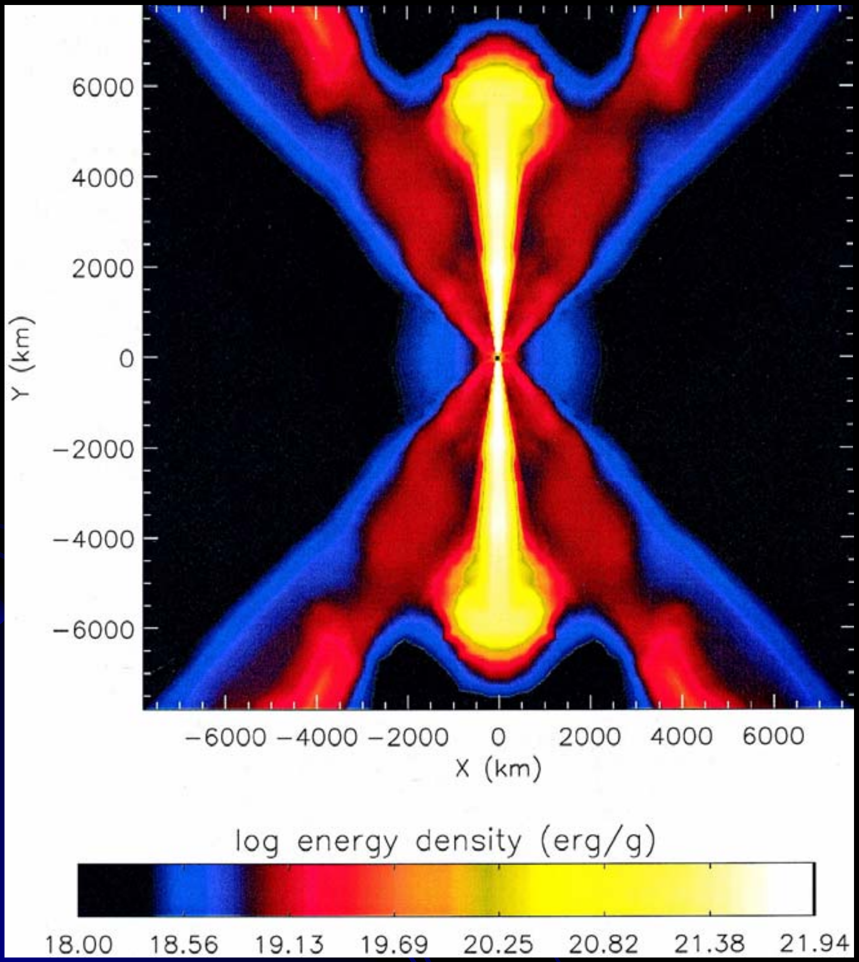
- Likely evolved descendents of massive O-type stars with extensive mass loss
- Stellar atmospheres stripped with interior products left
- WN are stripped CNO-burning stars
- WC stars are evolved from WN stars
- WO stars evolved from WC stars
- O→ Of/OBN→ LBV→ Of/WN→WN→ WC→WO



WR environments

- Often surrounded by ring nebulae
- Ring nebulae are enriched (often with He and N)
- Material from original WR star present in the nebulae
- Often in binaries
- No hydrogen envelope!!!

What happens to WR stars?



- Although extensive mass loss occurs, the WR star is still huge and ends its life as a type Ib supernova
- Supernovae emission has been observed in the light curves of many GRBs (gamma ray bursts)
- It is believed that the WR undergoes core collapse resulting in a black hole and an accretion disk
- The axis of accretion is attributed to repaid rotation, magnetic fields, or companion stars
- GRB occurs when a relativistic jet propagates through the collapsing star emerges, only if the hydrogen envelope is gone.