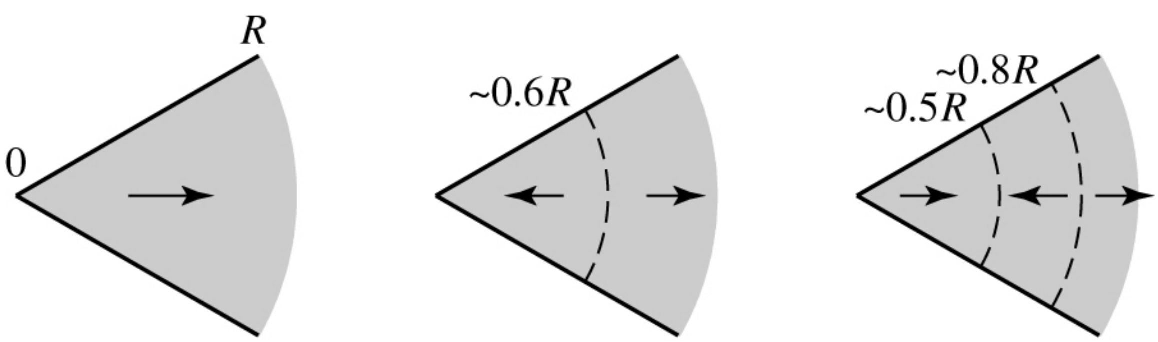
Astronomy 404
November 15, 2013

Stellar Pulsation

The radial oscillations of a pulsating star are the result of **sound waves resonating in the star's interior.**

Period-mean density relation:

$$\Pi \approx \sqrt{\frac{3\pi}{2\gamma G\rho}}.$$



Fundamental mode **First overtone** **Second overtone**

To drive pulsation, a layer have to reach maximum pressure *after* the maximum compression.

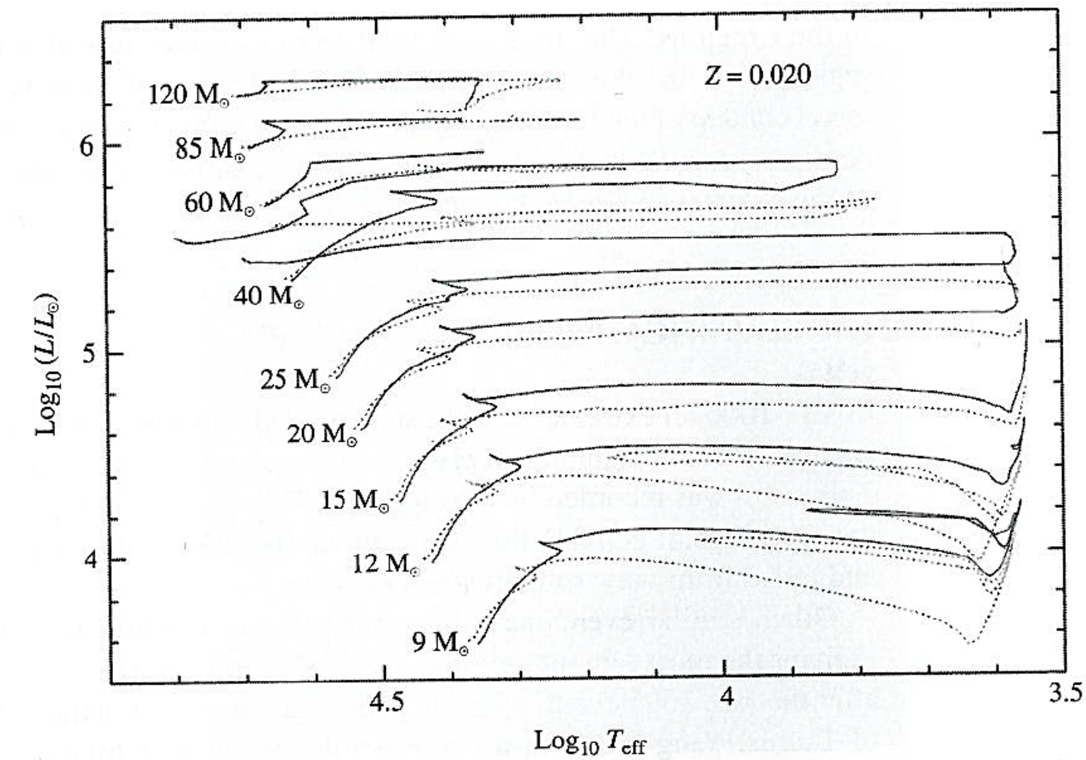
Nuclear ε mechanism (in the core)

κ- and γ-mechanisms (partial ionization zone)

Temperature > 7500 K, not enough mass to drive pulsation
Temperature < 4500 K, convective envelope dampens pulsation

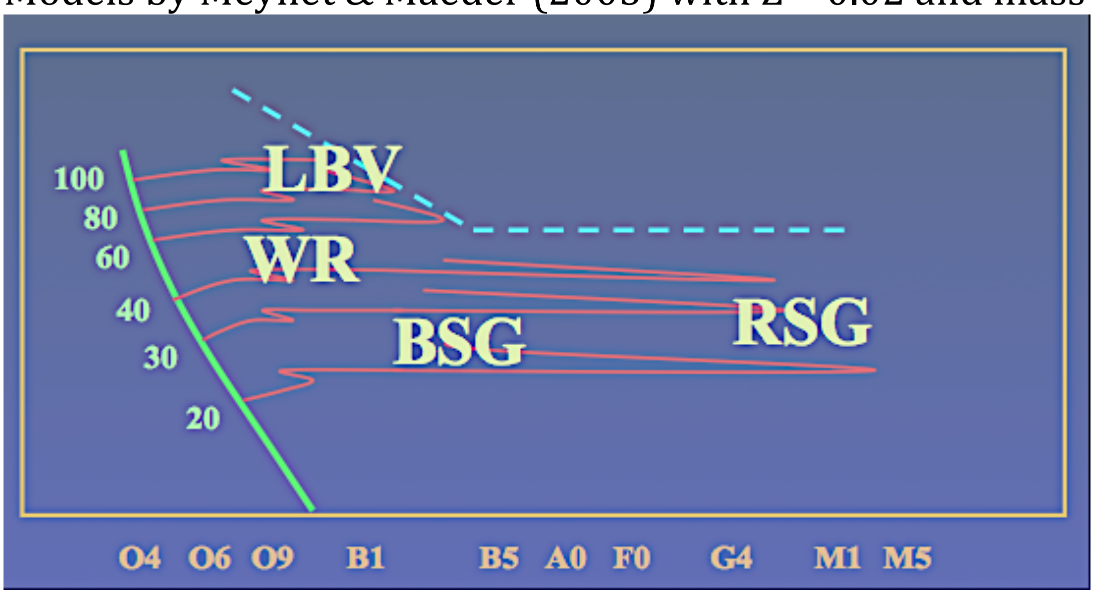
Pulsations of cool stars (LPV, classical Cepheids, RR Lyrae) are driven by H and/or He partial ionization zones; pulsation of hot stars (β Cephei) are driven by Fe partial ionization zones.

Chapter 15. The Fate of Massive Stars



Evolutionary tracks: solid line – with initial $V_{rotation}$ = 300 km/s
dotted line – no rotation

Models by Meynet & Maeder (2003) with Z = 0.02 and mass loss.

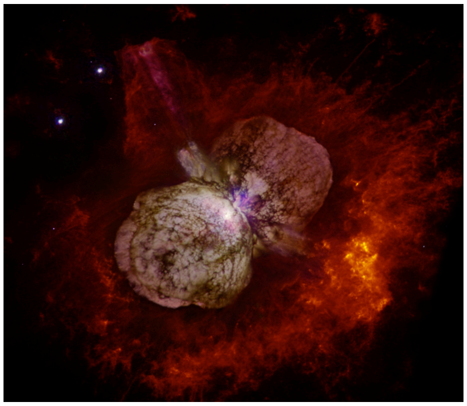


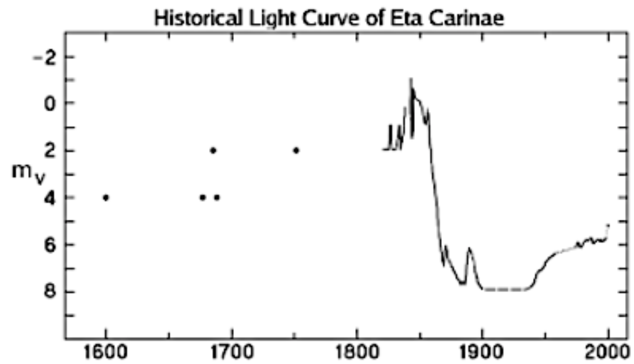
RSG – red supergiant
BSG – blue supergiant
LBV – luminous blue variable
WR – Wolf-Rayet stars

Humphreys-Davidson Luminosity Limit (blue dashed line)

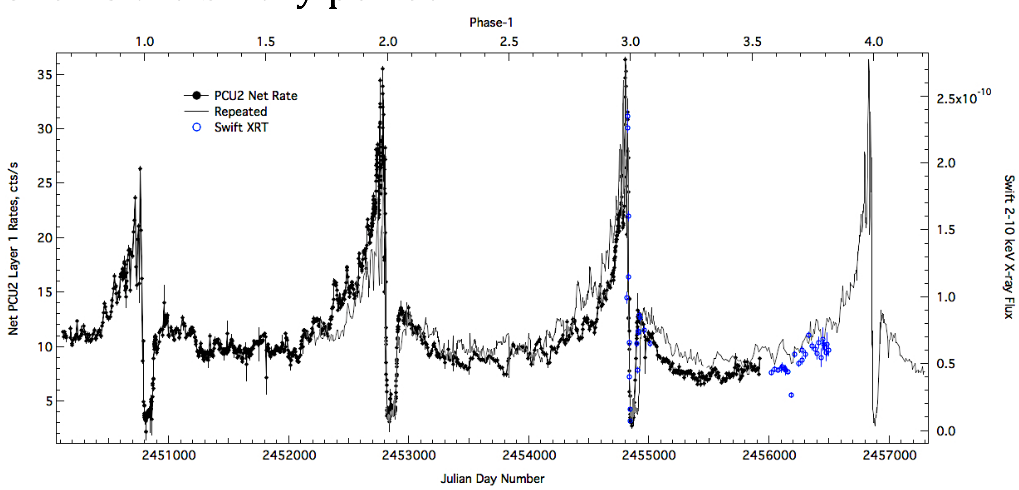
Luminous Blue Variable (LBV)

The most famous LBV is η Carinae.





Below is the X-ray light curve of η Car. The X-ray emission originates from colliding winds. η Car has a massive binary companion that has a fast stellar wind. The X-ray light curve shows the binary period.



η Car is a LBV. P Cygni is also a LBV. Many other variable blue stars are called LBVs, but they are not as luminous as η Car. Humphreys and Davidson suggest to call them S Dor variables.

LBVs lose mass possibly because they are close to L_{Ed}. The mass loss from LBVs form circumstellar nebulae.

Wolf-Rayet Stars

Wolf-Rayet (WR) stars have three different sequences:
WN – nitrogen sequence
WC – carbon sequence
WO – oxygen sequence
Within each sequence, subtypes are defined.

WN 2 – WN 5	early-type WN	(WNE)
WN 6 – WN9	late-type WN	(WNL)
WC 4 – WC 6	early-type WC	(WCE)
WC 7 – WC 9	late-type WC	(WCL)

WR stars have mass loss rate $\sim 10^{-5}\ M_\odot\ yr^{-1}$ and wind velocity of 800-3000 km s^{-1}.

The effective temperature of WR stars ranges from 25,000 K to 100,000 K. The earliest WN stars (WN2) are hot enough to photoionize helium to He^{+2} (or He III). These nebulae would emit He II 468.6 nm line.

WN – WC – WO represent a sequence of different amount of surface layer has been stripped to reveal the nucleosynthesized material.

Peter Conti suggested the following evolutionary paths (1976):

$$M > 85\ M_\odot : O \rightarrow Of \rightarrow LBV \rightarrow WN \rightarrow WC \rightarrow SN$$

$$40\ M_\odot < M < 85\ M_\odot : O \rightarrow Of \rightarrow WN \rightarrow WC \rightarrow SN$$

$$25\ M_\odot < M < 40\ M_\odot : O \rightarrow RSG \rightarrow WN \rightarrow WC \rightarrow SN$$

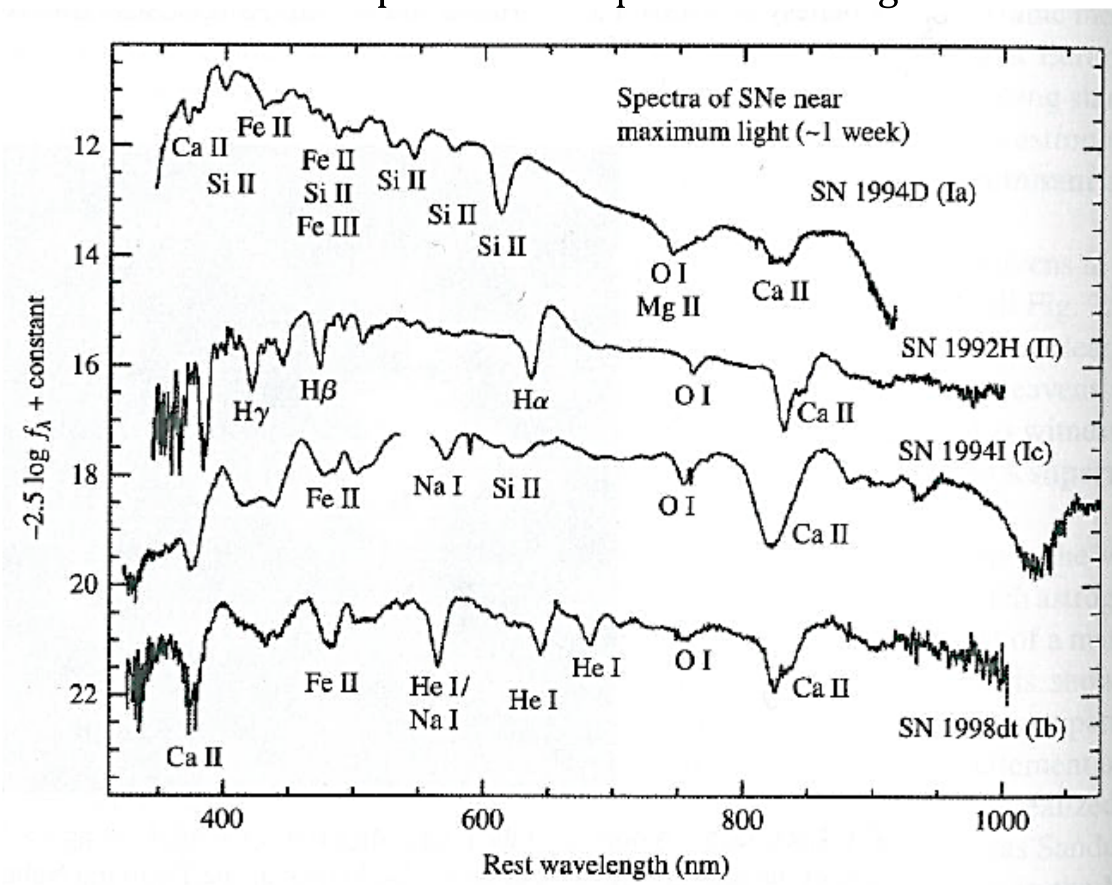
$$20\ M_\odot < M < 25\ M_\odot : O \rightarrow RSG \rightarrow WN \rightarrow SN$$

$$10\ M_\odot < M < 20\ M_\odot : O \rightarrow RSG \rightarrow BSG \rightarrow SN$$

The Classification of Supernovae

Historical supernovae (SNe):
SN 1006, SN 1054 (Crab Nebula), Tycho's SN,
Kepler's SN in the Milky Way and SN 1987A in the LMC.

SNe show different spectra at the peak of their light curve:

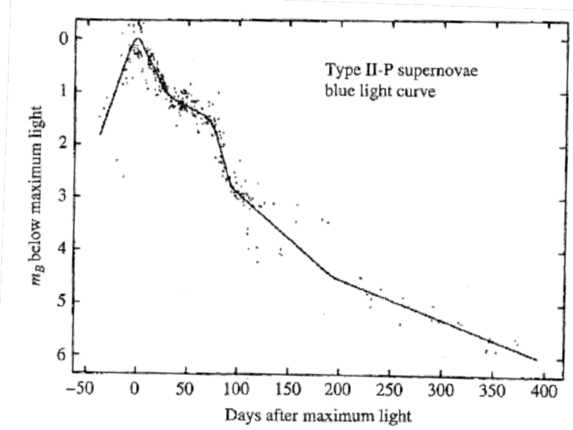


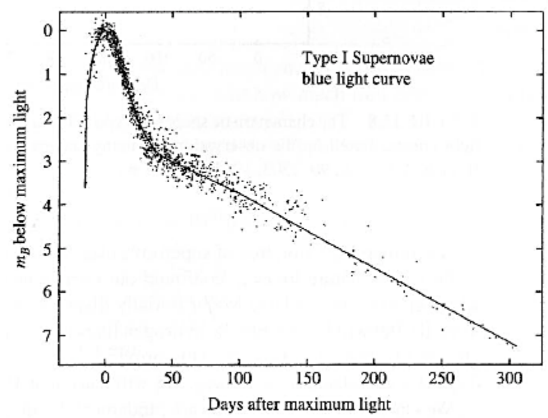
Type I – no hydrogen lines

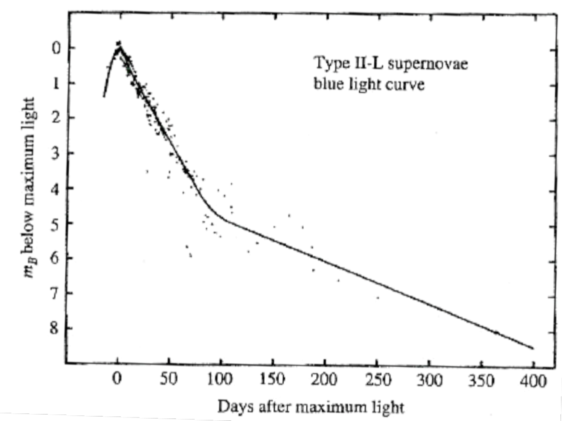
- Ia - shows Si lines
- Ib - no Si lines, but shows He lines
- Ic - no Si lines, and no He lines

Type II – show hydrogen lines

Type Ia SNe result from white dwarfs and the others are from core-collapse of massive stars. Type Ia SNe at peak (M_B = -18.4) are ~1.5 mag brighter than the core-collapse SNe.







Supernova Classification Scheme
(spectra at maximum light)