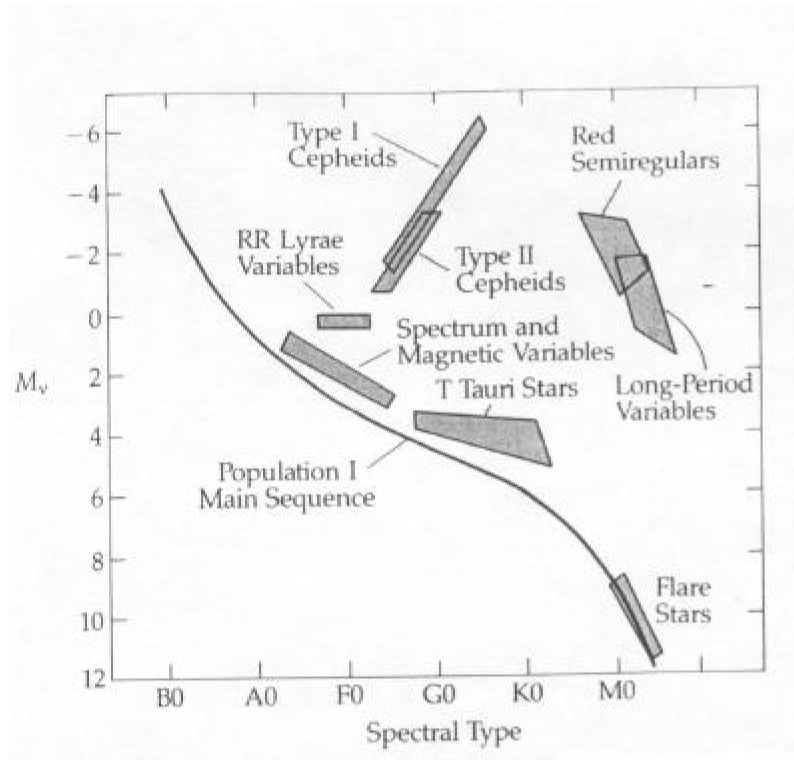
Variable Stars

Regular or irregular changes on short (measurable) time scales. Large variety measured, due to variations in velocity or energy flux.

• Pulsating Stars: periodic expansion and contraction, e.g., Cepheids, RR Lyrae's

• Catacylsmic and Eruptive Variables: sudden large changes, e.g., novae and supernovae

• Others: changes in luminosity *L* due to surface or interior activity, e.g., T Tauri (pre-MS) stars, Flare stars, Magnetic variables.

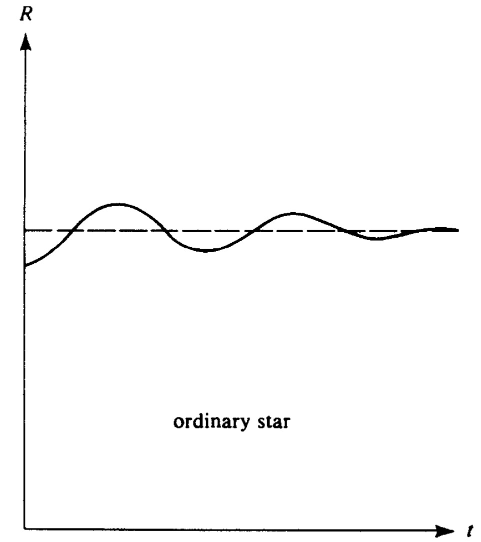


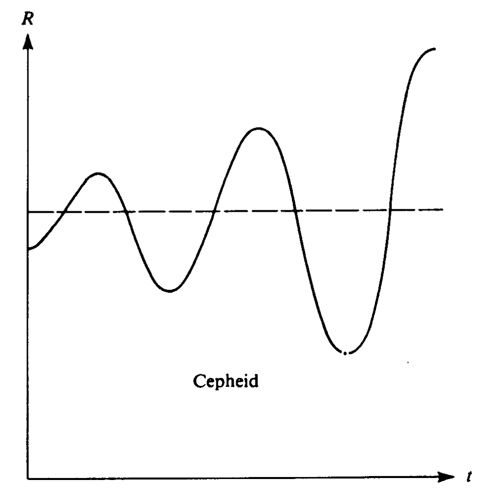
Most stars not on MS

Pulsating Stars

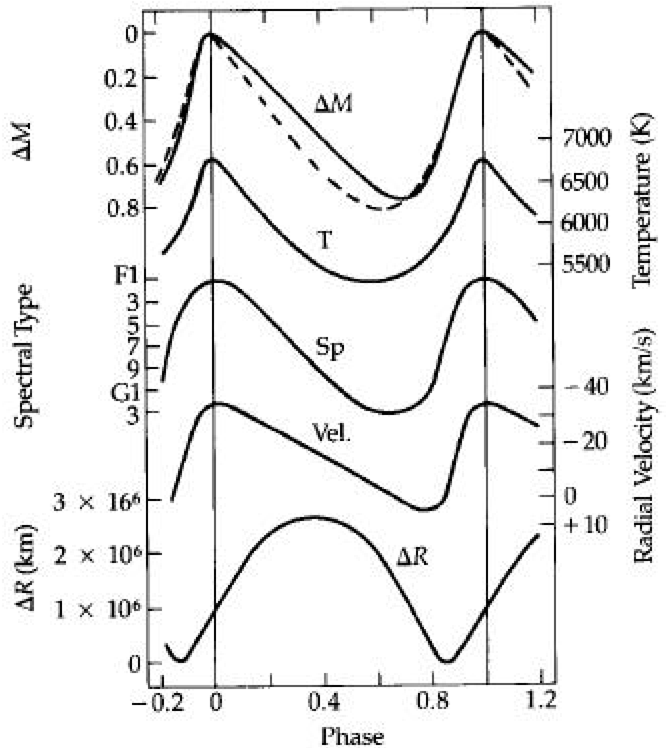
Stars are normally in a stable equilibrium. Small departures => oscillations; e.g., compression => pressure increase => expansion, and vice versa. Opacity effects usually *damp* the oscillation; recall κ *decreases* upon compression if *T* increases.

In a pulsating star, opacity κ *increases* upon compression, giving an extra kick to the pulsation => <u>overstability</u>.





Pulsating Stars



Measure regular pulsations in luminosity, surface temperature, surface velocity, and radius.

Why pulsators only in certain parts of the H-R diagram?

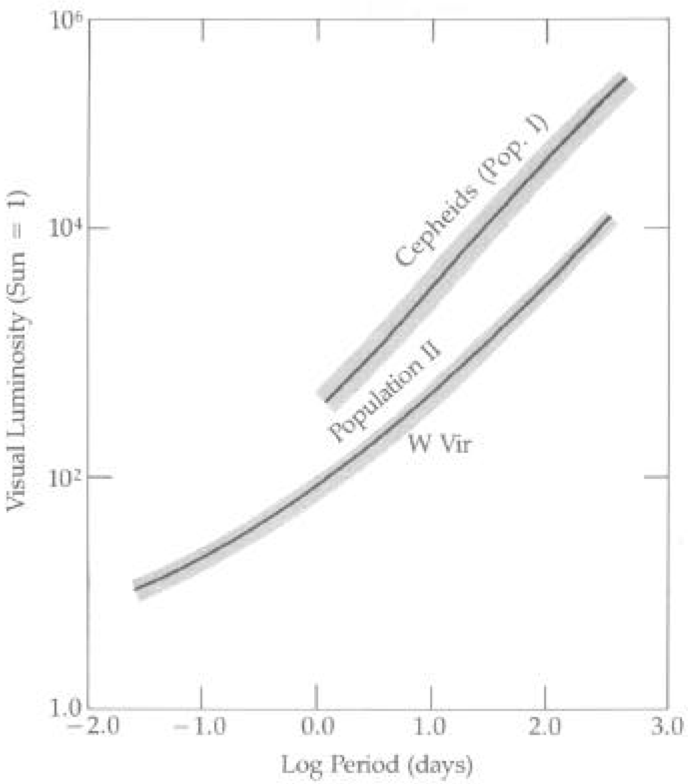
Need He II zone within star => compression *increases* κ. Why?

He II zone must be present, and neither too shallow nor too deep within the star. This occurs only for certain stars at certain stages of their motion across the H-R diagram (usually core He burning).

Pulsating Stars

Cepheid variables: giant stars, *very luminous*

Type II Cepheids: lower Z (Pop II stars), found in globular clusters



Note P-L relation. Once known: measure P and m_V for a Cepheid => get distance. Cepheids are key to extragalactic "distance scale".

Why a P-L relation? Newton's Laws (Kepler's 3rd Law) imply

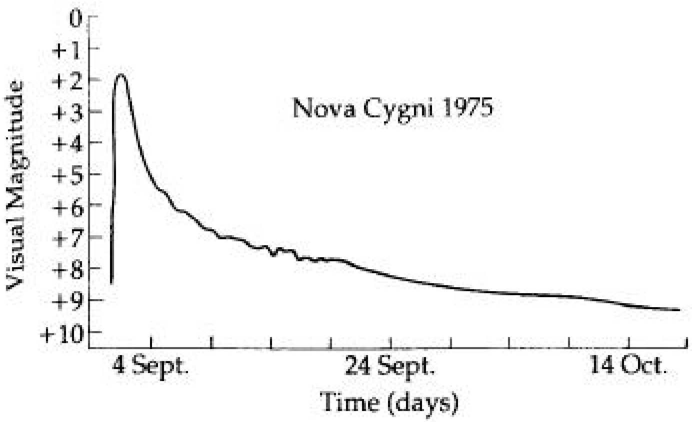
$$\frac{P^2}{R^3} = \frac{4p^2}{GM} \quad \Rightarrow \quad P \propto \sqrt{\frac{1}{G r}}.$$

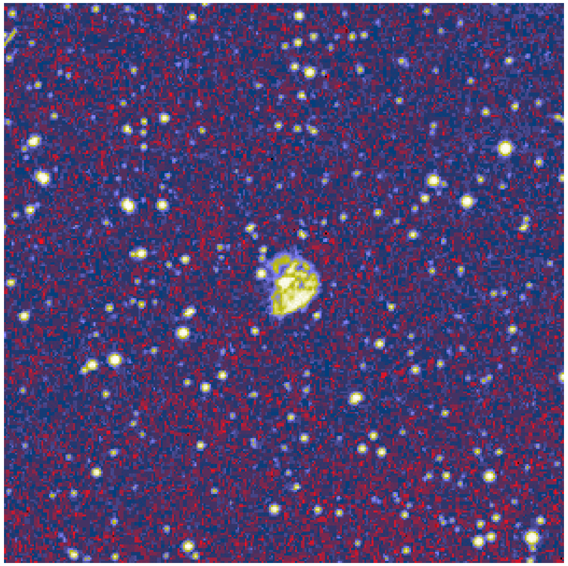
Note: free-fall time and pulsation time are comparable.

Novae

Eruptions characterized by huge changes in luminosity L (typically ~ 10 mag change).

A <u>nova</u> ("new star") releases typical energy 10^{37}-10^{38} J. Ejection speeds approaching 2000 km/s.



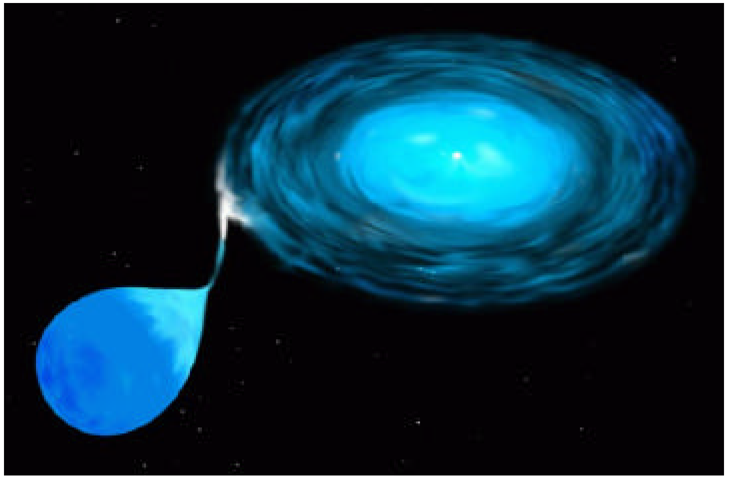


Nova Persei; erupted 1901

Novae

Believed to be a white dwarf primary and secondary (on or near MS) which has expanded to fill its Roche limit. Material flows through accretion disk onto WD. Enough material accumulates every ~ 10^5 yr to lead to *explosive* fusion reactions on surface.

Why not stable nuclear reactions like in the Sun, i.e., no safety valve?



Illustration

Supernovae Revisited

Energy release ~ 10^{46} J! Some 100 times more than released by the Sun in its entire lifetime.

Type I: Similar in origin to novae in binary systems.

Type II: End stage of massive star life. A rebound occurs after the collapse of the core to form a neutron star.

Energy budget OK?

Yes!

$$|U_{grav}| \approx \frac{GM^2}{R} \approx 2\times10^{46}\ \text{J}$$

for $M \approx M_{Sun}, R = R_{NS} \approx 15\,\text{km}.$

Supernovae: Last Word

How are elements heavier than Fe formed in the universe?

Answer: during the supernova explosion, energetic neutrons released and absorbed by heavy elements in outer part of star. This drives the endothermic reactions which convert Fe to increasingly heavier elements. This neutron capture occurs through rapid (r-process) or slow (s-process) reactions.

For example,

$$^{56}\mathrm{Fe} + 5n \quad \rightarrow \quad ^{61}\mathrm{Fe},$$

$$^{61}\mathrm{Fe} \quad \rightarrow \quad ^{61}\mathrm{Co} + e^{-} + n.$$