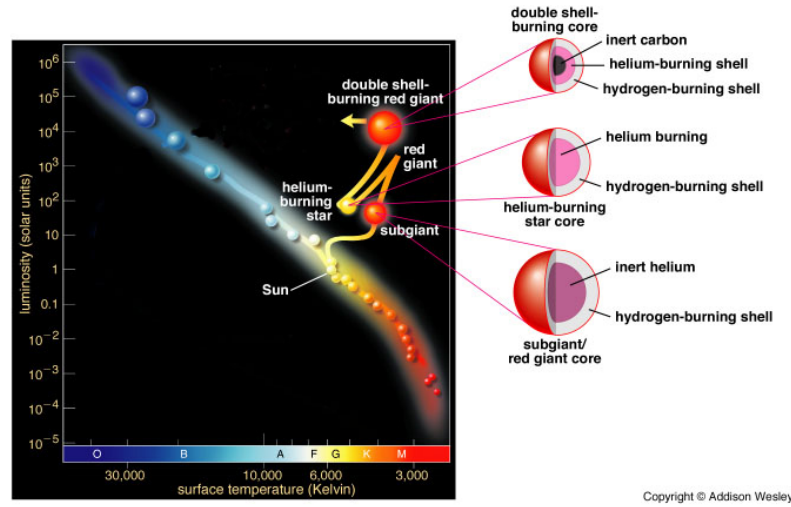
Agenda for Ast 309N, Oct. 30

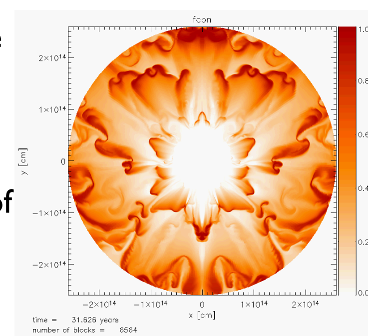
- HW 2 due; Quiz 6, 10/25 card feedback
- Review life stories of low and high-mass stars
- Star-to-gas recycling and element enrichment
- Neutron stars and pulsars; video clips
- Card
- Reading: - Kaler, ch. 7
  - Wheeler, ch. 8; next topic - chs. 3, 4, & 5

Second Red Giant Phase: AGB or Double Shell-Burning Star

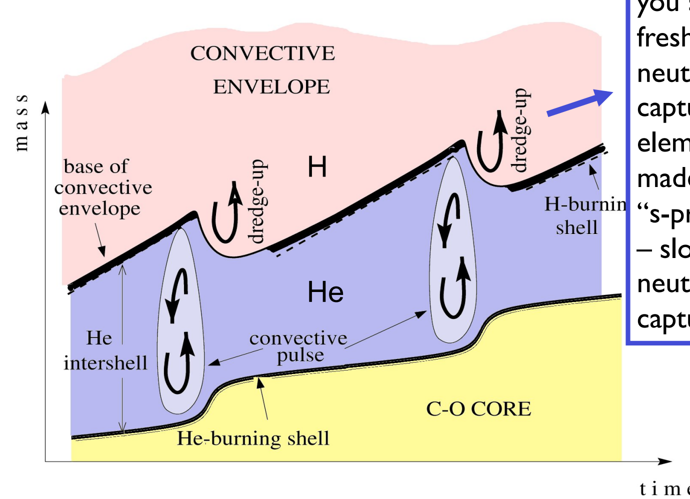


He-Shell Flashes and "Dredge-up"

- AGB stars are rather unstable.
- Every few thousand years, the He-burning shell flares up in brief nuclear runaways called He shell-flashes or *thermal pulses,* which release a burst of energy inside the star.
- With each flash, convection scoops or "dredges" C and other products up from core and transports it to surface.



"Dredge-up" in AGB Stars



At the stellar surface: you see fresh C and neutron capture elements made by the "s-process" – slow neutron captures

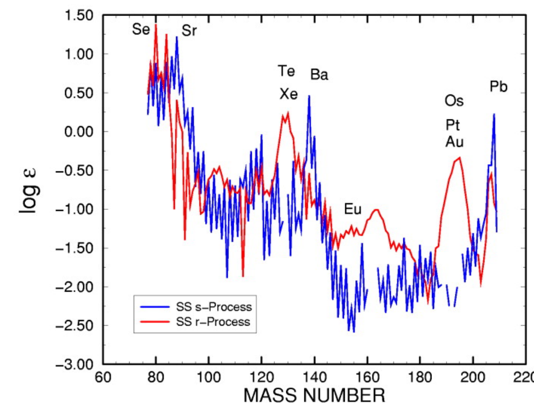
“Dredge-up” in AGB Stars

Enough freshly-made C is brought to the surface that it reverses the initial ratio of C/O, which was 1:3, and C becomes more abundant than O. The star is then a “carbon star.”

Other elements are made as well, notably many of the elements heavier than iron. These are made by the “s-process” or slow neutron capture (adding one neutron at a time), as described by Neil Tyson in a video clip.

Trans-Iron Elements in the Solar System

About half the nuclei heavier than iron in the Solar System came from AGB stars, the other half from supernovae



Truran, Cowan, Pilachowski & Sneden PASP (2002)

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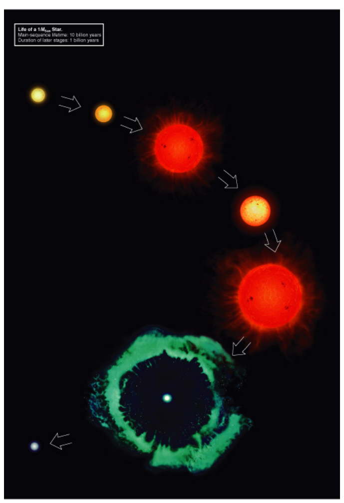
Overview: Life Story of a Low-Mass Star



1. Main Sequence: H core-burning: H → He in core
2. Red Giant: H shell-burning: H → He outside the He core
3. Horizontal Branch: He → C in the core, H → He in shell
7. AGB or Double Shell Burning: H and He both fuse in shells, CO core becomes degenerate
5. Planetary Nebula lifts off, leaves white dwarf behind

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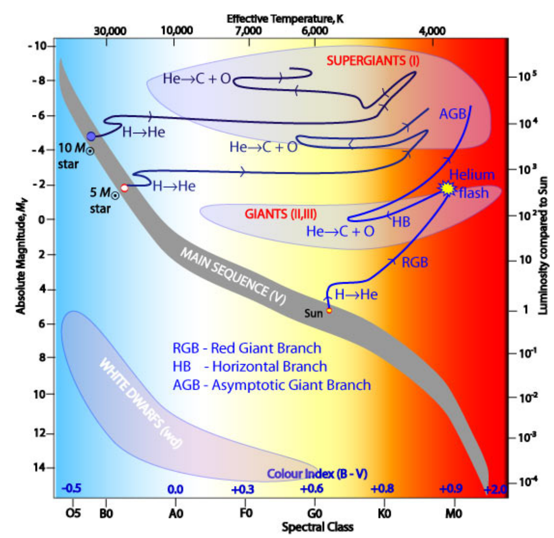
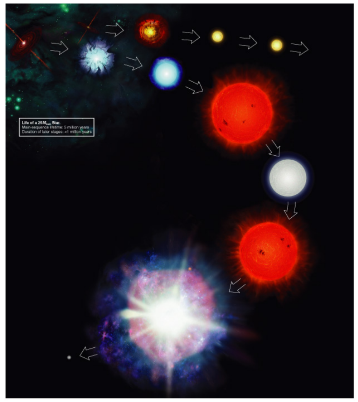
Evolutionary Tracks for Various Masses

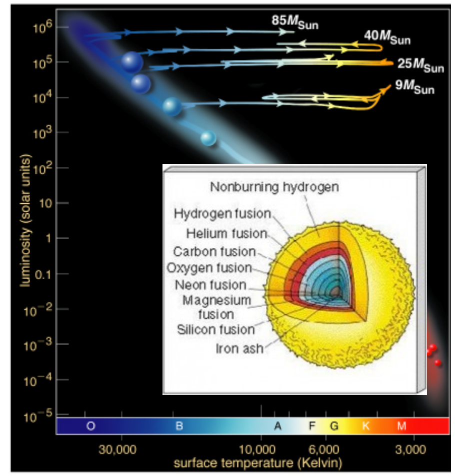


Early Life Stages of High-Mass Stars

- The first few life stages of high-mass stars are more or less similar to those of lower-mass stars:
  - Hydrogen core fusion (Main Sequence)
  - Hydrogen shell burning (red supergiant)
  - Helium core fusion (blue supergiant)



Later Life Stages of High-Mass Stars

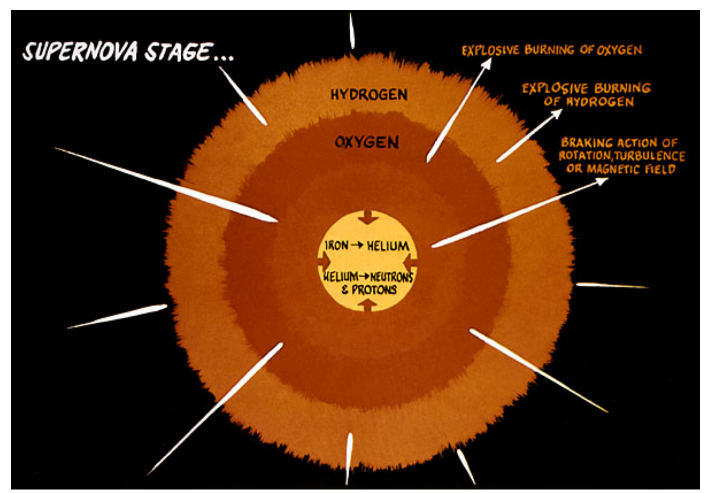


- As the shells of fusion around the core increase in number, the star swings "back and forth" between the red and blue sides of the HR diagram.
- Once the core has turned to Fe "ash," it can no longer produce thermal energy, so it collapses, producing ....
- a neutron star at the center, and an expanding cloud of gas: a "supernova remnant."

The "Iron Catastrophe"

- The non-degenerate iron core contracts & heats;
- No new energy-producing fusion reactions possible
- Instead, the nuclei *disintegrate*: Fe $\Rightarrow$ He, p+, e^-, n' s
- But this *uses up* energy, so the thermal pressure falls.
- When you take away the pressure support, gravity "wins" the eternal battle of the forces, and
- an even faster collapse takes place (0.25 sec)

The "Iron Catastrophe"



Formation of the Neutron Core/Star

The core continues to collapse, until the protons and electrons get "squeezed" into neutrons,

producing a burst of neutrinos by the reaction:

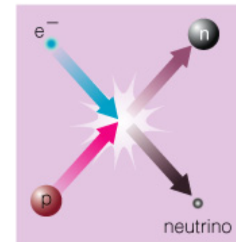
$$p^+ + e^- \rightarrow n + \nu$$

When the density reaches 10^{14} gm/cm^3 (the density of nuclear matter), neutron degeneracy pressure stops the collapse [analogous to the white dwarf]

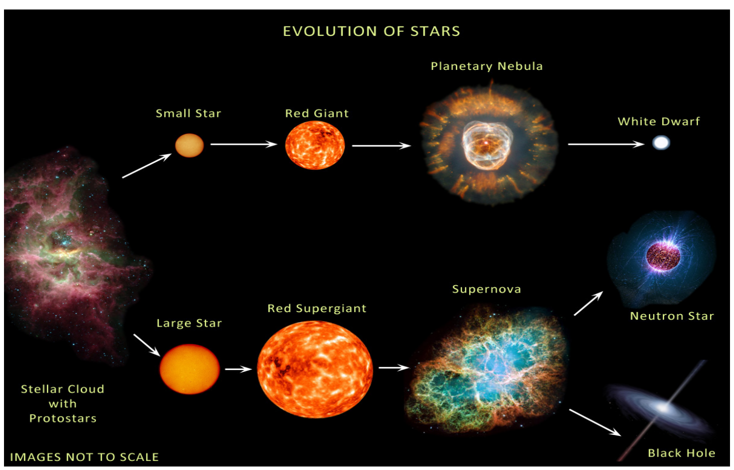
"Core Collapse" Supernova

- The Fe nuclei break up into protons, electrons, neutrons, and alpha particles ("photodisintegration") uses up heat, so the thermal pressure drops and the core suddenly collapses .
- Electrons and protons are forced together into neutrons.
- This process also releases a *neutrino*.

- The core contracts until it is stopped by neutron degeneracy pressure; it becomes a *neutron star*
  - this takes only seconds
  - The upper layers fall onto the core, rebound, & go flying into space

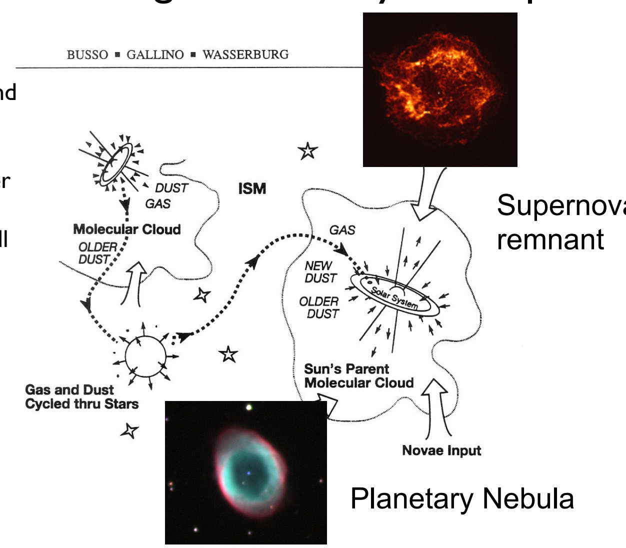


Life Stories of Low vs. High-Mass Stars

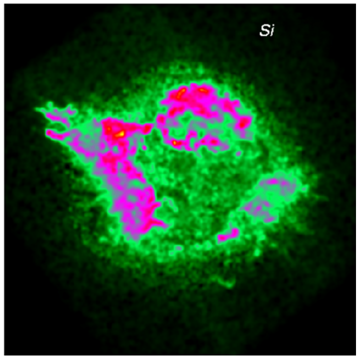


How Stars Change the Galaxy's Composition

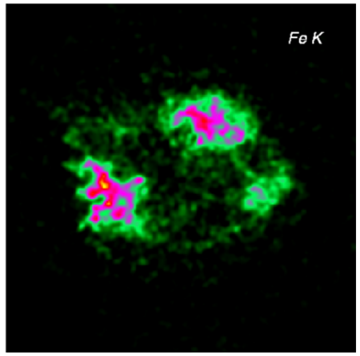
Each time around the cycle, larger amounts of the elements heavier than He (which astronomers call "metals") are included in the next generation of stars.



Chandra Observatory X-ray Map of Ejected Elements in Cas A



Silicon in Cas A



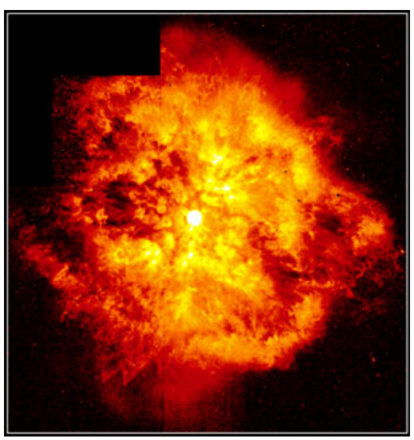
Iron in Cas A

"Winds" from Hot, Luminous Stars

- What are they? outflows from stellar surfaces
- How do we recognize them?

  - spectra: broad emission lines (why broad?)
  - in some cases, see the expanding cloud of gas
- Removal of outer layers exposes nuclear fusion products: He, N, C, as in "Wolf-Rayet" stars
- Such stars can lose a large fraction of their mass through these winds (precursor of SN 1987A?)

The Winds from the Stars



Wolf-Rayet star 124 and its nebula

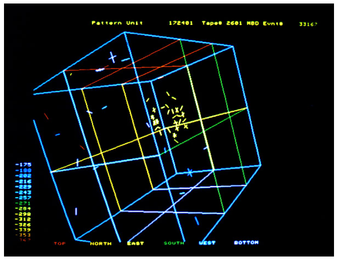
This image should look familiar! Where have you seen it before?

Types of Pressure

Type	depends on …	where it matters
Thermal	Temperature as well as density	Main Sequence & most other stars
Degeneracy	Density only	Brown dwarfs, white dwarfs, neutron stars
Radiation	Luminosity	AGBs, supergiants, high mass stars

SN 1987A in the LMC

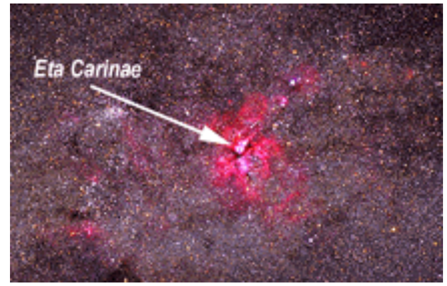
The neutrino burst

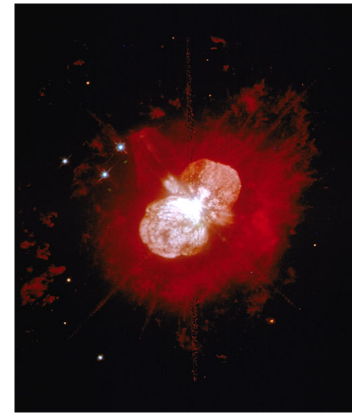


At maximum optical brightness

Before it blew up: a blue supergiant

Eta Carinae: Possibly the Most Massive Star in the Milky Way

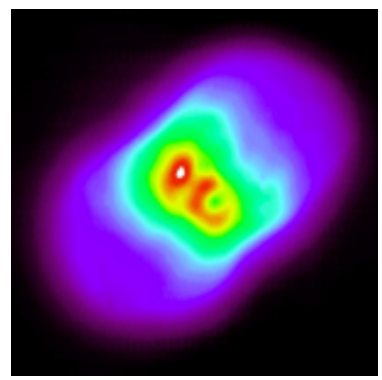




Eta Carinae: Superstar

- Brightened dramatically – to become of the brightest stars in the southern sky - in the mid-1800's (the "Great Eruption")
- Today, it is still the brightest source in the sky, in the mid-infrared spectral region (this is because it is shrouded in a 'cloak' of self-made dust)
- We see a nebula with two dusty "lobes" now
- There is strong evidence that it is actually a binary system with a period of 5.5 years

Eta Carinae: Infrared View



Large amounts of dust formed during the giant outburst of the 19^{th} century. The dust absorbs the light from the central hot star (binary star), gets heated but to a cooler temperature than the star, and re-radiates the energy as infrared radiation.

The Serendipitous Discovery of Pulsars

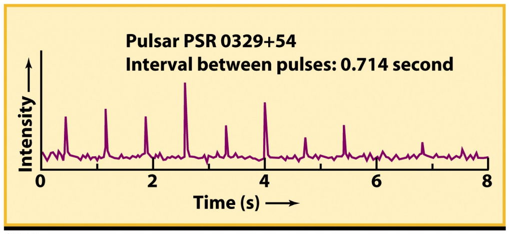
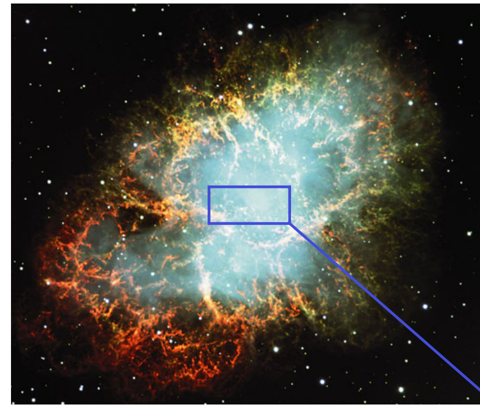


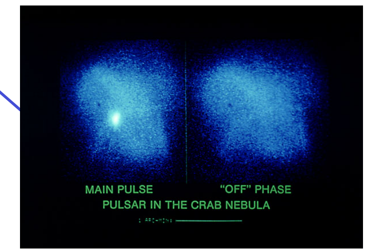
Figure 21-2
Universe, Eighth Edition

- Using a radio telescope in 1967, Jocelyn Bell noticed very regular pulses of radio emission from one place in the sky
- When several similar sources were discovered in known supernova remnants (the Crab Nebula), it was realized that they were coming from a spinning neutron star—a *pulsar.*

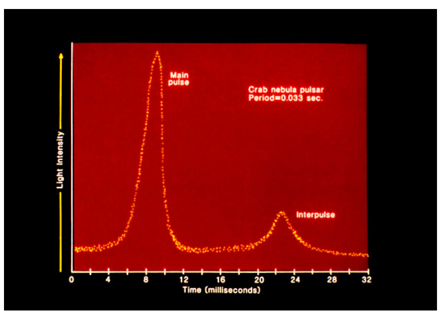
The Crab Nebula Pulsar



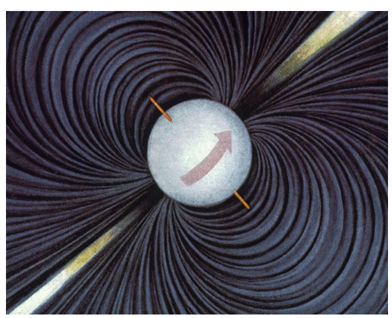
The pulsar at center of the Crab "flashes" 30 times per second



Basic idea: Pulsars as Lighthouse Beacons



Light curve of the Crab Nebula pulsar: two unequal peaks



Interpretation: spinning neutron star, radiating mainly in two polar beams

Synchrotron Radiation (Non-Thermal)

Electrons spiral around the magnetic field lines; this "twisting" motion is accelerated motion, so the electrons radiate photons (strongly at radio wavelengths).

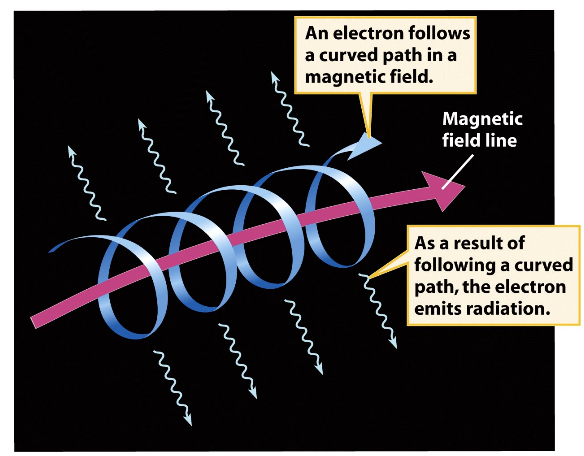


Figure 21-6a
Universe, Eighth Edition