

Astro 210
Lecture 34
April 18, 2011

Announcements

- HW 10 due Friday: computer-based, pick one of two
for the theory-inclined: simulate a star
for the observation-inclined: cosmology data analysis
- also due Friday: OBAFGKM(LT) mnemonic contest
win 10 bonus points, and maybe also glamorous prizes

Last time: life and death of the Sun

Q: what will happen when all H fuel burned to He in Sun?

Q: how will the Sun die? what remains are left?

↳ *Q: what about stars with $M < 0.9M_{\odot}$?*

Q: what about stars with $0.9M_{\odot} < M < 8M_{\odot}$?

Lives and Deaths of Stars

a star's life history, death controlled by its **mass**

$$M < 0.9M_{\odot}$$

history like that of the Sun to date

burn $H \rightarrow He$

lifetime $>$ age of universe: live “forever”

i.e., none have yet died

$$0.9M_{\odot} < M < 8M_{\odot}$$

history like that of the Sun

life: burn $H \rightarrow He$ (“main sequence” phase)

then “giant” phase burning $He \rightarrow C$

death: eject $>$ 50% of mass as enriched gas—“planetary nebula”

leave behind compact object: white dwarf

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$$M > 8M_{\odot}$$

history begins like Sun, but then very different...

Evolution of High Mass Stars

high mass: $M > 8M_{\odot}$ (approximate—low mass limit not precisely known)
initially: burn $H \rightarrow He$: "main sequence" phase

after core H gone:

- contract, ignite core $He \rightarrow C$ burning
- shell H burning: outer layers expand to **supergiant**

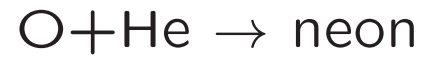
www: HST Betelguese

www: HR diagram

Mass large \rightarrow gravity strong \rightarrow core T large
can and do burn carbon, heavier elements

ever more rapid cycles:

core contraction → heating → ignition → burning



... up to iron

ash → fuel: cosmic recycling!

outside core:

- onion-skin structure develops
- previous phases “remembered” in shell burning
- the star’s structure recapitulates its history!

www: pre-SN structure

core burning (fusion): makes ever heavier elements
phases ever hotter, faster
but this can’t go on forever

when core is **iron** (Fe)

nuclear physics: iron is most stable nucleus

→ fusion with iron **endothermic** and **not** exothermic

Q: *what does this mean?*

Fe fusion **endothermic**:

→ Fe can't be fuel! inert!

when core is Fe:

- fusion stops
- core solidifies: iron white dwarf forms!

but immediately outside of iron core

shell burning of silicon → iron

→ core mass increases

→ this is a losing game!

Q: why? what happens?

Massive Stars: The End

Star structure:

- inert (non-burning) iron core
- supported against gravity by quantum motion of degenerate electrons (i.e., a white dwarf = solid)
- but shell burning keeps increasing core mass

but recall: white dwarfs have maximum mass!

eventually: $M_{\text{core}} > M_{\text{Chandra}}$:

gravity overwhelms degeneracy pressure

star finally loses lifelong struggle against gravity!

Catastrophic results:

→ core **collapses!**

→ speeds **$\sim 10\%c!$**

→ overlying layers lose support, collapse too

Supernova Explosions (Type II)

Gravitational Collapse

core compression to tiny volume!

→ nuclei “touch”: nuclear density

very hard to compress more!

core → giant atomic nucleus, supported by nuclear force

infalling envelope “bounces” off stiff core

ejected at high speed (up to 10% c)

→ **supernova explosion**

Demo: AstroBlaster

one supernova briefly as luminous as a Galaxy of stars

www: SN 1994D

∞

Q: what's left after explosion? what are the leftovers like?

Supernova Debris

supernova ejects $> 90\%$ of star's initial mass

Ejecta are:

1. hot
2. fast—up to $10\%c$
3. enriched with products of nuclear burning
heavy elements (e.g., O, iron)

www: Cas A Chandra image

most of the elements in the periodic table
(i.e., most of the diversity of the elements) originate in super-
nova explosions
we are made atoms once in exploding stars!

Nucleosynthesis

cosmic production of elements
low-mass stars are source of C
Supernovae are source of O, Si, Fe ...

www: circle of life cartoon

iClicker Poll: Supernova Neutrinos

We saw that the Sun is a confirmed source of neutrinos in fact: a few percent of the Sun's luminosity (energy release) is in neutrinos rather than light

Now consider a massive star, exploding as a supernova and vote your conscience:

Which best describes a supernova's energy release?

A < 1% of energy released in neutrinos, > 99% in photons

B \approx 50% of energy released in neutrinos, \approx 50% in photons

C > 99% of energy released in neutrinos, < 1% in photons

Supernova Neutrinos

In supernova explosion, core compressed to huge density
→ also huge temperature: $> 10^9$ K!

particles in core have huge energies: $kT > 10^6$ eV $\approx m_e c^2$!

in this energetic environment, neutrinos produced abundantly
much more so than in the Sun

also: supernova core so dense that even neutrinos interact in it
scatter repeatedly before leaving core

theoretical predictions:

- huge burst of neutrinos created in explosion
- $> 99\%$ of supernova energy release is in neutrinos!
- scatterings in dense core → signal spread over several seconds

Q: how to test this?

Historical Supernovae

supernovae rare: only ~ 3 /century in our Galaxy

Supernova 1054 “guest star” in Taurus
no record in Europe, but noted by Chinese, Anasazi (Pueblos)
www: Anasazi drawing, Y1K, www: present-day view: Y2K

Supernova 1572 Tycho www: sketch

On the 11th day of November in the evening after sunset ... I noticed that a new and unusual star, surpassing the other stars in brilliancy, was shining ... and since I had, from boyhood, known all the stars of the heavens perfectly, it was quite evident to me that there had never been any star in that place of the sky ...

I was so astonished of this sight ... A miracle indeed, one that has never been previously seen before our time, in any age since the beginning of the world.

– Tycho Brahe

Q: What did Tycho get right? Where was he wrong?

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*Q: What did Tycho get **right**? Where was he **wrong**?*