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 glamourous 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 $M < 0.9 M_\odot$*?*

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

Lives and Deaths of Stars

a star’s life history, death controlled by it **mass**

$M < 0.9 M_\odot$

history like that of the Sun to date
burn H $\rightarrow$ He
lifetime $>$ age of universe: live “forever”
i.e., none have yet died

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

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

$M > 8 M_\odot$

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 $\rightarrow$ heating $\rightarrow$ ignition $\rightarrow$ burning

C+He $\rightarrow$ O

O+He $\rightarrow$ neon

... up to iron

ash $\rightarrow$ 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
$\rightarrow$ 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:
$\rightarrow$ core collapses!
$\rightarrow$ speeds $\sim 10\% c$!
$\rightarrow$ overlying layers lose support, collapse too

Supernova Explosions (Type II)

Gravitational Collapse

core compression to tiny volume!

$\rightarrow$ nuclei "touch": nuclear density

very hard to compress more!

core $\rightarrow$ giant atomic nucleus, supported by nuclear force

infalling envelope "bounces" off stiff core

ejected at high speed (up to 10% c)

$\rightarrow$ 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 supernova 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
$\rightarrow$ 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 abdunantly
much moreso 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 $\rightarrow$ 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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