

Astro 596/496 NPA
Lecture 30
Nov. 2, 2009

Announcements:

- **No class meeting Wednesday!**
- Problem Set 5 due Friday ... but next Monday okay too
- Astro Colloquium here, tomorrow, **3:30pm**
George Sonneborn (NASA) on *James Webb Space Telescope*
- Physics Colloquium Thursday, 4pm, 141 Loomis
Matthew Strassler (Rutgers) on the *Large Hadronic Collider*

Supernova Energetics:

- mechanical (kinetic) energy in visible (baryonic) explosion
 $E_{\text{ejecta}} \sim M_{\text{ej}} v^2 \sim 10^{51} \text{ erg} \equiv 1 \text{ foe}$
- explosion energy release: grav binding of proto-neutron star
 $\Delta E \sim GM_{\text{NS}}^2/R_{\text{NS}} \sim 3 \times 10^{53} \text{ erg} = 300 \text{ foe}$

Q: *Where does the rest go?*

Q: *Implications for models of baryonic explosion?*

Supernova Neutrinos

two phases of neutrino emission:

1. **neutronization**
2. **thermal emission**

neutronization neutrinos produced before collapse
emitted over < 1 sec, leave freely

during collapse: thermal ν s still produced, initially leave freely
but core \rightarrow nuke density:

- very high $T \sim 4 - 8$ MeV $\sim 10^{10}$ K
- very high $n_\nu \sim T^3$

neutrino mean free path $\ell_\nu = 1/(n_{\text{nuc}}\sigma_\nu)$ becomes small
i.e.: $\ell_\nu \lesssim R_{\text{NS}}$

- ~
- Q: *what happens to these thermal neutrinos?*
 - Q: *will they ever escape? if so, how?*
 - Q: *neutrino telescope time signature? flavors? anti- ν ?*

Supernova Neutrinos

when dense core has $\ell_\nu \lesssim R_{\text{NS}}$: neutrinos trapped
proto-neutron star develops “neutrinosphere”
size set by radius where ~ 1 scattering to go: $r \sim \ell_\nu(r)$

inside r_ν : weak equilibrium \rightarrow “neutrino star”

- all species ν_e, ν_μ, ν_τ and $\bar{\nu}_e, \bar{\nu}_\mu, \bar{\nu}_\tau \approx$ equally populated
- ν_e have extra charged-current interactions
slightly different T_ν and r_ν

neutrinos still leave, but must diffuse

emit neutrinos & energy (cool) over diffusion time

$$\tau_{\text{diff}} = 3r^2/\ell_\nu \sim 10 \text{ s}$$

ω

Q: how to test this? Two ways! ...only one worked so far...

Supernova 1987A

explosion: Feb 23, 1987, in Large Magellanic Cloud (LMC)

$d_{\text{LMC}} \sim 50$ kpc – nearest (known) event in centuries spectrum:
shows H: Type II event → core collapse pre-explosion images:
progenitor $M \sim 20M_{\odot}$ blue supergiant

(baryonic) explosion energy 1.4 ± 0.6 foe

no pulsar seen (yet) → could there be a black hole instead?

ejecta: $M(\text{O}) \sim 2M_{\odot}$ observed

also N, Ne, Mg, Ni ...

↳ light echoes: outburst reflections off surrounding material
allow for 3-D reconstruction of pre-explosion environment!

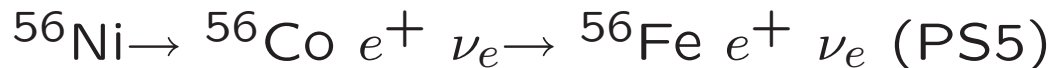
SN1987A: Light Curve

light curve: luminosity L vs t

www: 1987A bolometric (all-wavelength) light curve

- initially, powered by thermal energy, then adiabatically cool

- after ~ 1 month: powered by ^{56}Ni decay:



Q: how can you test that this is the power source?

- really: decay to excited state $^{56}\text{Ni} \rightarrow ^{56}\text{Co}^* \rightarrow ^{56}\text{Co}^{\text{gs}} + \gamma$
 ^{56}Co de-excitation γ s seen at 0.847 MeV and 1.238 MeV

but: seen earlier than expected for onion-skin star

Q: what does this mean?

SN 1987A Neutrino Signal

SN 1987A detected in neutrinos

first extrasolar (in fact, extragalactic!) ν s
birth of neutrino astrophysics

Reliable detections: water Čerenkov

- Kamiokande, Japan
- IMB, Ohio, USA

observed ~ 19 neutrinos (mostly $\bar{\nu}_e$) in 12 sec

www: ‘‘neutrino curve’’

detected \sim few hrs before optical signal

Q: Why?

o Q: what info—qualitative and quantitative—do the ν s give?

Qualitatively

neutrino detection demonstrates basic correctness of core-collapse picture

Quantitatively

ν time spread: probes diffusion from protoneutron star

ν flux, energies: $\langle E_\nu \rangle^{\text{obs}} \sim 15 \text{ MeV}$

\Rightarrow -neutrino energy release $\mathcal{E}_{\bar{\nu}_e} \sim \mathcal{E}_\nu/6 \sim 8 \times 10^{52} \text{ erg}$

Q: why divide by 6?

$\Rightarrow \mathcal{E}_\nu \sim 4 \times 10^{53} \text{ erg}$

\Rightarrow observational confirmation:

by far, most ΔE released in ν s

\Rightarrow basic core collapse picture on firm ground!

Also: signal probes ν & particle physics

✓

www: 2002 Nobel Prize in Physics: Masatoshi Koshiba

Nearby Supernovae: May We Have Another?

Today: ready for another SN!

for event at 10 kpc, Super-K will see ~ 5000 events
gravity waves?

candidates: Betelgeuse? Eta Carinae?

But don't get too close!

- minimum safe distance: ~ 8 pc

Q: why would this ruin your whole day?

Q: should we alert Homeland Security today?