Ay 20 # 24 — Supernovae

Supernovae are the observed deaths of stars.

* Energetics: for $M = 10 M_\odot$, $R \sim 3 R_\odot$, the gravitational binding energy is

$$E_g \sim \frac{3}{5}\frac{GM^2}{R} \sim 10^{50} \text{ erg}.$$

Similarly, for a $M = 1.4 M_\odot$, $R = 0.02 R_\odot$ white dwarf,

$$E_g \sim 2 \times 10^{51} \text{ erg}.$$

Of course, these are typical supernova (kinetic) energies!

Observed bolometric luminosities ×time of 10^{49}–10^{51} erg, and peak @ $\sim 10^{43}$ erg $s^{-1} \sim 10^9 L_\odot$.

SN1987A was observed to produce 10^{53} erg in neutrinos. Electron capture mechanism (only in heavy nuclei) $e^- + p \to n + \nu_e$ releases ~ 30 MeV / n. Thus, $\sim 1.7 M_\odot$ of protons need to be converted to neutrons.

Supernovae have a ridiculous classification scheme: Type I a – Si II, b – no Si, but He – c – no He. All no H.

What happens to accretion onto ONeMg WDs drives above the Chandrasekhar limit?

Type II : hydrogen present.

* Type Ia supernovae.

An increase in the mass of a C-O WD (through e.g., accretion from a companion, collision with another C-O WD) to near the Chandrasekhar limit ($\sim 1\%$)

→ convection triggered ($\sim 10^3$ yr)

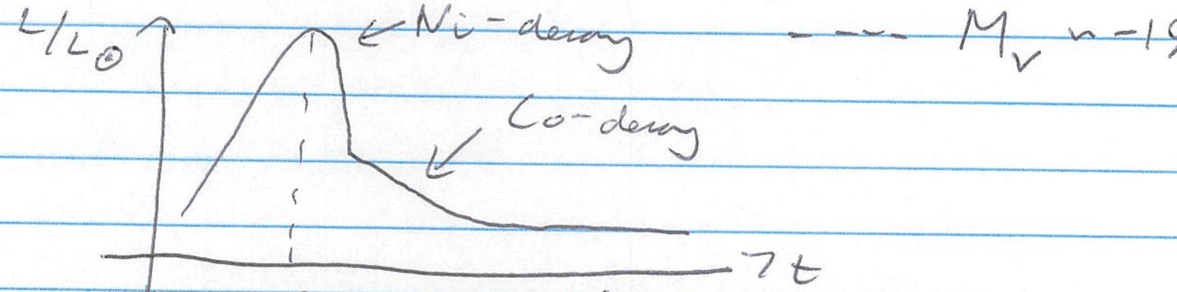
→ C - fusion deflagration wave

→ sudden consumption of C & O (few s)

→ $\sim 10^{51}$ erg deposited in star

→ shockwave @ $5\times10^3 - 2\times10^4$ km s^{-1}

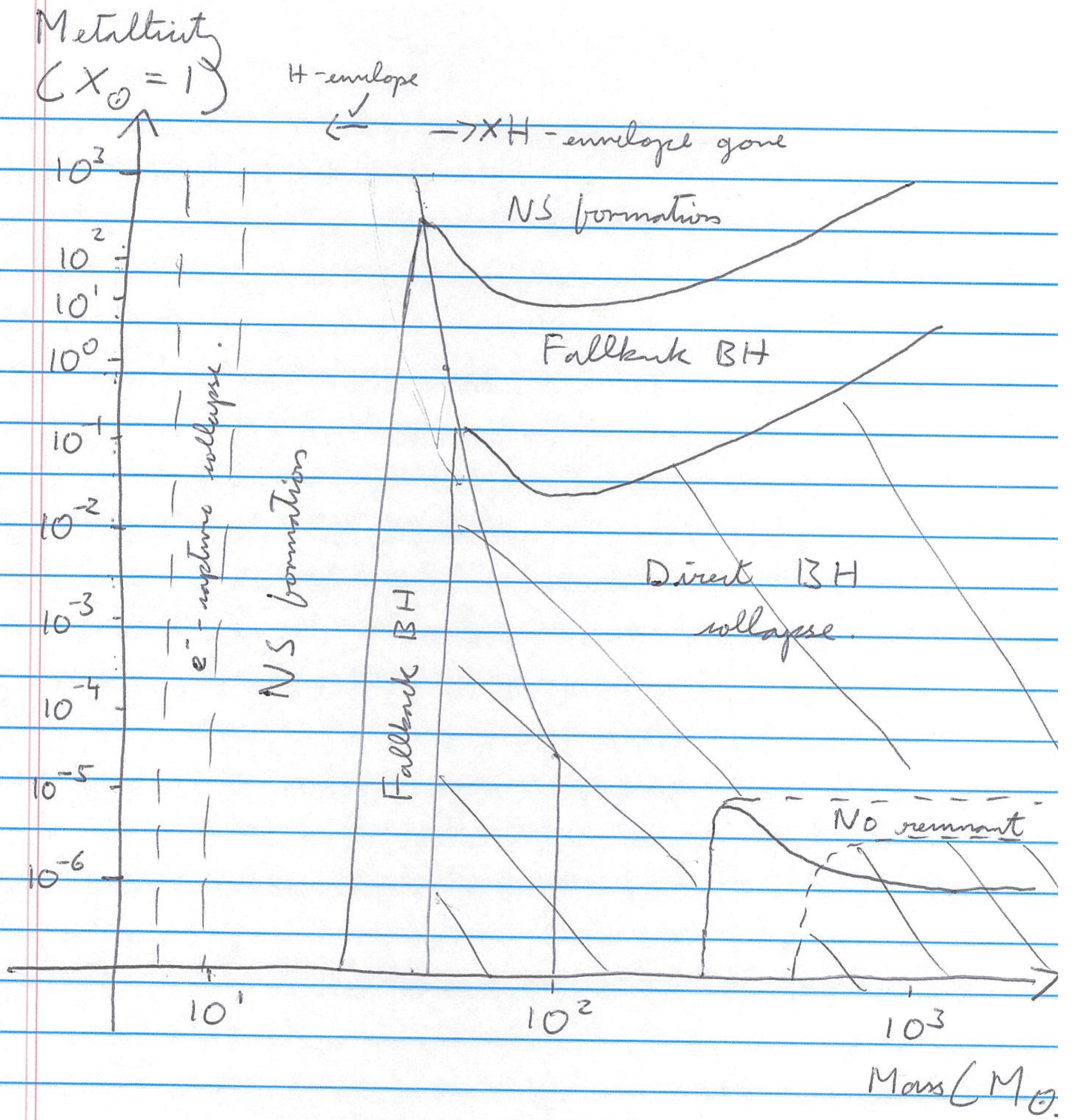
→ decay of $^{56}Ni \to {}^{56}Co \to {}^{56}Fe$ powers characteristic lightcurve



~20 days - related to L_{peak}!

* Core-collapse supernovae.

The end products of $\gtrsim 9 M_\odot$ stars.



* Electron capture in ONeMg core → NS formation. (9-10 $M_\odot$, II-P SN)

* Iron core collapse after exceeding Chandrasekhar limit.

10-25 $M_\odot$ -> II-P supernova, NS formation

@ high metallicity, 25-40 $M_\odot$ -> II-L/b SN, NS formation

>40 $M_\odot$ -> NS, Ib/c SN.

25-40 $M_\odot$ normally forms BH after fallback onto NS. (II-L/b)

also >40 $M_\odot$ @ solar metallicity.

In other cases, there is direct collapse to a BH because of the lack of metal opacity

* Pair-instability SNe (runaway pair-production due to γ-rays in core) occur between 140-250 $M_\odot$, leaving no remnant. $\gamma \to e^- + e^+$ removes radiation pressure, leading to runaway fusion. Low metallicity II-P supernova.
* Finally, low-metallicity >250 $M_\odot$ stars photodisintegrate the cores due to γ-ray emission, driving rapid collapse to BHs.

Taxonomy: II-P has light-curve plateau, II-L has linear decrease in lightcurve. II-b is Type II that becomes I-b.

Supernovae explode due to a rebounding shock following core collapse, or a shock powered by runaway fusion.

What we see is a rapidly expanding photosphere with heavily Doppler-broadened lines. Nucleosynthesis during collapse (rapid capture of neutrons: r-process), fusion up to ^{34}S, photodisintegration & further burning between ^{36}Ar & ^{56}Ni.

<u>Open questions</u>

* What re-accelerates initially stalled shocks in CC SNe?
* What are the progenitors of Type Ia SNe?
* Are theories about direct BH collapse correct
* How do pre-supernova mass-loss episodes influence the observations?
* How do jets launched from accretion onto NSs or BHs, sometimes observed as GRBs, affect the observations?
* What were the fates of the first stars, formed in metal-free gas?