Transient <-> some equilibrium broken

release energy $t_{rel} \lesssim t_{dyn} << t_{thermal}$

- supernovae $t_{rel} < t_{dyn} << t_{th}$
- nova $(t_{rel} > t_{dyn}) << t_{th}$
- variable/eruption $t_{rel} \sim t_{dyn} << t_{th}$
- mergers / TDE
- accretion disk instab. $(t_{rel} > t_{dyn}) << t_{th}$

Others : magnetar flare : reconnection

solar flare $t_{rel} \lesssim t_{Alven}$

→ typically get shocks & heat the whole stars

Exceptions : accr. disk instab → remains grav. confined

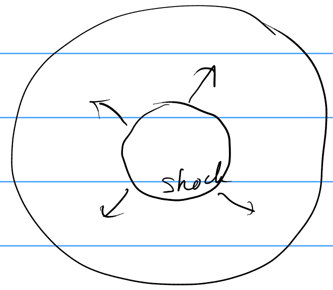
X-ray burst on NS

magnetar flare → part escapes / → part magn. confined

Star gets shocked as a whole

What do we see

* Initially, nothing
* shock break-out
  → flash of light
  → Star is hot throughout



* rapid expansion
  → start to cool

$$t_{exp} = \frac{R}{v} = \frac{100 R_\odot}{7000 \, km/s} = 10^4$$

* heat starts diffusing out

$$t_{diff} = \frac{R}{c} \frac{R}{\ell_{mfp}} = \frac{R^2 \kappa\rho}{c}$$

$$\ell_{mfp} = 1/\kappa\rho$$

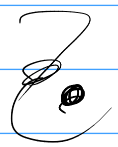
What keeps the ejecta hot?

* embedded heating : radioactive decay ^{56}Ni
  recombination of H
  internal shocks
* engine — sending out shells or jets
  magnetar → superluminous SN
* exterior dense circumstellar material
  ⇒ causes shocks & heating
  (also why SNR are hot ↔ interaction w/ ISM)

Observed prop of a SN

L? like a galaxy

$\sim 10^{11} L_\odot$



Arnett: $\sim 10^{10} L_\odot$

assume $T \simeq T_\odot$ $\}$ $R \sim 10^5 R_\odot$

reality $T \gtrsim 2T_\odot \Rightarrow R \simeq 100\,AU$

LARGE RADIUS

duration? weeks – months $2 \times 10^6\,s$

$10^{10} L_\odot \times 2 \times 10^6\,s = 10^{50}\,ergs$

LOTS OF ENERGY

Expansion vel.? $10^4\,km/s$

$t_{exp} = R/v \simeq 2 \times 10^6\,s$

$E_{kin} = \frac{1}{2} M v^2 \simeq 10^{51} \frac{M}{M_\odot}\,ergs$ f.o.e. Bethe

What carries the thermal energy?

$T = 10^4 K$

$\rho = \frac{M_\odot}{\frac{4\pi}{3}(2 \times 10^{15}\,cm)^3} \simeq 10^{-13}\,g/cm^3 \Rightarrow n \simeq 3 \times 10^{10}/cm^3 \Rightarrow \frac{\rho}{\mu m_H} kT = 0.05\,erg/cm^3$

$\frac{1}{3} a T^4 = 25\,erg/cm^3$

FIRE BALL

Simple lightcurve model

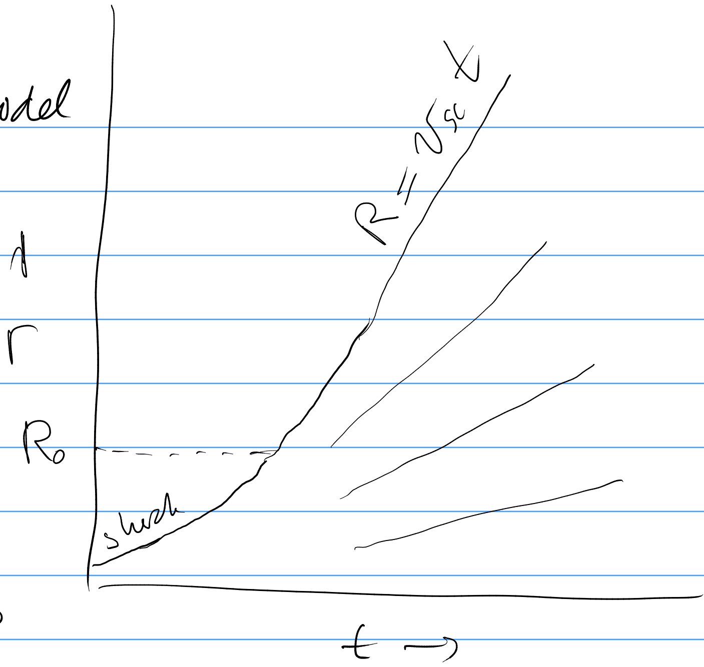
Acceleration happened within a few R_*

→ take v = constant

homologous

$$\frac{v(r)}{v(R)} = \frac{r}{R}$$

$$\frac{\rho(t)}{\rho_0} = \left(\frac{R(t)}{R_0}\right)^{-3}$$



ρ roughly constant for most mass

→ simplifies diffusion problem