Introduction

Cosmic explosions – stellar transients – Novae, Supernovae, Gamma Ray Bursts, ...

Motivation:

- Fascinating events: bright, temporary objects, driven by exploration, observations. Usually new discoveries only understood/physically explained much later
  Still a lot of work todo for theorists! (and observers)
- Interesting physical problems involving many areas of physics:
  - Gas dynamics, gravity
  - Nuclear physics (fusion, radioactive decay)
  - Atomic physics (Radiation)
  - Plasma physics, (Particle acceleration, CR's)
  - QM (EOS)
  - Electrodynamics (Radiation, mag. fields, ..)
- Relevance for other fields of physics
  - galaxy evolution (dynamics, feedback)
  - Stellar evolution (→ end points)
  - Chemical enrichment (Nucleosynthesis for everything heavier > O)
  - Distance measurements/cosmology (SNe Ia)
  - Tests of GR, fundamental physics
  - ...

Finding transients

Historic observations of galactic SN

Around 20 SN recorded by Chinese astronomers ~~in~~ in 2000 yrs

Famous examples:

SN 1006: Described to have "quarter of brightness of the Moon"
recorded in Europe, Egypt, Iraq, China Japan

SN 1054: Recorded by Arab, Chinese, Japanese
four times as bright as Venus, visible during daytime
for ~20 days,

SN 1572: Described in detail by Tycho Brahe

SN 1604: Systematically studied by Kepler,
last visible SN in Milky Way

Until ~ 1990.

Finding SN and Novae manually with telescopes

Around 200 known SN

Repeatedly observe selected galaxies, compare

(R. Evans found 42 SN by comparing ~1500 galaxies to memory)

Now: robotic telescopes, automatic comparisons find
candidate transients, ~ 10^3 SN found per year

PAN-STARRS: ~ 10^4 SN per year

LSST: ~ 10^3 per day

Swift / FERMI: ~ 100 GRBs / year

FRBs: 6! total by chance

Remnants (in MW and nearby galaxies)

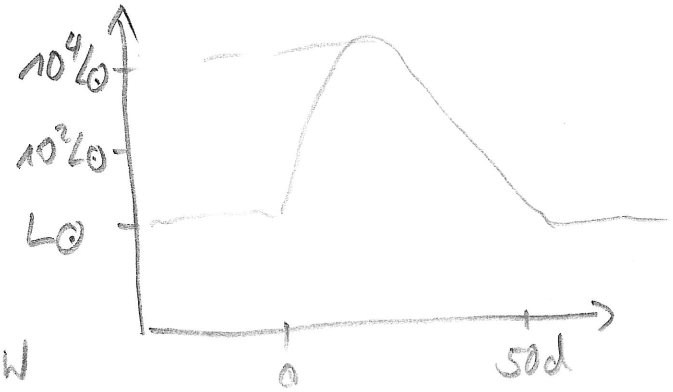
Lightcurves

Nova

$L \lesssim 10^5 L_\odot$

duration up to a few 100 days

~ 100 per year in MW

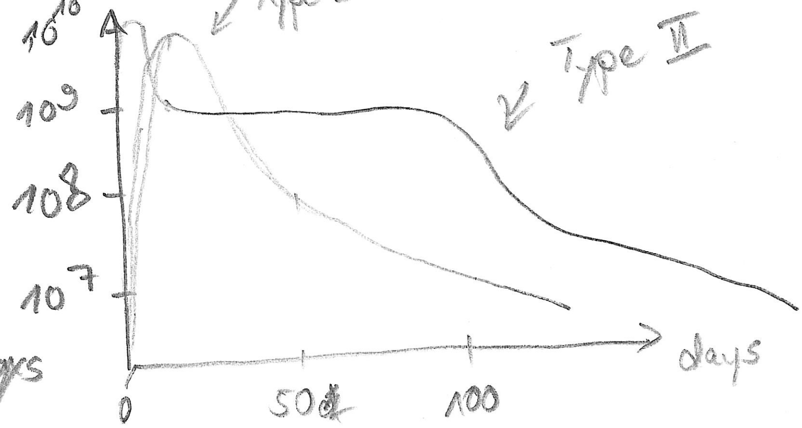


Supernova

~ 1-2 per century in MW

L up to $10^{10} L_\odot$

duration 10 - 200 days



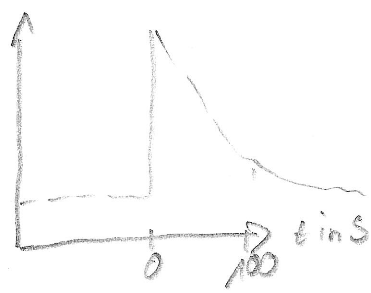
Gamma Ray Bursts

None observed in MW

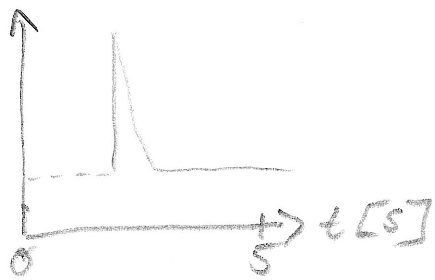
estimated rate:
$10^{-5} - 10^{-6}$ per year in MW

but: not isotropic!

GRB 990316A:



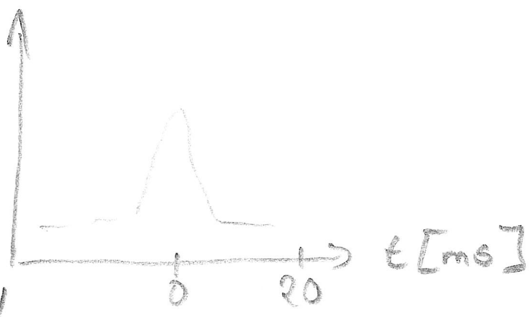
GRB 910711:



Fast Radio Bursts:

- Extragalactic
- Rate ~ $3 \cdot 10^4$ per day on full sky

~ 10^{38} erg total energy in Radio if isotropic



What powers the LC?

Adiabatic expansion: $T_{new} = T_{old} \left(\frac{V_{old}}{V_{new}} \right)^{\varkappa - 1}$ $\varkappa = \frac{5}{3}$

$= T_{old} \cdot \left(\frac{V_{old}}{V_{new}} \right)^{2/3}$

Expansion velocity: $v \approx 10^4 \frac{km}{s} = 10^9 \frac{cm}{s}$ for SN, Novae

$R_{RG} \sim 100 R_\odot = 10^{13}$ cm

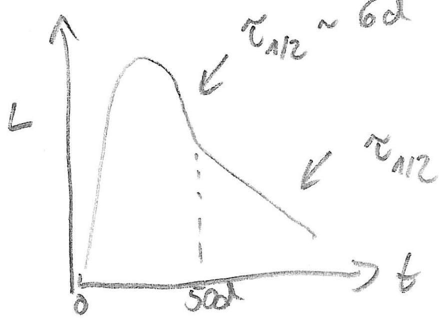
$1d \approx 8.6 \cdot 10^4 s \sim 10^5 s$

$\Rightarrow R_{1D} \sim 10^{14}$ cm RG: $T_{new,1d} = T_{old} \cdot 10^{-6}$

$R_{WD} \approx 10^8$ cm $\Rightarrow T_{new,1d} = T_{old} \cdot 10^{-12}$

$\Rightarrow$ LC's not powered by heat of the explosion

LC of Type Ia SN:



$\tau_{1/2} \sim 6d$ → Radioactive decay: $^{56}Ni \rightarrow {}^{56}Co$

$\tau_{1/2} \sim 77d$ → $^{56}Co \rightarrow {}^{56}Fe$ (stable)

To power optical LC:

SN Ia: 0.5 - 1.0 $M_\odot$ ^{56}Ni

SN II: ~ 0.1 $M_\odot$ ^{56}Ni, but varies a lot

Additional power source: Interaction with CSM

Size of the explosion from causality:

	Change on	Max size
(Super) Novae	$\sim 1d$	$3\,10^{10}\,\frac{cm}{s} \cdot 10^5\,s \approx 10^{15}\,cm$
GRBs:	$\sim 1s - 100\,s$	$10^{10} - 10^{12}\,cm$ remember: $R_\odot \sim 10^{11}\,cm$
FRBs:	$\sim 1ms$	$10^7\,cm \Rightarrow NS?$

Reasonable velocities: $v_{ej} \sim 10^4\,\frac{km}{s} \sim 0.1c$

($\hookrightarrow R \leq 10^{14}\,cm,\; 10^9\,cm,\; ??$)

Total energy in radiation:

Nova: $10^5\,L_\odot \cdot 100d \sim 10^{38}\,\frac{erg}{s} \cdot 10^7 s = 10^{45}\,erg$

SN: $10^{10}\,L_\odot \cdot 10d \sim 10^{43}\,\frac{erg}{s} \cdot 10^6 s = 10^{49}\,erg$

GRBs: Isotropic $\sim 10^{18}\,L_\odot \cdot 10s \sim 10^{51}\,\frac{erg}{s} \cdot 10\,s = 10^{52}\,erg$

$\hookrightarrow$ Prob. not isotropic

Focused beam $\sim$ few degree $\Rightarrow E \sim 10^{49}\,erg$

FRB's: Isotropic: $\sim 10^{38}\,erg$

But: Kinetic energy much larger:

SN: $E_{KIN} = \frac{1}{2} m v^2 \sim \frac{1}{2} \cdot 1 M_\odot \cdot \left(10^4\,\frac{km}{s}\right)^2 = 10^{33} g \cdot \left(10^9\,\frac{cm}{s}\right)^2 =$

$= 10^{51}\,erg$

Possible energy sources:

- Gravitational energy $U = \frac{3GM^2}{5r}$ spherical mass, uniform density

Collapse of stellar core to NS:

$r_{core} \sim 5000\,km = 5 \cdot 10^8\,cm$

$r_{NS} \sim 5\,km = 5 \cdot 10^5\,cm$

$\Delta U = U_2 - U_1 =$

$= \frac{3GM^2}{5}\left(\frac{1}{r_{NS}} - \frac{1}{r_{core}}\right) =$

$= \frac{3GM^2}{5 r_{NS}} \approx 3 \cdot 10^{50}\,erg$

No problem with timescales...

- Nuclear energy

$1eV = 1.6 \cdot 10^{-12}\,erg$

BE ^4He : $7.1 \frac{MeV}{\text{per nucleon}} = 7.1 \cdot 10^6\,eV \approx 3 \cdot 10^{-6}\,erg$

→ Energy of fusing $1 M_\odot$ of H to ^4He:

$\frac{M}{u} \cdot E = \frac{2 \cdot 10^{33}\,g}{6.4 \cdot 10^{-24}\,g} \cdot 3 \cdot 10^{-6}\,erg \approx 10^{51}\,erg$

Total energy release sun:

$L_\odot \cdot 10^{10}\,yr = 4 \cdot 10^{33}\,\frac{erg}{s} \cdot 10^{10} \cdot 3.1 \cdot 10^7\,s \sim 1.3 \cdot 10^{51}\,erg$

BE ^{12}C : 7,6 MeV/nuc
BE 56 Ni : 8,7 MeV/nuc
} Energy release: 1.1. MeV/nuc

for $1 M_\odot$: $\Delta E \sim 2.2 \cdot 10^{51}\,erg$

^{56}N: 3rd mostbound nucleus (after ^{62}Ni, ^{58}Fe)

but: mostbound with N=Z