Astrophysics of gravitational wave sources

Lecture 2: Introduction to the physics of astronomical transients

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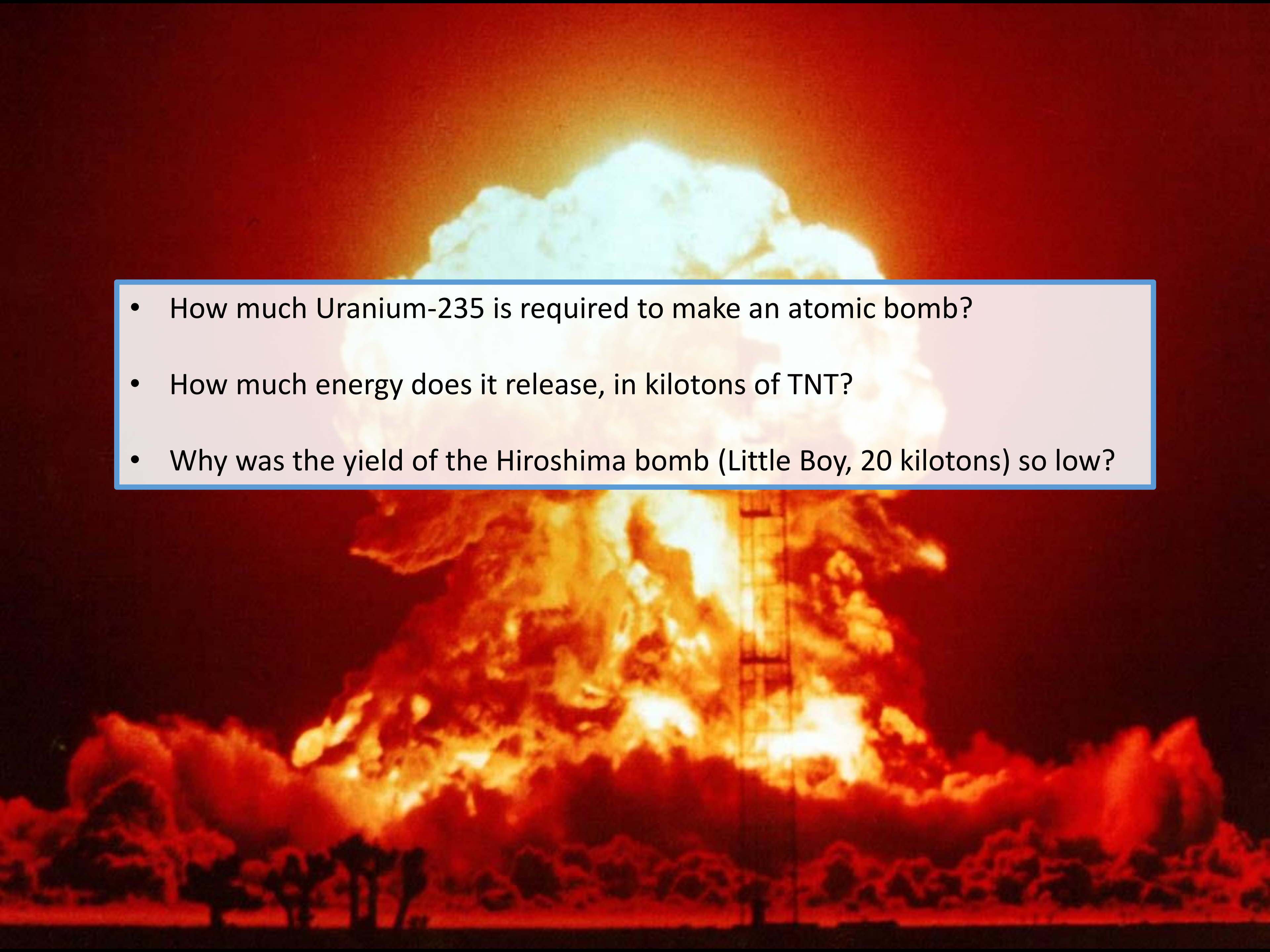
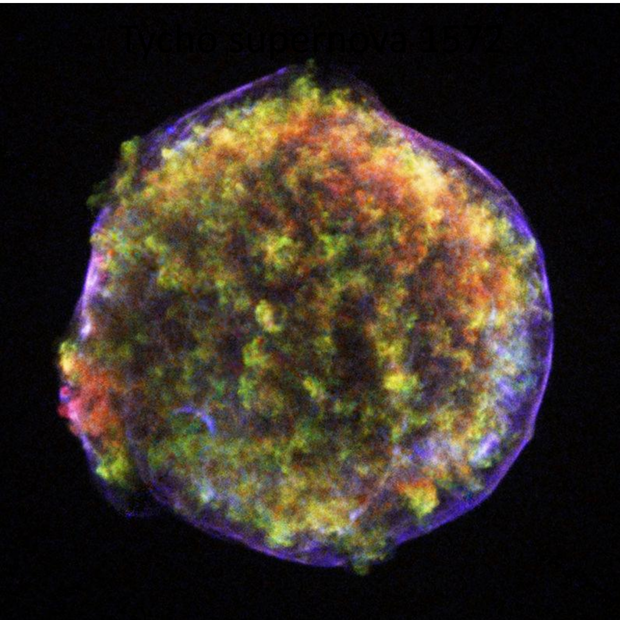
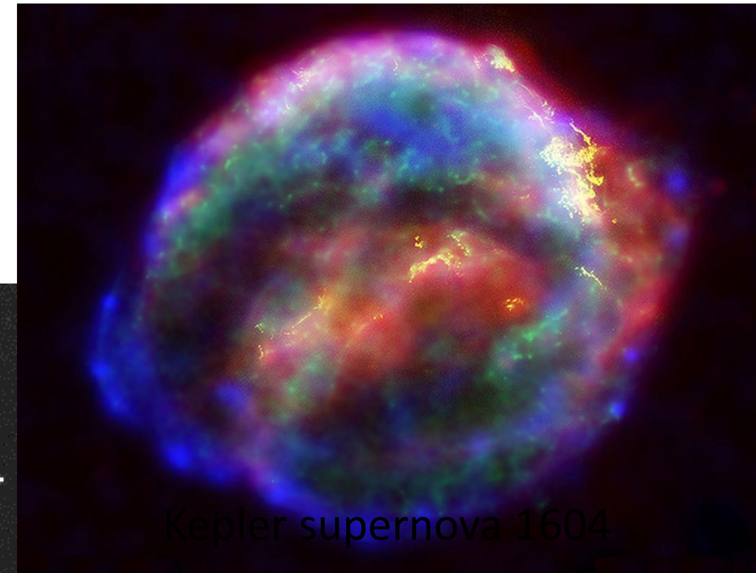


- How much Uranium-235 is required to make an atomic bomb?
- How much energy does it release, in kilotons of TNT?
- Why was the yield of the Hiroshima bomb (Little Boy, 20 kilotons) so low?

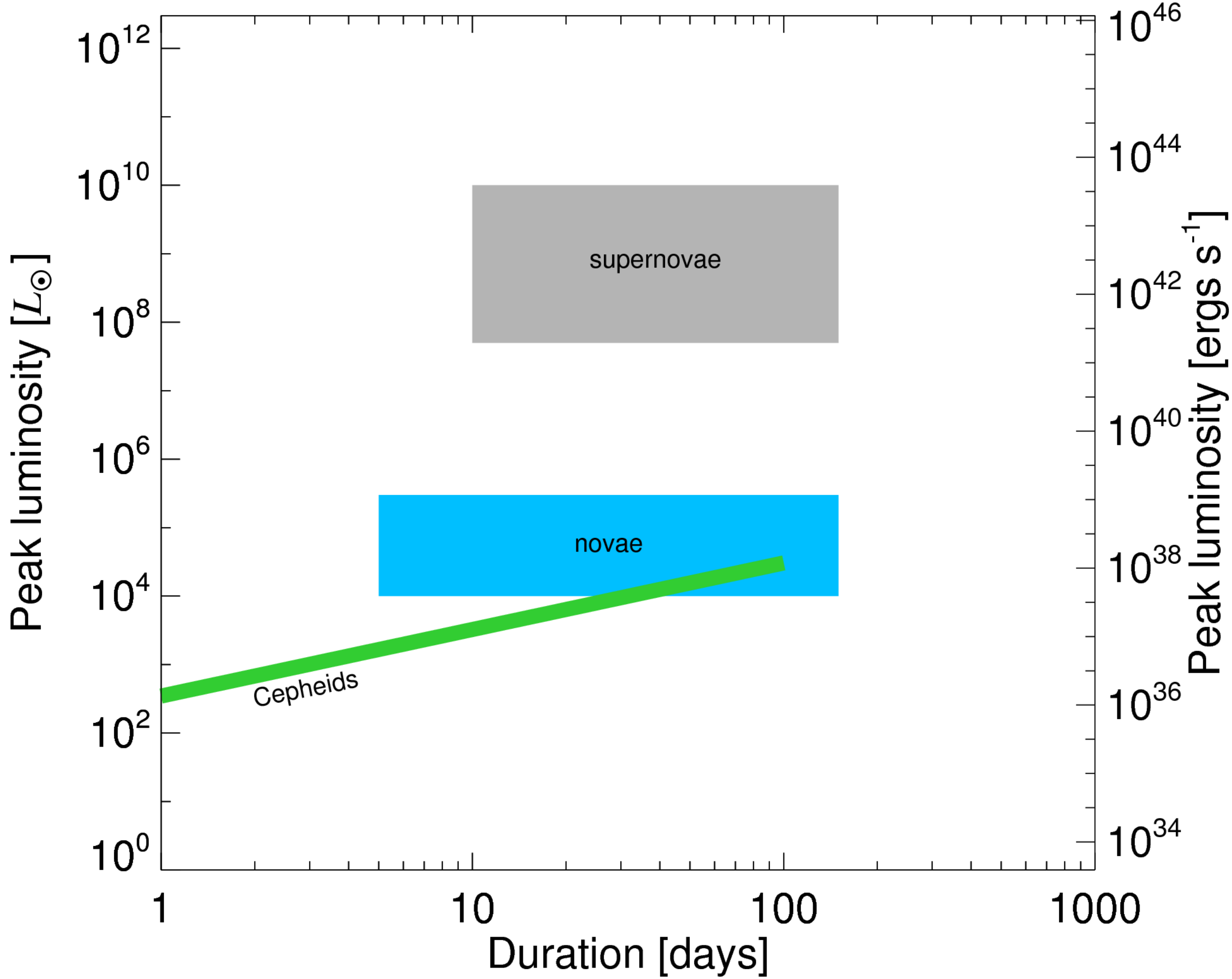
Astronomical transients

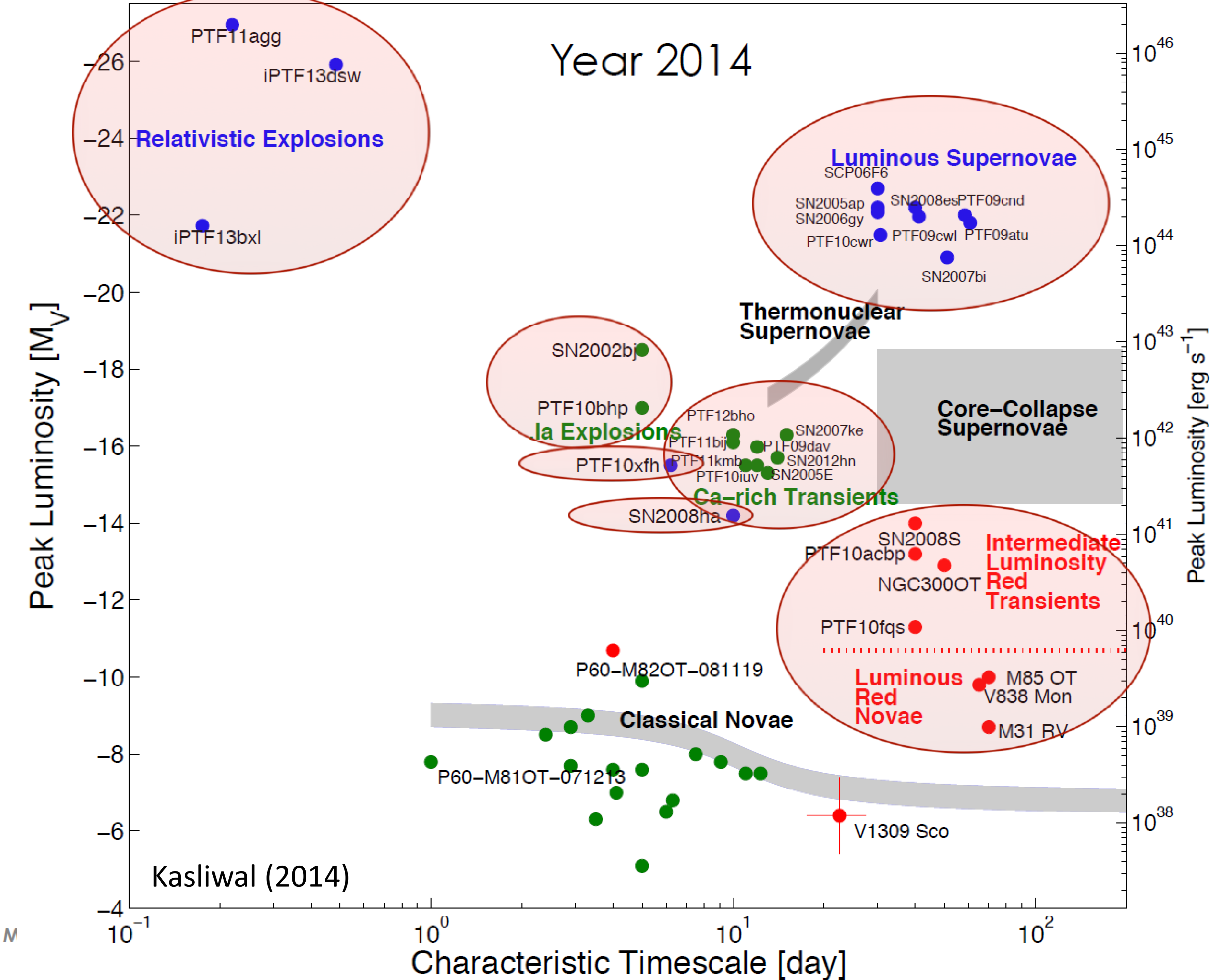
= non-repeating brightenings, “new stars”





Zwicky & Baade(1934)





Year 2014
Relativistic Explosions
PTF11agg
iPTF13dsw
iPTF13bxl
Luminous Supernovae
SCP06F6
SN2005ap
SN2006gy
SN2008es
PTF09cnd
PTF10cwr
PTF09cwl
PTF09atu
SN2007bi
Thermonuclear Supernovae
SN2002bj
PTF10bhp
Ia Explosions
PTF10xfh
SN2008ha
PTF12bho
PTF11bij
PTF11kmb
PTF10iuv
SN2007ke
PTF09dav
SN2012hn
SN2005E
Ca–rich Transients
Core–Collapse Supernovae
SN2008S
PTF10acbp
NGC300OT
PTF10fqs
Intermediate Luminosity Red Transients
Luminous Red Novae
M85 OT
V838 Mon
M31 RV
P60–M82OT–081119
Classical Novae
P60–M81OT–071213
V1309 Sco
Kasliwal (2014)
Peak Luminosity [M_V]
Peak Luminosity [erg s^{-1}]
Characteristic Timescale [day]

Analytic model of light curves of transients

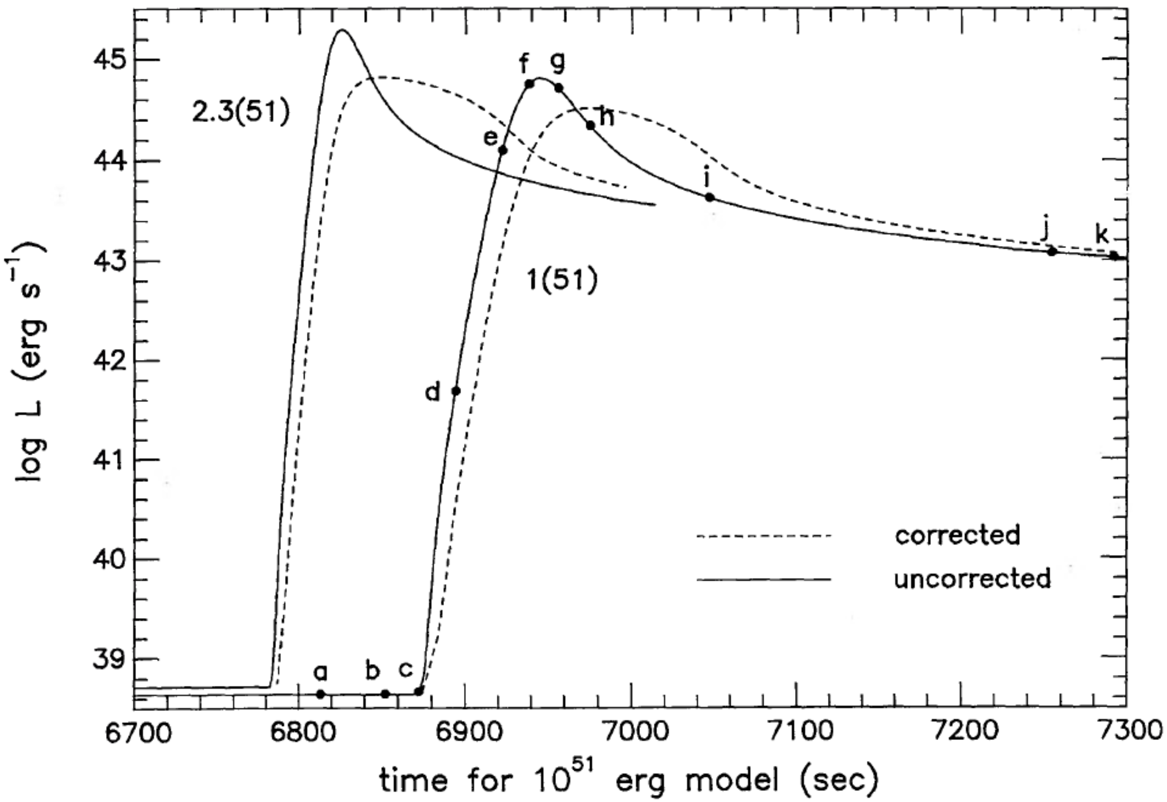
Thermonuclear supernovae

- Nuclear burning of CO white dwarf (likely close to Chandrasekhar limit)
- 10^{51} ergs of energy (1.4 $M_{\odot}$ is ~10^{57} baryons, burning of CO produces 1 MeV/baryon)
- About as much as the Sun in ~10 billion years of its main sequence life

Analytic model of light curves of transients with radioactivity

Shock breakout

Advection time across shock: Δ/v
Diffusion time of photons: $\tau\Delta/c$
Shock optical depth $\tau \sim c/v$
Duration: R/c -> can find the radius of the star!



Ensman & Burrows (1992)

Interaction-powered transients

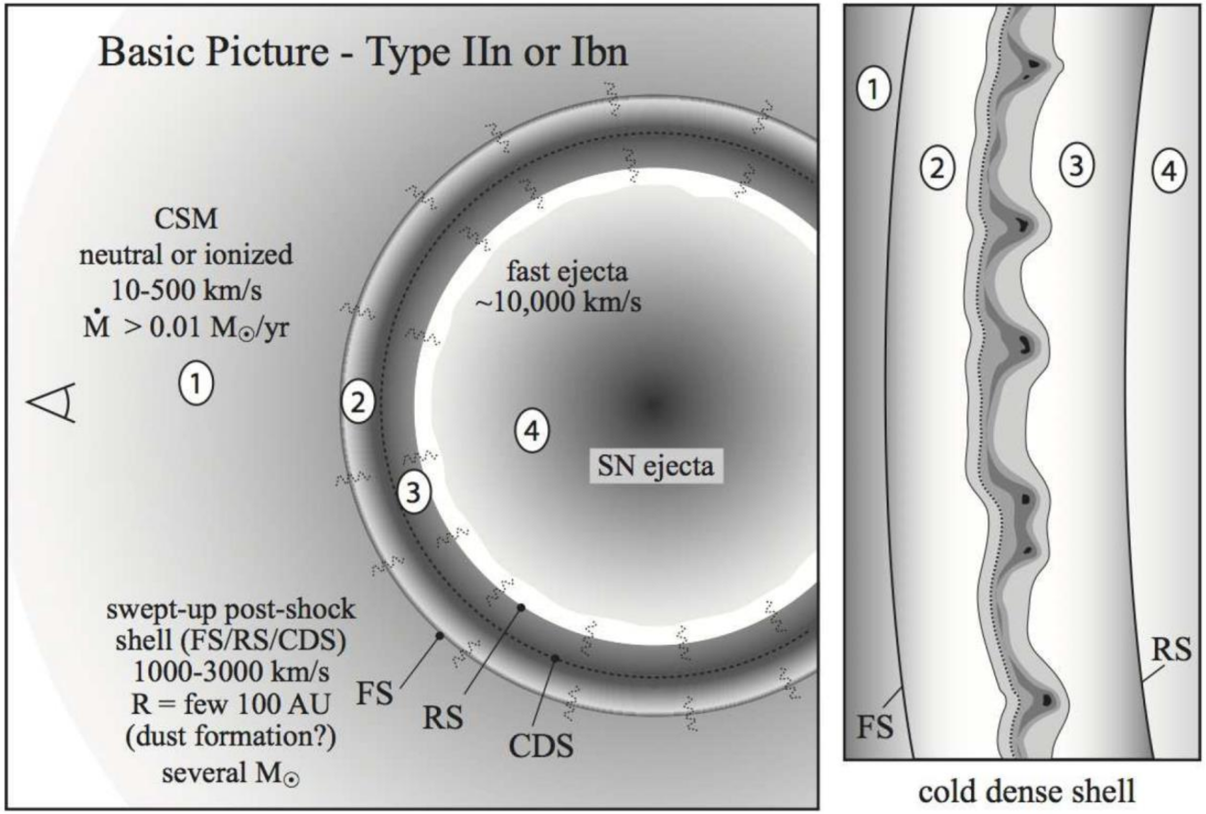


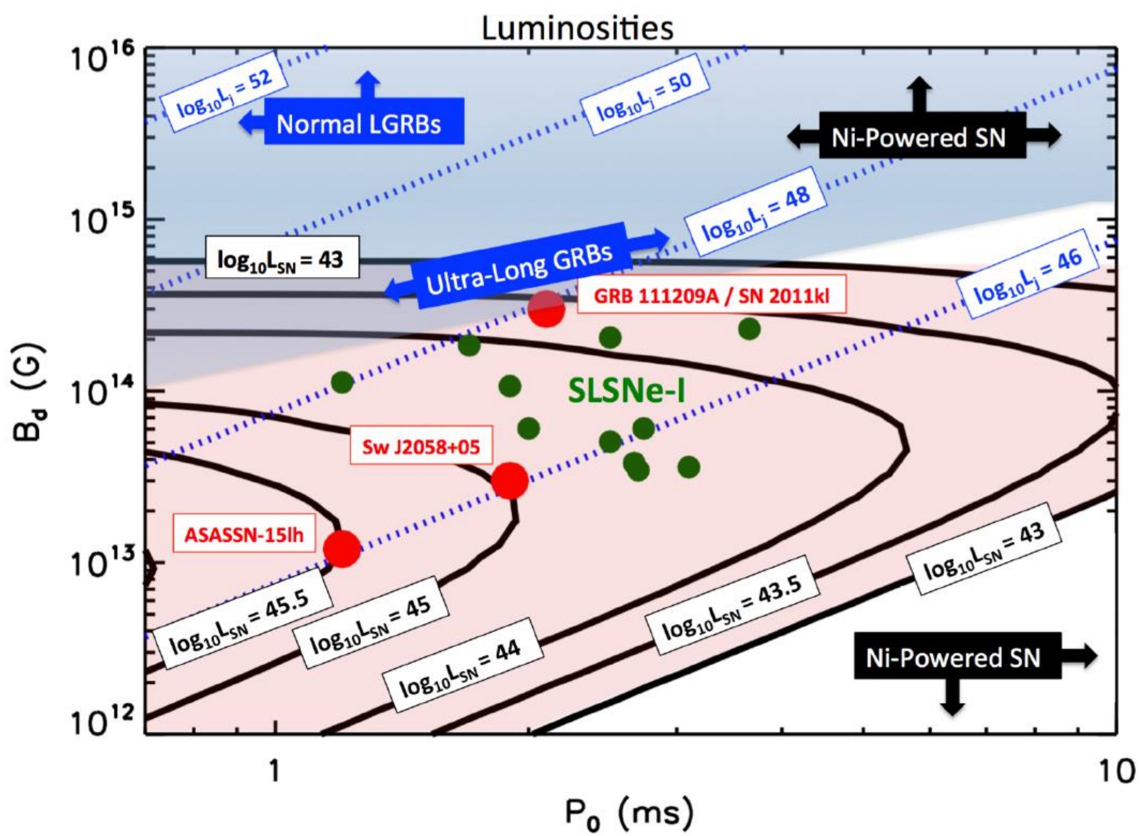
Fig. 1 Sketch of the basic picture in CSM interacting SNe. Four different zones are noted with numbers: (1) the pre-shock CSM, (2) the shocked CSM, (3) the shocked SN ejecta, and (4) the freely expanding SN ejecta. These zones are divided by boundaries corresponding to the forward shock, the reverse shock, and the contact discontinuity between the shocked CSM and shocked ejecta where material cools, mixes via Rayleigh-Taylor instabilities, and piles up. This is often called the cold dense shell (CDS) in a SN IIn or Ibn. The squiggly radial lines are meant as a reminder that X-rays and UV radiation generated in the shock can propagate out to the CSM or inward to the unshocked ejecta, changing the physical state of the gas there. A zoom-in of zones 2 and 3 is shown at the right. In practice, efficient radiative cooling can cause these two zones to collapse to very thin layers, and mixing can make them merge into one thin clumpy shell. This figure is adapted from Smith et al. (2008).

Smith (2017)

Magnetar-powered transients

Rotational energy
$$E_{\rm p} = \frac{I_{\rm ns}\Omega_{\rm i}^2}{2} = 2 \times 10^{50} P_{10}^{-2} \text{ ergs},$$

Spindown timescale
$$t_{\rm p} = \frac{6 I_{\rm ns} c^3}{B^2 R_{\rm ns}^6 \Omega_{\rm i}^2} = 1.3 B_{14}^{-2} P_{10}^{2} \text{ yr},$$



Metzger et al. (2015)