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Long-lived engines in stripped envelope supernovae

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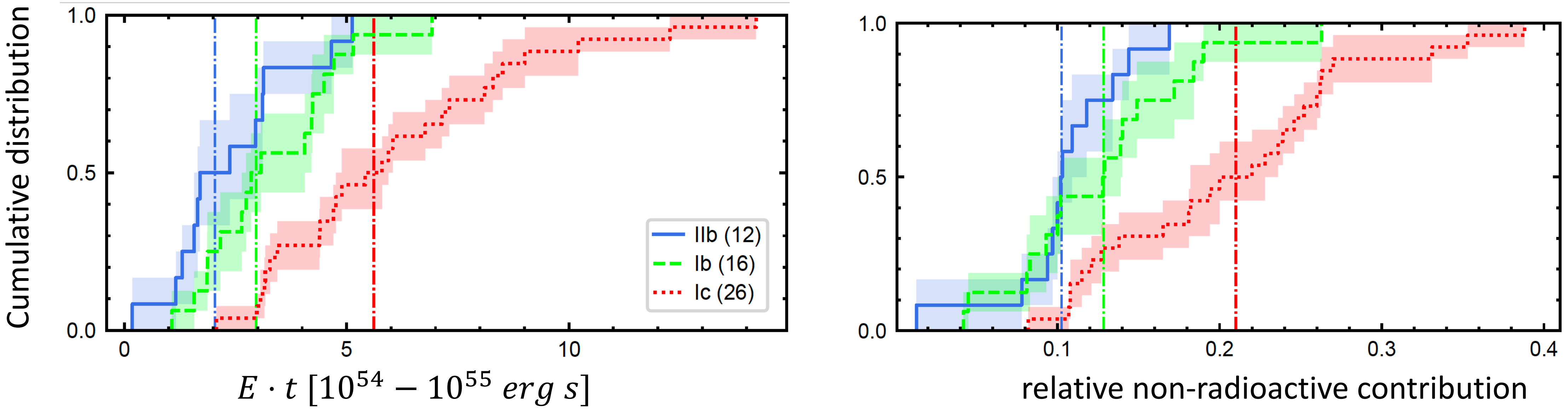
There seems to be a disagreement between the peak luminosity and the radioactive tail of stripped-envelope SNe:

- Sharon & Kushnir 20 find in observations a residual of non-radioactive energy
- Afsariardchi et al., 21 find that in numerical models the Ni cannot explain the peak luminosity
- Ertl et al., 20, Woosley et al., 21 and Sollerman, J. et al. find that explosion models do not produce enough ^{56}Ni to explain the peak luminosity

A sample of 54 regular stripped-envelope SNe

- Measure the ^{56}Ni mass from the tail
- Remove the ^{56}Ni contribution to the light using the Katz integral (Katz et al 2013)
- Measure the non-radioactive residual (Deposited E × Deposition time)



A non-radioactive residual - $E \cdot t \sim 10^{54} - 10^{55}\ erg\ s$

A ~~systematic~~* error; cooling ~~envelope~~ emission; ~~interaction~~; a central engine

*Needs our modeling of the γ-ray escape to be very wrong

$$E_{eng}t_{eng} \sim 10^{54} - 10^{55} erg\ s$$

$$10^{48} - 10^{49}\ erg < E_{eng} < 10^{51} - 10^{52}\ erg$$

$$10^{3}\ s < t_{eng} < 10^{6} s$$

If the engine is a magnetar: $B \approx 10^{15} G$; initial rotation period 1-100 ms

If the engine is accretion over a compact object: accreting $10^{-5} M_{\odot}$ is enough

The Katz integral

(Katz et al . 2013)

A homologous expanding sphere (r=vt) with radiation dominated internal energy

Trapped internal energy (dominated by radiation) — Adiabatic losses — Deposited energy — Emitted energy

$$\frac{dE(t)}{dt} = -\frac{E(t)}{t} + Q_{\mathrm{dep}}(t) - L(t)$$

After some algebra

$$E(t)\,t - E(t_0)\,t_0 = \int_{t_0}^{t} \left(Q_{\mathrm{dep}}(t') - L(t')\right) t'\,dt'.$$

$$E(t)\,t - E(t_0)\,t_0 = \int_{t_0}^{t} \left(Q_{\rm dep}(t') - L(t')\right) t'\,dt'.$$

$E(t) \to 0$

$t \gg t_{diff}$

radioactive decay

Central engine

$$Q_{\rm dep} = Q_{\rm nuc} + Q_{\rm eng}$$

observable

$$LT_{-\rm nuc} \equiv LT(t) - QT_{\rm nuc}(t) \approx ET + QT_{\rm eng}(t) \quad ; \quad t \gg t_{\rm diff}$$

$LT(t) = \int_{t_0}^{t} L(t')\,t'\,dt'$

$QT_{\rm nuc}(t) = \int_{t_0}^{t} Q_{\rm nuc}(t')\,t'\,dt'$

$ET = E(t_0)\,t_0$

$QT_{\rm eng}(t) = \int_{t_0}^{t} Q_{\rm eng}(t')\,t'\,dt'$