大質量星の超新星爆発: ガンマ線バーストと金属欠乏星

冨永 望
(東京大学)

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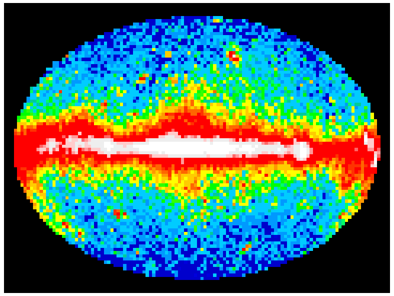
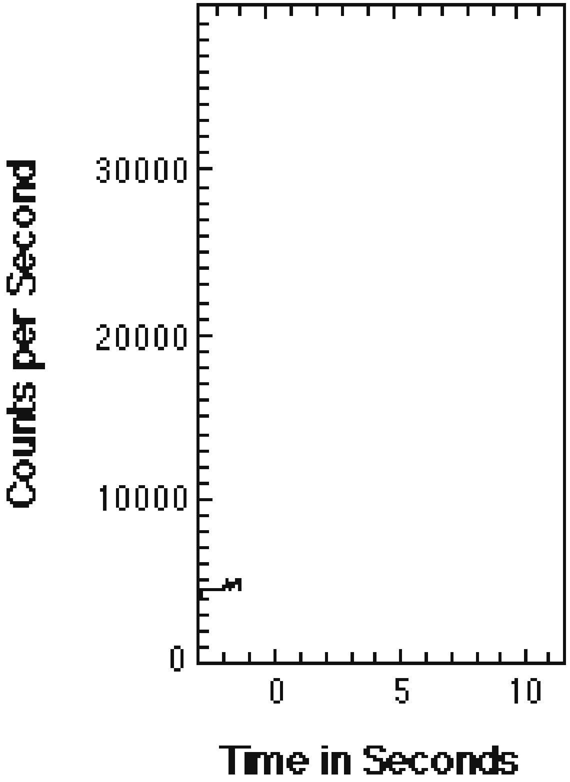
Collaborators:
前田啓一, **梅田秀之**,
野本憲一, **田中雅臣**(**東大**),
岩本信之(JAEA),
P. A. Mazzali(MPA)

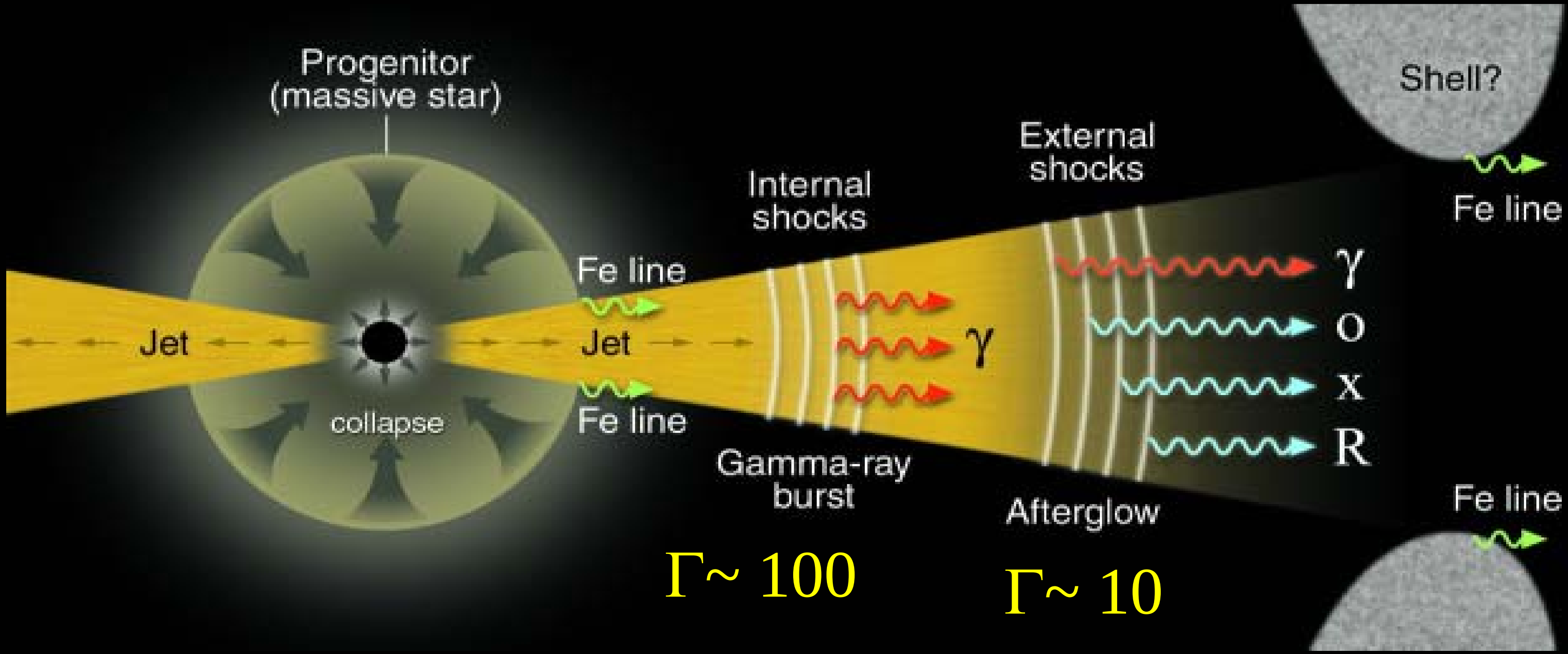
Gamma-ray bursts **(***GRBs***)**

Discovered in 1970's.
Gamma-ray (~100keV) is emitted instantly.





Long GRBs with HNe



Γ~ 100

Γ~ 10

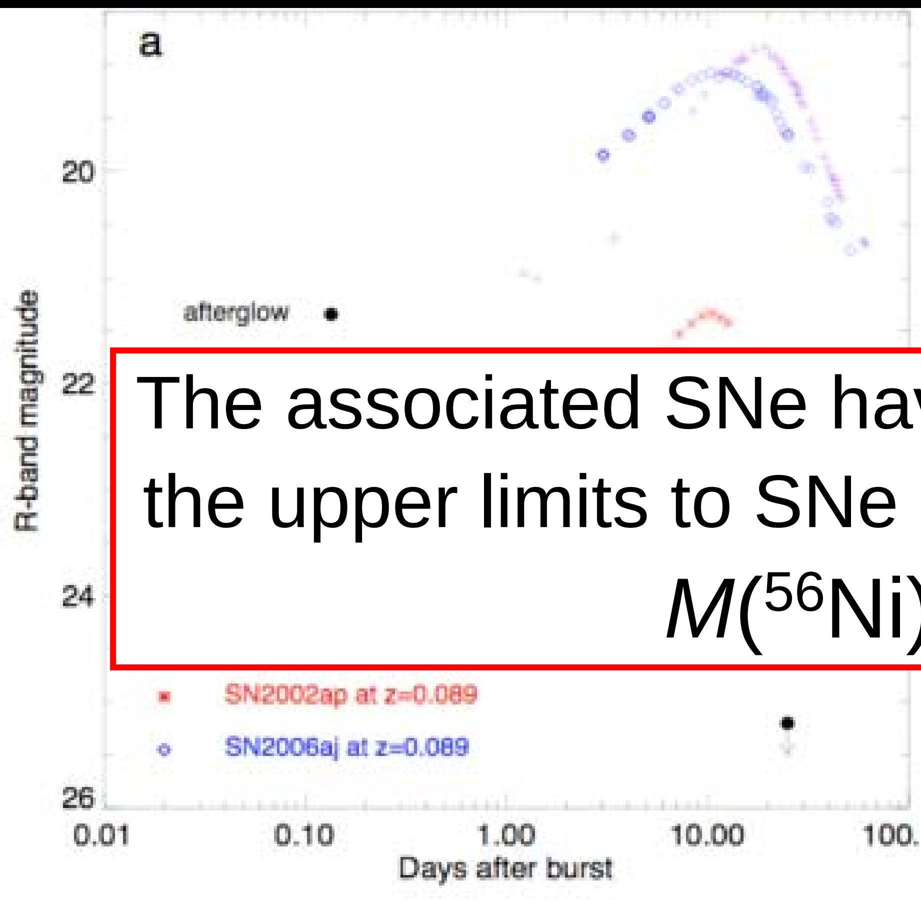
The luminosities are very high.

$M(^{56}\mathrm{Ni}) \sim 0.3 M_\odot$

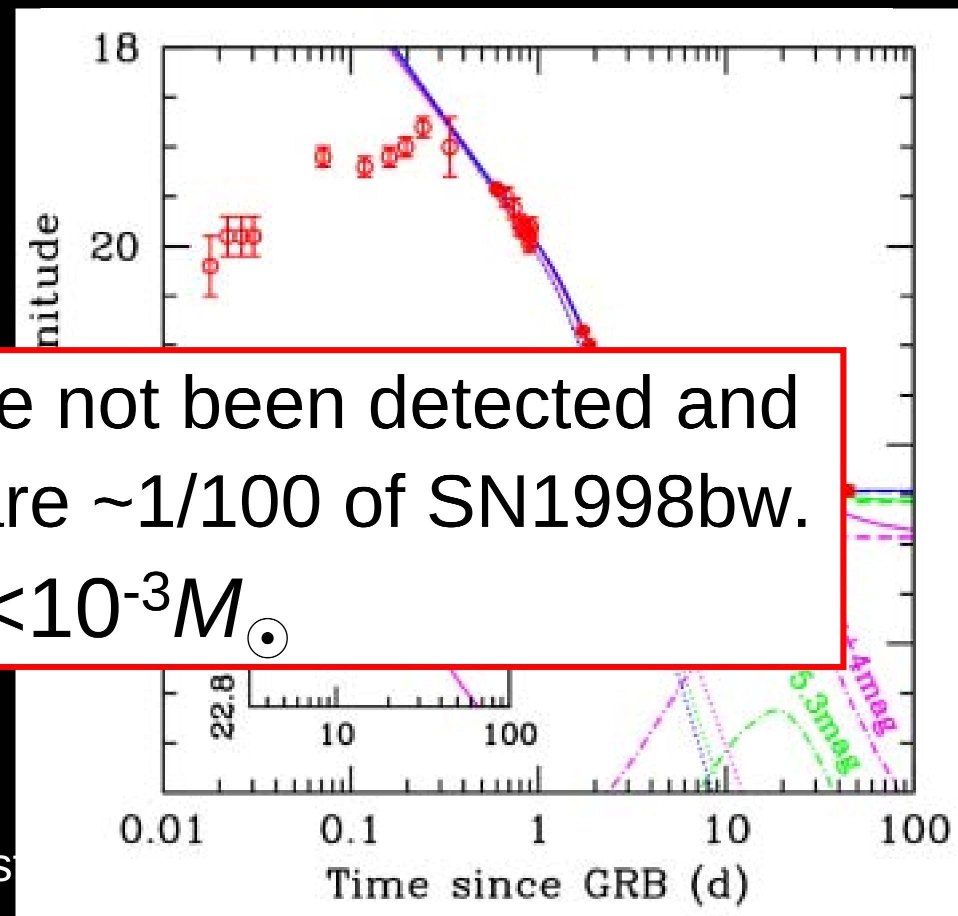
GRB 060505 & GRB 060614

Della Valle et al. 2006, Gal-Yam et al. 2006, Fynbo et al. 2006, Gehrels et al. 2006

GRB 060505 at z=0.089



GRB 060614 at z=0.125



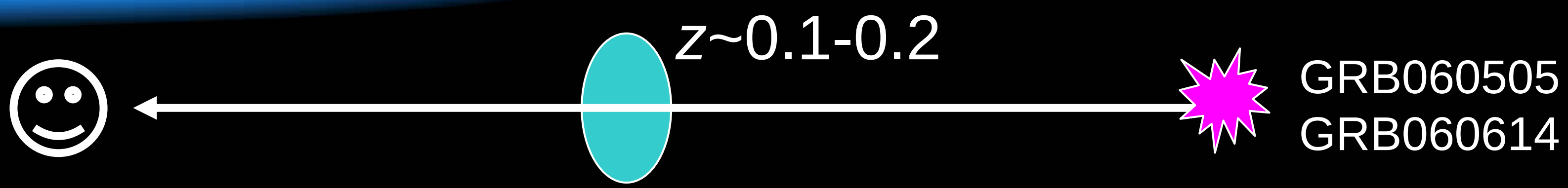
The associated SNe have not been detected and the upper limits to SNe are ~1/100 of SN1998bw.

$M(^{56}\mathrm{Ni})<10^{-3}M_\odot$

Why the SNe were not detected?

Chance superposition?

Schaefer & Xiao 2006, Cobb et al. 2006



Cobb et al. 2006

We examine the galaxy distribution of the field of GRB 060614 and find that the probability of a chance association with a galaxy at least as bright as the putative host is only ∼ 0.5–1.9%. However, for the current ensemble of ≈ 180 *Swift* GRBs it is likely that several such coincidences

but....

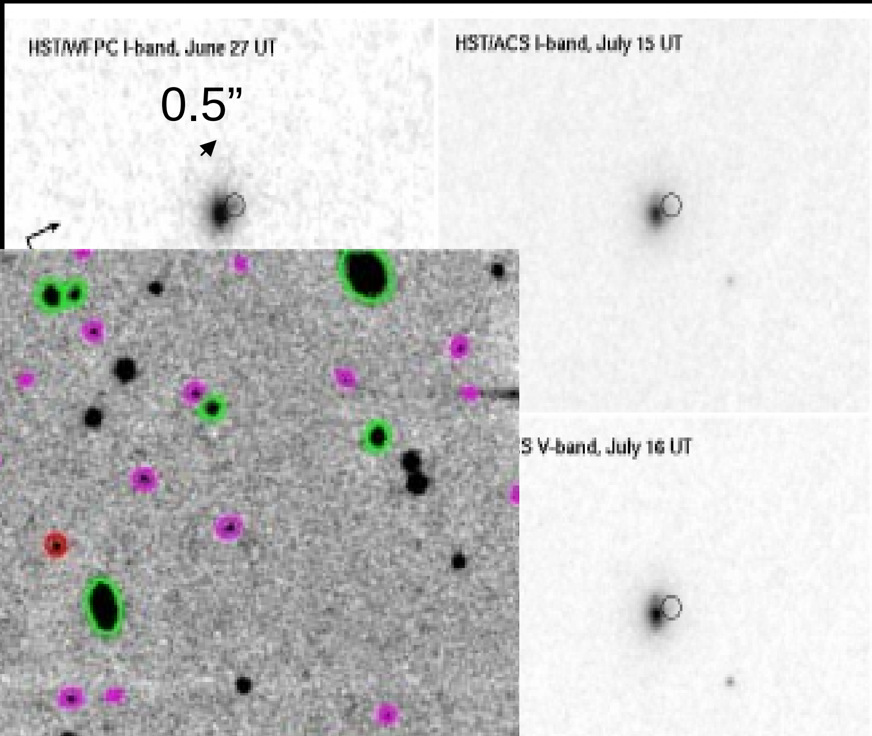
Gehrels et al. 2006

We find the suggestion[18,19] of a chance alignment between a background GRB and foreground galaxy at z=0.125 to not be credible; the chance probability of the observed 0.5" offset between the GRB and the z=0.125 galaxy to be by chance is only 2×10^{-5}. Also, fits to the combined UVOT and XRT spectra give z<1.3 at the 99.99% confidence level, excluding the suggested[18] location at z>1.4.

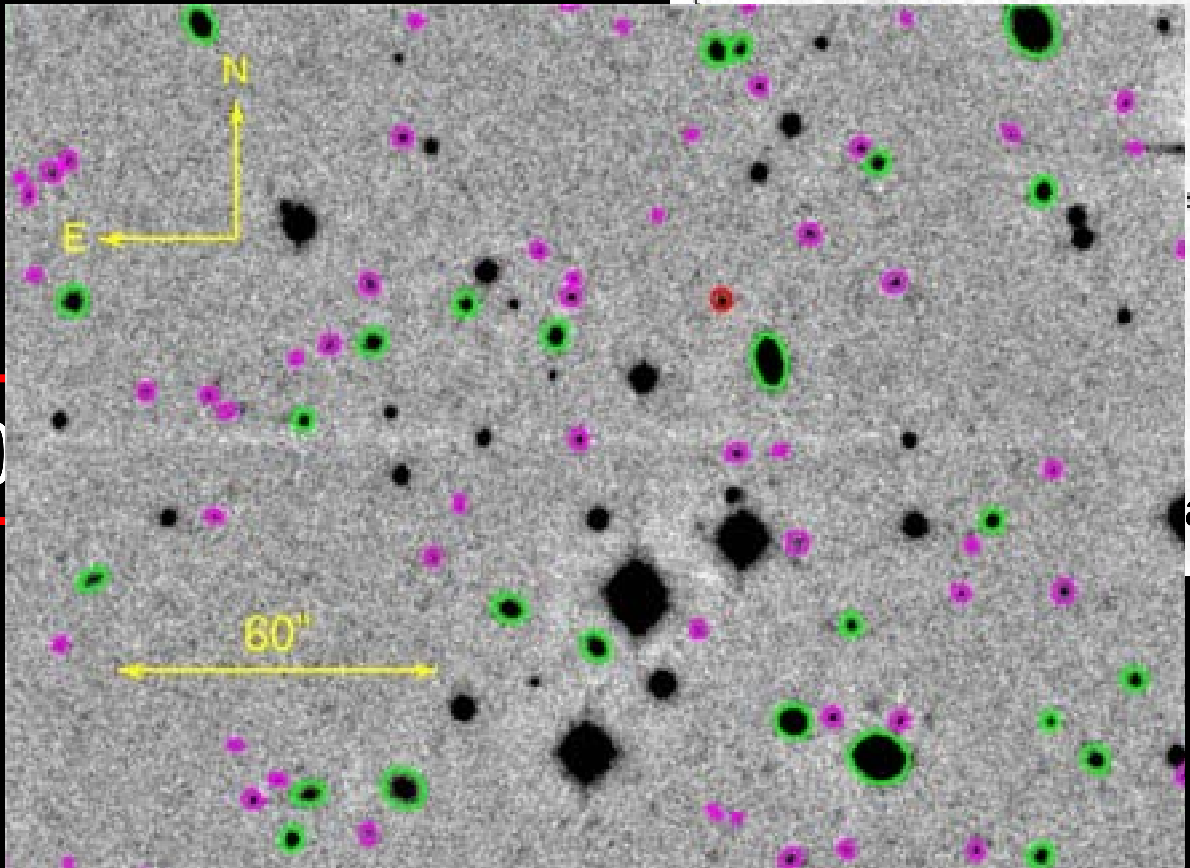
Possibilities: chance superposition

- Galaxy counts → 1%
- HST

0



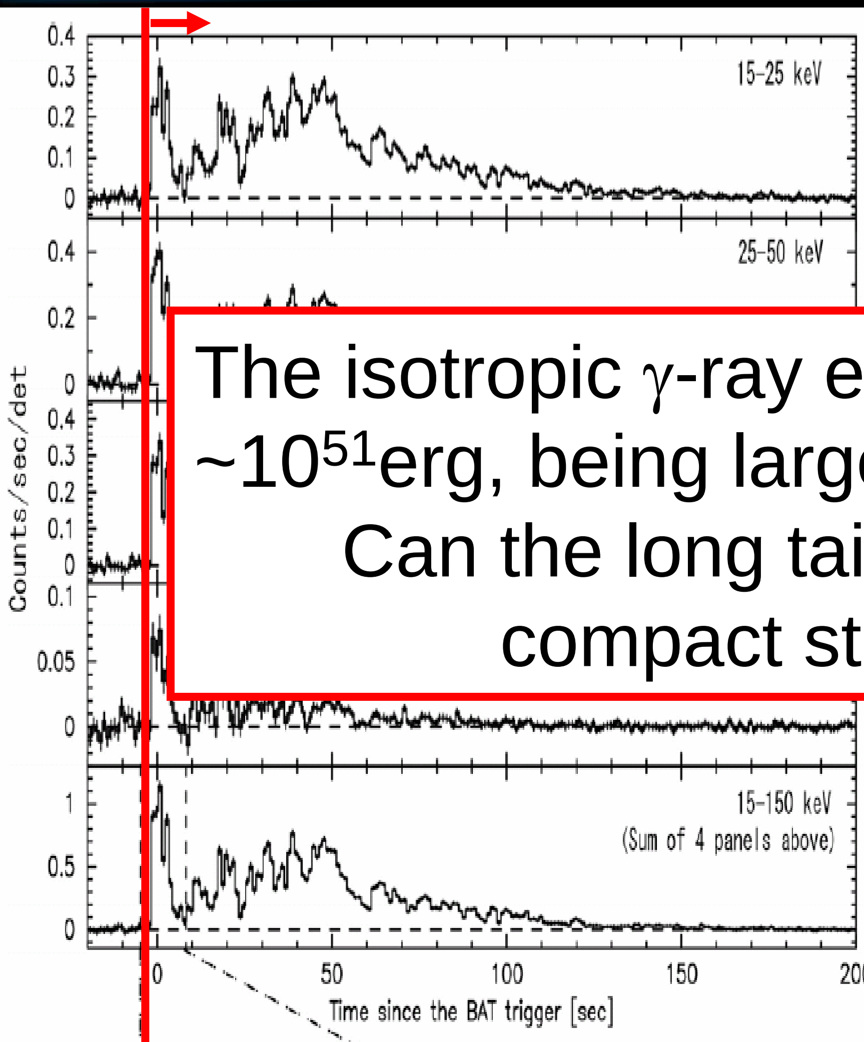
al. 2006 (HST)

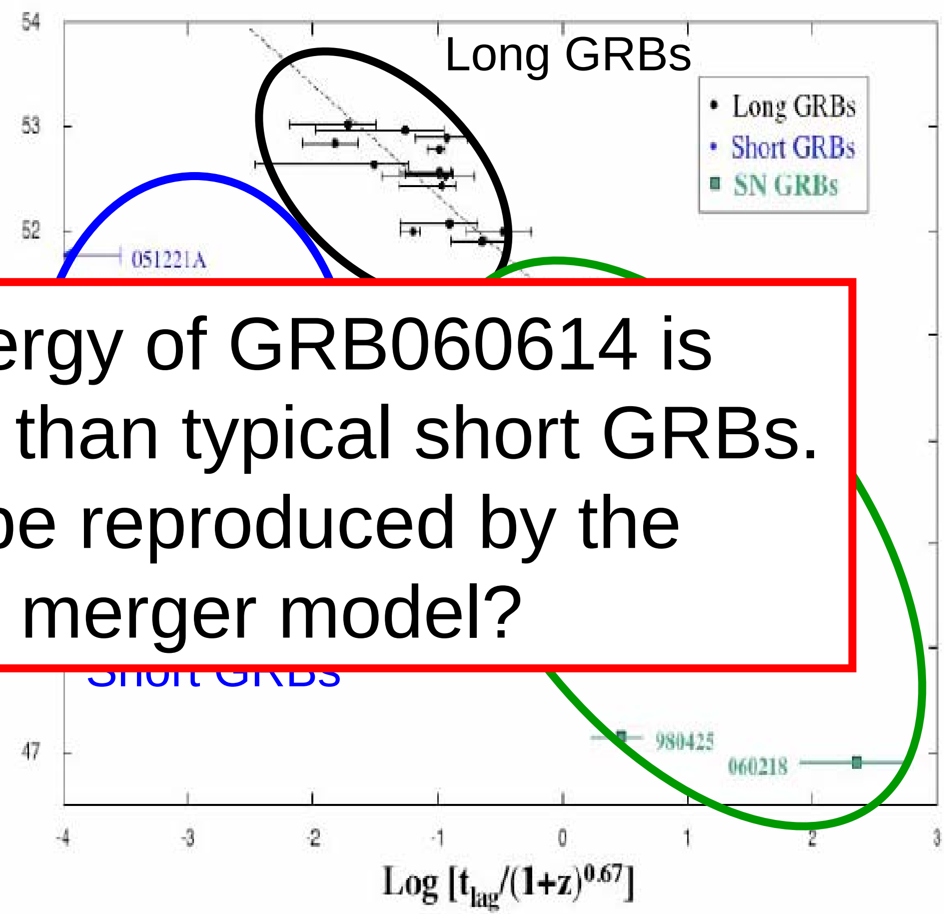


Short GRBs with long tails?

t_{lag}

GRB060614: Gehrels et al. 2006





The isotropic γ-ray energy of GRB060614 is ~10^{51}erg, being larger than typical short GRBs. Can the long tail be reproduced by the compact star merger model?

Long GRBs with Faint SNe?

- Faint SNe are Type II SNe.

(Detected by bright plateau.)

  - SN 1994W (Sollerman et al. 1998)

    $M(^{56}\mathrm{Ni}) < 2.6 \times 10^{-3} M_\odot$

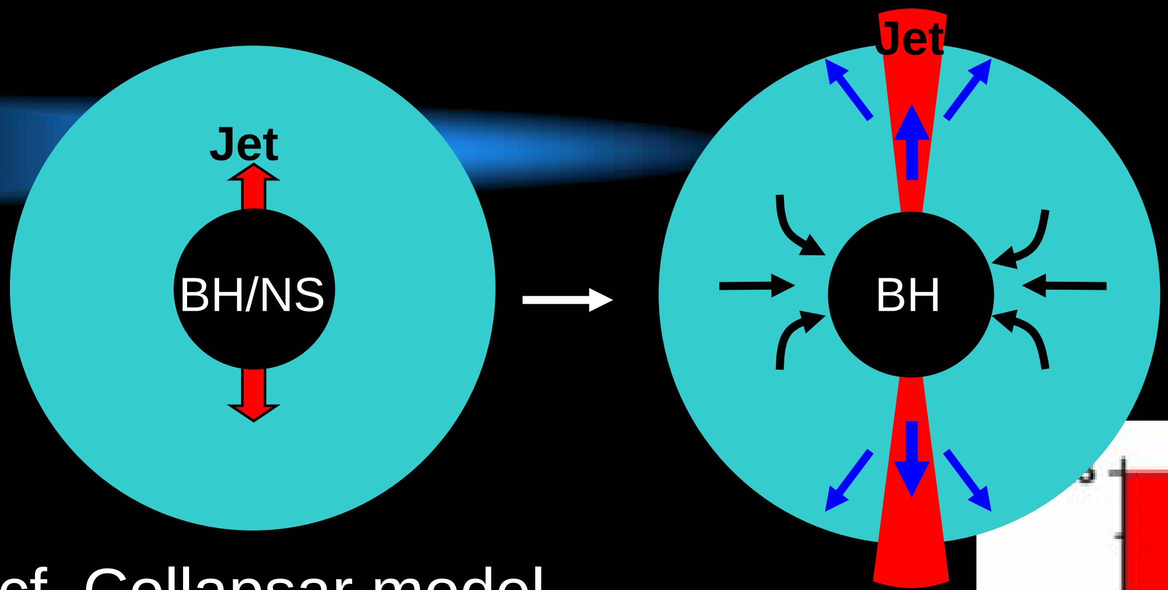
  - SN 1997D (Turrato et al. 1998)

    $10^{-3} M_\odot < M(^{56}\mathrm{Ni}) < 10^{-2} M_\odot$

The explosion energies are small ($E < 10^{51}$ ergs).

Can small $M(^{56}\mathrm{Ni})$ be compatible with the formation of energetic GRBs?

Jet-induced explosion

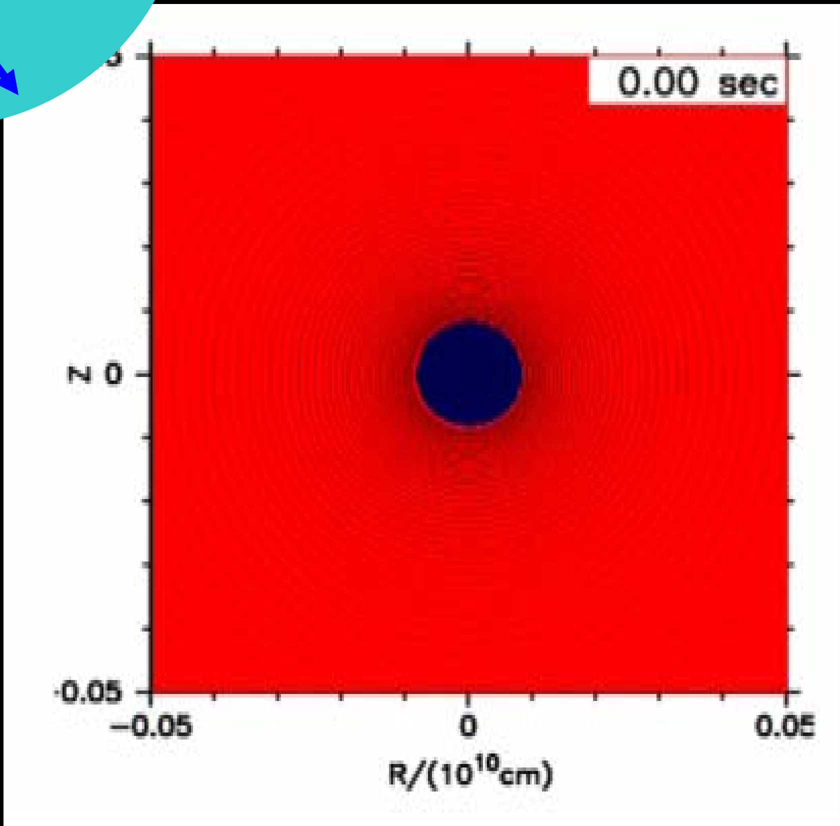


Relativistic jets induced Nucleosynthesis

cf. Collapsar model

(MacFadyen, Woosley, & Heger 2001)

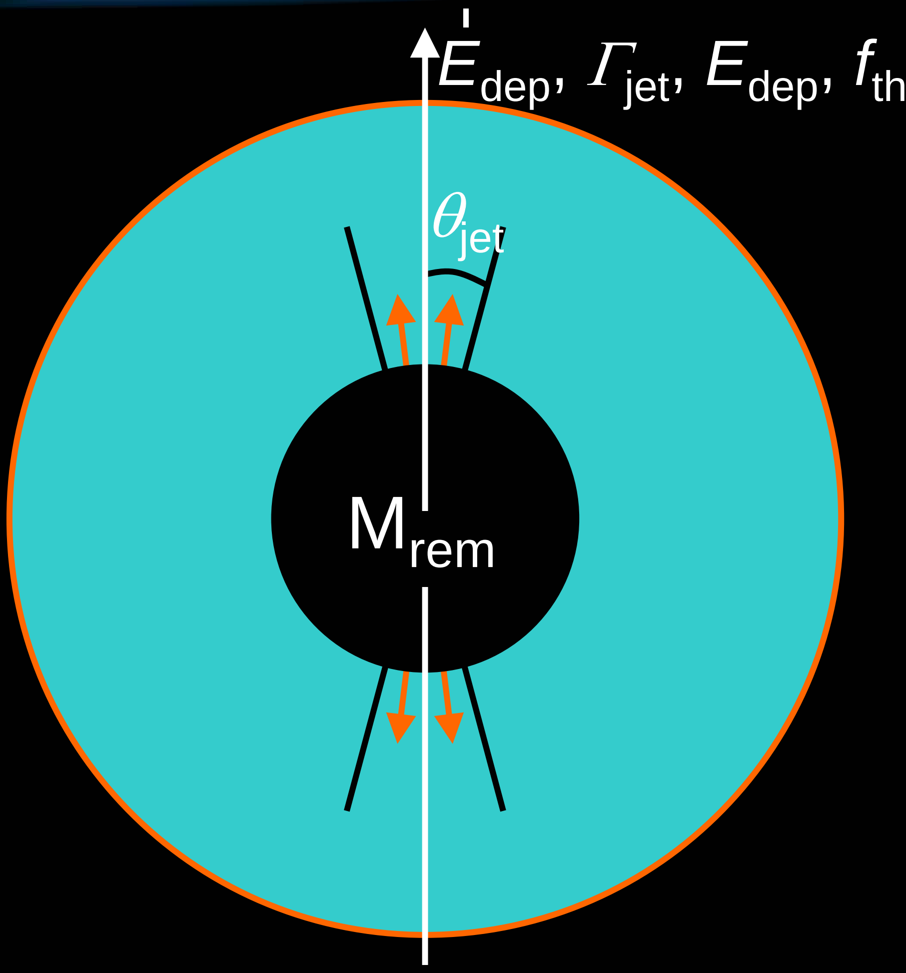
$\dot{E}_{\rm dep}$:
Energy deposition rate
(Rotation etc.)



Same mass and explosion energy

$40M_\odot$ 15×10^{51}erg

Jet parameters



$\dot{E}_{dep}$:
Energy deposition rate

Progenitor: Z=0, M_{MS}=40$M_\odot$

Total deposited enegy:

E_{dep}=1.5x10^{52}erg

Initial remnant mass:

M_{rem}=1.4$M_\odot$

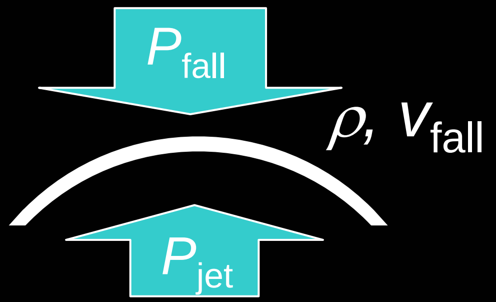
Initial opening angle: θ_{jet}=15^o

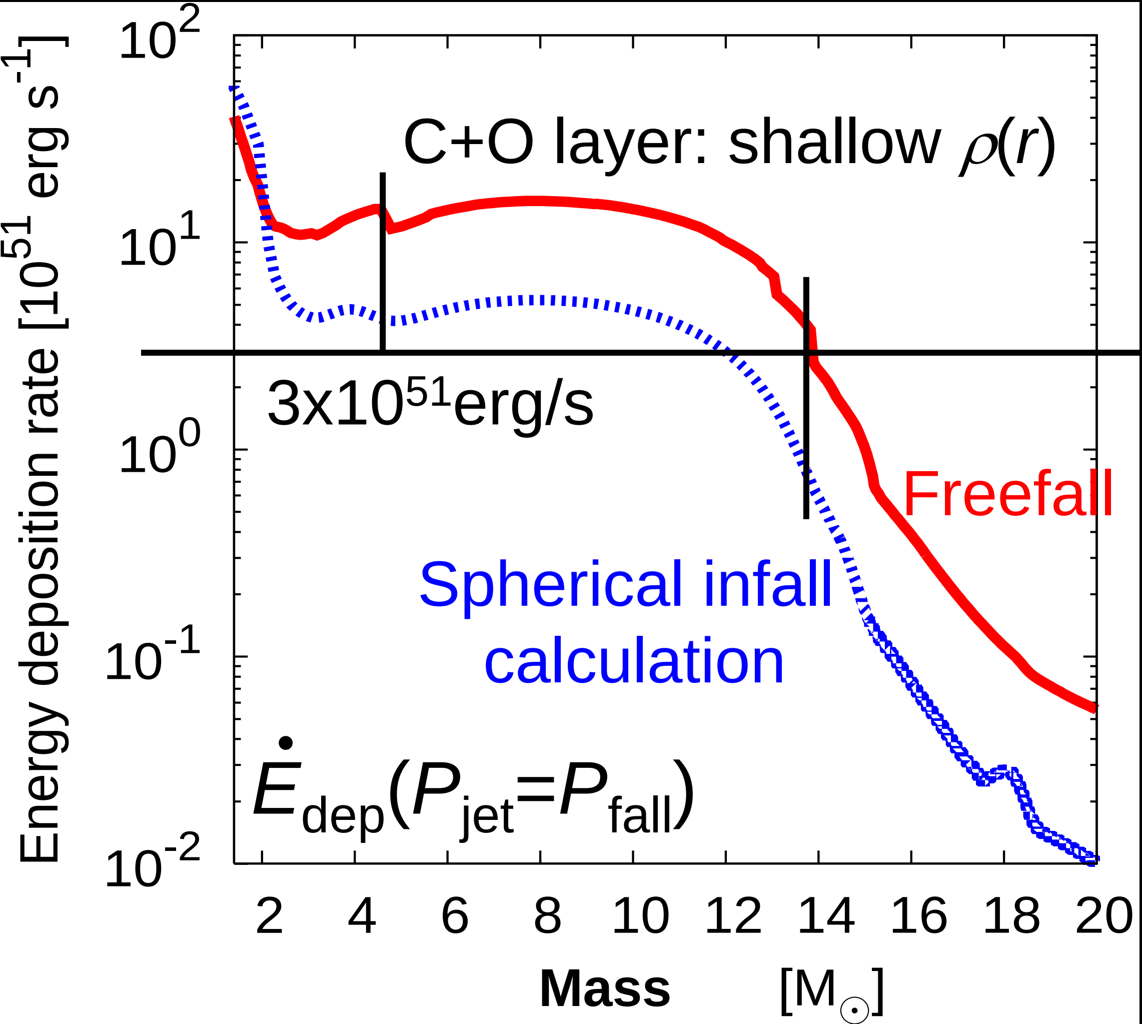
Initial velocity: Γ_{jet}=100

Ratio of thermal to total deposited energies:

f_{th}=E_{th}/ E_{dep}=10^{-3}

Initiation of the jet injection





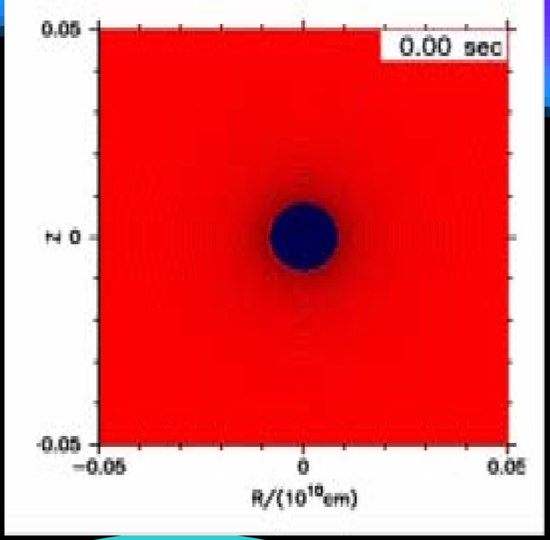
In order to initiate the jet injection,

$$P_{jet} > P_{fall}$$

$$P_{fall} \propto \rho v_{fall}^2 \propto \rho_0^2 r_0^{9/2}$$

Fryer & Meszaros 2003
Maeda & NT 2007
NT et al. 2007

Sites of ^{56}Ni production

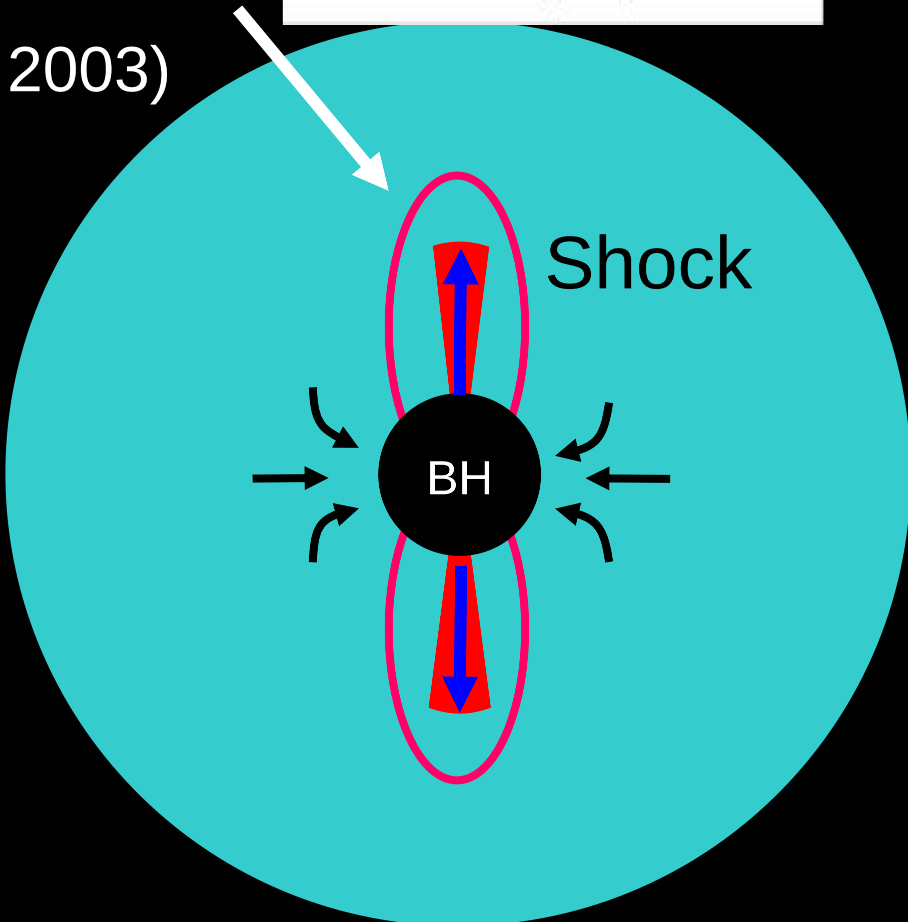


- Explosive nucleosynthesis
  (e.g. Maeda & Nomoto 2003)

- Jet

$$M_{\mathrm{jet}} \sim E_{\mathrm{dep}}/c^2/\Gamma_{\mathrm{max}}$$
$$\sim 10^{-4} M_\odot$$

(E_{dep} =1.5x10^{52}ergs, Γ_{max}=100)

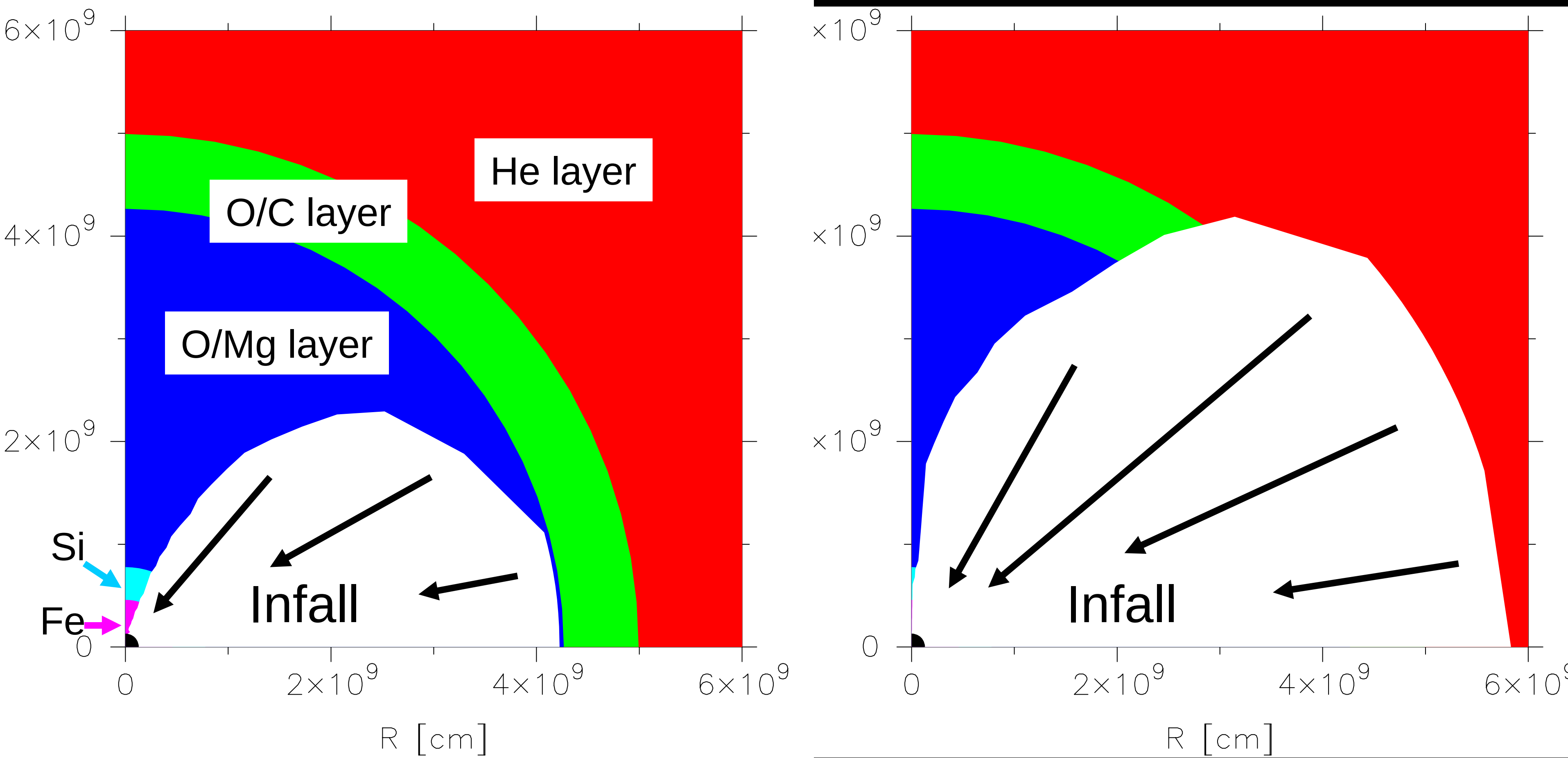


Dependence: $\dot{E}_{dep}$

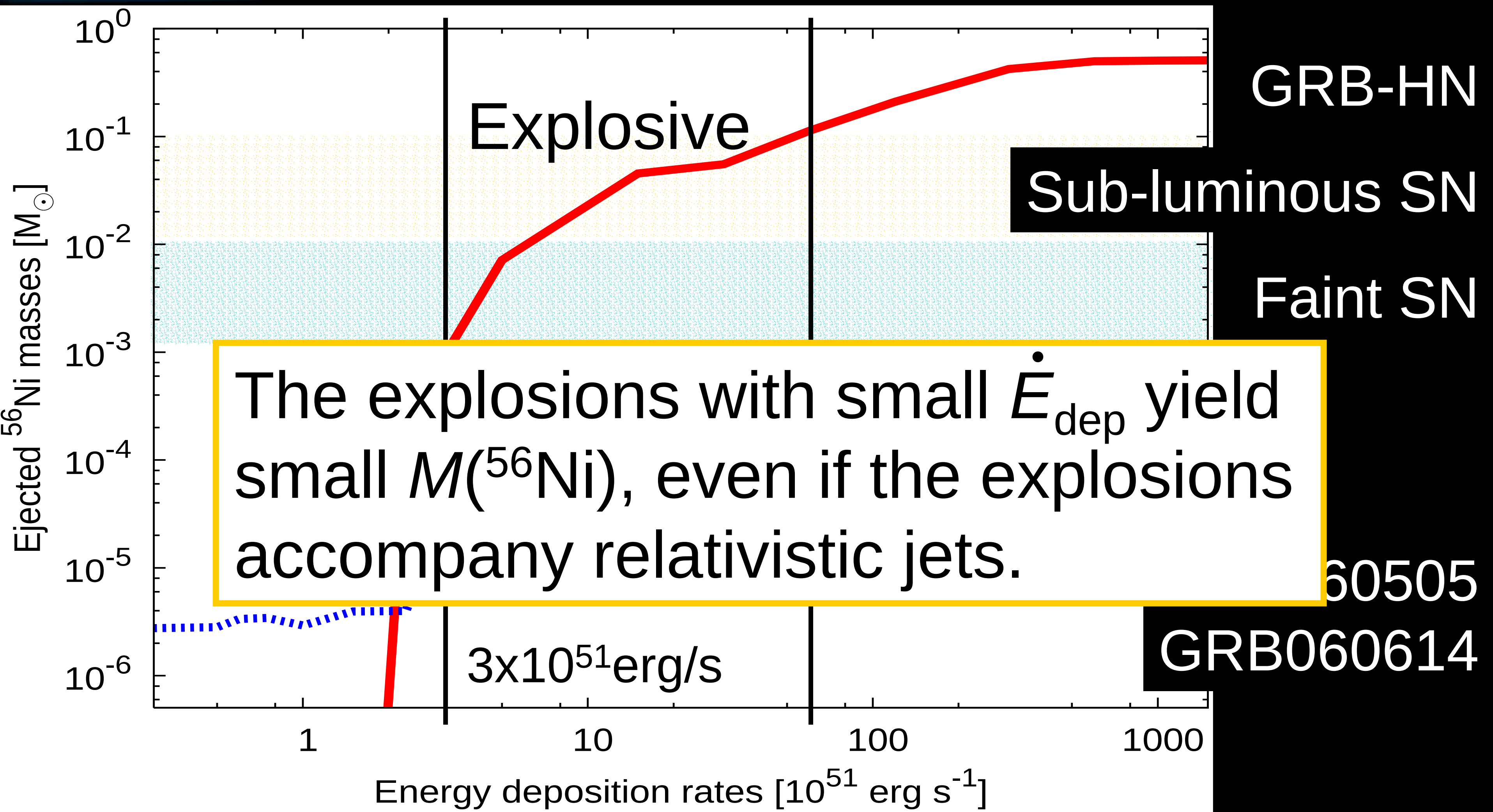
$\dot{E}_{dep}\downarrow$: Infall $\uparrow$

$M(^{56}Ni)\downarrow$

Smaller $\dot{E}_{dep}$



Ejected ^{56}Ni masses



The explosions with small $\dot{E}_{dep}$ yield small M(^{56}Ni), even if the explosions accompany relativistic jets.

Other elements

Smaller $\dot{E}_{dep}$

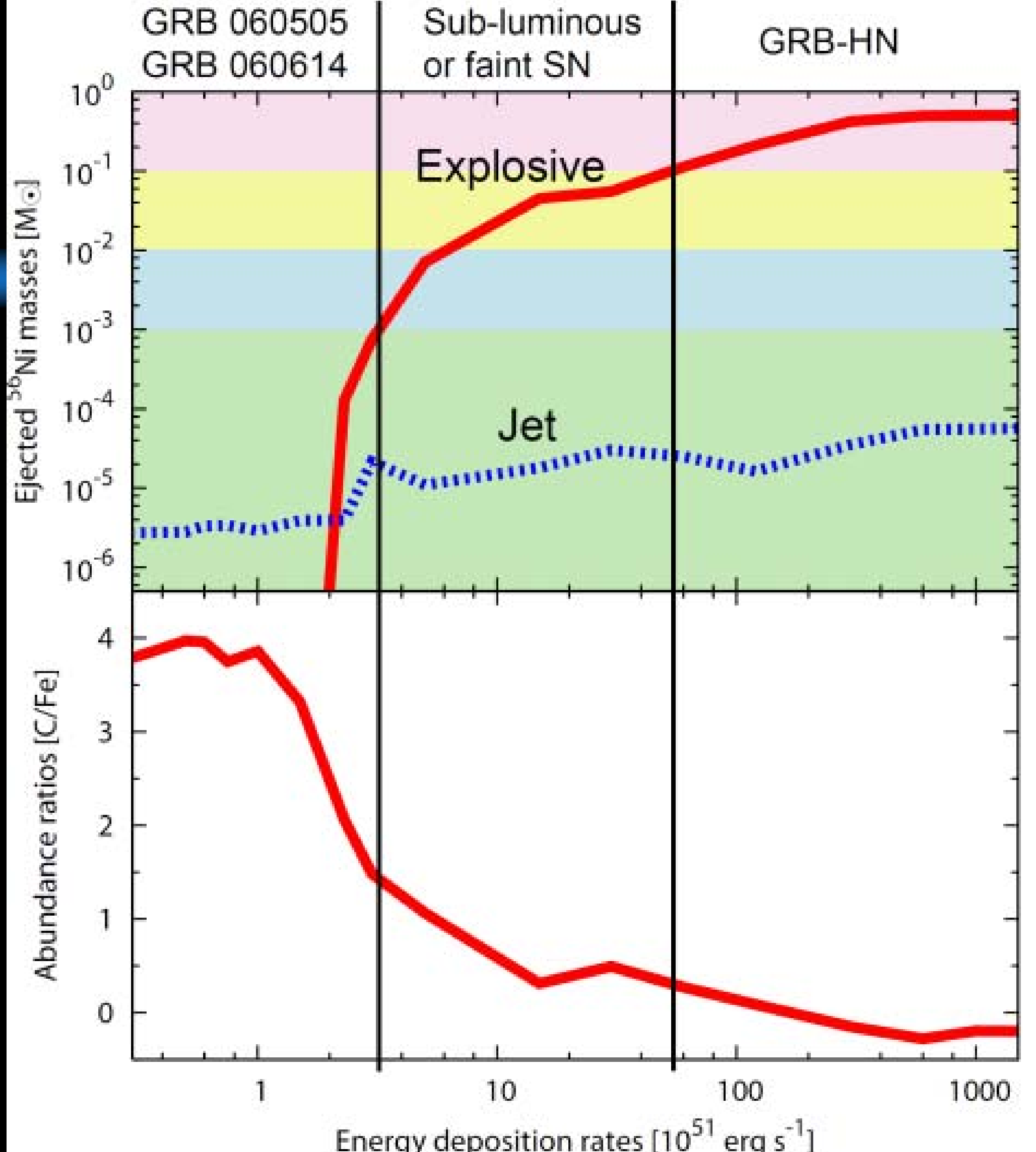
Smaller $M(^{56}Ni)$

Larger [C/Fe]

Nucleosynthesis in a single SN

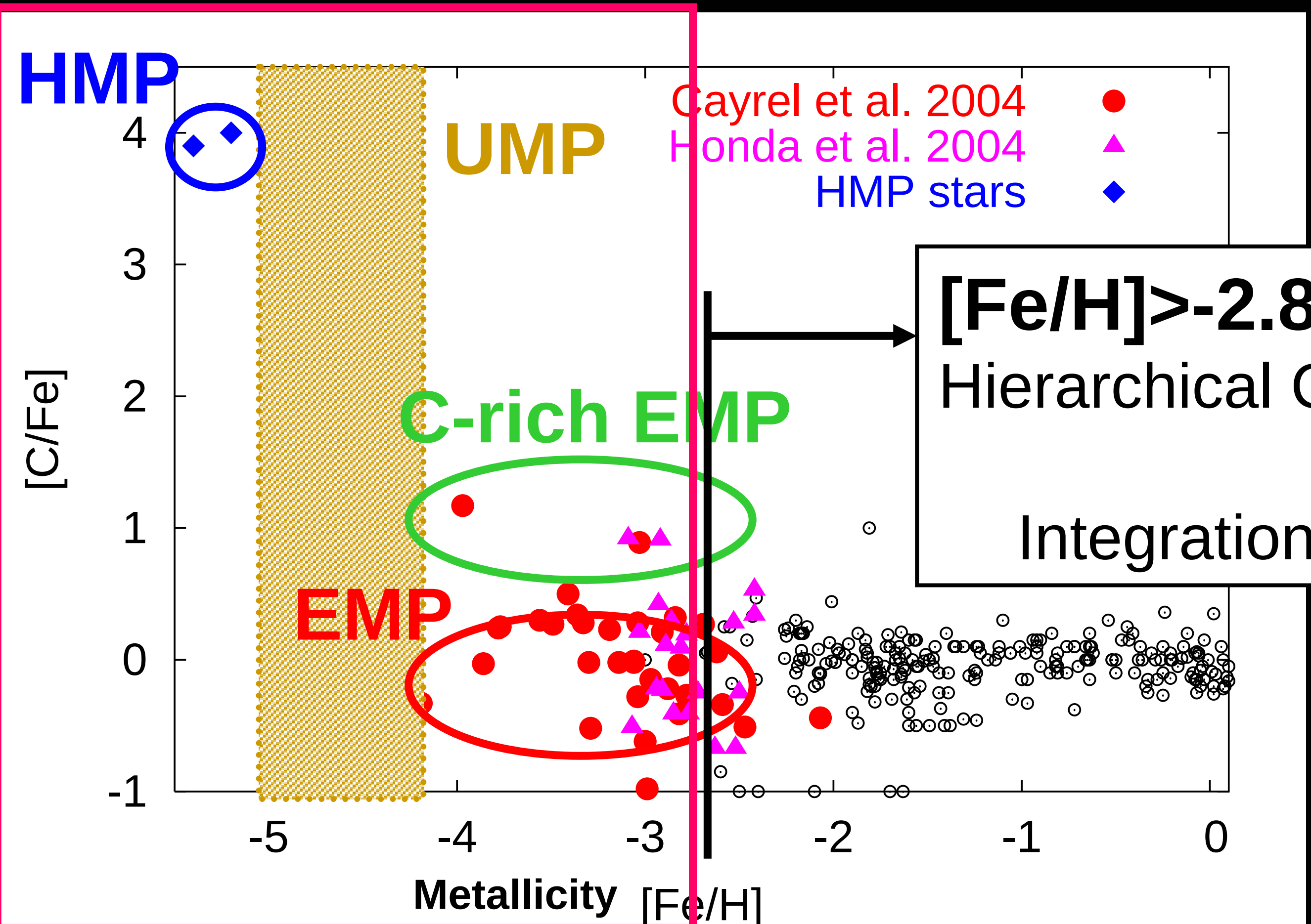
↕

Metal-poor stars



Metal-poor stars

These stars reflect nucleosynthesis in a single Pop III SN.



[Fe/H]>-2.8

Hierarchical Chemical Evolution

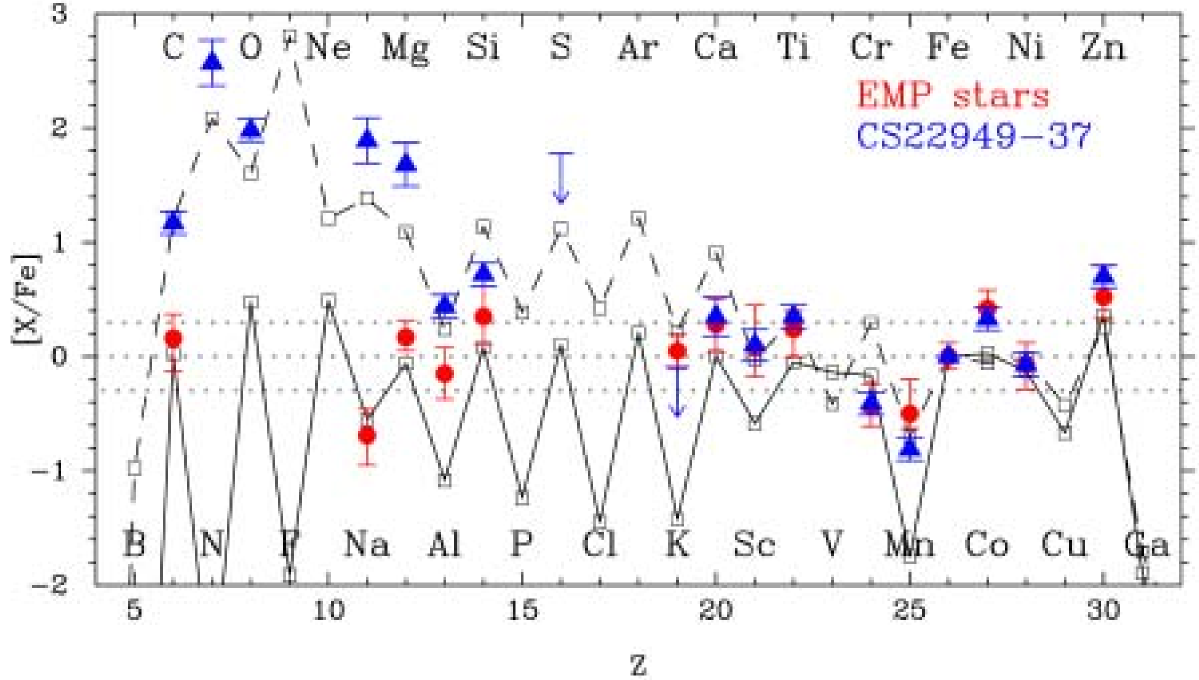
(Tumlinson 2006)

Integration of several SNe.

CEMP stars

(Depagne et al. 2002)

$M(^{56}Ni) \sim 8 \times 10^{-4} M_\odot$



EMP stars

(Cayrel et al. 2004)

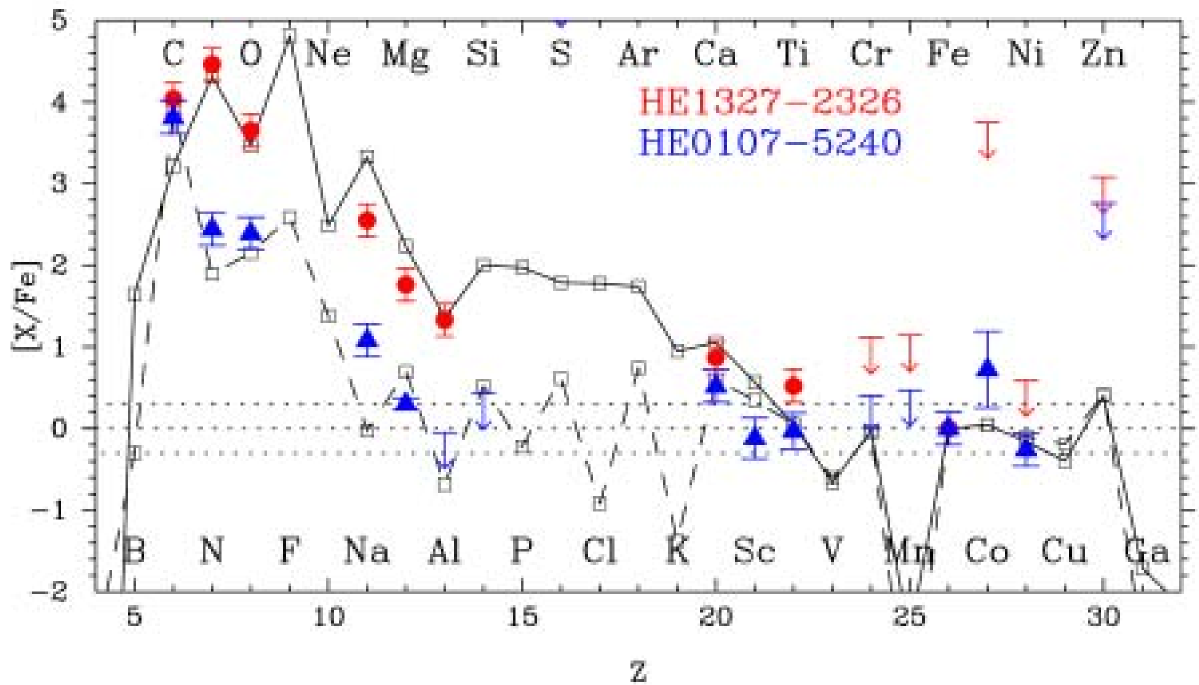
$M(^{56}Ni) \sim 0.2 M_\odot$

HMP stars

(Christlieb et al. 2002)

(Frebel et al. 2005)

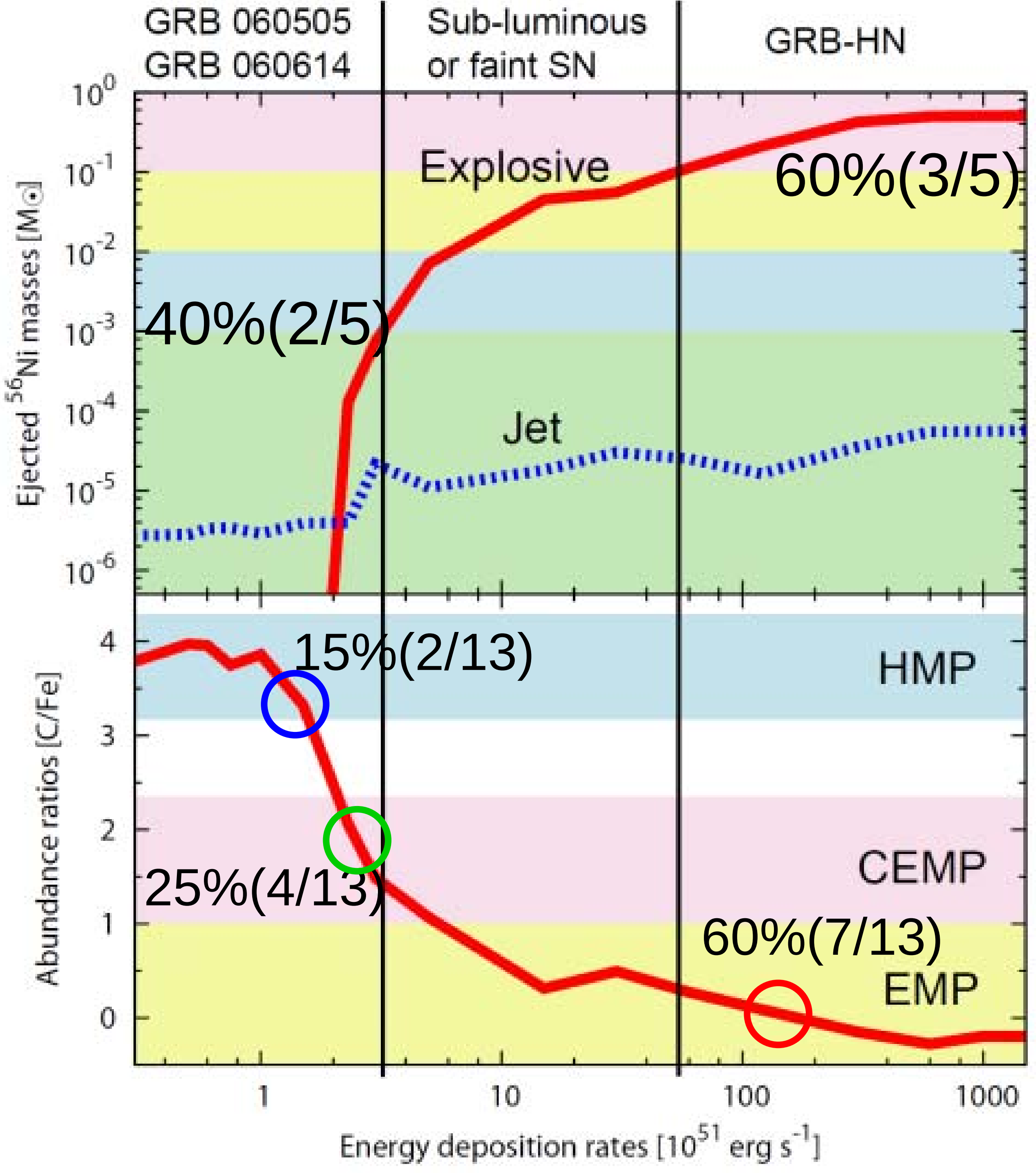
$M(^{56}Ni) \sim 3 \times 10^{-6} M_\odot$



Counts

5 nearby GRBs
  3 GRB-HNe
  2 no-SN GRBs
  (excluding XRF060218)

For [Fe/H]<-3.5
 13 metal-poor stars
   7 EMP stars
   4 CEMP stars
   2 HMP stars



BH-forming SNe with relativistic jets

GRBs		**Metal-poor stars**
GRB-HNe	—	EMP stars
No-SN GRBs	—	CEMP stars HMP stars

$\dot{E}_{dep}$ (Smaller → Larger)

No-SN GRBs are also massive stellar deaths.
BH-forming SNe with relativistic jets are responsible for GRBs-HNe and no-SN GRBs and metal-poor stars.