Gamma-Ray Burst Remnants as TeV Unidentified Sources

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Opening of a postdoc in KEK (theoretical cosmophysics)
http://www.kek.jp/ja/jobs/IPNS08-1.html

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GRB overview

GRB-SN, Event rate, GRB-CR, GRB remnant

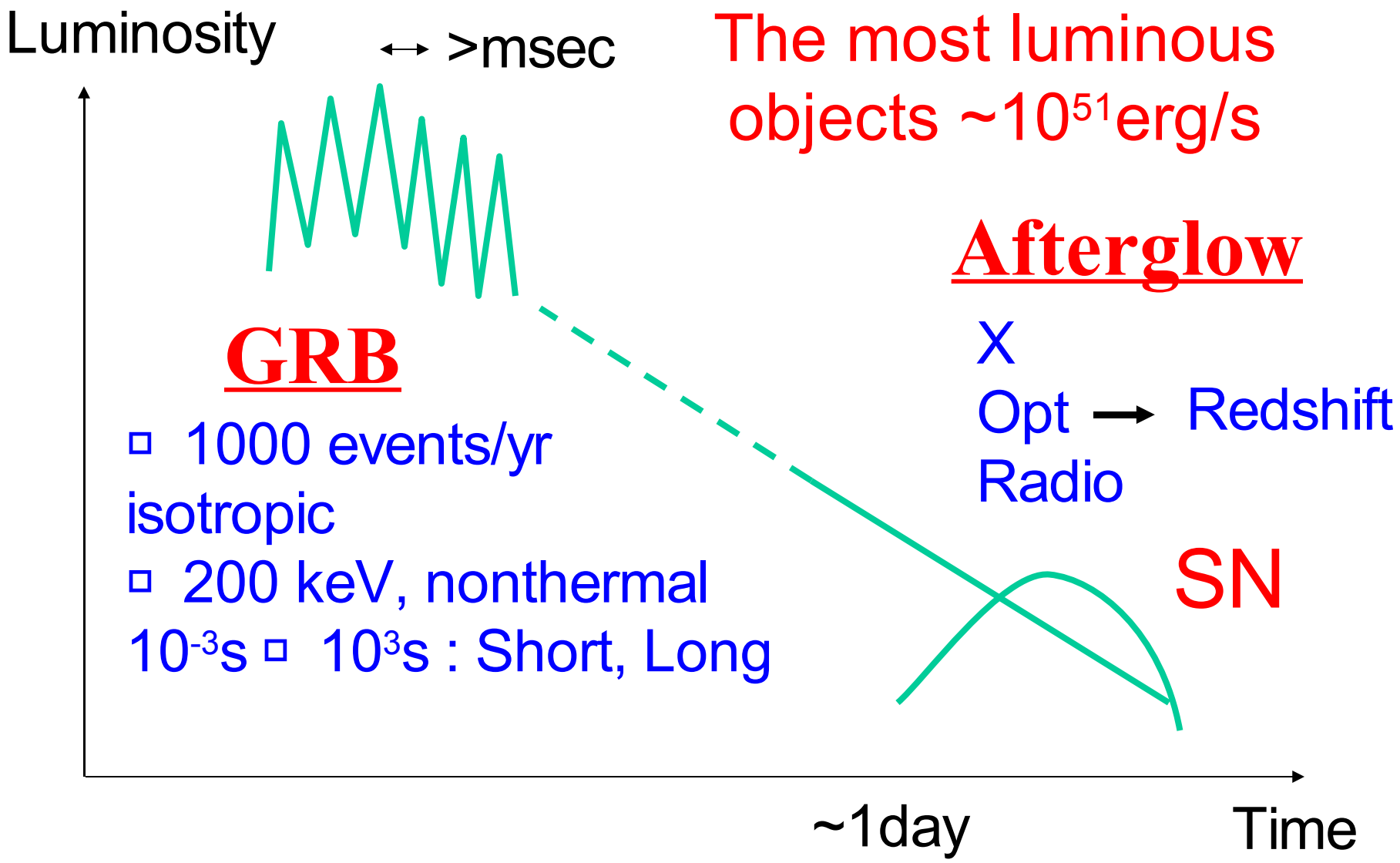
GRBR-TeV unID

Energetics

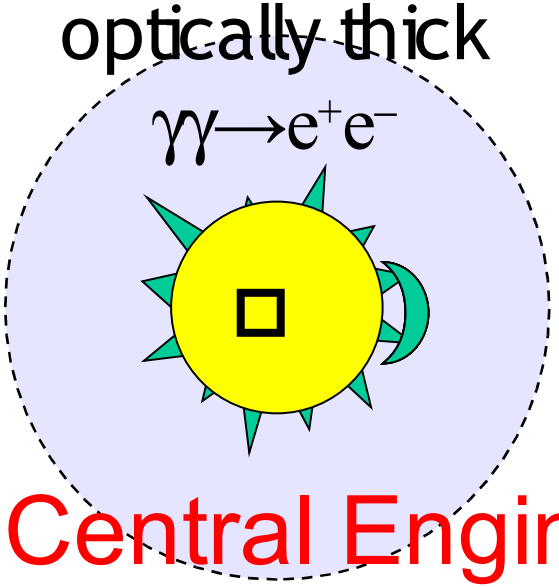
Possible scenarios

1. β decay + e-IC (KI, Kobayashi & Mészáros 04)
2. π^0 decay (Atoyan, Buckley & Krawczynski 06)
3. Radio Isotope (RI) decay (KI & Mészáros 08)

GRB


Luminosity
↔ >msec
The most luminous objects ~10^51 erg/s
Afterglow
X
Opt → Redshift
Radio
GRB
▫ 1000 events/yr
isotropic
▫ 200 keV, nonthermal
10^-3 s ▫ 10^3 s : Short, Long
SN
~1day
Time

Standard model



Central Engine

Internal shock

$\Gamma > 100$

ISM

External shock

GRB

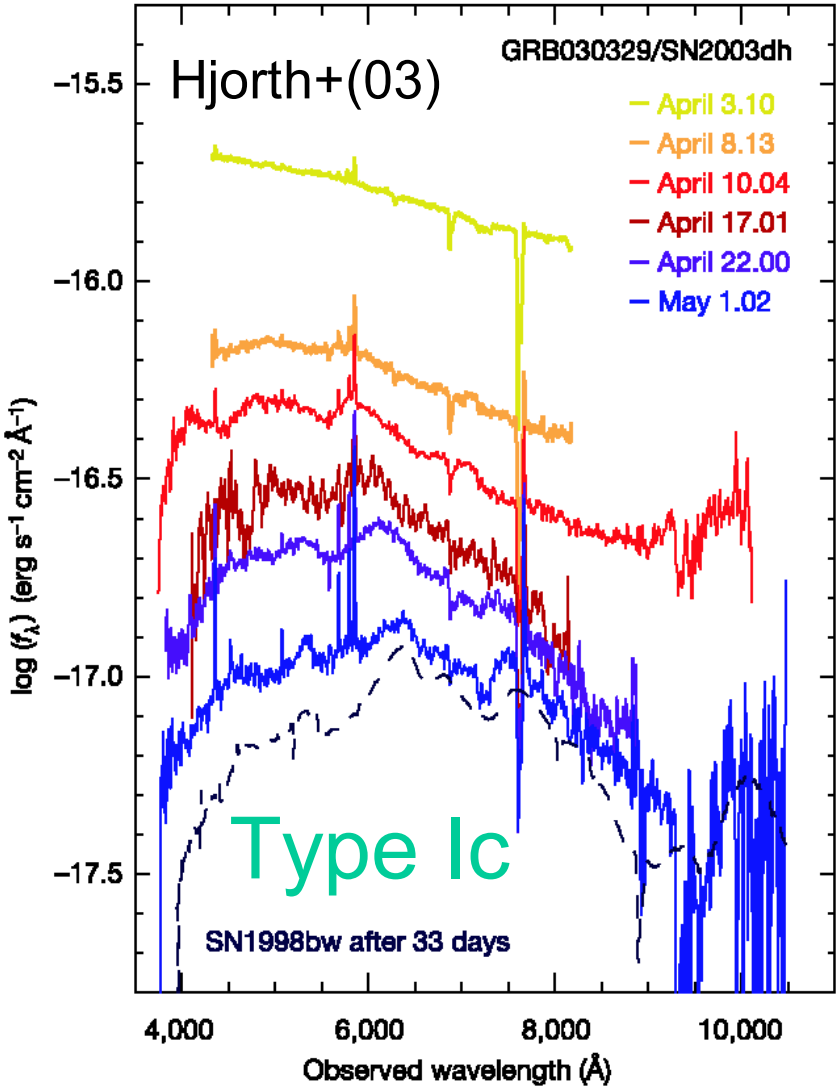
Afterglow

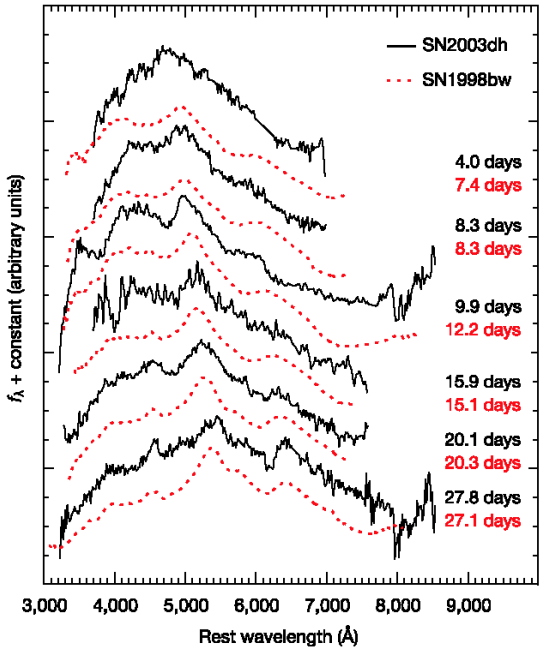
Kinetic energy

↓

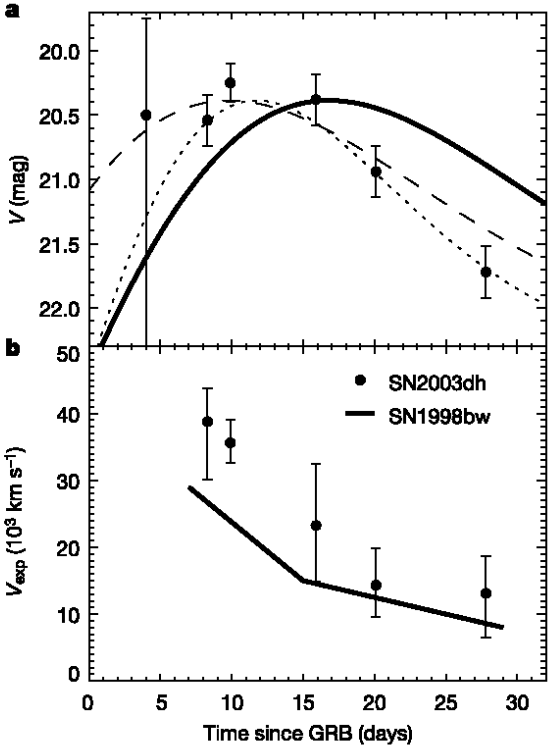
Shock dissipation

GRB030329





Wide line

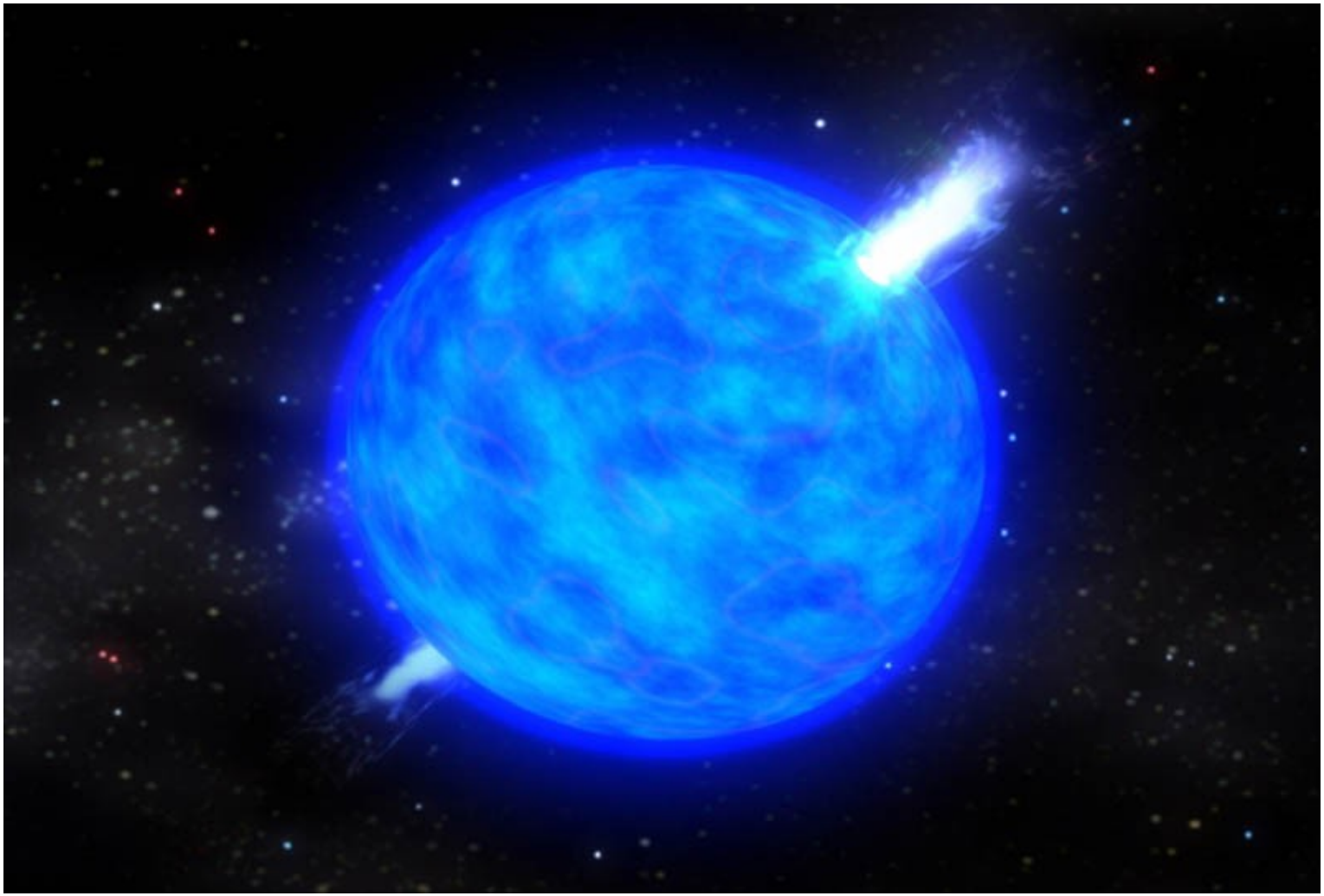


Within a few days

⇒ GRB associated with SN

Collapsar

Jet breaks out the stellar envelope



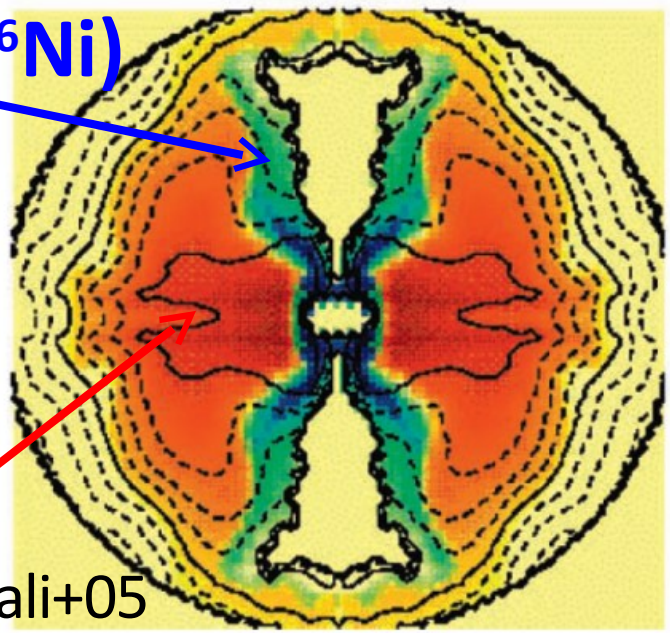
Event rate

R(SN Ibc)~1/10^3yr/galaxy

R(GRB)~1/$10^{5\text{-}6}$yr/galaxy

 after collimation-corrected

R(Hypernova)~1/10^4yr/galaxy



E_{HN}~10^{52}erg

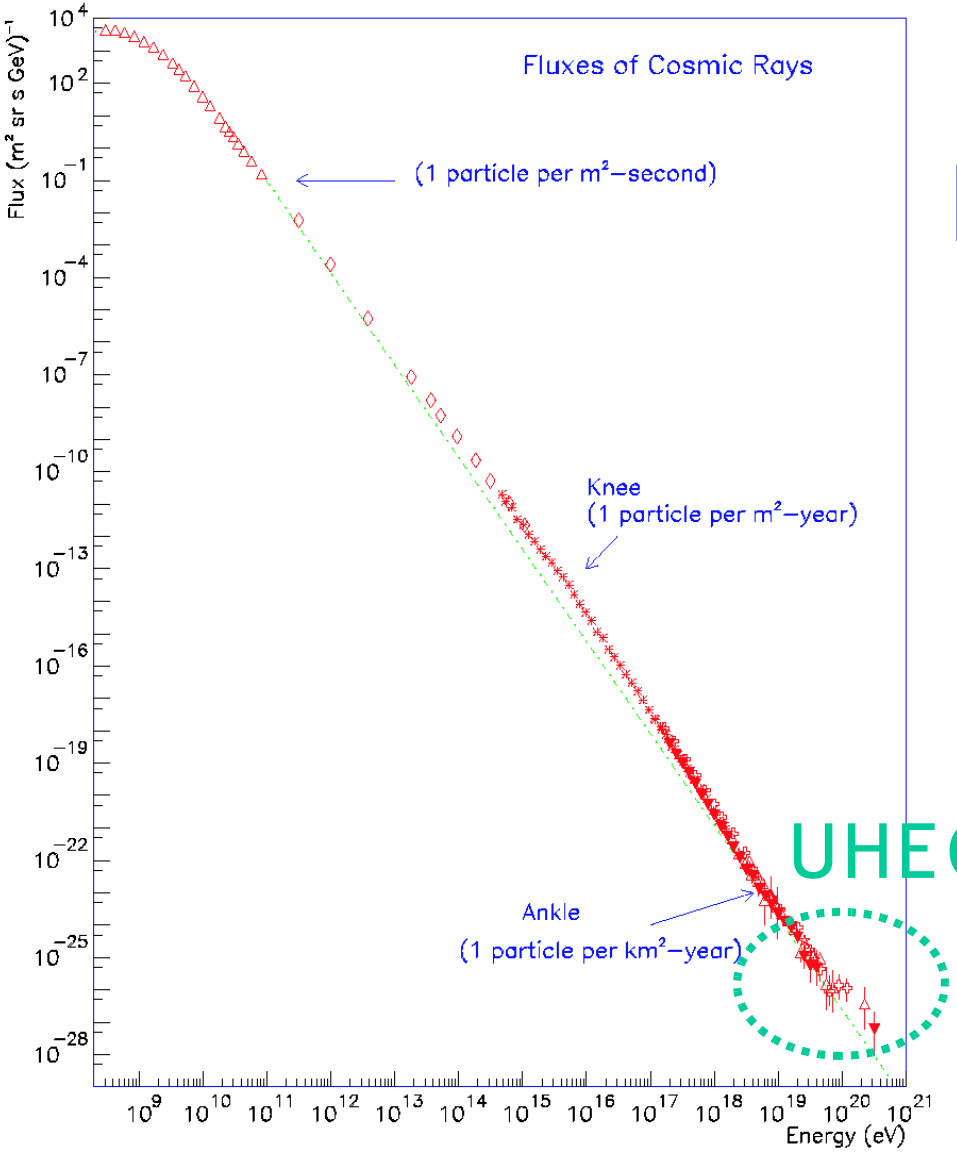
Observed line profile

⇒ Aspherical explosion

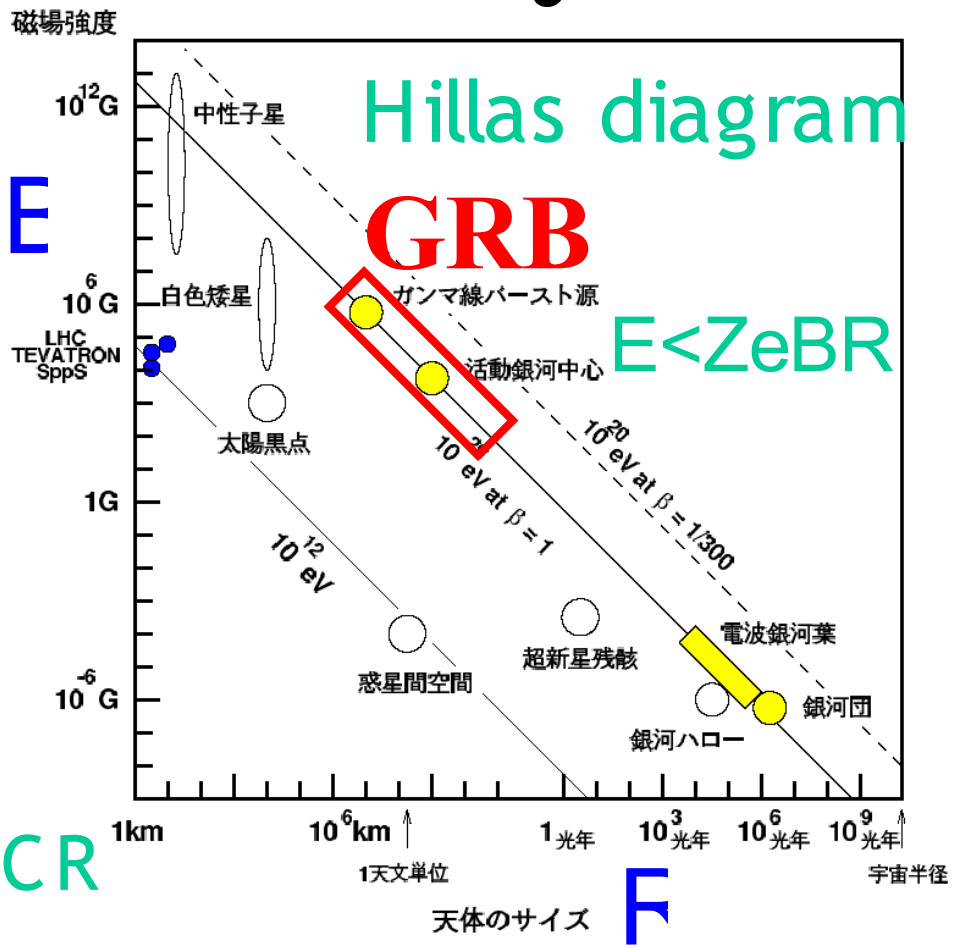
R(Low Luminosity GRB)

~10 x R(GRB)

GRB-Cosmic Ray



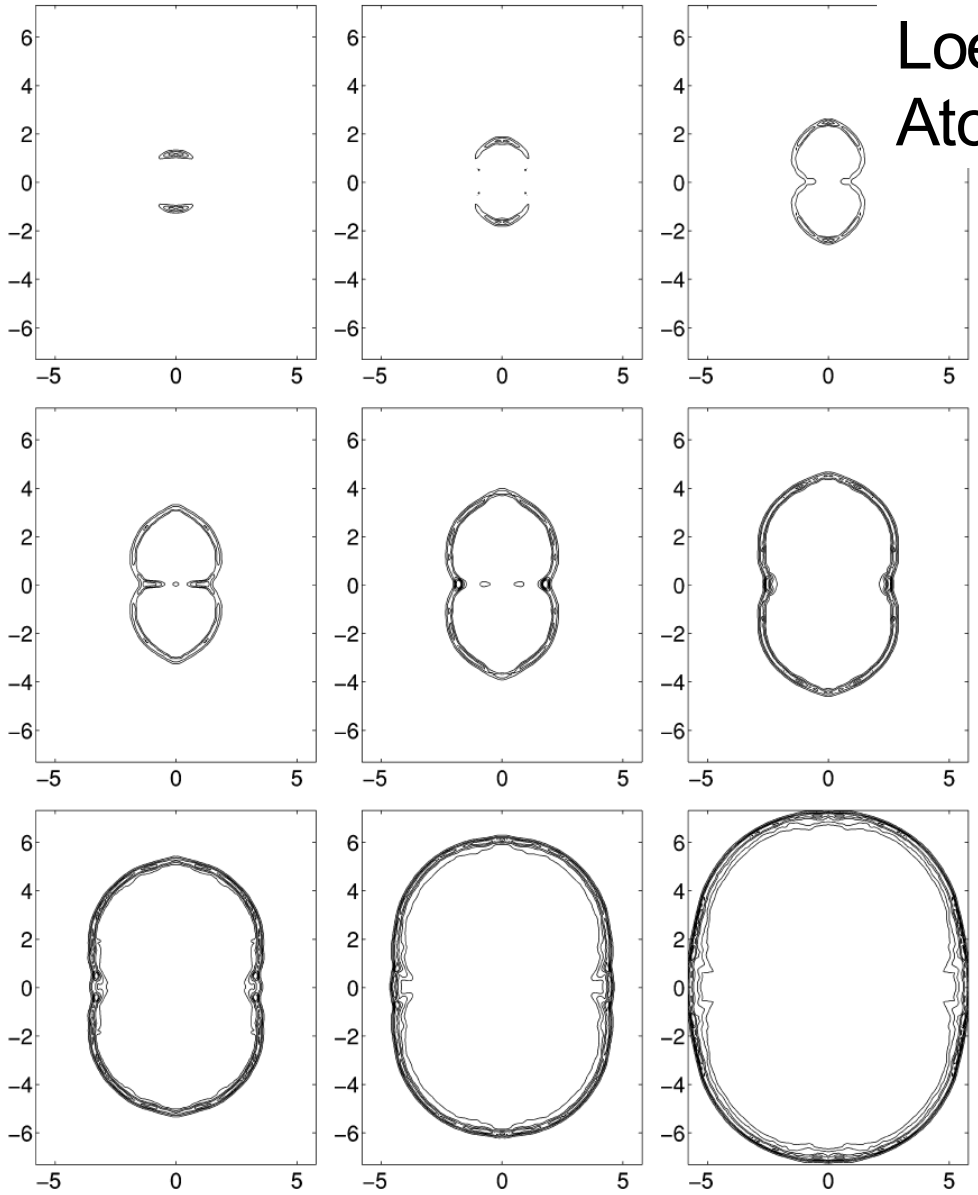
UHECR



$\approx 10^{44}\,\mathrm{erg/Mpc^3/yr}$

$\approx$ UHECR

GRB remnant (GRBR)



Loeb & Perna 98, Wick, Dermer & Atoyan 04, Dermer & Atoyan 06

After non-rela
⇒ Jet→Sphere
⇒ GRBR~SNR
hydrodynamically
(cf., $R \sim E^{1/5}$)

Metal distribution could be different

Ayal & Piran 01

Energetics

TeV unID

$$F \sim 10^{-11} - 10^{-12}\,\mathrm{erg\,s^{-1}\,cm^{-2}}$$

$$R \sim \theta d \sim 30\mathrm{pc}\left(\frac{\theta}{0.2^\circ}\right)\left(\frac{d}{10\mathrm{kpc}}\right)$$

$$L = 4\pi d^2 F \sim 10^{34-35}\,\mathrm{erg\,s^{-1}}\left(\frac{d}{10\mathrm{kpc}}\right)^2$$

$$N \sim 10 - 100$$

GRBR

? Energy fraction of TeV γ

? Total Energy

? Duration

$$L \sim \frac{fE}{t} \sim 3\times 10^{34}\,\mathrm{erg\,s^{-1}}\left(\frac{f}{10^{-4}}\right)\left(\frac{E}{10^{52}\,\mathrm{erg\,s^{-1}}}\right)\left(\frac{t}{10^{6}\,\mathrm{yr}}\right)^{-1}$$

$$N \sim Rt \sim 10\left(\frac{R}{1/10^{5}\,\mathrm{yr}}\right)\left(\frac{t}{10^{6}\,\mathrm{yr}}\right)$$

? Event rate $R < \frac{1}{10^{3}\,\mathrm{yr}}$

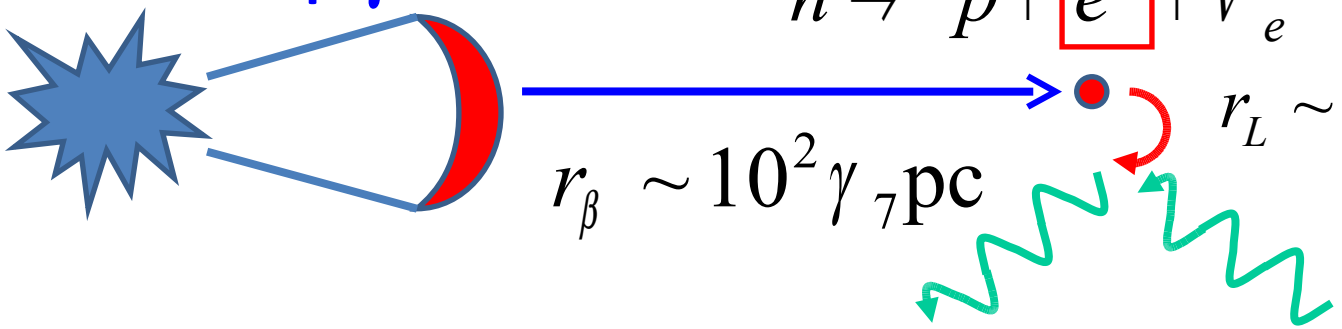
1. β decay

$\varepsilon_p \sim 10^{16} \gamma_7 \mathrm{eV}$

$p\gamma \rightarrow n\pi^+$

$t_{\mathrm{decay}} \sim 900\mathrm{s}$

$n \rightarrow p + e^- + \bar{\nu}_e$



$r_\beta \sim 10^2 \gamma_7 \mathrm{pc}$

$r_L \sim 2 \times 10^{-3} \gamma_7 B_{3\mu G}^{-1} \mathrm{pc}$

γ (CMB, …)

$$\varepsilon_\gamma \sim 9 \varepsilon_{\mathrm{CMB}} \gamma^2 \sim 1 \varepsilon_{\mathrm{CMB,meV}} \gamma_7^2 \ \mathrm{TeV}$$

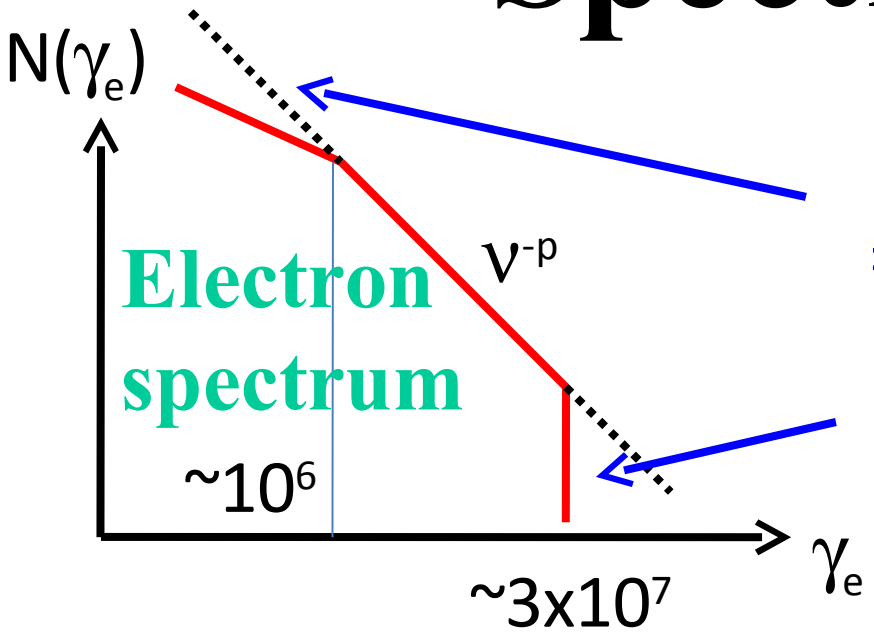
$$f \sim m_e / m_p \sim 10^{-3}$$

$$t \sim t_{\mathrm{cool}} \sim 10^5 \gamma_7^{-1} U_{\mathrm{CMB}}^{-1} \mathrm{yr} \Rightarrow \ N \sim 1 (-100)$$

$$E \sim \frac{Lt}{f} \sim 10^{50} \mathrm{erg}$$

KI, Kobayashi & Mészáros 04

Spectrum (β)

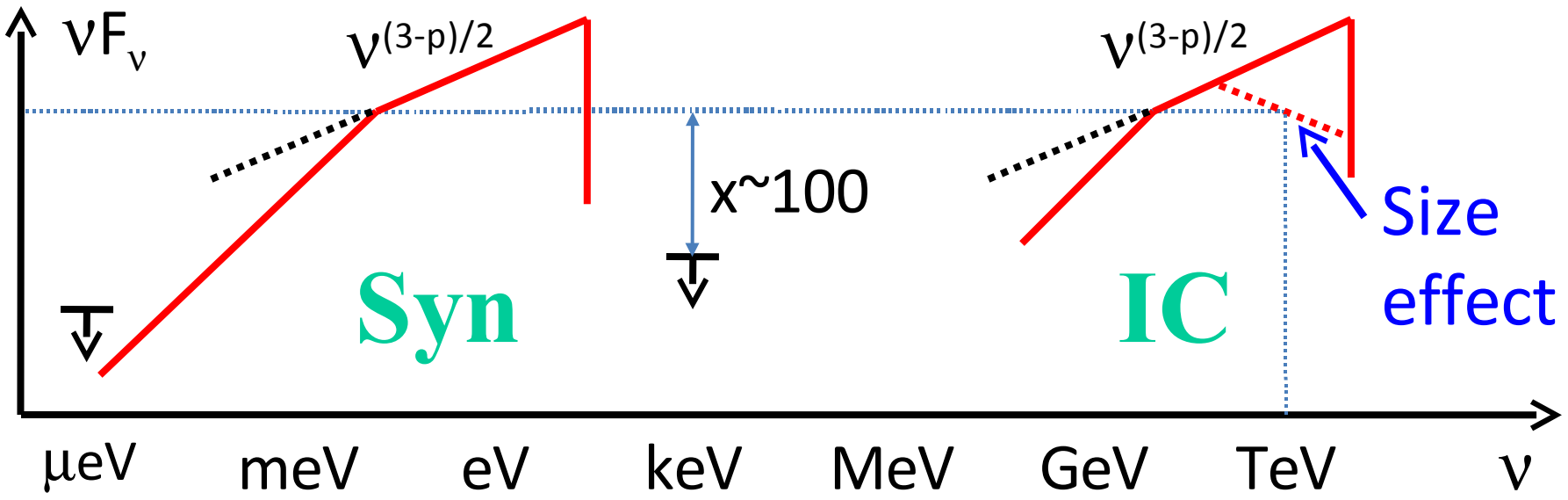


$p\gamma \rightarrow n\pi^+$: $\varepsilon_p\varepsilon_\gamma \sim 0.2\Gamma^2 GeV^2$

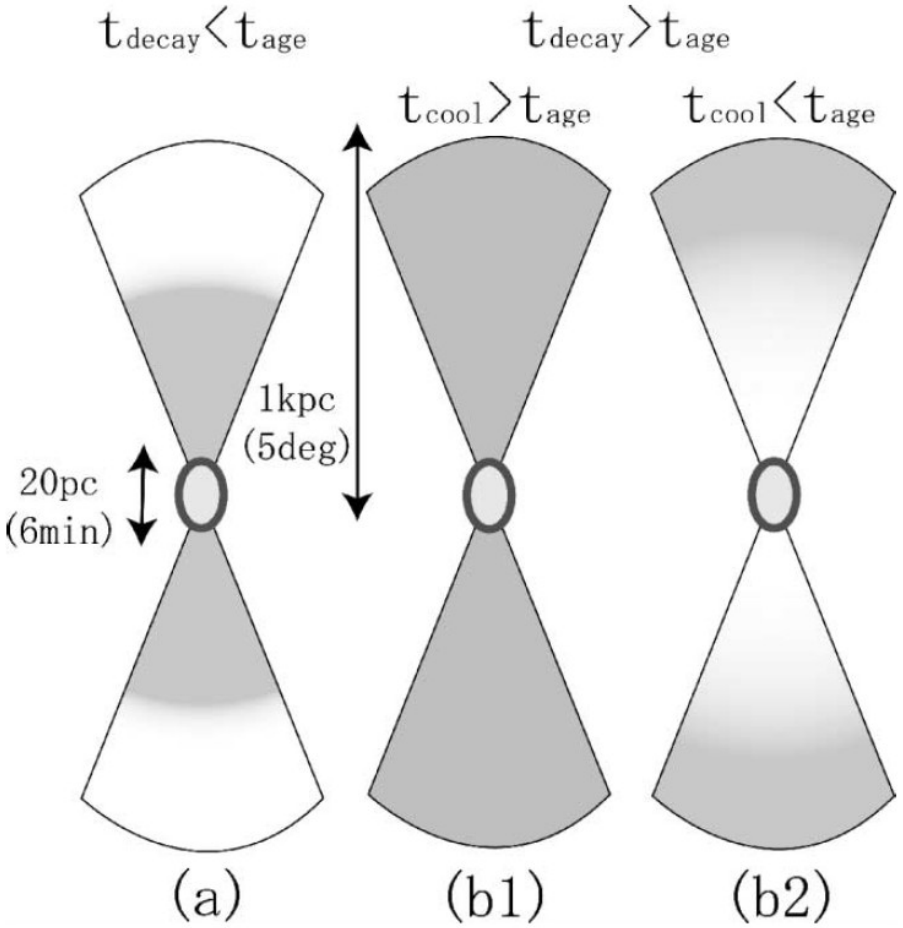
⇒ Less low-γ_e electron

? Cooling (No injection)

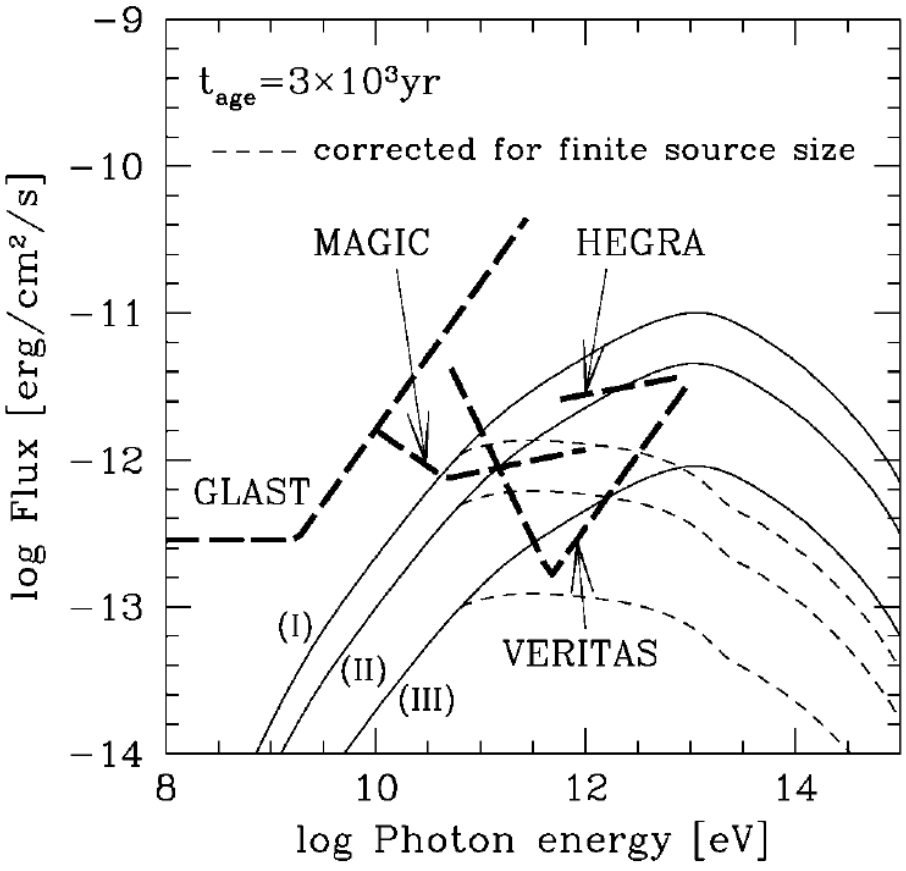
$t \sim 3\times10^4 yr$



Age/Energy dependence



KI, Kobayashi & Mészáros 04



Age/Energy dependent profile

SNR association

$t=3\times10^3$yr case

Dim @GeV

2. π^0 decay

$pp \rightarrow \pi^0 \rightarrow \gamma\gamma$

$$\tau_{pp} \sim n\sigma_{pp} ct \sim 3 \times 10^{-4} n \left(\frac{t}{10^4 \,\mathrm{yr}} \right)$$ Optical depth

$$f \sim \tau_{pp} \times \frac{1}{3} \times \frac{m_\pi}{m_p} \sim 10^{-5} n \left(\frac{t}{10^4 \,\mathrm{yr}} \right)$$ Energy fraction of TeV γ

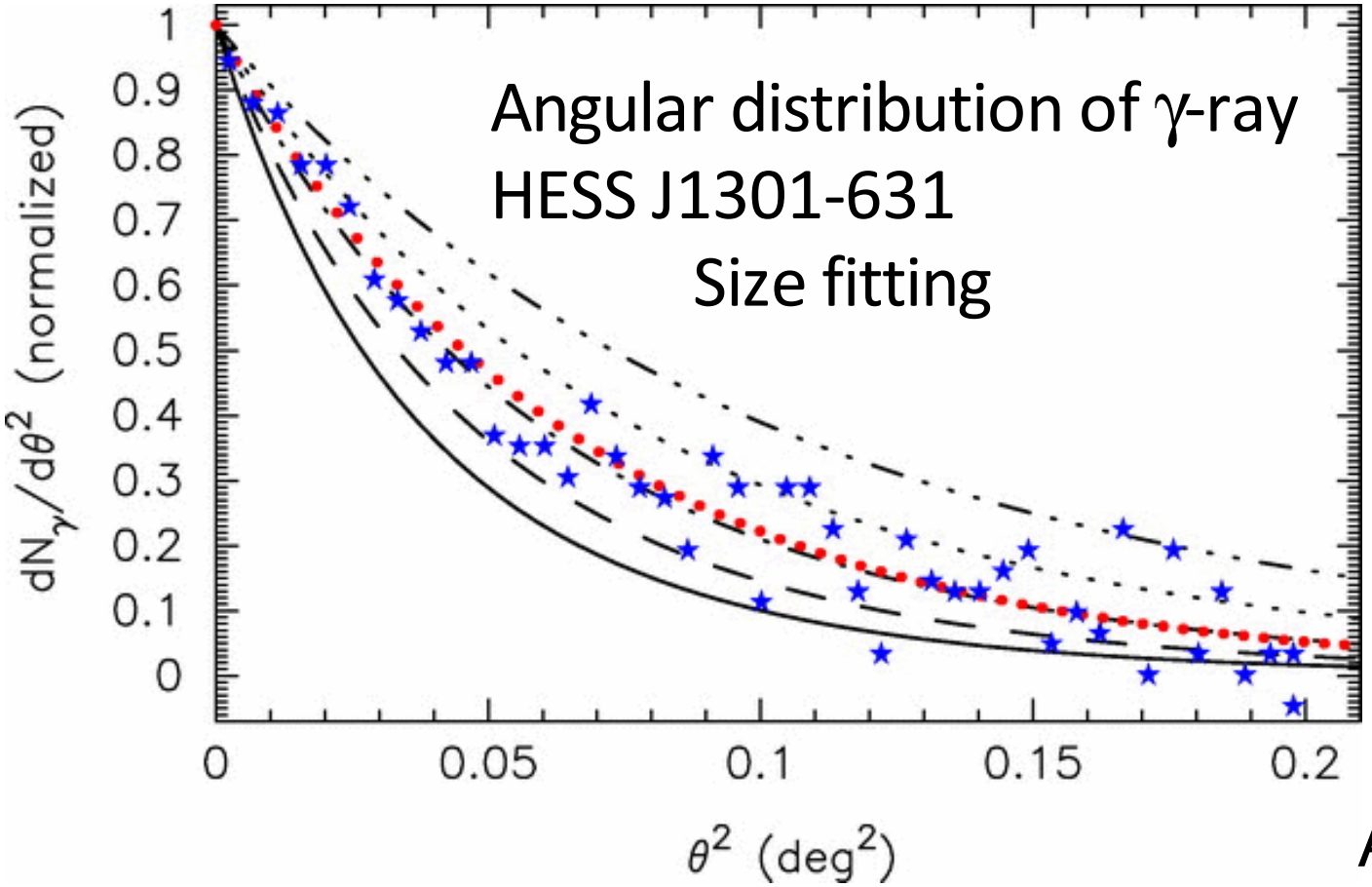
$$E \sim \frac{Lt}{f} \sim 10^{51} n^{-1} \mathrm{erg} \left(t\text{-independent} \right)$$ $\Rightarrow$ GRB

$$\mathrm{If}\ t \sim 10^4 \,\mathrm{yr}, N \sim 0.1 \left(- 10 \right)$$ $\Leftarrow$ Normal diffusion

SNR association

Atoyan, Buckley & Krawczynski 06

Diffusion

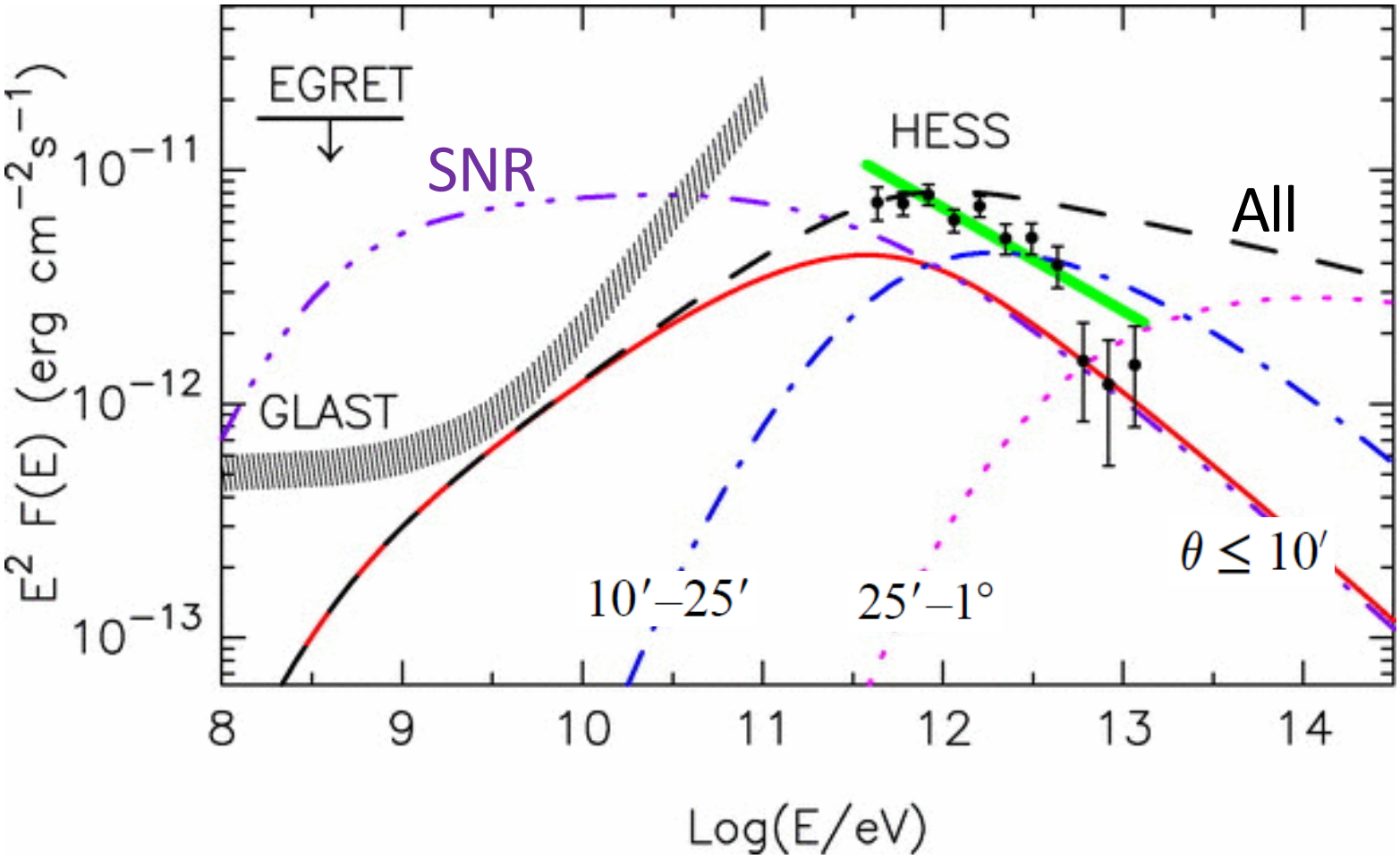


Atoyan+06

Normal diffusion $D=10^{27}E_{10GeV}^{0.5}$cgs

$\theta\sim(Dt)^{1/2}/d \Rightarrow$ Age $t\sim10^4 D_{27}^{-1} d_{10kpc}^{2}$yr

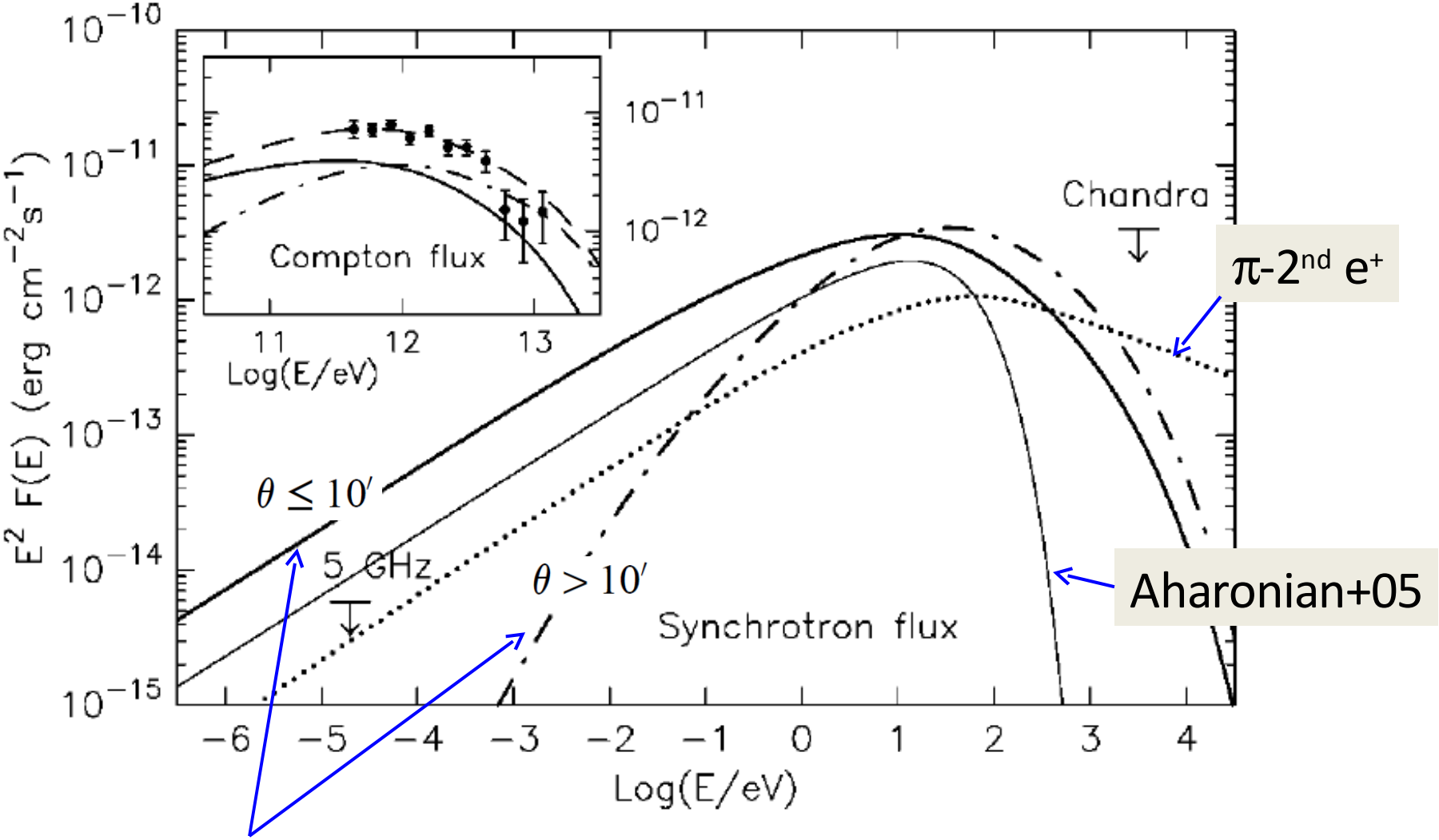
GeV-TeV (π^0)



Relativistic souces ⇒ low energy particle ↓

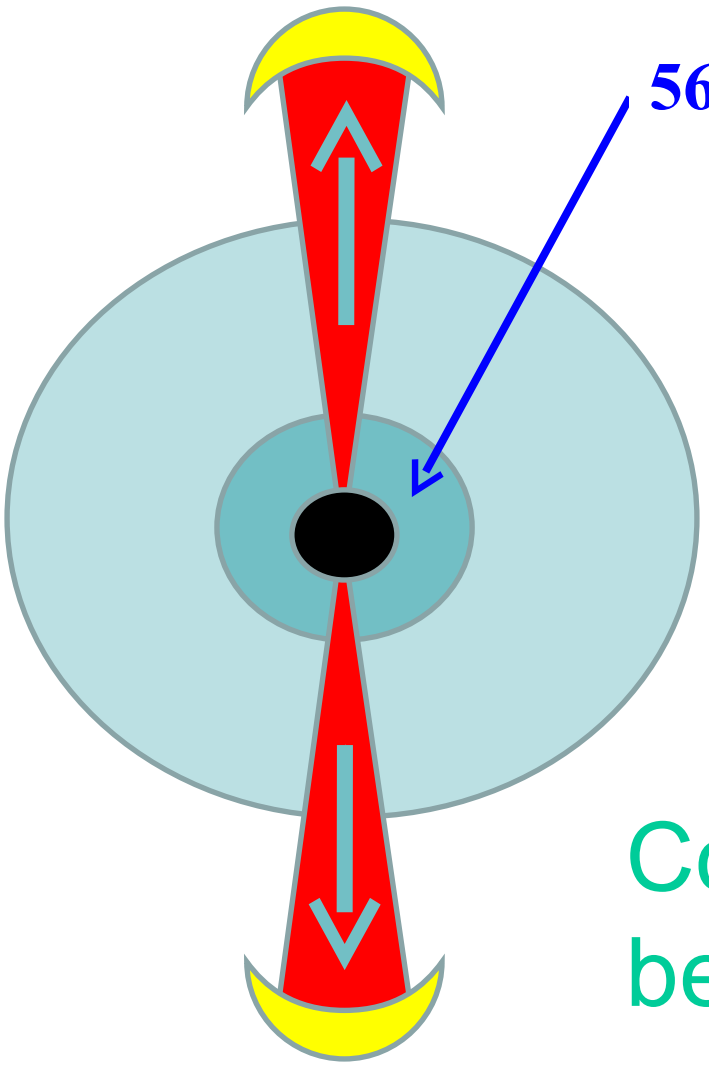
⇒ Low GeV & Radio emission

Radio-X (π^0, e)



Leptonic model overestimates radio fluxes

3. RI decay



^{56}Ni ⇐ SN light curve

1998bw: M(^{56}Ni)~0.4M$_\odot$

$$^{56}\mathrm{Co} \rightarrow {}^{56}\mathrm{Fe}^{*} + \mathrm{e}^{+} + \nu_{e}$$

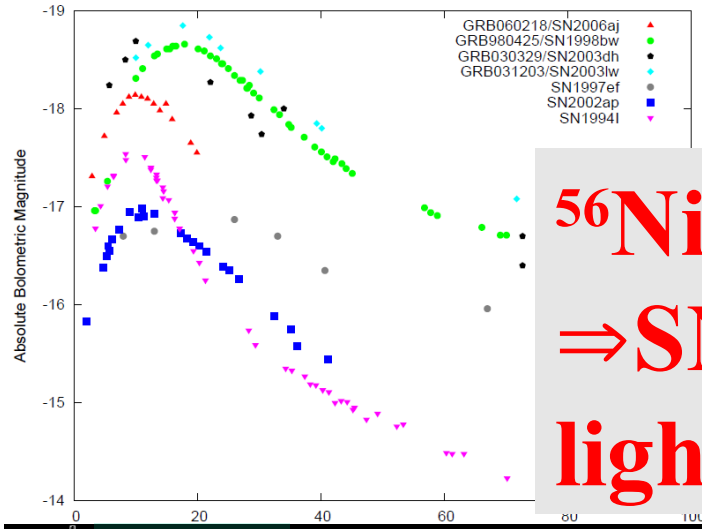
$$\gamma \qquad\qquad {}^{56}\mathrm{Fe} + \gamma$$

~2MeV

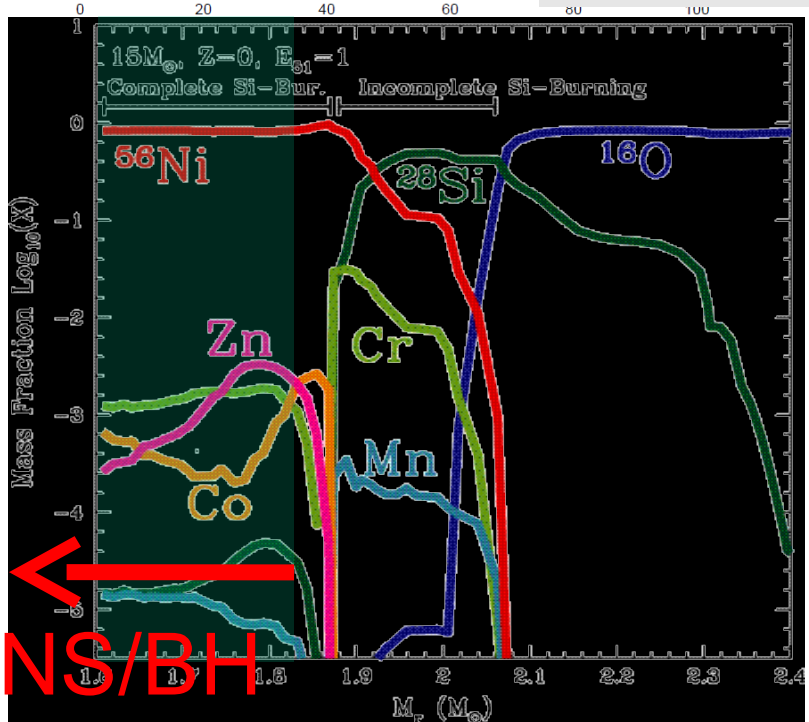
Could be shock-accelerated before decay (by reverse shock?)

GRB/Hypernova as RI beam factory

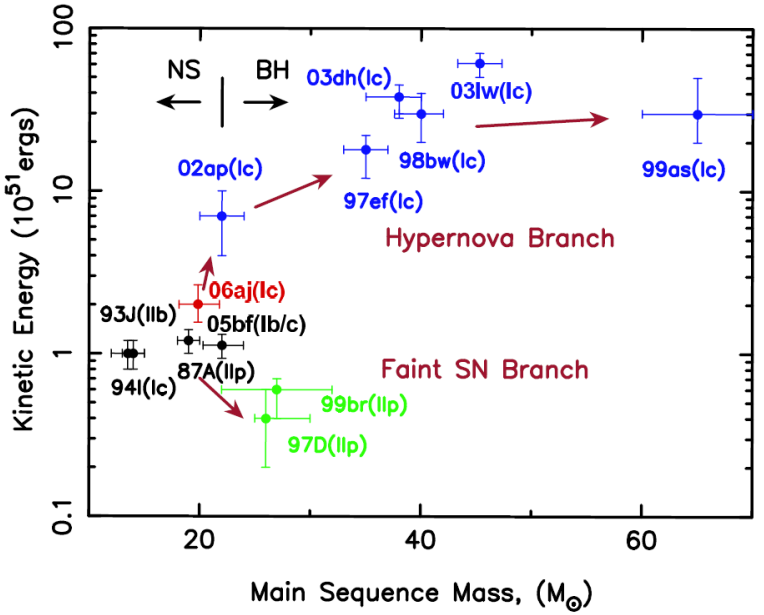
SN light curve

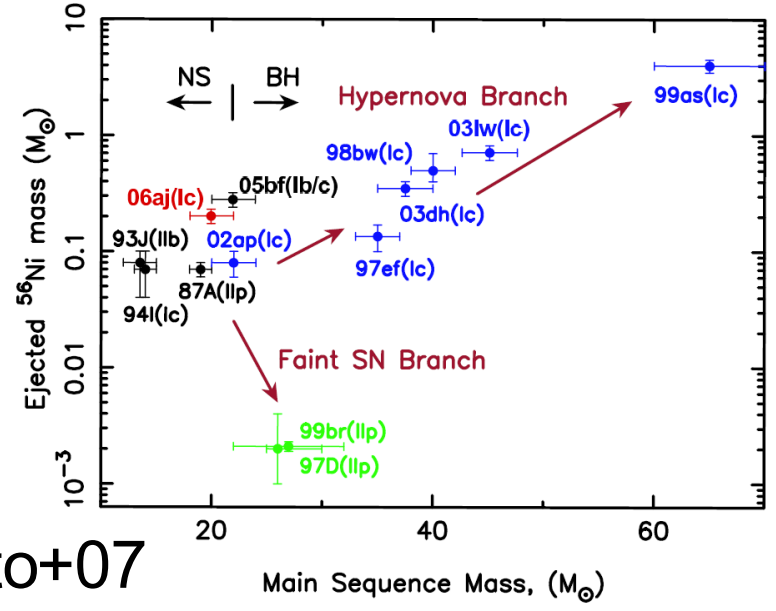


^{56}Ni decay ⇒SN light curve



NS/BH





Nomoto+07

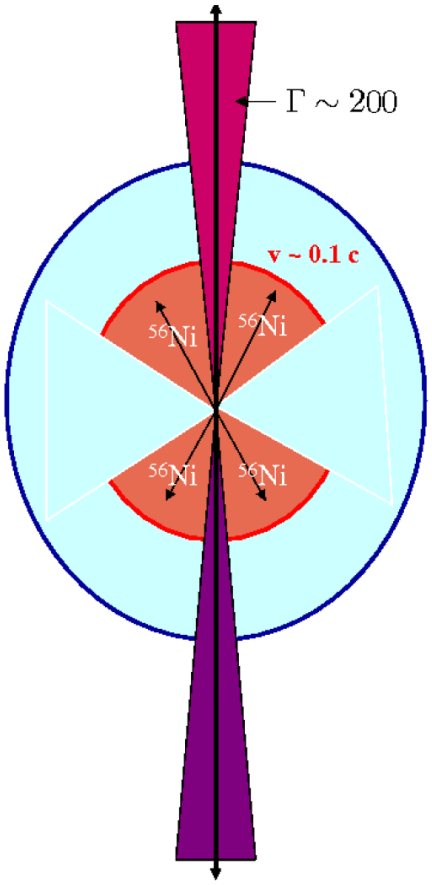
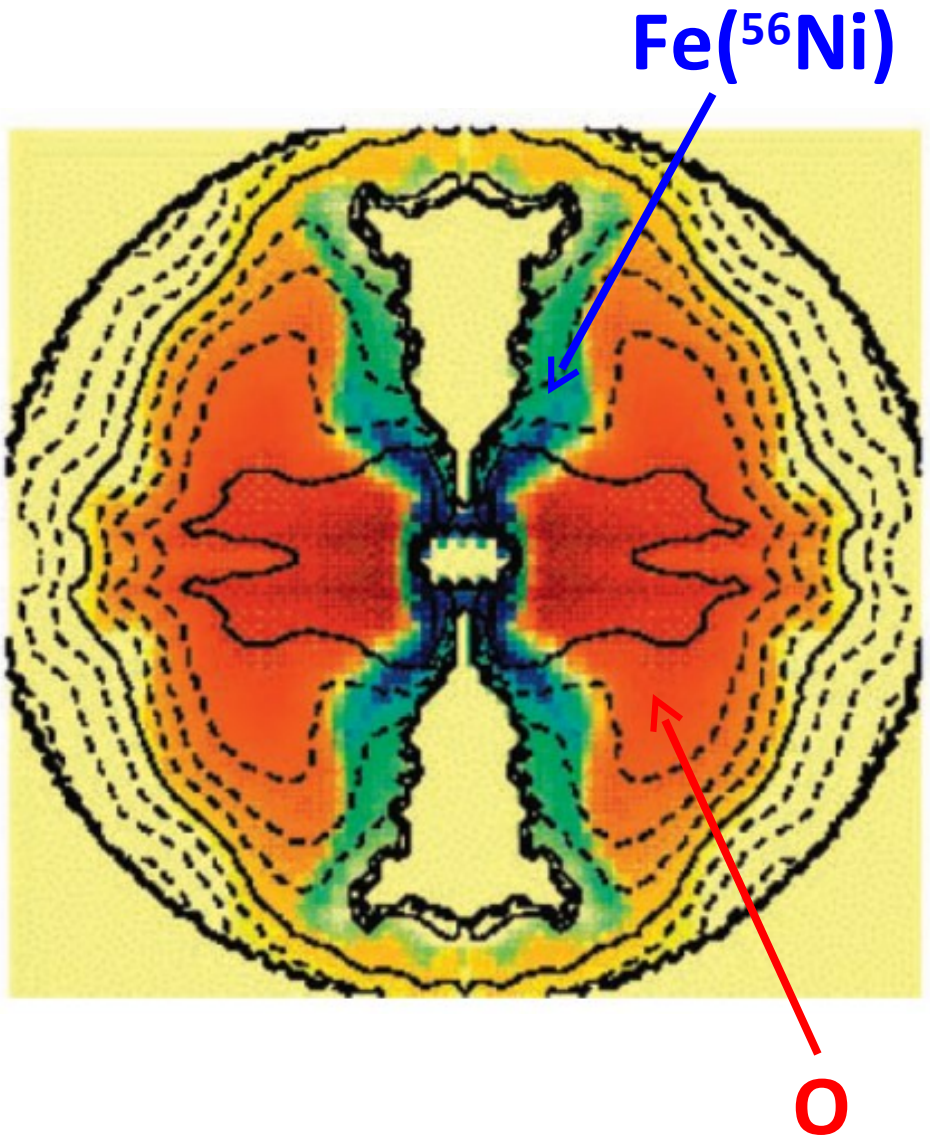


Figure 1. The jet in those GRBs which have accompanying supernovae must have at least two components - a narrow highly relativistic jet responsible for the burst itself and a broad subrelativistic outflow responsible for exploding the star and producing the ^{56}Ni to make it bright. The broad outflow extends to at least 1 radian. There may additionally be a mildly relativistic outflow (not shown) from the cocoon explosion that contributes to the afterglow and off-axis bursts.

Woosley & Zhang 07



Mazzali+05

Decay properties

	Decay mode	Half-life
^{56}Ni	Electron capture	6.1 day
		(>10^4yr: Ion)
^{56}Co	EC (81%)	77.2 day
	β+ (19%)	(x5: Ion)
^{57}Ni	EC	35.60 hr
	β+	

RI decay model

^{56}Co case

$$\varepsilon_\gamma \sim \gamma \varepsilon_{RI} \sim 2\mathrm{TeV}\left(\frac{\gamma}{10^6}\right)$$

^{56}Co energy

$$\gamma m_{RI} c^2 \sim 60\mathrm{PeV}\left(\frac{\gamma}{10^6}\right)$$

Hypernova OK

$$t \sim \gamma t_{RI} \sim 10^6\,\mathrm{yr}\left(\frac{\gamma}{10^6}\right)\left(\frac{t_{RI}}{1\mathrm{yr}}\right) \Rightarrow \quad N \sim 10\left(\sim 10^3\right)$$

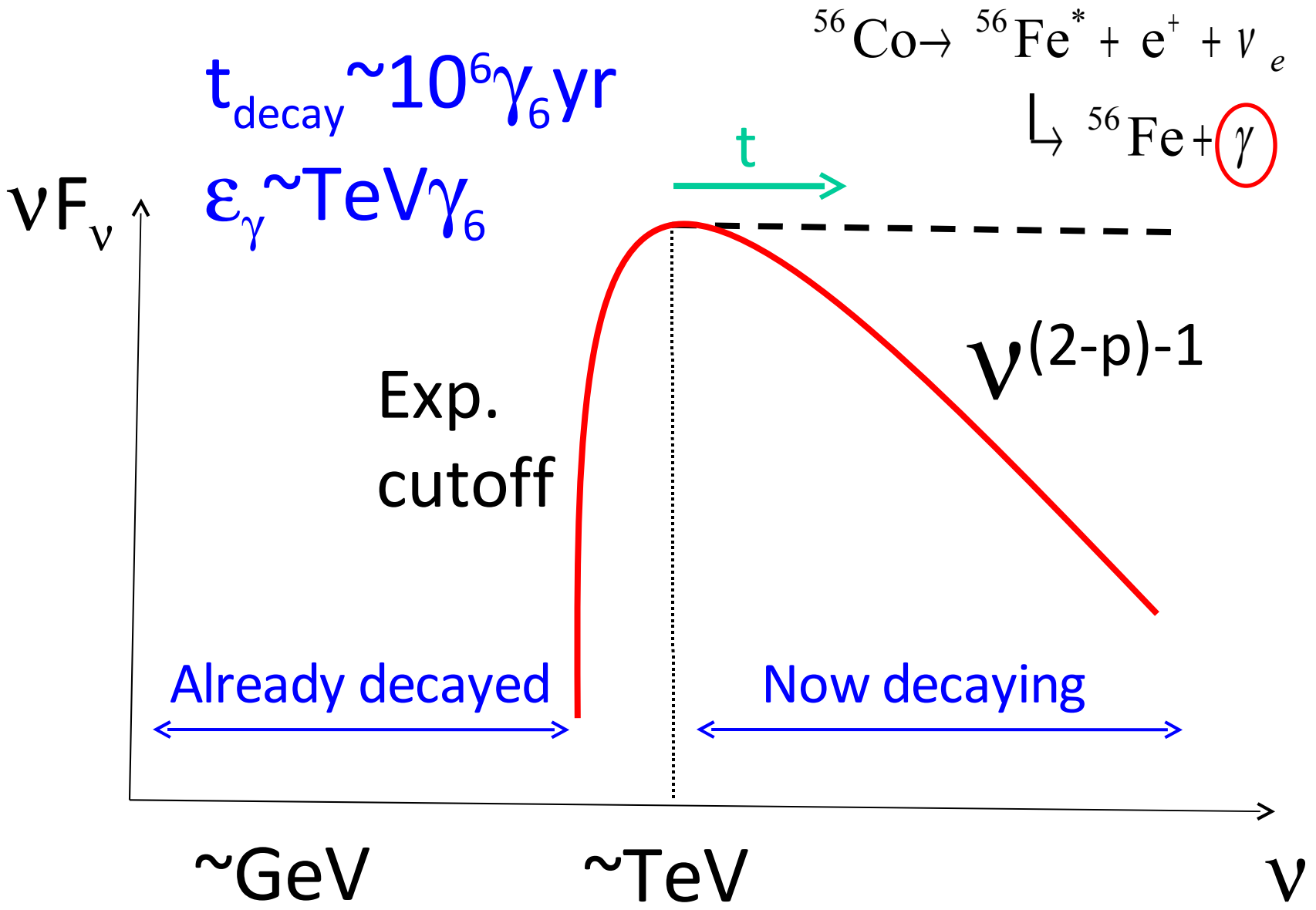
SNR disappears

$$f \sim \frac{\varepsilon_{RI}}{m_{RI} c^2} \sim \frac{2\mathrm{MeV}}{60\mathrm{GeV}} \sim 3 \times 10^{-5}$$

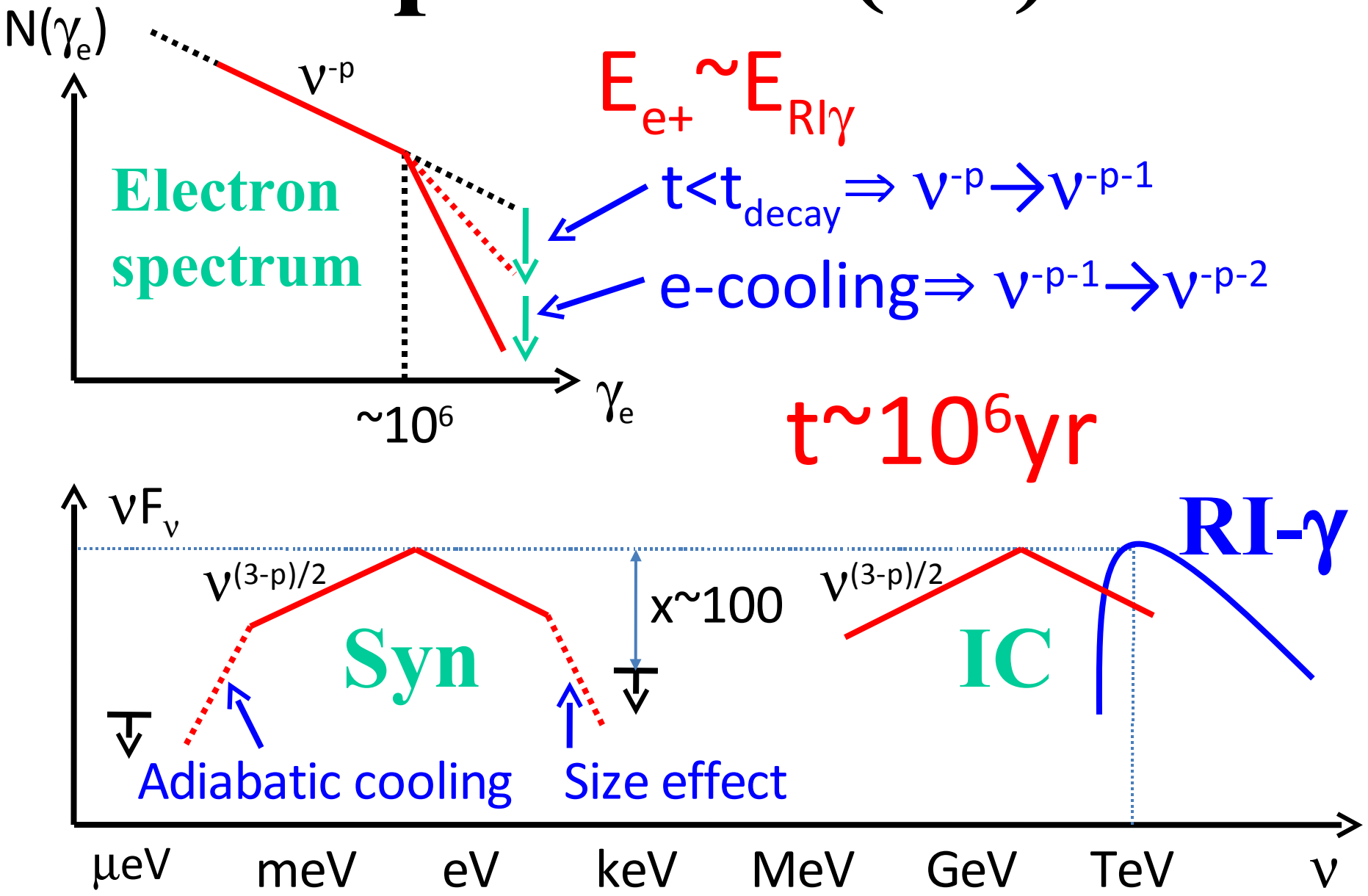
$$E \sim \frac{Lt}{f} \sim 3 \times 10^{52}\,\mathrm{erg}$$

(Nearby HNe may ease energy requirements)

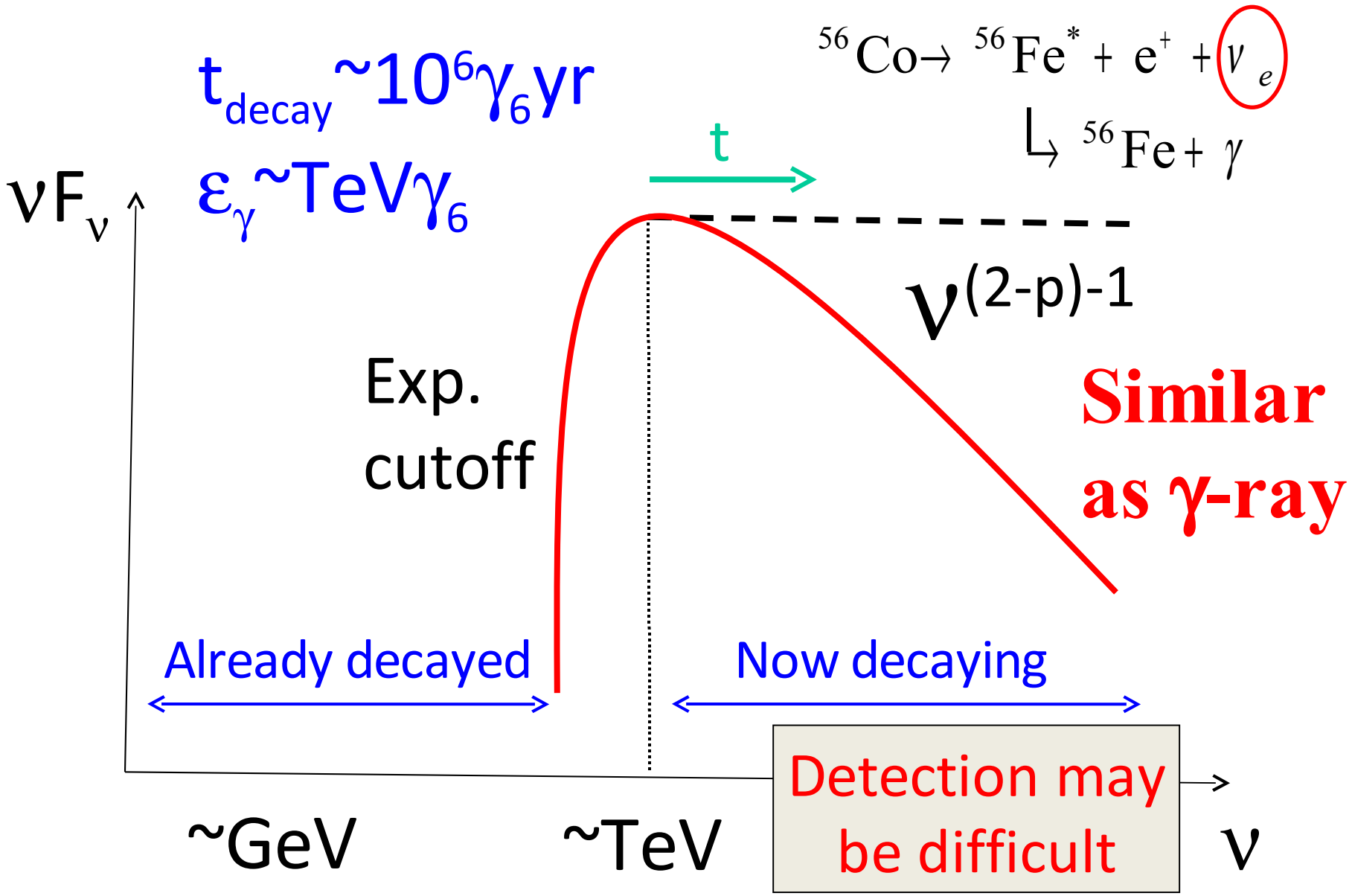
Spectrum


$^{56}Co \rightarrow {}^{56}Fe^{*} + e^{+} + \nu_e$
$\hookrightarrow {}^{56}Fe + \gamma$
$t_{decay} \sim 10^6 \gamma_6 yr$
$\varepsilon_\gamma \sim TeV\gamma_6$
t
νF_ν
$\nu^{(2-p)-1}$
Exp.
cutoff
Already decayed
Now decaying
~GeV
~TeV
ν

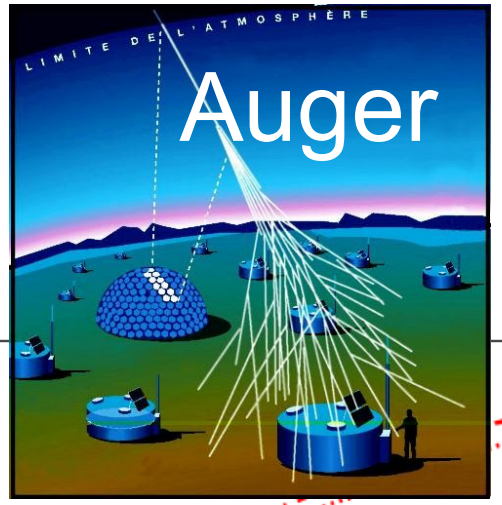
Spectrum (RI)


N(γe)
ν-p
Electron spectrum
~10^6
γe
Ee+ ~ ERIγ
t<tdecay ⇒ ν-p → ν-p-1
e-cooling ⇒ ν-p-1 → ν-p-2
t~10^6yr
νFν
ν(3-p)/2
Syn
x~100
ν(3-p)/2
IC
RI-γ
Adiabatic cooling
Size effect
μeV
meV
eV
keV
MeV
GeV
TeV
ν

High energy ν_e



Fe ?



Depth of air shower maximum

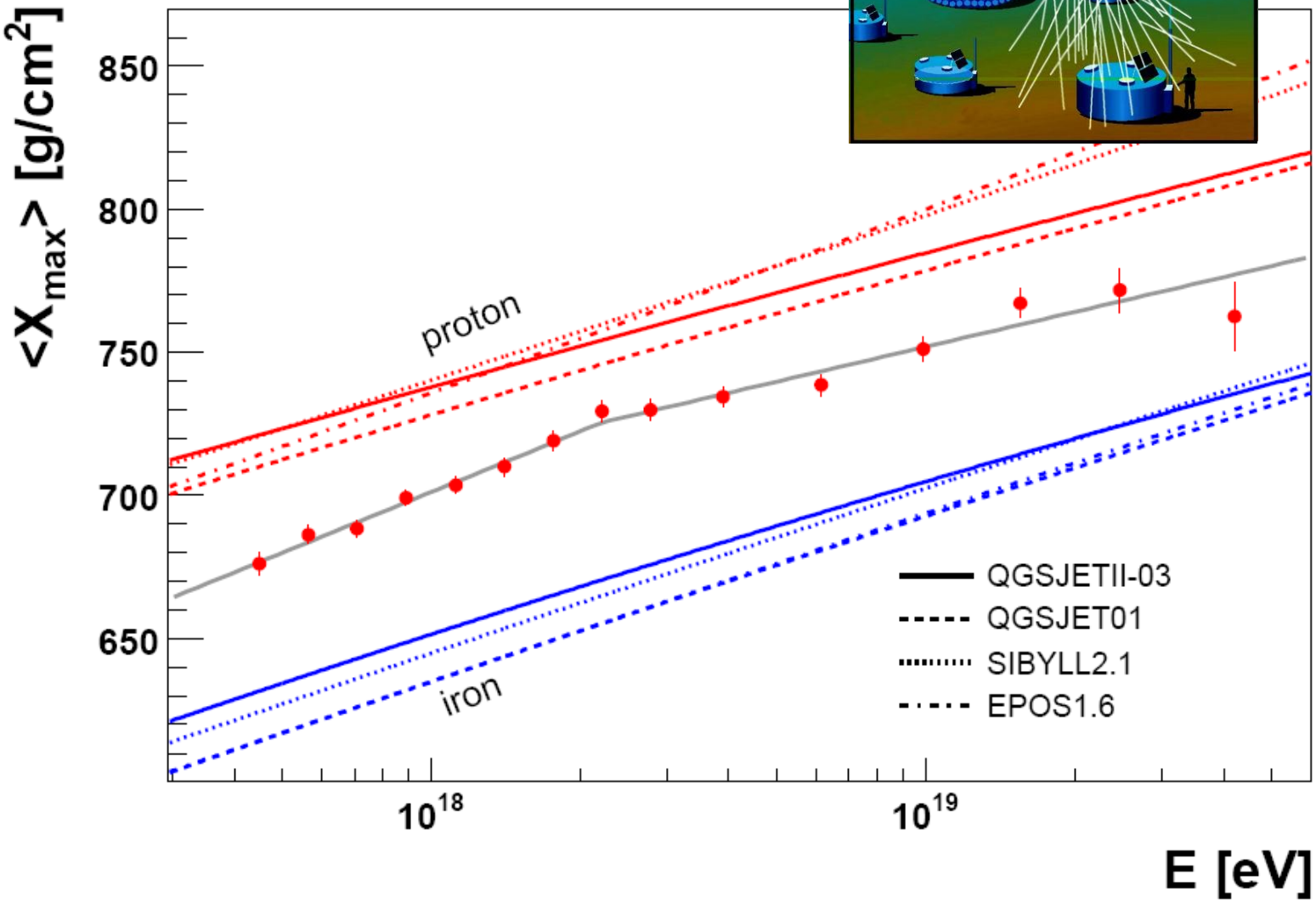
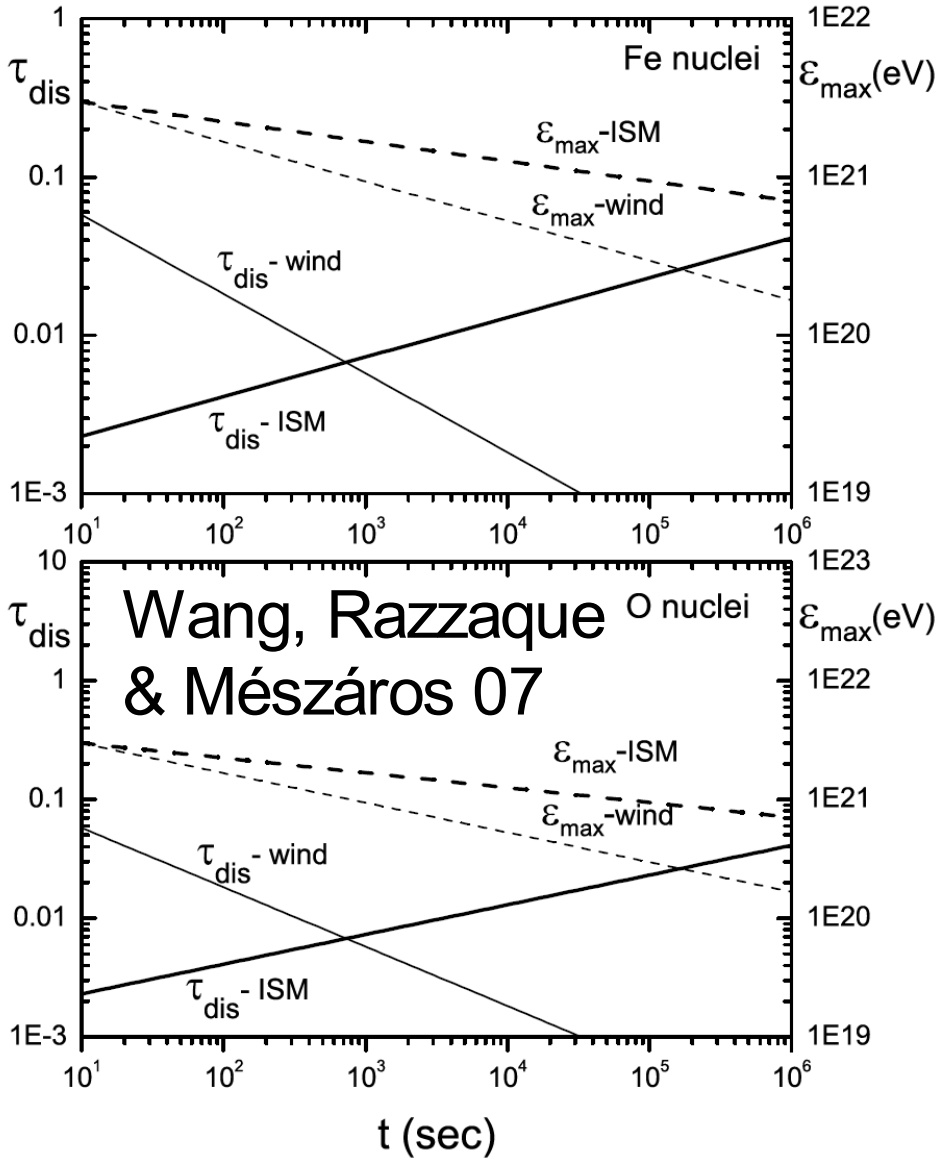
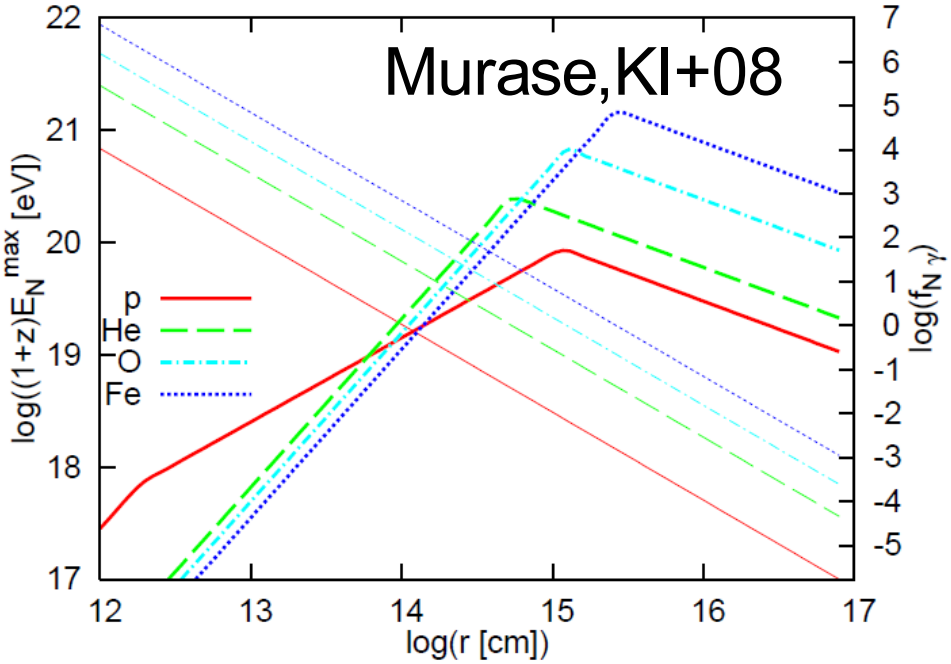


Photo-disintegration





Ni/Co/Fe can survive photo-disintegration (⇔ Fe UHECR implied by Auger X_{max})

Summary

	β	π	RI
$E\,[\mathrm{erg}]$	$10^{50\text{-}51}$	$10^{51} n^{-1}$	3×10^{52}
f	10^{-3}	$10^{-5} n t_4$	3×10^{-4}
$t\,[\mathrm{yr}]$	3×10^{4}	10^{4}	10^{6}
N	$0.3(-30)$	$0.1(-10)$	$10(-10^{3})$
SNR	w/	w/	w/o
Diffusion	normal	normal	small
GeV	w/o	w/o	w/
ν	w/o	$\nu_e \nu_\mu \bar{\nu}_\mu$	ν_e

GRBR/ HNR ⇒ TeV unID: Possible

GLAST is important