Congratulations to Nakamura-san, Maeda-san and

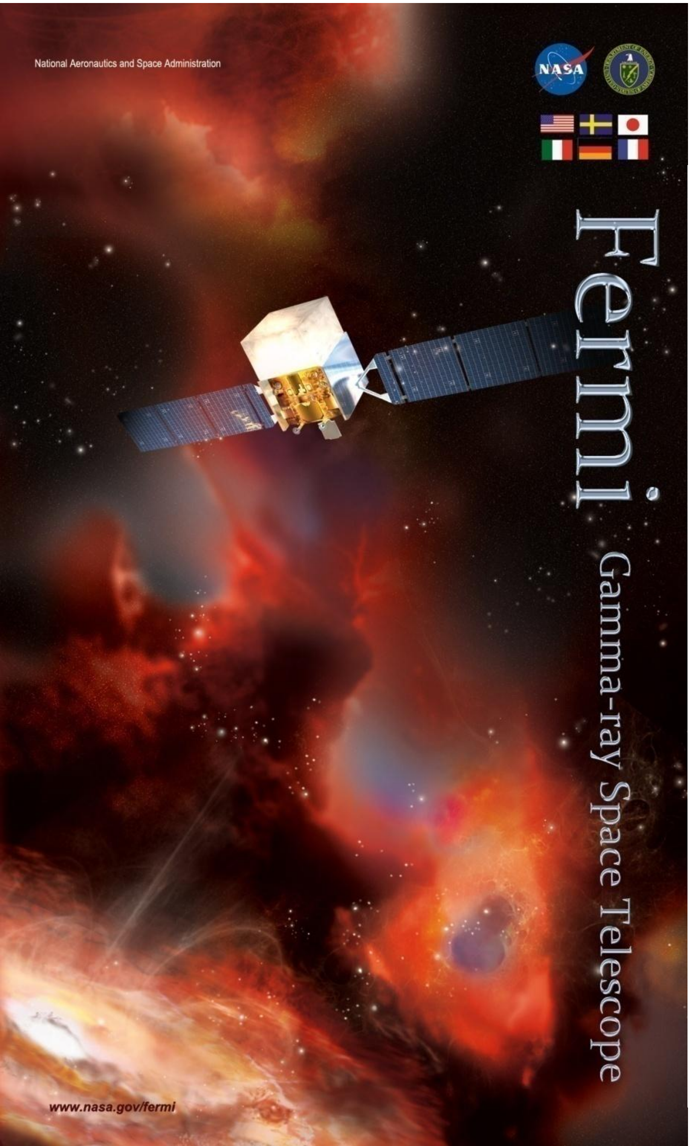
Gravitational Wave and High Energy Phenomena

Kunihito Ioka (KEK)

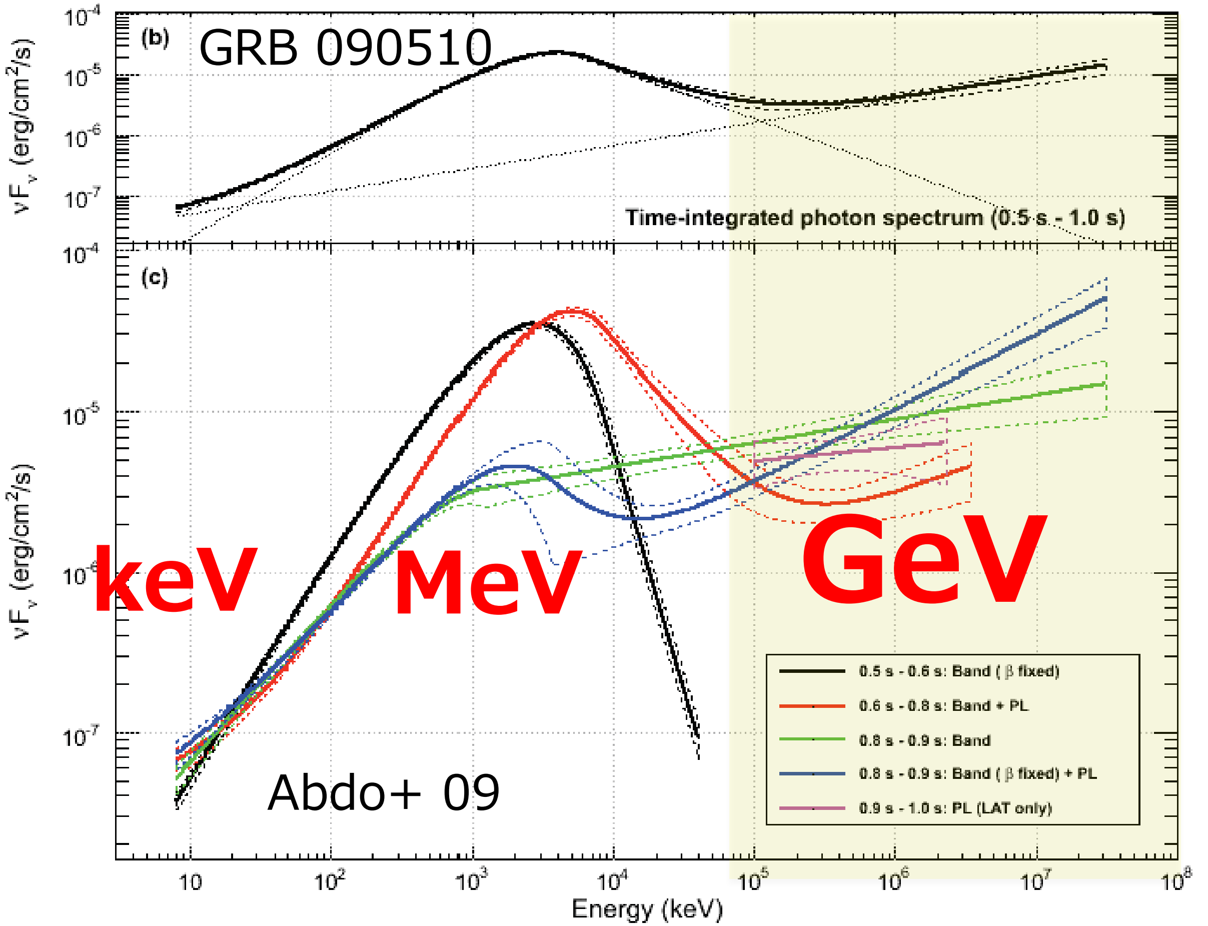
Y. Suwa (Kyoto), K. Kashiyama (Kyoto),
N. Kawanaka (KEK), Y. Ohira (KEK)

1. Gamma-Ray Burst
2. Cosmic-Ray

Fermi Revolution



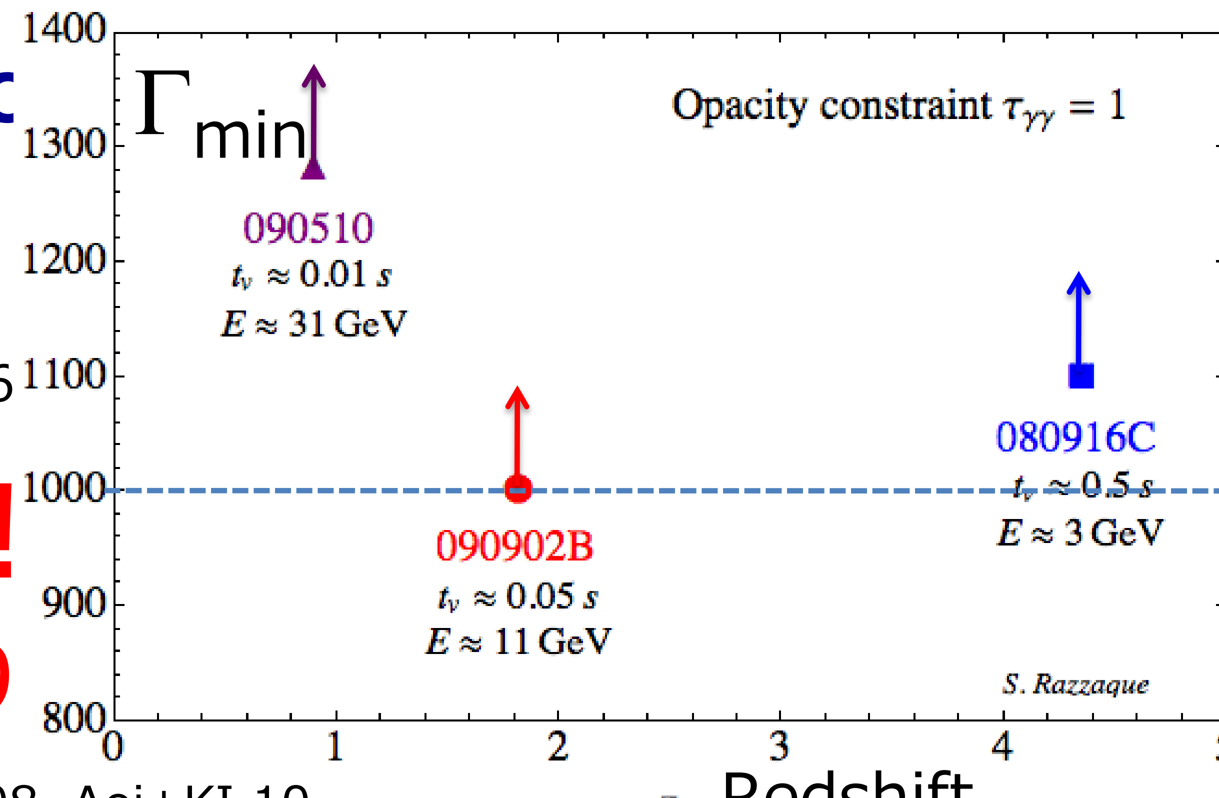
GeV γ from GRBs



High Lorentz Factor?

- $\gamma\gamma \rightarrow e^+e^-$ (ε_{th}~MeV)
  - $R \sim c\Delta t \Rightarrow \tau \sim \sigma_T N_\gamma / 4\pi R^2 \gg 1$ (γ-ray cannot escape)
- **Relativistic**
  - $R \sim \Gamma^2 c\Delta t$
  - Blueshift
  - $\tau \sim \Gamma^{2\beta-2} \sim \Gamma^{-6}$
- **$\Gamma > 10^3$!**

v>0.999999



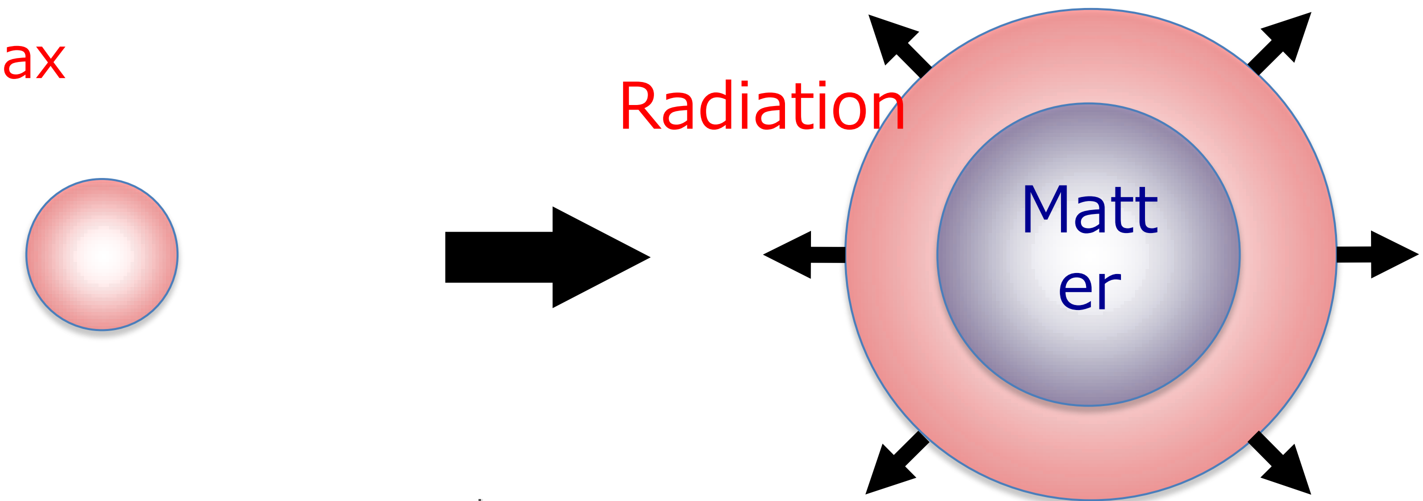
also Zou, Fan & Piran 10, Li 08, Aoi+KI 10

Conventional Γ_{max}

- Fireball expands by radiation pr
- In principle, Γ_{max} ~ Energy / Ma
- But, Mass↓ ⇒ Transparent before

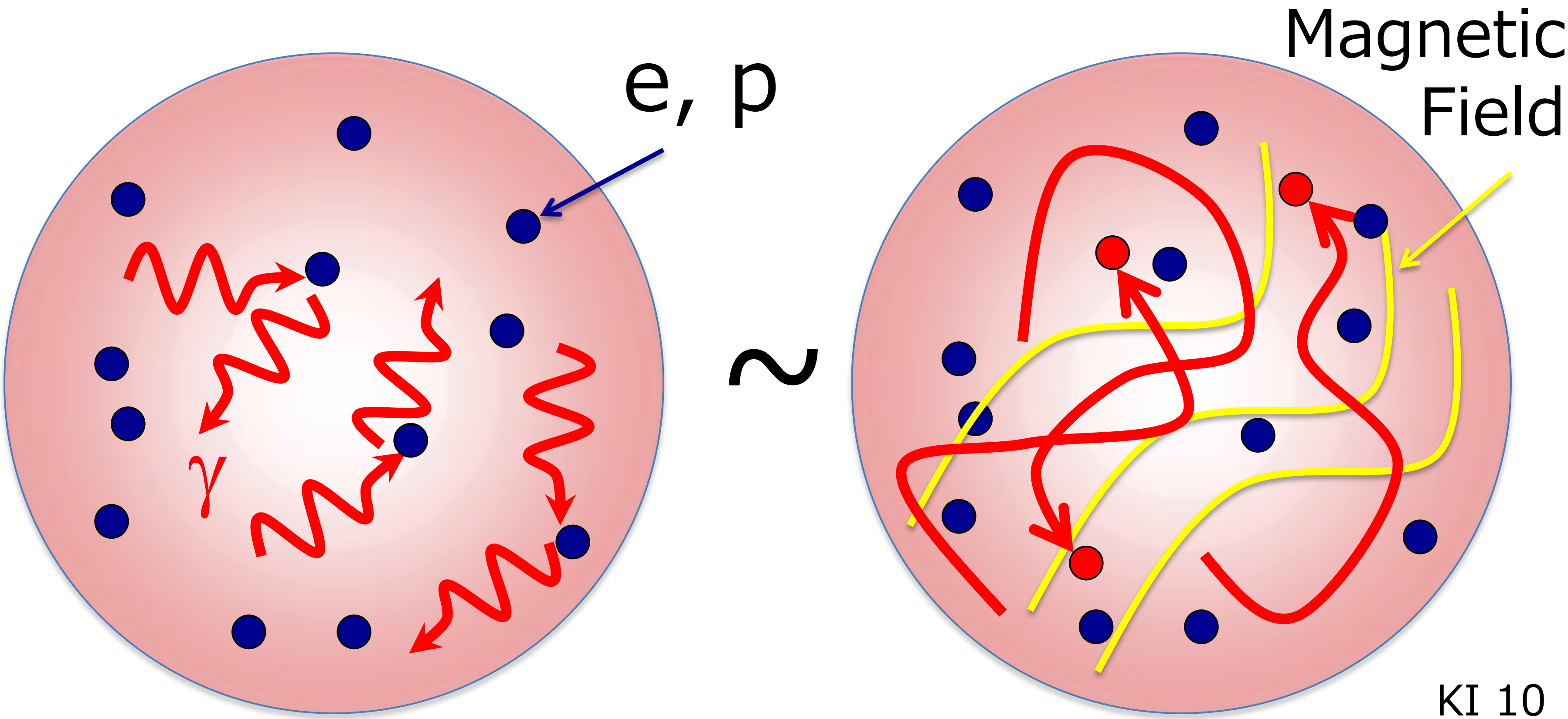
Paczynski 86
Goodman 86
Shemi & Piran 9
Meszaros & Ree

$\Gamma \sim \Gamma_{max}$



$$\Gamma_{max} = \left(\frac{L \sigma_T}{4 \pi m_p c^3 r_0} \right)^{1/4} \sim 10^3 L_{53}^{1/4} r_{0,7}^{-1/4}$$

Nonradiative Pressure

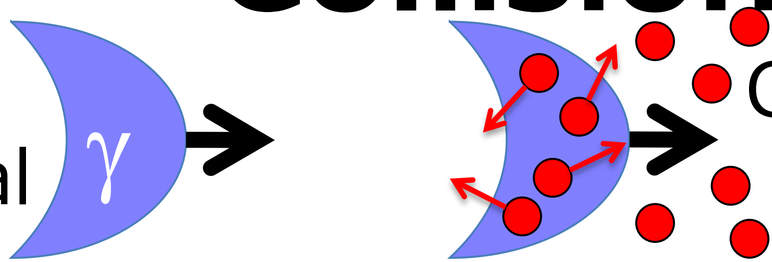


Radiation Pressure ~ Collisionless Pressure of Relativistic Particles

Not escape ⇒ Γ=Energy/Mass can be attai

Radiation to Collisionless

Initially Collisional



Collisionless but Opaqu
$\gamma \rightarrow$ Relativistic proton

Energy $$\underbrace{E_r \Gamma_r}_{\text{Fireball}} + Mc^2 = \Big(\underbrace{\Gamma_m Mc^2}_{\text{Rela. motion}} + \underbrace{E_m}_{\text{Radiation}}\Big)\Gamma_m$$

Momentum $$E_r \sqrt{\Gamma_r^2 - 1} = \left(\Gamma_m Mc^2 + E_m\right)\sqrt{\Gamma_m^2 - 1}$$

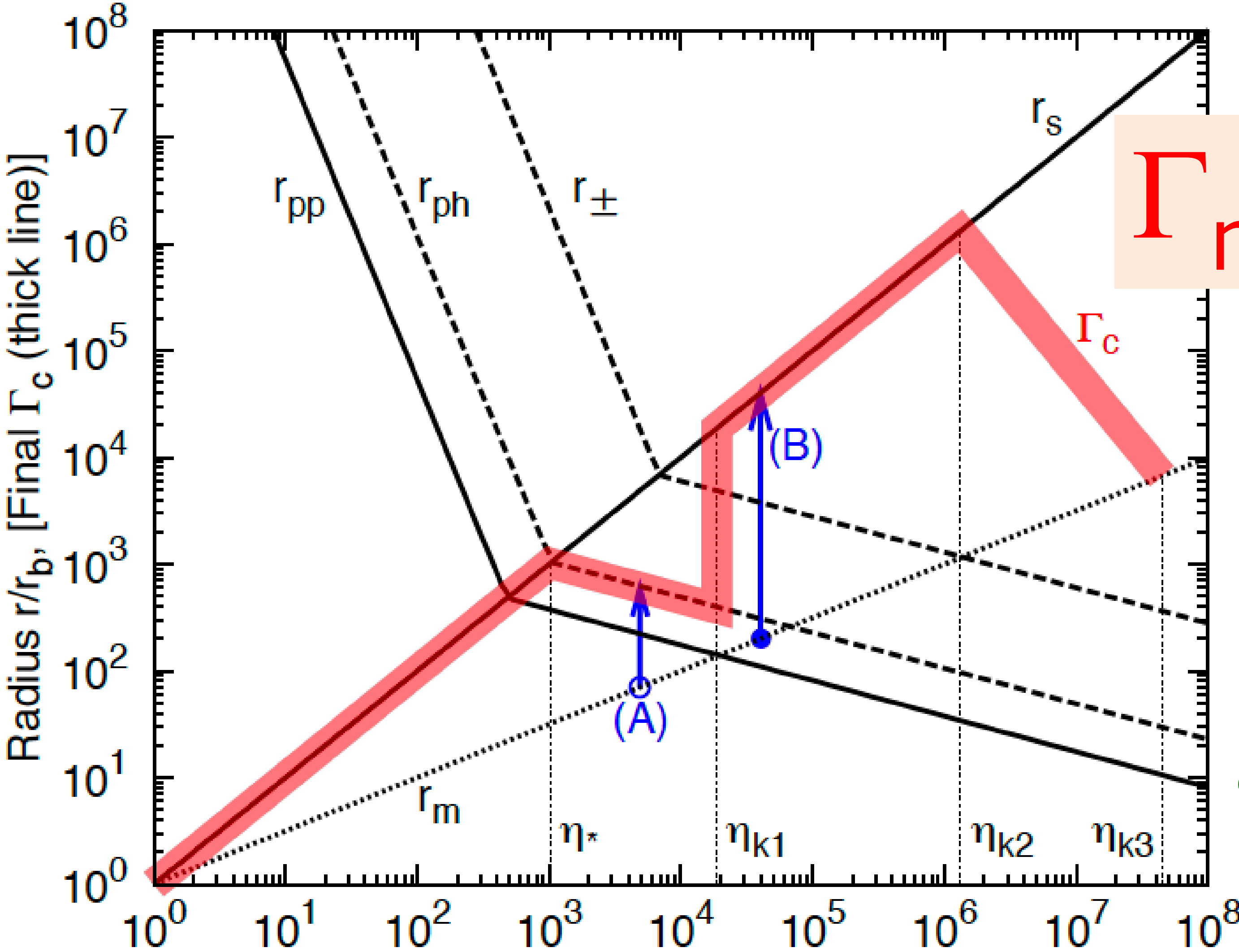
$$\Rightarrow \Gamma_m \sim \sqrt{\frac{E_r \Gamma_r}{2Mc^2}} \propto L^{1/2}$$

2 eqs. for 2 unknowns $\left(\frac{E_r}{\Gamma_r} < Mc^2 < E_r \Gamma_r\right)$

$E_m \sim \Gamma_m Mc^2$ **: Radiation ~ Relativistic motion**

$\propto r^{-4}$ $\propto r^{-4}$

Γ_{max} of Dissipated Fireball



Baryon-Rich

Baryon-Less

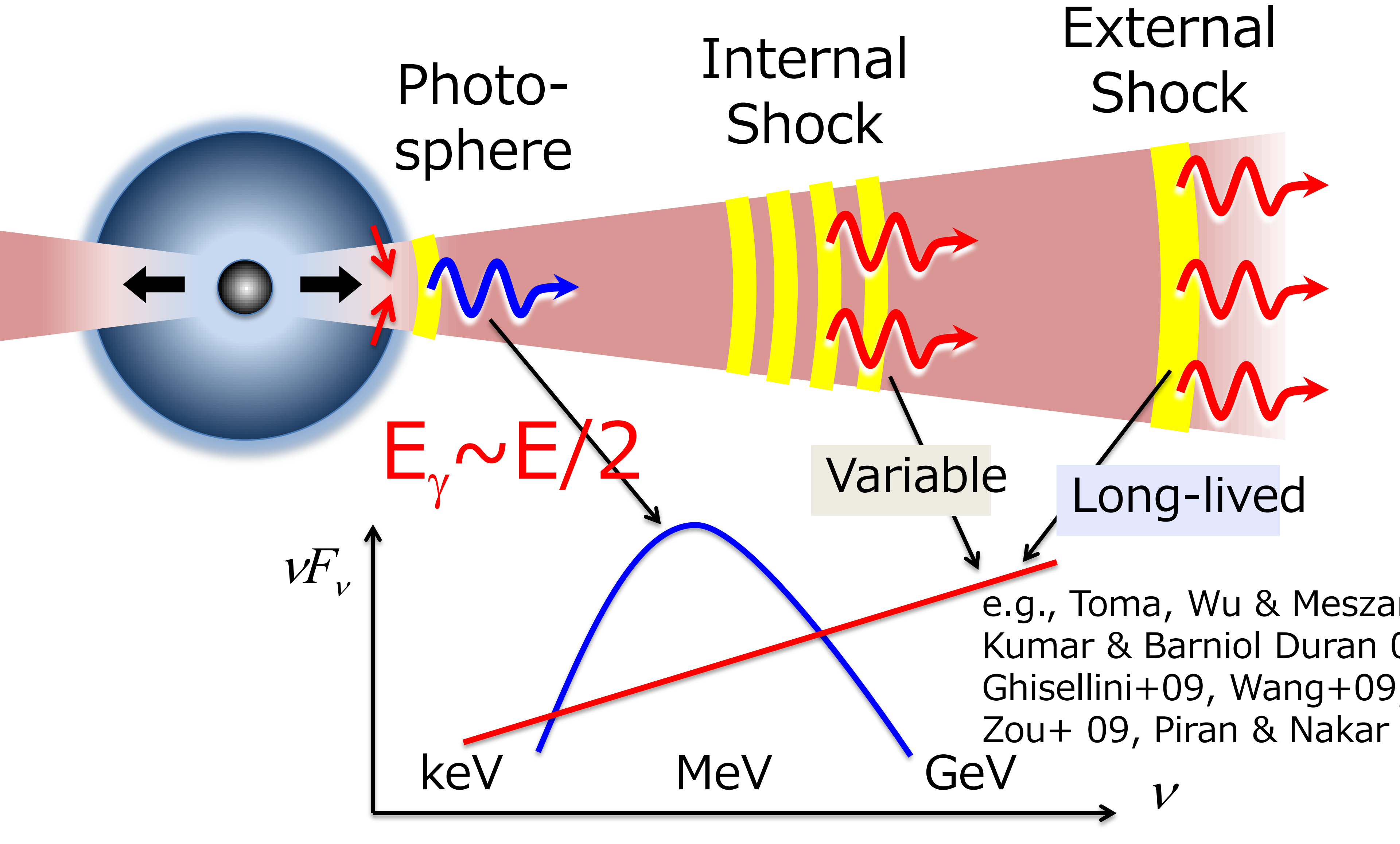
(To be opaque

Γ_{max}~10^6

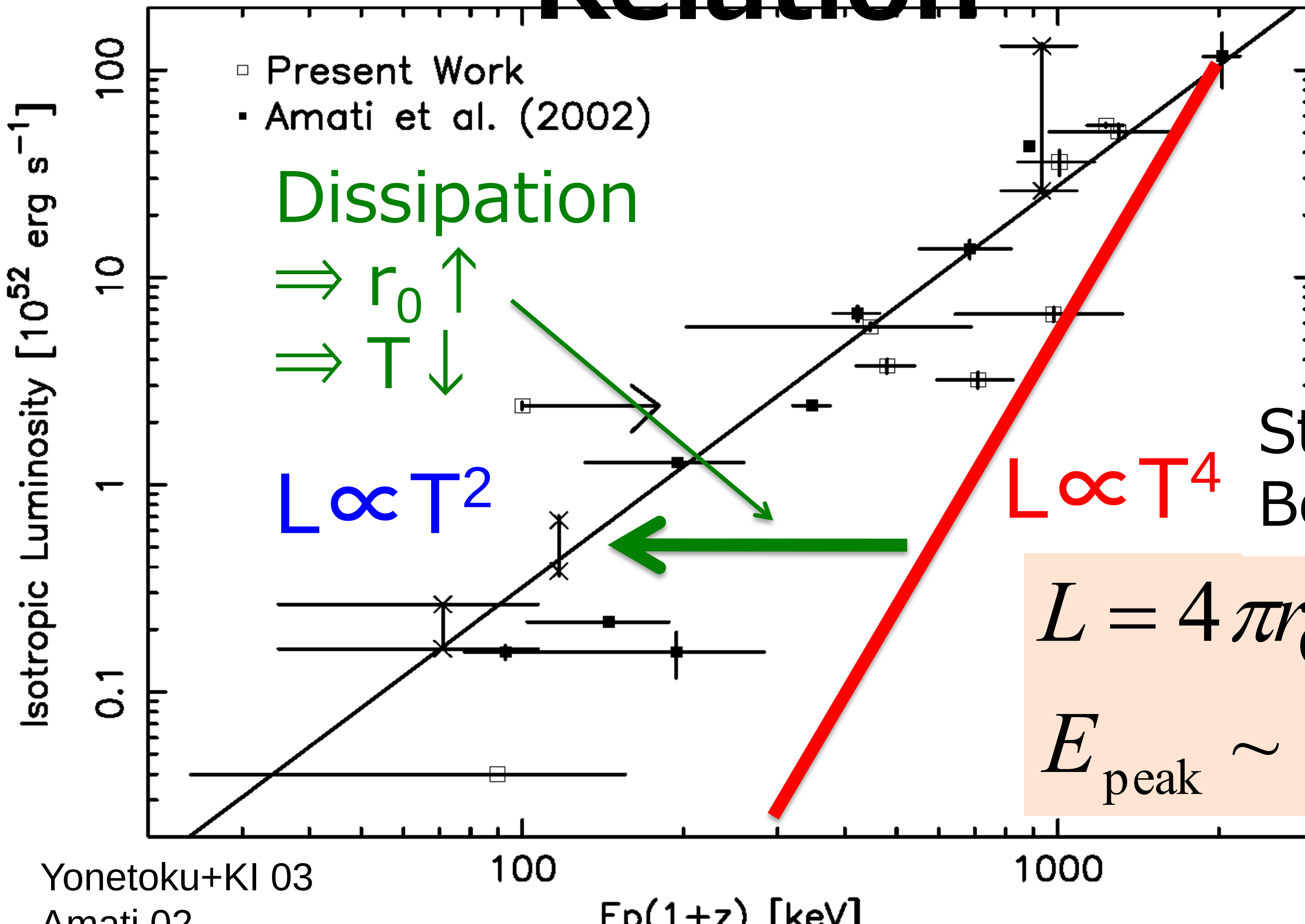
>Γ_{conv}~10

Collsionless bulk-acceleration

Photosphere-Internal-External Shock Model



E_{peak}-Luminosity Relation



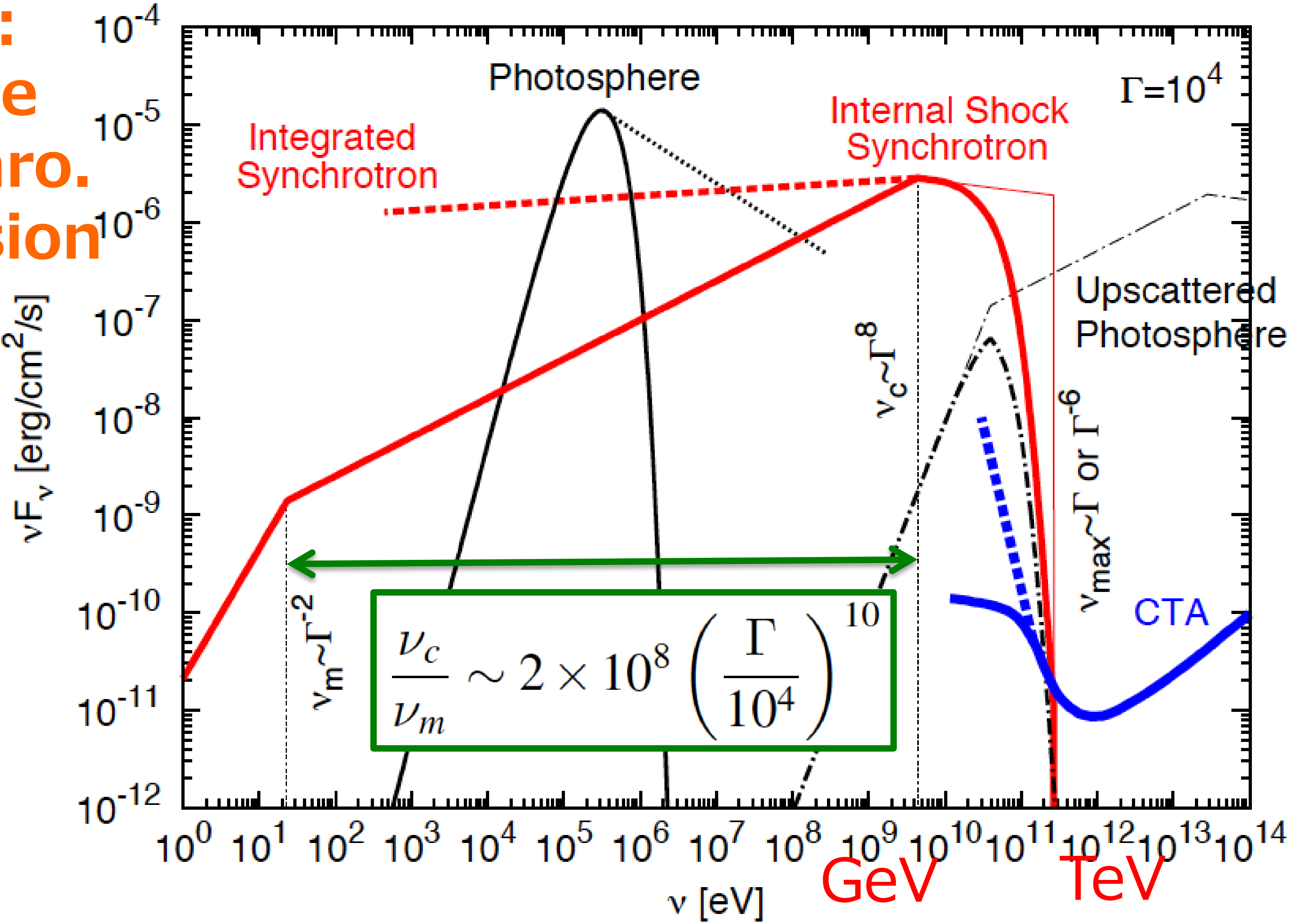
$$L = 4\pi r_0^2 c a T_0^4$$

$$E_{peak} \sim T_0$$

Yonetoku+KI 03
Amati 02

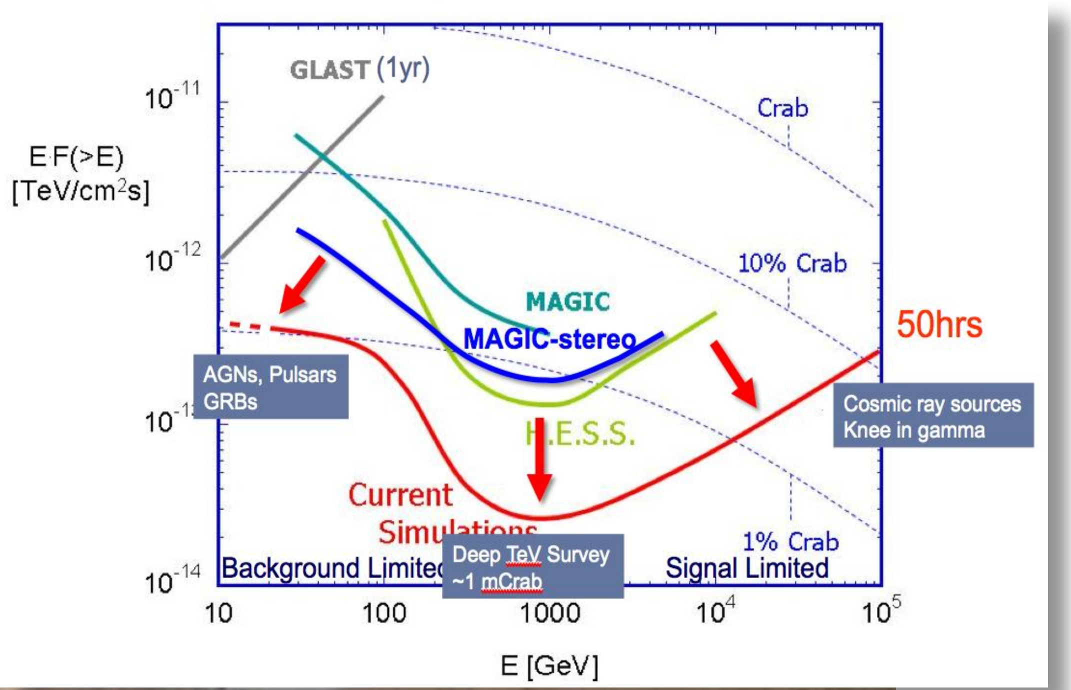
High Γ Internal Shock

GeV γ: Simple synchro. emission



CTA

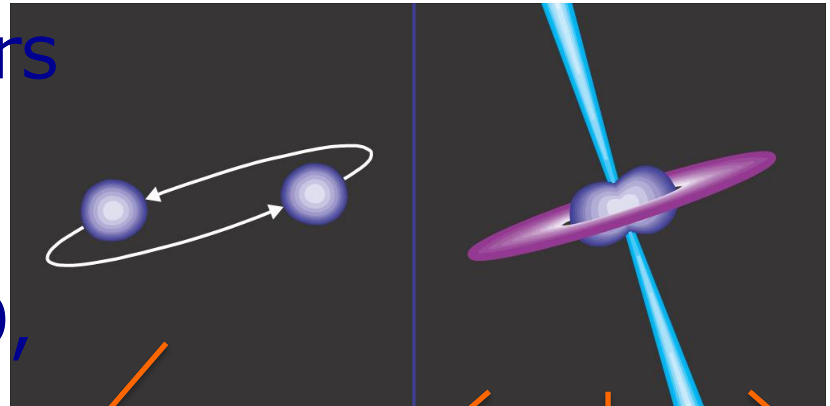
- ~20GeV-100Te
- x10 Sensitivity
- $\Delta\theta$~1-2 min
- FOV~5-10 deg
- ~20 s slew (LS
- ~2015 (?)
- ~150€



TeV γ from GRB or not?

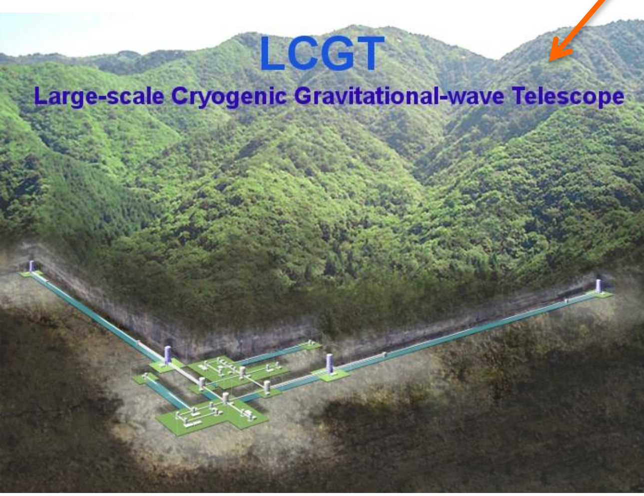
NS merger – Short GRB

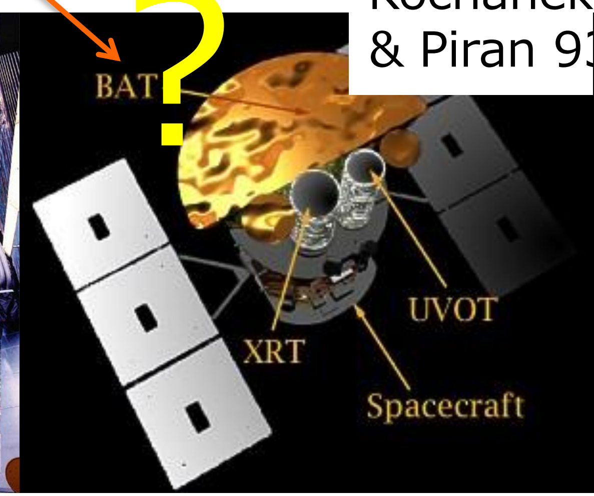
NS-NS mergers are promising GW sources
⇒ LCGT, LIGO, Virgo, GEO, ⋯



EM followup
- Short GRB?
- z ⇒ local H_0
- Degeneracie
- S/N

Schutz 86
Kochanek
& Piran 9





In most cases, GRB jets are off-

Off-Axis GRB

THE ASTROPHYSICAL JOURNAL, 554:L163–L167, 2001 June 20

PEAK LUMINOSITY–SPECTRAL LAG RELATION CAUSED BY THE VIEWING ANGLE OF THE COLLIMATED GAMMA-RAY BURSTS

KUNIHITO IOKA[1] AND TAKASHI NAKAMURA[2]
Received 2001 March 2; accepted 2001 May 17; published 200

I am involved in GRB ··

Medal of Acader

THE ASTROPHYSICAL JOURNAL, 571:L31–L35, 2002 May 20

X-RAY FLASHES FROM OFF-AXIS GAMMA-RAY B

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Received 2002 March 14; accepted 2002 April 16; published 2002 April 25

Black Hole MACHO

Black hole binary formation in the expanding universe: Three body problem approximation

Kunihito Ioka,[1] Takeshi Chiba,[2] Takahiro Tanaka,[3] and Takashi Nakamura[4]

My first paper

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(Received 9 February 1998; published 27 August 1998)

Low frequency gravitational waves from black hole MACHO binaries

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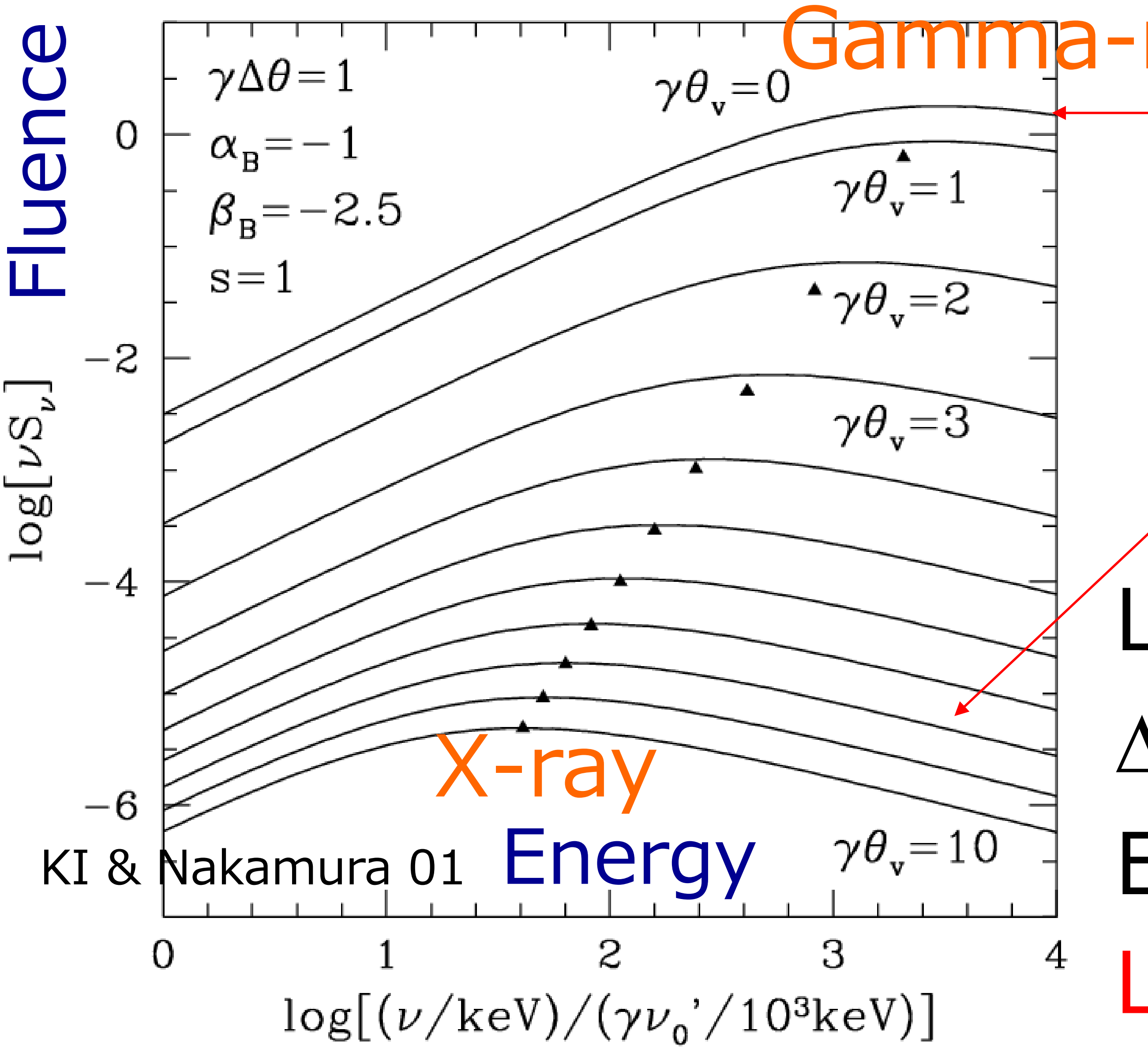
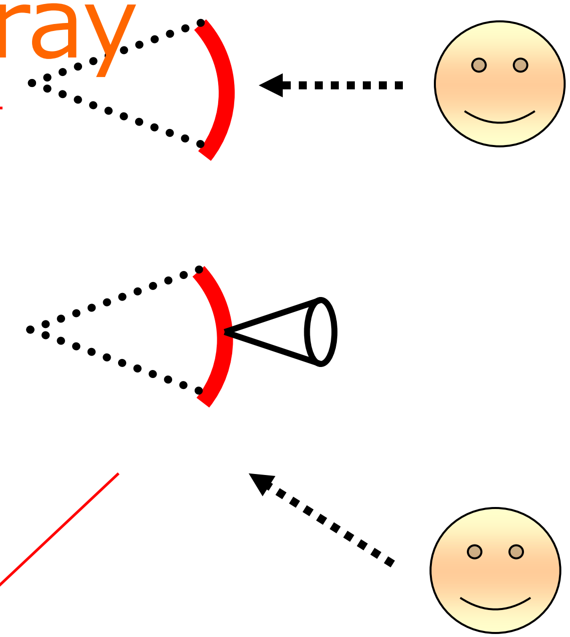
(Received 30 September 1998; published 24 September 1999)

CAN THE DENSITY DISTRIBUTION AND SHAPE OF THE GALACTIC DARK HALO BE DETERMINED BY LOW-FREQUENCY GRAVITATIONAL WAVES?

KUNIHITO IOKA,[1] TAKAHIRO TANAKA,[2] AND TAKASHI NAKAMURA[3]
Received 1999 April 27; accepted 1999 August 11

Off-Axis GRBs are Dim





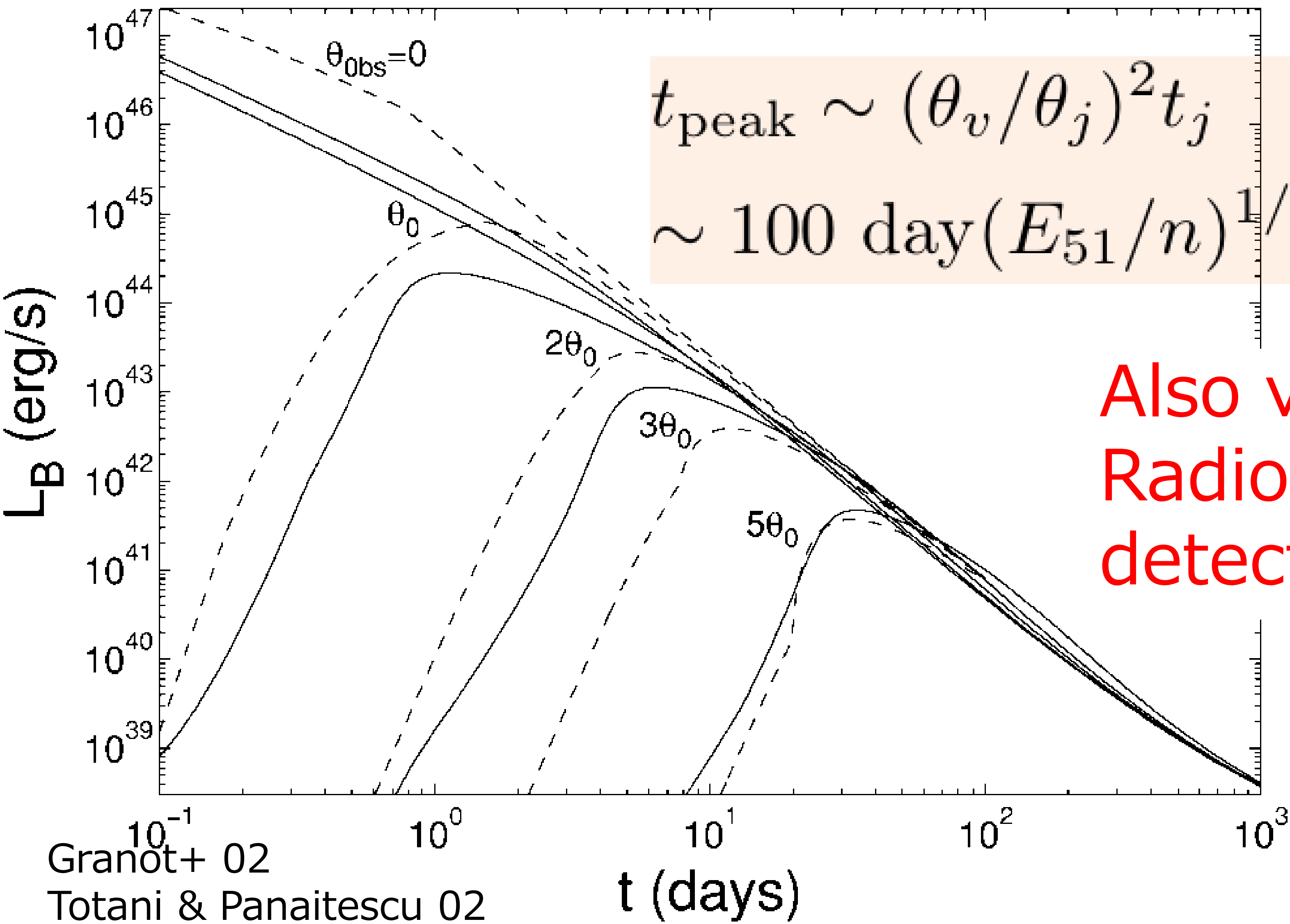
$L\Delta T \sim (\Gamma\theta_v)^{-6}$

$\Delta T \sim R\theta_j/c$

Even if $\Delta T \sim 0$.

$L<10^{39}$ erg/s

Off-Axis Afterglow



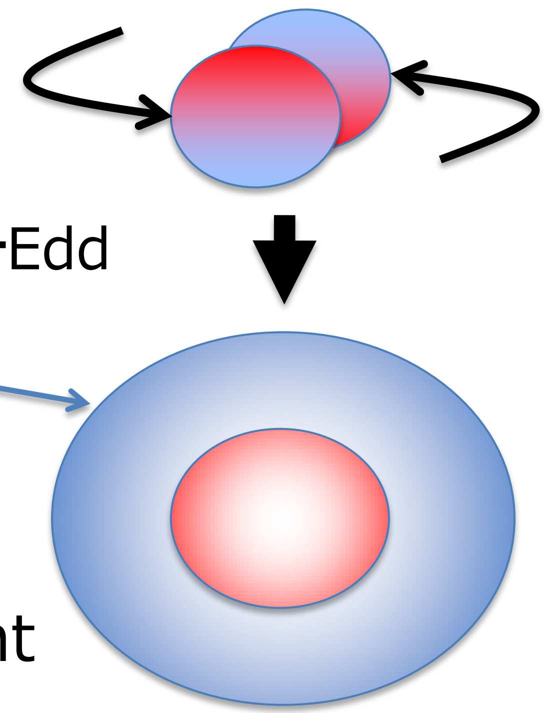
$$t_{\rm peak} \sim (\theta_v/\theta_j)^2 t_j$$

$$\sim 100\ {\rm day} (E_{51}/n)^{1/3} \theta_{j,-1}^{2/3} \theta_v^2$$

Also very dim
Radio might be
detectable

Granot+ 02
Totani & Panaitescu 02

Merged Neutron Star



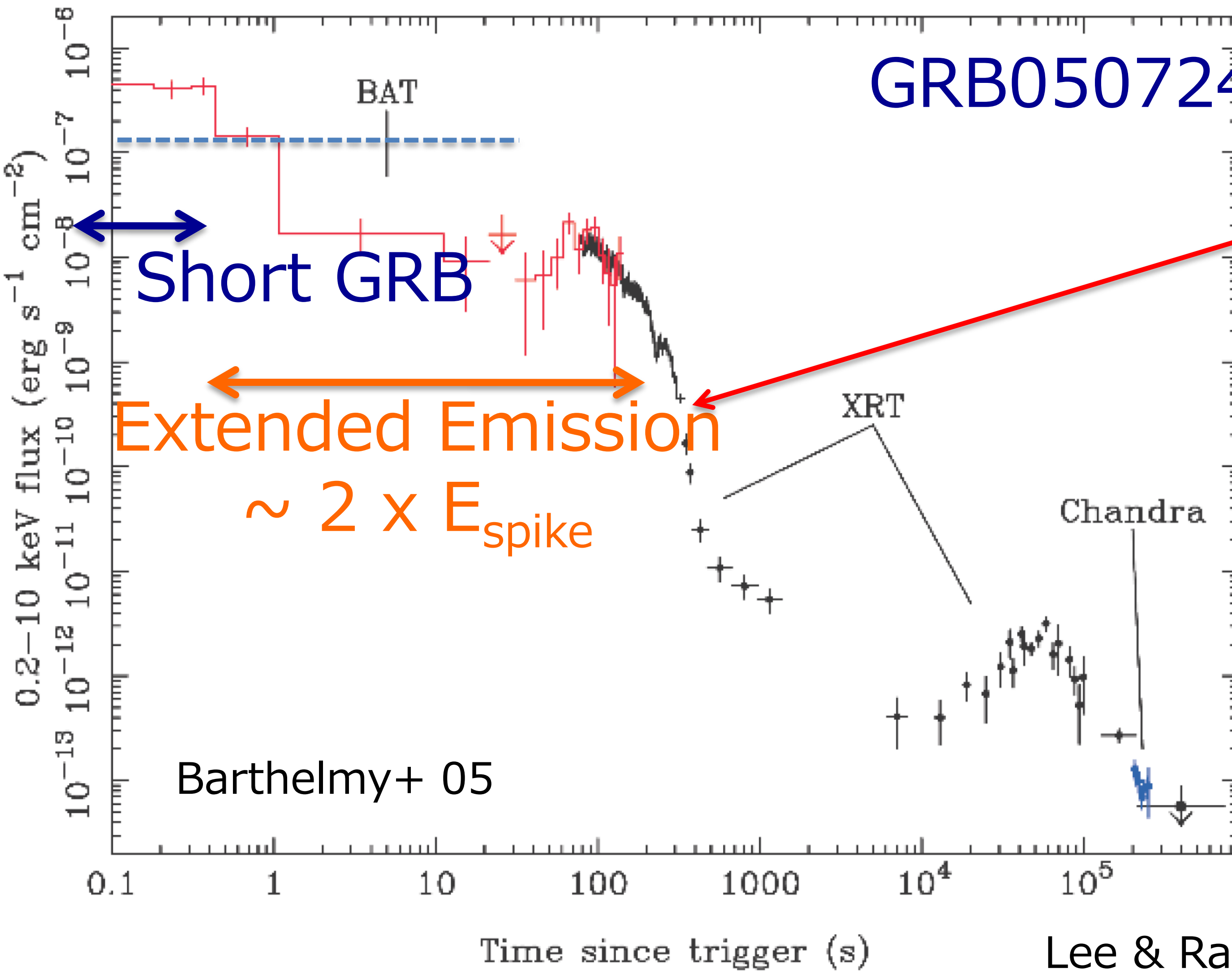
- Merged NS has T~10MeV
- $L=4\pi r^2 caT^4 \sim 10^{53}$erg/s » L_{Edd}
- **Outflow ~ $10^{-3}M_{\odot}$/s (?)**
  - ν-driven wind
  - Tidal tail/heating
  - Disk wind

Eichler+ 89
Rosswog 05
Dessart+ 09

⇔ n-rich element

- **Opaque** $\tau \sim 10^{15}\left(\frac{M_w}{10^{-5}M_{\odot}}\right)\left(\frac{r}{10^6\mathrm{cm}}\right)^{-2}$
  - L is suppressed by τ
- Followed by adiabatic cooling $T \sim r^{-1} \Rightarrow L/\tau \sim r^0$

Extended Emission



~1/2 SGRBs

Sharp Drop
⇒ ~~Afterglow~~
Engine origi

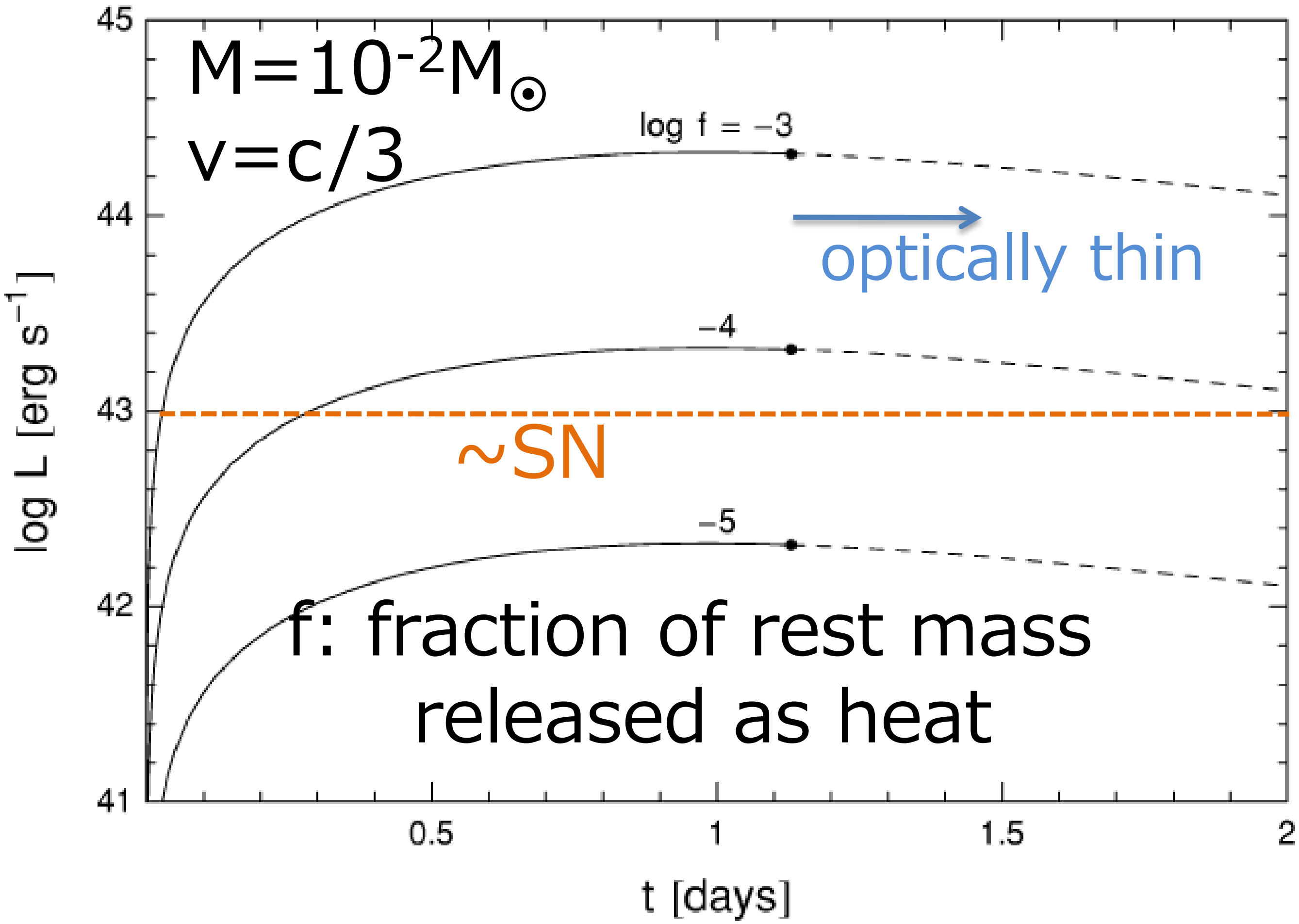
Wind Fallbac
$t_{acc} \sim 100$ s
$(r/10^9 \text{cm})$
$(\alpha/0.1)^{-1}(r/10$

Lee & Ramirez-Ruiz 07, Rosswo

Macronova

Li & Paczynski 9
Kulkarni 05

- Radioactive heating (β-decay,



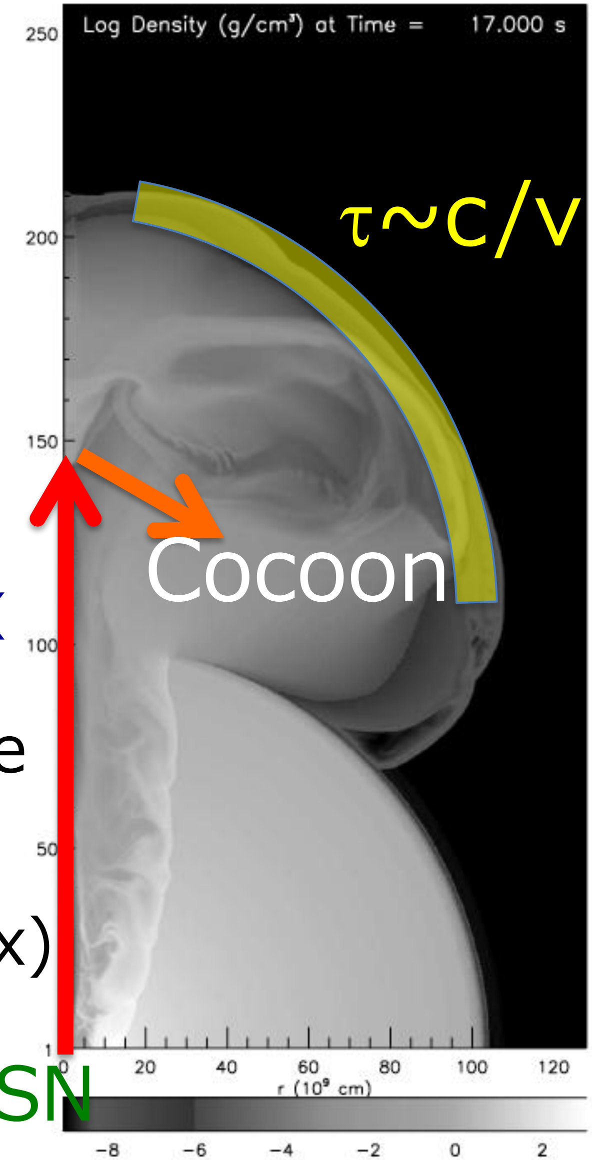
- Like SN
- Duration $\propto (M/v)^{1/2}$
- $T \propto (f^2/Mv)^1$
  ~ UV-Opt
- f~3x10^{-6}

(Metzger+ 10

⇒ Dim SN

Jet Penetration

Morsony+ 07



- Even ~$10^{-6} M_\odot$ causes baryon load problem
- Shocked mass ⇒ Cocoon like long GRB collapsar
- Γ~1 ⇒ Visible from off-ax

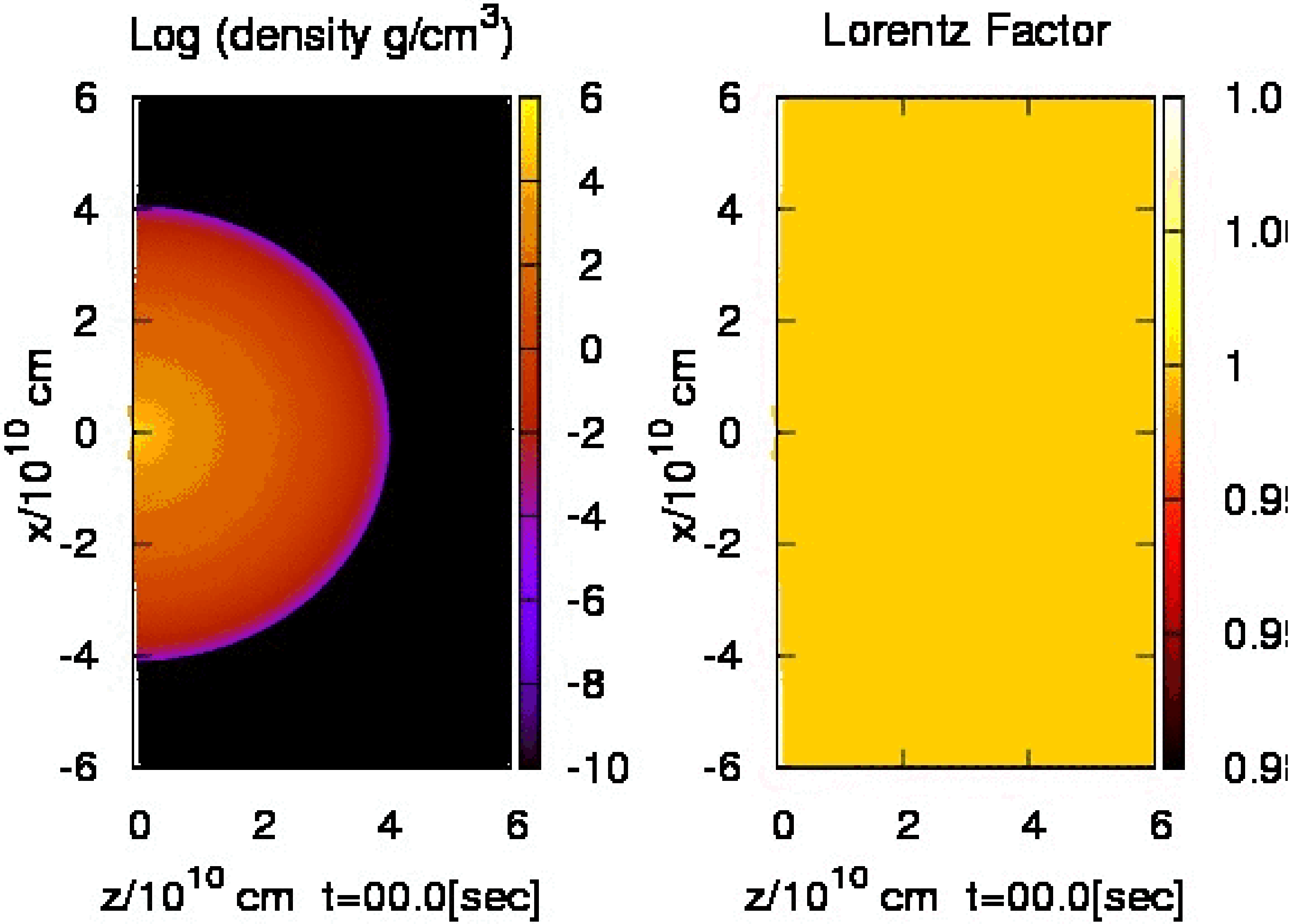
$$\tau \propto \sigma \frac{M}{R^3} \Delta R \sim \sigma \frac{E}{\beta^2 R^3} \Delta R \gg 1 \text{ still opaque}$$

$$L \sim \frac{\Delta R}{R} \frac{E}{R/c} \sim 10^{45} \left(\frac{R}{10^{12}\,\mathrm{cm}} \right) \tau \beta^2 \ \mathrm{erg/s} \ \text{(max)}$$

$$\Delta T \sim T_{\mathrm{extended}} \sim 100 \ \mathrm{sec}$$

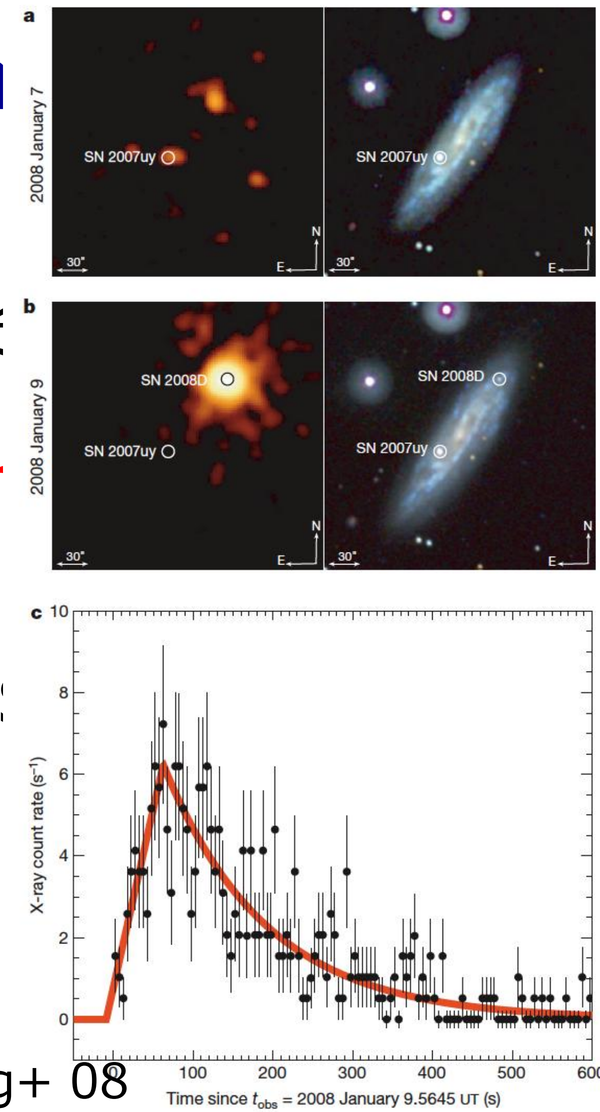
Brighter than SN

A. Mizuta's calculation



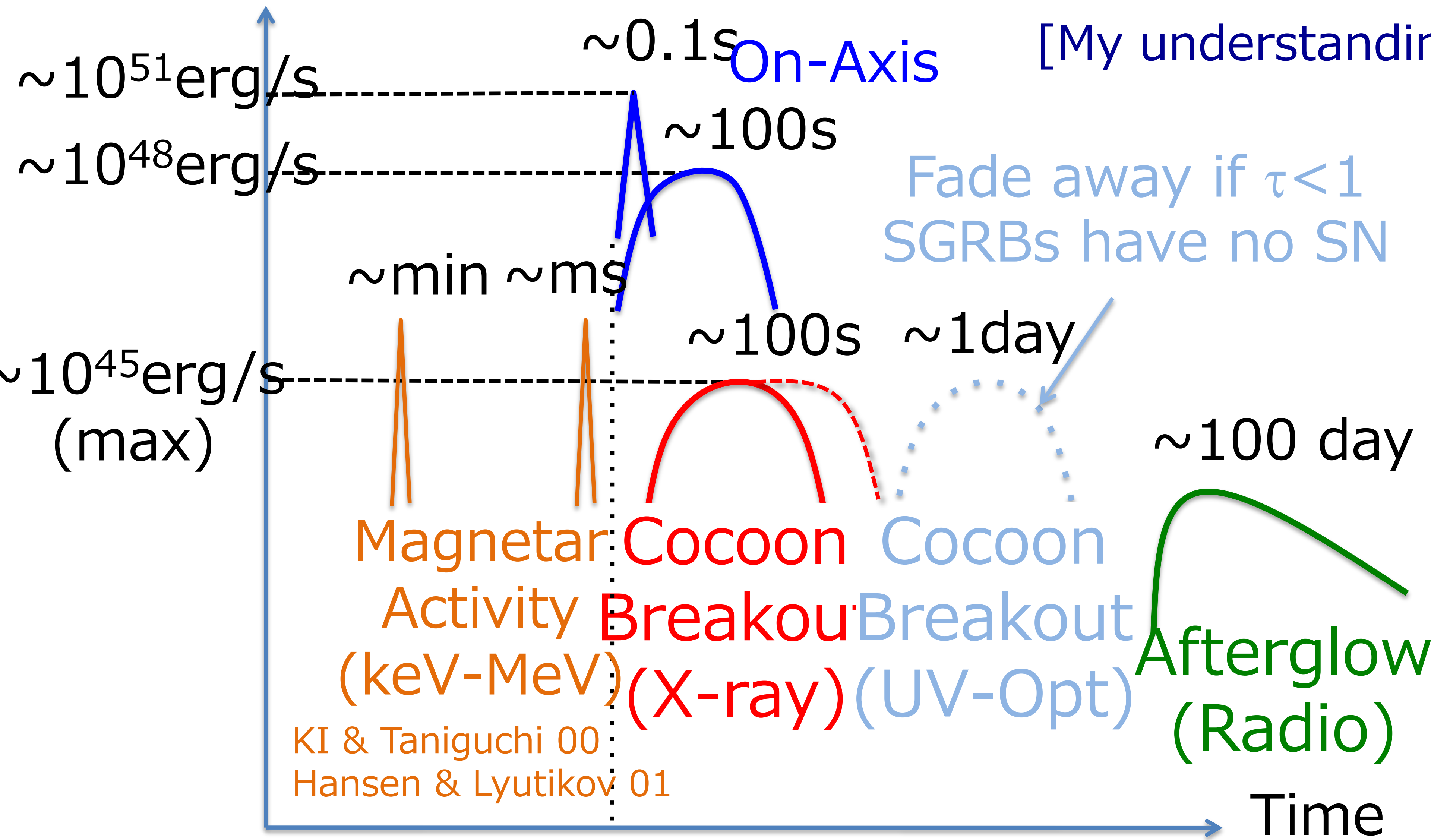
Shock Breakout

- Cocoon breakout from win
  ~ Supernova shock breako
- v/c>0.2 ⇒ ~~Thermal equilib~~
  T_{shock}~10-200keV > T_{dowr}
  (Klein & Chevalier 78, Weaver 76, Katz+ 10)
- X-ray SN shock breakout i
  detected recently @27Mpc
- Swift/XRT ⇒ up to 200Mp

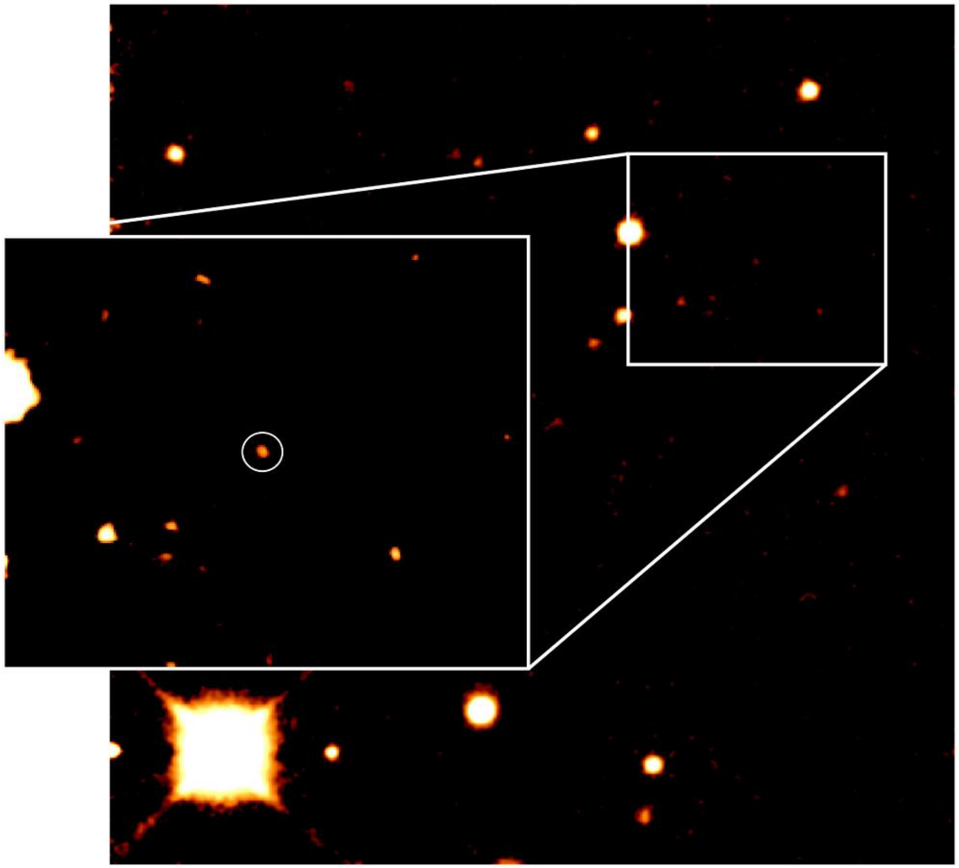


Soderberg+ 08

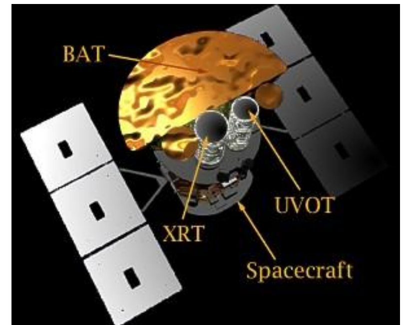
Off-Axis Short GRB

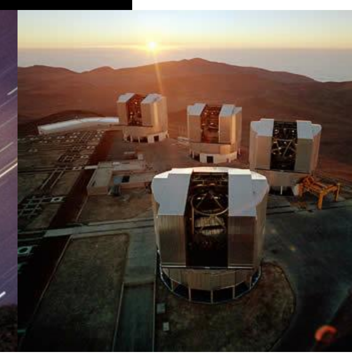


Most Ancient Object



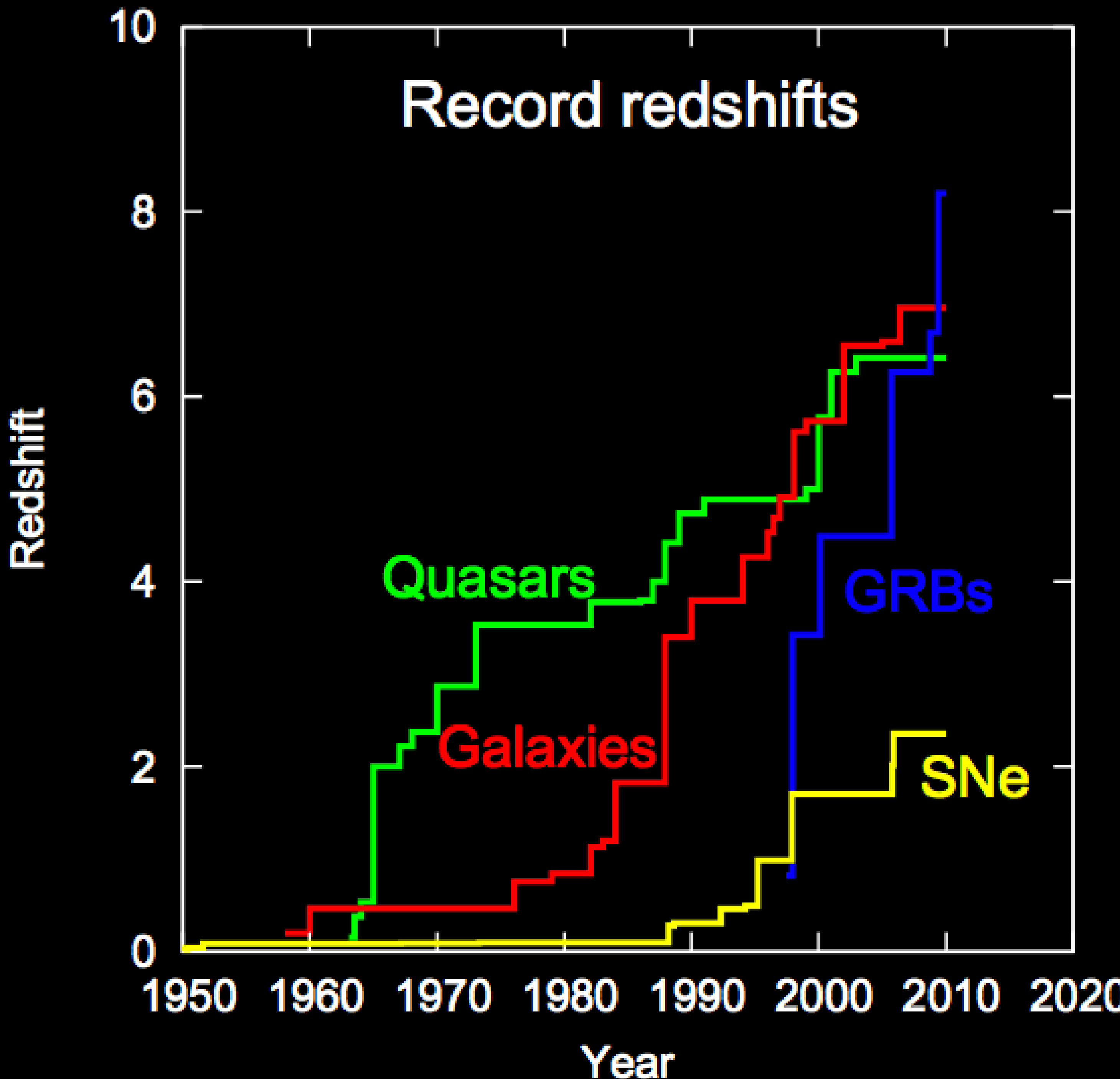
OAO-ISLE　J band　　国立天文台　岡山天体物理観測所





GRB 090423
@ z~8.2

A massive star's death just 600 Myr after the


Record redshifts
Quasars
Galaxies
GRBs
SNe
Redshift
Year
0
2
4
6
8
10
1950
1960
1970
1980
1990
2000
2010
2020

First GRB

Abel+ 02
Bromm+ 0
Omukai+ 0
Yoshida+ 0

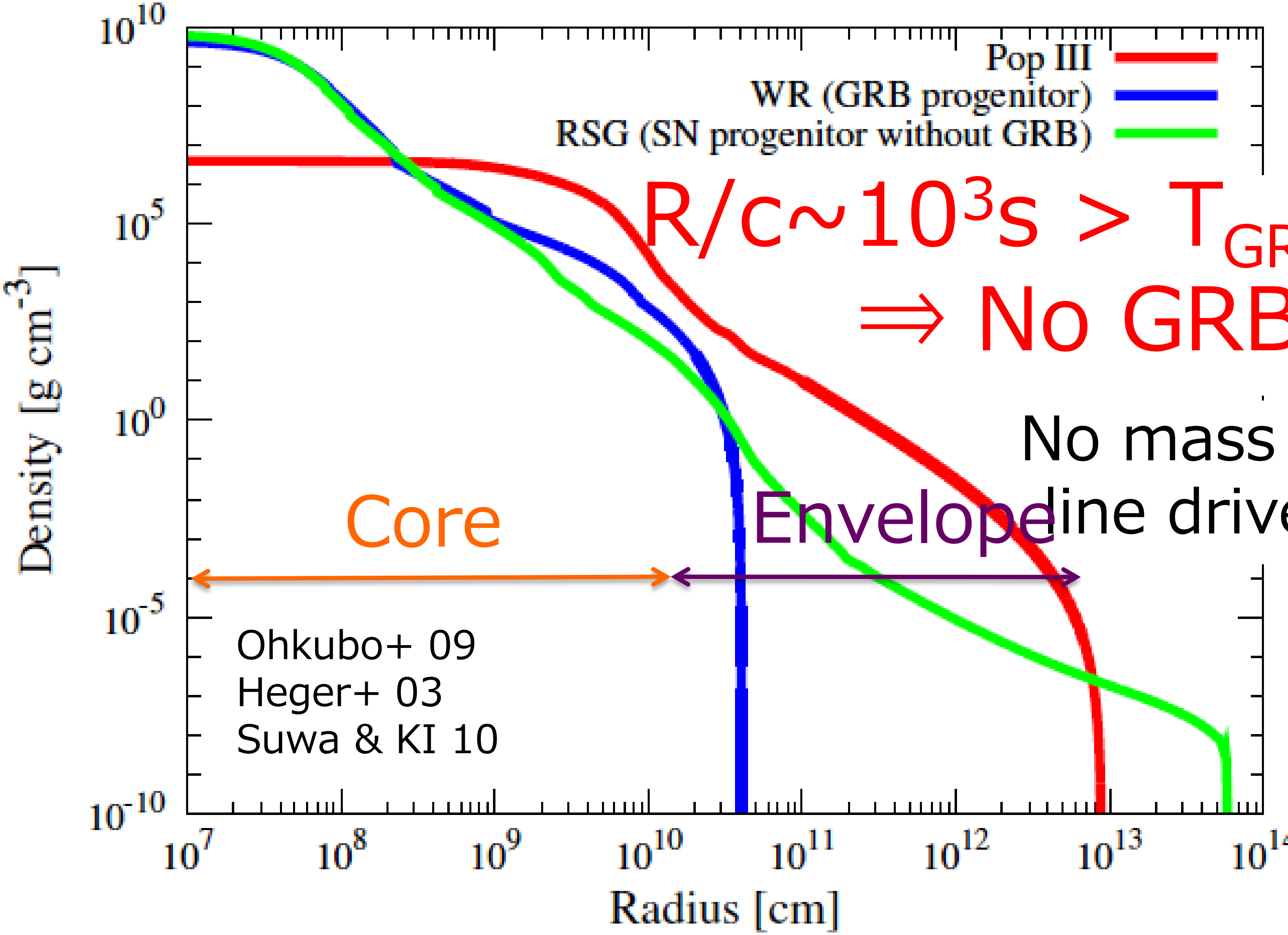
Present Day Massive Star $\sim 20M_{\odot}$

Pop III (Zero Metal) ~ 100-$1000M_{\odot}$(!?)

Komissarov & Barkov
Meszaros & Rees 10

Gigantic (x100) GRB @ z~10-30

Massive Envelope

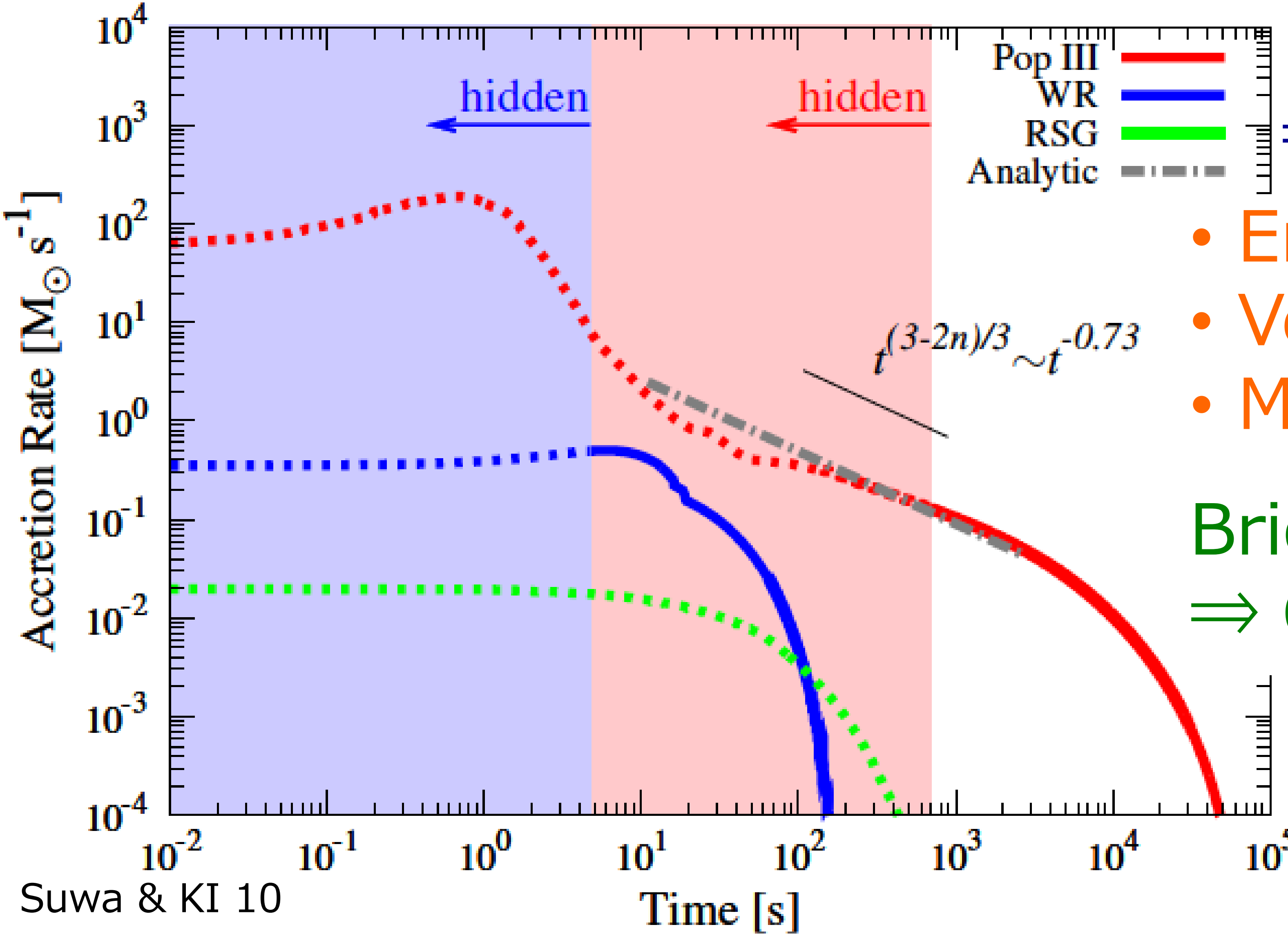


$R/c \sim 10^3$s > $T_{GRB} \sim 10$

⇒ No GRB?

No mass loss via line driven wind

Envelope Accretion



Suwa & KI 10

$L \propto \dot{M}$

⇒ $v_{\text{Jet hea}}$

- Energetic
- Very long
- Modest L

Bright phas

⇒ Cocoon

Analytic Expressions

$$R_* \sim 10^{13}\ \mathrm{cm} \left(\frac{R_c}{10^{10}\ \mathrm{cm}}\right) \left(\frac{M_c}{400 M_\odot}\right)^{-2.5} \left(\frac{M_{\mathrm{env}}}{500\ M_\odot}\right)^{2.5} \quad (9)$$

$$t_b \sim 700\ \mathrm{s} \left(\frac{\eta}{10^{-3}}\right)^{-0.79} \left(\frac{\theta_j}{5^\circ}\right)^{1.6} \left(\frac{R_c}{10^{10}\ \mathrm{cm}}\right)^{1.1} \times \left(\frac{M_c}{400 M_\odot}\right)^{-2.9} \left(\frac{M_{\mathrm{env}}}{500 M_\odot}\right)^{2.8}, \quad (11)$$

$$L_{\mathrm{iso}}(t = t_b) \sim 5 \times 10^{52} \left(\frac{\eta}{10^{-3}}\right)^{1.6} \left(\frac{\theta_j}{5^\circ}\right)^{-3.2} \times \left(\frac{R_c}{10^{10}\ \mathrm{cm}}\right)^{-1.2} \left(\frac{M_c}{400 M_\odot}\right)^{3.2} \left(\frac{M_{\mathrm{env}}}{500 M_\odot}\right)^{-2.0} \mathrm{erg\ s^{-1}} \quad (13)$$

$$t_{\mathrm{ff}}(r = 0.1 R_*) \sim 3000 \left(\frac{R_c}{10^{10}\ \mathrm{cm}}\right)^{1.5} \left(\frac{M_c}{400 M_\odot}\right)^{-3.8} \times \left(\frac{M_{\mathrm{env}}}{500 M_\odot}\right)^{3.8} \left(\frac{M_c + 0.4 M_{\mathrm{env}}}{600 M_\odot}\right)^{-0.5} \mathrm{s} \quad (14)$$

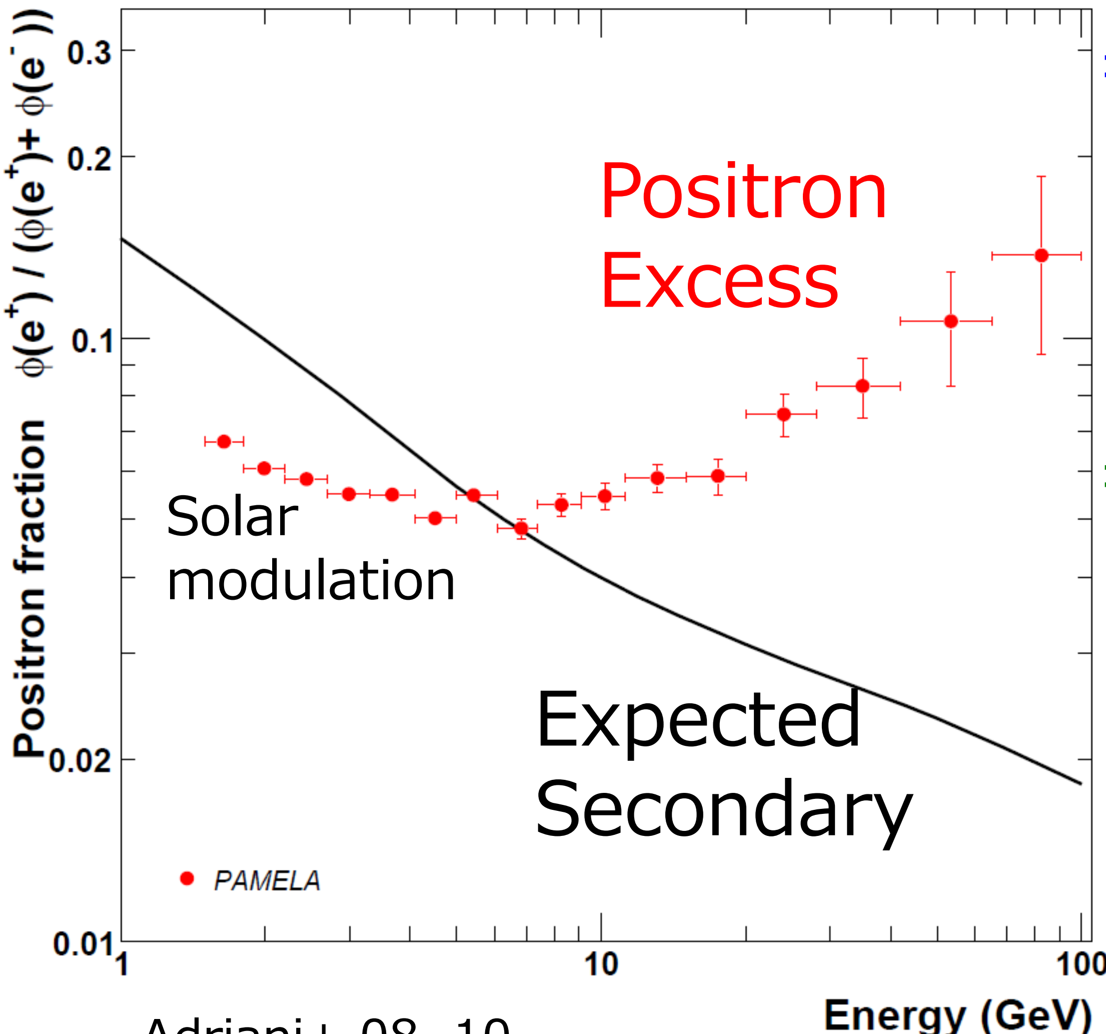
$$L_{\mathrm{iso}}[t = t_{\mathrm{ff}}(r = 0.1 R_*)] \sim 2 \times 10^{52} \left(\frac{\eta}{10^{-3}}\right) \left(\frac{\theta_j}{5^\circ}\right)^{-2} \times \left(\frac{R_c}{10^{10}\ \mathrm{cm}}\right)^{-1.5} \left(\frac{M_c}{400 M_\odot}\right)^{3.9} \left(\frac{M_{\mathrm{env}}}{500 M_\odot}\right)^{-2.8} \times \left(\frac{M_c + 0.4 M_{\mathrm{env}}}{600 M_\odot}\right)^{0.37} \mathrm{erg\ s^{-1}} \quad (15)$$

GRB jet can breakout the first s

Yudai SUWA P-68

PAMELA

Positron excess above the predicted second



Adriani+ 08, 10

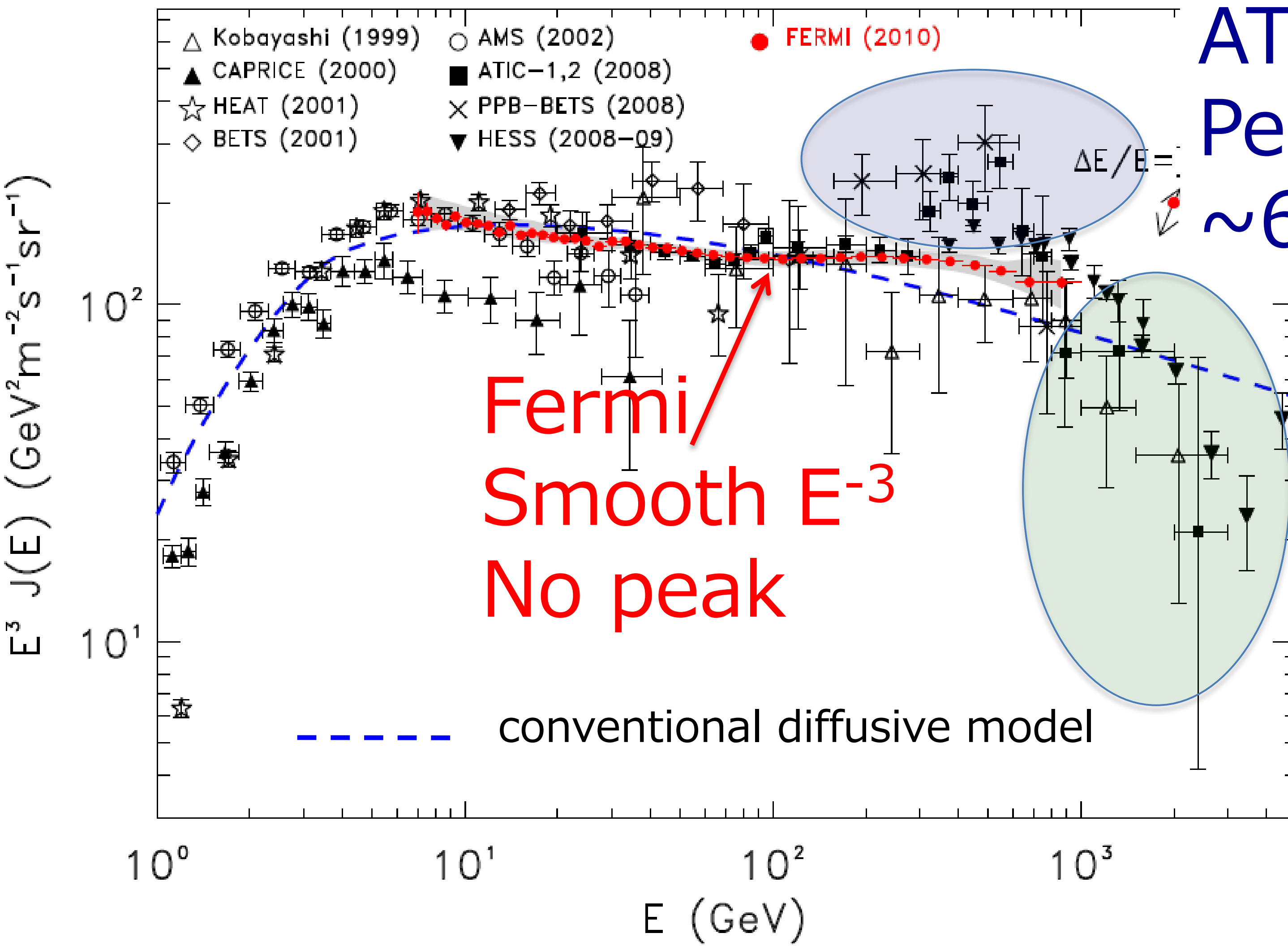
⇒ Primary sources
– Dark matter?
– Astrophysical?

⇒ (Too) Many pap
>500

Jul 06 - Feb 08
151672 e-, 9430 e+

Cosmic-Ray Electron

An Excess also in $(e^+ + e^-)$ Spectrum



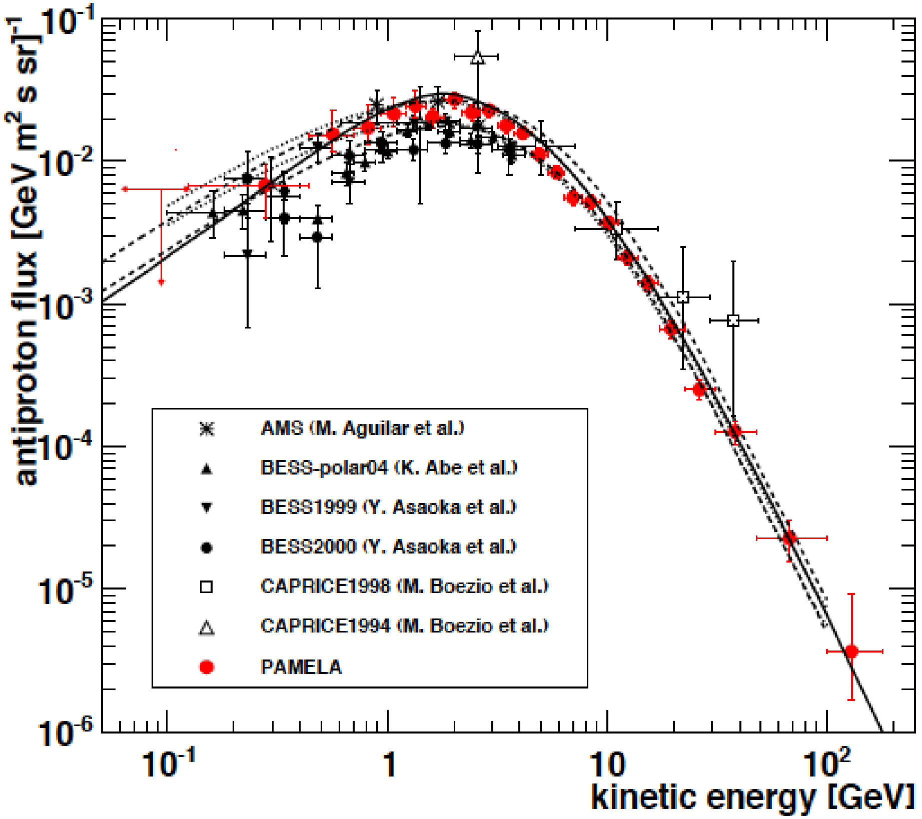
ATIC/PPB-BET
Peak + Cutoff
~600GeV DM

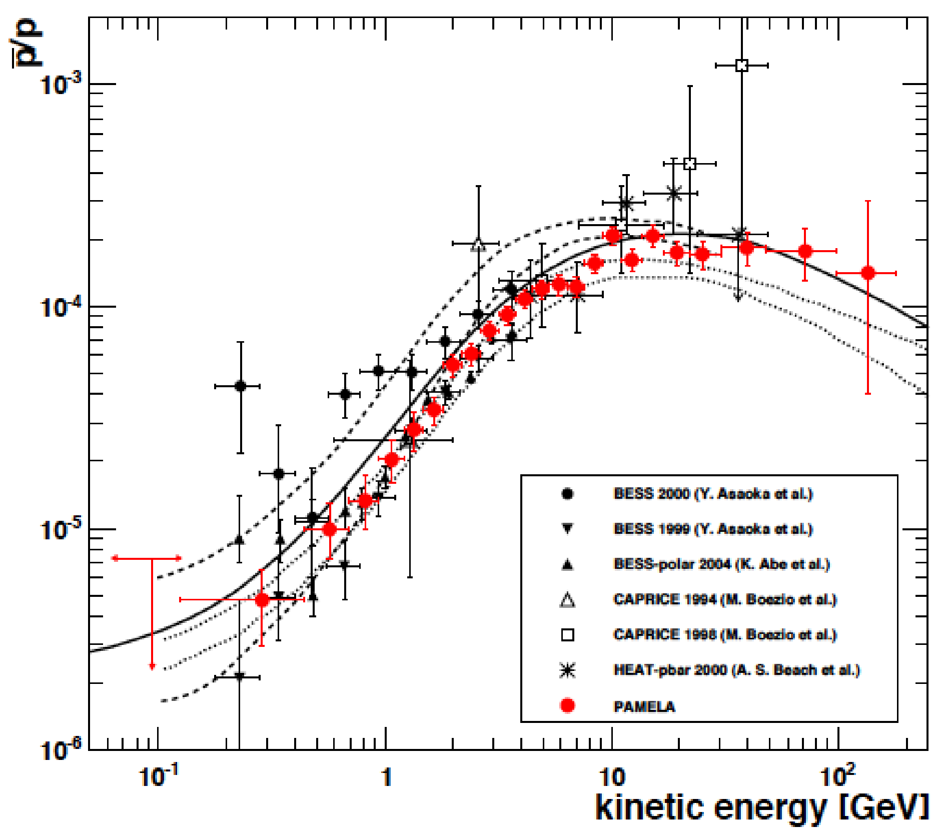
HESS
~TeV cutof

Abdo+ 09
Ackermann+ 10
Chang+ 08, Torii+
Aharonian+ 08, 09

Antiproton as predicted

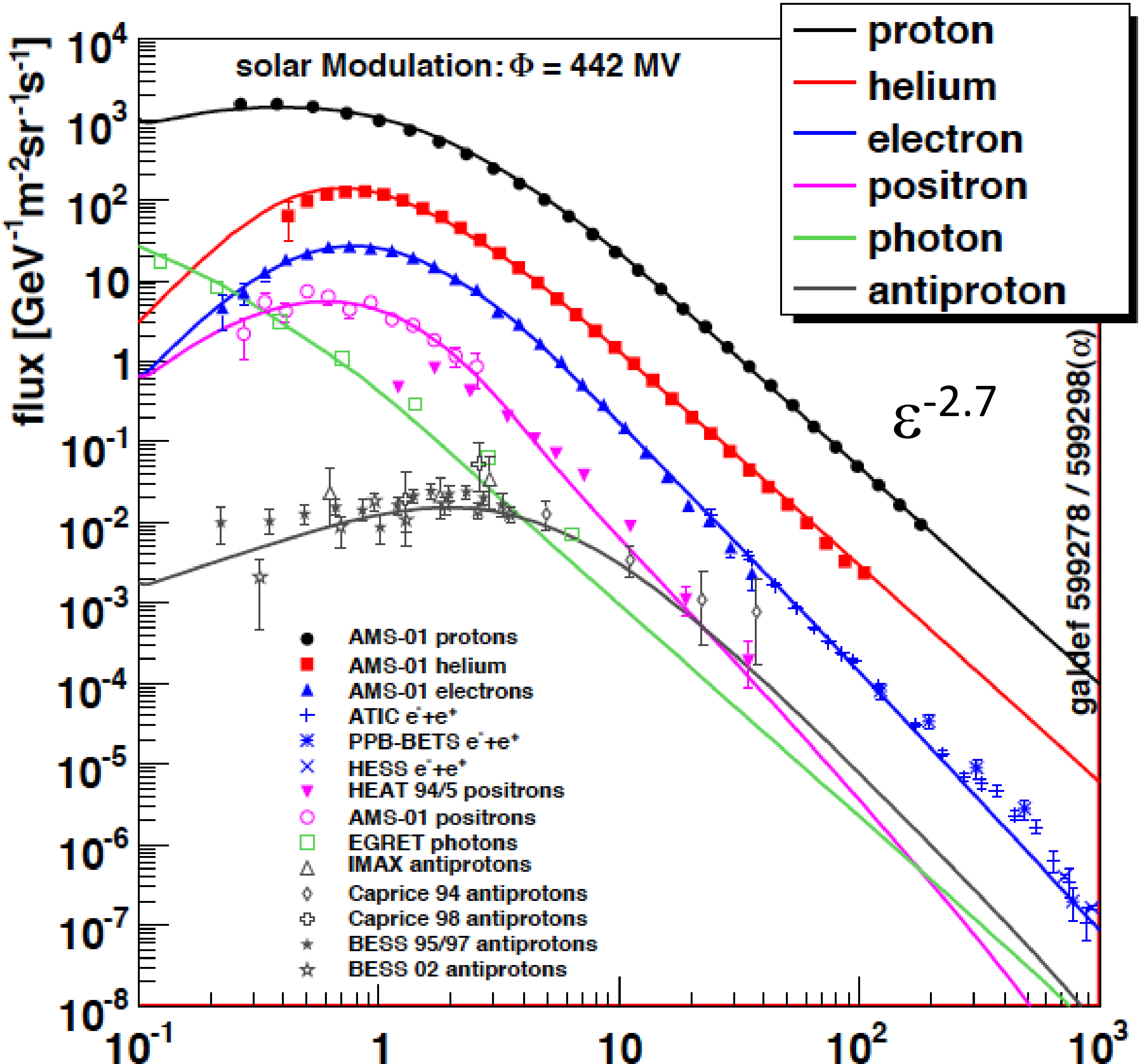
No excess for antiproton





Adriani+(PAMELA) 08, 10
BESS 95-97, 99

Cosmic-Ray Inventory



0903.1987

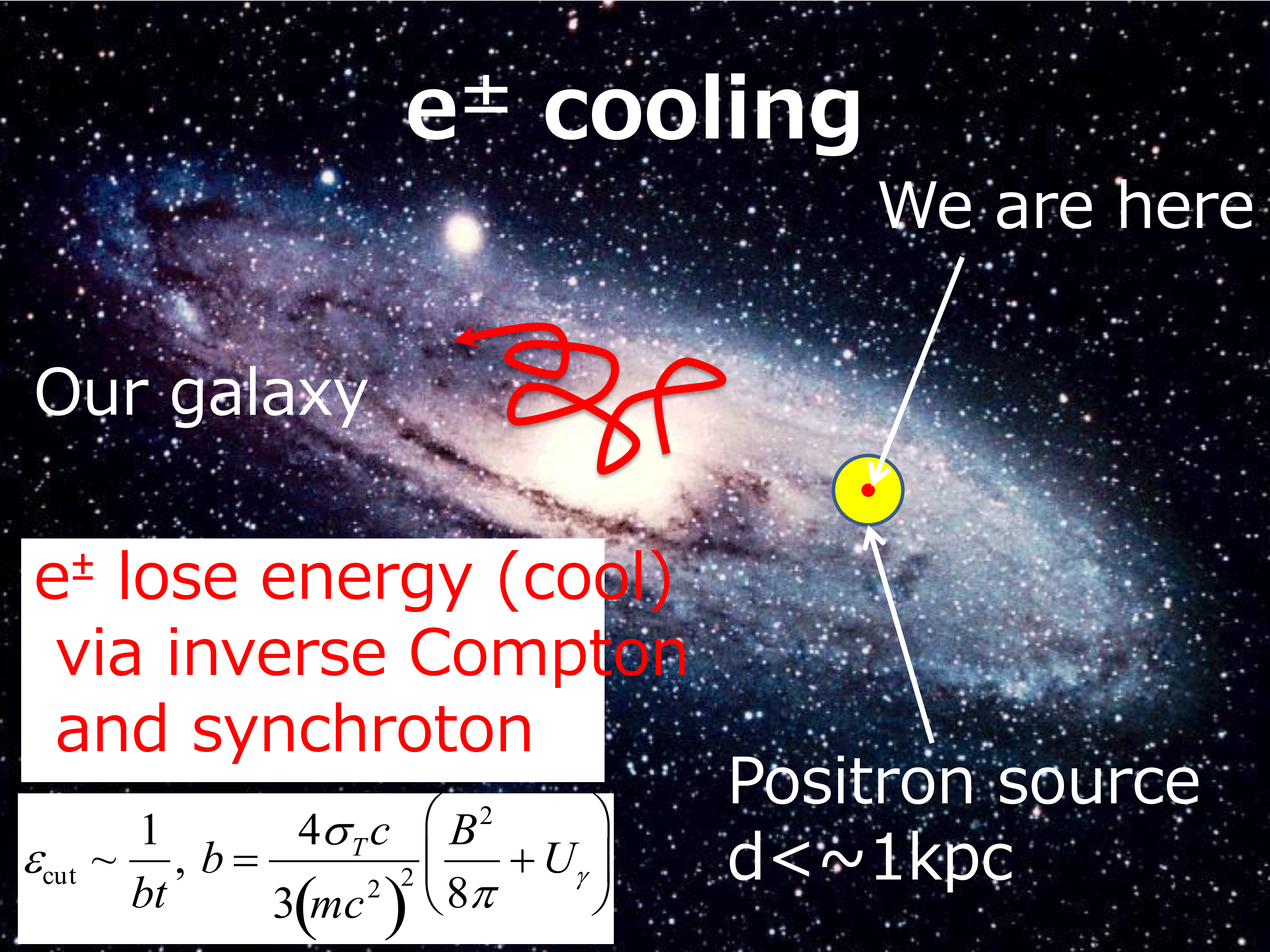
ρ(proton) ~1eV/cm^3
~Suprenova Remnants

ρ(electron) ~10^{-2}eV/cm^3

ρ(positron) ~10^{-3}eV/cm^3
~ 0.1% of p

Origin unknown

e± cooling

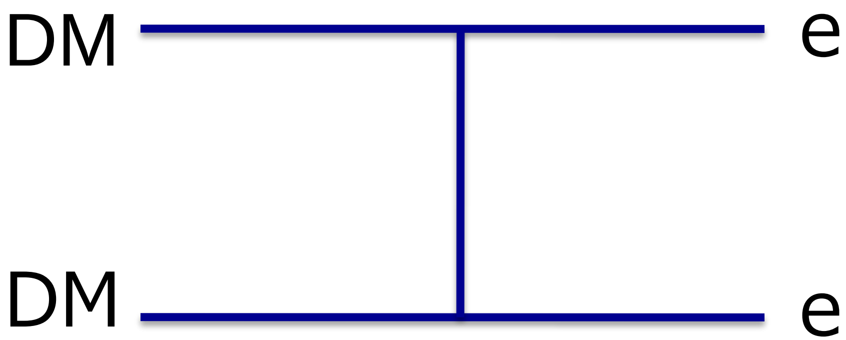


e± lose energy (cool) via inverse Compton and synchroton

$$\varepsilon_{\mathrm{cut}} \sim \frac{1}{bt},\ b = \frac{4\sigma_T c}{3\left(mc^2\right)^2}\left(\frac{B^2}{8\pi} + U_\gamma\right)$$

Dark Matter?

Annihilation



$Q \sim n^2$

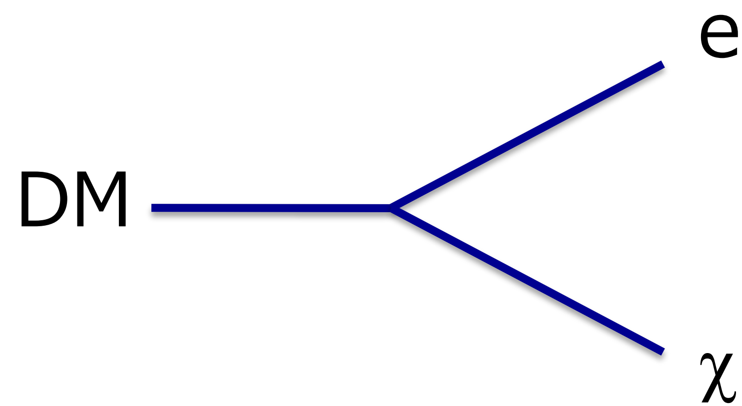
$E_{cut} \sim m_{DM}$

$<\sigma v> \sim 3x10^{-24} cm^3/s$

$> 3x10^{-26} cm^3/s$

boost factor ~100

Decay



$Q \sim n$

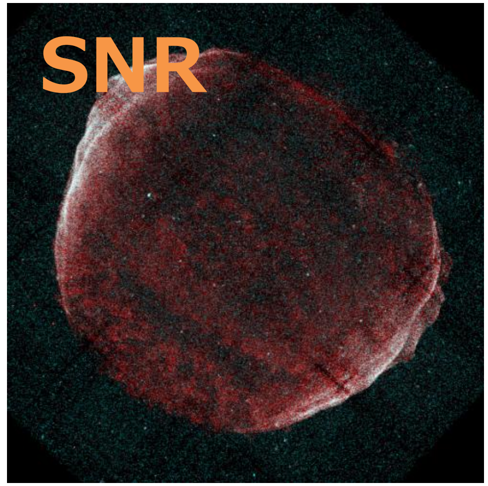
$E_{cut} \sim m_{DM}/2$

$\tau_{decay} \sim 10^{26}$sec (>H

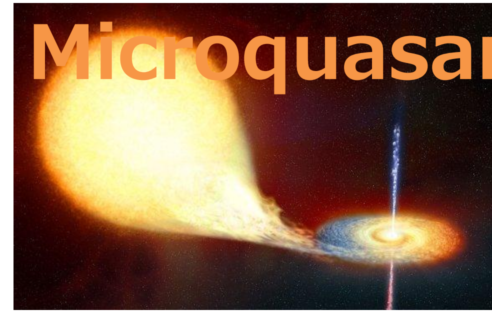
γ-ray constraints are getting tight

Astrophysical Models

Shen 70; Aharonian+ 95; Atoyan et al. 95; Chi+ 96; Zhang & Cheng 01; Grimani 07; Yuksel+ 08; Buesching+ 08; Hooper+ 08; Profumo 08; Malyshev+ 09; Grasso+ 09; Kawanaka, KI & Nojiri 09;



Shen & Berkey 68; Pohl & Esposito 98; Kobayashi+ 04; Shaviv+ 09; Hu+ 09; Fujita+KI 09; Blasi 09; Blasi & Serpico 09; Mertsch & Sarkar 09; Biermann+ 09



Heinz & Sunyaev 02

KI 10
Calvez & Kusenk
10

Proton Comtami.

Fazely+ 09; Schubnell 09

Propagation

Delahaye+ 08;

Cosmic-ray proton energy

$$10^{-3} \times \underbrace{10^{50}\,\mathrm{erg/SN}}_{\text{Cosmic-ray proton energy}}$$

$$\sim 10^{50}\,\mathrm{erg}/10^{3}\,\mathrm{SN}$$

Astrophysical Models

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Fazely+ 09; Schubnell 09

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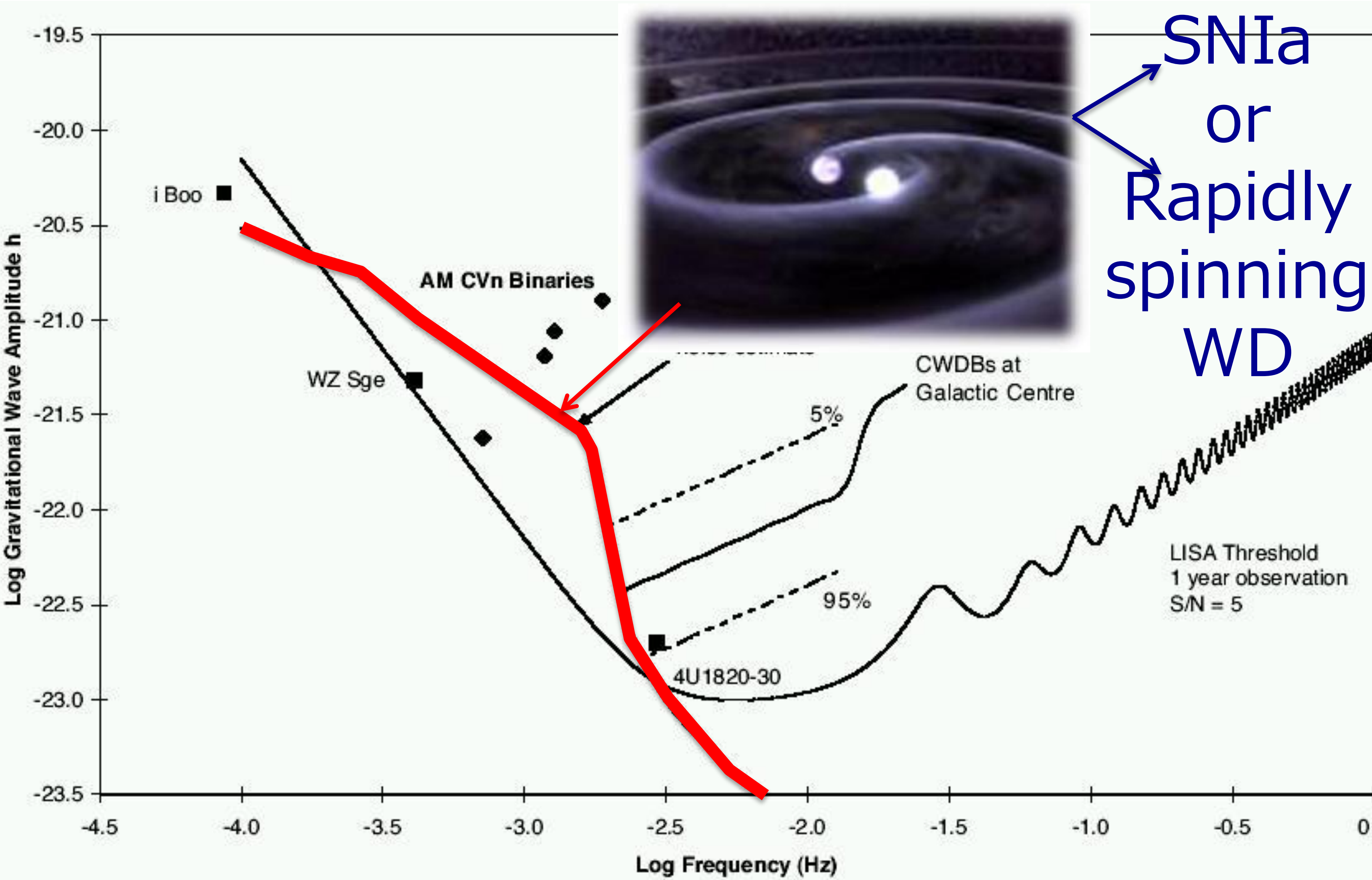
Delahaye+ 08;

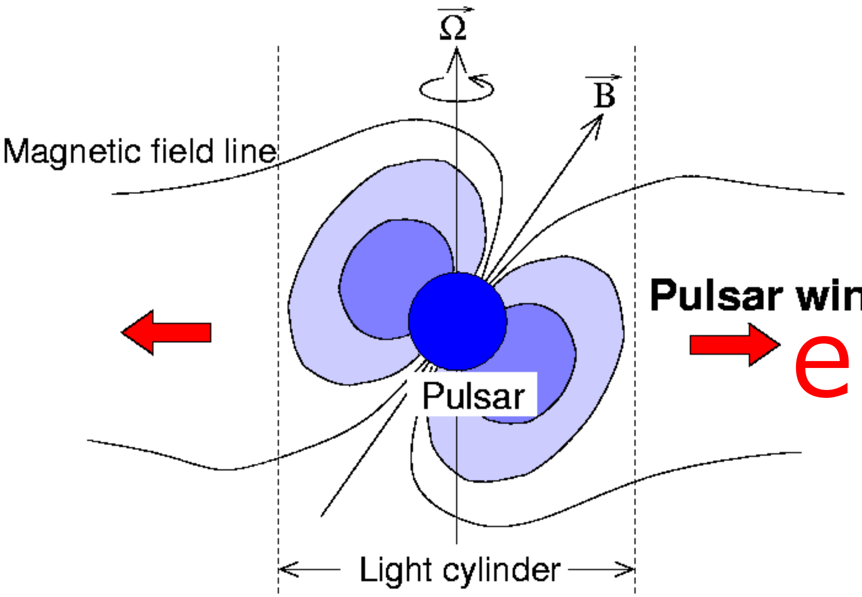
LISA Background



Energy Budget

Neutron Star Pulsar		White Dwarf Pulsar
$\sim 10^{50}\mathrm{erg}\left(\frac{R}{10^6\,\mathrm{cm}}\right)^2\left(\frac{\Omega}{10^2\,\mathrm{s}^{-1}}\right)^2$	Rotational Energy	$\sim 10^{50}\mathrm{erg}\left(\frac{R}{10^9\,\mathrm{cm}}\right)^2\left(\frac{\Omega}{0.1\,\mathrm{s}^{-1}}\right)^2$
~1/100yr	Event Rate	~1/100yr
~1%	Energy Loss/High B Fraction	~1%
$\sim 10^{48}$erg/SN		$\sim 10^{48}$erg/SN

e± Factory



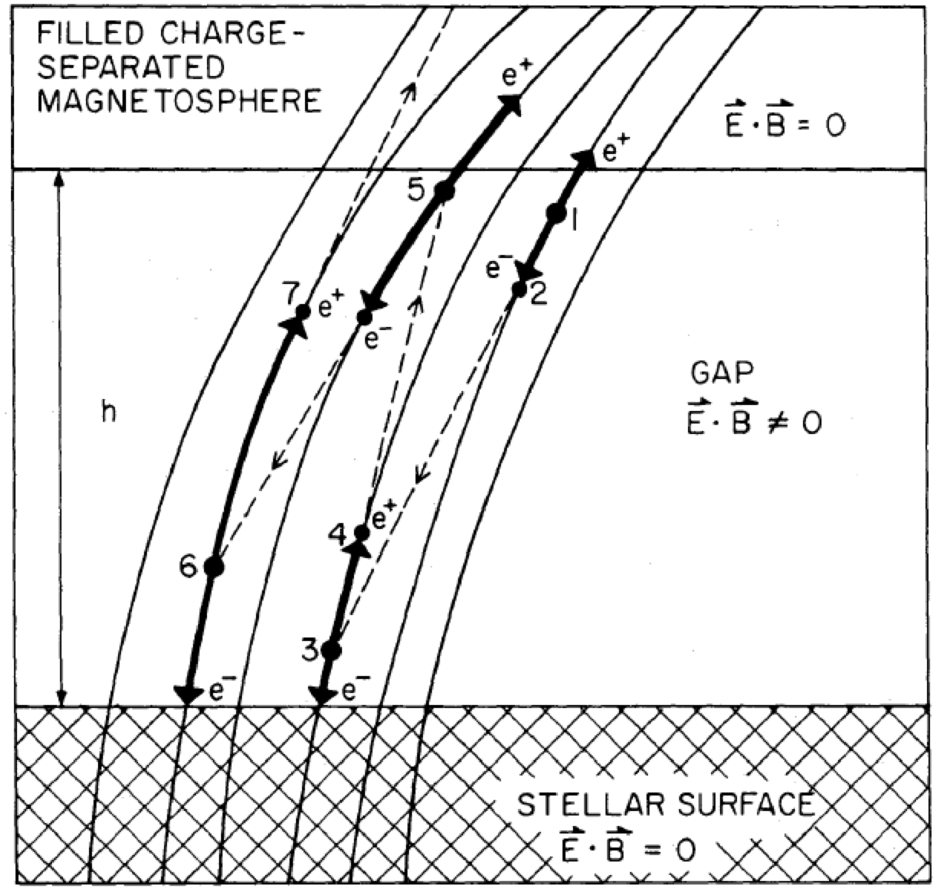
Pulsar wind e±

$$\Delta V \approx \frac{\Omega^2 B R^3}{2c^2}$$

Unipolar Inducti

$$\sim 10^{13}\mathrm{V}\left(\frac{\Omega}{0.1\ \mathrm{s}^{-1}}\right)^2\left(\frac{B}{10^8\mathrm{G}}\right)\left(\frac{R}{10^{8.7}\mathrm{cm}}\right)^3$$

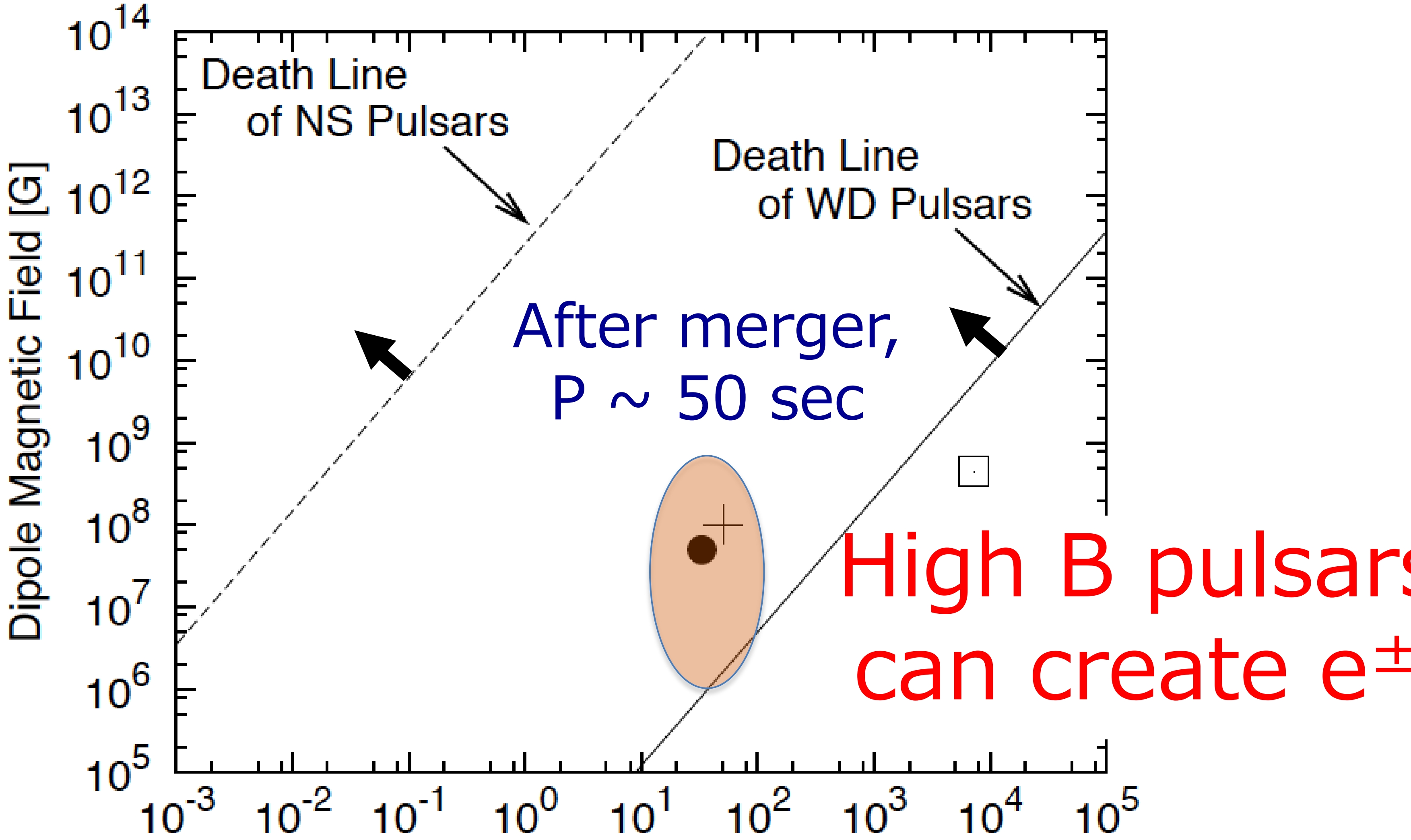
~10TeV Goldreich & Julian 69



e± cascade

Ruderman & Sutherland 75

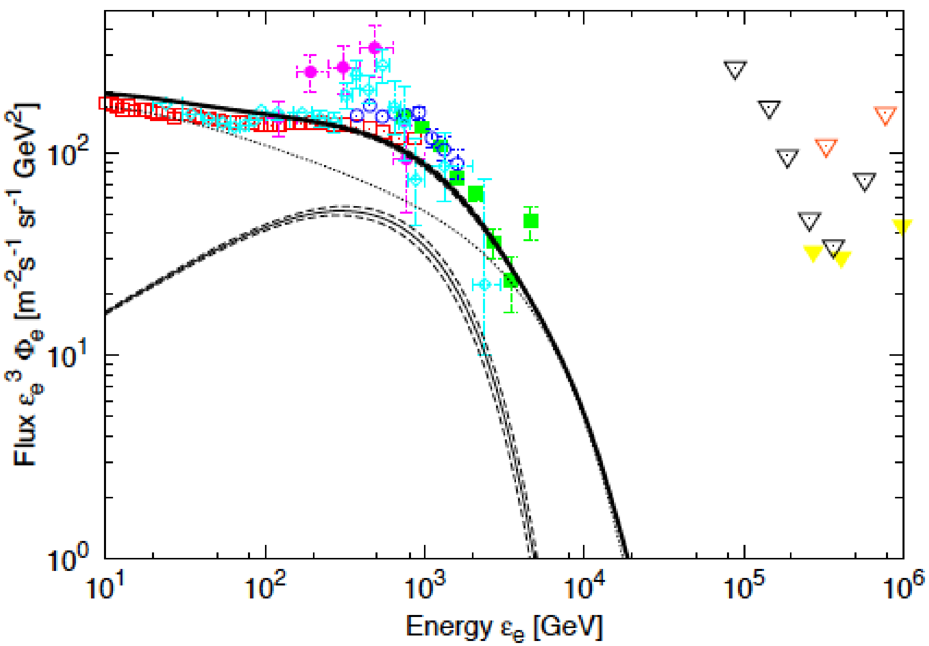
Pulsar Death Line



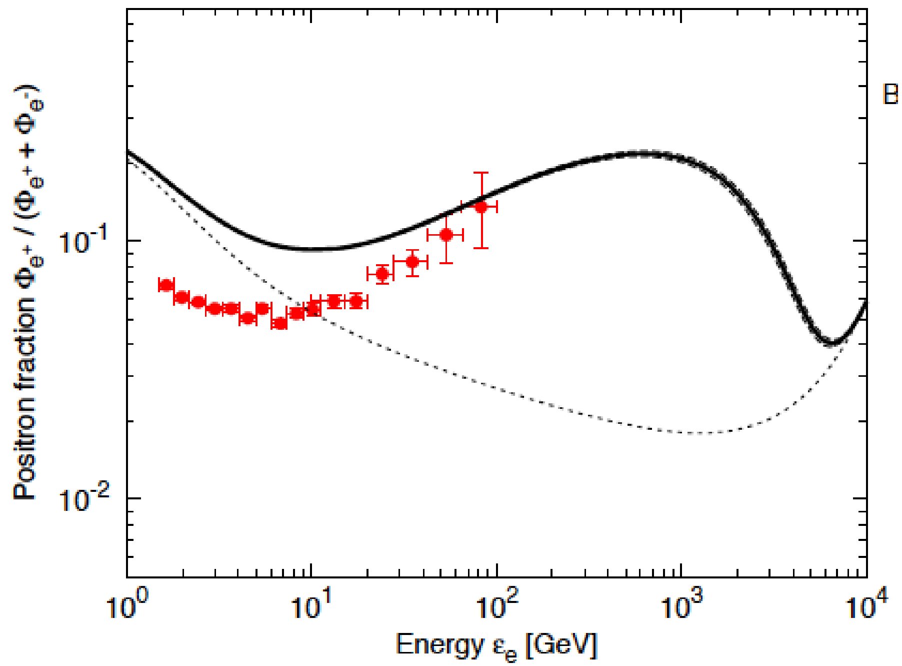
Kashiyama+ 10

Only WD Pulsar Model

Electron



Positron

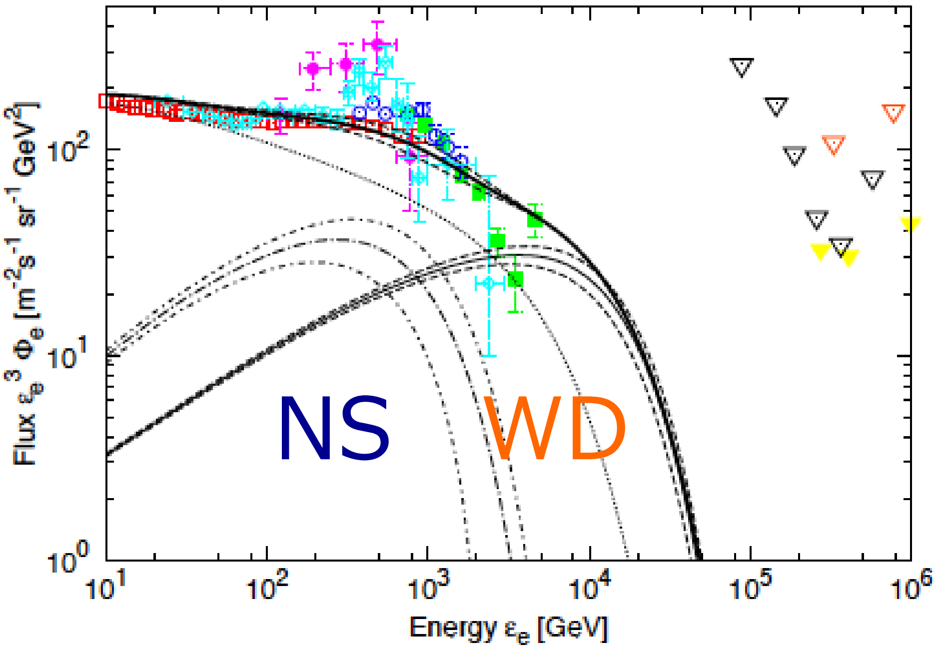


WD pulsars are long-lived (~10^9yr⇔10^5yr

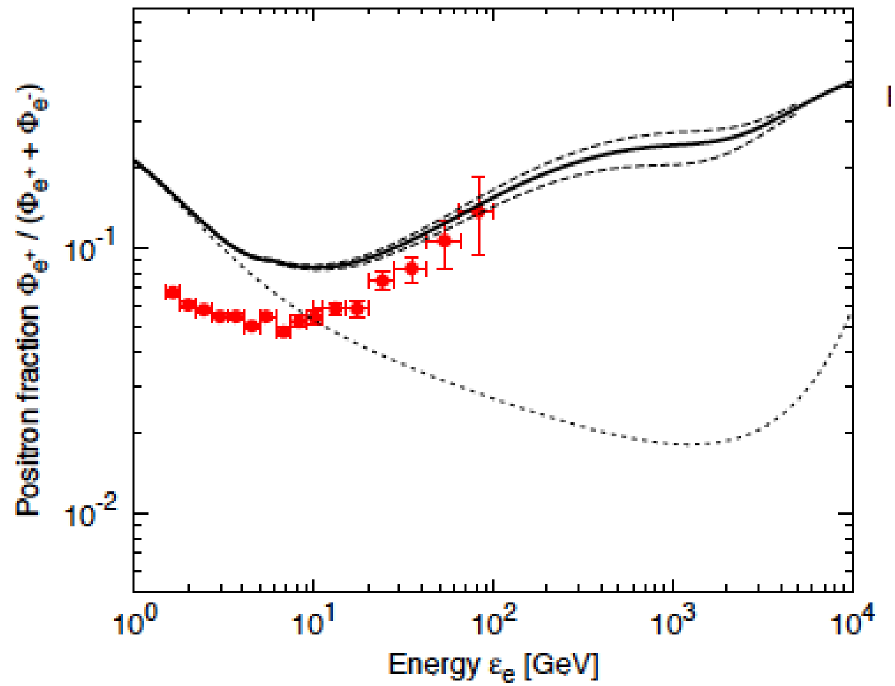
⇒ Many nearby sources (~100⇔1)

NS+WD Mixed Model

Electron



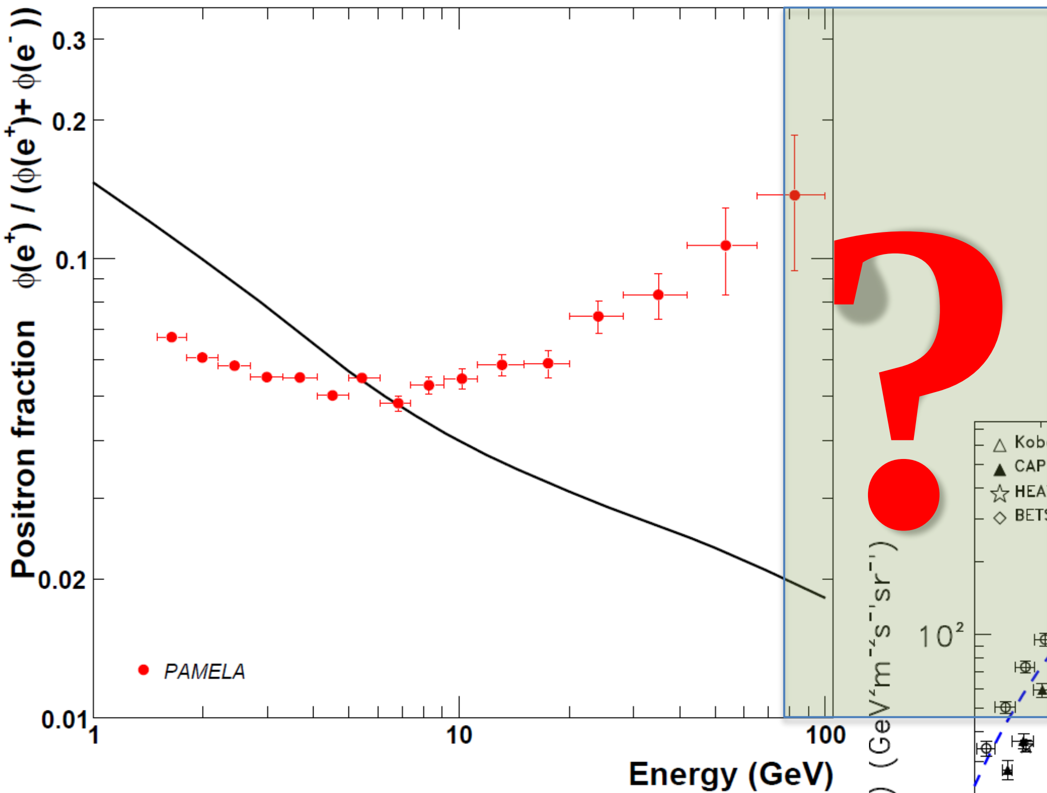
Positron



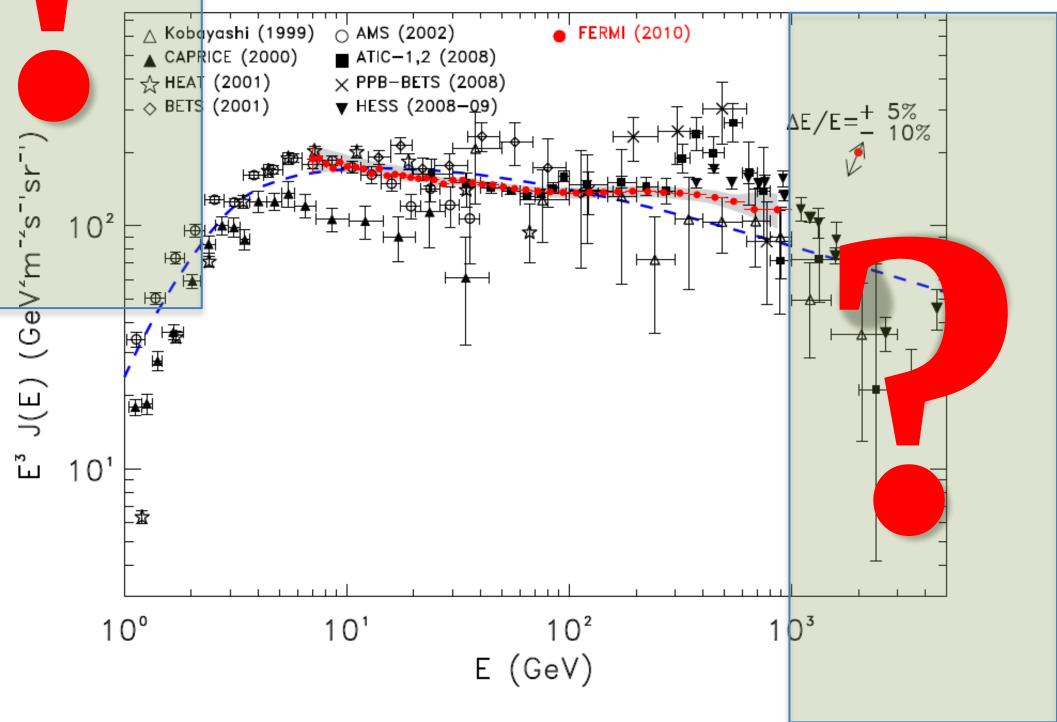
WD pulsars are long-lived (~10^9yr⇔10^5yr

⇒ Each WD is too dim to detect

New Window

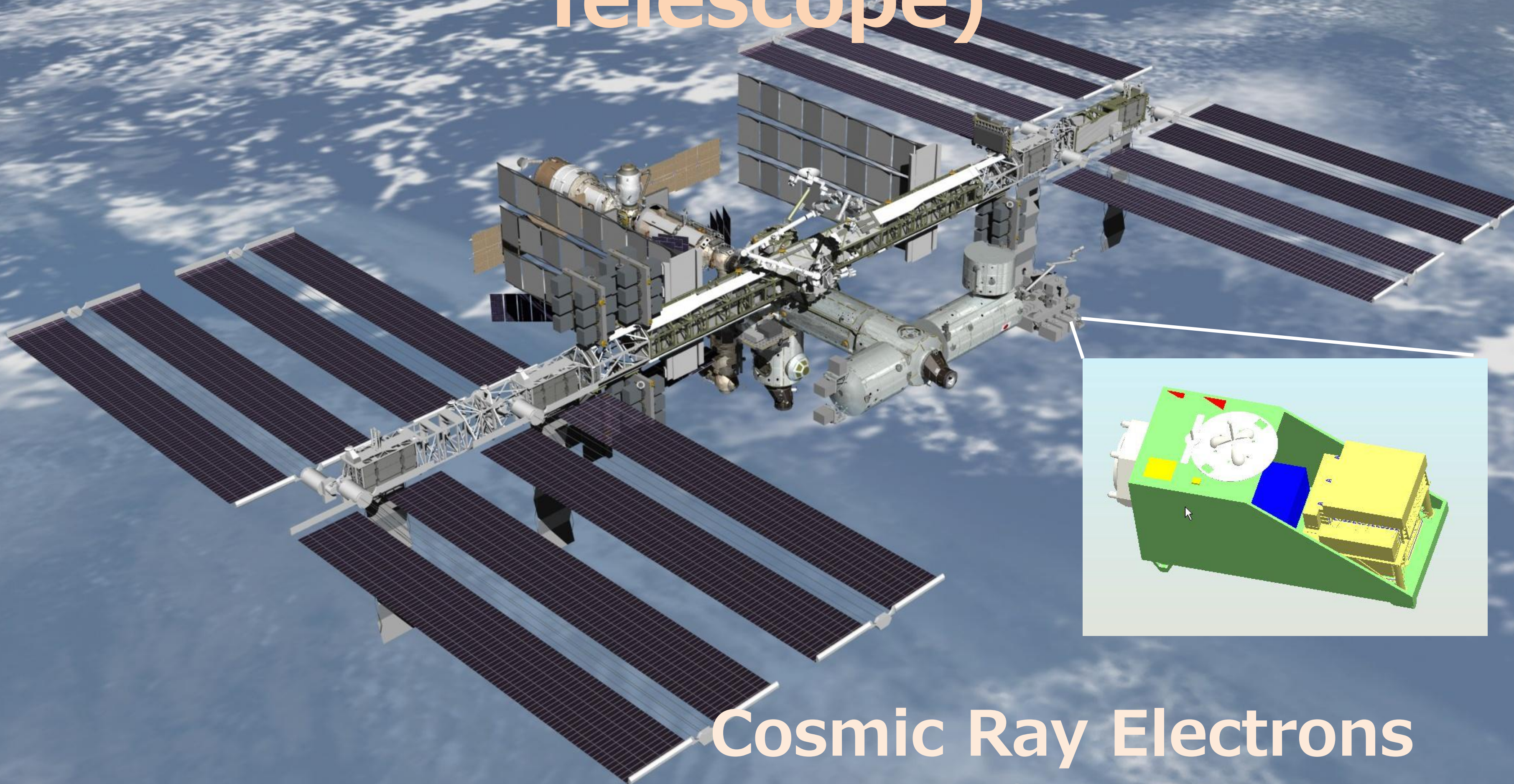


Electron CR
CALET (2013-)
CTA (2015-)



Positron CR
AMS-02 (2011-)

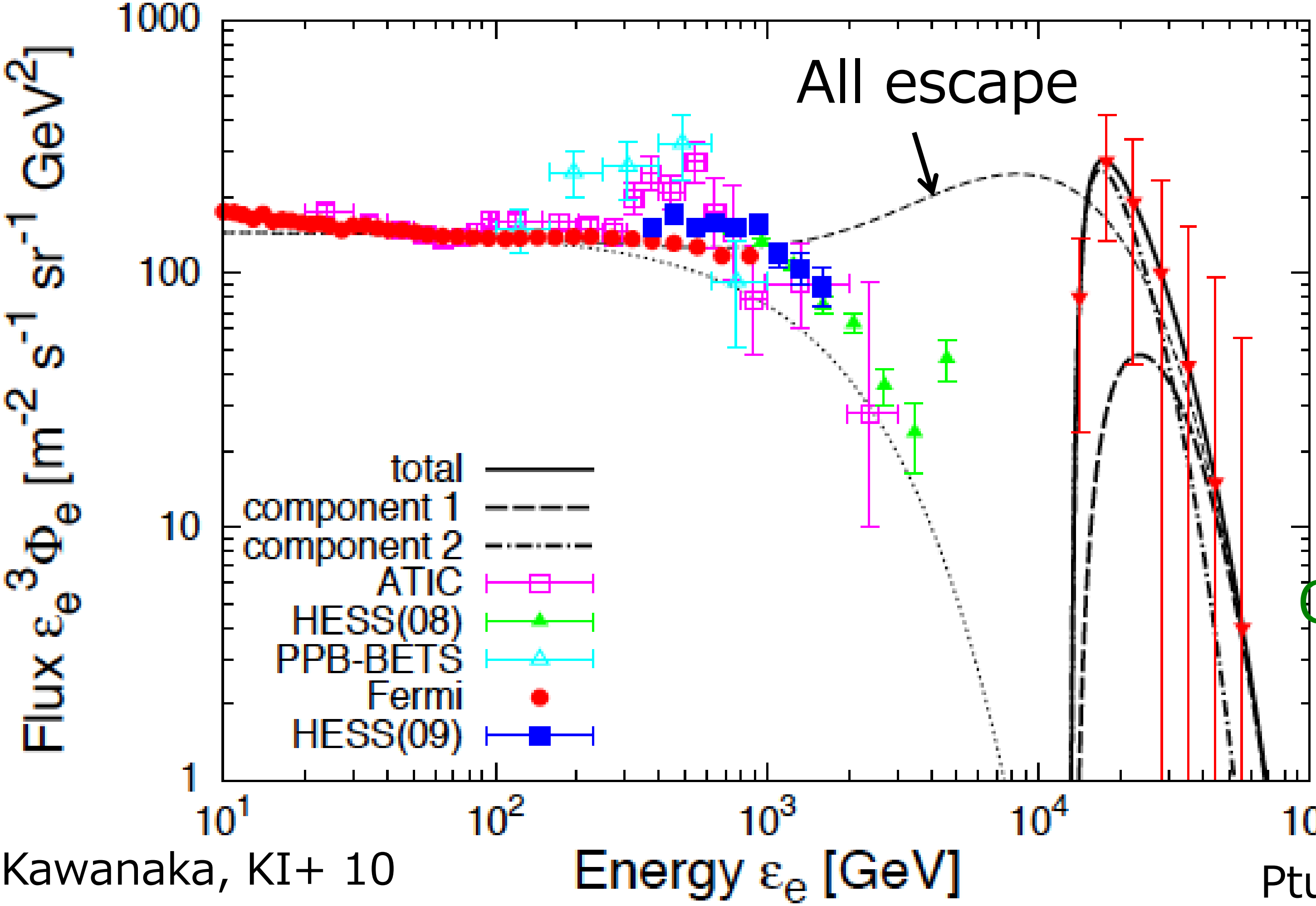
CALET
(CALorimetric Electron Telescope)



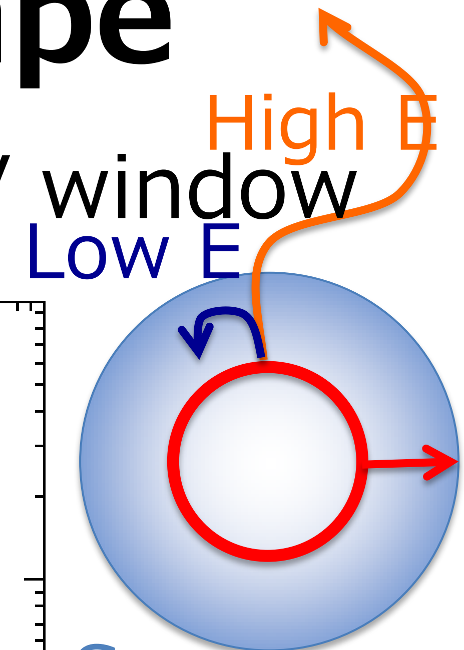
Cosmic Ray Electrons
up to ~10TeV
w/ ΔE~a few % (>100GeV

Cosmic Ray Escape

Only ~1 source (e.g., Vela) in TeV window



Kawanaka, KI+ 10



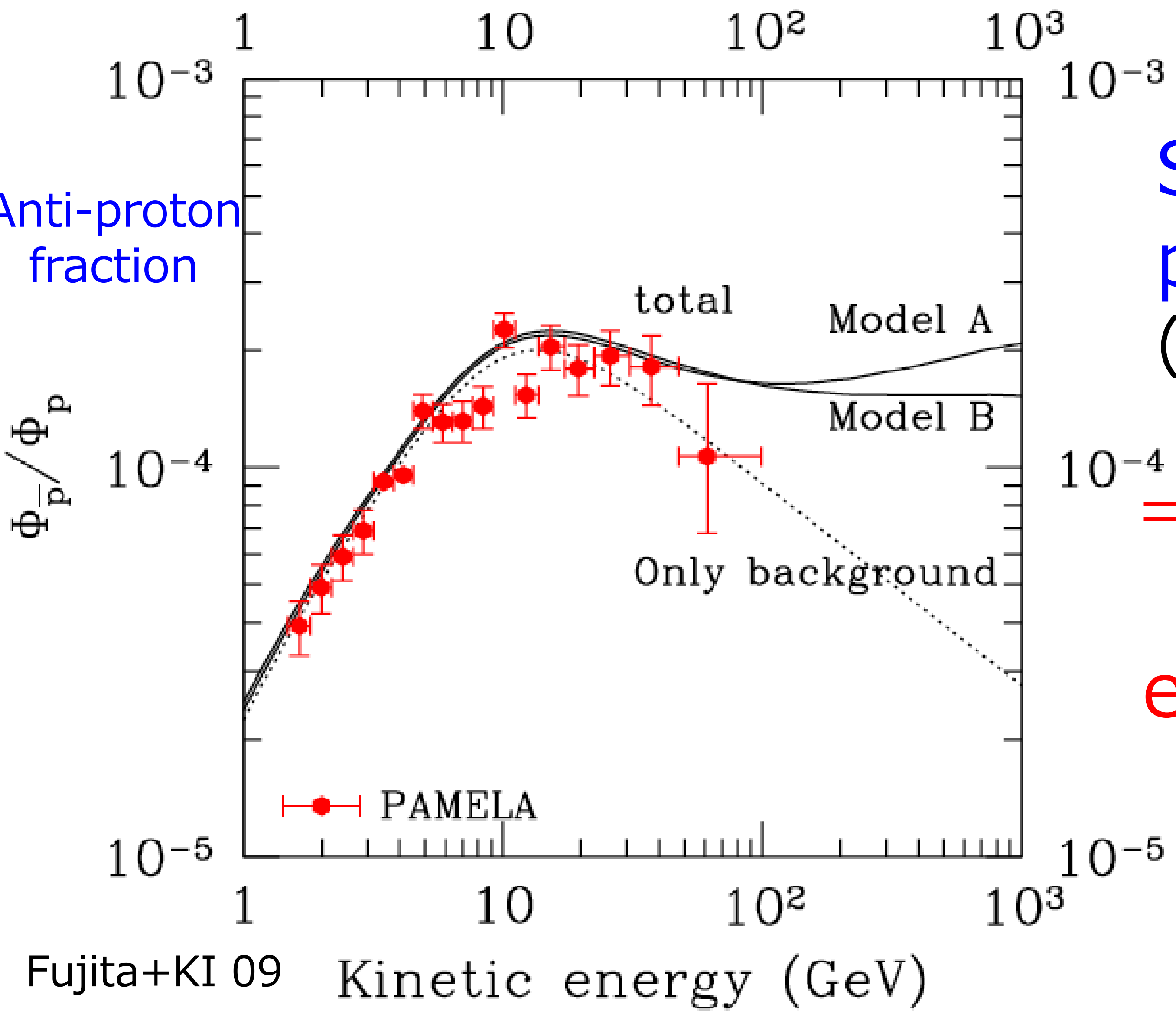
Supernova Remnant

If confined, CR lose energy
⇒ $F \propto E^{-2}$ is changed
⇒ CR Origin

Ptuskin & Zirakashvili

Hadronic v.s. Leptonic

Anti-proton fraction



Fujita+KI 09

SNR model:
pp → π^+ → e^+
(w/ surrounding

⇒ Inevitably anti-proton excess above ~100 GeV

Summary

- **Gamma-Ray Burst**
  - Fireball Γ_{max}**~10^6** in principle ⇔ Fermi GRB
  - Off-axis NS merger: **Cocoon breakout**
  - GRB jet can breakout the first star **(P-68)**
- **Cosmic-Ray**
  - CR $e^{\pm}$ from white dwarf pulsars **(P-91)**

Thanks
and
Congratulations to
Nakamura-san
Maeda-san
and JGRG