W49B: the first GRB remnant?

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CXC Press Release: 04-05 (June 2, 2004)

Ioka, Kobayashi & Meszaros, astro-ph/0406555 (ApJL accepted)

CANGAROO ICRR Group seminar, 23-AUG-2004

“Engine” of Gamma-ray bursts?

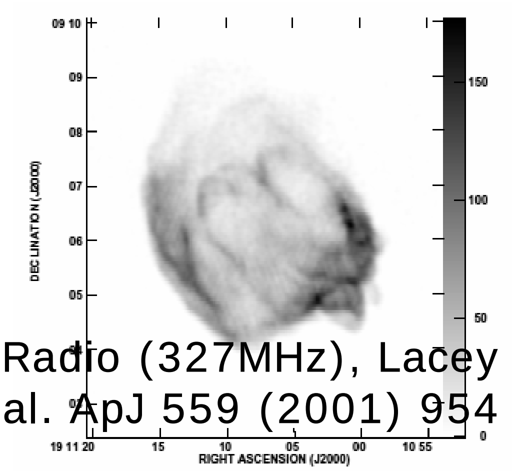
E_γ~10^{51}erg (after beaming correction) in ~10s

- 超大質量星の崩壊(”hypernova” or “collapsar”)
  - Woosley 1993, …
  - 発生率 ~1/($10^{4\sim5}$SNe): OK
  - 星生成領域で起こるため周囲の物質密度は高い(星風で hot bubbleになっている可能性もあり)
- 中性子星・中性子星や中性子星・ブラックホールの合体
  - Eichler et al. 1989, …
  - 発生率: だいたいOK
  - 中性子星はできてから時間が経っており、周囲の物質密度はあまり高くない

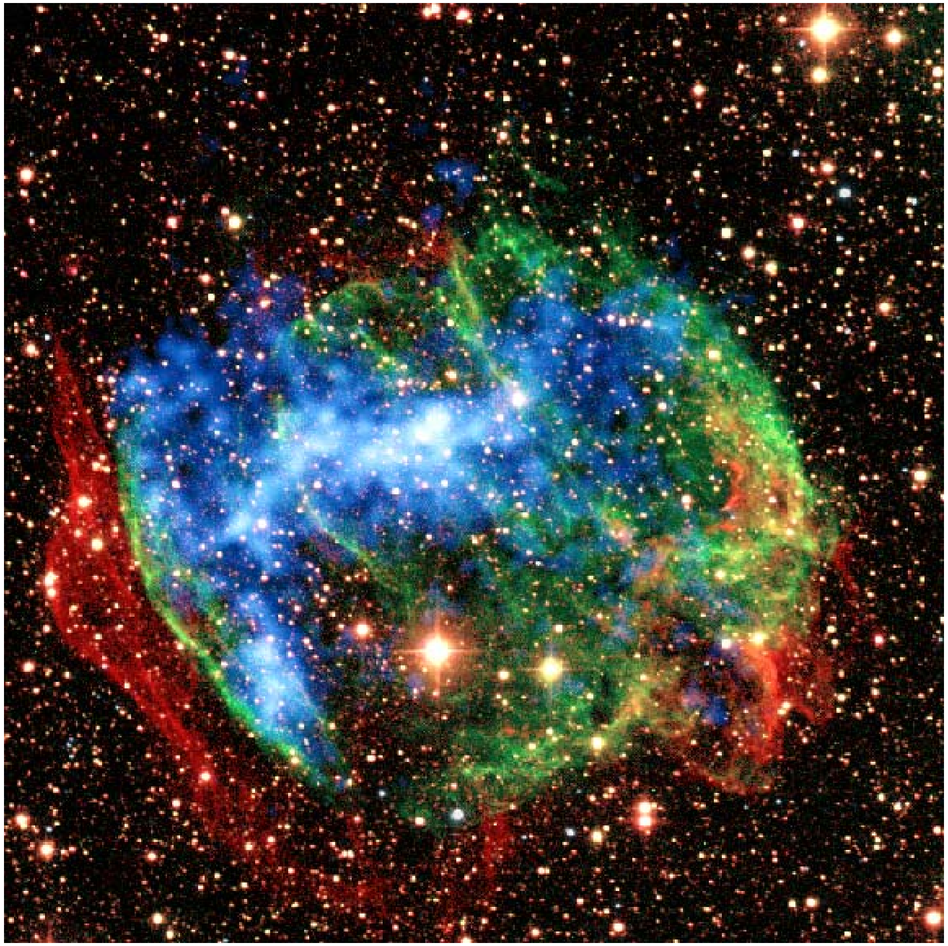
Perna, Raymond & Loeb, ApJ 533 (2000) 658

超新星残骸　W49B

- チャンドラが捉えた超新星残骸W49B。疑似カラーの青はX線の観測、赤と緑は赤外線の観測（提供：X線：NASA/CXC/SSC/J. Keohane et al., 赤外線：Caltech/Palomar/J. Keohane et al.）



Radio (327MHz), Lacey et al. ApJ 559 (2001) 954



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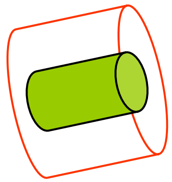
W49B = GRB残骸?



- 樽型･･･赤外線の箍と、中心線に沿ったFe･NiからのX線
  ⇒ コアの物質が放出されている！
  (通常の超新星ではFe･Niコアは中性子星になり、飛散するのは周囲の物質)
- Feに富む超大質量星が爆発時に双極ジェットとして噴射?
  (GRBのcollapsar説では、大質量星が重力崩壊してブラックホールを作るときに周囲に磁化した高温の高速回転円盤ができ、落ち込む物質の一部が軸方向に双極ジェットとして放出される。)
- X線放射は爆風が周囲の物質と作る衝撃波面でhot capをつくり終焉
- 星が濃い塵の中で生成され、2-3百万年輝く間に空洞を作り、重力崩壊型超新星爆発を起こしてGRBとなったと考えられる。

- *結局、W49Bは超大質量星の超新星残骸(“hypernova remnant”)と考えられる。(GRBとの直接的関連が示されているわけではない。)*

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VLA image near SGR1900+14

19h11'08"

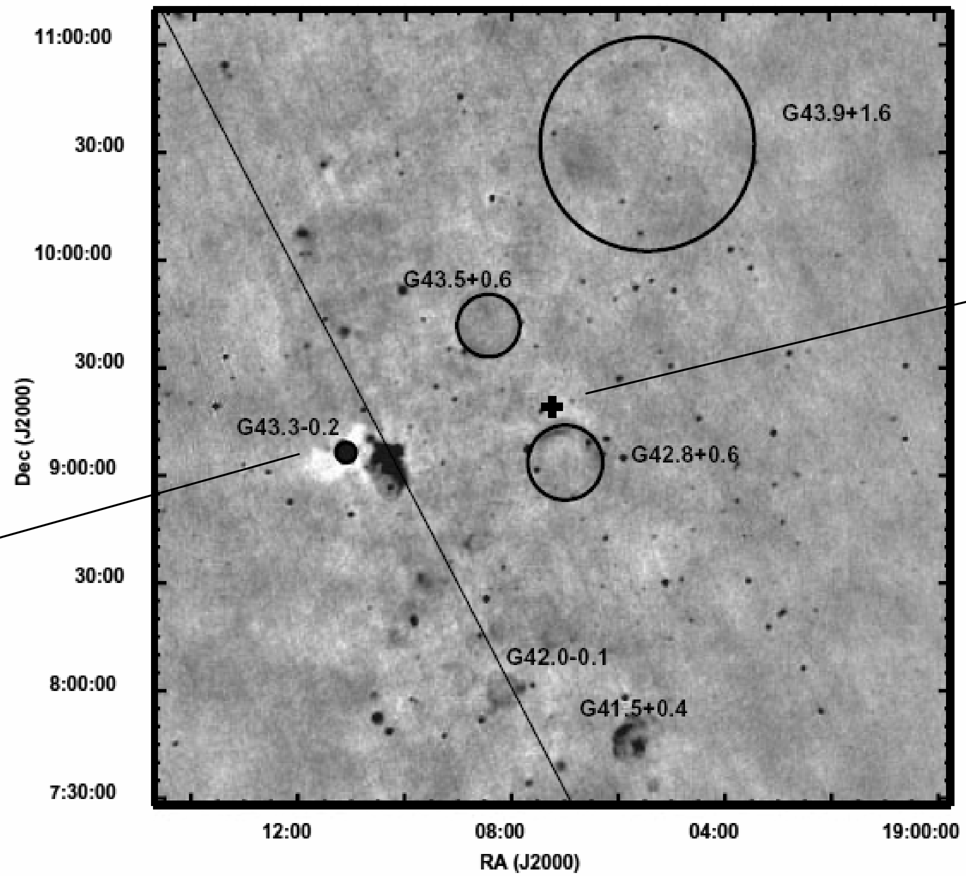
+09deg06'

4' x 3'

D ~ 10kpc

Age ~ 3000yr

W49B

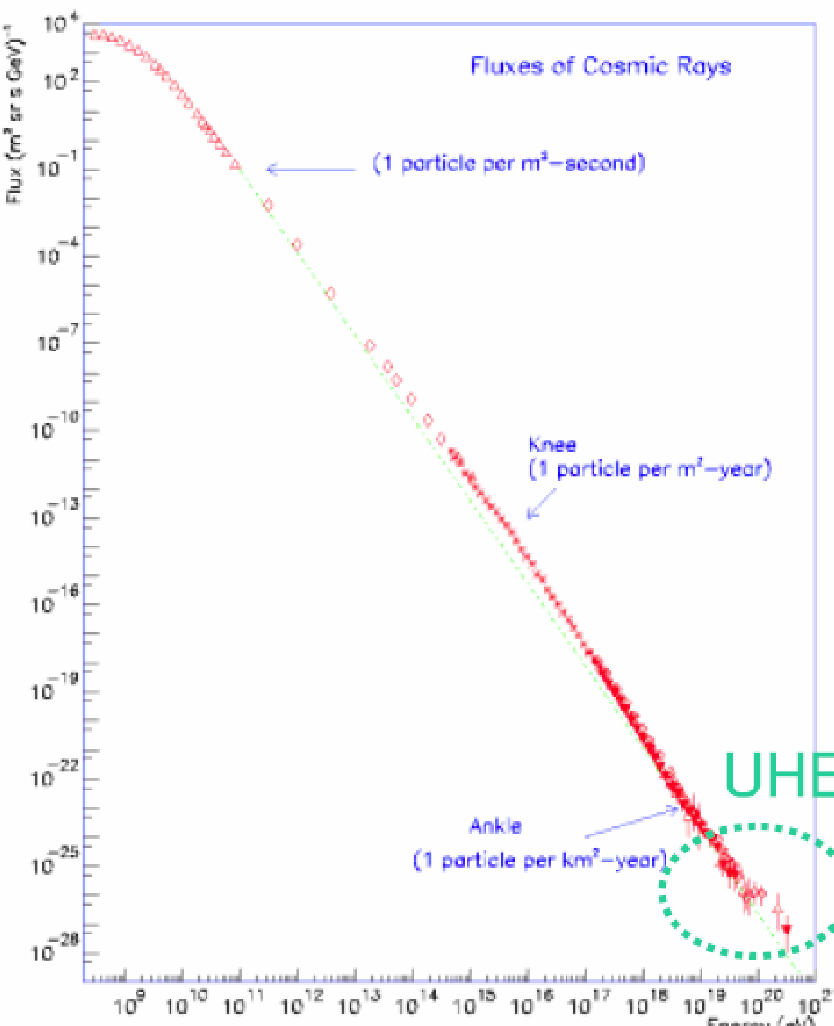


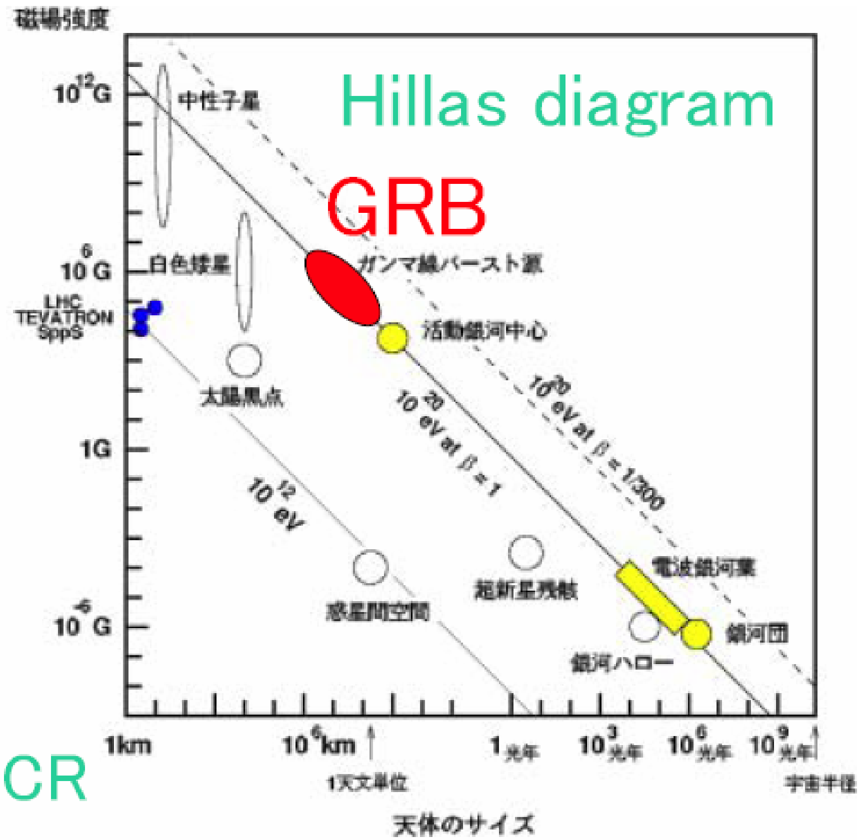
SGR 1900+14

FIG. 5.—Wide-field 332 MHz VLA image of the region around SGR 1900+14. SNRs are marked by circles and/or labeled. The diagonal line is the Galactic plane. The cross marks the position of SGR 1900+14. G043.5+00.6, G042.0−00.1, and G041.5+00.4 are new candidate SNRs; see also § 3.2.1 and Figs. 10 and 11. There are a number of smaller H II regions that we have not labeled. The horizontal and vertical lines visible in some places are artifacts created when the planar facets were combined (see § 2.3).

Kaplan et al., ApJ 566 (2002) 378

GRB = UHECR origin(?)





$$E_{\max} \le 4\times10^{20} Z\left(\frac{B_{\rm rms}}{100\mu{\rm G}}\right)\left(\frac{\beta_{\rm shock}}{0.3}\right)\left(\frac{R_{\rm scale}}{100{\rm kpc}}\right)$$

Hillas, Ann.Rev.A.Ap. (1994)

Emission from GRB remnants

- Energetics

$$E_p^2 \frac{d\dot{n}_p^{\rm CR}}{dE_p}\,(10^{19}-10^{21}{\rm eV}) \simeq \dot{\varepsilon}_\gamma^{\rm GRB}(0.02-2{\rm MeV})\ ,$$

- *Assume* shock-accelerated protons ($\sim 10^{51}$erg)
  $p\,\gamma \rightarrow n\,\pi^+$
  $\Rightarrow\ n \rightarrow p\,e^-\,\nu$, $t_{\rm decay} \sim 3\times10^3(\gamma_n/10^8)$ yr
  $\Rightarrow$ Synchrotron & IC emission from e^-
- Extended emission: consider only $\gamma_e \sim \gamma_n > 10^6$, so that $ct_{\rm decay} > R$ (outside)

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Emission from electrons

- Synchrotron
  - B~3μG (assumed) or U~4E-13erg/cm^3
- Inverse Compton
  - IR/optical/CMB as targets
  - T_{IR}~100K, T_{opt}~6000K, T_{CMB}=3K
  - U_{IR}~2E-13erg/cm^3, U_{opt}~7E-13erg/cm^3, U_{CMB}~4E-13erg/cm^3

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Extended emission

- Cooling time $t_{\rm cool}(\gamma_e) \sim \frac{3m_e c}{4\gamma_e \sigma_T U_{\rm total}} \sim 1 \times 10^4 \gamma_{e,8}^{-1} U_{\rm total,-12}^{-1}$ yr,

(a) fast decay: $t_{\rm decay} < t_{\rm age}$

$$\Omega \sim 4\theta (ct_{\rm decay}/d)^2 \sim (1\theta_{-1}\gamma_{e,8})^\circ \times (10\gamma_{e,8})^\circ \sim 3 \times 10^{-3} \theta_{-1} \gamma_{e,8}^2 \ {\rm sr},$$

(b) slow decay : $t_{\rm decay} > t_{\rm age}$

(b1) $t_{\rm cool} < t_{\rm age}$

$$\Omega \sim 4\theta (ct_{\rm age}/d)^2 \sim (1\theta_{-1} t_{\rm age,3.5})^\circ \times (10 t_{\rm age,3.5})^\circ \sim 4 \times 10^{-3} \theta_{-1} t_{\rm age,3.5}^2 \ {\rm sr}.$$

(b2) $t_{\rm cool} > t_{\rm age}$

$$\begin{aligned} \Omega &\sim 4\theta (ct_{\rm age}/d)(ct_{\rm cool}/d) \sim (1\theta_{-1} t_{\rm age,3.5})^\circ \times (30 \gamma_{e,8}^{-1} U_{\rm total,-12}^{-1})^\circ \\ &\sim 1 \times 10^{-2} \theta_{-1} t_{\rm age,3.5} \gamma_{e,8}^{-1} U_{\rm total,-12}^{-1} \ {\rm sr}. \end{aligned}$$

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(fast decay) $t_{decay} < t_{age}$ $t_{decay} > t_{age}$ (slow decay)

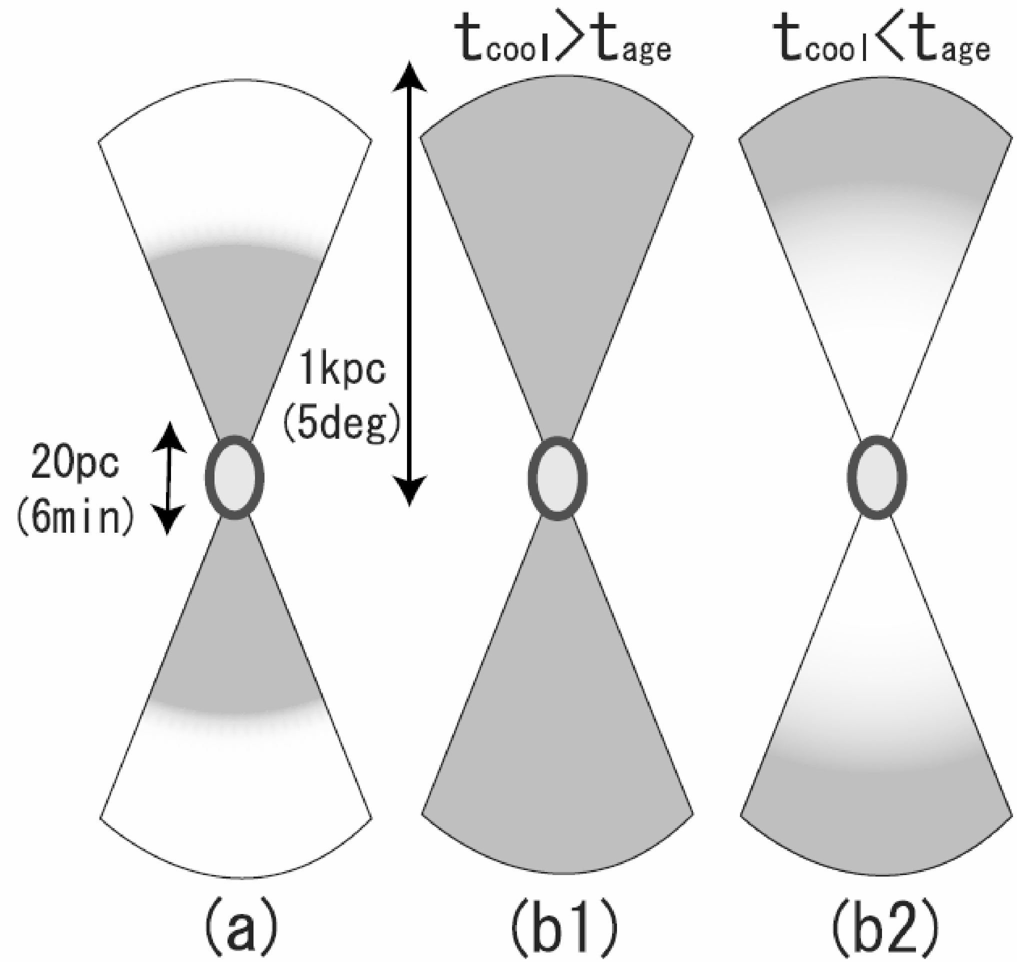

Fig. 1.— The GeV-TeV emission region (shaded region) on the sky is shown schematically. (a) The β-decay time is shorter than the remnant age $t_{\rm decay}(\gamma_e) < t_{\rm age}$, so that the radius of the emitting region is about the β-decay length in equation (2). The surface brightness on the sky is nearly homogeneous. (b1) $t_{\rm decay}(\gamma_e) > t_{\rm age}$ and the initial cooling time is longer than the remnant age $t_{\rm cool}(\gamma_e) > t_{\rm age}$. The radius of the emitting region is about $\sim ct_{\rm age} \sim 1 t_{{\rm age},3.5}$ kpc. The surface brightness is nearly homogeneous. (b2) $t_{\rm decay}(\gamma_e) > t_{\rm age}$ and $t_{\rm cool}(\gamma_e) < t_{\rm age}$. The radius of the emitting region is about $\sim ct_{\rm age} \sim 1 t_{{\rm age},3.5}$ kpc. The jet head region, of size $\sim ct_{\rm cool}(\gamma_e)$, has a flux $\sim t_{\rm age}/t_{\rm cool}$ times larger than the rest. The GRB remnant W49B, shown in the center, has a radius ~ 10 pc.

Gamma-ray Flux

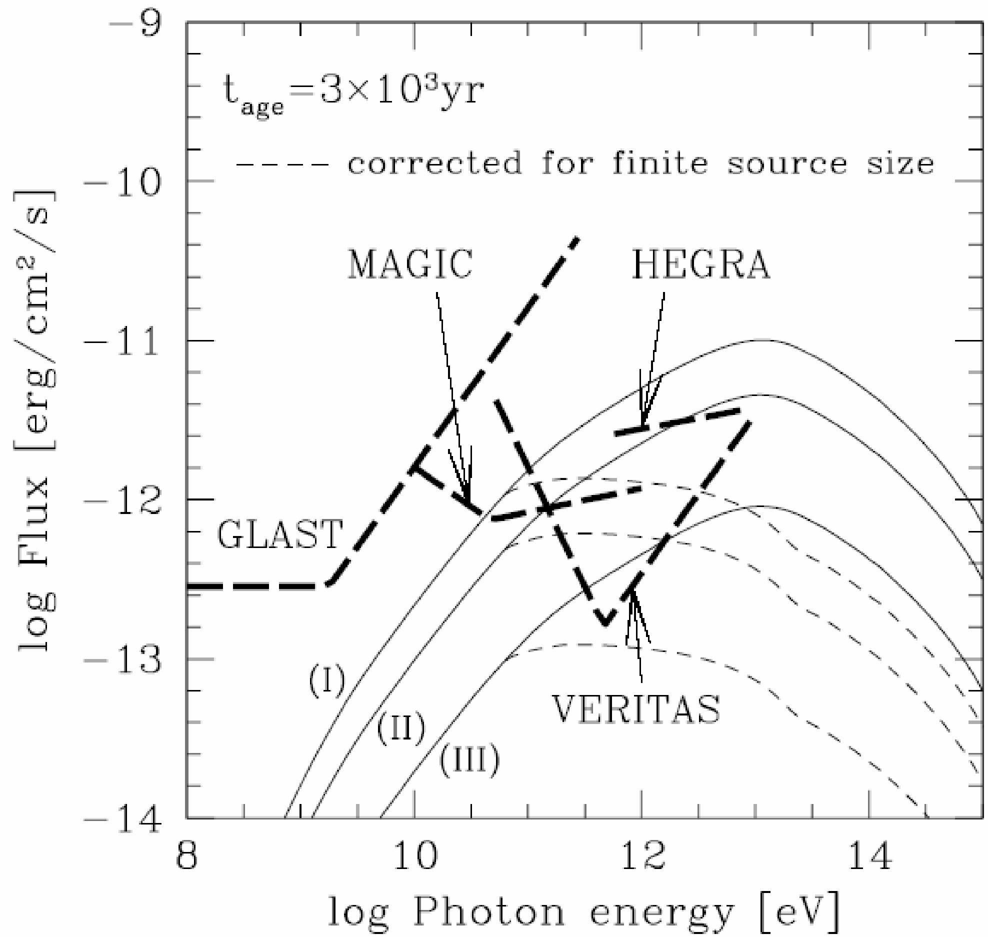

Fig. 2.— The flux of IC emission from the β-decay electrons (solid lines) is compared with the detector sensitivity (bold long dashed lines). Three cases for the total energy are plotted: (I) Neutrons in the range $10^{10} < \gamma_n < 10^{12}$ have the geometrically corrected energy 3×10^{51} erg according to equation (1). (II) The energy 3×10^{51} erg is spread among all neutrons with $1 < \gamma_n < 10^{11}$. (III) The energy of case (II) is further reduced by a factor 5. The dashed lines are the flux of β-decay emission multiplied by $(\Omega/\pi\theta_{cut})^{-1/2}$ in order to take the finite source size into account, where Ω is the solid angle of the emitting region on the sky and $\theta_{cut} \sim 0.1°$ is the angular cut in the analysis. The sensitivities of HEGRA, MAGIC and VERITAS should be compared with the dashed lines. The remnant age is $t_{age} = 3 \times 10^3$ yr, and the distance is $d = 10$ kpc.

Discussion

- HEGRA upper limit for W49B
  0.14 Crab or 7×10^{-12}erg cm^{-2}s^{-1}, assuming 0.1° circle ⇔ 0.1°x1° in this model
- Uncertainties
  - Nearby HII region ⇒ photon field may be denser
  - Doppler boost? (i~20° ?)
  - Electron diffusion diffusion length $r_D \sim (\kappa t_{\rm age})^{1/2} \sim 100\gamma_{e,7}^{1/6} t_{\rm age,3.5}^{1/2}$ pc
  - GRB rate ~10^{-5}yr^{-1}galaxy^{-1} ⇒ W49B is not typical?

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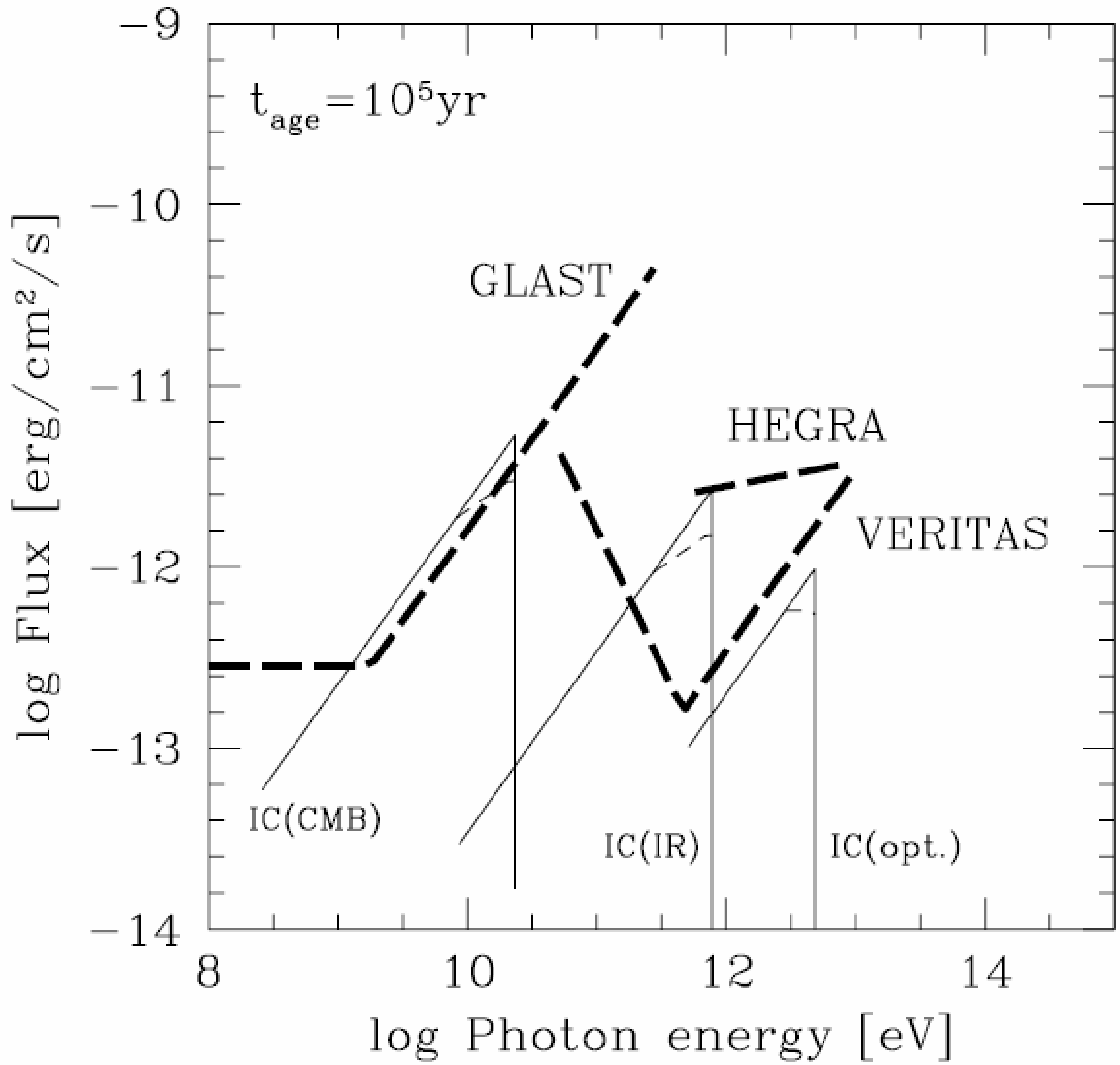

Fig. 4.— Same as Figure 3 except for the remnant age, which is taken here as $t_{age} = 10^5$ yr.