

Status of neutrino astronomy

(Sources of high-energy neutrinos)

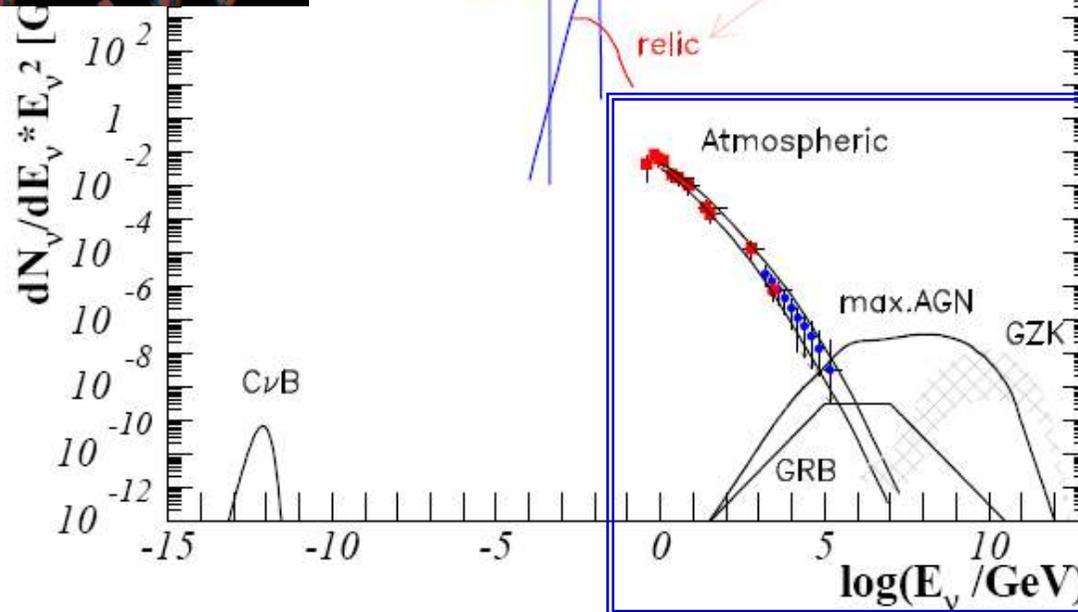
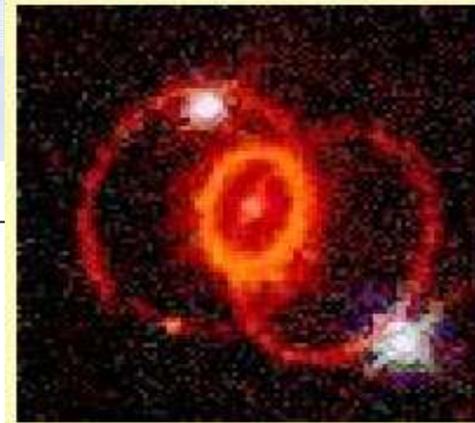
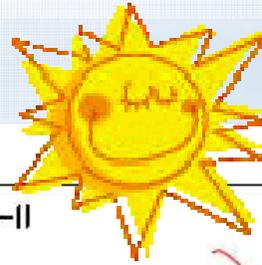
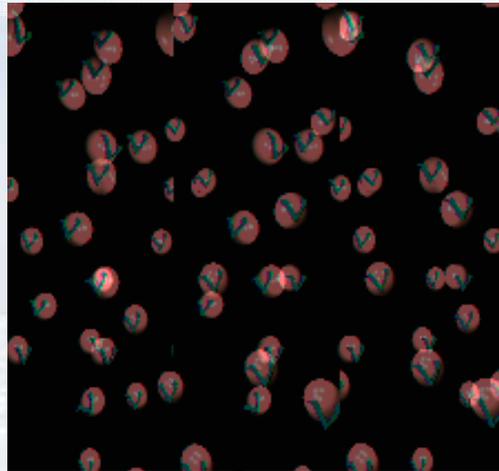
Julia K. Becker

Göteborgs Universitet, Sweden

see also Physics Reports **458**, [ArXiv:0710.1557](https://arxiv.org/abs/0710.1557) (2008)



Astrophysical Neutrinos





Overview

- Production of high-energy neutrinos
 - how?
 - why?

- Potential emitters

- Neutrino flux models for extragalactic sources
 - Active Galactic Nuclei
 - Gamma Ray Bursts



Neutrino production



- $p\gamma \rightarrow \Delta^+ \rightarrow \pi^+ n / \pi^0 p$
 - $\pi^+ \rightarrow \mu^+ \nu_\mu \rightarrow e^+ \nu_e \nu_\mu \nu_\mu$
 - $\pi^0 \rightarrow \gamma \gamma (E_\gamma \sim \text{TeV})$
 - **Pions:** Correlation TeV **Photons – Neutrinos**
 - Optically thick environment: $E_\gamma \sim \text{keV-GeV}$
- Main assumption:
 - $L_\gamma \sim L_p \sim L_\nu$
 - Photon luminosity:
Sources can be identified
 - Proton luminosity $\sim \text{TeV sources}$
 - **Careful!** → Other processes (**Inverse Compton, proton synchrotron** can contribute, too!)



Neutrino flux from a single source

$$\frac{d\Phi_{\nu}}{dE_{\nu}} = A_{\nu} \cdot E_{\nu}^{-\alpha_{\nu}} \cdot \exp\left(-\frac{E_{\nu}}{E_{\max}}\right)$$

- Spectral index neutrinos \sim spectral behavior protons ~ 2
- Maximum neutrino energy \sim proton maximum energy
- Normalization A_{ν} : electromagnetic or hadronic emission \rightarrow

$$L_{\nu} \propto L_{radio} / L_{X-ray} / L_{TeV-\gamma} / L_p / \dots$$

(dependent on the underlying model)



Diffuse neutrino flux

$$\frac{dN_\nu}{dE_\nu}(E_\nu^0) = \int_z \int_L dz dL \frac{d\Phi_\nu}{dE_\nu}(E_\nu^0, L, z) \cdot \frac{dn}{dL dV}(L, z) \cdot \frac{dV}{dz} \cdot \frac{1}{4\pi d_L(z)^2}$$

$$\frac{d\Phi_\nu}{dE_\nu}(E_\nu^0, L, z)$$

single source flux

$$\frac{dn}{dL dV}(L, z)$$

source distribution function

$$\frac{dV}{dz}$$

comoving volume

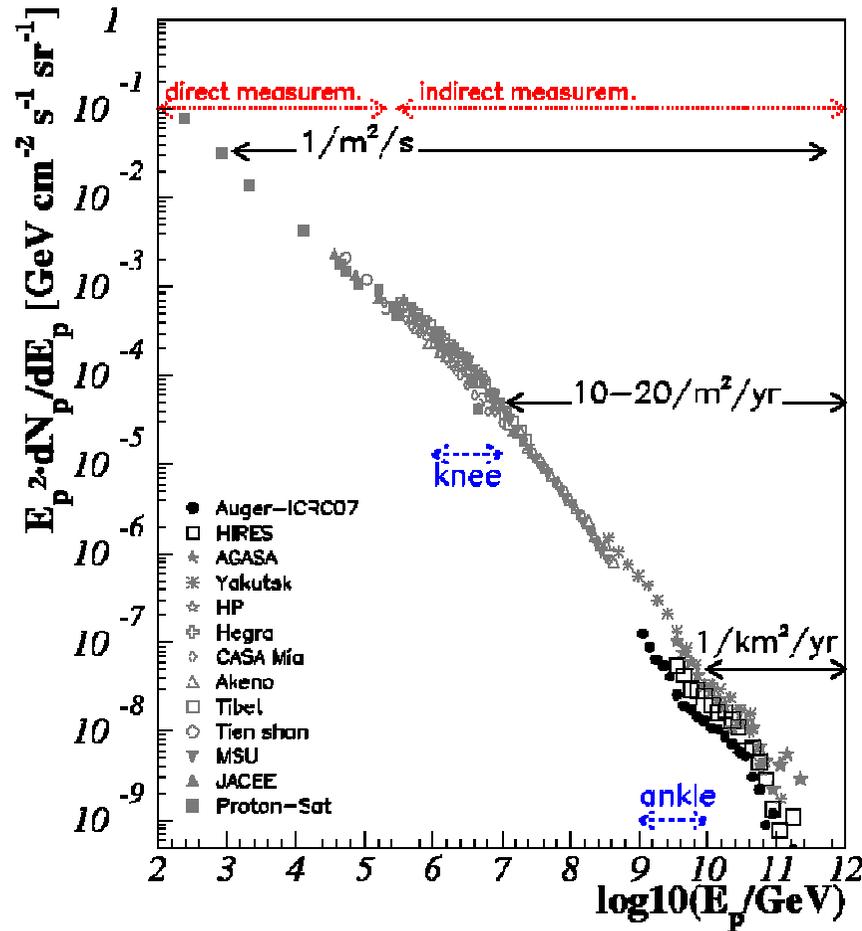
$$\frac{1}{4\pi d_L(z)^2}$$

flux decreases
with distance d



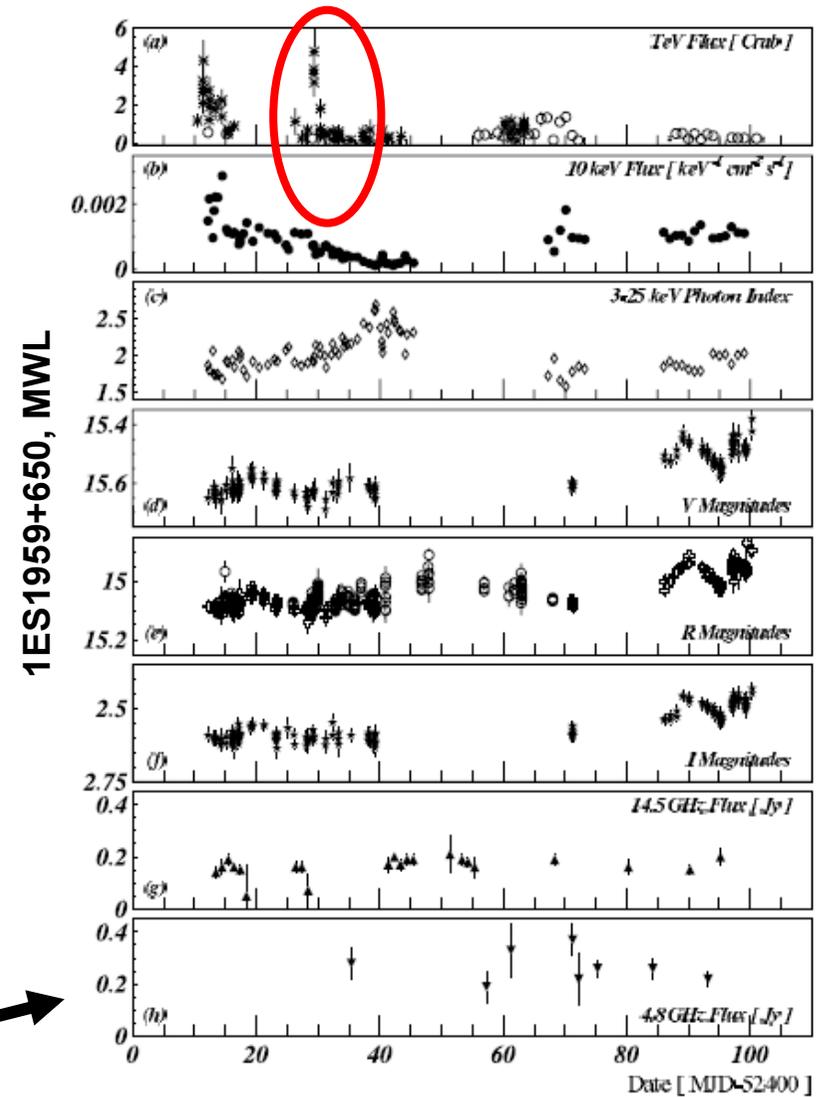
Why neutrinos, anyway? (I)

(a) Charged Cosmic Rays



Krawczynski et al., ApJ 601 (2004)

(b) TeV Photons





Why neutrinos, anyway? (II)



Figure: Wolfgang Wagner, PhD thesis

Potential HE neutrino sources

galactic:

extragalactic:

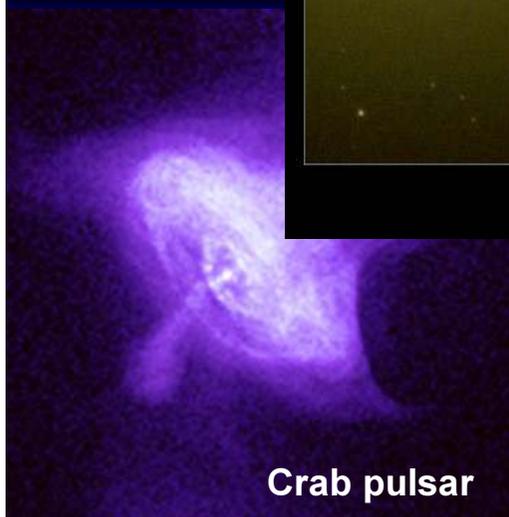
SNRs
XRBs
 μ quasars
Pulsars
Mol. clo
...

AGNs
GRBs
Blazars
...

The M87 Jet



Hubble Heritage



Hubble Heritage



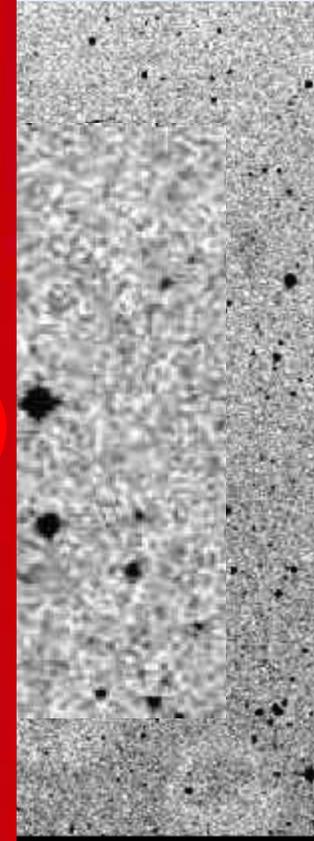
➤ **1962**
stellar

➤ core of
not r
looks

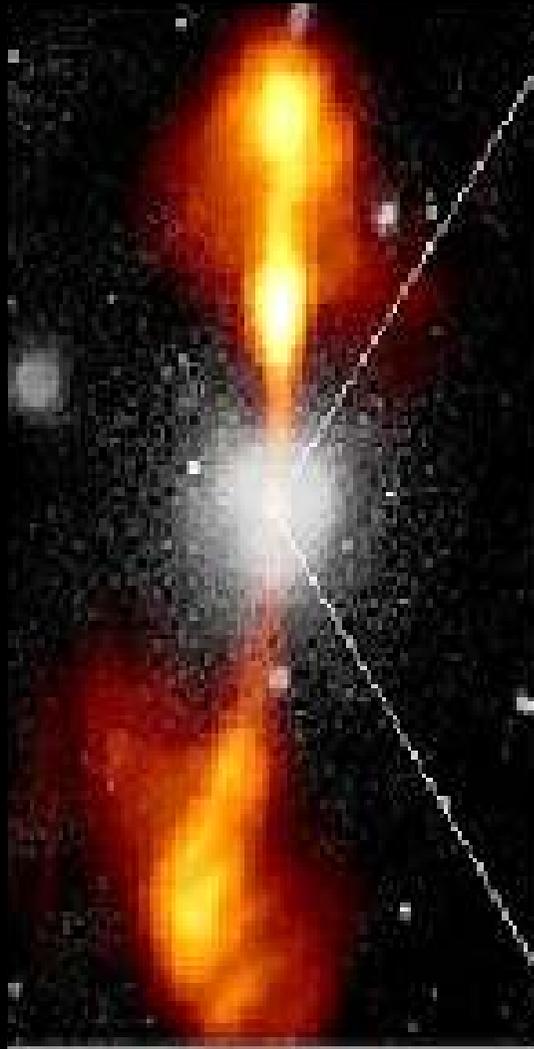
➤ High

➤ 1963:
Activ
(Maar
[www.tif](http://www.tif.nl)

May 31st Neutrino



*Ground based
optical/ radio*



380 arcsec
88 000 ly

*HST Image of the Torus
and the core*

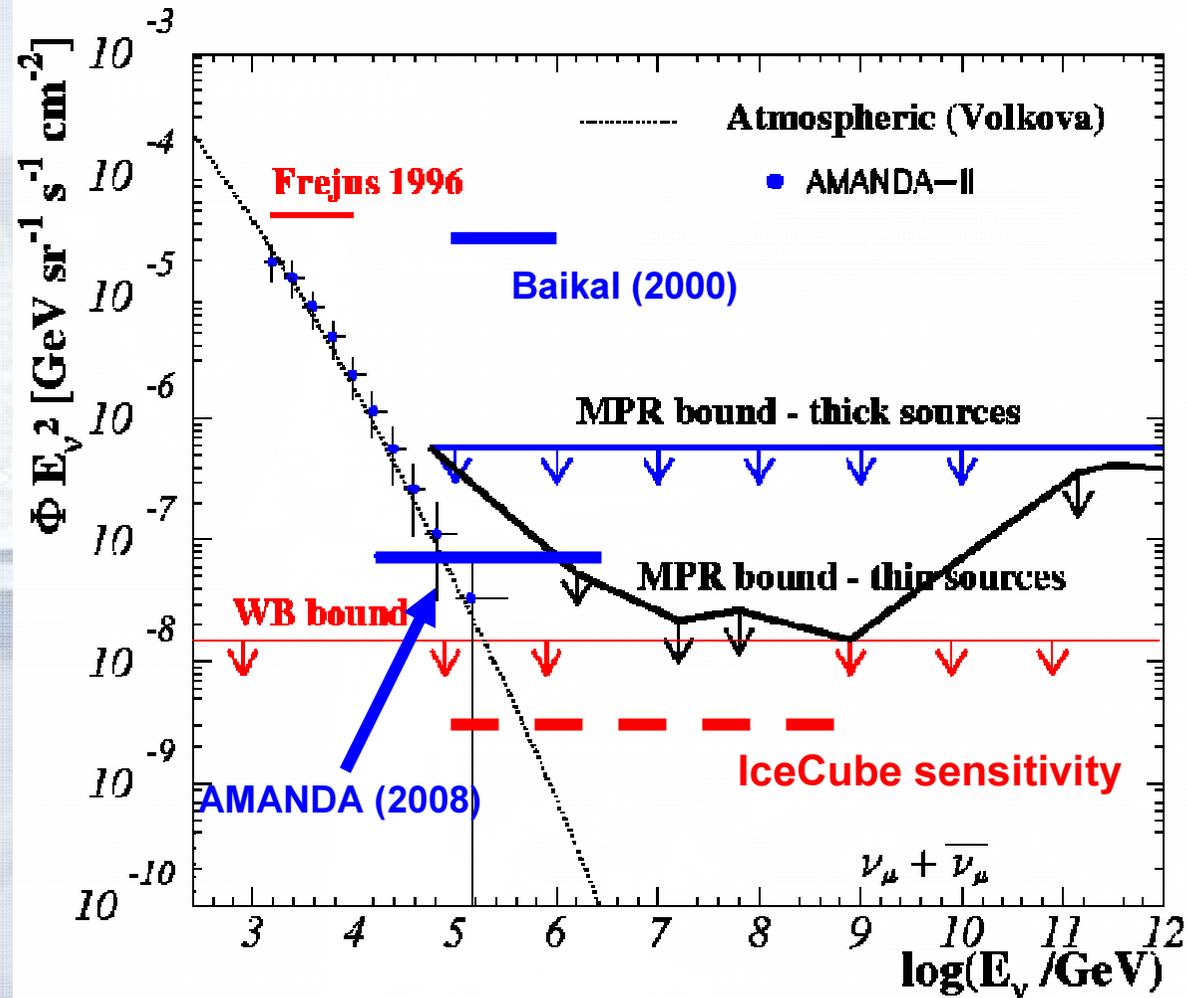


1.7 arcsec
400 ly

NGC 4261



Theoretical bounds?



Waxman&Bahcall, PRD **59**:23002 (1999)

Mannheim et al., PRD **63**:23003 (2001)



AGN: Neutrinos & X-rays?

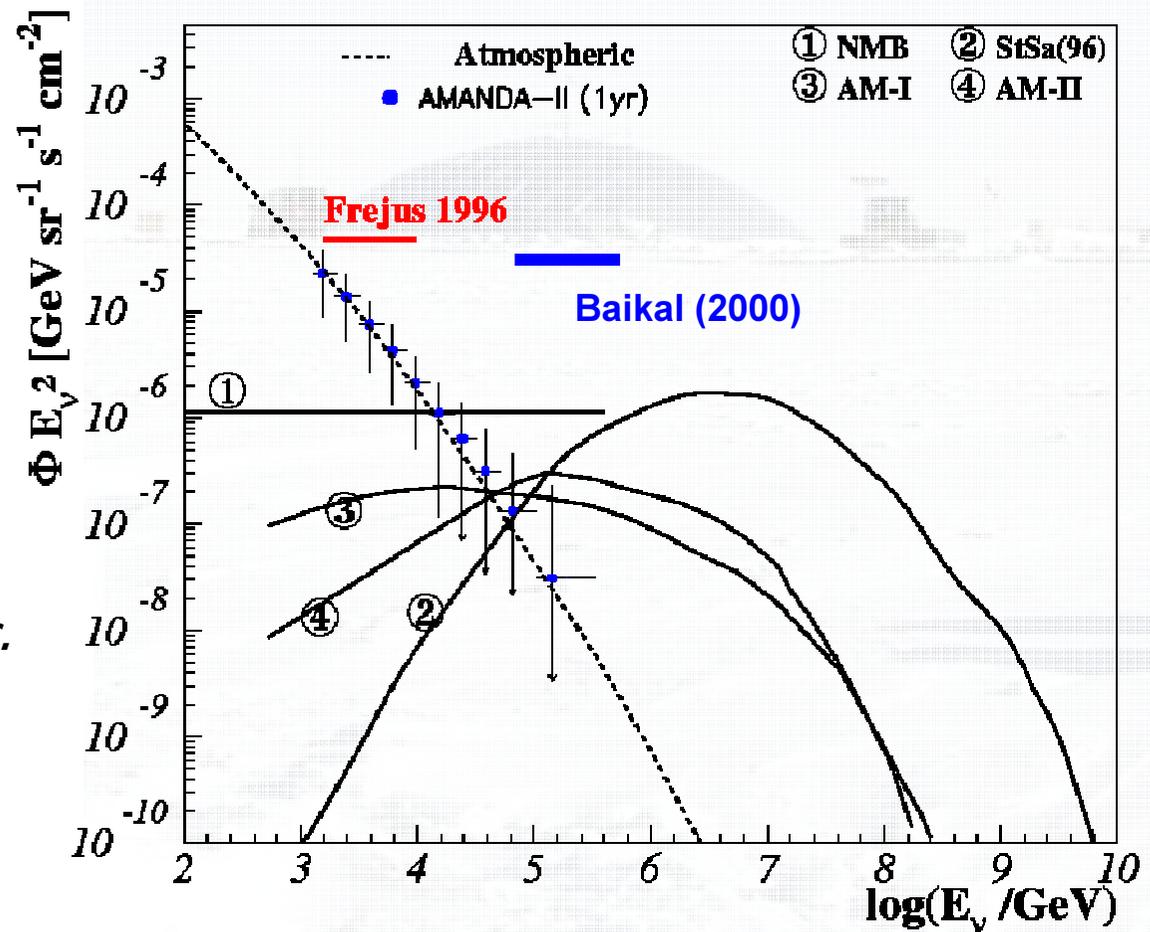
Nellen, Mannheim & Biermann
Phys.Rev.D (1993)

Stecker & Salamon
Space Science Rev. (1996)

Alvarez-Muñiz & Mészáros
PRD **70** (2004)

Fréjus:
Rhode & Daum, Astropart. Phys.
4:217 (1996)

Baikal:
Dzhilkibaev et al.,
Phys.Atom.Nucl. **63**:951 (2000)





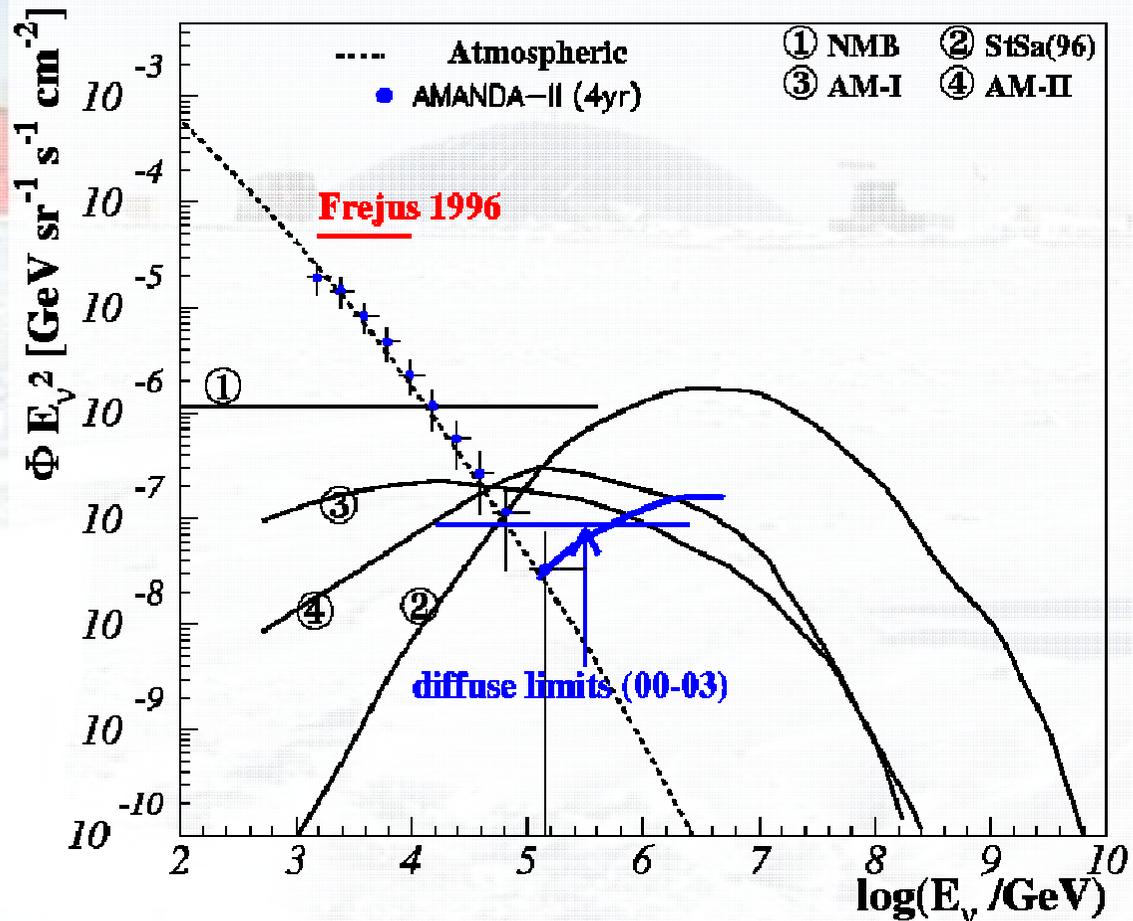
AGN: Neutrinos & X rays?

(1)
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(2)
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(3)
Alvarez-Muñiz & Mészáros
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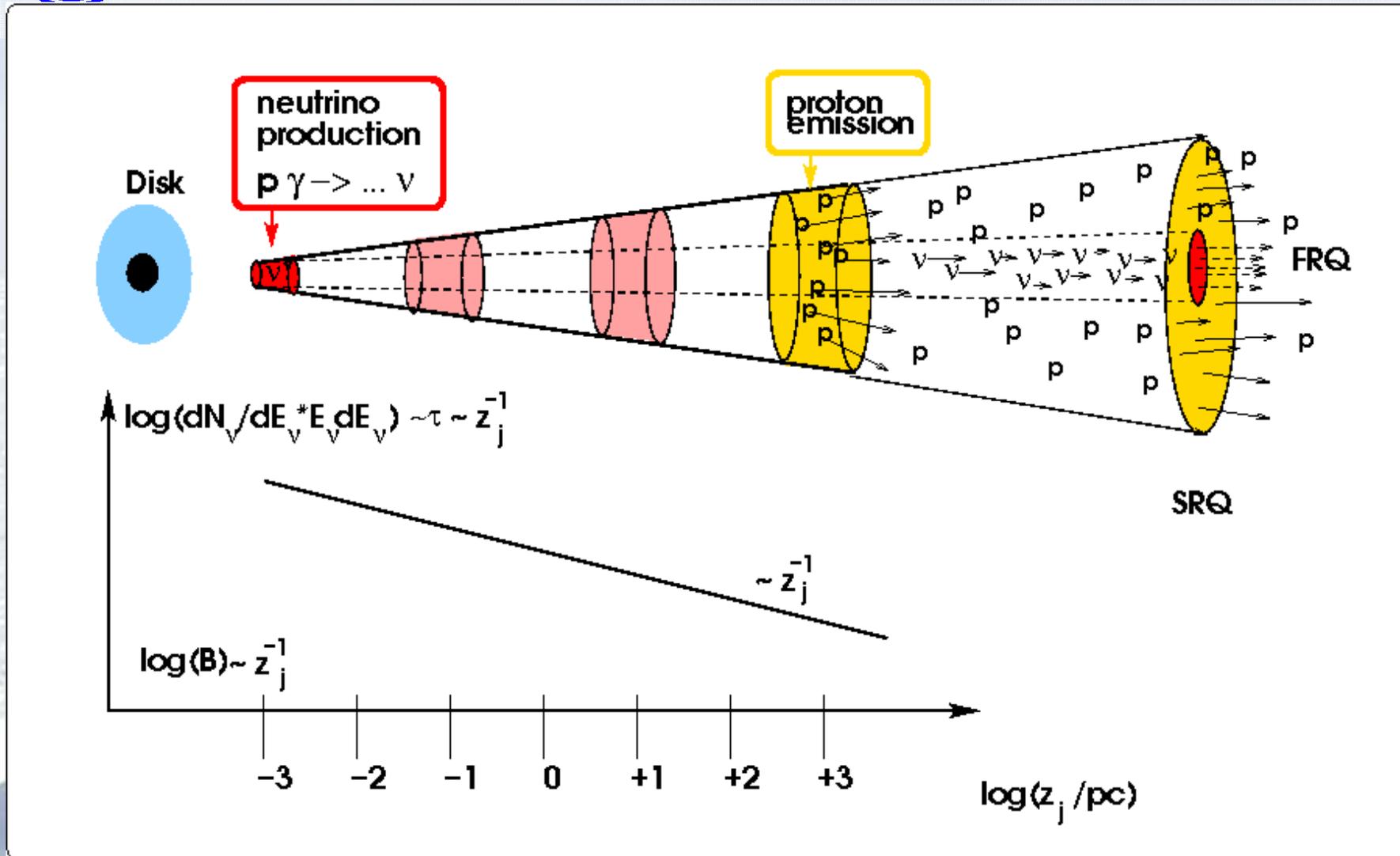
Data:
AMANDA (2000-2003)
Spectrum: Münich et al.,
ICRC 2007
Limits: Achterberg et al, PRD
75 (2007)



JKB et al, Astrop. Phys. **28:98** (2007)



Steep or flat spectrum sources?

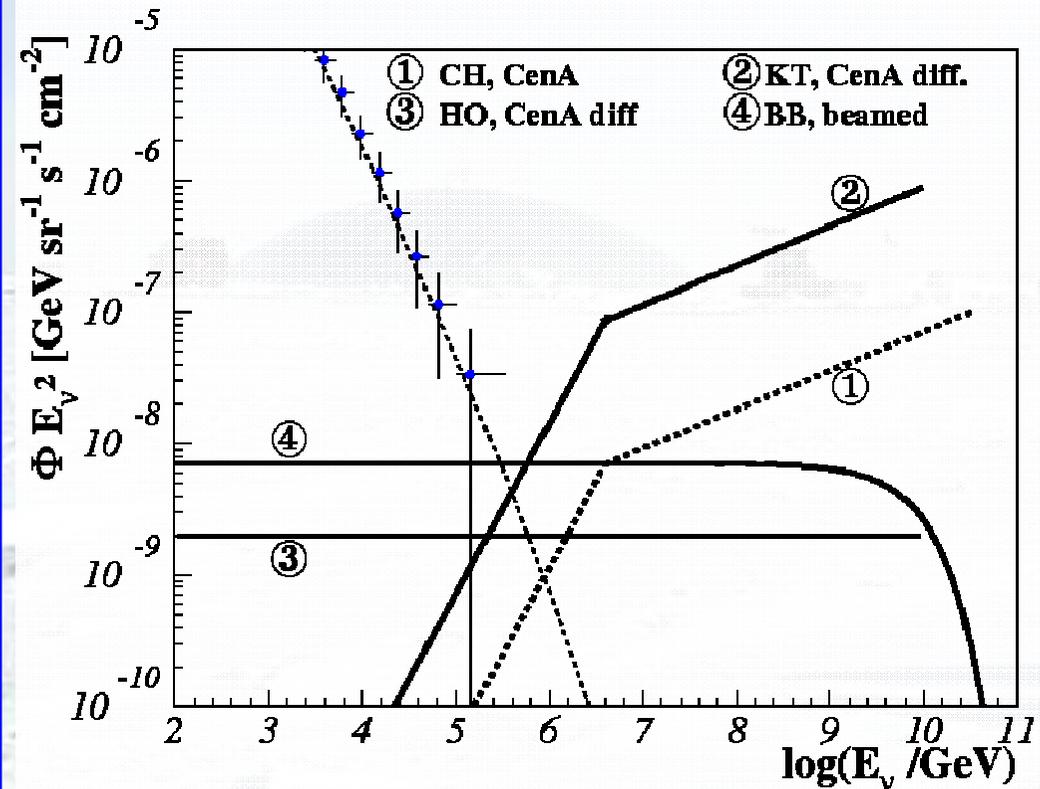


JKB & P. L. Biermann, ArXiv:0805.1498



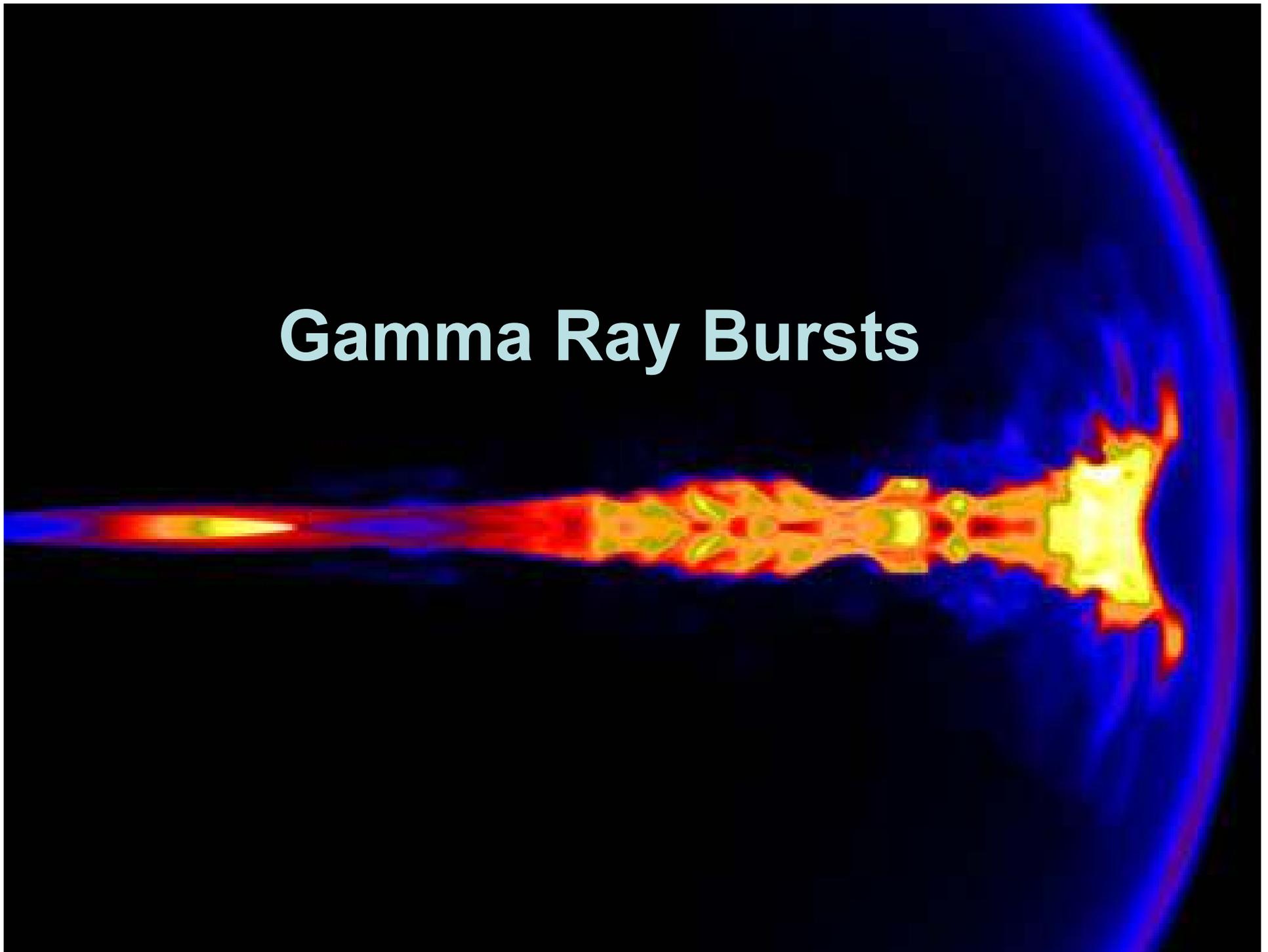
Neutrino flux & Cosmic Rays

- Normalize to **Auger** correlation
- Neutrino production at the foot of the jet
➔ Flat spectrum radio q.
- Model fits recent observations of **BL Lac** (*Marscher et al, Nature 2008*) and **M 87** (*Walker et al, ArXiv:0803.1837*)



- (1) Cuoco & Hannestad, ArXiv:0712.1830
- (2) Koers & Tinyakov, ArXiv:0802.2431
- (3) Halzen & Ó Murchacha, ArXiv:0802.0887
- (4) JKB & Biermann, ArXiv:0805.1498
- (5) Kachelrieß et al., ArXiv:0805.2608

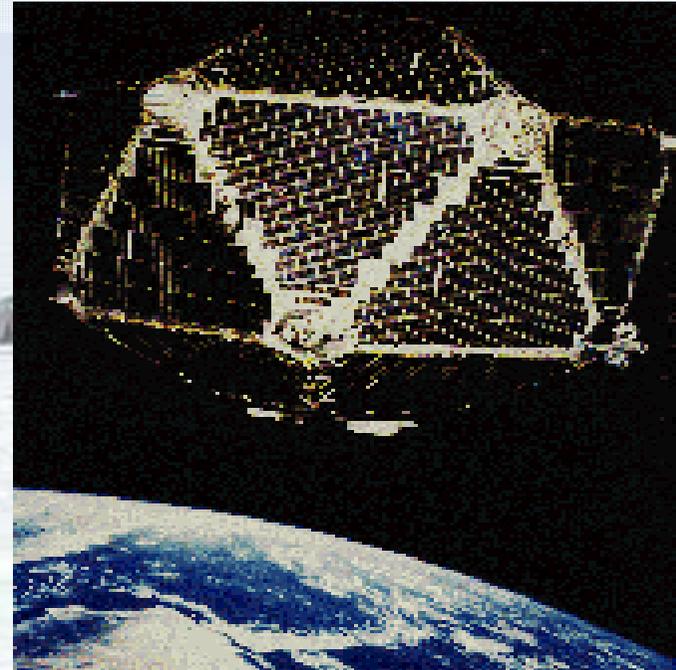
Gamma Ray Bursts





Unvoluntary Pioneer - Vela

- 1967 – 1979
- original goal: controlling nuclear tests (USA/Soviet Union)
- Coincidental detection of Gamma Ray Bursts



OBSERVATIONS OF GAMMA-RAY BURSTS OF COSMIC ORIGIN

RAY W. KLEBESADEL, IAN B. STRONG, AND ROY A. OLSON

University of California, Los Alamos Scientific Laboratory, Los Alamos, New Mexico

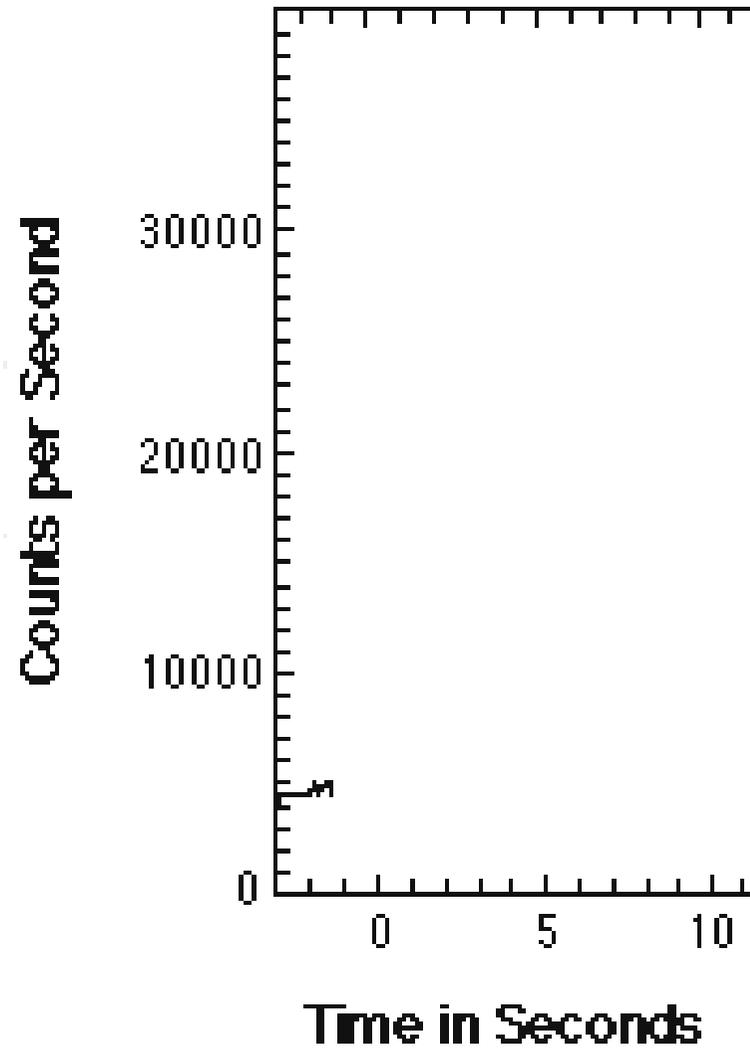
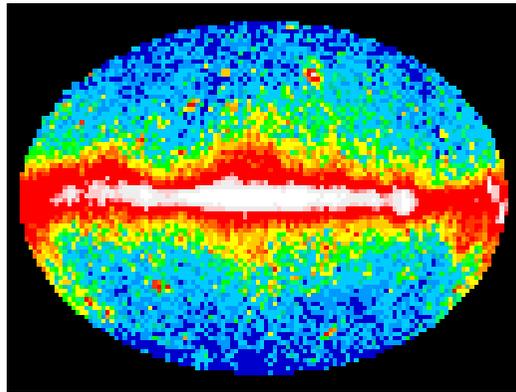
Received 1973 March 16; revised 1973 April 2

ABSTRACT

Sixteen short bursts of photons in the energy range 0.2–1.5 MeV have been observed between 1969 July and 1972 July using widely separated spacecraft. Burst durations ranged from less than

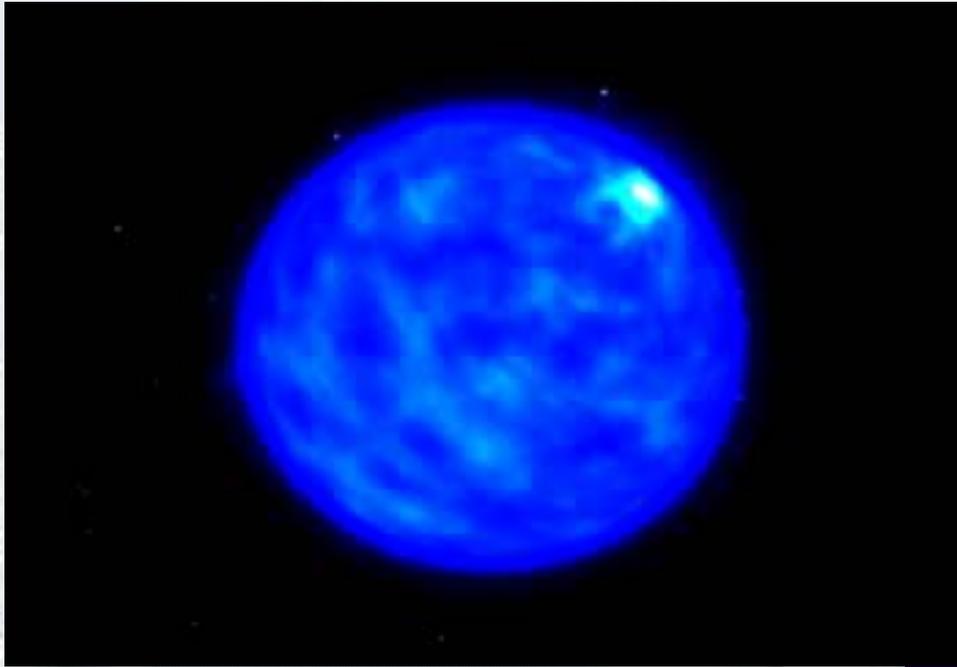


Gamma Ray Burst – time profile





GRB progenitors



Long GRBs \leftarrow Supernova Explosions
duration > 2 s
typically ~ 40 s

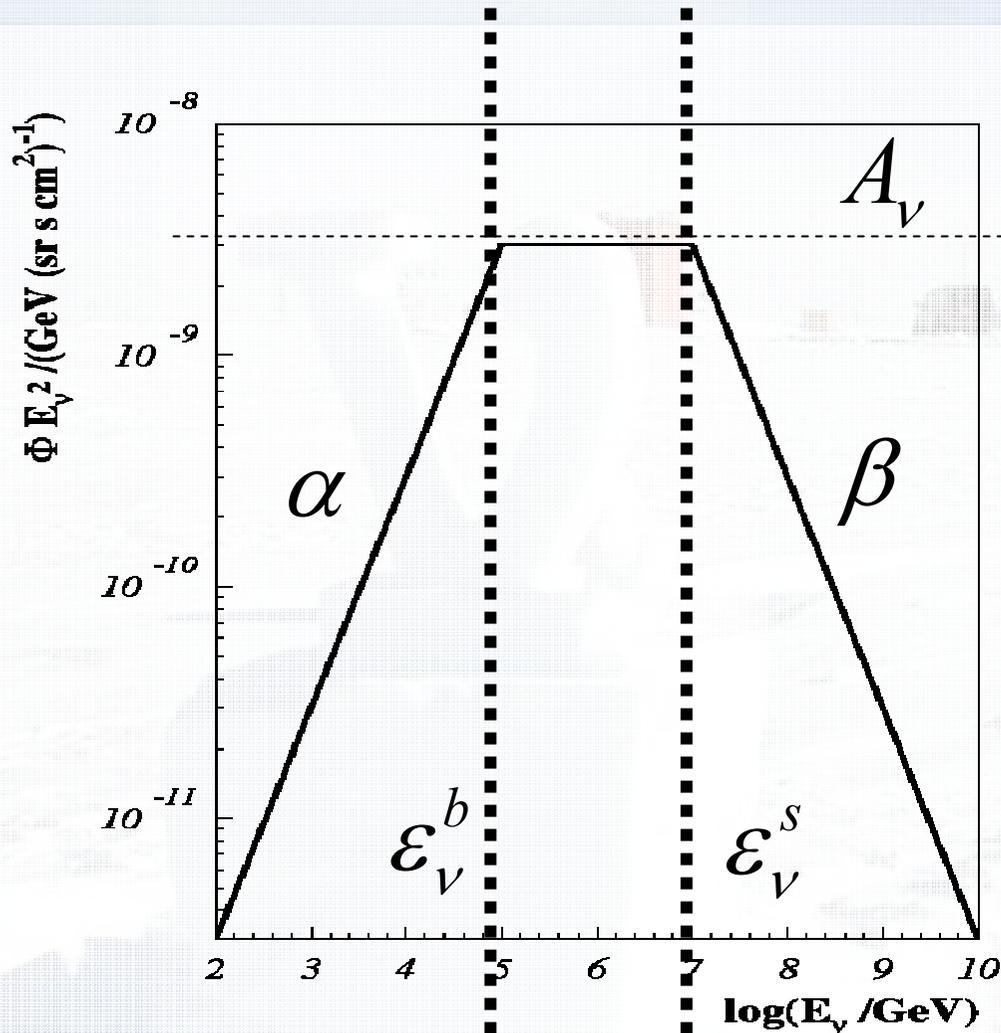


Short GRBs \leftarrow binary mergers
duration < 2 s
 \sim ms - s

Animated movies: Nasa



Prompt GRB ν Spectrum



$$\alpha = \beta_\gamma + 1$$

$$\beta = \alpha_\gamma + 1$$

$$\epsilon_\nu^b = \epsilon_\nu^b(E_0, z)$$

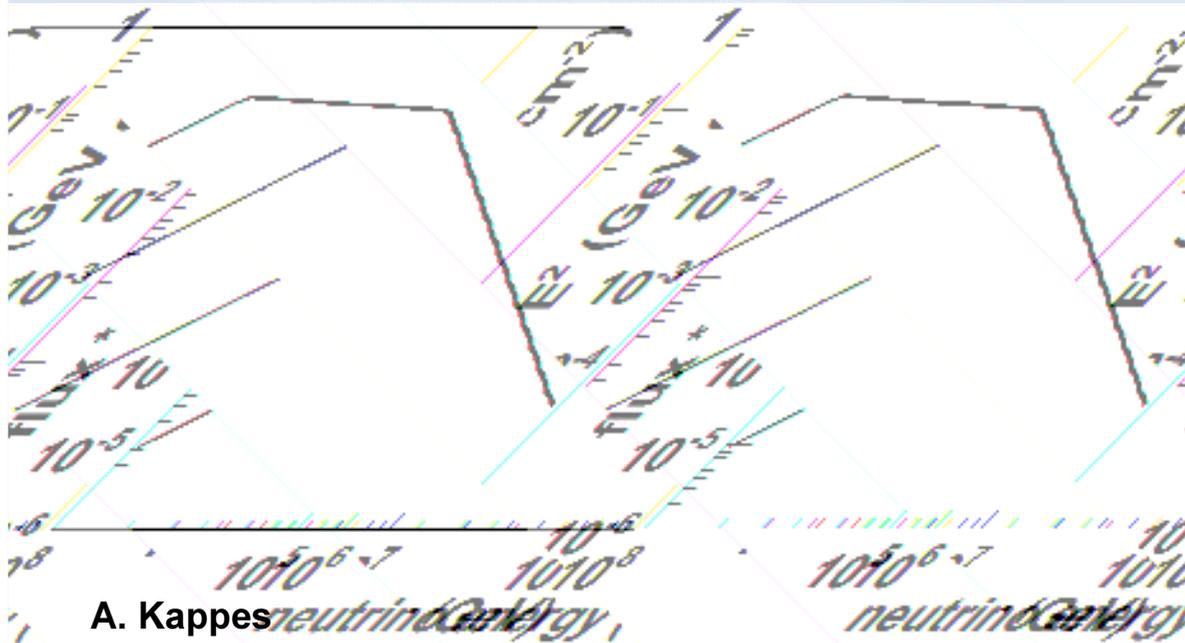
$$\epsilon_\nu^s = \epsilon_\nu^s(F_\gamma, t_{90}, z)$$

$$A_\nu \propto F_\gamma$$

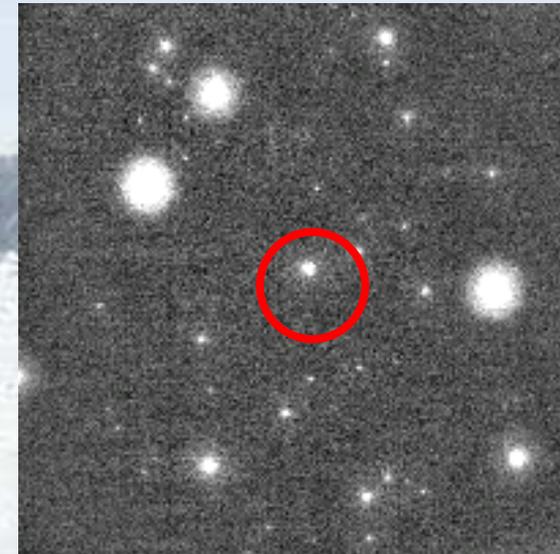
Waxman & Bahcall, PRL 78:2292 (1997)



GRB080319B



A. Kappes



<http://grb.fuw.edu.pl/pi/index.html>

$$\begin{aligned} z &= 0.94 \\ t_{90} &= 60\text{s} \\ \Gamma &= 285 \end{aligned}$$

$$\begin{aligned} F_{\gamma} &= 5.72\text{e-}4 \text{ erg/cm}^2 \\ \alpha_{\gamma} &= 0.82 \\ \beta_{\gamma} &= 3.87 \\ \varepsilon_{\gamma}^b &= 0.651\text{MeV} \end{aligned}$$

IceCube-9: ~0.1 event
IceCube-80: ~1 event

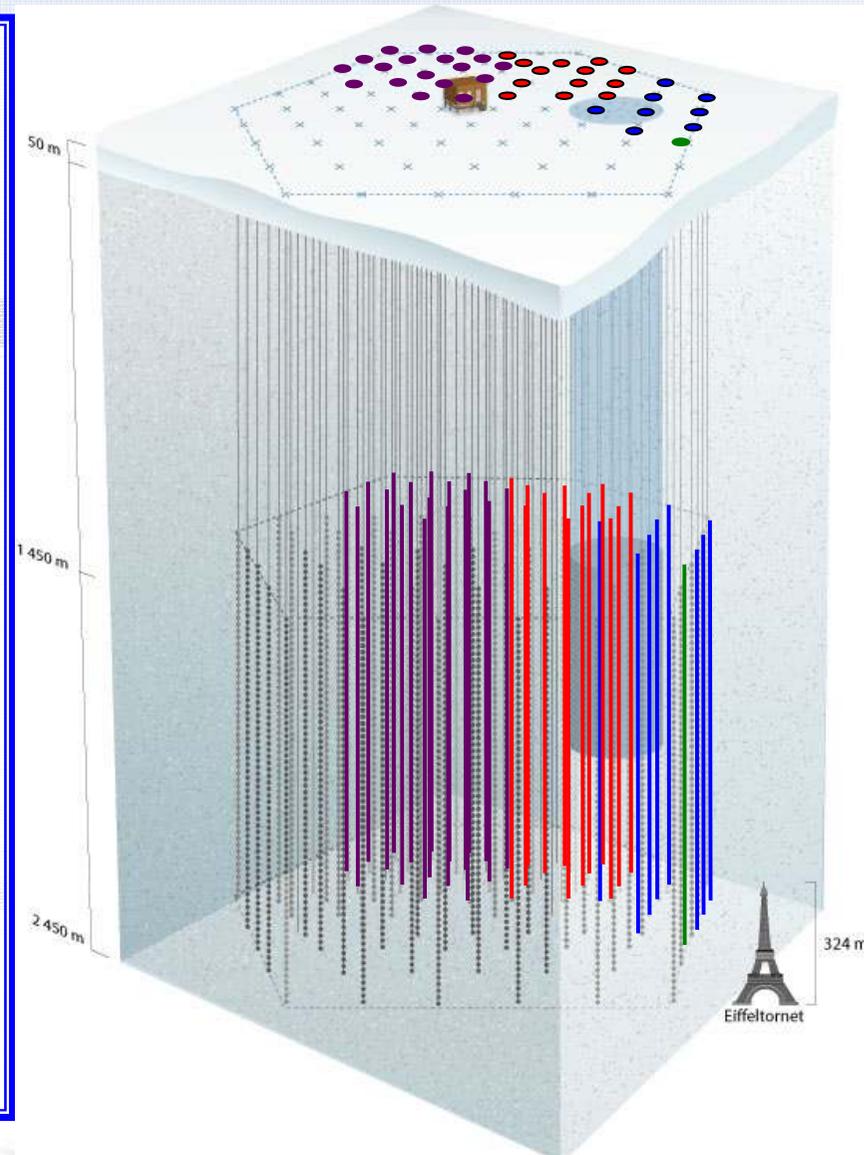


Towards the next generation

- ***IceCube & Km3NeT***
 - **North & South** view

- **Acoustic & radio** technique for the **highest energies**
 - ***ANITA, Aura, ARIANNA, AMADEUS, SaSa, LUNASKA, ...***

- Together with ***Glast, CTA, Hawk, ...; Auger South & north, ...*** → create a **complete view of the non-thermal Universe**





High-energy neutrinos

- Produced in **$p\gamma/pp$** interactions
- Potential sources:
 - **Galactic** (only **up to 10-100 TeV**) – SNR, XRB, μ quasars, pulsars, ...
 - **Extragalactic** (**up to 10^{11} GeV**) – AGN, GRBs, ...
- Experiments
 - **Improvement** of limits by **2.5 orders of magnitude** in the past 7 years
 - First physics conclusions (X-ray emitting AGN, ...)
 - New generation to come (**IceCube, Km3NeT**), explore **optically thin & thick sources**