Astrophysical Sources of 10 GeV Neutrinos

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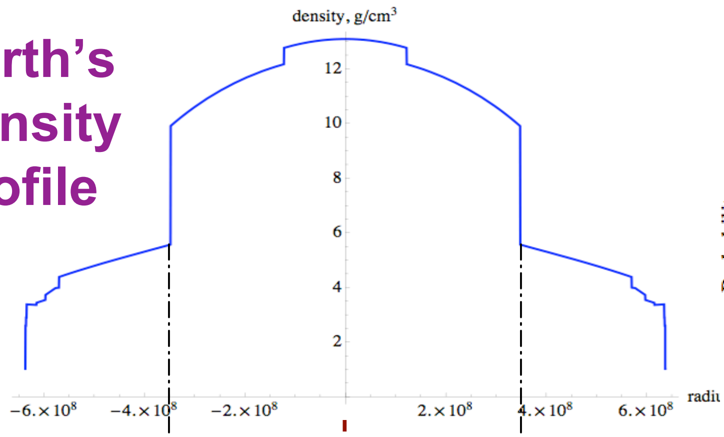
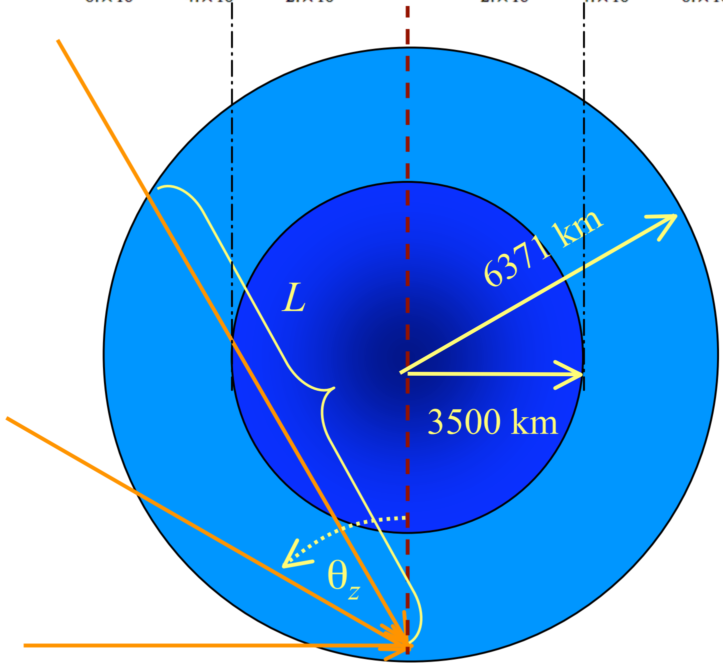
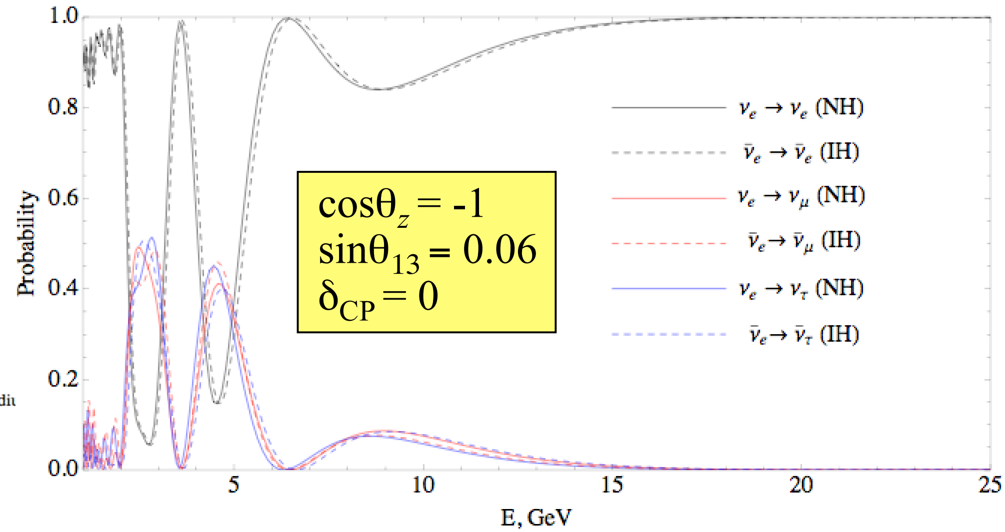
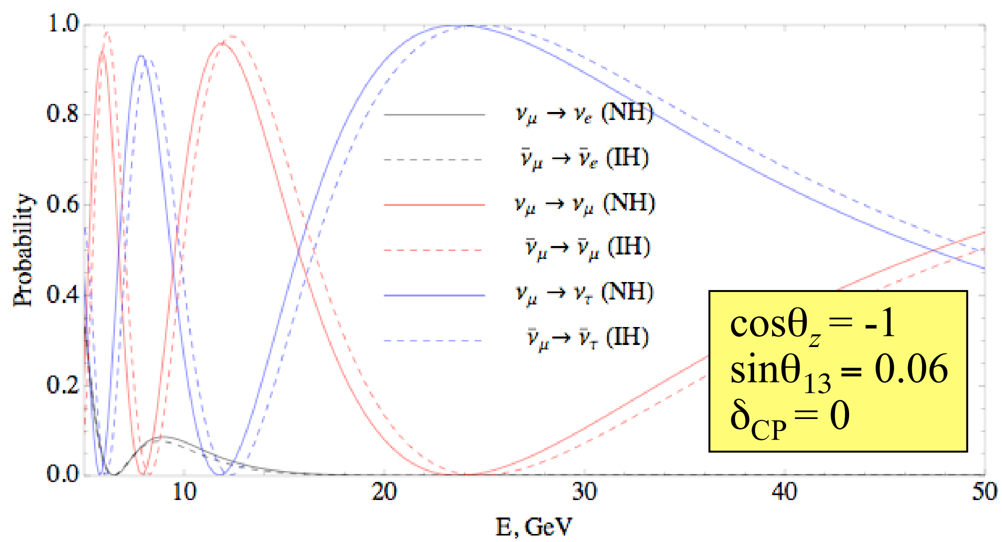
Matter Oscillation Affects 10 GeV Event Rate

Earth's density profile

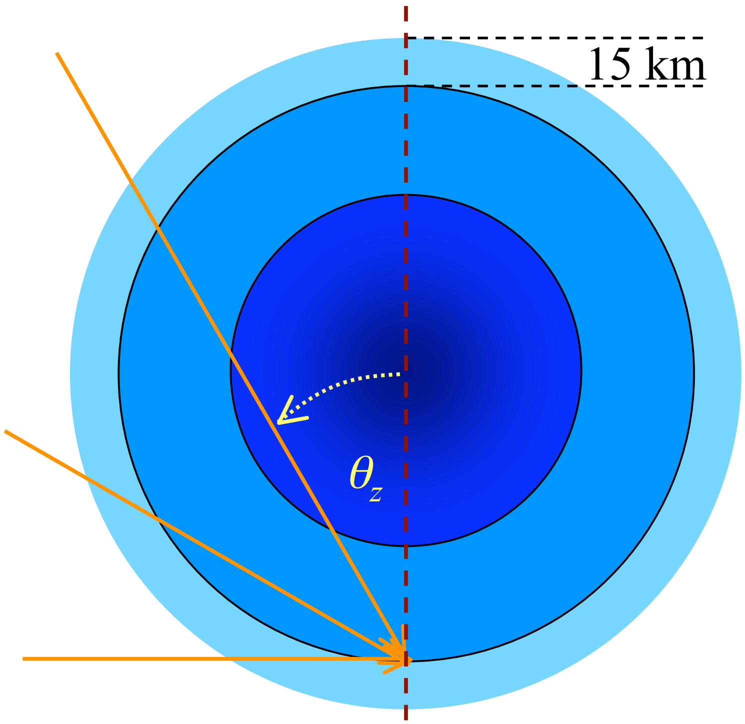


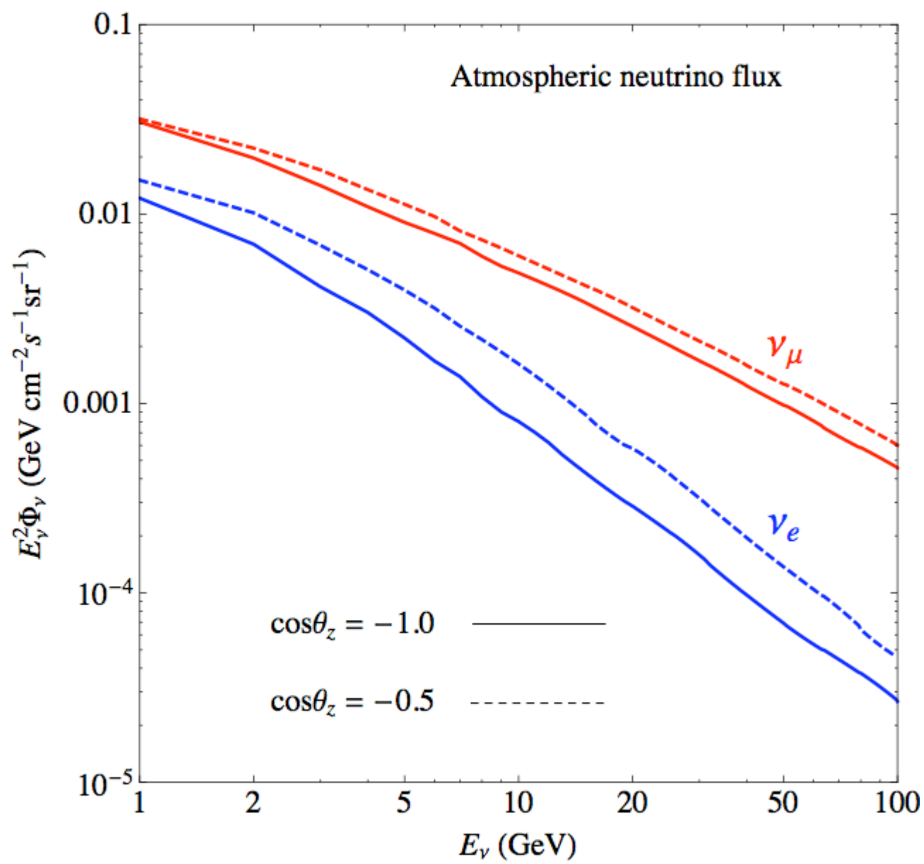






Background: Atmospheric Neutrino Flux





Flux parameterization ~7-100 GeV

$$\Phi[\nu_e(\bar{\nu}_e)] = 0.014(0.012) E_{\nu,\mathrm{GeV}}^{-3.5}\ \mathrm{GeV}^{-1}\mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1}$$

$$\Phi[\nu_\mu(\bar{\nu}_\mu)] = 0.24\, E_{\nu,\mathrm{GeV}}^{-2.95(3.05)}\ \mathrm{GeV}^{-1}\mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1}$$

Numerical results from Honda et al. model

Detection Probability: Signal/Background

Atmospheric neutrino event rate in deep core

no oscillation

Neutrino-nucleon cross-section

$$\sigma(\nu N) = 0.73 \times 10^{-38} E_{\nu,\mathrm{GeV}}\ \mathrm{cm}^2$$

$$\sigma(\bar{\nu} N) = 0.38 \times 10^{-38} E_{\nu,\mathrm{GeV}}\ \mathrm{cm}^2$$

Solid angle

Total nucleons in 10 Mt volume

$$N_\nu(E_\nu) = (0.2\pi)(10^4 10^9 \times 6 \times 10^{23}) E_\nu \Phi_{\mathrm{atm}}(E_\nu)\sigma(E_\nu)$$
$$= 6.6(3.5) \times 10^{-4} E_{\nu,\mathrm{GeV}}^{-0.95(1.05)}\ \mathrm{s}^{-1} \text{ for } \nu_\mu(\bar{\nu}_\mu)$$

- Few thousands a year at ~10 GeV
- Strongly depends on threshold

For ≥1 integrated event rate in ~10-100 GeV requires

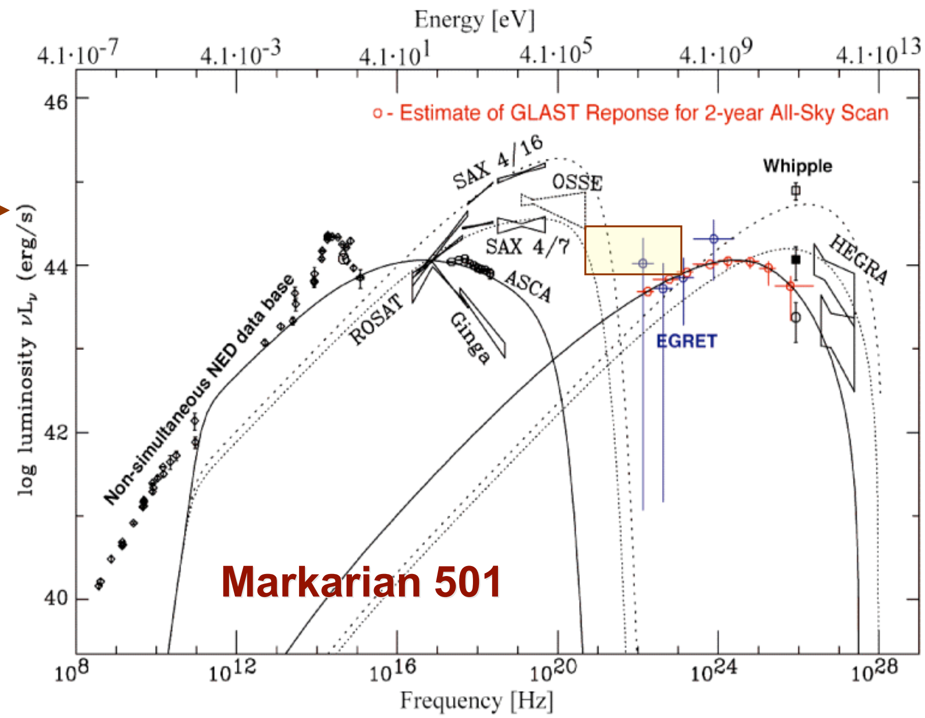
Fluence ≥ 4×10^{-4} erg cm^{-2} !!!

From an astrophysical source in ≤10^4 s for $N_{\mathrm{signal}}/N_{\mathrm{background}}$ ≥1

Optically Thin Sources: $p\gamma$ Processes

Threshold $E_\gamma \geq \dfrac{0.2\Gamma^2}{E_{\nu,10\mathrm{GeV}}/0.05}\mathrm{GeV} \cong 1\Gamma^2\ \mathrm{MeV}$

Active Galactic Nuclei, Blazars →



Known sources of VHE γ-rays

$$\tau_{p\gamma} = \frac{10^{44}\,\mathrm{erg}}{4\pi R_{15}^2 c\ 1\mathrm{MeV}} R_{15}\sigma_{p\gamma} \approx 10^{-5}$$

$$\Phi_\gamma = \frac{10^{44}\,\mathrm{erg\ s^{-1}}}{4\pi d_{170\mathrm{Mpc}}^2} \approx 3\times 10^{-11}\mathrm{erg\ cm^{-2}\ s^{-1}}$$

Too low!!

Gamma Ray Bursts

- Typical GRB fluence in MeV photons ~10^{-5} erg cm^{-2} , typical z~1-2 **Maybe OK**

➔ typical z~1-2, huge *isotropic* energy release in ~10^{52} - 10^{54} erg

- However, $\Gamma > 100$! MeV → ~keV
- Opacity $\tau_{p\gamma}$ can be ~1 with in-situ keV photons, but <<1 at MeV **Too low!**

Optically Thin Sources: *pp* processes

Acceleration of proton → Beam dump $pp \to \pi, K \to$ **neutrinos**

Similar to the atmospheric neutrinos from cosmic-ray interactions

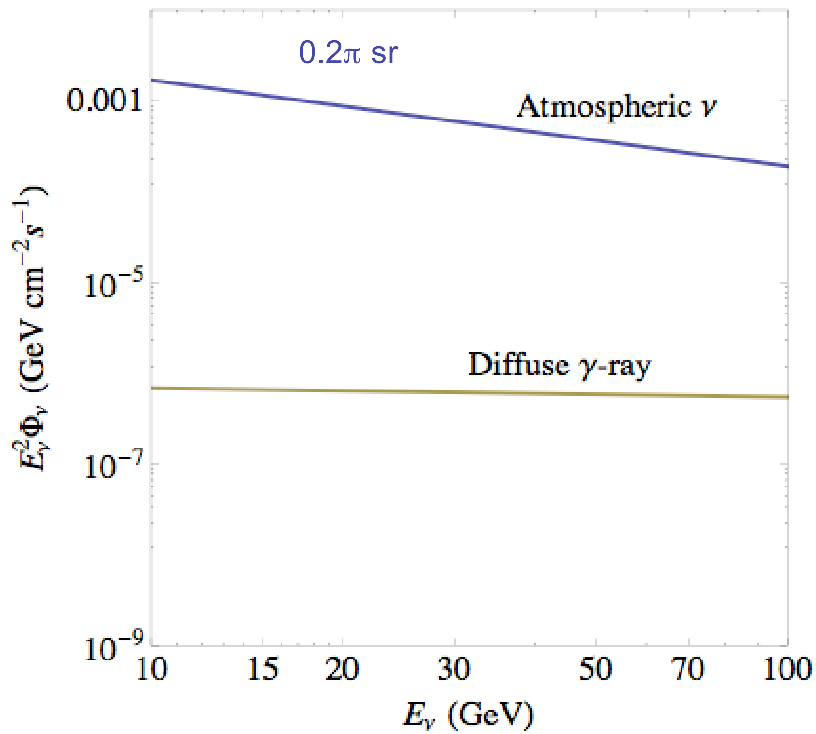
More effective to produce low energy neutrinos in astrophysical sources than $p\gamma$ processes, *if* sufficient target material is available

A Benchmark measurement →

Extragalactic gamma-ray background flux 30 MeV - 120 GeV

Sreekumar et al. [EGRET collaboration] 1997

$$\Phi_\gamma = 7.32 \times 10^{-6} \left(\frac{E_\gamma}{0.451\ \text{GeV}} \right)^{-2.1} \text{GeV}^{-1}\text{cm}^{-2}\text{s}^{-1}\text{sr}^{-1}$$



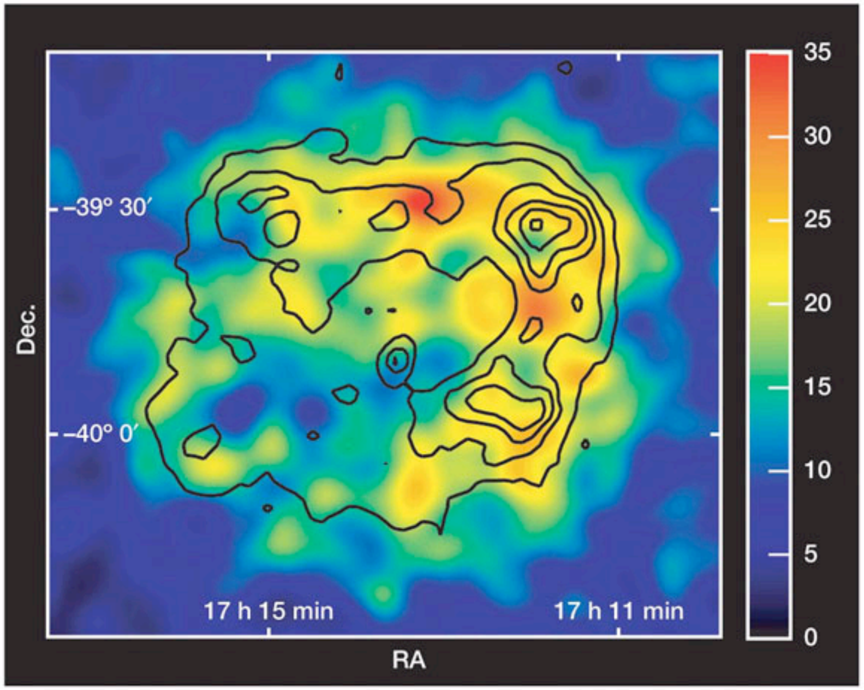
Dominated by π^0 decay γ–rays from pp interactions

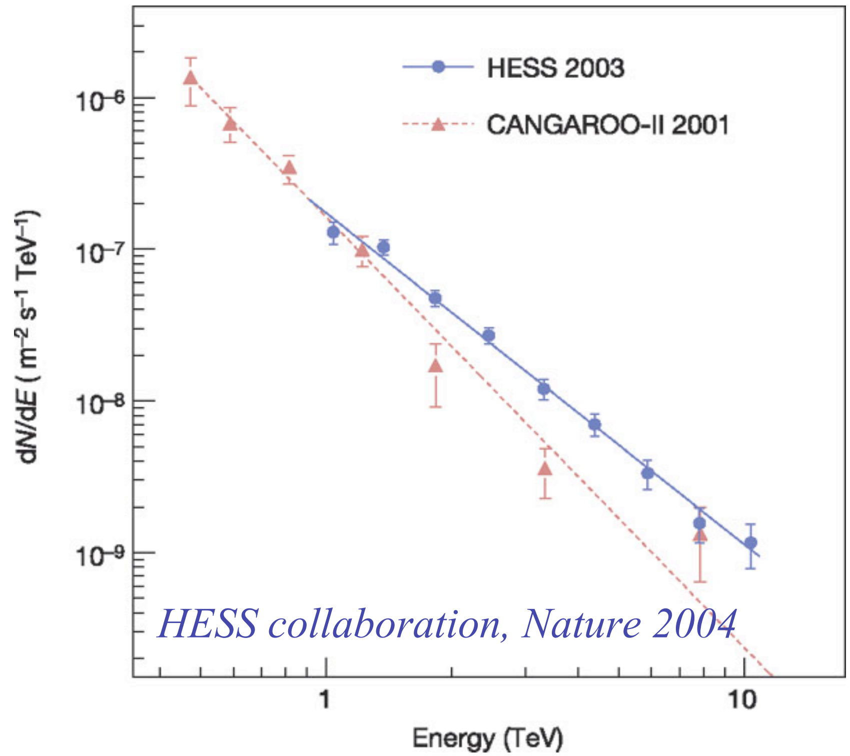
Neutrino flux is comparable to γ–ray flux

Persistent sources of ~10 GeV neutrinos are less likely detectable

Galactic Supernova Remnants

HESS source RXJ 1713.7-3946





Gamma-ray flux 1-10 TeV

$$\Phi_\gamma = 6.77 \times 10^{-8} \left(\frac{E_\gamma}{\text{GeV}} \right)^{-2.2} \text{GeV}^{-1}\text{cm}^{-2}\text{s}^{-1}$$

Probable origin:

Cosmic-ray from SN ➔ *pp* interaction with nearby molecular cloud $\pi^0 \to \gamma\gamma$

Neutrino Event Rate: Supernova Remnants

HESS source RXJ 1713.7-3946

- Calculate neutrino fluxes from observed TeV γ-ray flux assuming pp interaction

  Alvarez-Munhiz & Halzen 2002
  Costantini & Vissani 2005

- Take into account vacuum oscillation to calculate neutrino fluxes on Earth

$$\Phi_{\rm SNR}(\nu_\mu) = 1.55\times 10^{-8}\left(\frac{E_\nu}{\rm GeV}\right)^{-2.2} {\rm GeV}^{-1}{\rm cm}^{-2}{\rm s}^{-1}$$

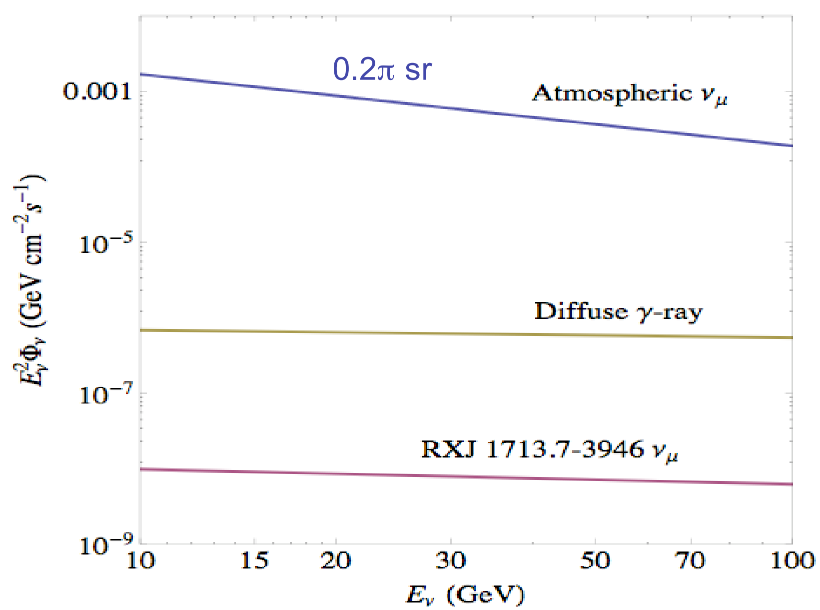
Too low for detection at 10-100 GeV

May be detectable (~50 yr^{-1}) at ≥TeV energy with a faster declining atmospheric background and improved angular resolution

ν to γ-ray flux ratios in *pp* interaction with *p* spectrum $dN/dE \sim E^{\text{-spectr. index}}$

spectr. index	ν_μ/γ	$\overline{\nu}_\mu/\gamma$	ν_e/γ	$\overline{\nu}_e/\gamma$
2.0	0.50	0.50	0.30	0.22
2.1	0.46	0.46	0.29	0.19
2.2	0.43	0.43	0.28	0.18
2.3	0.40	0.41	0.26	0.16
2.4	0.37	0.38	0.25	0.15

Costantini & Vissani 2005 using Thom Gaisser's book or Paolo Lipari's 1993 article



Galactic Soft Gamma Repeaters

- Highly magnetized neutron stars at surface $B \geq 10^{15}$ G
- Total energy stored in magnetic field $\sim \text{Volume} * B^2/(8\pi) \geq 10^{48}$ erg

Giant flares from SGR →

- Transfer magnetic energy to γ–rays by "star quakes"
- Thermal γ-rays or Non-thermal?

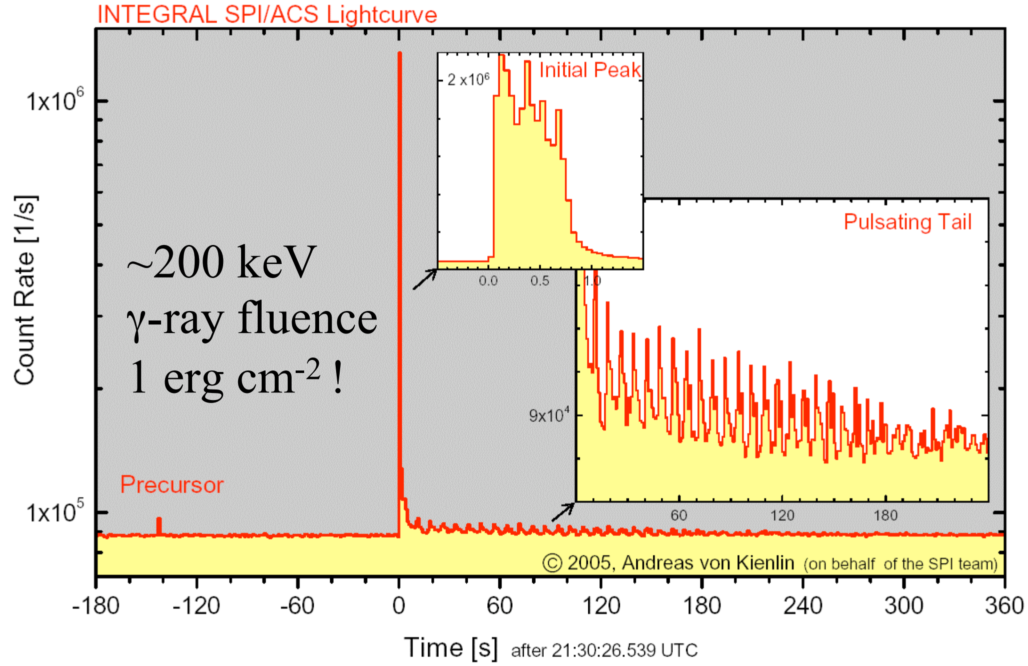
Particle acceleration by shocks

Proton acceleration ➔ neutrinos

TeV flux predicted by

Ioka, Razzaque, Kobayashi & Meszaros 2005
Halzen, Landsman & Montaruli 2005

SGR 1806-20 Outburst on December 27, 2004



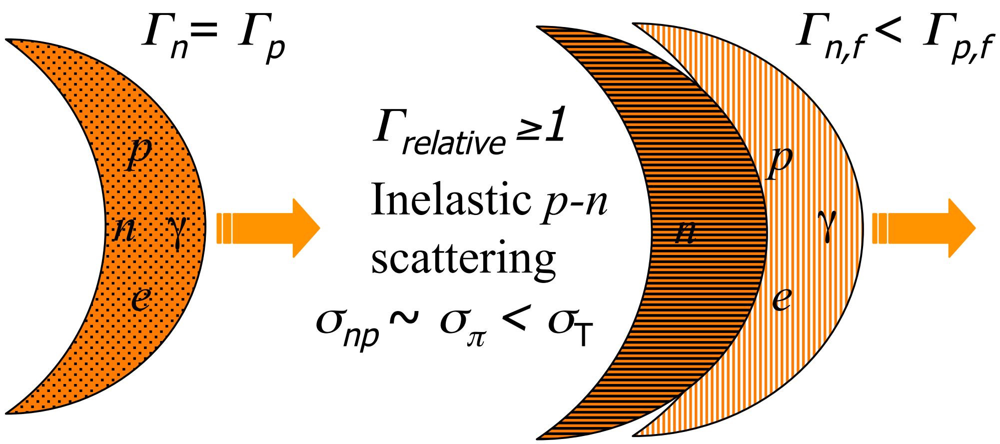
Non detection by IceCube

➔ However, many unknown parameters!

10 GeV neutrino fluence

$$6\times10^{-3}[330+30\ln(E_{\nu,10\,\mathrm{GeV}})]E^{-1}_{\nu,10\,\mathrm{GeV}}\ \mathrm{erg\ cm^{-2}}$$
$$\times\ \xi_{i,-1}L^{2}_{\mathrm{kin},48.5}d^{-2}_{10kpc}\Gamma_1^{-5}\Delta t_{-1}^{-1}$$

Neutron Loaded GRB Jet



Neutron-proton decouple when the jet is optically thick to Thomson ➔ τ_{pn}~1

$$pn \rightarrow \begin{cases} nn\pi^+ & \pi^+ \rightarrow \mu^+\nu_\mu \rightarrow e^+\nu_e\bar{\nu}_\mu\nu_\mu \\ pp\pi^- & \pi^- \rightarrow \mu^-\bar{\nu}_\mu \rightarrow e^-\bar{\nu}_e\nu_\mu\bar{\nu}_\mu \\ pn\pi^0 & \pi^0 \rightarrow \gamma\gamma. \end{cases}$$

~10-50 GeV neutrinos from long and short GRBs *if* neutron-proton decouple

Derishev, Kocharovsky & Kocharovsky 1999; Meszaros & Bahcall 2000; Razzaque & Meszaros 2006

Neutrino fluence

$$\tau_{pn}\frac{L_p t}{4\pi d_L^2}\frac{E_\nu}{m_p c^2\Gamma} = \begin{cases} 7\times 10^{-6}\,\dfrac{\tau_{pn}L_{p,52}t_2}{d_{z=1}^2\Gamma_{2.5}}\,\mathrm{erg\ cm^{-2}} & \text{10 GeV, long GRB} \\ 4\times 10^{-8}\,\dfrac{\tau_{pn}L_{p,49}t_0}{d_{z=0.1}^2\Gamma_{2.8}}\,\mathrm{erg\ cm^{-2}} & \text{50 GeV, short GRB} \end{cases}$$

✔ if z<0.2
e.g. GRB 030329

Jetted Core Collapse SNe: Hypernovae

Core-collapse SNe (type Ib/c, type II) with semi-relativistic jet

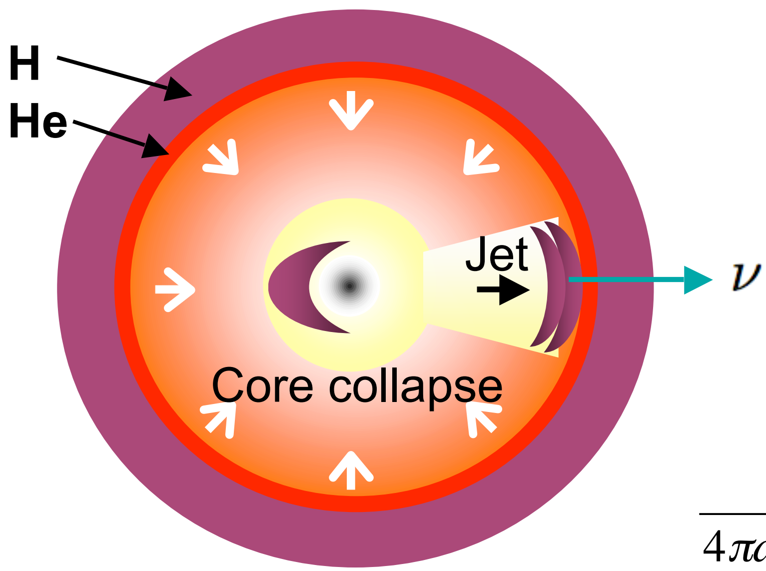
➔ Common origin of Supernovae - Gamma Ray Bursts

Razzaque, Meszaros & Waxman 2004

High expansion velocity (30-40 x 1000 km/s) as in SN 1998bw

Radio afterglow not associated with gamma-ray emission

Asymmetric explosion: polarimetry observations of SN type Ib/c



10 GeV neutrino fluence

$$\frac{\tau_{pp} E_{\text{jet,iso}}}{4\pi d_L^2 \ln(E_{p,\max}/E_{p,\min})} \frac{E_\nu}{E_p} = 7 \times 10^{-4} \frac{\tau_{pp} E_{\text{jet},52}}{d_{20\text{Mpc}}^2} \text{erg cm}^{-2}$$

MODEL

~4000 galaxies known within 20 Mpc with a combined rate of >1 SN/yr

Summary

- ❖ While many astrophysical sources may produce ~10 GeV neutrinos, detection of the sources is difficult
- ❖ Optically thin sources, persistent γ-ray sources are less likely to produce large ~10 GeV neutrino flux
- ❖ Optically thick and transient sources related to SN-GRB are more likely to produce detectable ~10 GeV neutrinos