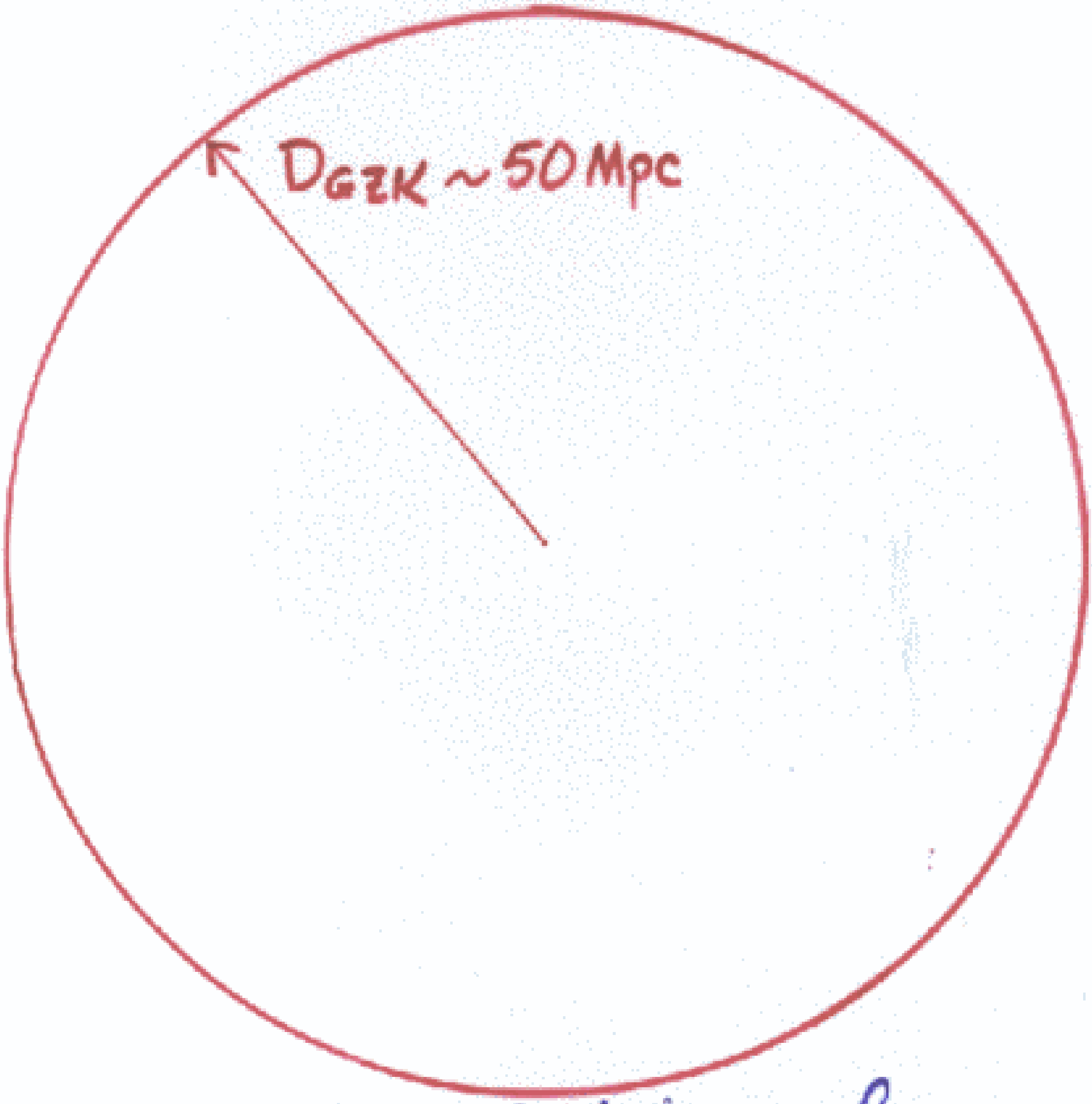
THE HIGH-ENERGY NO-ENERGY CONNECTION:

EECR's & RELIC ν's

TOM WEILER

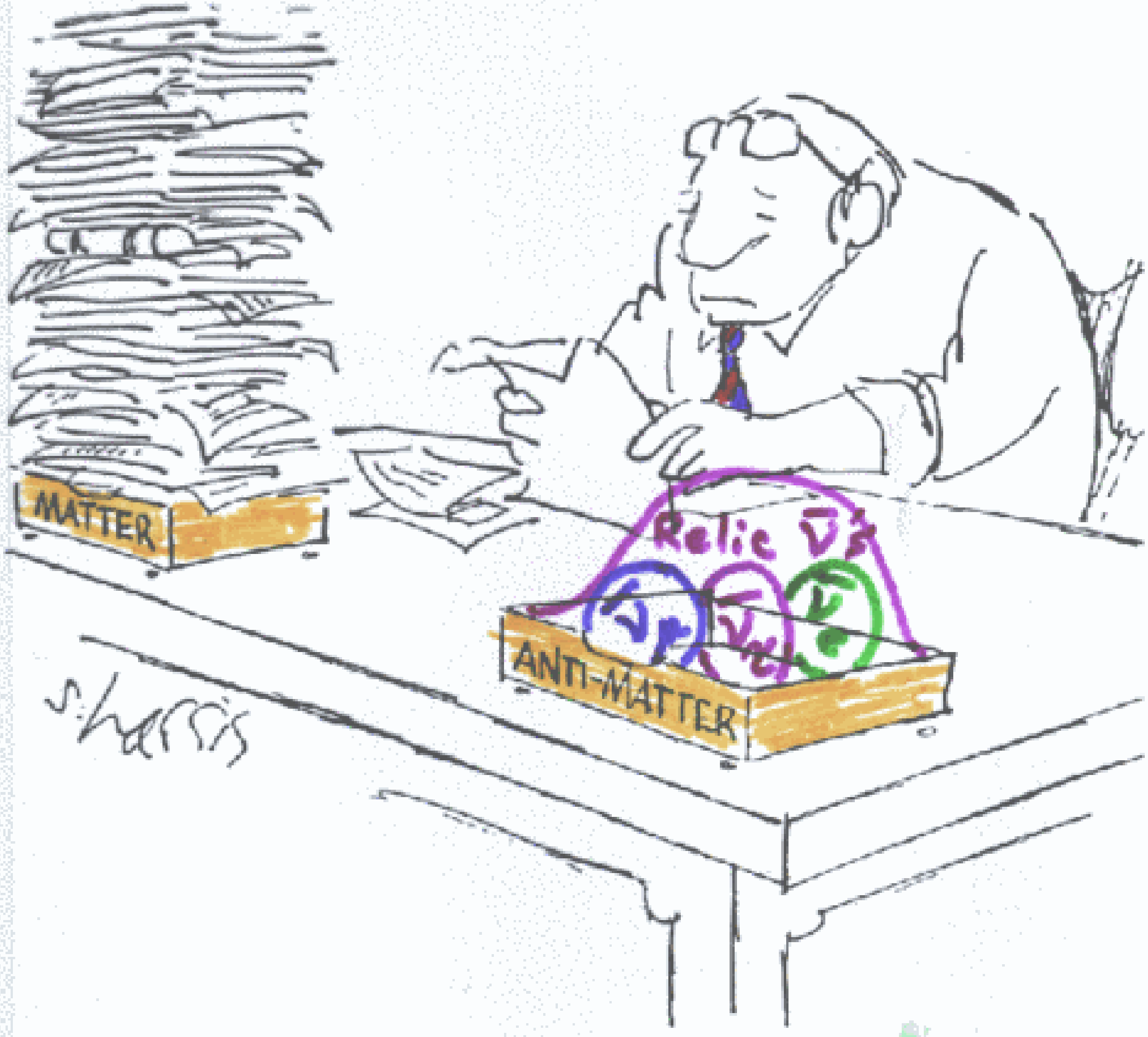


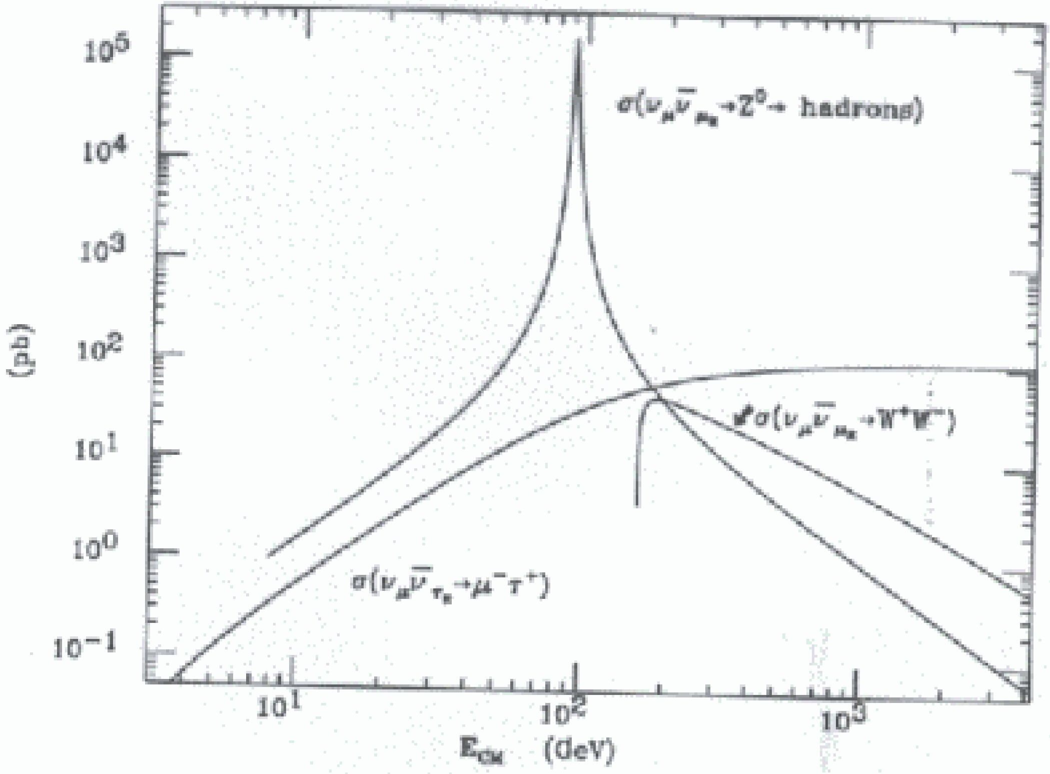
Find ~1% probability for resonant $\nu \rightarrow$ z-burst within D_{GZK}

ApJ '84
Astropart. Phys '99
Fargion, Mele, Salis ApJ '99

in search of the CNB,
Cosmic Neutrino Background

Z-BURSTS


MATTER
ANTI-MATTER
Relic $\bar{\nu}$'s
$\bar{\nu}_\mu$
$\bar{\nu}_\tau$
$\bar{\nu}_e$
s.harris



$$s \overset{cms}{=} M_Z^2 \overset{Lab}{=} 2 m_\nu E_\nu$$

$$\Rightarrow E_{Res} = \frac{M_Z^2}{2 m_\nu} = \frac{4\,\mathrm{ZeV}}{(m_\nu/\mathrm{eV})}$$

$$E_{Z\text{-burst}} = \frac{M_Z^2}{2m_\nu} = \frac{4\cdot10^{21}\,\text{eV}}{m_{\text{eV}}}$$

$$\text{With}\quad m_\nu > \sqrt{\delta m^2} = \begin{cases} 0.5 \text{ to } 1.5 & \text{LSND} \\ 0.1 \text{ to } 0.03 & \text{Atm} \\ 3\cdot10^{-3} \text{ to } 10^{-5} & \text{Sun} \end{cases}$$

$$\text{get}\quad E_{Z\text{-burst}} \lesssim \begin{cases} 10^{22}\,\text{eV} & \text{LSND} \\ 10^{23}\,\text{eV} & \text{Atm} \end{cases}$$

$$\text{and}\quad E_{\gamma/p/n} \lesssim \begin{cases} 3\cdot10^{20}\,\text{eV} & \text{LSND} \\ 3\cdot10^{21}\,\text{eV} & \text{Atm} \end{cases}$$

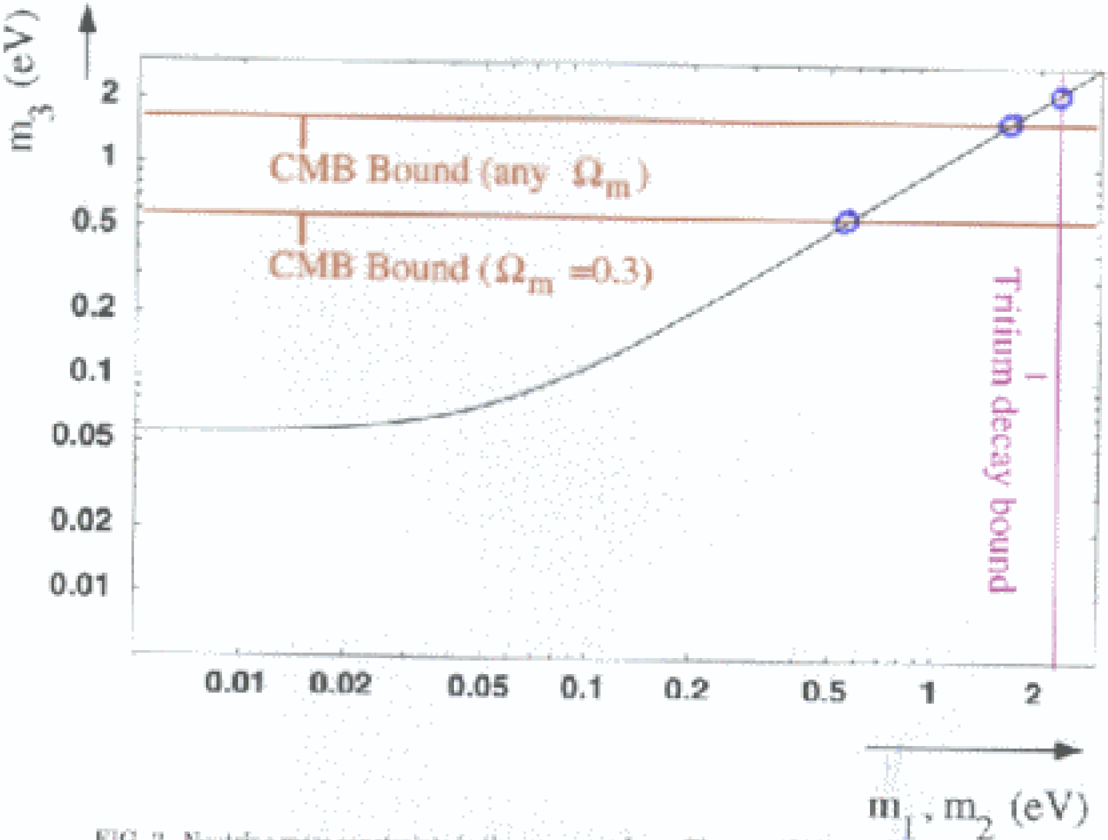
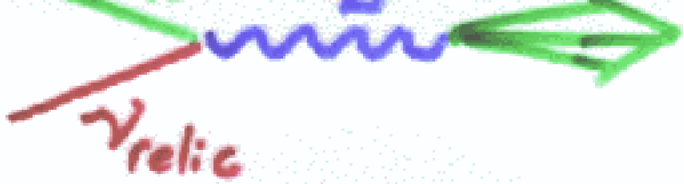


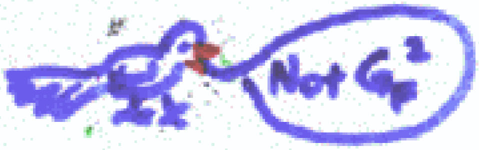
FIG. 2. Neutrino mass constraints in the $m_{1,2}$–m_3 plane. The curved line corresponds to allowed values according to the solar and atmospheric neutrino data. Direct mass measurements from CMB and tritium beta decay exclude the regions beyond their respective straight lines.

but



is **RESONANT**

$$\langle\sigma\rangle \equiv \int \frac{ds}{M_Z^2}\,\sigma(s) = 2\sqrt{2}\,\pi\, G_F$$



$$\lambda_{\nu\nu} = 30\left(\frac{50\,\mathrm{cm}^{-3}}{n_\nu}\right) D_H$$

$$\therefore P(\nu_{CR}\nu_{relic}\text{-annihilate})\,dx$$

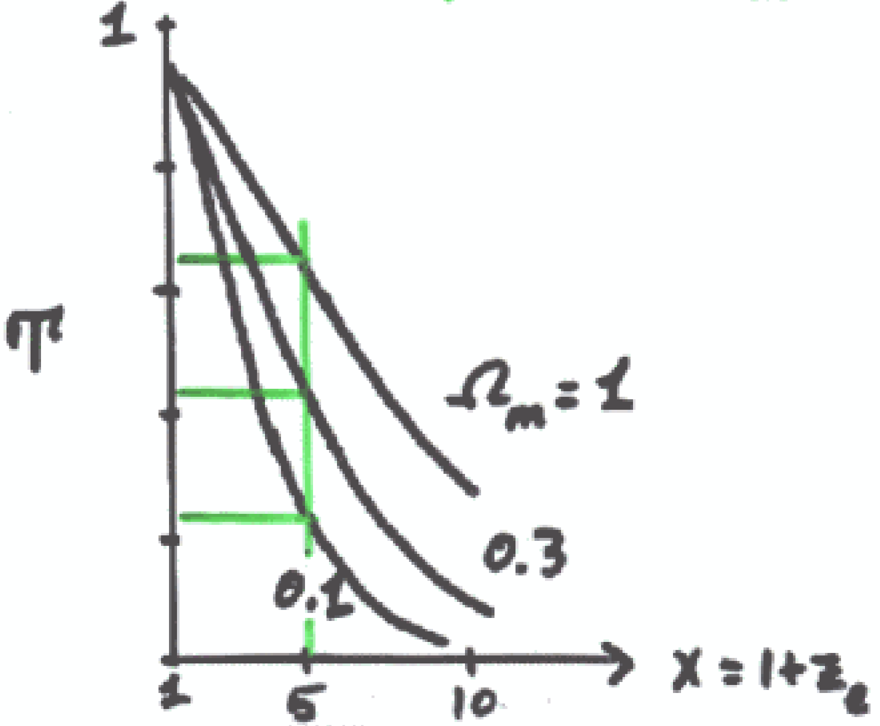
$$= \frac{dx}{\lambda} = 3\%\left(\frac{n_\nu}{50\,\mathrm{cm}^{-3}}\right)\frac{dx}{D_H}$$

$$T = e^{-\tau},$$

$$\tau\left(x = \frac{E_R}{E_\nu}, h, n_\nu, \Omega_m, \Omega_\Lambda, \dots\right)$$

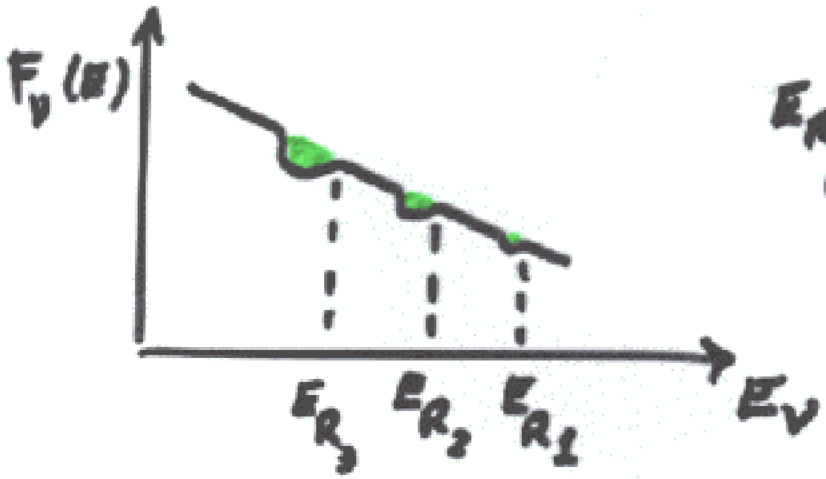
$$= \frac{0.03\left(\frac{n_\nu}{54\,cm^{-3}}\right)\, x^3}{h_{65}\sqrt{1+\Omega_m(x^3-1)}}$$

[low density Uni, $\Omega_m \sim 0.3$, helps]



L. Song
T.W.

Absorption Spectroscopy



$$E_{R_j} = \frac{4\,\text{ZeV}}{(m_j/\text{eV})}$$

* dips power diffuse ~GeV γ's
(EGRET)

Want z_ν small to maximize absorption.

$$\mathrm{Rate}_\nu(E) =$$

$$F_\nu(E) \cdot \sigma_\nu(E) \cdot \frac{M}{m_N}$$

$\simeq 1$ ton

$\simeq 0.6 \times 10^{30}\, m_N$

$F_{obs}(10^{20}\,\mathrm{eV})$

$= 2 \times 10^{-30} /\mathrm{cm}^2/\mathrm{s}/\mathrm{sR}$

$0.6 \times 10^{-30}\, E_{22}^{0.4}\, \mathrm{cm}^2$ [McKay Ralston]

$$= 6 \times 10^{-2} /\mathrm{yr}/\mathrm{sr}/\mathrm{teraton}$$

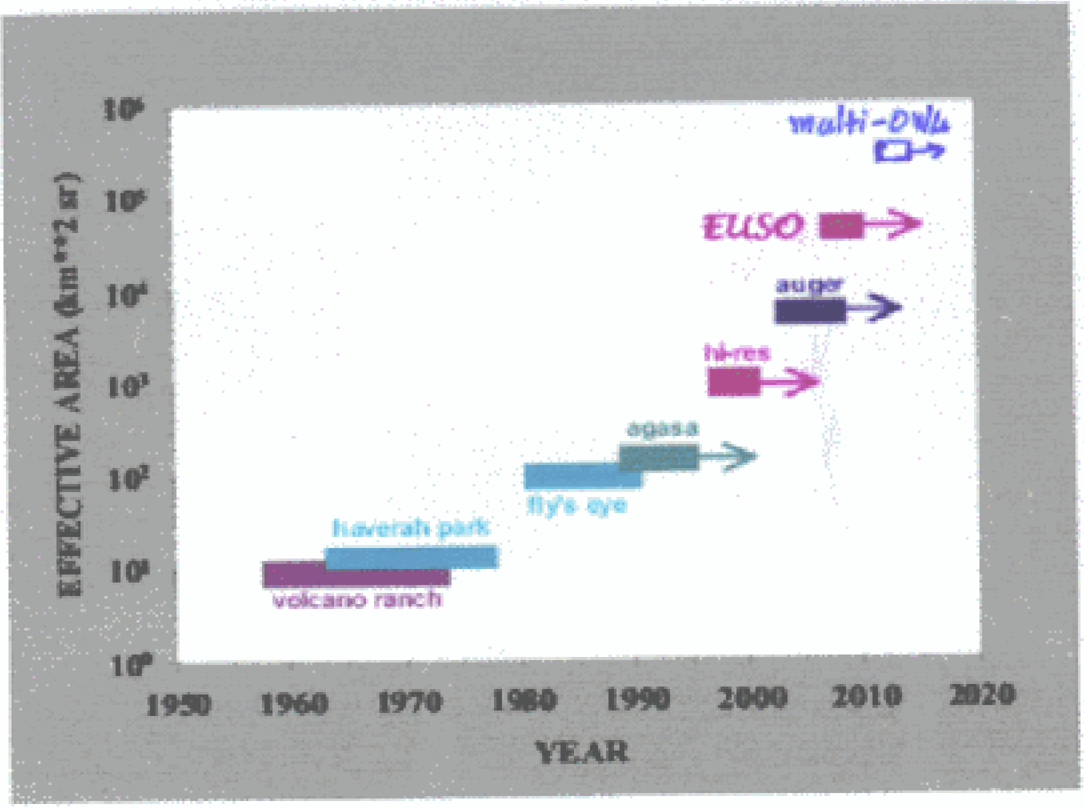
If Volume $\gtrsim$ teraton (OWL/EUSO)

and $F_\nu(10^{22}) > F_{obs}(10^{20})$, perhaps

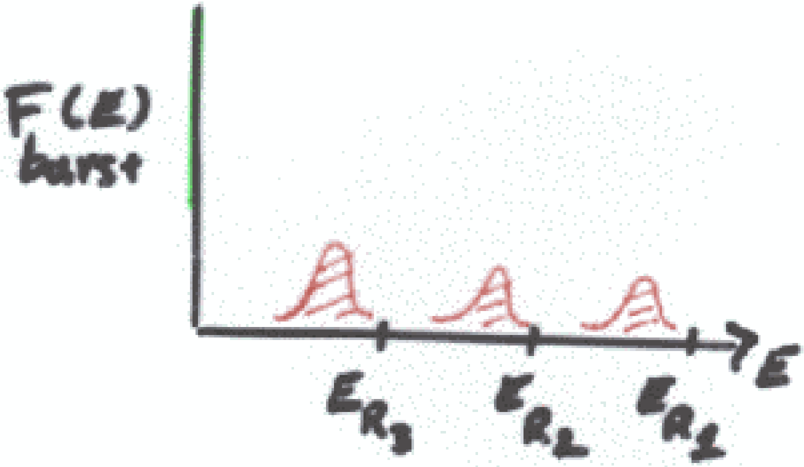
can do absorption spectroscopy.

[Fig.]

• **Figure 4.5.** A comparison of the EUSO effective area with ground based facilities.



Emission Spectroscopy



$$P(\gamma\text{-burst}) = e^{-D_H/\lambda} \qquad \frac{D_{GZK}}{\lambda}$$

maximized at $\lambda = D_H$ [Gelmini & Kusenko]
(neglecting expansion)

Lepton Asymmetry

[Kusenko

$$\Delta\nu \equiv \frac{n_\nu - n_{\bar\nu}}{n_\gamma} = 0.025(\pi^2\xi + \xi^3), \; \xi \equiv \frac{\mu}{T} .$$

$\Sigma_\nu \equiv \frac{n_\nu + n_{\bar\nu}}{n_\gamma}$ increases monotonically with ξ.

$\Sigma_\nu(\xi=6) \simeq 30\,\Sigma_\nu(0)$

$\Rightarrow \lambda \simeq D_H$

$\Rightarrow P(Z_{burst} \lesssim 60\,\mathrm{Mpc}) \simeq 0.2\, h_{65}\,\%$

$$\left[\Omega_\nu \leq 0.15 \Rightarrow \xi^3 \frac{m_\nu}{eV} < 65 \xrightarrow{\xi=5} m_\nu < 0.4\right]$$

Might "local" Z-bursts explain the events above 10^{20} eV ?

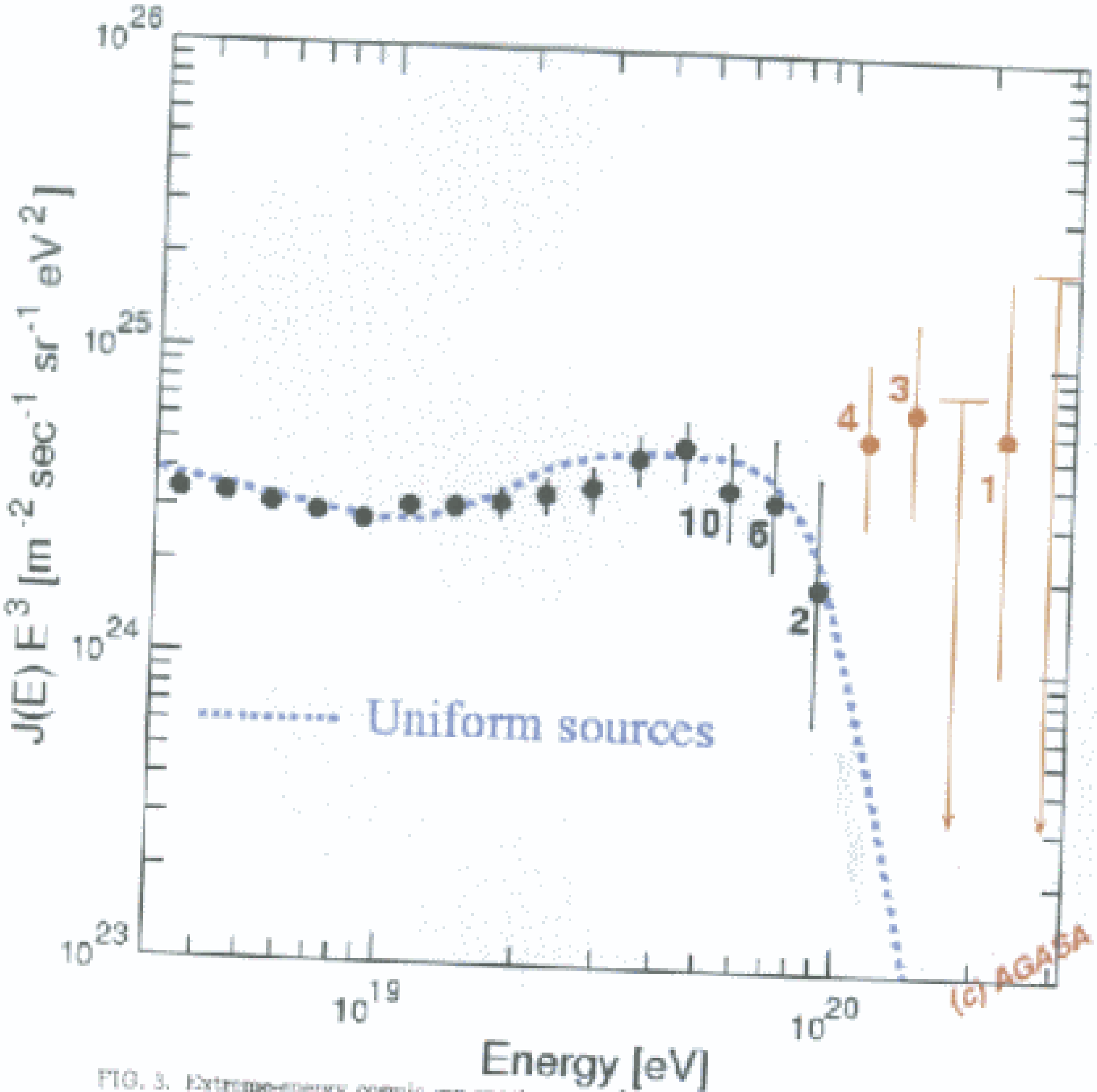


FIG. 3. Extreme-energy cosmic ray spectrum as observed by AGASA. Error bars correspond to 68 % C.L. and the numbers count the events per energy bin. The dashed line revealing the G2K cutoff is the spectrum expected from uniformly distributed astrophysical sources.

AGASA sees

~~13~~ 5 → Nov 2000, UCLA/RADHEP

pairs and 1 triplet

within $\theta_{\text{resolution}} \sim 2.5^{\circ}$

P(chance) < ~~1%~~ 4 σ

Highly Significant:

- ☆ Cosmic $\vec{B}$ bends charged-particles
- ☆ Bend is E-dependent

No Bending ⇒
[$\vec{B}$ caustics?]
- close source [unlikely] halo SMPIA?
- no $\vec{B}$ [untenable]
- $Q = 0$

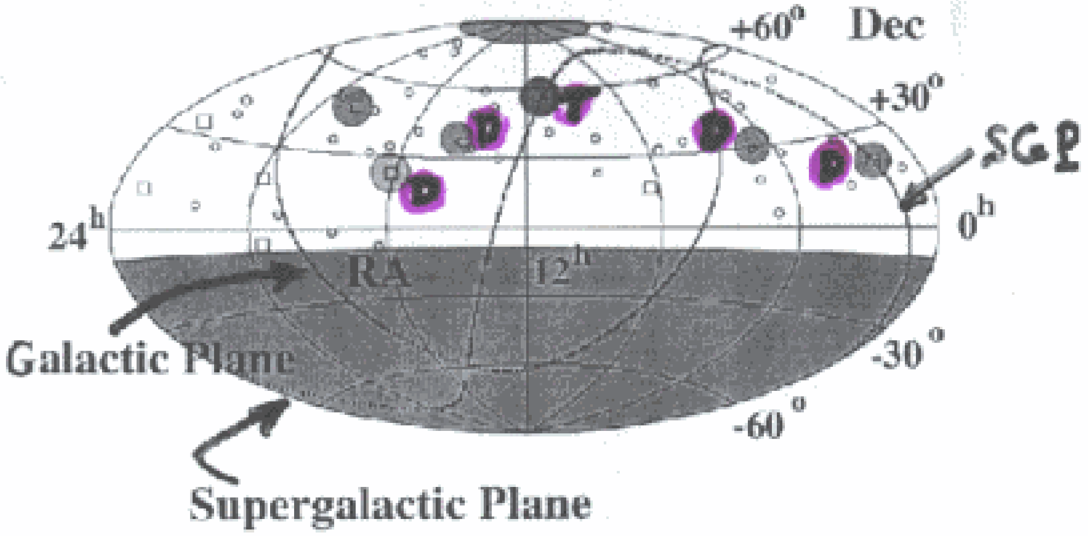
No GZK Cutoff ⇒
- close source
- $Q=0$, mag. moment ~ 0

? ν's ARE PROPAGATING PARTICLE ?!

Uchihori et al.

58 Highest energy ($> 4 \cdot 10^{19}$ eV) events.

AGASA + A20



∘ $4 \cdot 10^{19} \le E < 10^{20}$ eV ○ 2.5° clusters

□ $10^{20} \le E$

PRIMARY

 ’s?

RU 98 22

Correlation between Compact Radio Quasars and Ultra-High Energy Cosmic Rays

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(June 17, 1998)

astro-ph/9806242 17 Jun 1998

PRL

Abstract

Some proposals to account for the highest energy cosmic rays predict that they should point to their sources. [~~We study the five highest energy events ($E > 10^{20}$ eV) and find they are all aligned with compact, radio-loud quasars. The probability that these events are coincidental is 0.005, given the accuracy of the position measurements and the density of such sources. The source quasars have redshifts between 0.3 and 2.2.~~] If the correlation pointed out here is confirmed by further data, the primary must be a new hadron or one produced by a novel mechanism. (large F_ν).

\pacs{}

? Anchordoqui .... Sigl

? ... McKay ... Ralston

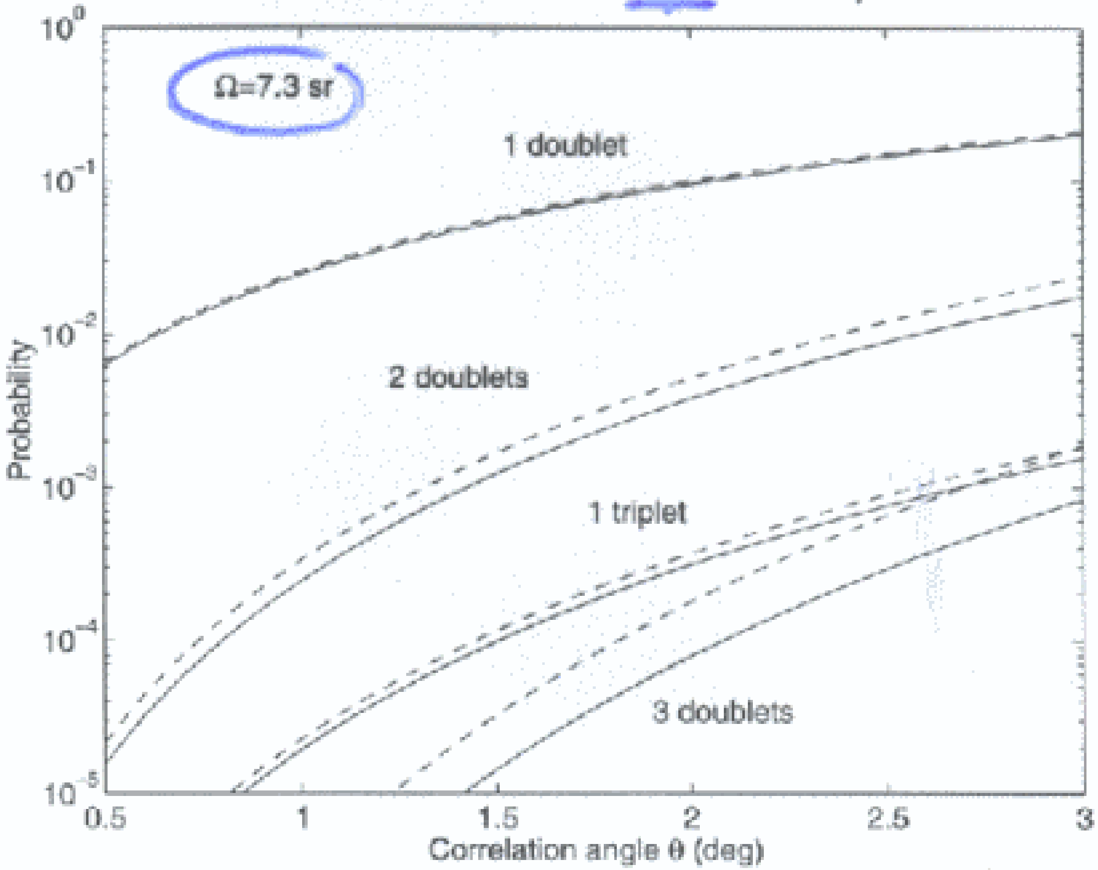
and 2001,

Tinyakov ; Tkachev

Typeset using REVTEX

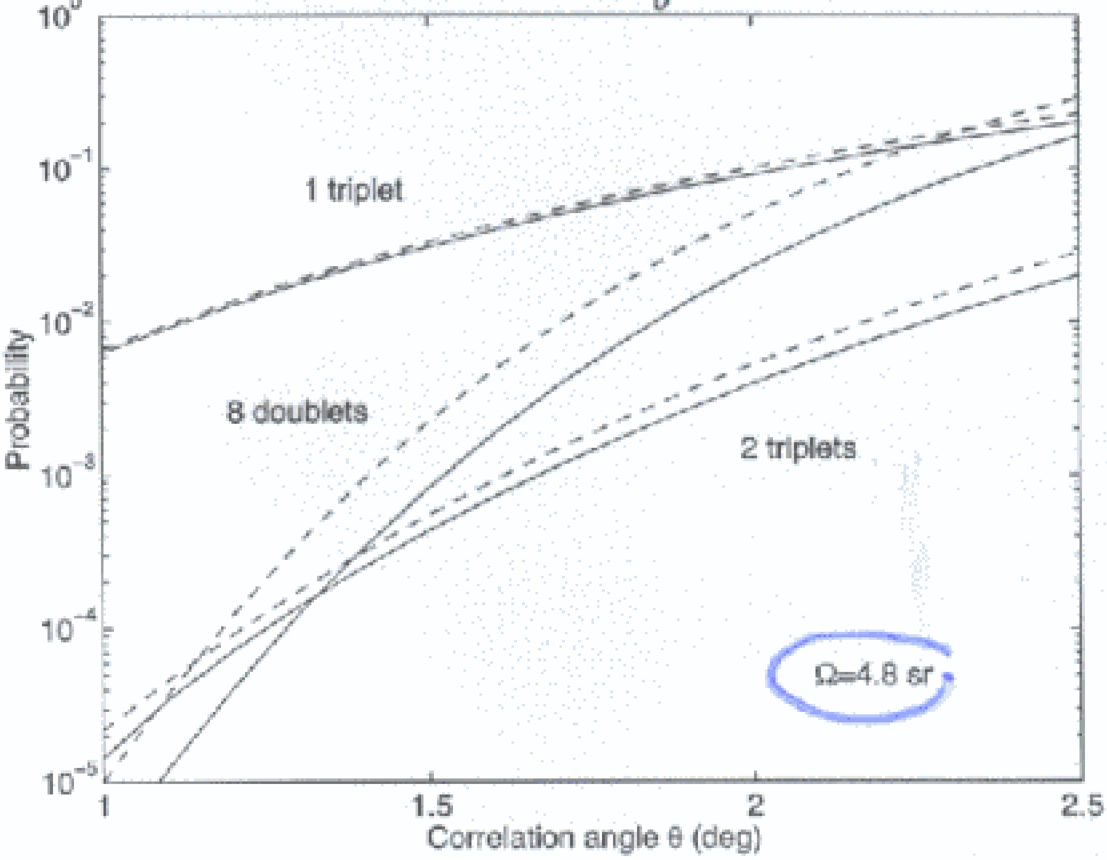
(2000)

20 event HiRes sample



Goldberg, IW
(2000)

100 event Auger sample



Compare Dynamical Clustering to Chance

→ Waxman, Fisher, Piran
→ Dubovsky, Tinyakov, Tkachev
→ Blasi & Sheth
→ Fodor & Katz
→ Medina-Tanco
→ Stanev, Biermann, ... , Watson
→ Bahcall & Waxman
→ Kalashev, Kuzmin, Semikoz
→ Blanton, Blasi, Olinto
→ Tinyakov, Tkachev

Conjectured Origins

- Nearby "Accelerators"
  - Galactic Supershocks
  - Magnetars (Fe isotropized by big B)
  - M87 or (now quiescent) AGNs by " "
  - Nearby GRBs
  - Late DKing SuperMassive Particles
    - GUT masses
    - 10^{12-14} GeV "Wimpzillas"
    - Q-balls
    - Topological Defects (eg. Vortons)
    - Monopolonium
  - Cen A [excellent for Auger]

- Relativistic Dust

Origins (continued)

Exotic Primaries

- Glueballino $(\tilde{g}g)$,
  S^0 baryon $(\tilde{g}\,uds)$ } light gluino

- Monopoles w/ $M \lesssim 10^{20}\,\mathrm{eV}$

  $[E_K \sim g_0 B \xi \sqrt{n} \sim 10^{22\pm2}\,\mathrm{eV}]$

Exotic Physics

- Broken Lorentz Invariance
- $\frac{1}{M_P}$ operators $\left[\frac{E_{CR}}{M_P} \sim 10^{-8}\,(E/10^{20}\,\mathrm{eV})\right]$

- Metric foam/Q. Gravity

Origins (continued)

⊙ Neutrino Primaries

- $\nu_{CR} + \nu_{C\nu B} \rightarrow Z$ burst ($\gamma_Z = 10^{10} E_\nu / 10^{21}\,\mathrm{eV}$)
- Strong $\sigma_{\nu N}$ ($E \gtrsim 10^{20}\,\mathrm{eV}$)

EECR Models/Signatures

Reviewed in

hep-ph/0103023 [T.W.]

Discriminators

- Anisotropies
  - large scales: SGC
    Local Group
    Gal. Cluster
    Halo
    Galaxy
  - Small scales: pairing, tripping, ...

$\delta\theta \sim 0.5^\circ \sqrt{D_{Mpc} \lambda_{Mpc}}\; B_{nG}/E_{20}$

- Energy - time [correlations] in θ

e.g. 1.06 ~~Z~~ 10^{20} eV event 3 yrs after
0.44 ~~Z~~ eV event

$\Rightarrow [\Delta t]_{source} \sim \frac{\text{several yrs}}{(1+z)}$;

disfavors burst/decay models.
[GRB] [TD, SMP]

From $\Delta \equiv t(p) - t(\gamma) \sim \left(\frac{D}{Mpc}\right)\left(\frac{Z B_{nG}\, \lambda_{Mpc}}{E_{20}}\right)^2$ [300 yrs],

& $t(E_1) - t(E_2) \sim 2 \frac{\delta E}{E} \Delta \sim \mathcal{O}(\Delta)$

Fly's Eye Event, $E = 3 \times 10^{20}$ eV

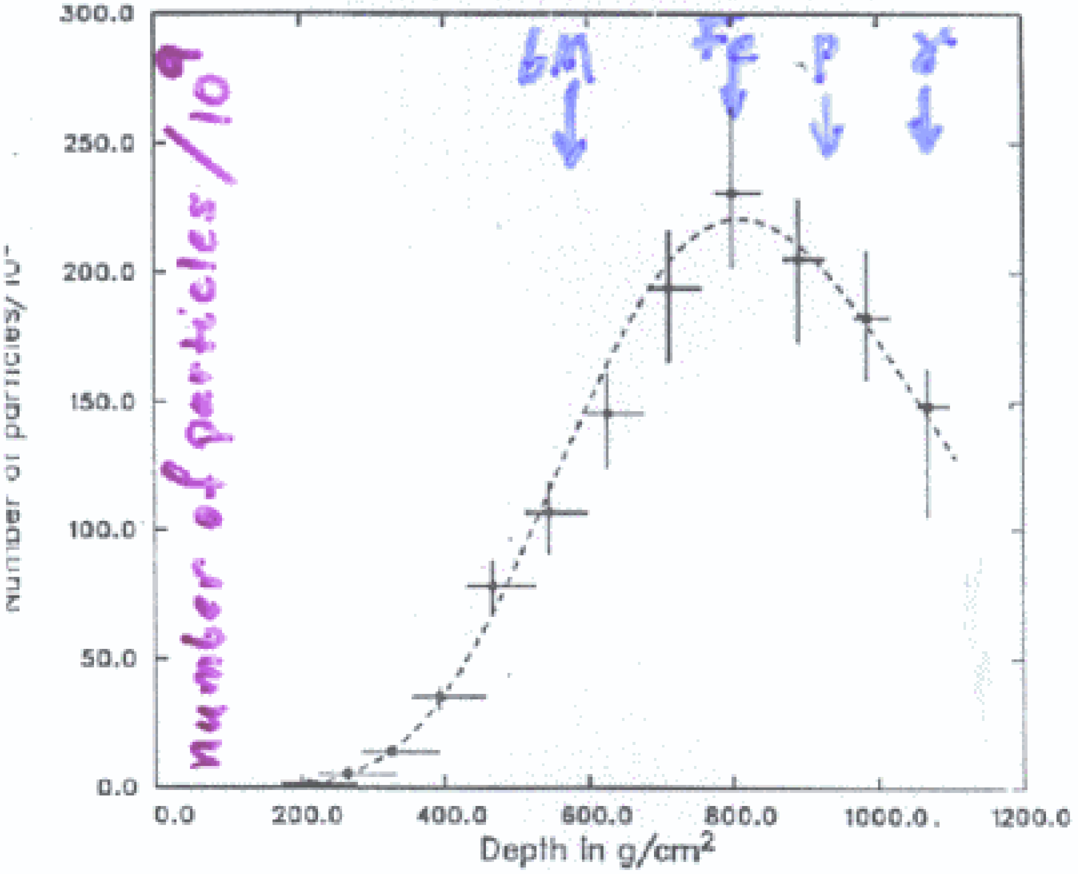


FIG. 3.—The three-parameter best-fit shower profile is shown along with oints obtained from the data in 5° intervals. The size at maximum is greater an 200 billion particles.

- **Primary Composition**

  p vs. γ vs. Fe vs. NEW

  - Fly's Eye profile at $3\cdot10^{20}$ eV disfavors γ [x_{max} diagnostic]
  - e.g. particle jet models have $\frac{\gamma}{N} \sim 10$ at origin

    $$\star \Longrightarrow \frac{\pi^0}{N} \sim \frac{5}{1}$$

	$\lambda(10^{20}$ eV$)$
γ	10 Mpc
N	40 Mpc

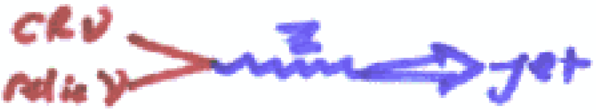
- disfavors nearby particle jets

- and EGRET diffuse (Xgal) γ's at $10^{0\pm2}$ GeV in EM cascades also disfavors local jets.

new: $N_\mu(r)$ for p vs. γ vs. Fe ...
- Watson, Zas, Ave, Hinton, Vazquez

- **North vs. South** Hemispheres
  - Galactic & local $\vec{B}$ different
    - eg M87 model, Cen A model
  - line of sight sources different
  - Galactic Center in South Hemi.

- **E_{max} cutoff**
  - e.g. TD/SMP $\quad E_{max} \sim \frac{M}{2}$
  - e.g. Z-bursts



$$E_{max} \sim \frac{M_Z^2}{2m_\nu} \sim \frac{4\cdot 10^{22}\,\mathrm{eV}}{(m_\nu/0.1\,\mathrm{eV})}$$

  - e.g. Zevatron

$$E_{max} \sim eZB\zeta \sim 10^{21}\,\mathrm{eV}$$

- $F(E<GZK)/F(E>GZK)$

in various species, p, γ, ν, ...

i.e. $\int_{uni} dV$ vs. $\int_{GZK} dV$

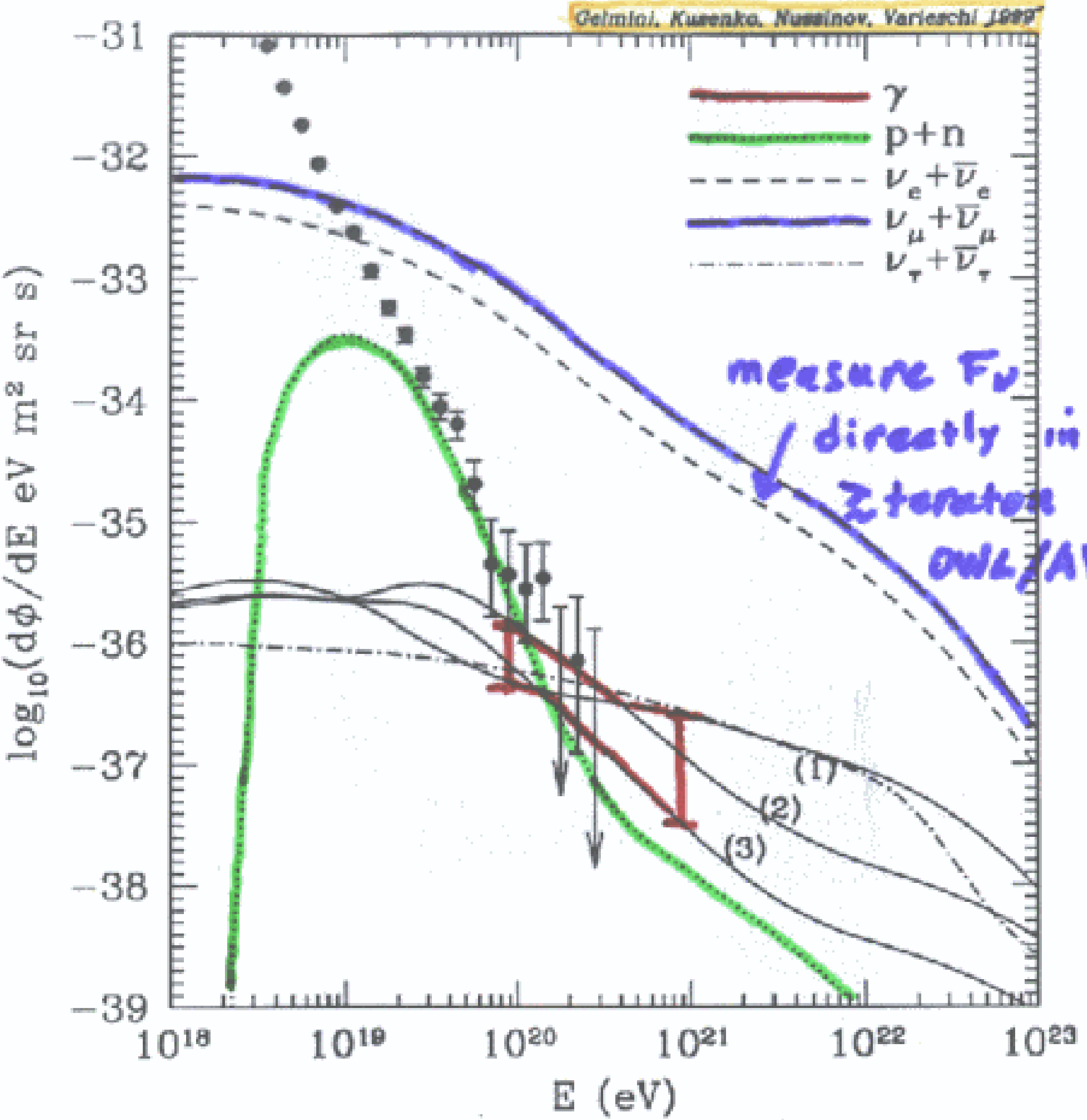
i.e. continuity (no bumps, no gaps) to ankle at $E \sim 3\cdot 10^{18}\,\mathrm{eV}$

← look for GZK p-bump & ν's from $\pi^\pm \to \mu\nu\nu$

G. Farrar

2000

Gelmini, Kusenko, Nussinov, Varieschi 1999



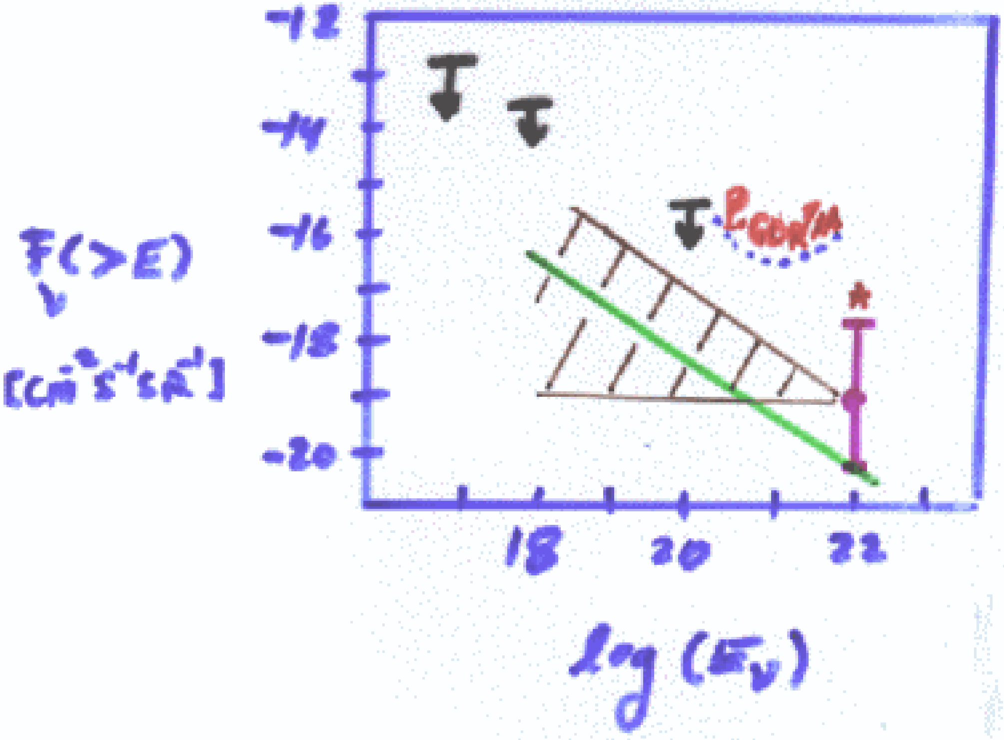
measure F_ν directly in Zteraton OWL/AW

NEUTRINO FLUX
ISSUE

$$F_{\text{observed}}(\geq E_{GZK})$$

$$\sim \underbrace{\mathrm{Prob}(\nu \to Z)}_{\sim 1\%} \times \overset{\uparrow}{\underset{4\cdot 10^{21}\,\mathrm{eV}/m_{eV}}{E_R}} \times F_\nu(E_R) \times \underbrace{\langle N \rangle_Z}_{20}$$

$$\Rightarrow \quad F_\nu(\geq E_R \sim 10^{22}) \sim 5 \cdot F_{obs}(\geq 10^{20})$$



I Z-burst model

* sans ν clustering/asymm.

↧ Fly's Eye upper limits (80's)

— $WB = \frac{5 \cdot 10^{-19}}{E_{20}}$

◺ T T wedge (norm'd to $\bar{F}_z$ requirement)

Momentum (not Energy) Redshifts,

so today

$p_\nu \sim 3T \sim 0.6 \times 10^{-3} \mathrm{eV}$

$\Rightarrow$ $m_\nu \gtrsim 10^{-3}$ eV are Non Rel.

$(\beta < \frac{p}{m} \sim 0.6)$

and so can cluster

"Local" neutrino overdensity $\xi \equiv \frac{n_\nu}{\langle n_\nu \rangle}$

alleviates

(i) Flux requirement

(ii) Egret diffuse (GeV) γ limit.

$P(\text{z burst}) = 1\%$ if $\xi L \sim 10^3 \text{Mpc}$; i.e.

$\xi = 10^4$ within 100 kpc;
10^3 within 1 Mpc;
70 within 20 Mpc

25 within 50 Mpc.

$m_{TG} \sim 2\text{eV}$
$\sim 0.2\text{eV}$

Tremaine Gunn Phase-Space Limit

For fermions, per mass/flavor e-state,
per spin state,

$$N \leq \int d^3x \int \frac{d^3p}{h^3}$$

i.e. $n = \frac{N}{V} \leq \frac{4\pi}{3}\left[\frac{p_{max}}{h} \sim \frac{m_\nu \sigma}{h}\right]^3$

where $\sigma \sim \sqrt{MG/L}$ is virial velocity

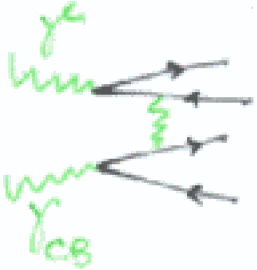
$$\Rightarrow \frac{n}{54\,\mathrm{cm}^{-3}} \lesssim 10^3 \left(\frac{m_\nu}{\mathrm{eV}}\right)^3 \left(\frac{\sigma}{200\,\mathrm{km/s}}\right)^3 \text{[Galaxy]}$$

$$\lesssim 100 \left(\frac{m_\nu}{0.1\,\mathrm{eV}}\right)^3 \left(\frac{\sigma}{1000\,\mathrm{km/s}}\right)^3 \left[\begin{matrix}\text{Rich} \\ \text{G-Cluster}\end{matrix}\right]$$

[but, Clusters are too young?!]

EGRET Problem:

$$Z\text{burst} \Rightarrow \begin{matrix} 10\,\pi^0 \\ 17\,\pi^\pm \\ 2\,N \\ \vdots \end{matrix} \longrightarrow \underbrace{20\,\gamma\text{'s at } E \sim 10^{20}\,\text{eV}}_{\text{cascade down to }\sim\text{GeV }\gamma\text{'s on }\gamma_{CB}}$$



and ultimately,

mitigated by "local" ν-clustering.

Require $n_\nu L > 10 \langle n_\nu \rangle \lambda_{\gamma\text{-attenuation}}$ {Sigl, Lee, Yoshida

ie $$\frac{n_\nu}{\langle n_\nu \rangle} \frac{L}{\text{Mpc}} > 100 \frac{\lambda_\gamma}{10\,\text{Mpc}}$$

Σ If $\exists$ $F_\nu\left(\frac{4\,\mathrm{ZeV}}{m_\nu/\mathrm{eV}}\right)$,

then $\exists$ Z-bursts.

Their Direct Detection

- Emission -

or Indirect Detection

- Absorption -

would reveal the

Nature of the CνB

and of the Uni: at $t = 1$ second!

Nature provides*

$m_\nu \sim 0.1$ to $1\,eV$.

Does She provide F_ν ?

* puts E_R above "background"

* allows ν-clustering