THE HIGH-ENERGY NO-ENERGY CONNECTION:

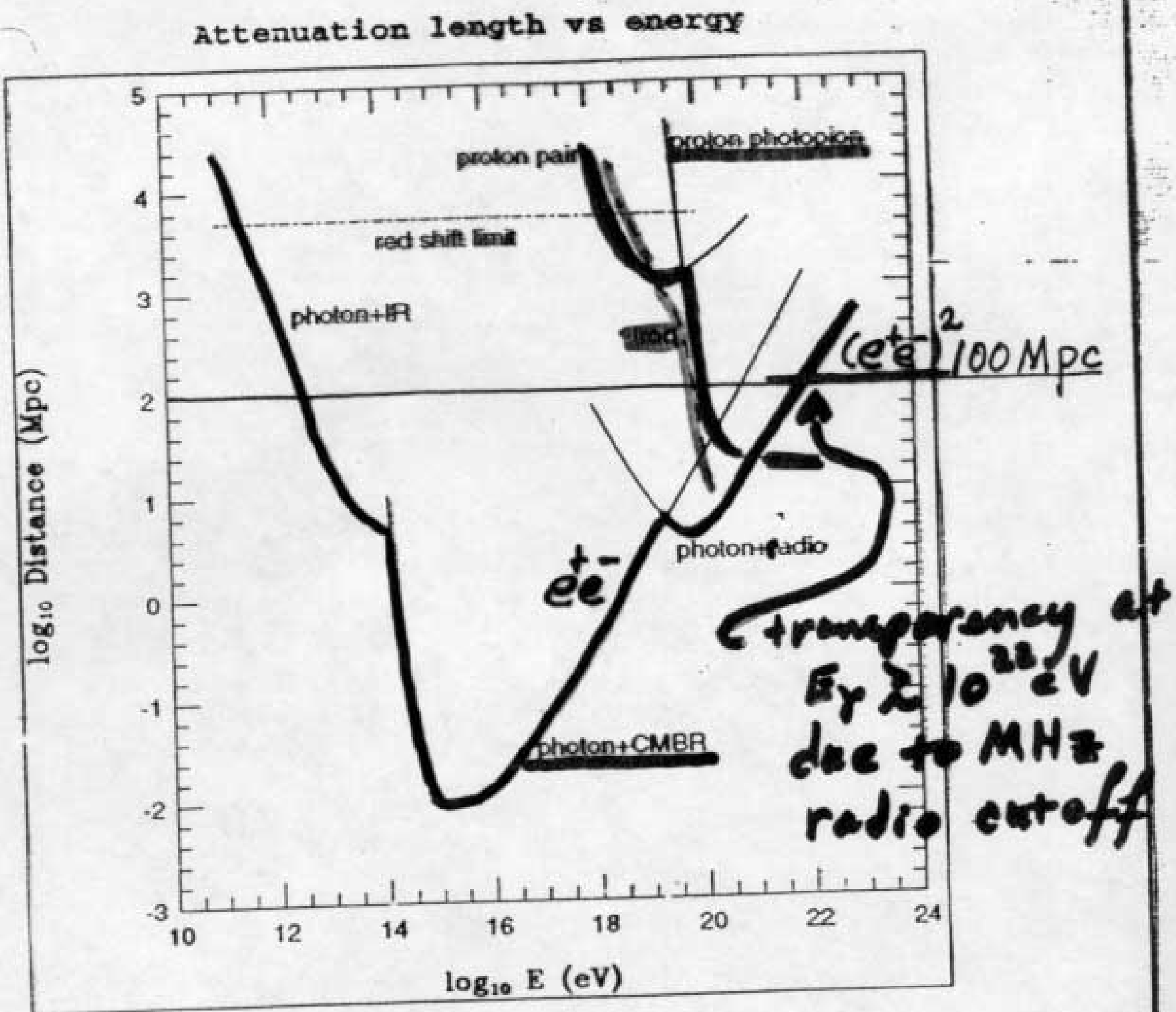
EECR's & RELIC ν's

RADHEP 2000

TOM WEILER

Attenuation of cosmic rays

– sig



All particles except neutrinos

undergo interactions with the CMBR :

This is the **GZK cutoff**

Conjectured Origins

- Nearby "Accelerators"
  - Galactic Supershocks
  - Magnetars (Fe isotropized by big B)
  - M87 or (now quiescent) AGNs w/ " "
  - Nearby GRBs
  - Late DKing SuperMassive Particles
    - GUT masses
    - 10^{12-14} GeV "Wimpzillas"
    - Q-balls
    - Topological Defects (e.g. Vortons)
    - Monopolonium

- Relativistic Dust

Origins (continued)

Exotic Primaries

- Glueballino ($\tilde{g}g$), S^0 baryon ($\tilde{g}qq$) } light gluino
- **Monopoles** w/ $M \lesssim 10^{20}$ eV

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

Exotic Physics

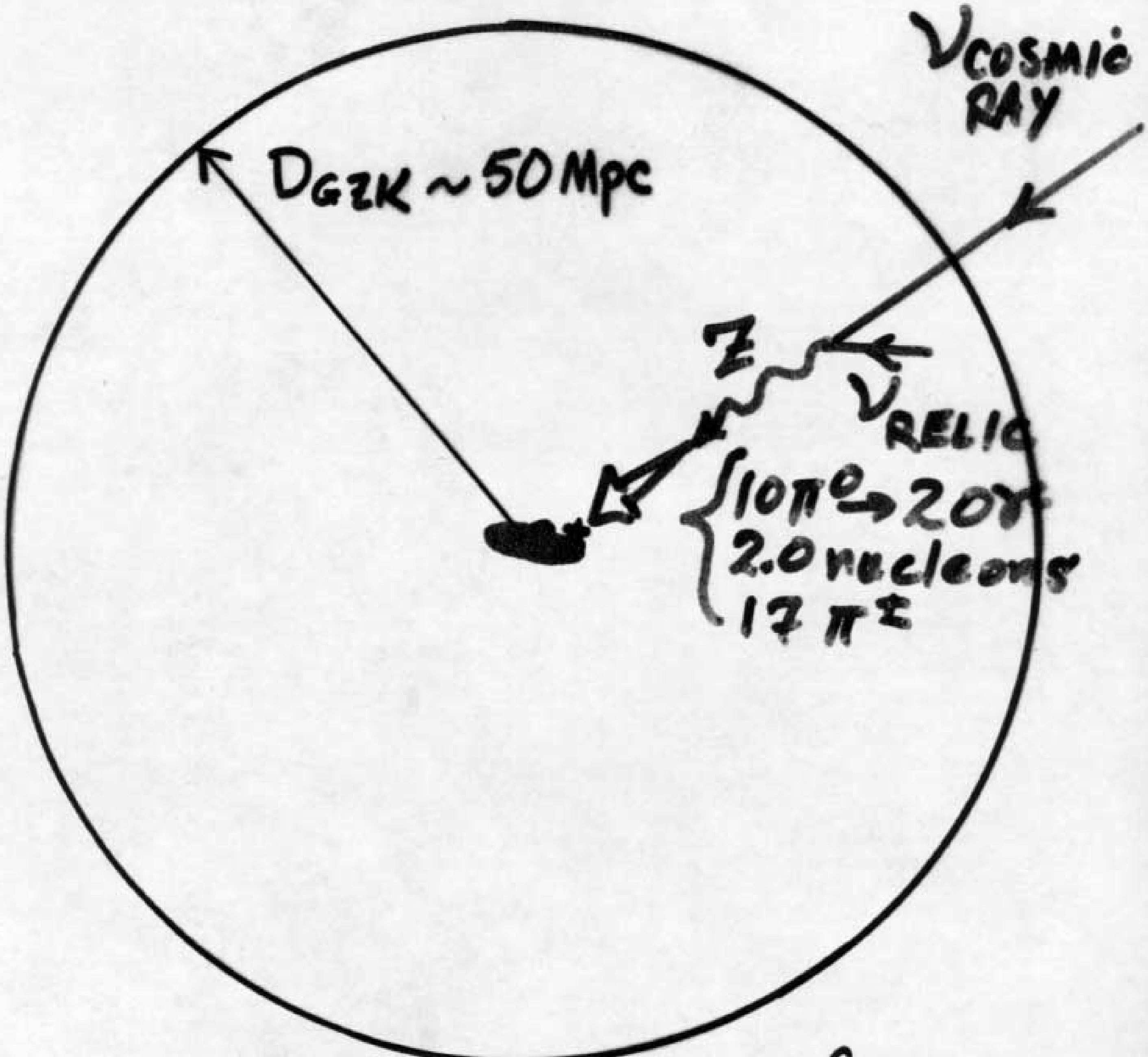
- Broken Lorentz Invariance
- $\frac{1}{M_P}$ operators $\left[\frac{E_{CR}}{M_P} \sim 10^{-8} (E/10^{20}\,\mathrm{eV}) \right]$
- Metric foam / Q. Gravity

Origins (continued)

⊙ Neutrino Primaries

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

T.W. PRL '82
ApJ '84
Astropart. Phys '99
Fargion, Mele, Salis: ApJ '99.



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


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

$$E_{Z\text{-burst}} = \frac{M_Z^2}{2m_\nu} = \frac{4\cdot 10^{21}}{m_{eV}}\, eV$$

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

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

and $E_{\gamma/p/n} \lesssim \begin{cases} 3\cdot 10^{20}\, eV & LSND \\ 3\cdot 10^{21}\, eV & Atm \end{cases}$

Davoudiasl
Hewett
Rizzo

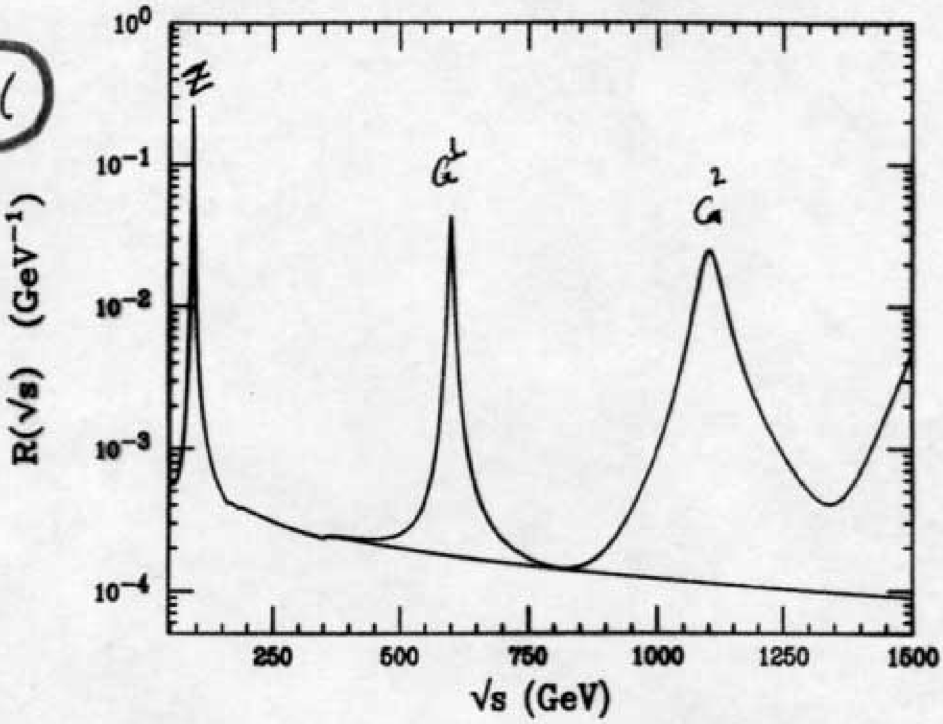


Figure 1: Energy weighted total cross section for hadron production in units of that for the Z pole in the Weiler Z-burst model for $\lambda = 0$ as a function of center of mass energy for the SM(the relatively flat lower blue curve) and in the RS model(the upper red curve) with $c = k/\overline{M}_{Pl} = 0.1$ and $m_1 = 600$ GeV. The small irregularities in the curves are due to WW, ZZ, hh and $t\bar{t}$ thresholds.

To get an idea of what this ratio looks like as a function of energy we show the simplest specific case where $\lambda = 0$ in **Fig.** 1.

↑

Flat Spectrum

NEUTRINO FLUX ISSUE

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

$$\sim \underbrace{Prob(\nu \to Z)}_{\sim 1\%} * E_R * F_\nu(E_R) * \underbrace{\langle N \rangle_Z}_{20}$$

E_R: $4 \cdot 10^{21}\, eV/m_{eV}$

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

$$\lambda_\nu = [\langle\sigma_{ann}\rangle\langle n_\nu\rangle]^{-1} = 30\, h_{65}\, D_H$$

where $D_H = \frac{c}{H_0} = 5000\, h_{65}^{-1}$ Mpc

$$\langle\sigma_{ann}\rangle = \int \frac{ds}{M_Z^2}\,\sigma_{ann}(s) = \frac{4\pi G_F}{\sqrt{8}} = 4.2\times10^{-32}\ \mathrm{cm}^2$$

$$\langle n_\nu\rangle = \frac{3\,\zeta(3)\,T_\nu^3}{4\pi^2} = 54/\mathrm{cm}^3$$

from $T_\nu = \left(\frac{4}{11}\right)^{1/3} T_\gamma = 1.95\,K$

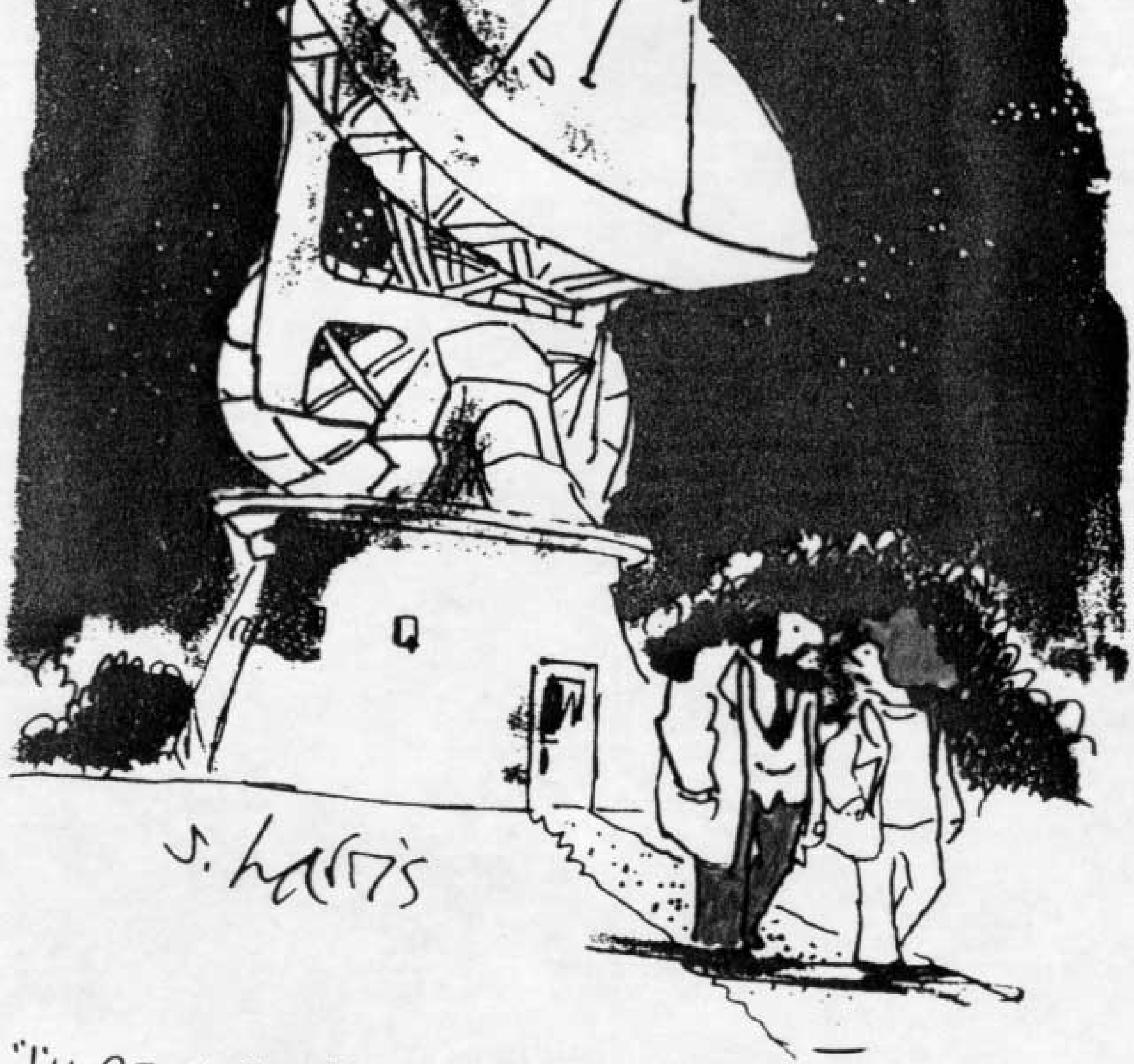
$\Rightarrow \frac{D_H}{\lambda} = 3.6\, h_{65}^{-1}$ % $\approx$ Prob for resonant ν from large z to annihilate

[Show Fig.]

$\Rightarrow P(Z \to had \lesssim 100$ Mpc)

$$= BR \times \frac{100\ \mathrm{Mpc}}{D_H} \times \frac{D_H}{\lambda} = \frac{1\%}{20}$$

$$\Rightarrow P(had \lesssim 100\ \mathrm{kpc}) = \frac{1\%}{20{,}000}$$



"I'LL BE WORKING ON THE LARGEST AND SMALLEST OBJECTS IN THE UNIVERSE — SUPERCLUSTERS AND NEUTRINOS. I'D LIKE YOU TO HANDLE EVERYTHING IN BETWEEN."

AGASA sees

3 pairs and 1 triplet

within $\theta_{resolution} \sim 2.5°$

P(chance) < 1°

Highly Significant:

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

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

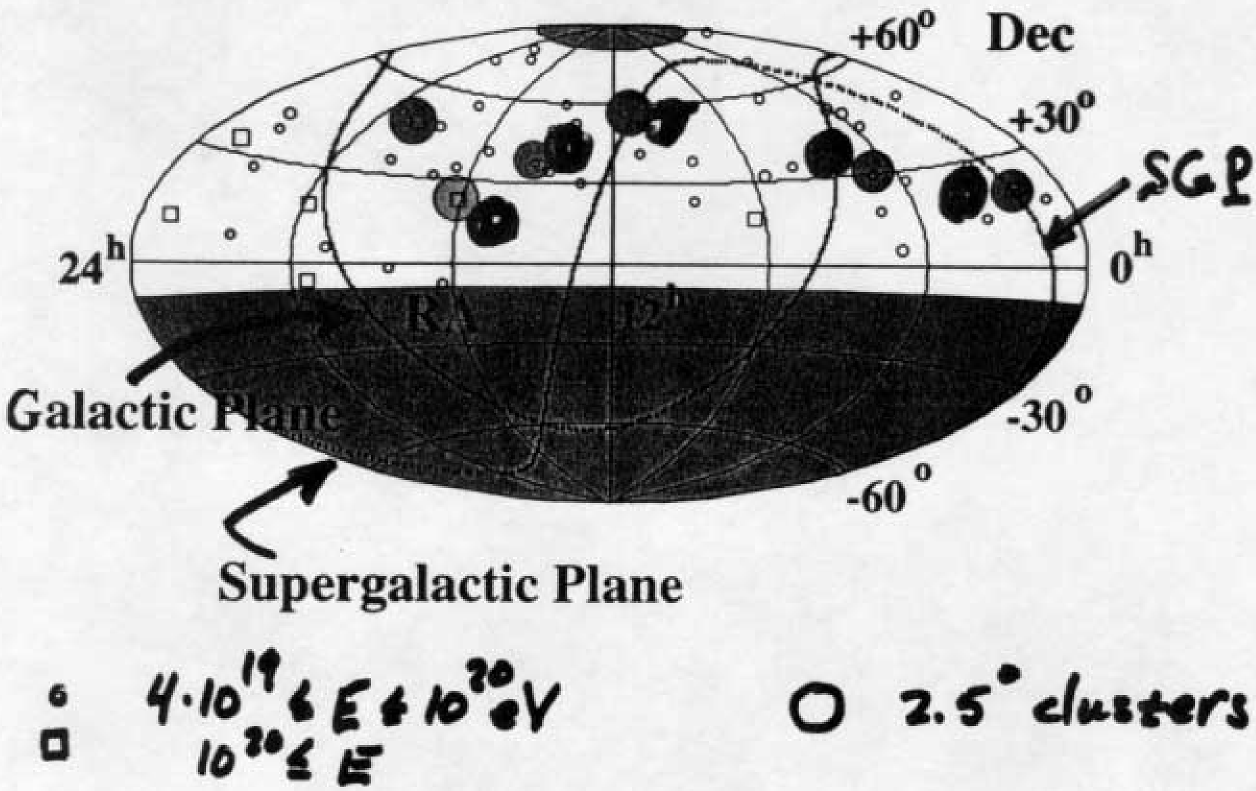
No GZK Cutoff ⇒ • close source
• Q=0, mag. moment ~ 0

ν's ARE PROPAGATING PARTICLE ?!

Uchihori et al.

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

AGASA + A20



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

□ $10^{20} \leq E$

Momentum (not Energy) Redshifts,

so today

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

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

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

and so can cluster

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

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

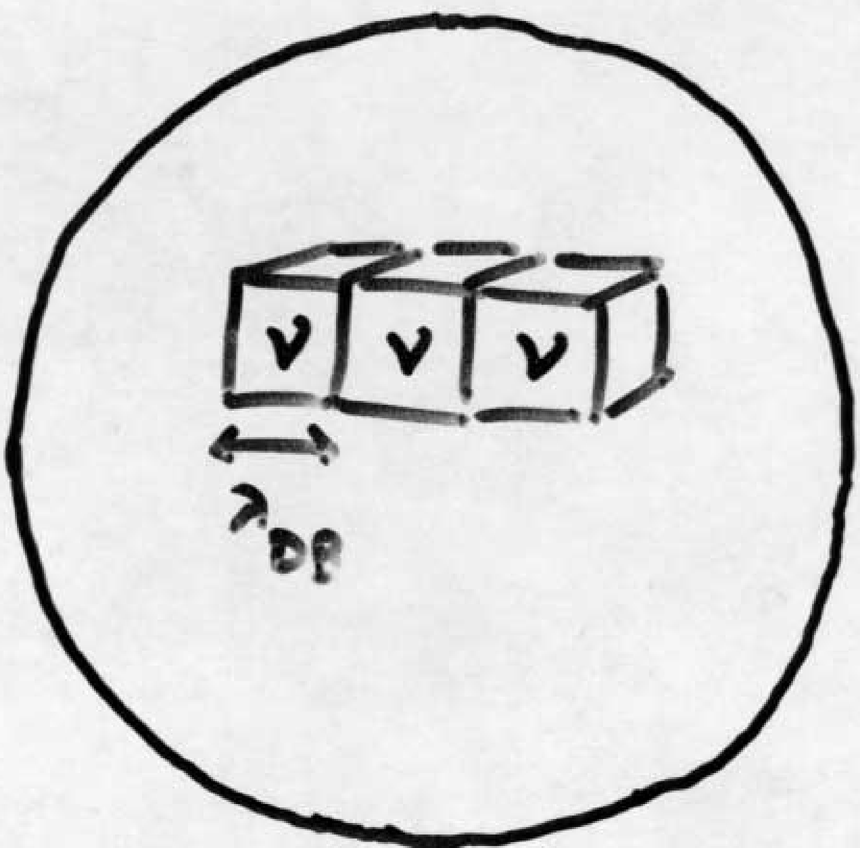
$$\lesssim 100 \left(\frac{m_\nu}{0.1\,eV}\right)^3 \left(\frac{\sigma}{1000\,km/s}\right)^3 \left[\begin{matrix}\text{Rich} \\ \text{G-Clus}\end{matrix}\right.$$

[but, Clusters are too young

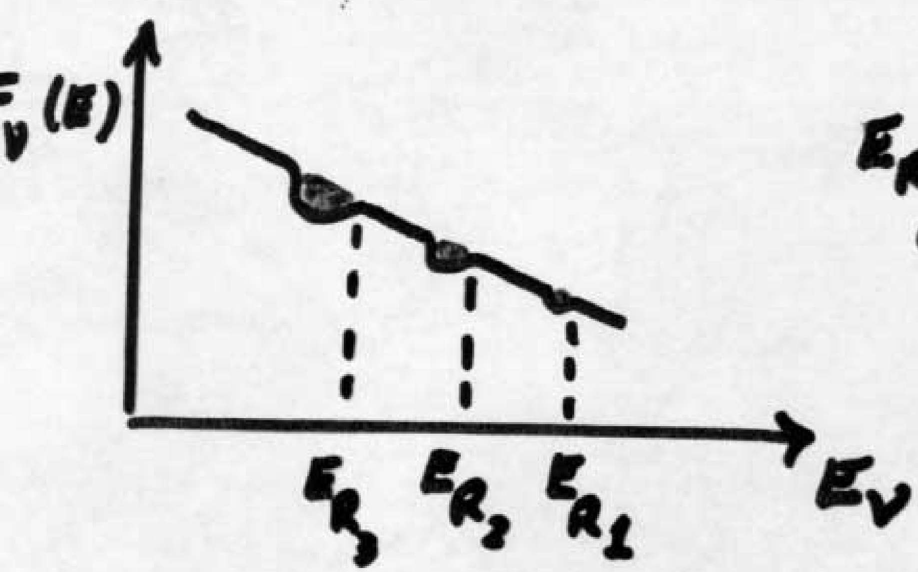
Another View – Phase Space Limit

$$\lambda_{DB} = \frac{h}{p} \geq \frac{h}{m\sigma} \sim n^{-1/3}$$

i.e. $N \approx \frac{V}{(\lambda_{DB})^3_{min}}$ {in 3D, longer λ's make negligible contribution}



Absorption Spectroscopy

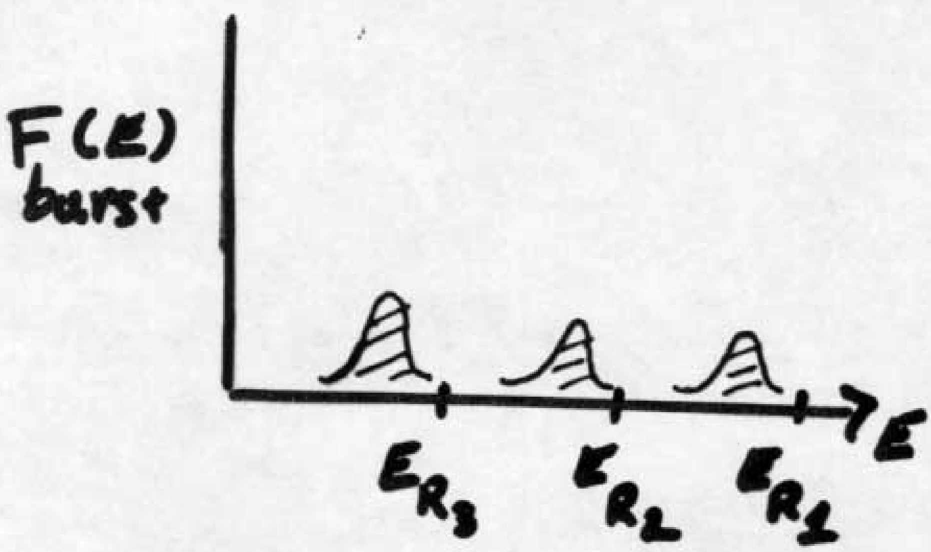


$$E_{R_y} = \frac{4\ ZeV}{(m_\chi/eV)}$$

* dips power diffuse ~GeV γ's (EGRET)

Want ν small to maximize absorption.

Emission Spectroscopy



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

maximized at $\lambda = D_H$ [Gelmini & Kusenko]

(neglecting expansion)

Lepton Asymmetry [Gelmini; 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.

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

$\Rightarrow \lambda = D_H$

$\Rightarrow P(\text{Z burst} \lesssim 50\,\text{Mpc}) = 0.2\, h_{65}\,\%$

[$\Omega_\nu \leq 0.15 \Rightarrow \xi^3 \frac{m_\nu}{eV} < 65 \xrightarrow{\xi = 5} m_\nu < 0.4\,\text{e}$

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

$F_\nu(E) \cdot \sigma_\nu(E) \cdot \frac{M}{m_N}$ ← 1 ton $= 0.6 \times 10^{30}\, m_N$

$F_\nu(E)$ ← $F_{obs}(10^{20}\text{eV}) = 2 \times 10^{-20}/\text{cm}^2/\text{s}/\text{sR}$

$\sigma_\nu(E)$ ← $0.6 \times 10^{-30}\, E_{22}^{0.4}\, \text{cm}^2$ [McKay Ralston

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

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

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

can do absorption spectroscopy.

[Fig.]

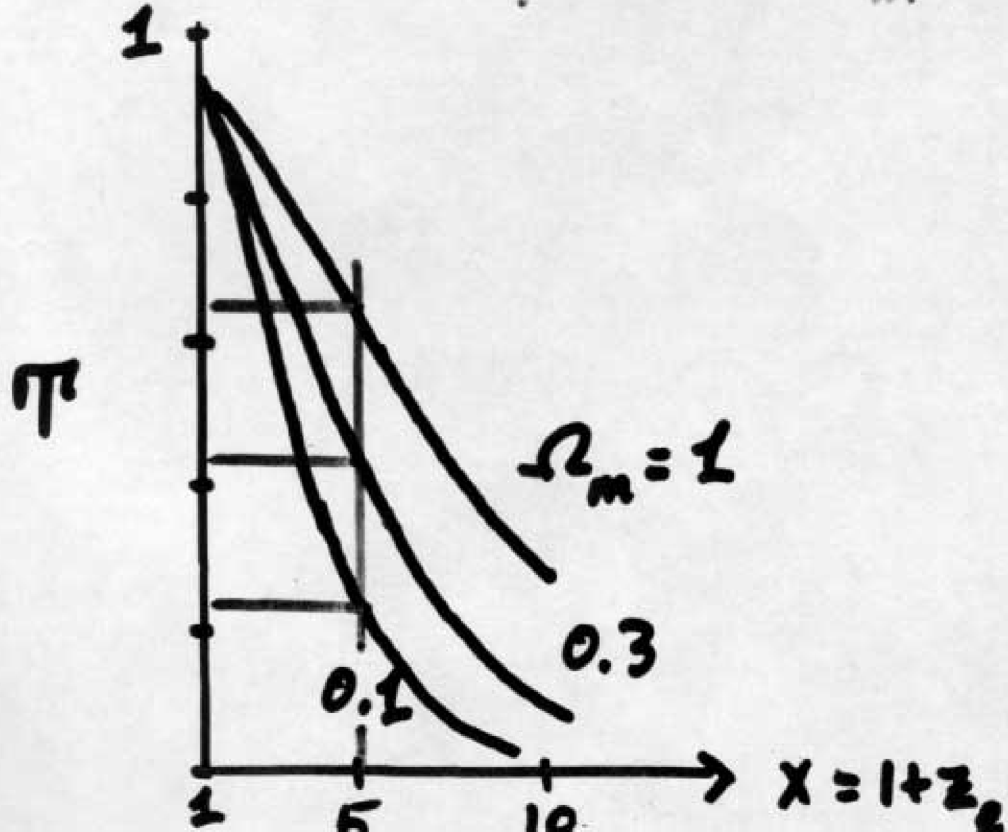
Transmission of ν's

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

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

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

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



L. Song
T.W.