UHE NEUTRINOS:

FROM CONVENTIONAL TO NEW PHYSICS

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UHE NEUTRINOS with $E > 10^{17}$ eV

Cosmogenic neutrinos

Reliable prediction guaranteed by observations of UHECR.

Production: $p + \gamma_{CMB} \rightarrow \pi^{\pm} \rightarrow \mathrm{neutrinos}$

Limited maximum energy: $E_{\nu}^{max} < E_{\mathrm{acc}}^{\mathrm{max}} < 10^{22}$ eV

Neutrinos in top-down models

Signature: high E_{ν}^{max} up to $M_{\mathrm{GUT}} \sim 10^{25}$ eV.

- **Topological Defects**
- **Superheavy Dark Matter**
- **Mirror Matter**

COSMOGENIC NEUTRINOS

$$p + \gamma_{CMB} \rightarrow \pi^{\pm} \rightarrow neutrinos$$

$$J_\nu(E) = \frac{2}{3} 3 \left(\frac{E_\nu}{E_p}\right)^{\gamma_g - 1} \frac{1}{1-\alpha^{\gamma_g - 1}} \; J_p^{unm}(E)$$

$$\frac{E_\nu}{E_p} \approx \frac{0.2}{4} = 0.05$$

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COSMIC RAYS AT ULTRA HIGH ENERGIES (NEUTRINO?)

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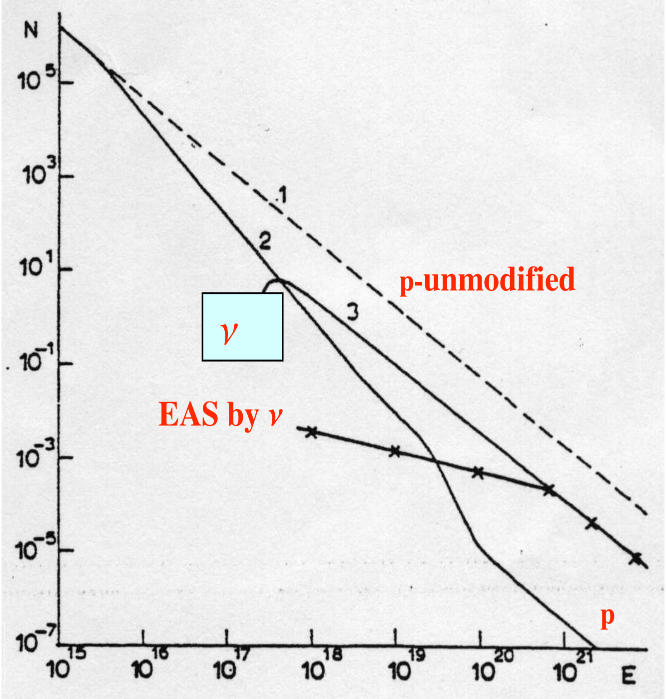
The neutrino spectrum produced by protons on microwave photons is calculated. A spectrum of extensive air shower primaries can have no cut-off at an energy E> 3 x 10^{19} eV. If the neutrino-nucleon total cross-section rises up to the geometrical one of a nucleon.

Greisen [1] and then Zatsepin and Kusmin [2] have predicted a rapid cut-off in the energy spectrum of cosmic ray protons near E~3x10^{19} eV because of pion production on 2.7° black body radiation. Detailed calculations of the spectrum were made by Hillas [3]. Recently there were observed [4] three extremely energetic extensive air showers with an energy of primary particles exceeding 5 x 10^{19} eV. The flux of these particles turned out of be 10 times greater than according to Hillas' calculations.

In the light of this it seems to be of some interest to consider the possibilities of absence of rapid (or any) fall in the energy spectrum of shower producing particles. A hypothetic possibility we shall discuss* consists of neutrinos being the shower producing particles at $E > 3 \times 10^{19}$ eV due to which the energy spectrum of shower producing particles cannot only have any fall but even some flattening.



RECENT WORKS

- Engel, Seckel, Stanev 2001
- Kalashev, Kuzmin, Semikoz, Sigl 2002
- Fodor, Katz, Ringwald , Tu 2003
- VB, Gazizov, Grigorieva 2003
- Hooper et al. 2004
- M. Ave et al. 2004

APPROACH and RESULTS:

- **Normalization by the observed UHECR flux**
- **Neutrino flux is SMALL in non-evolutionary models with $E_{\rm max} \leq 10^{21}$ eV**
- **Neutrino flux is LARGE in evolutionary models with $E_{\rm max} \geq 10^{22}$ eV**

COSMOGENIC NEUTRINOS
IN THE DIP MODEL FOR UHECR

The **dip** is a feature in the spectrum of UHE protons propagating through CMB:

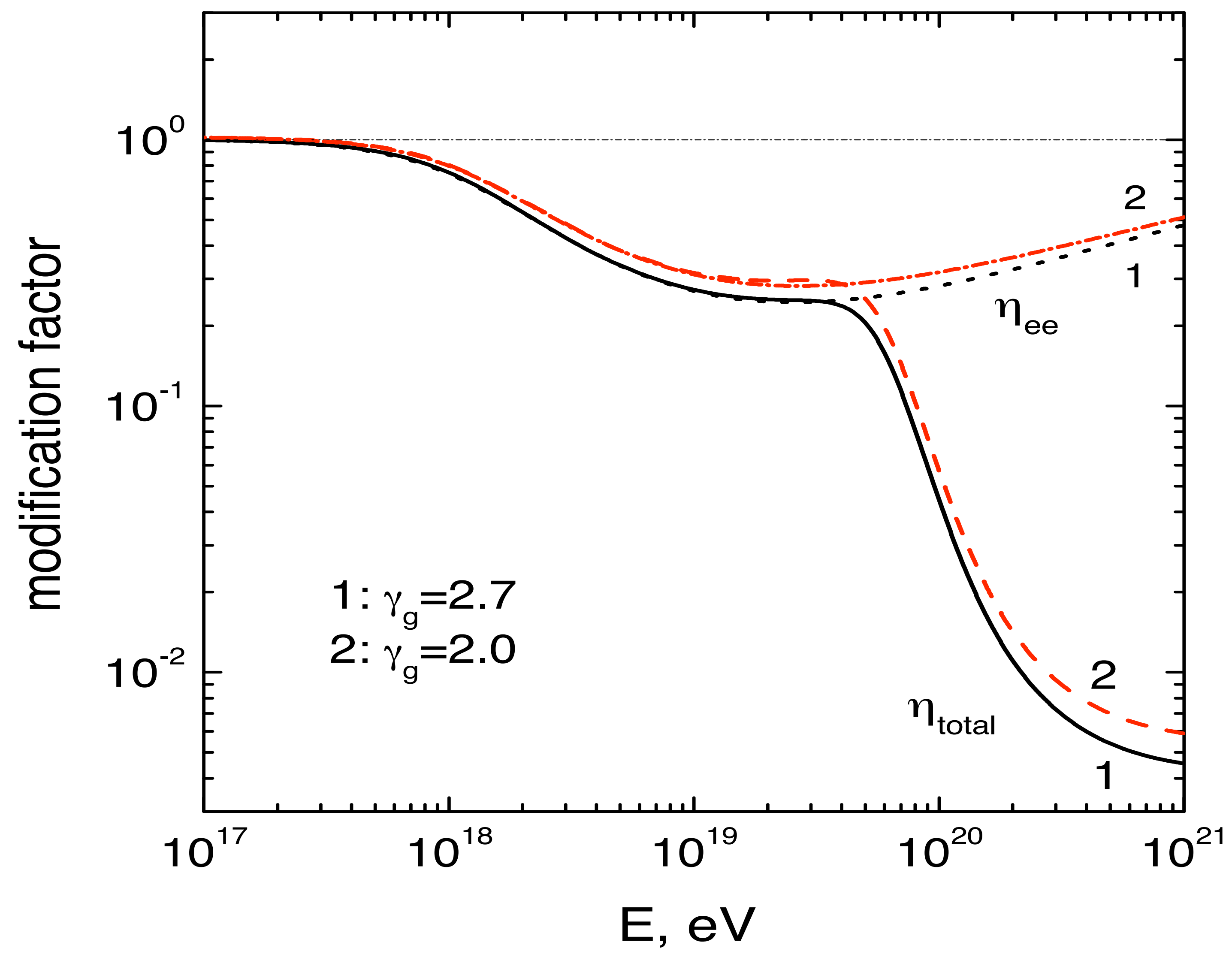
$$\mathbf{p} + \gamma_{\rm CMB} \to \mathbf{e}^+ + \mathbf{e}^- + \mathbf{p}$$

Calculated in the terms of **modification factor** $\eta(E)$ the dip is seen in all observational data.

$$\eta(\mathbf{E}) = \frac{\mathbf{J_p(E)}}{\mathbf{J_p^{\rm unm}(E)}}\,,$$

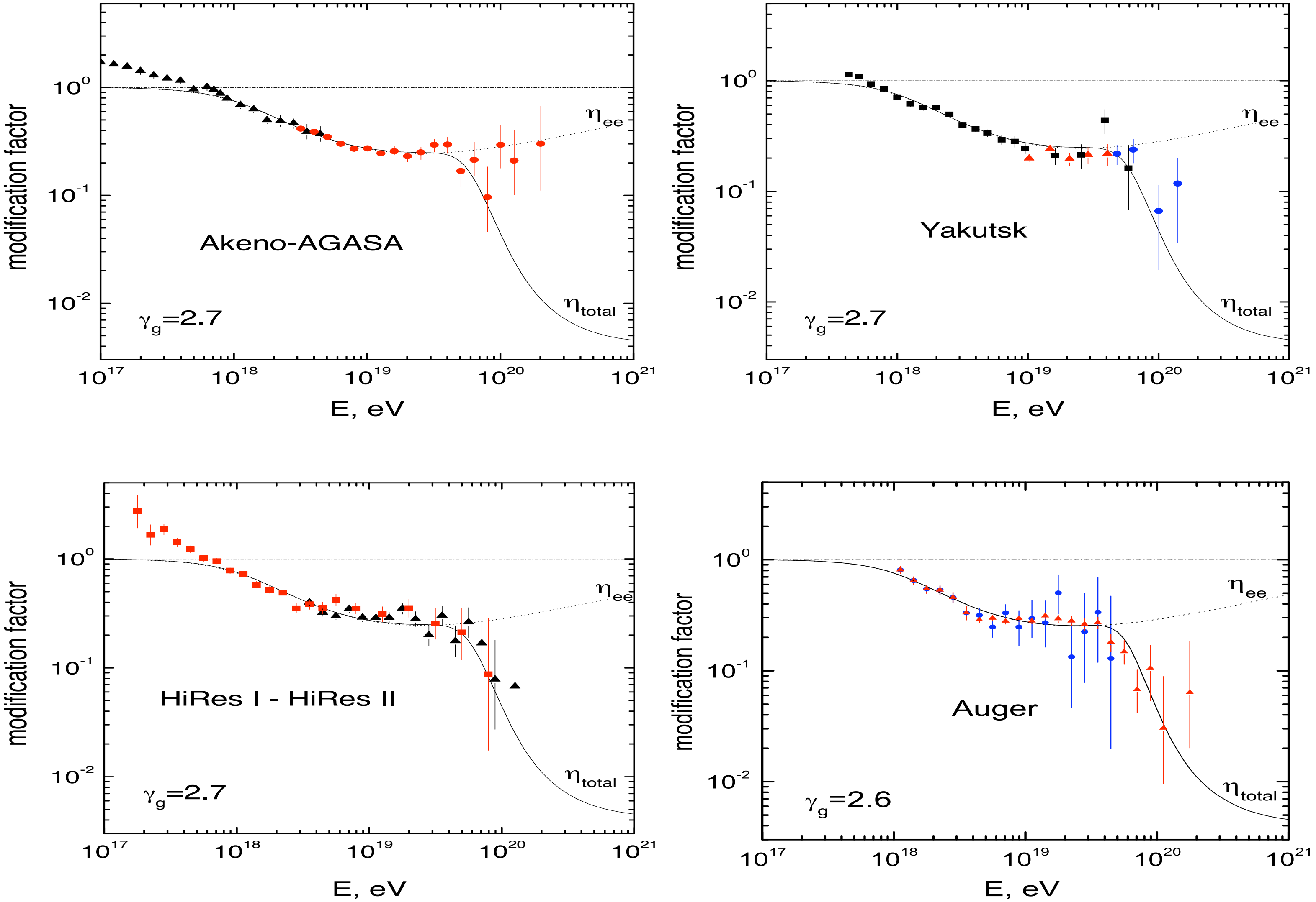
where $J_p^{\rm unm}(E)$ includes only adiabatic energy losses and $J_p(E)$ - all energy losses.

DIP AND GZK CUTOFF IN TERMS OF MODIFICATION FACTOR



The dotted curve shows η_{ee}, when only adiabatic and pair-production energy losses are included. The solid and dashed curves include also the pion-production losses.

COMPARISON OF DIP WITH OBSERVATIONS



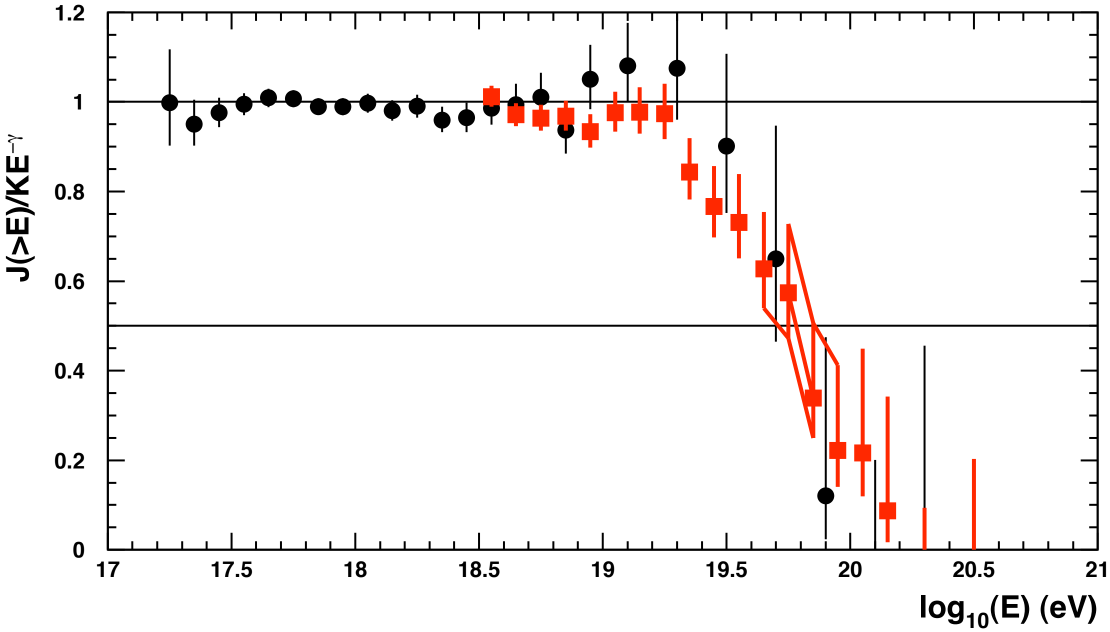
GZK CUTOFF IN HiRes DATA

In the integral spectrum GZK cutoff is numerically characterized by energy $E_{1/2}$ where the calculated spectrum $J(>E)$ becomes half of power-law extrapolation spectrum $KE^{-\gamma}$ at low energies. As calculations (V.B.&Grigorieva 1988) show

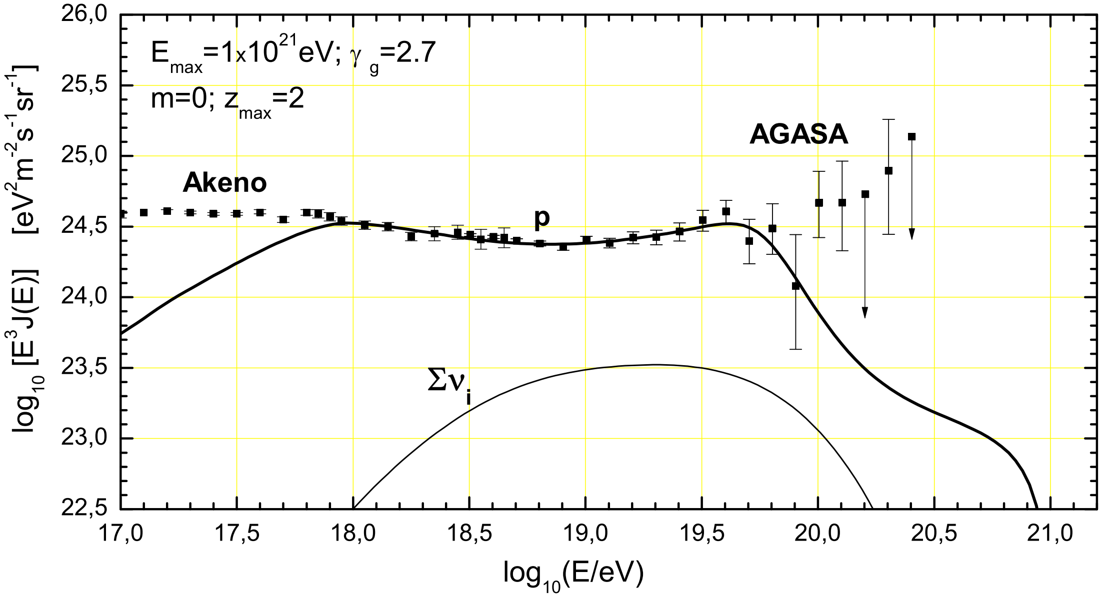
$$\mathrm{E}_{\mathbf{1/2}} = \mathbf{10^{19.72}}\ \mathrm{eV}$$

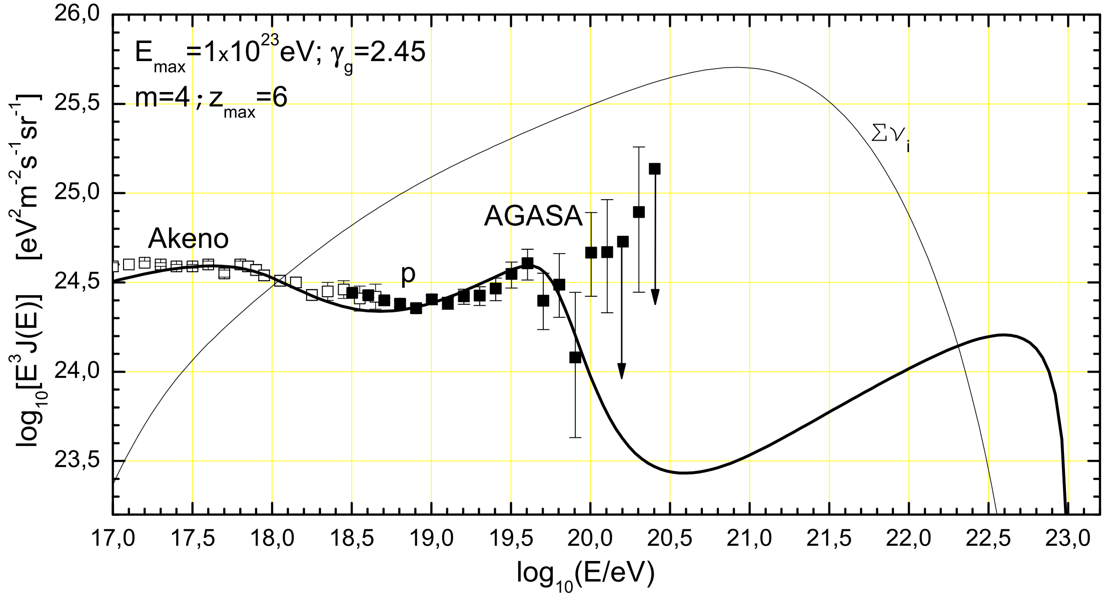
valid for a wide range of generation indices from 2.1 to 2.8. HiRes obtained:

$$\mathrm{E}_{\mathbf{1/2}} = \mathbf{10^{19.73\pm0.07}}\ \mathrm{eV}$$

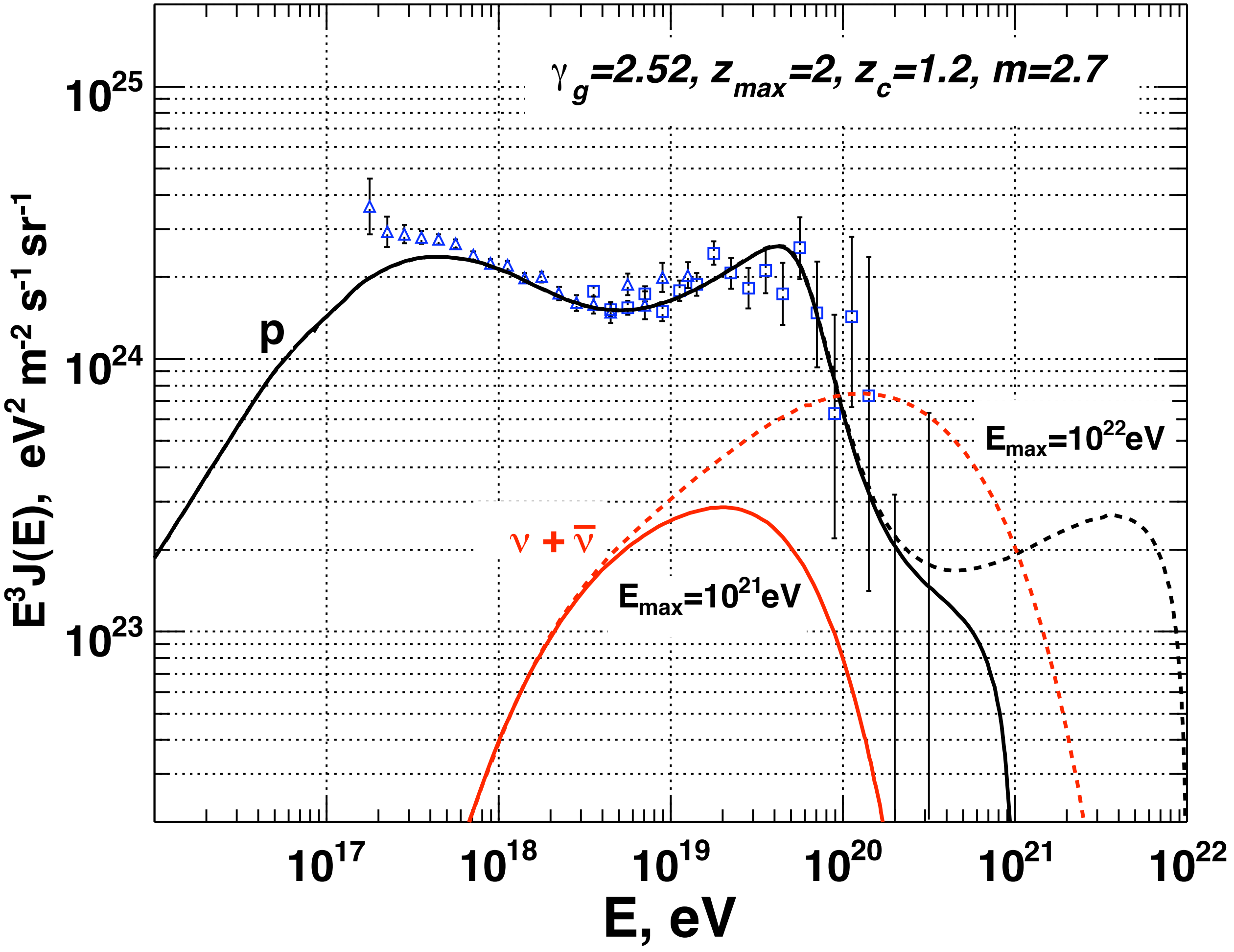


COSMOGENIC NEUTRINO FLUXES IN THE DIP MODEL





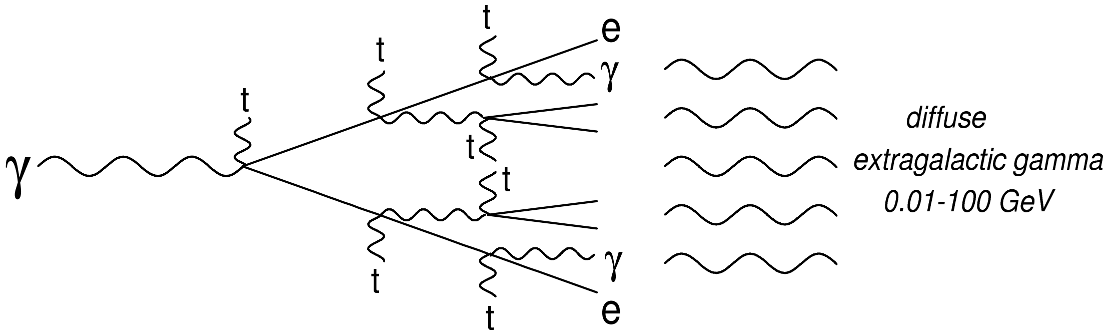
COSMOGENIC NEUTRINO FLUXES FROM AGN



CASCADE UPPER LIMIT

V.B. and A.Smirnov 1975

$$\text{e} - \text{m cascade on target photons}: \left\{ \begin{array}{l} \gamma + \gamma_{\rm tar} \to e^+ + e^- \\ e + \gamma_{\rm tar} \to e' + \gamma' \end{array} \right.$$



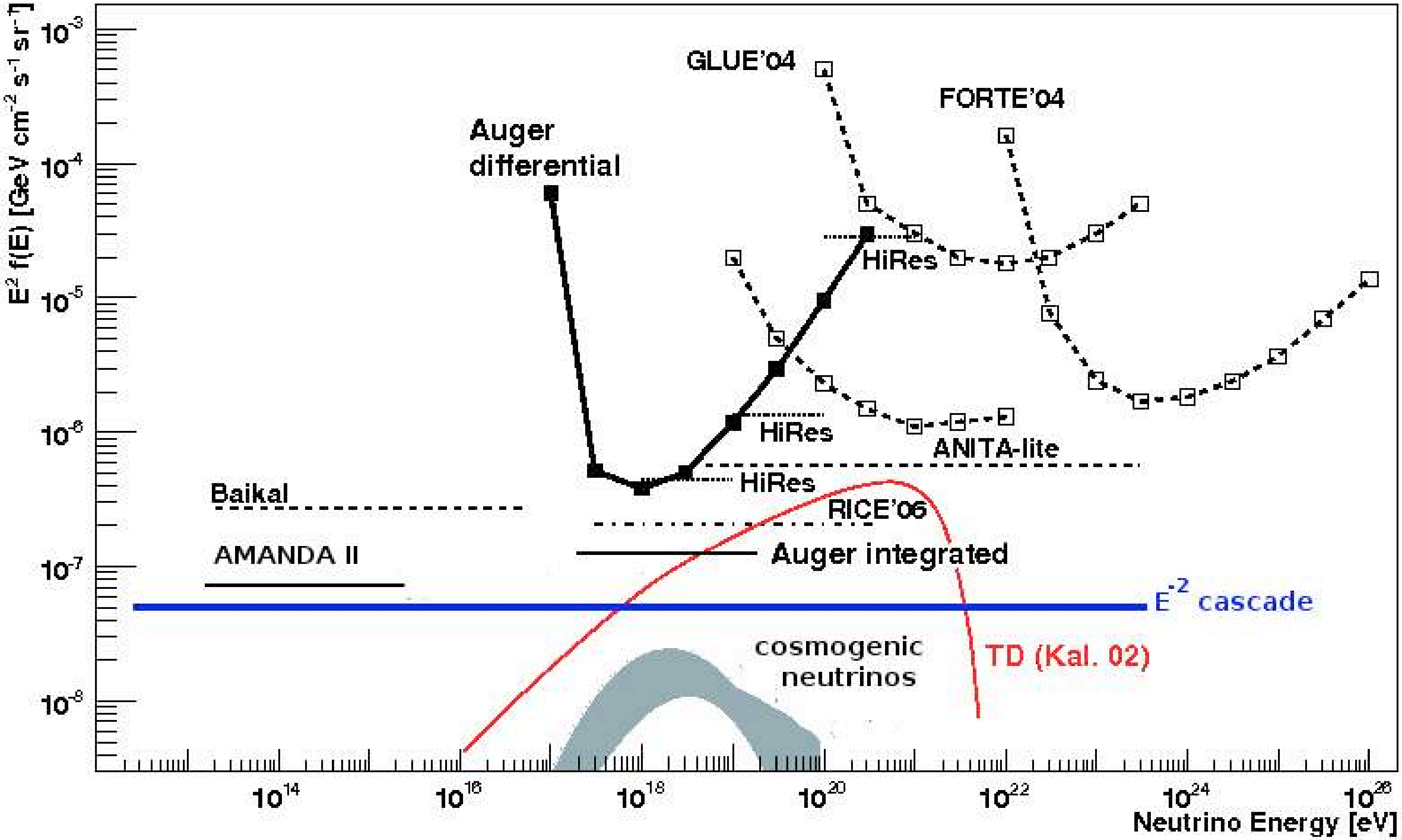
EGRET: $\omega_\gamma^{\rm obs} \sim (2-3) \times 10^{-6}{\rm eV/cm}^3$.

$$\omega_{\rm cas} > \frac{4\pi}{c} \int_E^\infty E J_\nu(E) dE > \frac{4\pi}{c} E \int_E^\infty J_\nu(E) dE \equiv \frac{4\pi}{c} E J_\nu(> E)$$

$$E^2 I_\nu(E) < \frac{c}{4\pi} \omega_{\rm cas.}$$

$$E^{-2} - \text{generation spectrum}: E^2 J_{\nu_i}(E) < \frac{c}{12\pi} \frac{\omega_{\rm cas}}{\ln E_{\rm max}/E_{\rm min}}, \; i = \nu_\mu + \bar{\nu}_\mu \;\; \text{etc.}$$

OBSERVATIONAL UPPER LIMITS



Kampert 2008 (modified)

UHE NEUTRINOS TN TOP-DOWN MODELS

Acceleration to $E_p \gtrsim 1 \times 10^{22}$ eV is a challenge for astrophysics.

TDs, SHDM and MIRROR MATTER naturally provide these energies due to production and decay/annihilation of superheavy particles.

UHE NEUTRINOS FROM SUPERHEAVY DARK MATTER

Stable or quasistable superheavy particles are candidates for DM particles.

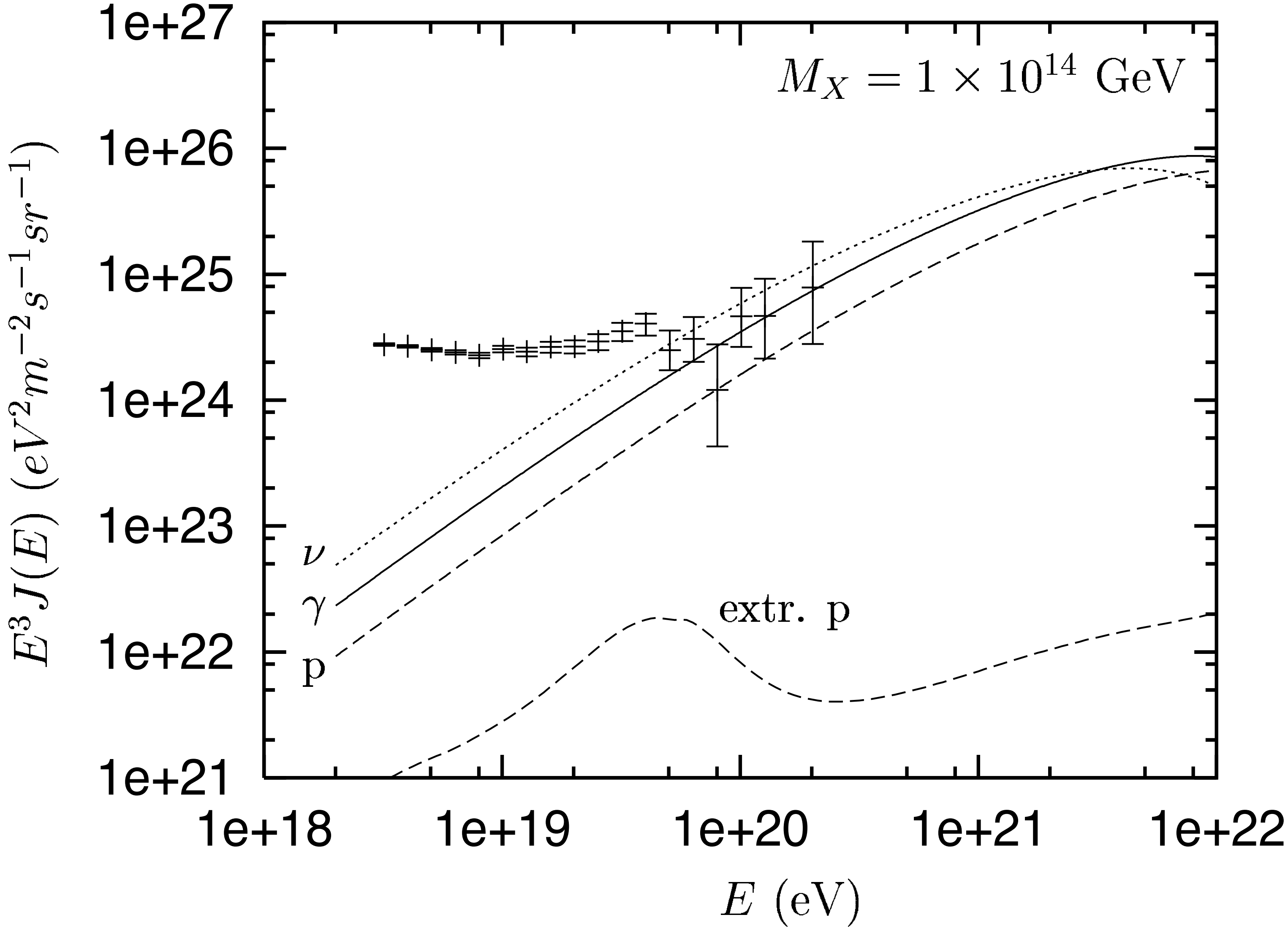
- **Production in time-varying gravitational field in post-inflashionary epoch. Creation occurs when $H(t) \sim m_X$.**

  $$m_X \sim 10^{13}\ \mathrm{GeV}.$$

  e.g. $m_X \sim 3 \times 10^{13}$ GeV results in $\Omega_X h^2 \sim 0.1$.

- **ACCUMULATION IN THE GALACTIC HALO. Like for any DM, overdensity=2.1$\times 10^5$.**

UHE NEUTRINOS FROM SHDM

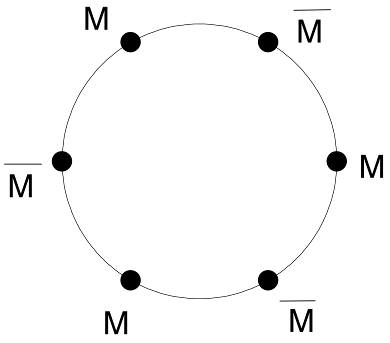


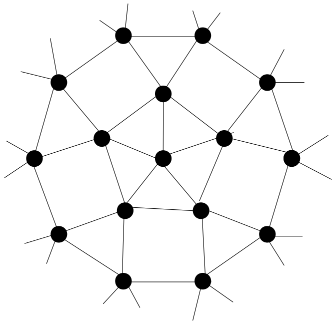
UHE NEUTRINOS FROM TOPOLOGICAL DEFECTS

Symmetry breaking in early universe results in phase transitions, which are accompanied by Topological Defects.

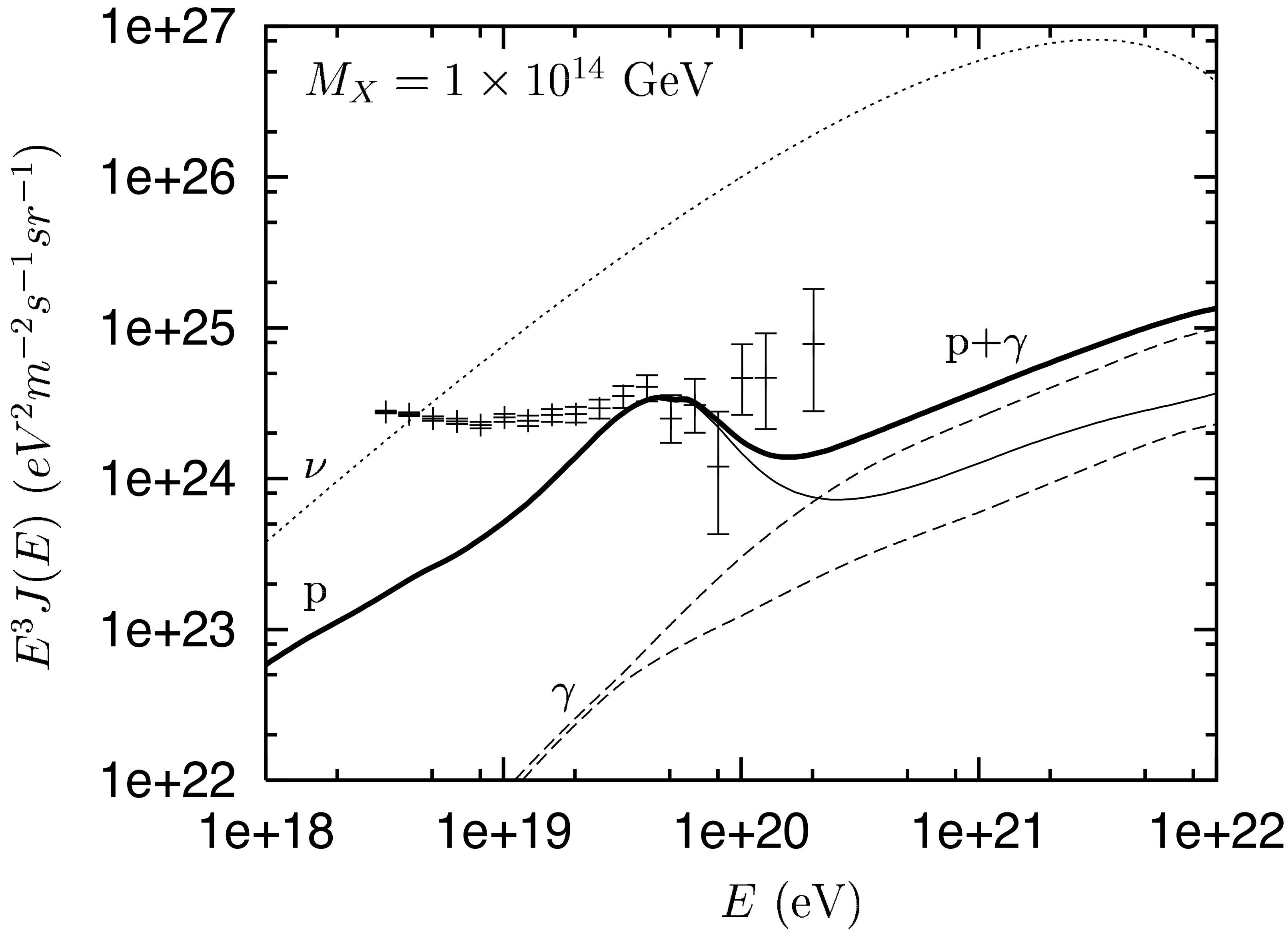
TDs OF INTEREST FOR UHE NEUTRINOS.

- **Monopoles:** $G \rightarrow H \times U(1)$
- **Ordinary strings:** $U(1)$ **breaking**
- **Superconducting strings:** $U(1)$ **breaking**
- **Monopoles connected by strings:** $G \rightarrow H \times U(1) \rightarrow H \times Z_n$
  e.g. necklaces $Z_n = Z_2$.


NECKLACE


MS NETWORK

UHE NEUTRINOS FROM NECKLACES



UHE MIRROR NEUTRINOS

1. CONCEPT OF MIRROR MATTER

Mirror matter is based on the theoretical concept of the space reflection, as first suggested by Lee and Yang (1956) and developed by Landau (1956), Salam (1957), Kobzarev, Okun, Pomeranchuk (1966) and Glashow (1986, 1987): see review by Okun hep-ph/0606202

Extended Lorentz group includes reflection: $\vec{\mathbf{x}} \to -\vec{\mathbf{x}}$.
In particle space it corresponds to **inversion** operation I_r.
Reflection $\vec{x} \to -\vec{x}$ and time shift $t \to t + \Delta t$ commute as coordinate transformations.
In the particle space the corresponding operators must commute, too:

$$[\mathcal{H}, I_r] = 0.$$

Hence, I_r must correspond to the conserved value.

- Lee and Yang: $I_r = P \cdot R$, where R transfers particle to mirror particle:

$$I_r \Psi_{\rm L} = \Psi'_{\rm R} \quad \text{and} \quad I_r \Psi_{\rm R} = \Psi'_{\rm L}$$

- Landau: $I_r = C \cdot P$, where C transfers particle to antiparticle.

2. OSCILLATION OF MIRROR AND ORDINARY NEUTRINOS

Kobzarev, Okun, Pomeranchuk suggested that ordinary and mirror sectors communicate only gravitationally.

COMMUNICATION TERMS include EW SU(2) singlet interaction term:

$$\mathcal{L}_{\mathrm{comm}} = \frac{1}{M_{\mathrm{Pl}}} (\bar{\psi}\phi)(\psi'\phi') \tag{1}$$

where $\psi_L = (\nu_L,\ \ell_L)$ and $\phi = (\phi_0^*,\ -\phi_+^*)$.
After SSB, Eq.(1) results in mixing of ordinary and mirror neutrinos.

$$\mathcal{L}_{\mathrm{mix}} = \frac{v_{\mathrm{EW}}^2}{M_{\mathrm{Pl}}} \nu\nu',$$

with $\mu \equiv v_{\mathrm{EW}}^2 / M_{\mathrm{Pl}} = 2.5 \cdot 10^{-6}$ eV.

It implies oscillations between ν and ν'.

Berezhiani, Mohapatra (1995) and Foot, Volkas (1995).

3. UHE NEUTRINOS FROM MIRROR TDs

In two-inflatons scenario with curvature-driven phase transition (V.B. and Vilenkin 2000) there can be:

$$\rho'_{\rm matter} \ll \rho_{\rm matter}, \quad \rho'_{\rm TD} \gg \rho_{\rm TD}$$

HE mirror ν's are produced by mirror TDs and oscillate into visible ν's.

All other HE mirror particles which accompany neutrino production remain invisible.

Probabibility of oscillation (V.B, Narayan, Vissani 2003):

$$\sum_\alpha P_{\nu'_\mu \nu_\alpha} = \frac{1}{2}.$$

Signature: diffuse flux exceeds cascade upper limit.

CONCLUSIONS

- **UHE neutrino astronomy has a balanced program of observations of well predicted fluxes of cosmogenic (accelerator) neutrinos, and more speculative fluxes predicted by the models beyond SM (e.g. topological defects and mirror matter).**
- **Energies of cosmogenic neutrinos are expected up to $E_\nu \sim 10^{21}$ eV. Acceleration to $E_p^{\max} \sim 1 \times 10^{22}$ eV is a problem in astrophysics. Energies in TD and Mirror Matter models can be much higher.**
- **Fluxes of cosmogenic neutrinos are high and detectable in case of UHECR proton composition (confirmed by observations of dip and GZK cutoff) and in case of $E_p^{\max} \gtrsim 1 \times 10^{22}$ eV and cosmological evolution of the sources.**
- **Fluxes of cosmogenic neutrinos are much lower in case of heavy-nuclei composition and could be undetectable by EUSO if source evolution is absent and/or $E_{\max}$ is small.**
- **Neutrinos with $E_\nu > 10^{21} - 10^{22}$ eV is a signal for a new physics.**