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:

$p + \gamma_{\text{tar}} \rightarrow \Delta^+ \rightarrow \pi^+ + n$

$\downarrow \mu^+ + \nu_\mu$

$\downarrow e^+ + \bar{\nu}_\mu + \nu_e$

$p + \gamma_{\text{tar}} \rightarrow \pi^- + \text{all}$

$\downarrow \mu^- + \bar{\nu}_\mu$

$\downarrow e^- + \nu_\mu + \bar{\nu}_e$

No $\tau$-neutrinos and deficit of $\bar{\nu}_e$ neutrinos. They appear due to oscillations, with equipartition at observations $\nu_\mu : \nu_e : \nu_\tau = 1 : 1 : 1$ as approximation.

Neutrinos beyond SM

- Topological Defects
- Superheavy Dark Matter
- Mirror Matter
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 \( E > 3 \times 10^{19} \) 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 \( E \approx 3 \times 10^{19} \) 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 \( 5 \times 10^{19} \) eV. The flux of these particles turned out to 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 $E_{\text{max}} \leq 10^{21}$ eV

• Neutrino flux is LARGE in evolutionary models with $E_{\text{max}} \geq 10^{22}$ eV
COSMOGENIC NEUTRINOS
IN THE DIP MODEL FOR UHECR


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

\[ p + \gamma_{\text{CMB}} \rightarrow e^+ + e^- + p \]

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

\[ \eta(E) = \frac{J_p(E)}{J_{p}^{\text{unm}}(E)}, \]

where \( J_{p}^{\text{unm}}(E) \) includes only adiabatic energy losses and \( J_p(E) \) - all energy losses.
DIP AND GZK CUTOFF IN THE DIFFUSE SPECTRUM

DEFINITION OF MODIFICATION FACTOR

\[ \eta(E) = \frac{J_p(E)}{J_p^{\text{unm}}(E')} \]

where \( J_p^{\text{unm}}(E) \) includes only adiabatic energy losses (redshift) and \( J_p(E) \) includes total energy losses, \( \eta_{\text{tot}}(E) \) or adiabatic, \( e^+e^- \) energy losses, \( \eta_{ee}(E) \).
The dotted curve shows $\eta_{ee}$, 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

Akeno-AGASA

\( \eta_{\text{total}} \)

\( \gamma_g = 2.7 \)

HiRes I - HiRes II

\( \eta_{\text{total}} \)

\( \gamma_g = 2.7 \)

Yakutsk

\( \eta_{\text{total}} \)

\( \gamma_g = 2.7 \)

Auger

\( \eta_{\text{total}} \)

\( \gamma_g = 2.6 \)
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

$$E_{1/2} = 10^{19.72} \text{ eV}$$

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

$$E_{1/2} = 10^{19.73 \pm 0.07} \text{ eV}$$
COSMOGENIC NEUTRINO FLUXES IN THE DIP MODEL

\[ E(E, \text{eV}) \times 10^{-1} \text{ster}^{-1} \text{sec}^{-2} \text{m}^{-2} \text{J}(E) \text{eV}^3 \]

For \( z_{\text{max}} = 2; E_{\text{max}} = 10^{23} \text{eV}; \gamma = 2.7; m = 0 \)

\[ E_{\text{max}} z = 10^{21}; \Sigma \nu = \Sigma \nu_E \]

For \( z_{\text{max}} = 5; E_{\text{max}} = 10^{23} \text{eV}; \gamma = 2.47; m = 3.2 \)

\[ E_{\text{max}} z = 10^{21}; \Sigma \nu = \Sigma \nu_E \]
COSMOGENIC NEUTRINO FLUXES FROM AGN

\[ J(E) \propto E^3 \]

\[ E_{\nu} = 10^{17} \text{ eV} \text{ to } 10^{22} \text{ eV} \]

\[ \gamma_g = 2.52, \quad z_{\text{max}} = 2, \quad z_c = 1.2, \quad m = 2.7 \]

\[ E_{\text{max}} = 10^{21} \text{ eV} \text{ and } 10^{22} \text{ eV} \]
LOWER LIMIT ON NEUTRINO FLUXES IN THE PROTON MODELS

V.B. and A. Gazizov 2009

\[ E, \text{ eV} \]
\[ 10^{18}, 10^{19}, 10^{20}, 10^{21} \]

\[ J(E) \text{ eV}^3 \times \text{ m}^{-2} \times \text{ sec}^{-1} \times \text{ ster}^{-1} \]

\[ E_{\text{max}} = 10^{21} \text{ eV}; m=0 \]

\[ z_{\text{max}} = 2; \]

\[ p \]

\[ \Sigma_{\nu_i} \]

HiRes II
HiRes I
CASCADE UPPER LIMIT

V.B. and A. Smirnov 1975

\[
\begin{align*}
e - m \text{ cascade on target photons:} & \quad \left\{ \begin{array}{ll}
\gamma + \gamma_{\text{tar}} & \rightarrow e^+ + e^- \\
\gamma + \gamma_{\text{tar}} & \rightarrow e' + \gamma'
\end{array} \right.
\end{align*}
\]

Spectrum of cascade photons

\[
J_{\gamma}^{\text{cas}}(E) = \begin{cases} 
K(E/\varepsilon_X)^{-3/2} & \text{for } E \leq \varepsilon_X, \\
K(E/\varepsilon_X)^{-2} & \text{for } \varepsilon_X \leq E \leq \varepsilon_a,
\end{cases}
\]

with a steepening at \( E > \varepsilon_a \), and \( \varepsilon_X = 1/3 (\varepsilon_a/m_e)^2 \varepsilon_{\text{cmb}} \).

\textbf{EGRET:} agreement with spectrum (1) and \( \omega_{\gamma}^{\text{obs}} \sim 3 \times 10^{-6} \text{eV/cm}^3 \).
UPPER LIMIT ON NEUTRINO FLUX

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

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

$E^{-2}$ - generation spectrum: $E^2 J_{\nu_i}(E) < \frac{c}{12\pi \ln E_{\text{max}}/E_{\text{min}}} \frac{\omega_{\text{cas}}}{\nu + \bar{\nu}}$ etc.
\[ \omega_{\text{cas}}^{\text{max}} = 5.8 \times 10^{-7} \text{ eVcm}^{-3} \]
OBSERVATIONAL AND THEORETICAL UPPER LIMITS

V.B., Gazizov, Kachelriess, Ostapchenko 2010.

\[ \nu : \bar{\nu} : \nu = 1:1:1 \]

[Graph showing energy spectrum and data points for different experiments such as ANITA, BAIKAL, Auger, ANITA-lite, RICE, JEM-EUSO, IceCube 5yr.]
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](image1.png)  
![MS NETWORK](image2.png)
ORDINARY and SUPERCONDUCTING STRINGS

Ordinary strings are produced at $U(1)$ symmetry breaking, i.e. by the Higgs mechanism: $\mathcal{L} = \lambda (\phi^+ \phi - \eta^2)^2$.

They are produced as long strings and closed loops.

The fundamental property of a loop is oscillation with periodically produced cusp, where $v \to c$.

In a wide class of particle physics strings are superconducting (Witten 1985)

$$\frac{dJ}{dt} \propto e^2 E$$

If a string moves through magnetic field the electric current is induced

$$J \sim e^2 v B t$$

The charge carriers $X$ are massless inside the string, and massive outside. When current exceeds the critical value $J_c \sim e m_X$, the charge carriers $X$ can escape. Energy of released particles is $E_X \sim \gamma e m_X$, they are emitted in a cone $\theta \sim 1/\gamma_c$.

In ordinary strings the neutral particles, e.g. Higgses, can escape through a cusp, too.
Basic parameter: symmetry breaking scale $\eta \gtrsim 1 \times 10^9$ GeV.

Lorentz factor of cusp $\gamma_c \sim 10^{12}$.

Electric current is generated in magnetic fields $(B, f_B)$.

Clusters of galaxies dominate.

$J \sim e^2 B l, \quad J_{\text{cusp}} \sim \gamma_c J, \quad J_{\text{cusp}}^{\text{max}} \sim i_c e \eta$.

Particles are ejected with energies $E_X \sim i_c \gamma_c \eta \sim 10^{22}$ GeV.

Diffuse neutrino flux:

$$E^2 J_\nu(E) = 2 \times 10^{-8} i_c B_{-6} f_{-3} \text{ GeV cm}^{-2} \text{s}^{-1}$$

does not depend on $\eta$ in a range $\eta > 1 \times 10^9$ GeV.

Signatures:

- Correlation of neutrino flux with clusters of galaxies.

- Detectable flux of 10 TeV gamma ray flux from Virgo cluster.

- Multiple simultaneous neutrino induced EAS in field of view of JEM-EUSO.
Necklaces
V.B., A. Vilenkin, PRL 79, 5202, 1997

\[ G \rightarrow H \times U(1) \rightarrow H \times Z_2 \]

mass of monopole: \( m = 4\pi \eta_m/e \), tension: \( \mu = 2\pi \eta_s^2 \)

Due to gravitational radiation, strings shrink, and monopoles inevitably annihilate.

\[ M + \bar{M} \rightarrow A_\mu, H \rightarrow \text{pions} \rightarrow \text{neutrinos} \]

Production rate of X-particles: \( \dot{n}_X \sim r^2 \mu/t^3 m_X \), where \( r = m/\mu d \).

Energy density \( \omega \sim m_X \dot{n}_X t \) must be less \( 2 \times 10^{-6} \text{ eV/cm}^3 \) (EGRET).

\[ r^2 \mu \leq 8.5 \times 10^{27} \text{ GeV}^2 \]

Neutrino energy: \( E_{\nu}^\text{max} \sim 0.1 m_X \sim 10^{13}(m_X/10^{14}) \text{ GeV} \)
UHE NEUTRINOS FROM NECKLACES

\[ M_X = 1 \times 10^{14} \text{ GeV} \]

\[ E^3 J(E) \text{ (eV}^2 \text{m}^{-2} \text{s}^{-1} \text{sr}^{-1}) \]

\[ E \text{ (eV)} \]

\[ p + \gamma \]

\[ \nu \]

\[ \gamma \]
Due to cosmological evolution monopoles become relativistic at \( t \sim t_0: \Gamma_0 \gg 1 \).

Monopoles oscillate due to \( f = \mu \) and obtain a proper acceleration \( a_{\text{max}} = \frac{2}{3\sqrt{3}}\Gamma_0^2\Omega \).

In case \( a \gg m_X \) (\( m_X \) is the boson mass) accelerated monopoles can radiate the massive gauge bosons with

\[
P = \frac{g^2}{16\sqrt{6}\pi^2} \Gamma_0^3\Omega^2,
\]

\[
E_{\text{max}} = \Gamma_0 a_{\text{max}} = \frac{\pi^2}{3}\Gamma_0^3\Omega
\]

\( E_{\text{max}} \) REACHES THE PLANCKIAN SCALE!
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: $\vec{x} \rightarrow -\vec{x}$.
In particle space it corresponds to inversion operation $I_r$.
Reflection $\vec{x} \rightarrow -\vec{x}$ and time shift $t \rightarrow t + \Delta t$ 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:

  $$I_r \Psi_L = \Psi'_R \quad \text{and} \quad I_r \Psi_R = \Psi'_L$$

- 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:

\[ \mathcal{L}_{\text{comm}} = \frac{1}{M_{Pl}} (\bar{\psi} \phi)(\psi' \phi') \]  

where \( \psi_L = (\nu_L, \ell_L) \) and \( \phi = (\phi^0, -\phi^+'). \)

After SSB, Eq.(2) results in mixing of ordinary and mirror neutrinos.

\[ \mathcal{L}_{\text{mix}} = \frac{v_{EW}^2}{M_{Pl}} \nu \nu', \]

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

It implies oscillations between \( \nu \) and \( \nu'. \)

3. UHE NEUTRINOS FROM MIRROR TDs

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

\[ \rho_{\text{matter}}' \ll \rho_{\text{matter}}, \quad \rho_{\text{TD}}' \gg \rho_{\text{TD}} \]

**HE mirror \( \nu \)'s are produced by mirror TDs and oscillate into visible \( \nu \)'s.**

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


\[
P_{\nu'_\mu \nu_e} = \frac{1}{8} \sin^2 2\theta_{12}, \quad P_{\nu'_\mu \nu_\mu} = P_{\nu'_\mu \nu_\tau} = \frac{1}{4} - \frac{1}{6} \sin^2 2\theta_{12}, \quad \sum_\alpha P_{\nu'_\mu \nu_\alpha} = \frac{1}{2}.
\]

**Signature:** diffuse flux exceeds cascade upper limit.
CONCLUSIONS

- UHE neutrino astronomy has a balanced program of observations of reliably existing cosmogenic neutrinos, and top-down neutrinos predicted by the models beyond SM (e.g. topological defects or SHDM).

- Fluxes of cosmogenic neutrinos are strongly bounded by the cascade upper limit with the new extragalactic gamma-ray background radiation measured by Fermi-LAT. With this upper limit detectability of neutrino flux depends on maximum acceleration energy $E_{\text{max}}$. Acceleration to $E_p^{\text{max}} \sim 1 \times 10^{22}$ eV is a problem in astrophysics. With this $E_p^{\text{max}}$ cosmogenic neutrinos can be detected only marginally by JEM-EUSO. Fluxes of cosmogenic neutrinos are further lowered if heavy-nuclei make the substantial contribution to primary radiation, and are undetectable in case heavy nuclei are dominant component.

- Energies of cosmogenic neutrinos are expected below $E_\nu \sim 10^{21}$ eV, while energies of neutrinos in top-down scenarios should be much higher. Thus neutrinos with $E_\nu > 10^{21} - 10^{22}$ eV are a signal for a new physics.
PRINCIPLES OF EUSO OBSERVATIONS
Field of View of EUSO

EUSO ~ 300 x AGASA ~ 10 x Auger
EUSO (Instantaneous) ~ 3000 x AGASA ~ 100 x Auger

400km

EUSO
AGASA
50km Auger
H-IIA Launch Vehicle

Nov. 29, 2003
Accident happened
for the H-IIA Launch Vehicle No 6

Feb. 26, 2005
The H-IIA Launch Vehicle No. 7 with MTSAT-1R was launched successfully.

Jan. 24, 2006
The H-IIA Launch Vehicle No. 8 with the Advanced Land Observing Satellite "Daichi" (ALOS) was launched successfully.

Feb. 18, 2006
The H-IIA Launch Vehicle No. 9 with the Multi-functional Transport Satellite 2 (MTSAT-2) was launched successfully.