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:

$$p + \gamma_{\rm tar} \to \Delta^+ \to \pi^+ + n$$
$$\hookrightarrow \mu^+ + \nu_\mu$$
$$\hookrightarrow e^+ + \bar{\nu}_\mu + \nu_e$$

$$p + \gamma_{\rm tar} \to \pi^- + \text{all}$$
$$\hookrightarrow \mu^- + \bar{\nu}_\mu$$
$$\hookrightarrow e^- + \nu_\mu + \bar{\nu}_e$$

No τ-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**

COSMOGENIC NEUTRINOS

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

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

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

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COSMIC RAYS AT ULTRA HIGH ENERGIES (NEUTRINO?)

V. S. BERESINSKY and G. T. ZATSEPIN

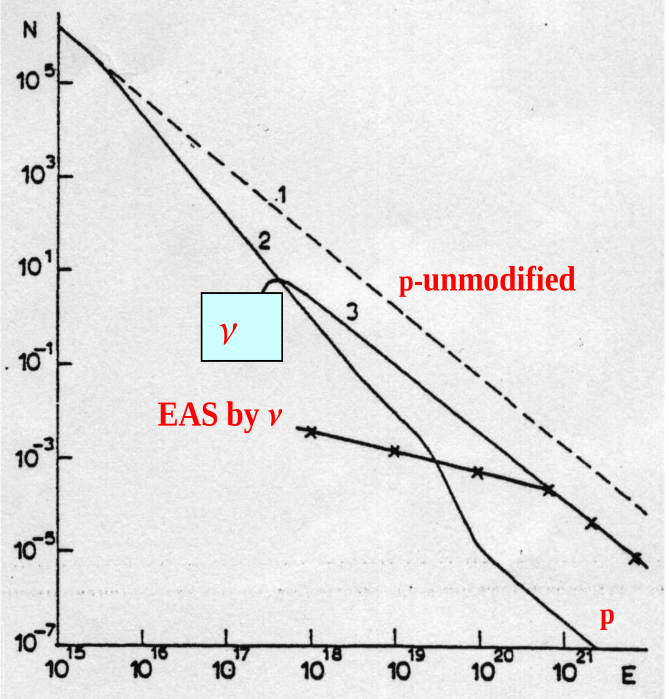
Academy of Sciences of the USSR. Physical Institute. Moscow

Received 8 November 1968

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 x 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 $E_{\max} \leq 10^{21}$ eV**
- **Neutrino flux is LARGE in evolutionary models with $E_{\max} \geq 10^{22}$ eV**

COSMOGENIC NEUTRINOS

IN THE DIP MODEL FOR UHECR

V.B. and Grigorieva 1988; V.B., Gazizov, Grigorieva 2005 - 2006.

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

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

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.

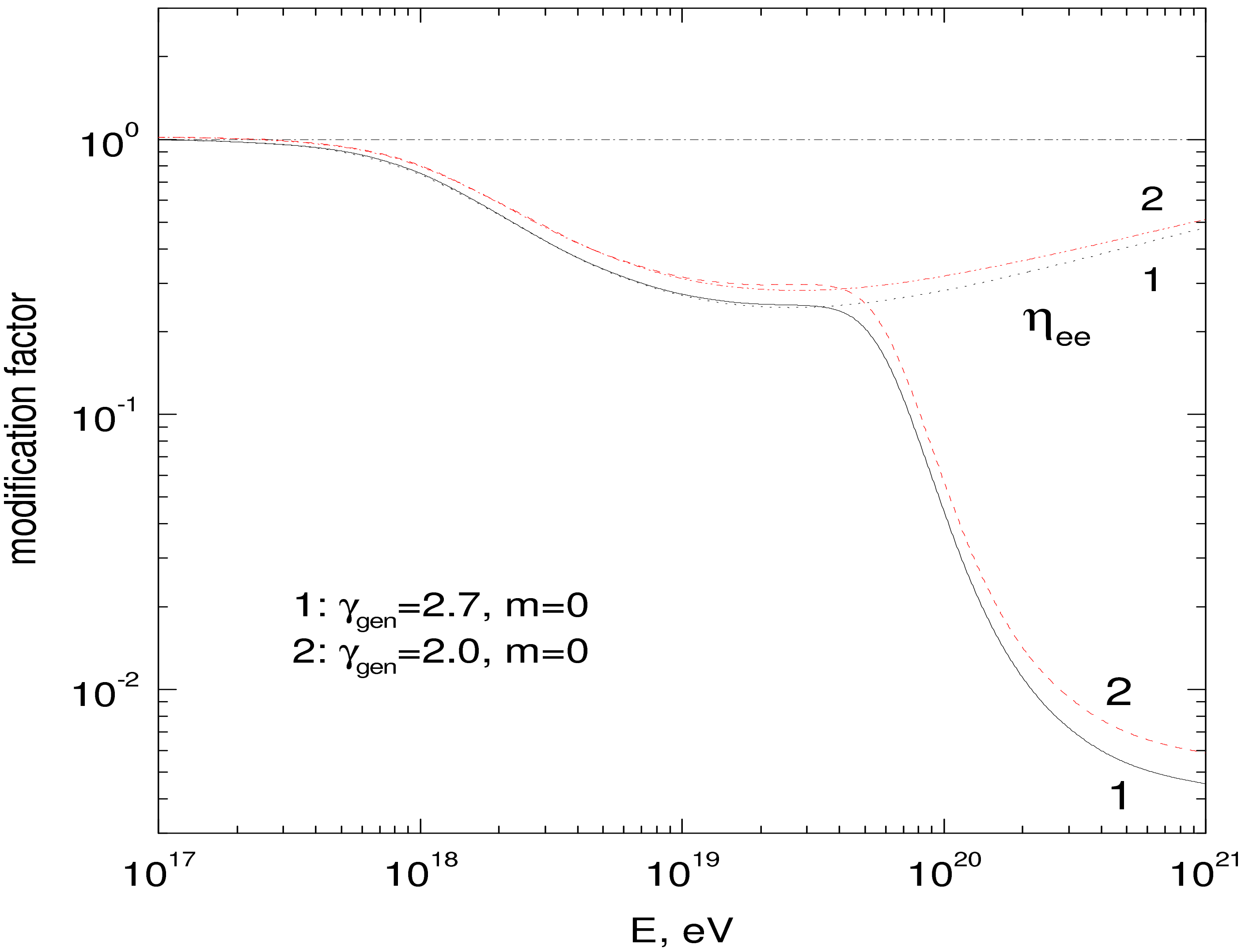
DIP AND GZK CUTOFF IN THE DIFFUSE SPECTRUM

DEFINITION OF MODIFICATION FACTOR

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

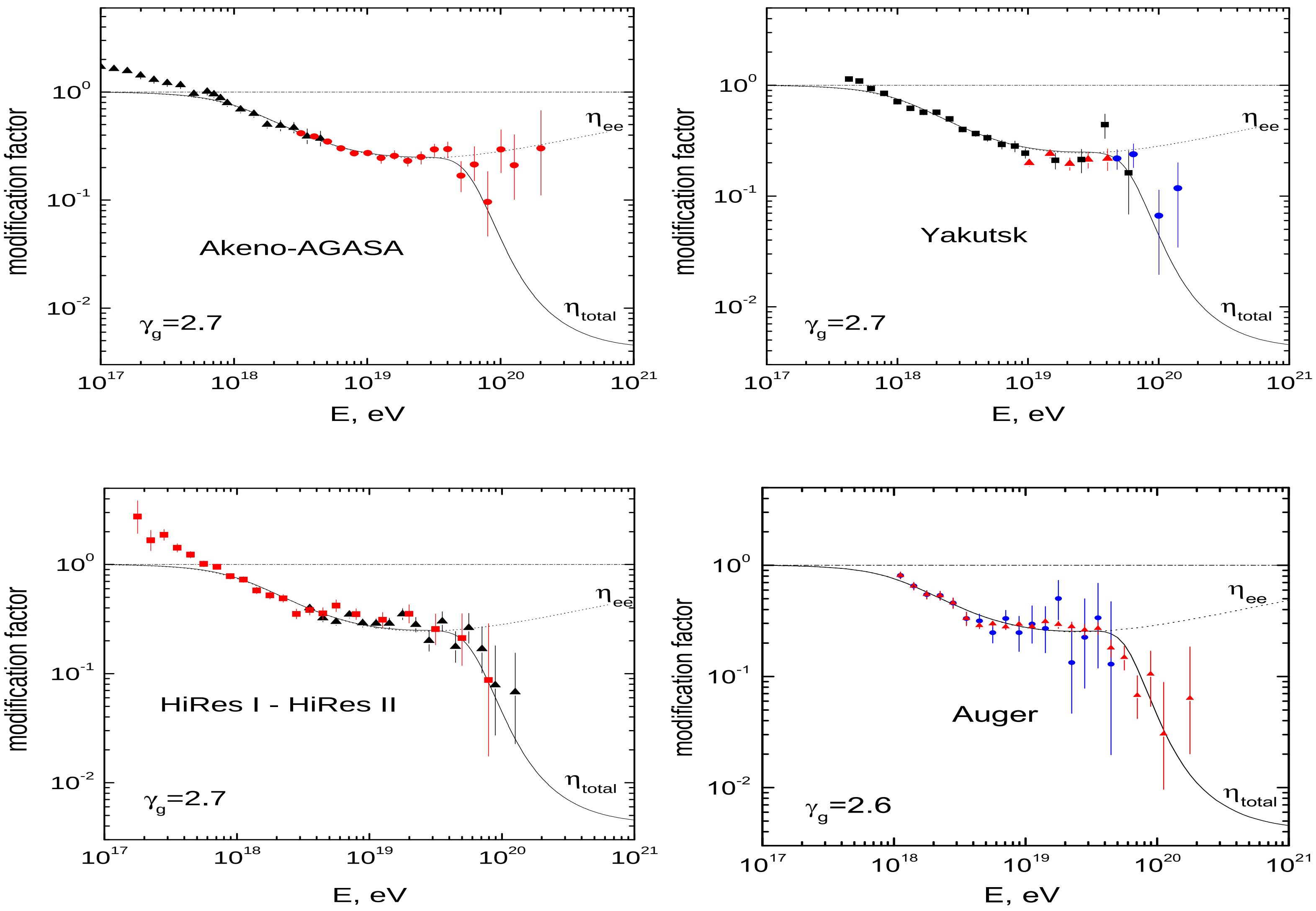
where $J_p^{\rm unm}(E)$ includes only adiabatic energy losses (redshift) and $J_p(E)$ includes total energy losses, $\eta_{\rm tot}(E)$ or adiabatic, e^+e^- energy losses, $\eta_{ee}(E)$.

DIP AND GZK CUTOFF IN TERMS OF MODIFICATION FACTOR

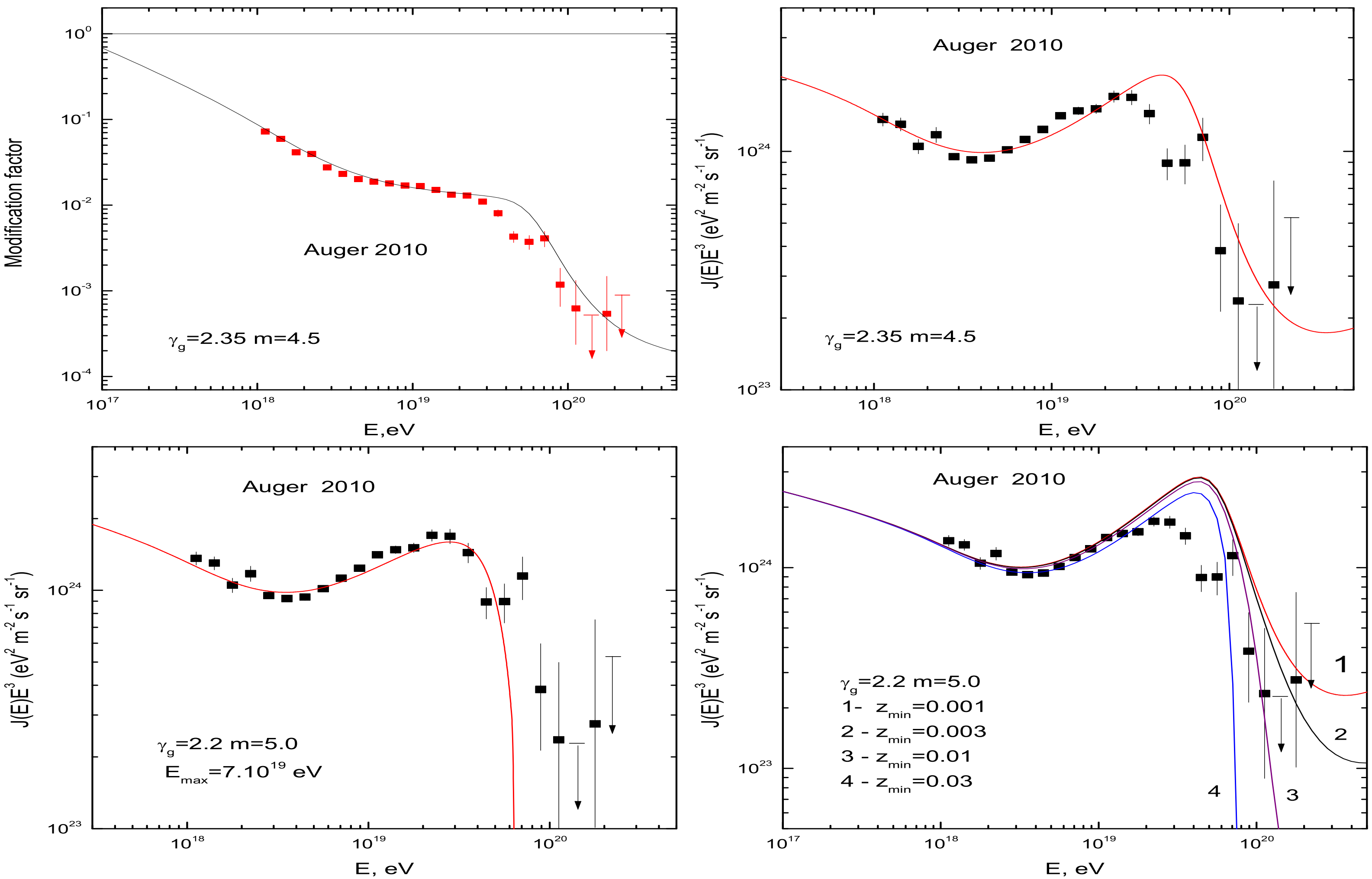


The dotted curve shows η_{ee}, when only adiabatic and pair-production energy losses are included. The solid and dashed curves include also the pion-production losses.

COMPARISON OF DIP WITH OBSERVATIONS



AUGER DATA 2010



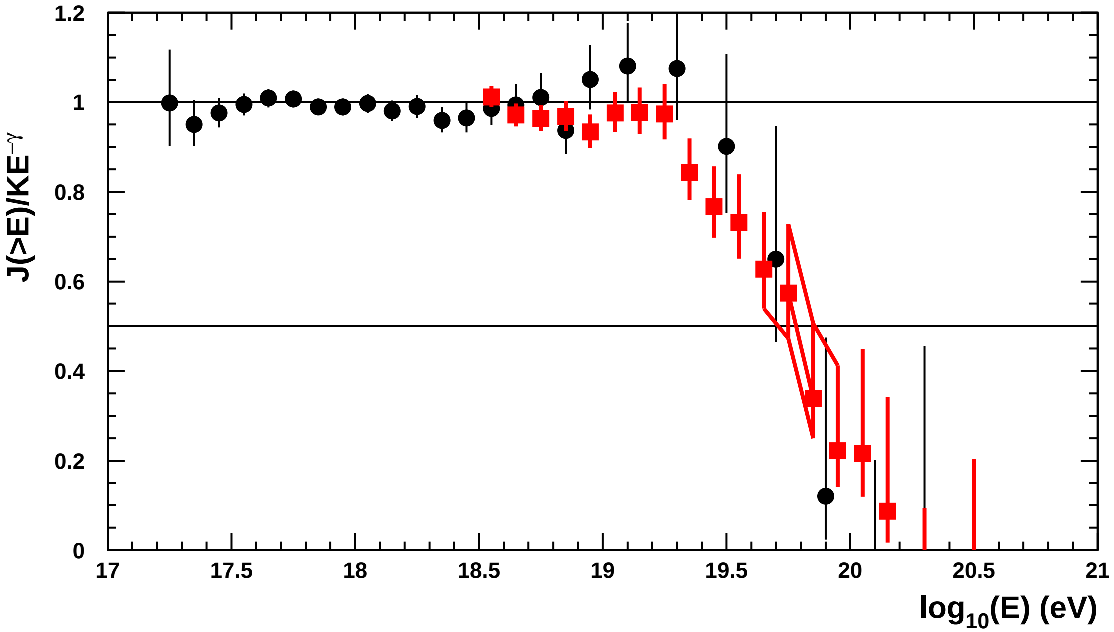
GZK CUTOFF IN HiRes DATA

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

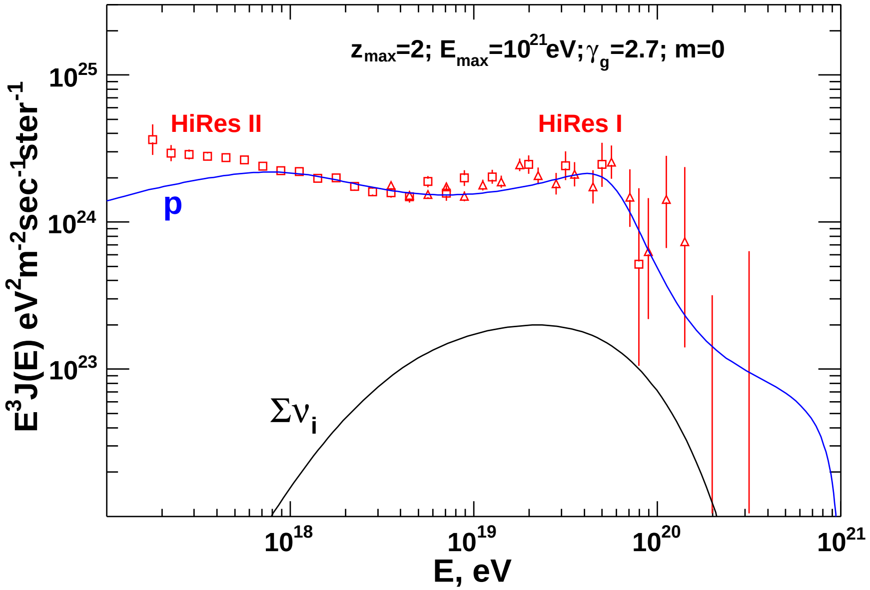
$$E_{1/2} = 10^{19.72}\ \mathrm{eV}$$

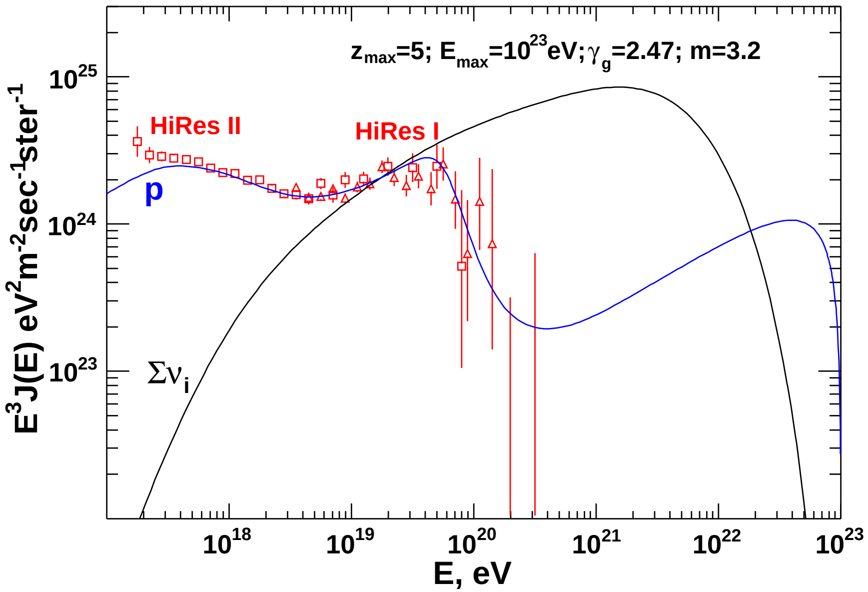
valid for a wide range of generation indices from 2.1 to 2.8. HiRes obtained:

$$E_{1/2} = 10^{19.73 \pm 0.07}\ \mathrm{eV}$$

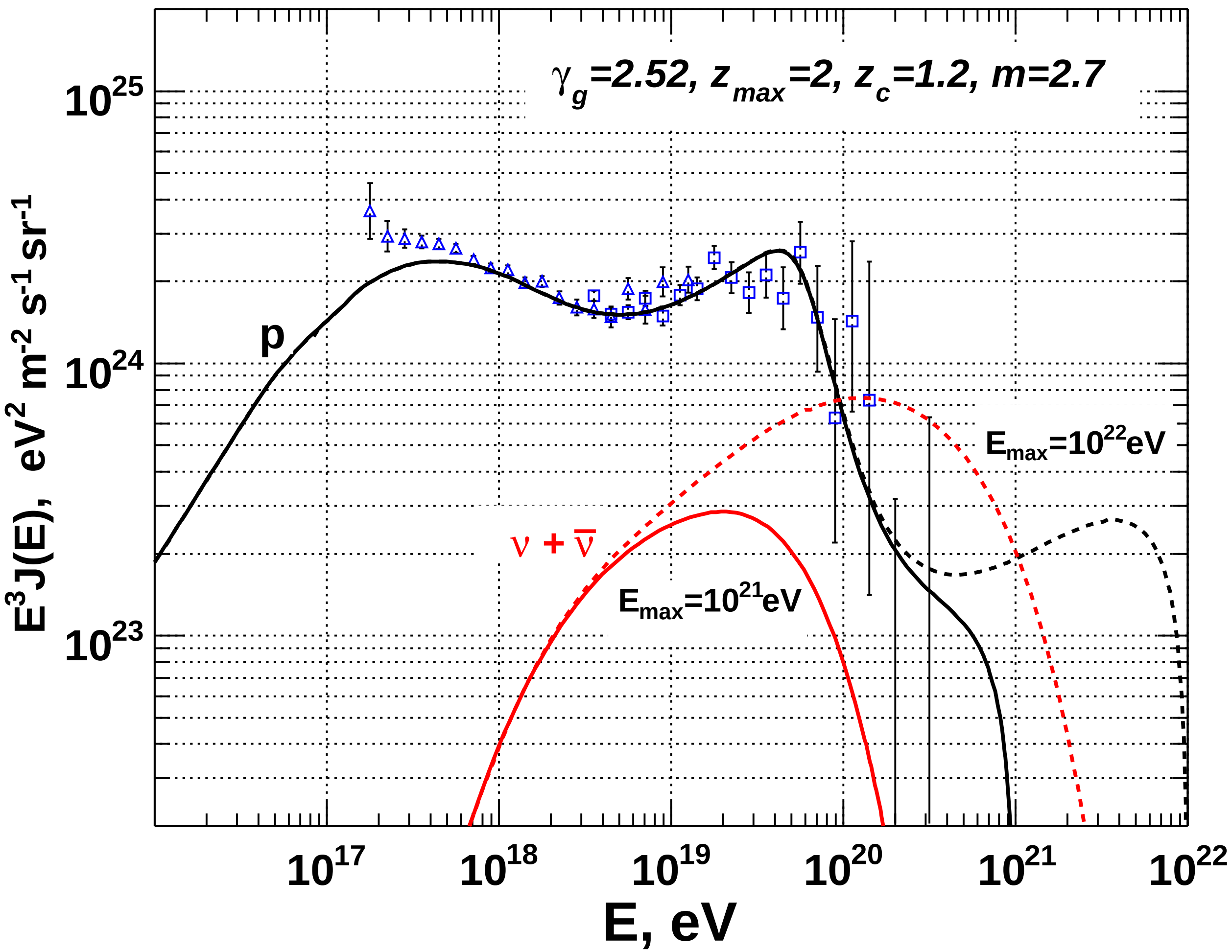


COSMOGENIC NEUTRINO FLUXES IN THE DIP MODEL



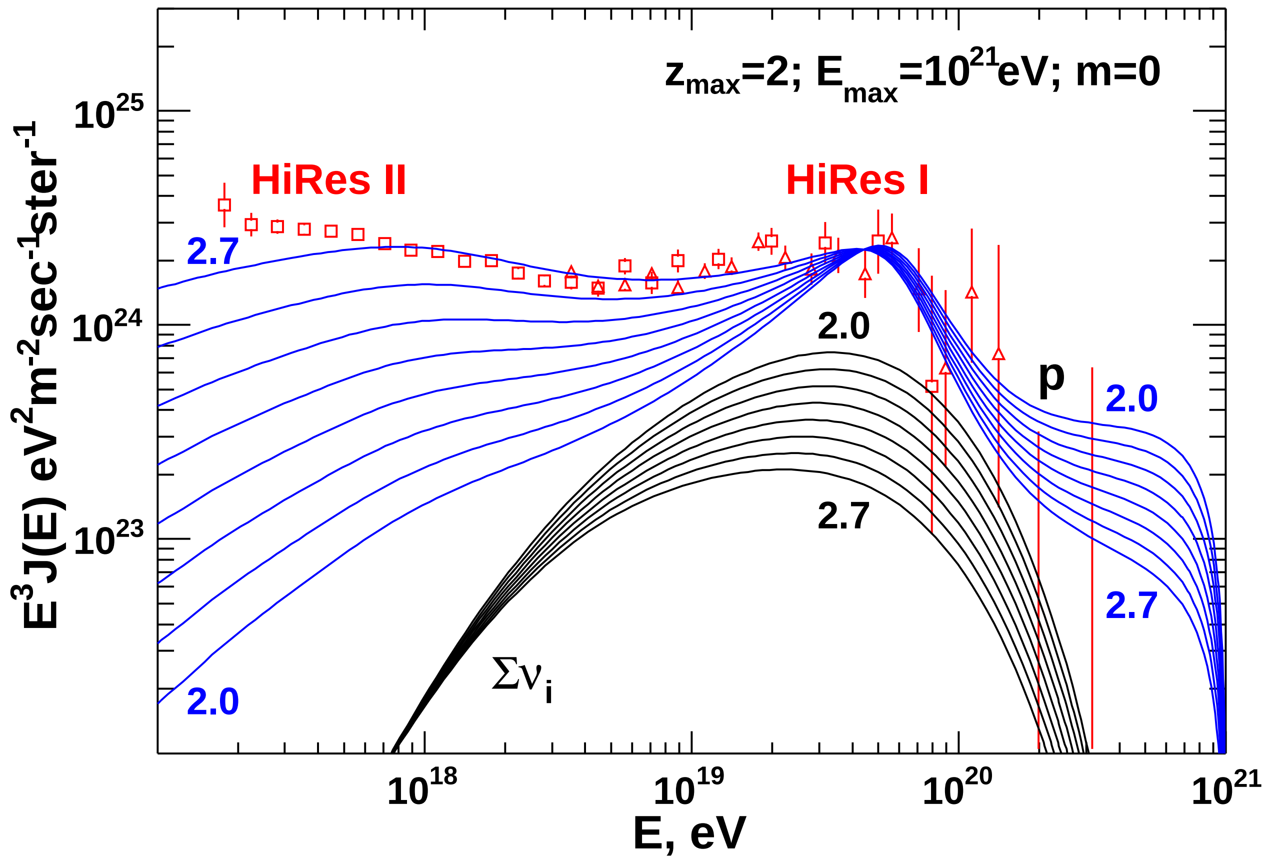


COSMOGENIC NEUTRINO FLUXES FROM AGN



LOWER LIMIT ON NEUTRINO FLUXES IN THE PROTON MODELS

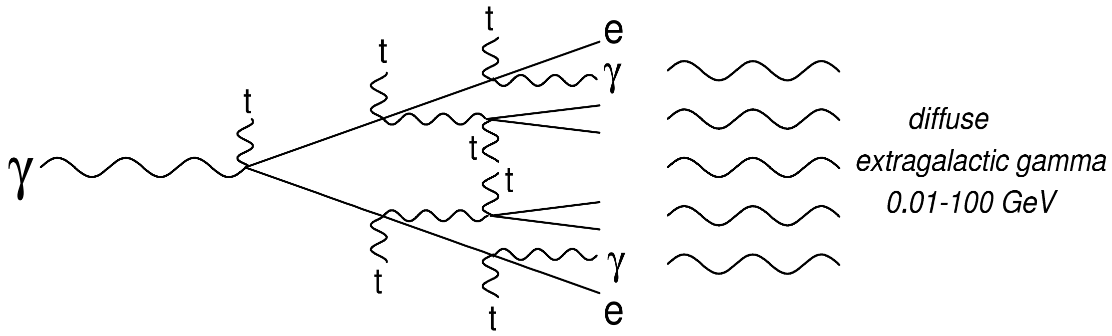
V.B. and A. Gazizov 2009



CASCADE UPPER LIMIT

V.B. and A.Smirnov 1975

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



Spectrum of cascade photons

$$J_\gamma^{\rm cas}(E) = \left\{ \begin{array}{lll} K(E/\varepsilon_X)^{-3/2} & \text{for} & E \leq \varepsilon_X\ , \\ K(E/\varepsilon_X)^{-2} & \text{for} & \varepsilon_X \leq E \leq \varepsilon_a\ , \end{array} \right. \quad (1)$$

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

EGRET: agreement with spectrum (1) and $\omega_\gamma^{\rm obs} \sim 3 \times 10^{-6}{\rm eV/cm}^3$.

UPPER LIMIT ON NEUTRINO FLUX

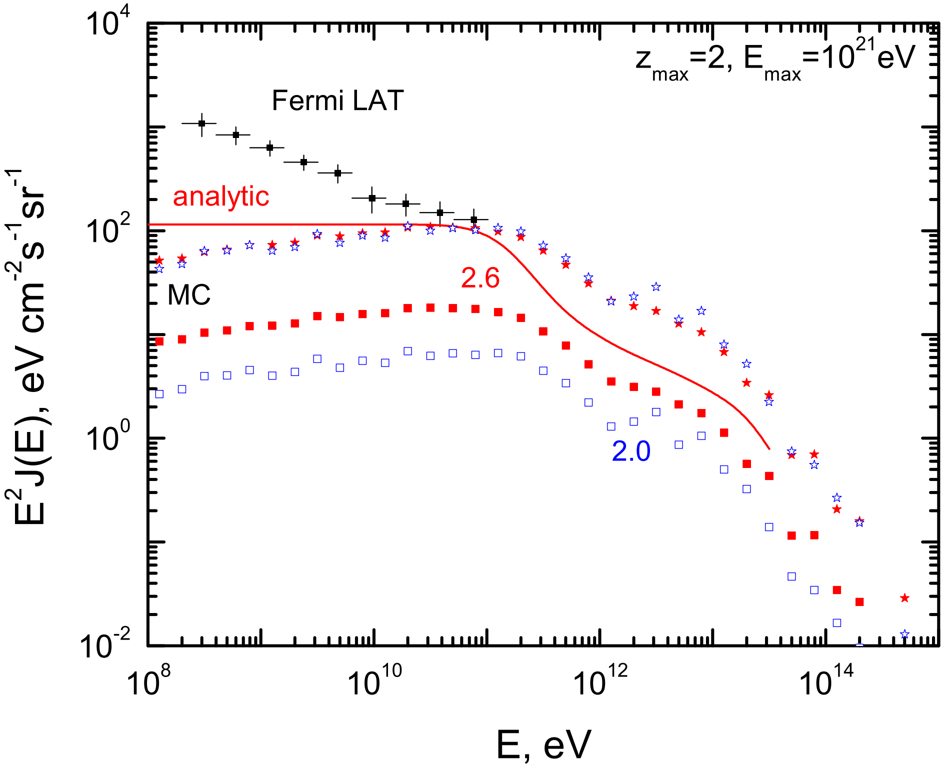
$$\omega_{\rm cas} > \frac{4\pi}{c}\int_E^\infty EJ_\nu(E)dE > \frac{4\pi}{c}E\int_E^\infty J_\nu(E)dE \equiv \frac{4\pi}{c}EJ_\nu(>E)$$

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

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

CASCADE UPPER LIMIT FROM FERMI LAT

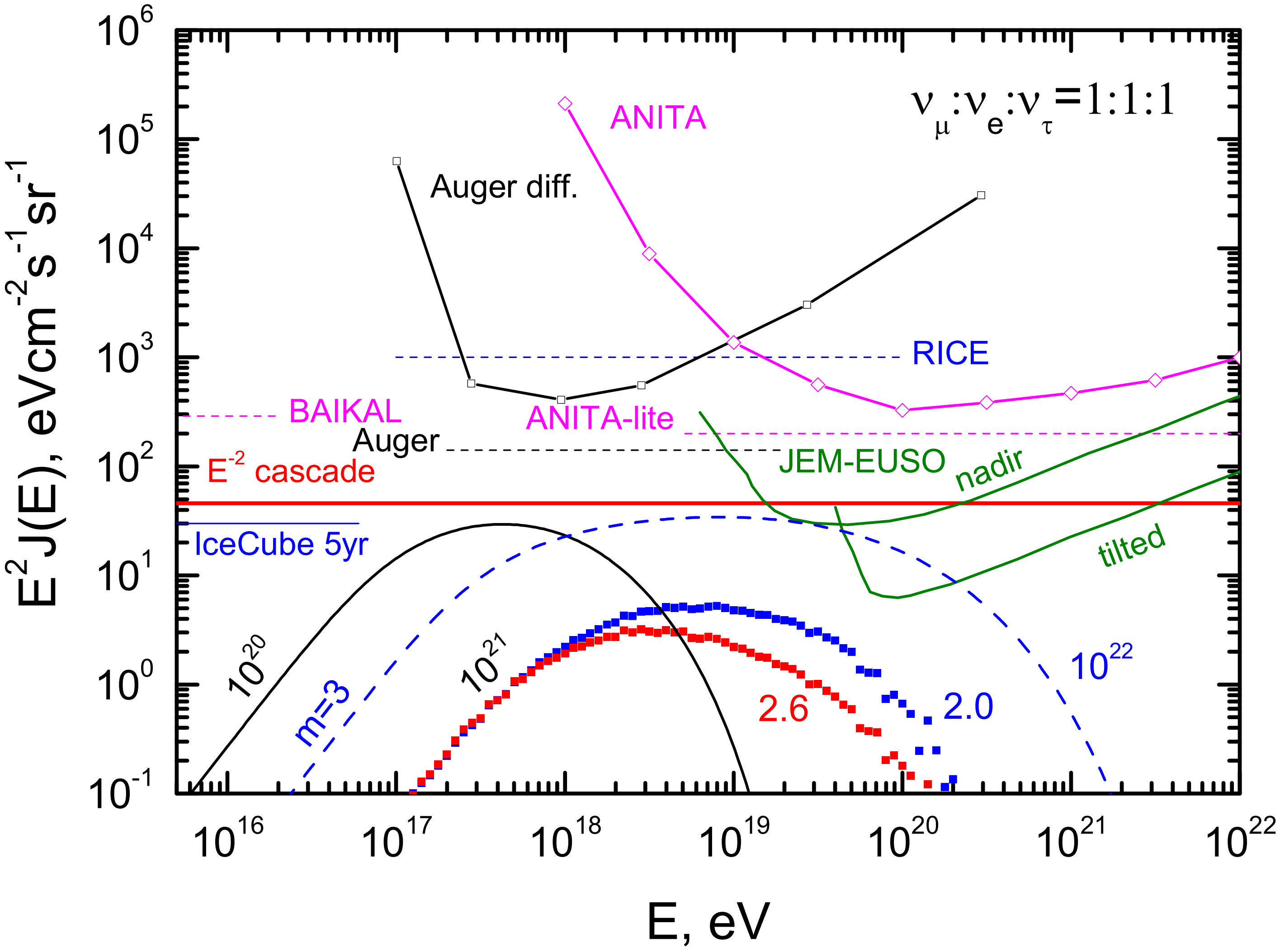
V.B., Gazizov, Kachelriess, Ostapchenko 2010.



$$\omega_{\text{cas}}^{\text{max}} = 5.8 \times 10^{-7} \text{ eVcm}^{-3}$$

OBSERVATIONAL AND THEORETICAL UPPER LIMITS

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



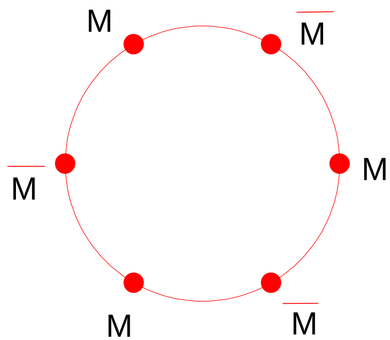
UHE NEUTRINOS FROM TOPOLOGICAL DEFECTS

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

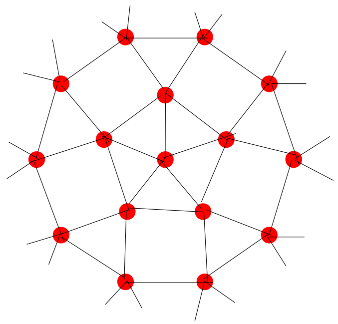
TDs OF INTEREST FOR UHE NEUTRINOS.

- **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 $Z_n = Z_2$**.**

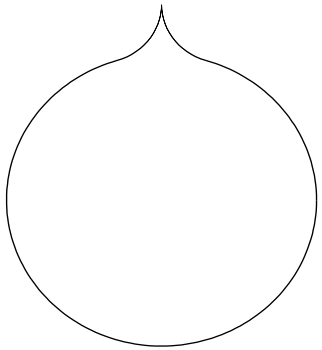
NECKLACE



MS NETWORK



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)

$$\mathbf{dJ/dt \propto e^2E}$$

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

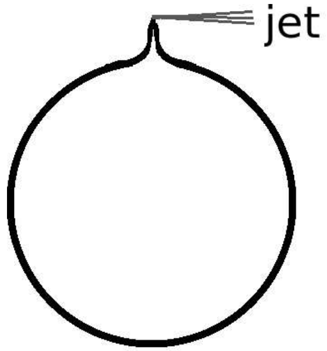
$$\mathbf{J \sim e^2vBt}$$

The charge carriers X are massless inside the string, and massive outside.
When current exceeds the critical value $J_c \sim em_X$, the charge carriers X can escape.
Energy of released particles is $E_X \sim \gamma_c m_X$, 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.

UHE neutrino jets from superconducting strings

V.B., K.Olum, E.Sabancilar and A.Vilenkin 2009



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.
$J \sim e^2 Bl,\quad J_{\rm cusp} \sim \gamma_c J,\quad J_{\rm cusp}^{\rm max} \sim i_c e\eta.$
Particles are ejected with energies $E_X \sim i_c \gamma_c \eta \sim 10^{22}$ GeV.

Diffuse neutrino flux :

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

does not depend on η 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

$$G \underset{\eta_m}{\longrightarrow} H \times U(1) \underset{\eta_s}{\longrightarrow} H \times Z_2$$

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.

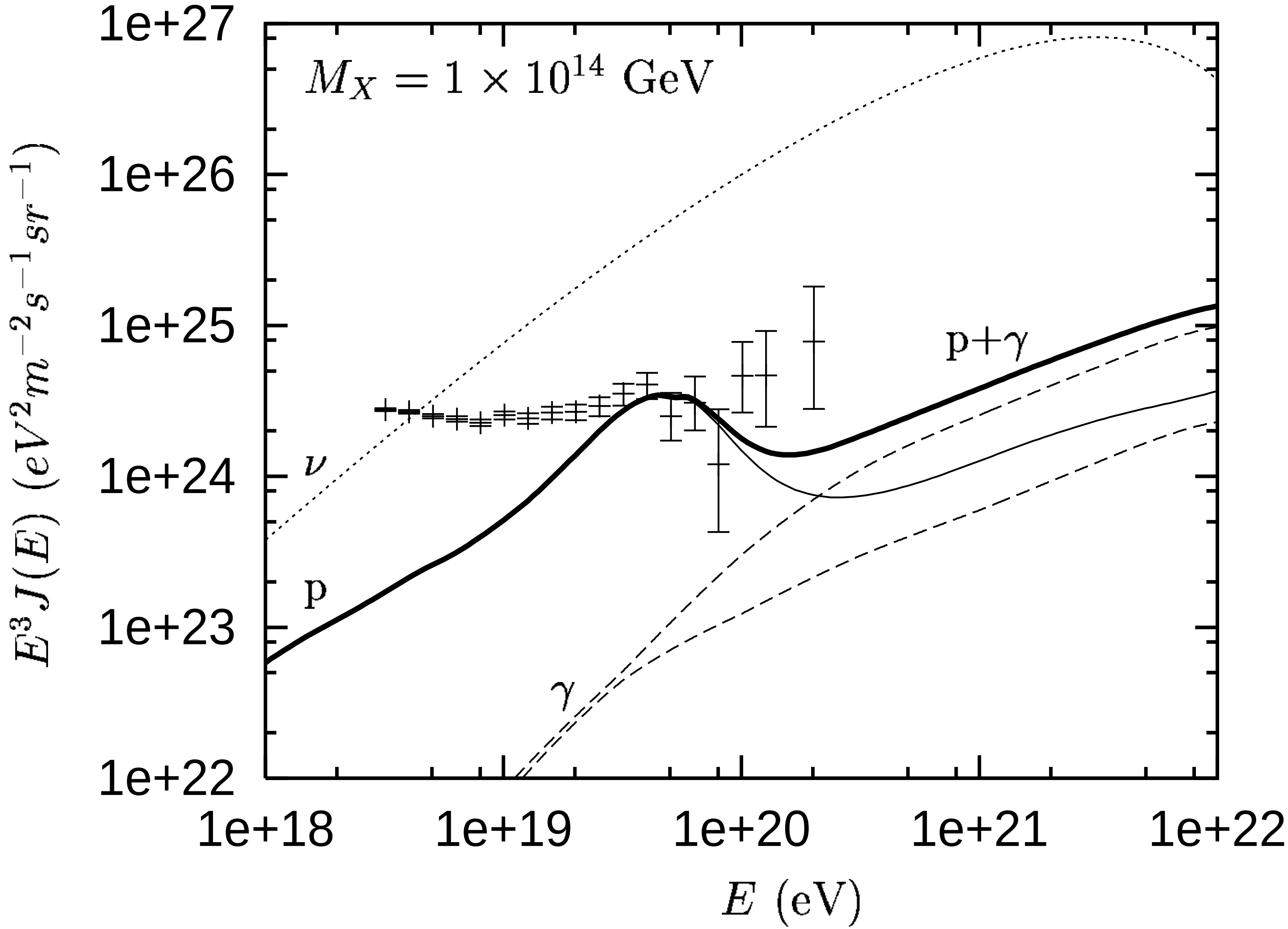
$$M + \bar{M} \to A_\mu, H \to \text{pions} \to \text{neutrinos}$$

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 2×10^{-6} eV/cm^3 (EGRET).

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

Neutrino energy: $E_\nu^{\max} \sim 0.1 m_X \sim 10^{13}(m_X/10^{14})$ GeV

UHE NEUTRINOS FROM NECKLACES



MONOPOLES CONNECTED BY STRINGS

V.B., X.Martin, A.Vilenkin, PR D56, 2024, 1997

$$G \underset{\eta_m}{\longrightarrow} H \times U(1) \underset{\eta_s}{\longrightarrow} H \times Z_N$$

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 $a_{\max} = \frac{2}{3\sqrt{3}}\Gamma_0^2\Omega$.

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

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

$$E_{\max} = \Gamma_0 a_{\max} = \frac{\pi^2}{3}\Gamma_0^3\Omega$$

$E_{\max}$ REACHES THE PLANCKIAN SCALE !

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:

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

- 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:

$$\mathcal{L}_{\rm comm} = \frac{1}{M_{\rm Pl}}(\bar{\psi}\phi)(\psi'\phi') \tag{2}$$

where $\psi_L = (\nu_L,\ \ell_L)$ and $\phi = (\phi_0^*,\ -\phi_+^*)$.
After SSB, Eq.(2) results in mixing of ordinary and mirror neutrinos.

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

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

short-distance and **long-distance** oscillations (V.B, Narayan, Vissani 2003):

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

Signature: diffuse flux exceeds cascade upper limit.

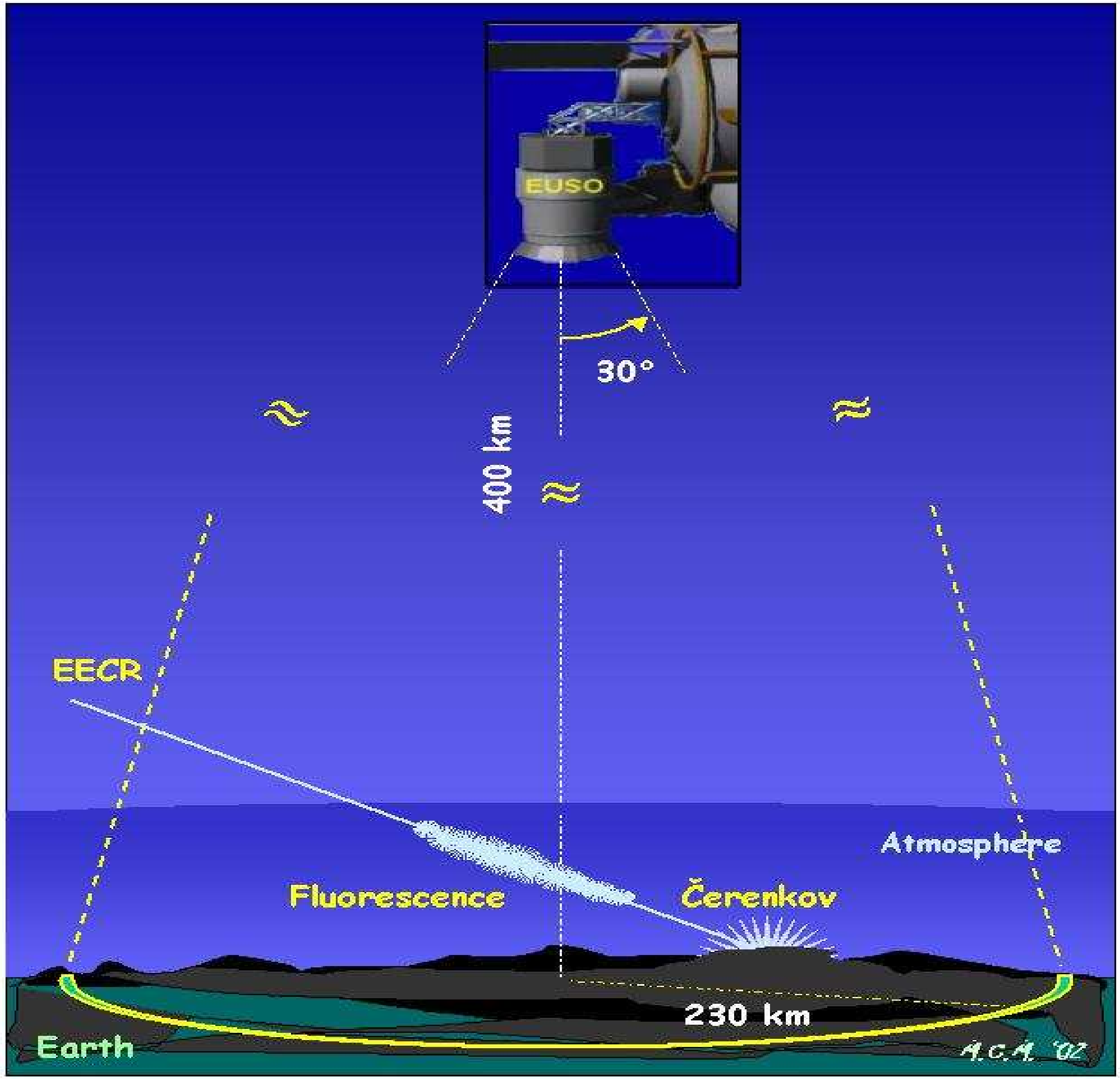
CONCLUSIONS

- **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 $E_{\max}$. Acceleration to $E_p^{\max} \sim 1 \times 10^{22}$ eV is a problem in astrophysics. With this $E_p^{\max}$ 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.**

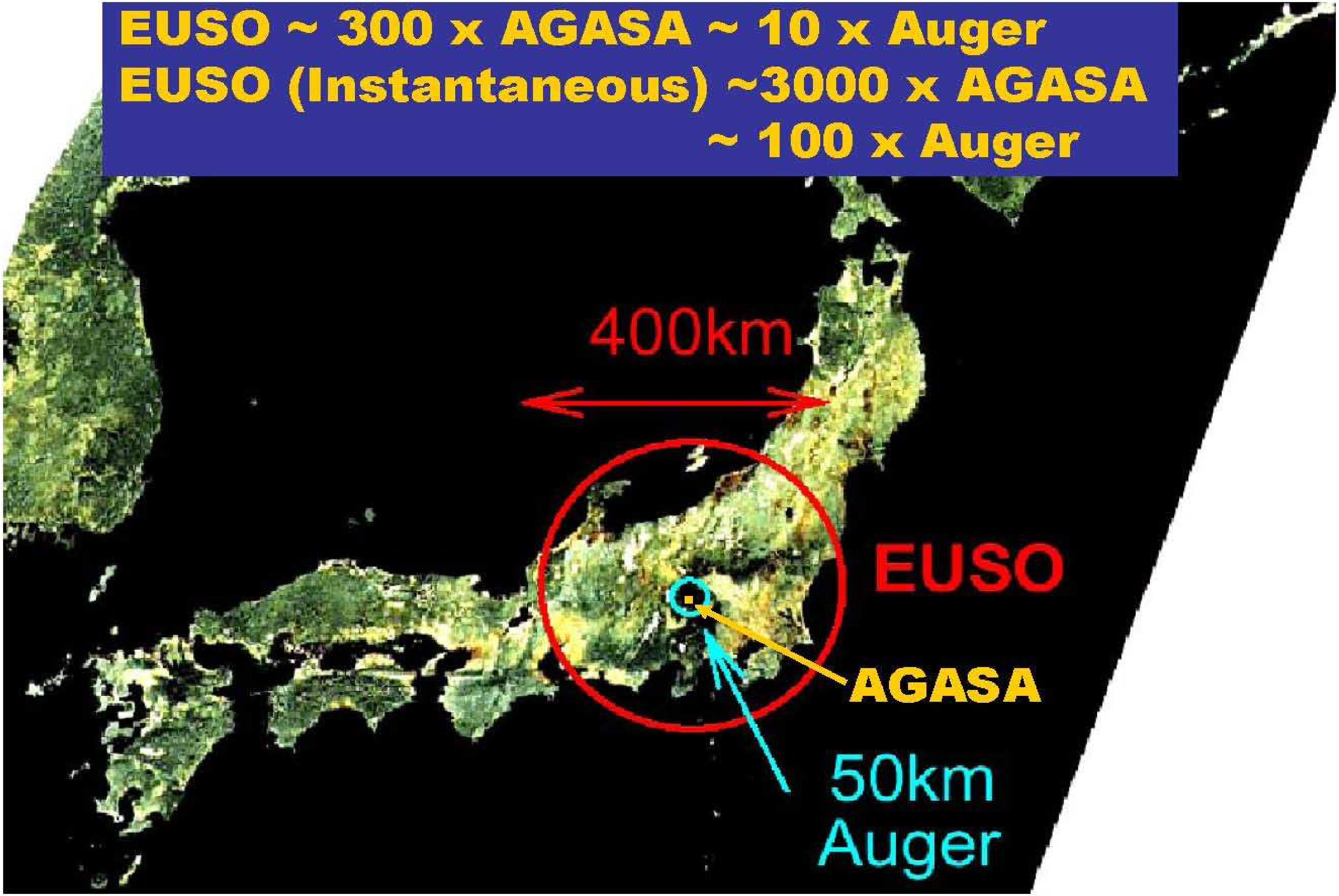
- **Energies of cosmogenic neutrinos are expected below $E_\nu \sim 10^{21}$ eV, while energies of neutrinos in top-down scenarios should be much higher. Thus neutrinos with $E_\nu > 10^{21} - 10^{22}$ eV are a signal for a new physics.**

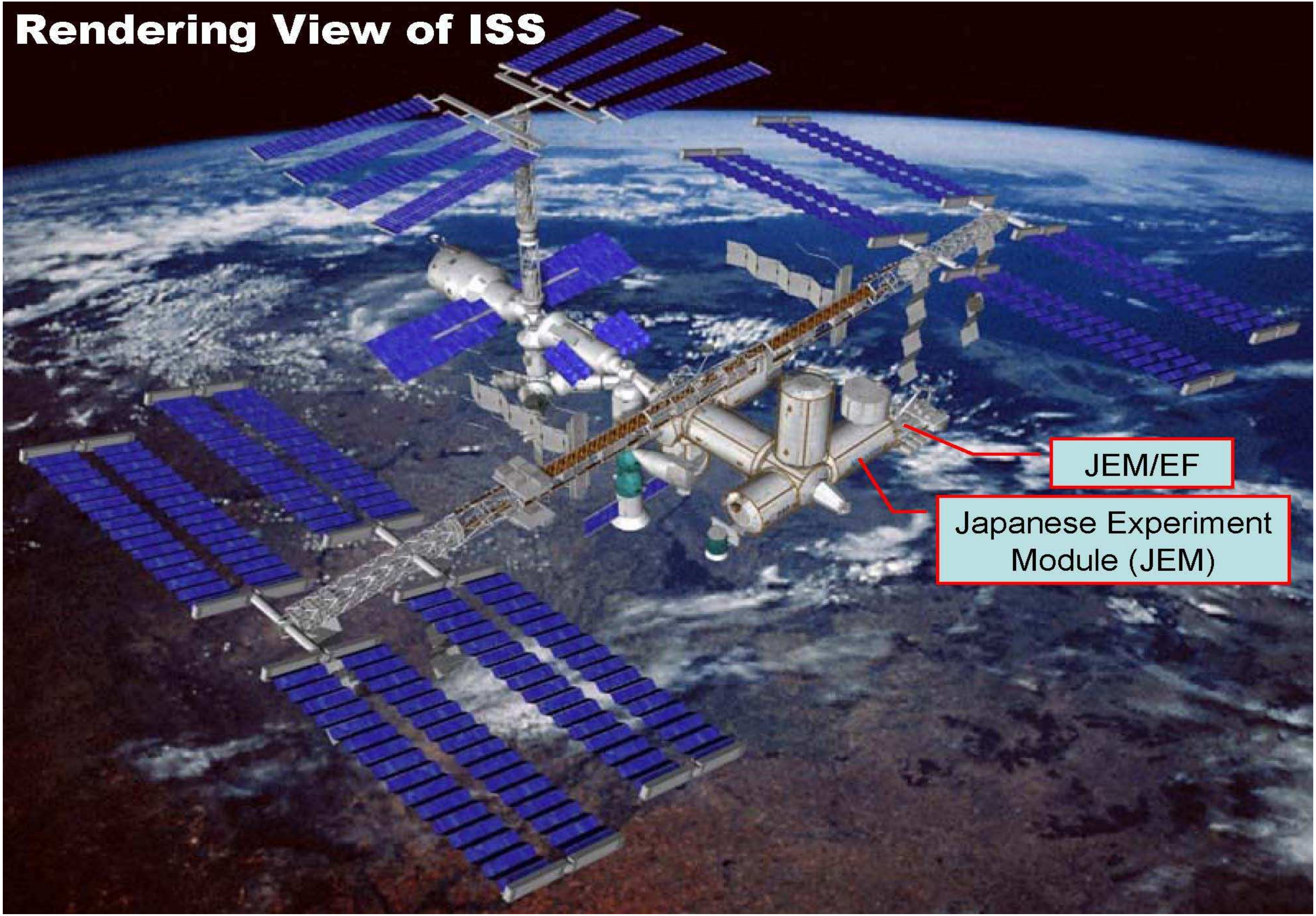
PRINCIPLES OF EUSO OBSERVATIONS



Field of View of EUSO

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




Rendering View of ISS
JEM/EF
Japanese Experiment
Module (JEM)

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.