IMPACT OF OSCILLATIONS ON UHE NEUTRINO ASTRONOMY

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Oscillations of HE and UHE cosmic neutrinos

Characteristic distances to the sources are $r \gg \ell_{\rm osc}$.

$$\ell_{\rm osc}^{\rm max} = \frac{4\pi E_{\rm max}}{(\Delta m^2)_{\rm min}} \approx 120{\rm pc}\left(\frac{E}{10^{20}{\rm eV}}\right)\left(\frac{7\times 10^{-5}{\rm eV}^2}{\Delta m^2}\right)$$

mixing: $\nu_\alpha = U_{\alpha k}\nu_k, \quad \alpha = e, \mu, \tau, \quad k = 1, 2, 3$

mixing matrix for $U_{e3} = 0$ and $\theta_{23} = \pi/4$:

$$U = \begin{pmatrix} c_{12} & s_{12} & U_{e3} \\ -s_{12}c_{23} & c_{12}c_{23} & s_{23} \\ s_{12}s_{23} & -c_{12}s_{23} & c_{23} \end{pmatrix} \to \begin{pmatrix} c_{12} & s_{12} & 0 \\ -\frac{s_{12}}{\sqrt{2}} & \frac{c_{12}}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ \frac{s_{12}}{\sqrt{2}} & -\frac{c_{12}}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{pmatrix}.$$

Since $< \sin r/l_{\rm osc} >= 0$ and $< \sin^2 r/l_{\rm osc} >= \frac{1}{2}$, the propagation matrix:

$$P_{\alpha\beta} = \sum |U_{\alpha i}|^2 |U_{\beta i}|^2$$

for normal generation composition: $\nu_e : \nu_\mu : \nu_\tau = 1 : 2 : 0 \quad \to 1 : 1 : 1$

for $\pi \to \mu\nu$ generation composition: $\nu_e : \nu_\mu : \nu_\tau = 0 : 1 : 0 \quad \to \frac{1}{2} : 1 : 1$

neutrino decays violate neutrino equipartition.

Observational effects caused by oscillations

Resonant events

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

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

Resonance interaction

Glashow resonance (1960): $\bar{\nu}_e + e^- \to W^- \to \mu^- + \bar{\nu}_\mu$

V.B. and Gazizov (1977): $\bar{\nu}_e + e^- \to W^- \to \text{hadrons}$

$$E_0 = \frac{m_W^2}{2m_e} = 6.3 \times 10^6 \text{GeV}$$

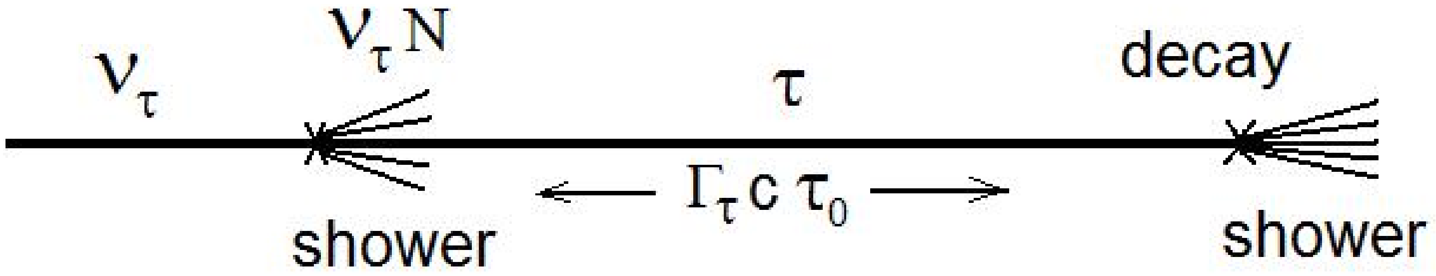
$$\nu_{\rm res} = 2\pi \sigma_{\rm eff} E_0 J_{\bar{\nu}_e}(E_0) N_e, \qquad \sigma_{\rm eff} = \frac{8\pi}{3\sqrt{2}} G_F = 2.7 \times 10^{-32} \text{cm}^2$$

deficit of $\bar{\nu}_e$ at generation: $\bar{\nu}_e : \bar{\nu}_\mu : \bar{\nu}_\tau \approx 0 : 1 : 0 \to \frac{1}{2} : 1 : 1$

$$\left(\frac{\text{signal}}{\text{bcgr}}\right)_{\nu_{pp}} = 33.4 \frac{0.2}{\eta}, \qquad \eta \text{ is energy resolution.}$$

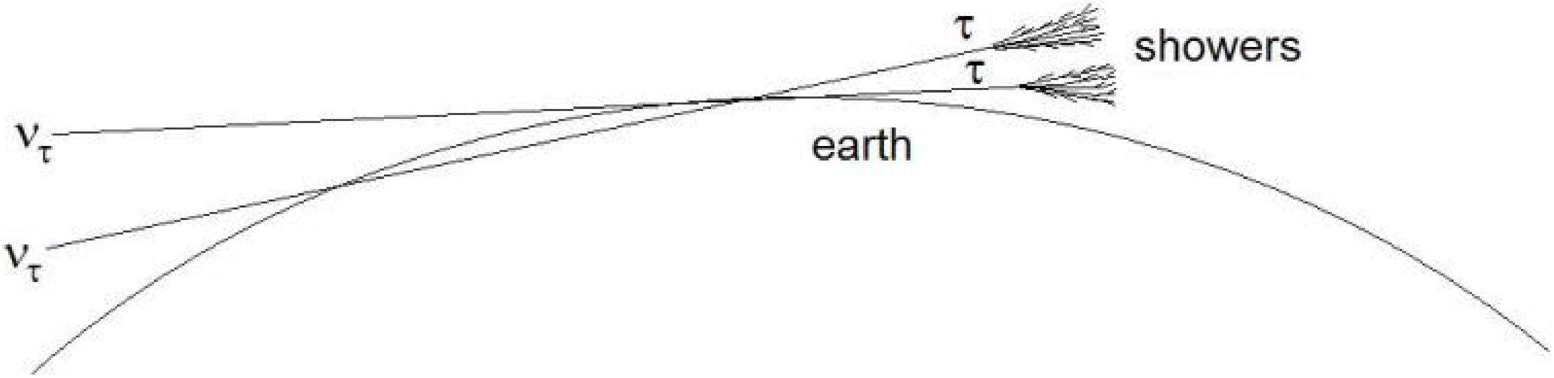
τ - neutrinos

Double-bang effect (Learned, Pakvasa 1995)



$E_\tau \sim 10^{15}$ eV:	$\Gamma_\tau c\tau_0 \sim 50$ m	IceCube
$E_\tau \sim 10^{18}$ eV:	$\Gamma_\tau c\tau_0 \sim 50$ km	Auger, EUSO

Earth skimming effect (Fargion 2000)



ULTRA HIGH ENERGY NEUTRINOS

$E_\nu \gtrsim 10^{18}$ **eV**

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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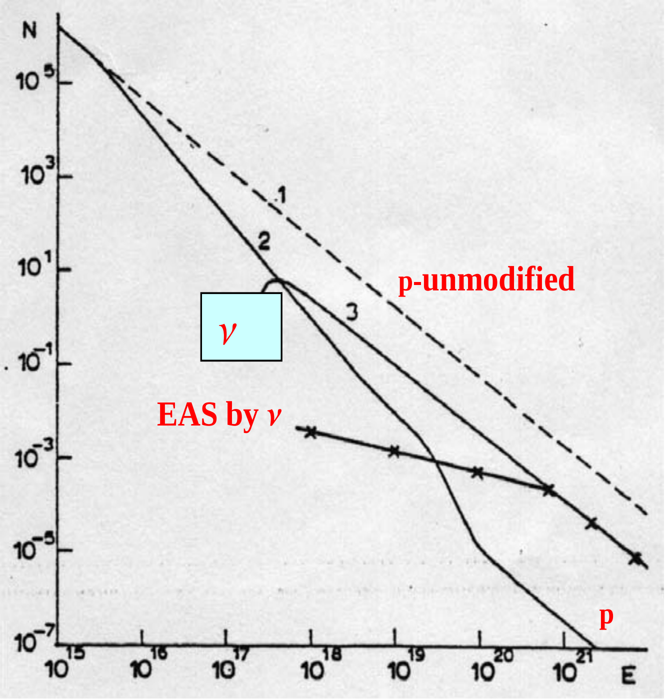
Received 8 November 1968

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~3xl0^{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 l0^{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** $E_{\max} \leq 10^{21}$ **eV**
- **Neutrino flux is LARGE in evolutionary models with** $E_{\max} \geq 10^{22}$ **eV**

COSMOGENIC NEUTRINOS
IN THE DIP MODEL FOR UHECR

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

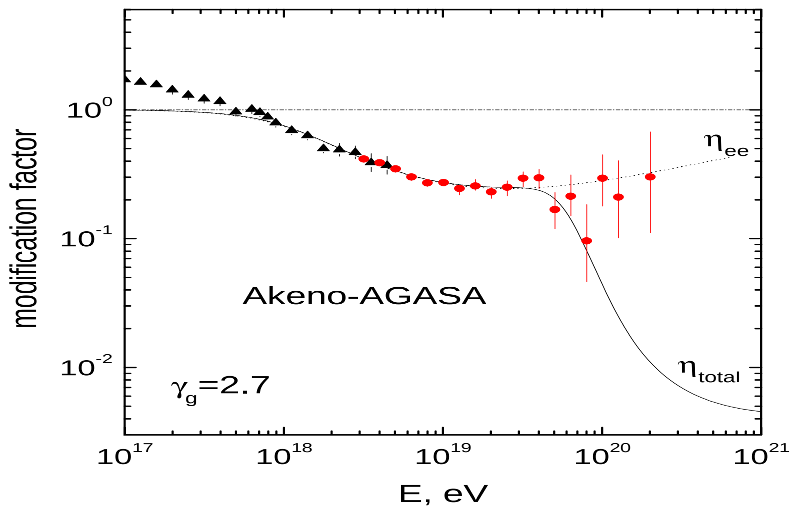
$$\mathbf{p} + \gamma_{\rm CMB} \rightarrow \mathbf{e}^+ + \mathbf{e}^- + \mathbf{p}$$

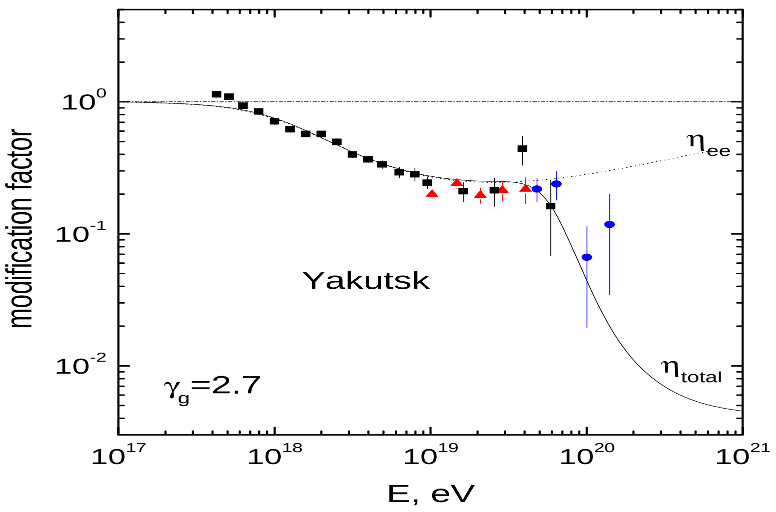
Calculated in the terms of **modification factor** $\eta(E)$ the dip is seen in all observational data.

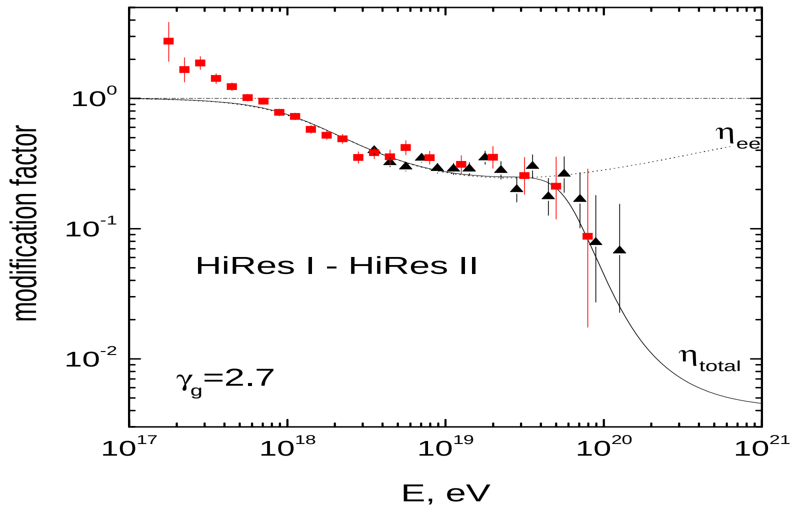
$$\eta(\mathbf{E}) = \frac{\mathbf{J_p(E)}}{\mathbf{J_p^{\rm unm}(E)}} \, ,$$

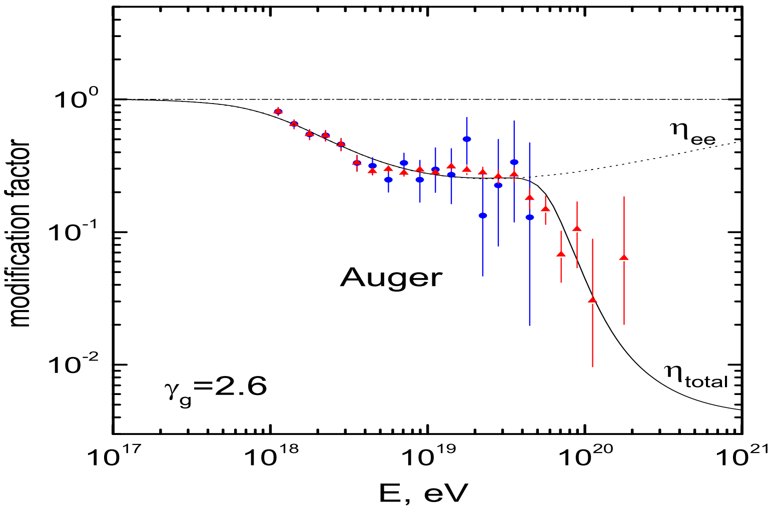
where $J_p^{\rm unm}(E)$ includes only adiabatic energy losses and $J_p(E)$ - all energy losses.

COMPARISON OF DIP WITH OBSERVATIONS

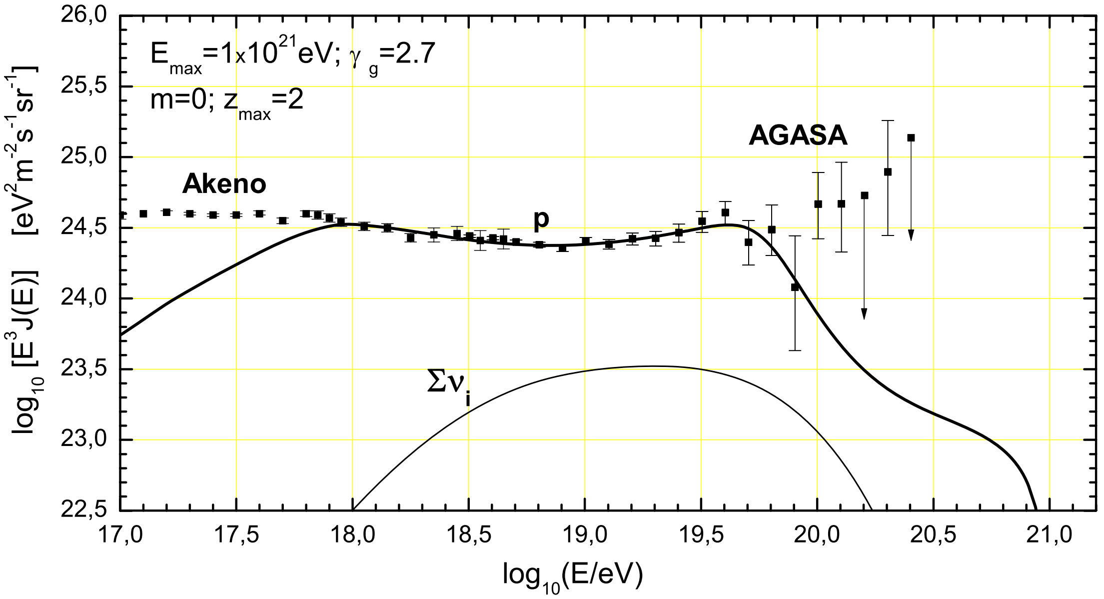


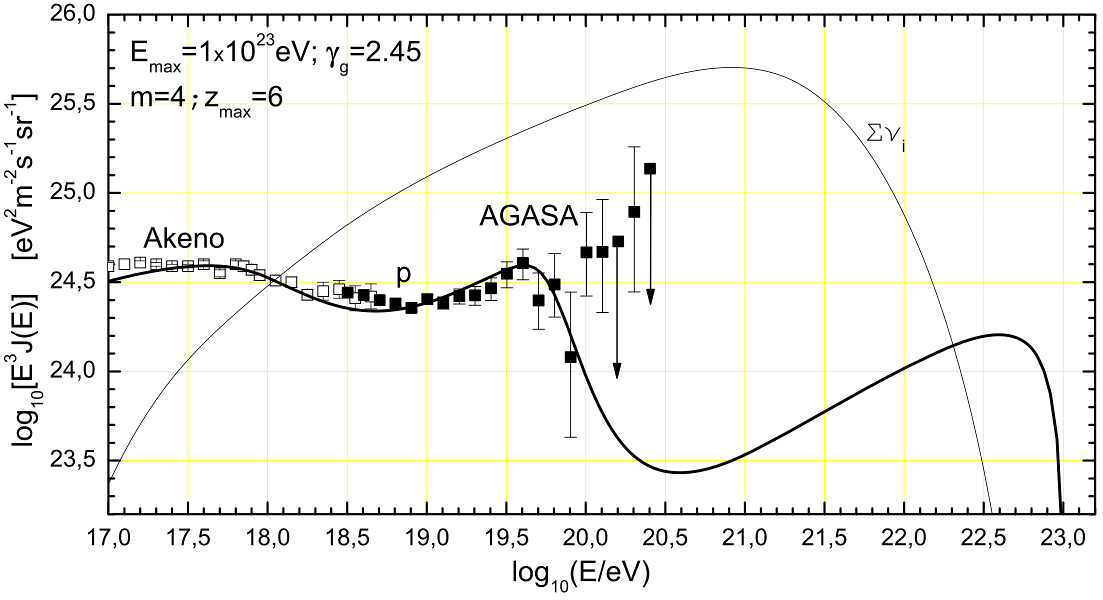




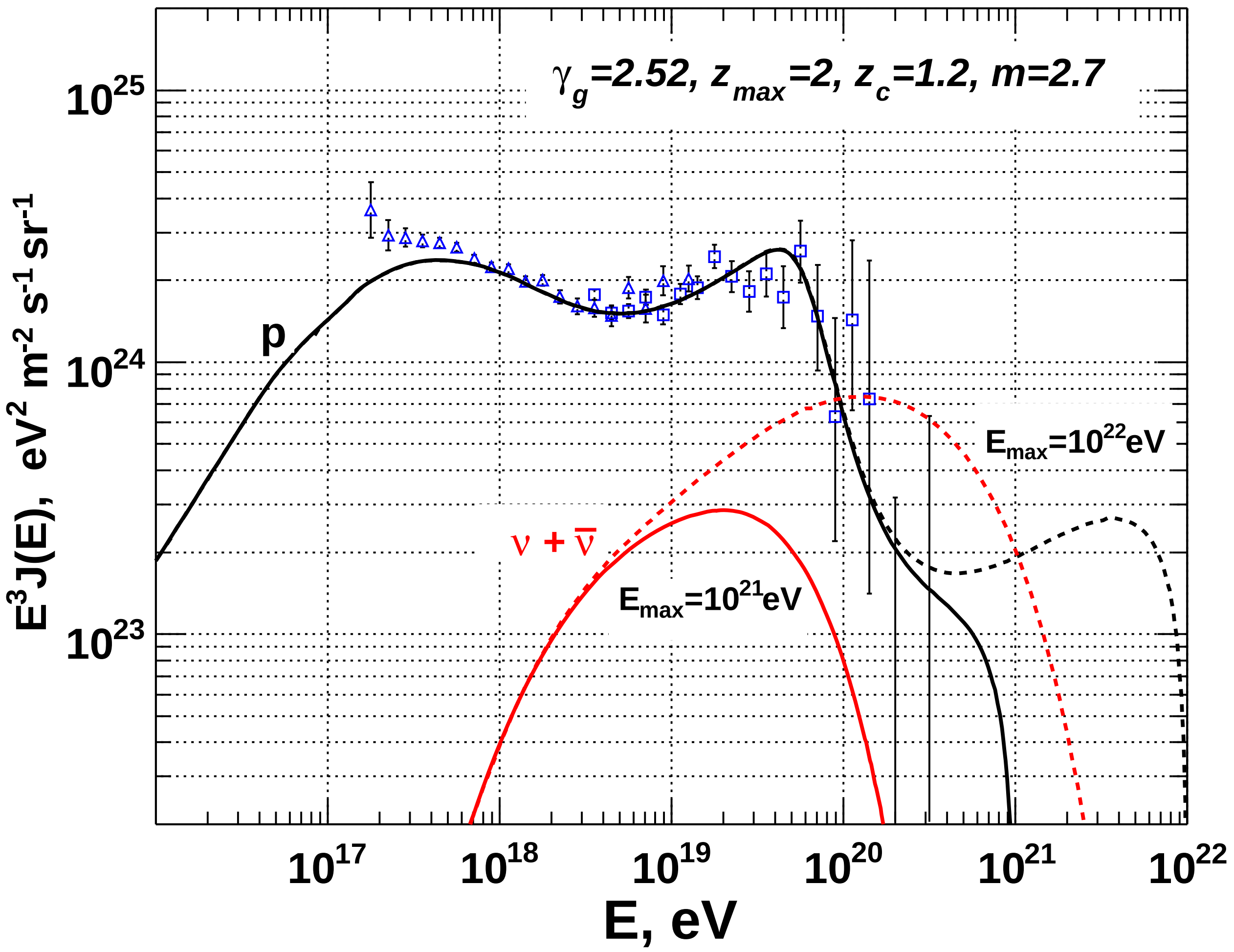


COSMOGENIC NEUTRINO FLUXES IN THE DIP MODEL





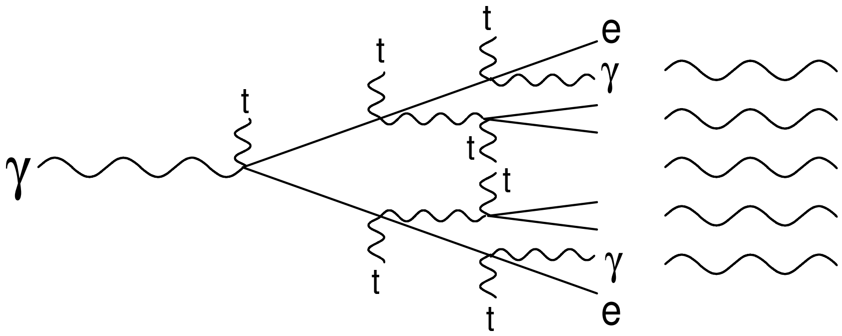
COSMOGENIC NEUTRINO FLUXES FROM AGN



CASCADE UPPER LIMIT

V.B. and A.Smirnov 1975

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



diffuse
extragalactic gamma
0.01-100 GeV

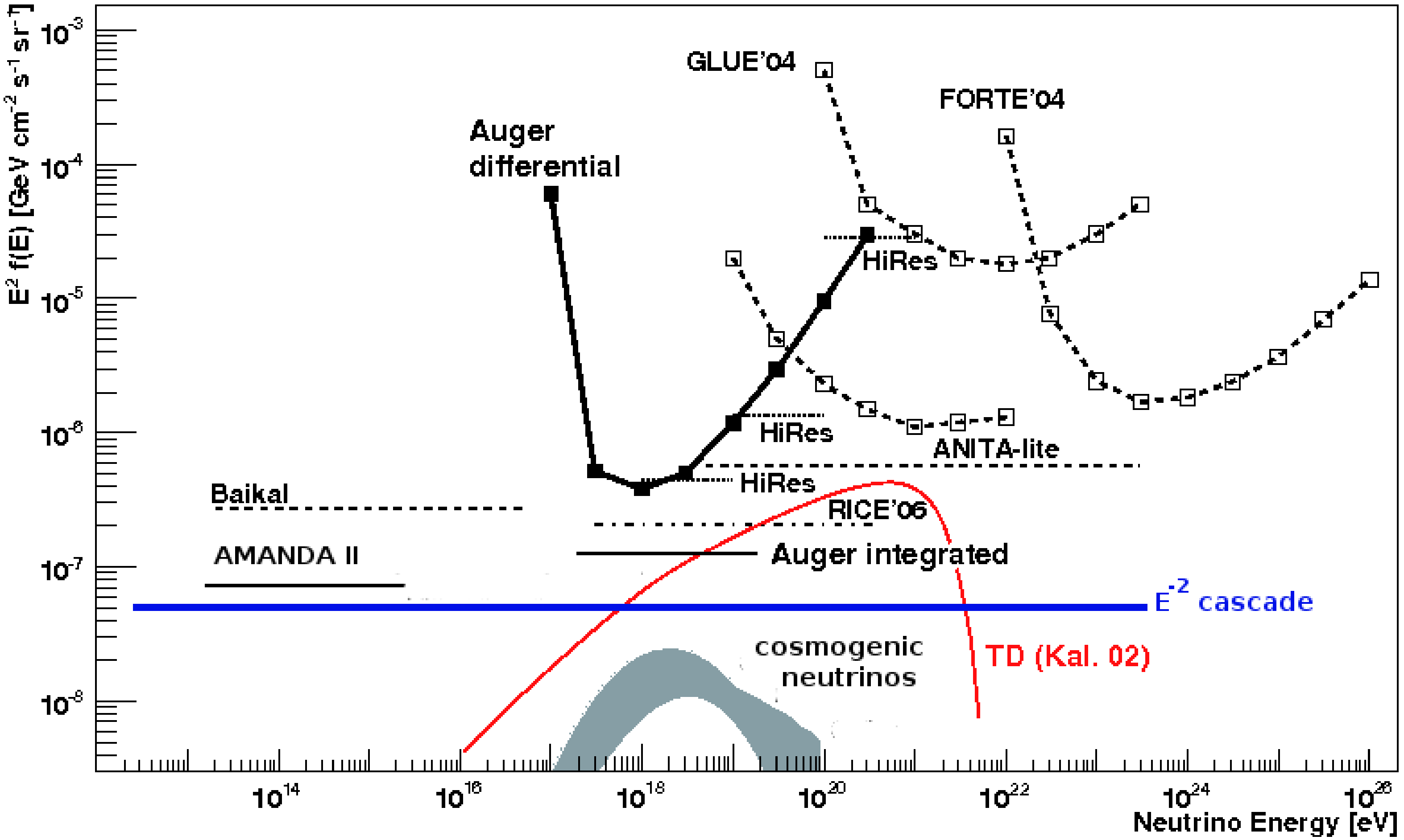
EGRET: $\omega_\gamma^{\rm obs} \sim (2-3)\times 10^{-6}{\rm eV/cm}^3$.

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

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

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

OBSERVATIONAL UPPER LIMITS



Kampert 2008 (modified)

Can oscillations provide flux above the cascade limit?

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

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

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

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

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

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):

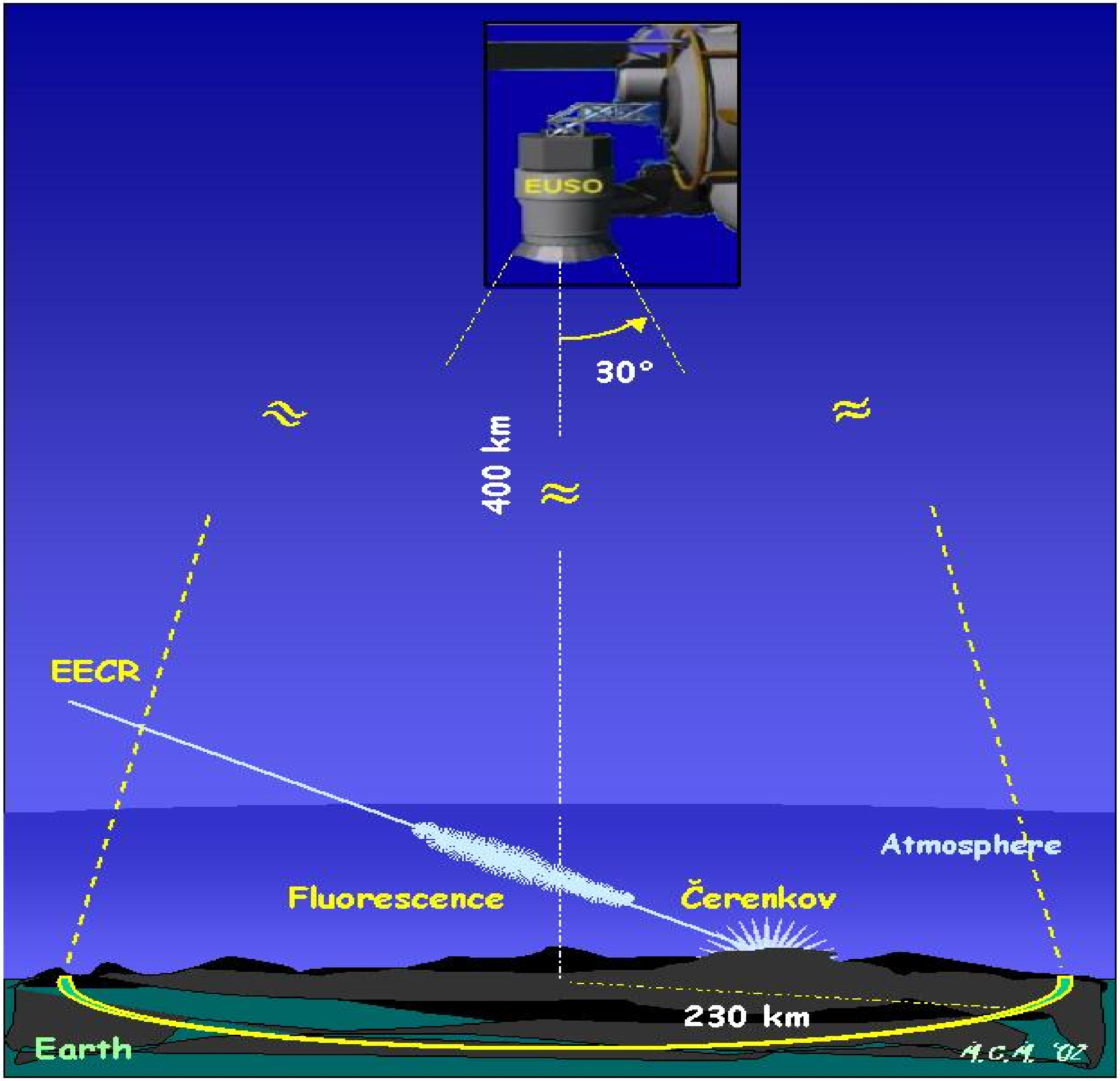
$$P_{\nu'_\mu \nu_e} = \frac{1}{8}\sin^2 2\theta_{12}\ , \quad P_{\nu'_\mu \nu_\mu} = P_{\nu'_\mu \nu_\tau} = \frac{1}{4} - \frac{1}{6}\sin^2 2\theta_{12}\ , \quad \sum_\alpha P_{\nu'_\mu \nu_\alpha} = \frac{1}{2}.$$

Signature: diffuse flux exceeds cascade upper limit.

PROSPECTS FOR UHE NEUTRINO OBSERVATIONS :

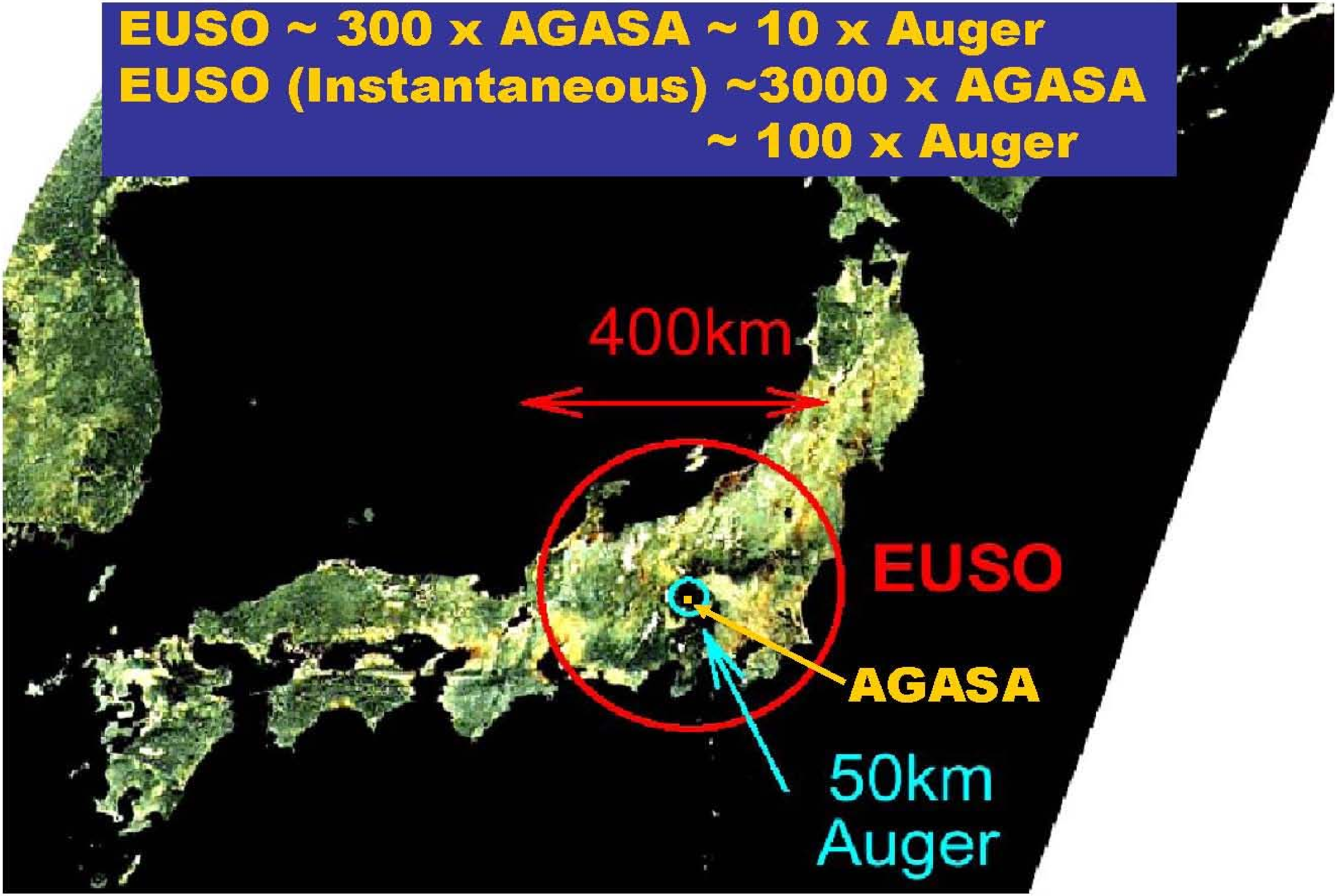
SPACE DETECTORS EUSO

PRINCIPLES OF EUSO OBSERVATIONS

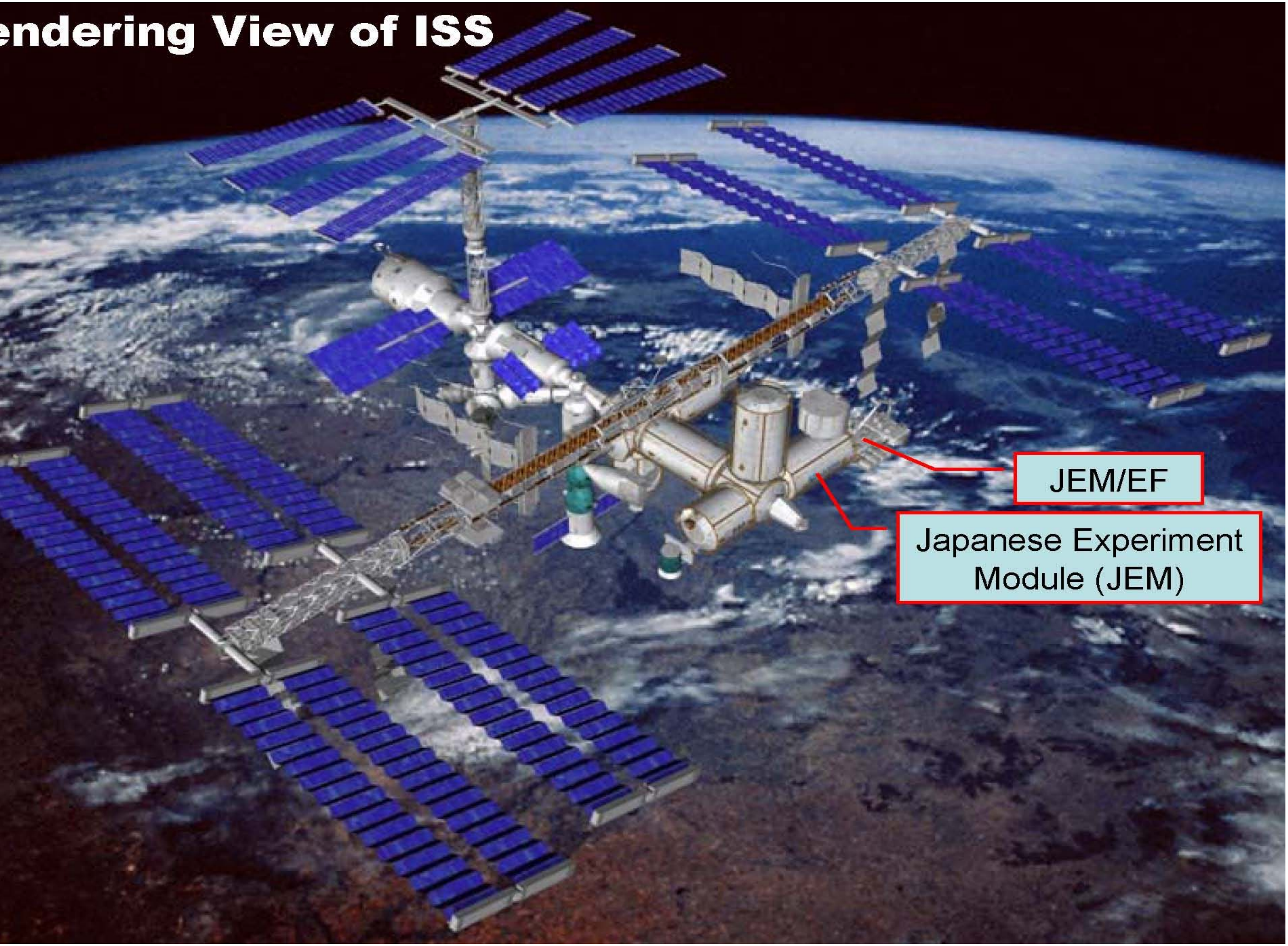


Field of View of EUSO

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



endering View of ISS



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.

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.**
- **The first space experiment JEM-EUSO is planning to start collecting data in 2012.**