UHE COSMIC NEUTRINOS: the view from 2012

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UHE NEUTRINOS: PRODUCTION and SOURCES

- **Astrophysical neutrinos** **(produced by CRs)**
  pp: $p + N_{\rm tar} \to \pi^{\pm} + {\rm all}$, **p$\gamma$:** $p + \gamma_{\rm tar} \to \pi^{\pm} + {\rm all}$

- **Top-Down neutrinos** **(direct pion production :)**
  TDs, annihilation of DM, decay of SHDM, oscillation of mirror neutrinos.

- **Hidden astrophysical sources:**
  Cocooned black hole: VB, Ginzburg 1981,
  Stecker AGN model: Stecker et al 1991,
  Collapsing galactic nuclei: VB, Dokuchaev 2001,
  Hidden jets: Razzaque, Smirnov 2010

- **Hidden Top-Down sources:**
  Annihilation of DM in the Earth and Sun,
  Mirror matter sources (oscillation of neutrinos)

- **Bright phase** **(Pop III stars at $z \sim 10-20$, $z_{\rm reion} = 11.0 \pm 0.14$ WMAP).**
  V.B., Ozernoy 1981, V.B.,Blasi 2012.

UHECR and COSMOGENIC NEUTRINOS

UHE protons propagating through CMB produce cosmogenic neutrinos:

$$p + \gamma_{cmb} \rightarrow \pi^{\pm} + N$$

Spectral signatures of this propagation are:

pair-production dip and GZK cutoff

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:

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

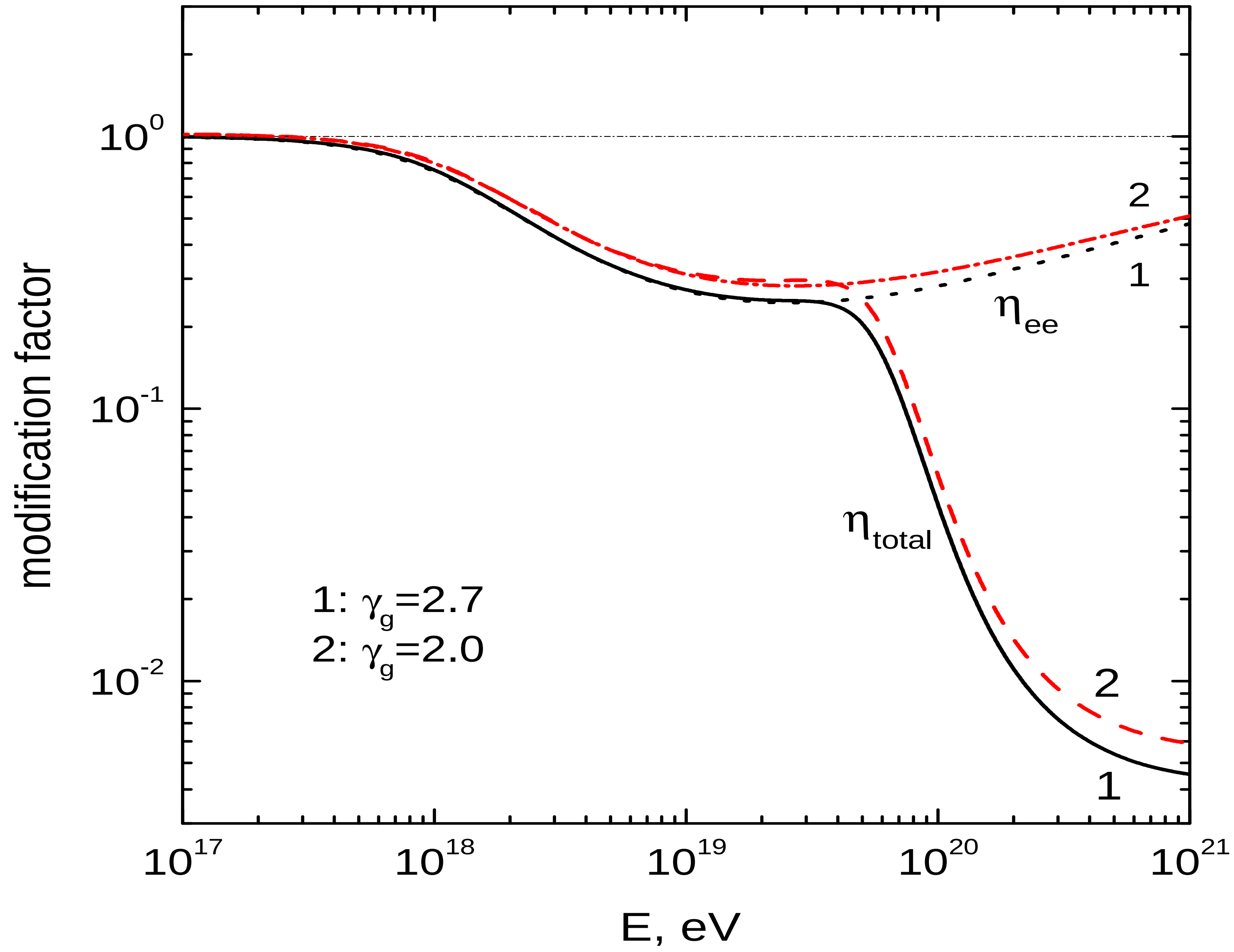
Dip is a faint spectral feature, seen better in terms of **modification factor**

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

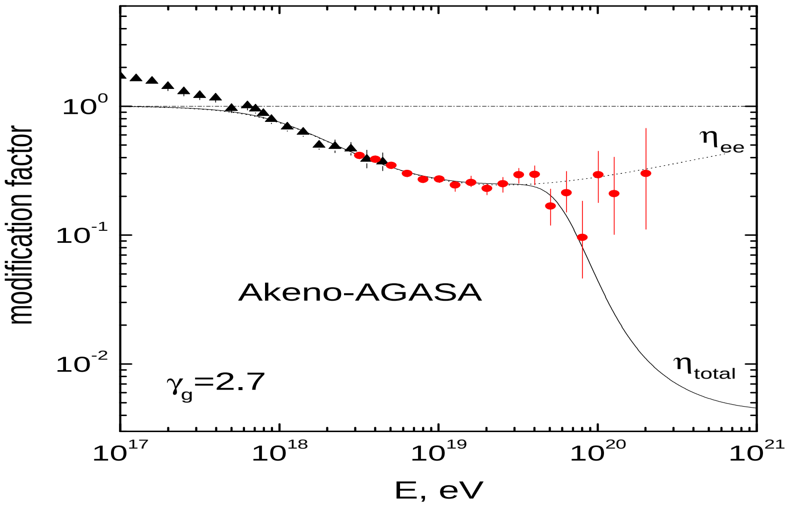
where $J_p^{\rm unm}(E) = KE^{-\gamma_g}$ includes only adiabatic energy losses (redshift),

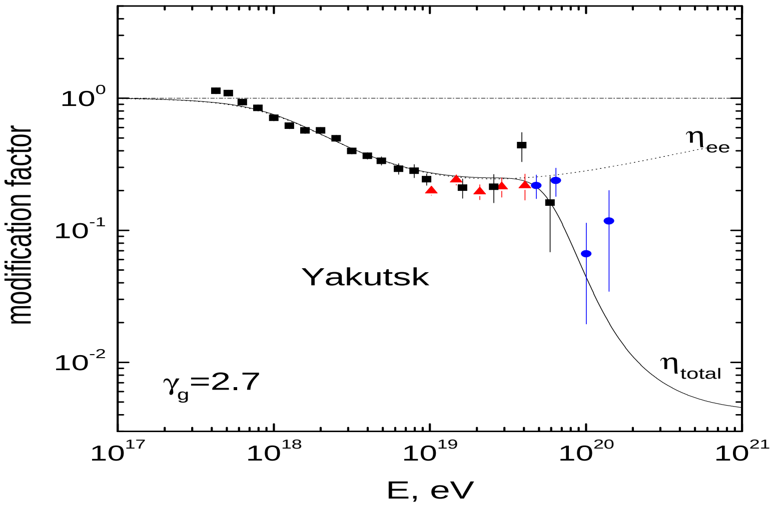
and $J_p(E)$ all energy losses.

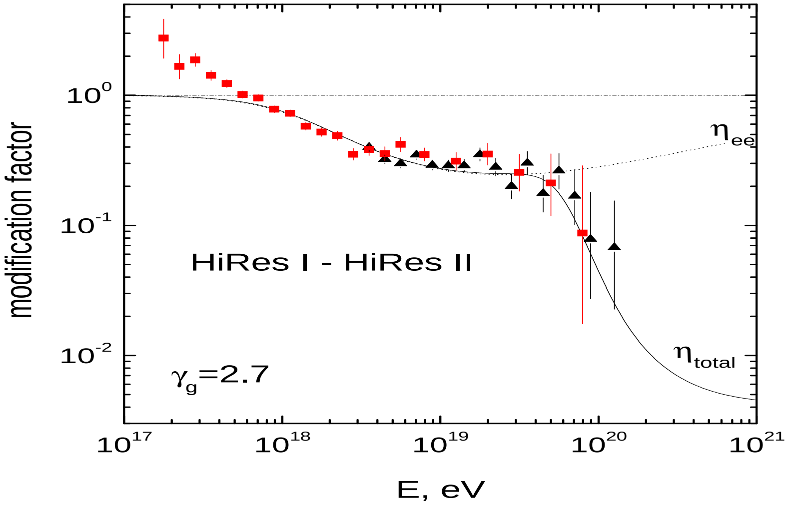
DIP AND GZK CUTOFF IN TERMS OF MODIFICATION FACTOR

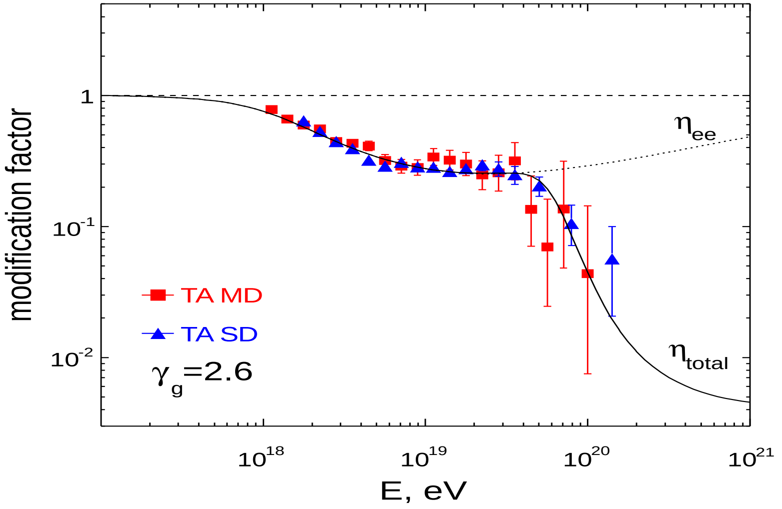


COMPARISON OF PAIR-PRODUCTION DIP WITH OBSERVATIONS



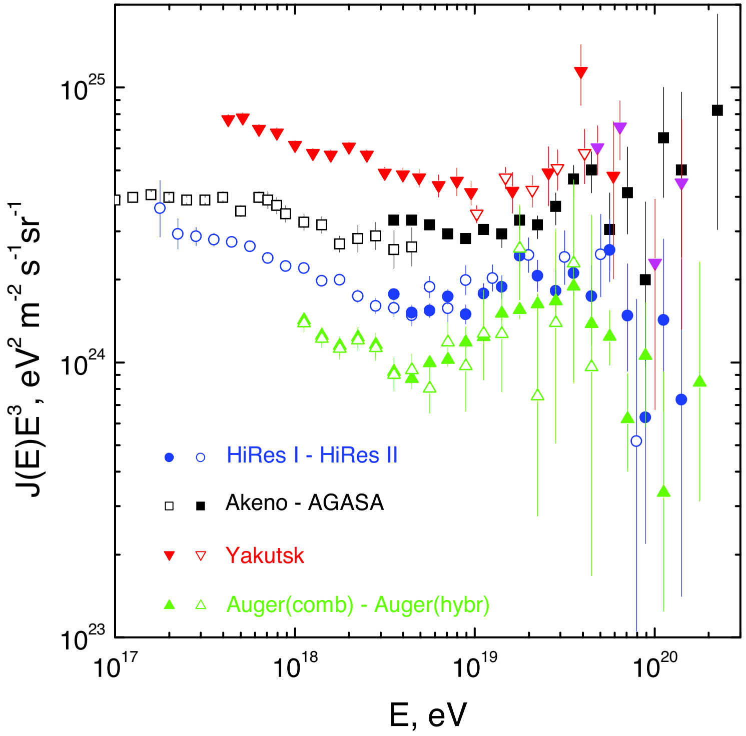


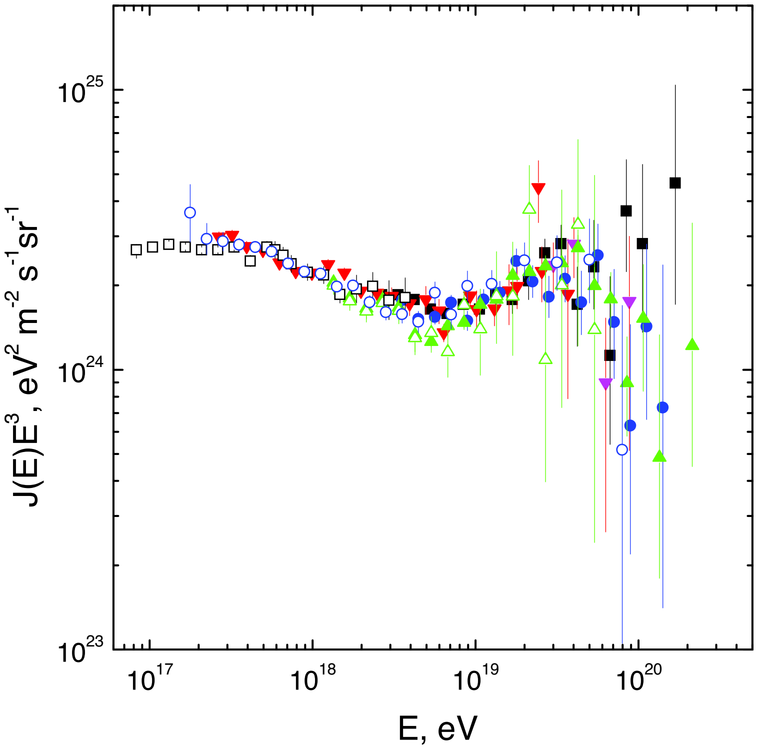




RECALIBRATION of AUGER, HIRES, AGASA, YAKUTSK FLUXES

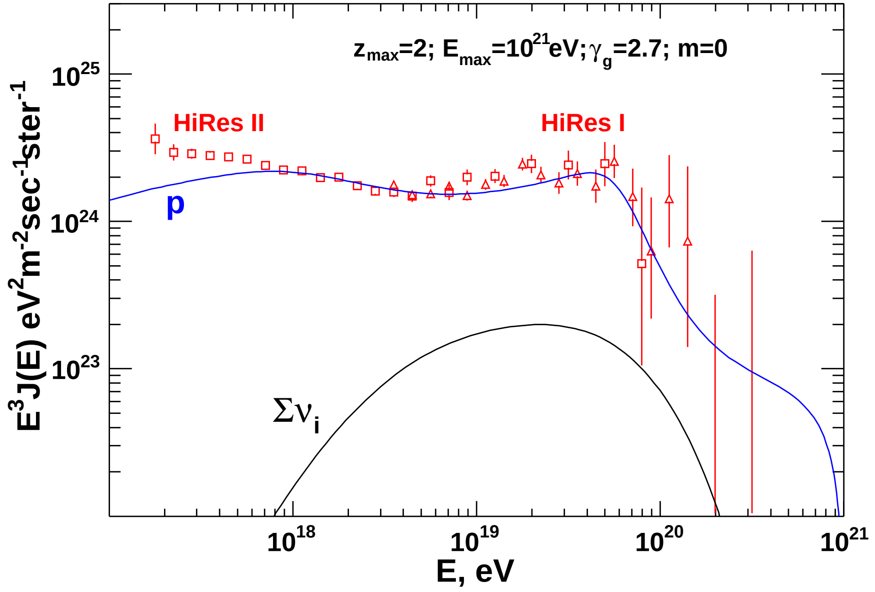
V.B., A. Gazizov, S. Grigorieva

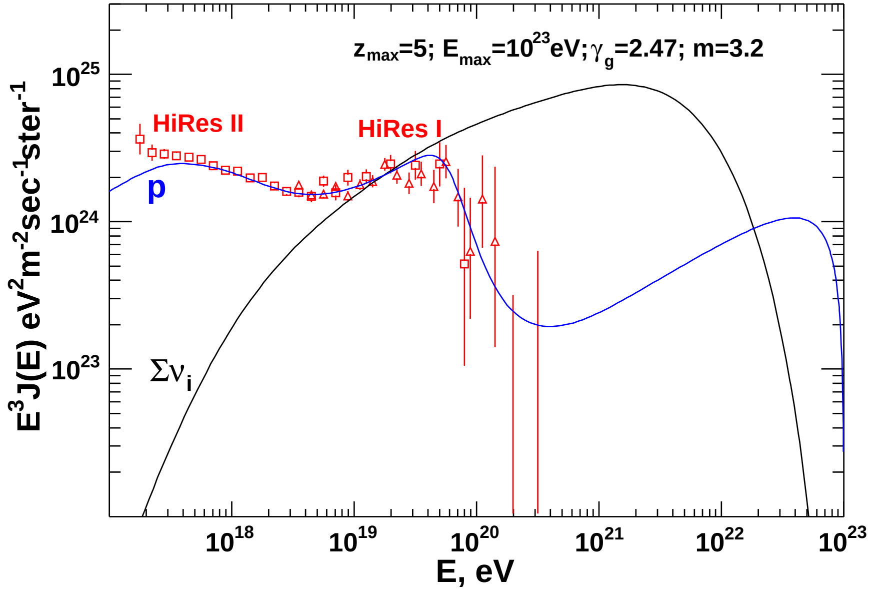




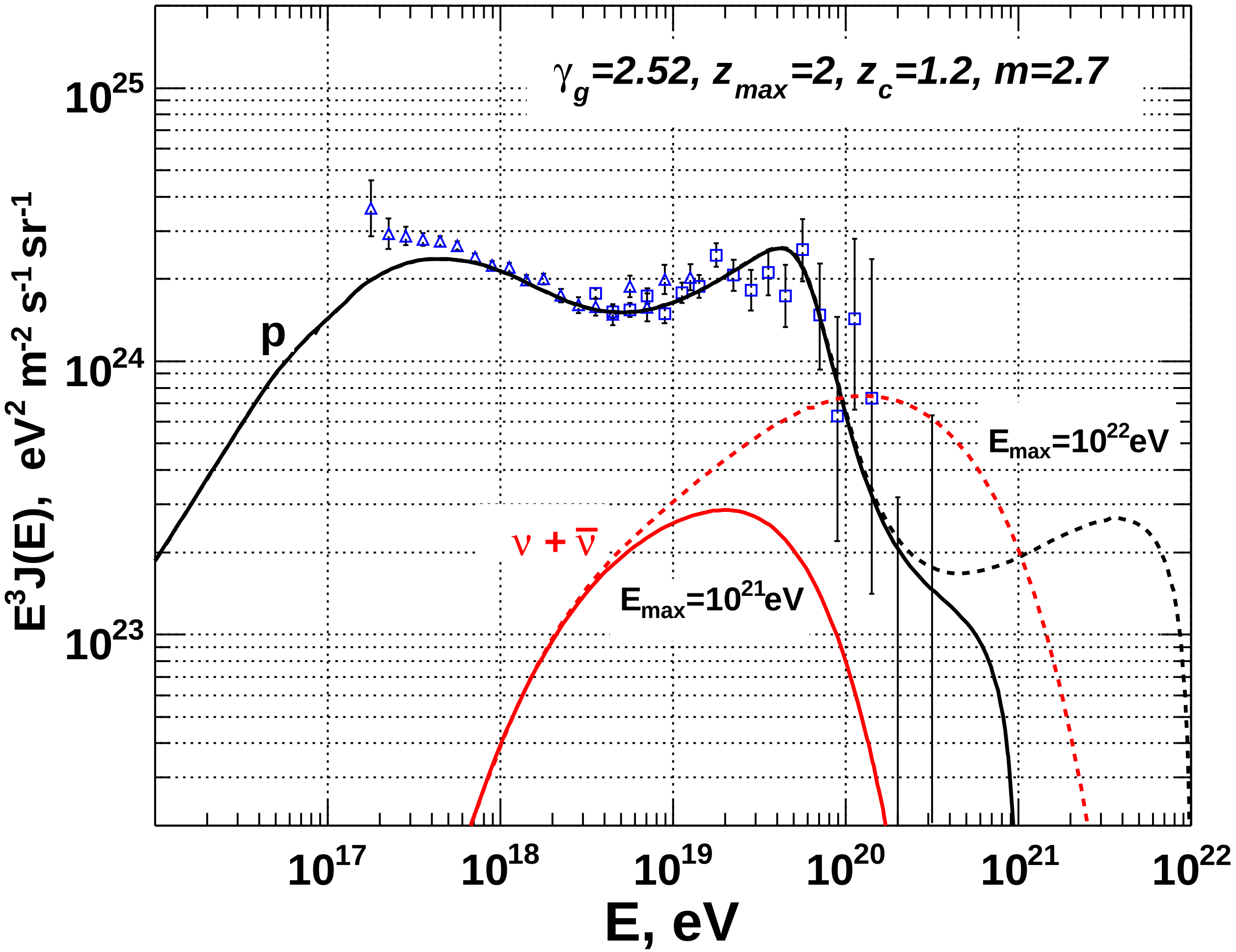
Recalibration factors: $\lambda = 1.2$ (Auger), $\lambda = 1.0$ (HiRes), $\lambda = 0.75$ (AGASA), $\lambda = 0.625$ (Yakutsk).

COSMOGENIC NEUTRINO FLUXES IN THE DIP MODEL





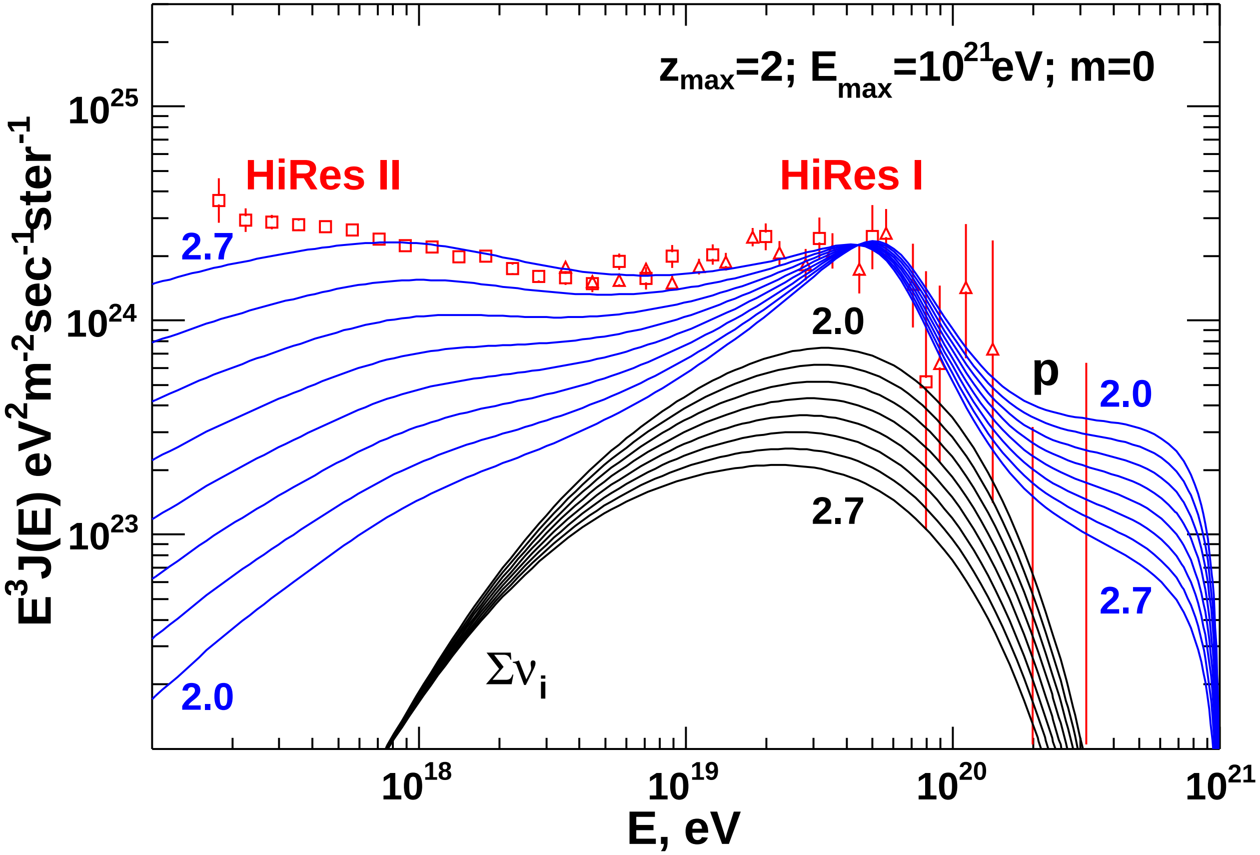
COSMOGENIC NEUTRINO FLUXES FROM AGN



LOWER LIMIT ON NEUTRINO FLUXES

IN THE PROTON MODELS

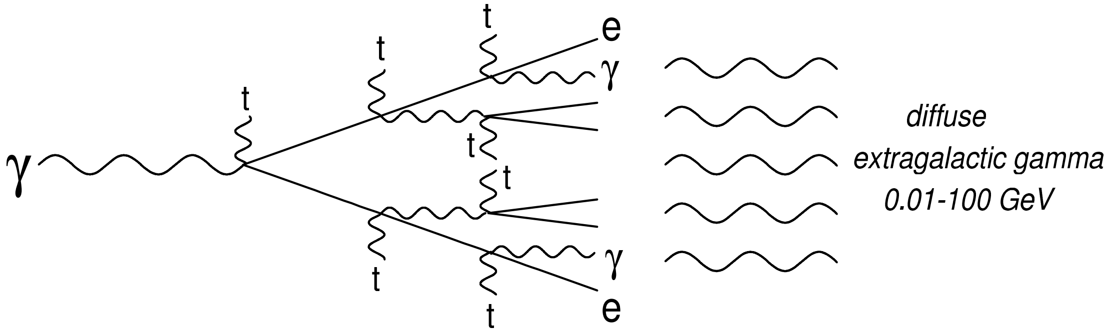
V.B. and A. Gazizov 2009



CASCADE UPPER LIMIT

V.B. and A.Smirnov 1975

$$\mathrm{e-m\ cascade\ on\ target\ photons:}\quad \begin{cases} \gamma+\gamma_{\rm tar}\to e^+ + e^- \\ e+\gamma_{\rm tar}\to e' + \gamma' \end{cases}$$



Spectrum of cascade photons

$$J_\gamma^{\rm cas}(E) = \begin{cases} K(E/\varepsilon_X)^{-3/2} & \text{for} \quad E \le \varepsilon_X\,, \\ K(E/\varepsilon_X)^{-2} & \text{for} \quad \varepsilon_X \le E \le \varepsilon_a\,, \end{cases} \tag{1}$$

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

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

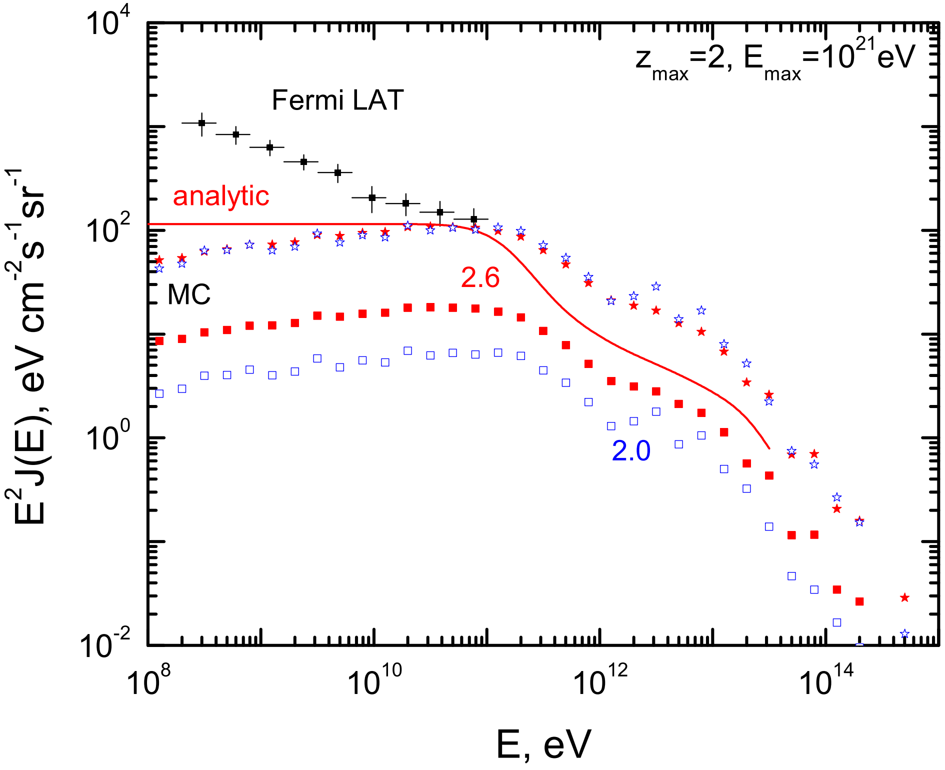
$$E^2 I_\nu(E) < \frac{c}{4\pi}\omega_{\rm cas.}$$

E^{-2}**- generation spectrum:**

$$E^2 J_\nu(E) < \frac{c}{4\pi}\frac{\omega_{\rm cas}}{\ln E_{\rm max}/E_{\rm min}}.$$

CASCADE UPPER LIMIT FROM FERMI LAT

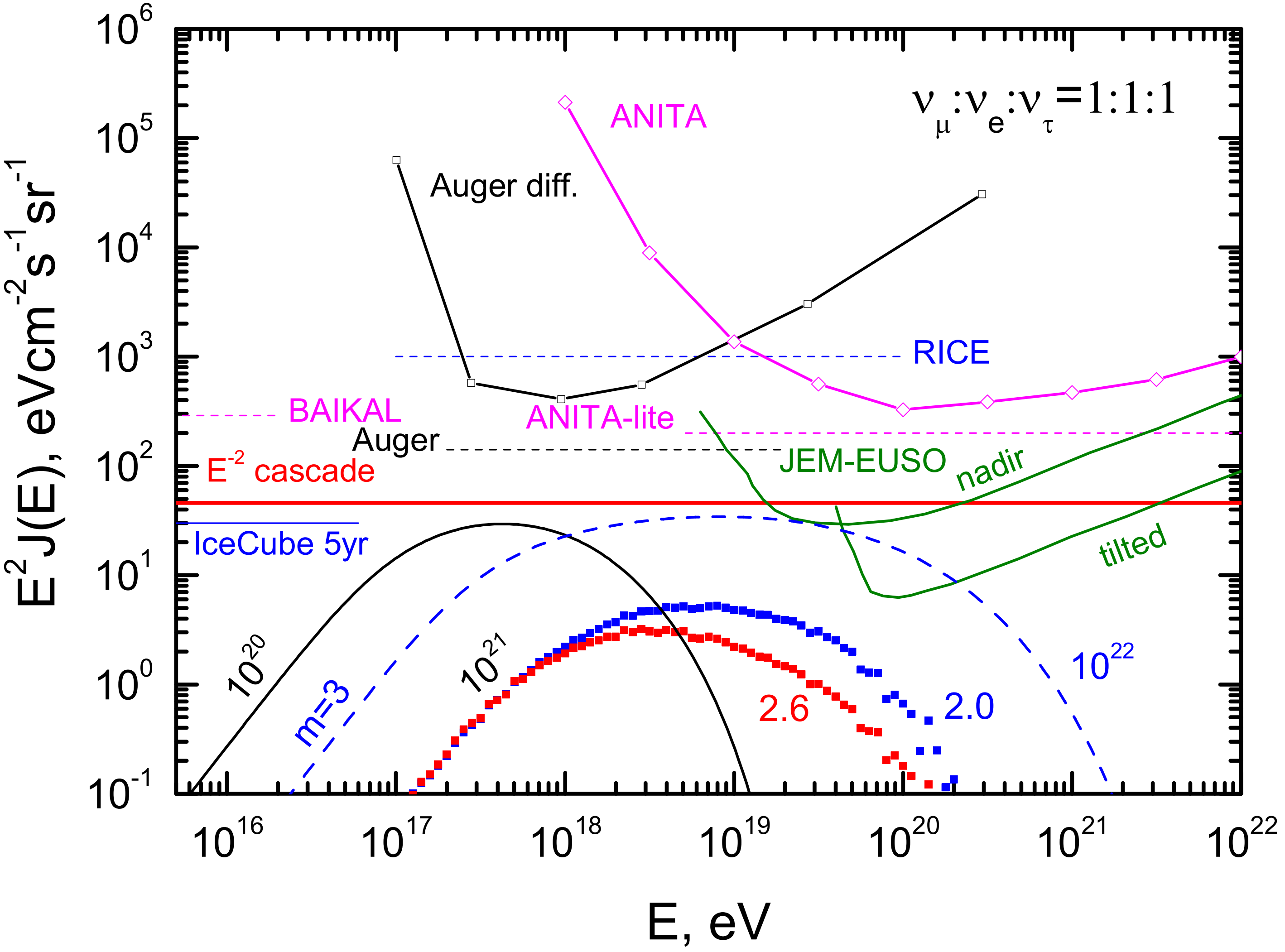
V.B., Gazizov, Kachelriess, Ostapchenko Phys. Lett. B 695 (2011) 13.
Ahlers, Anchordoqui, Gonzales-Garcia, Halzen, Sarkar Astrop. Phys. 34 (2010) 106.
G. Gelmini, O. Kalashev, D. Semikoz arXiv:1107.1672



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

OBSERVATIONAL AND THEORETICAL UPPER LIMITS

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



Reionization of Universe: Bright Phase

Burst of first massive star formation

- Cooling of universe and recombination at $T_{\rm dec} \sim 3600$ K, $z_{\rm dec} \sim 1100$.
- **DARK AGES:** Evolution of DM structures with neutral hydrogen.
- Cooling of baryonic gas by H_2 formation $z \leq 20 - 30$
- Formation of the first **Pop III** stars hosted by $M \sim 10^6 M_\odot$ DM halos. **Properties:** metal poor, massive ($M \geq 100 M_\odot$), hot ($\varepsilon \sim 30$ eV), short-lived, strong wind, finishing evolution by SN explosion with W_{SN} up to 10^{53} erg.
- **Reionization** by Pop III radiation and by Pop III SN, observed by WMAP. For model of **Instantaneous reionization** $z_{\rm reion} = 11.0 \pm 1.4$ (WMAP).

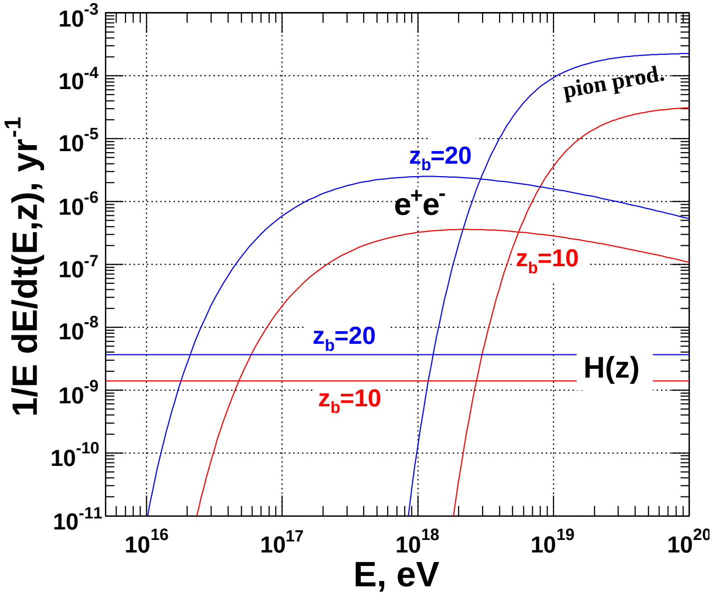
Pop III scenario fills several gaps:

- **Produce metals** needed for evolution of normal stars.
- Produce **reionization.**
- Produce **magnetic fields** in Universe.
  Pioneering proposal: Bisnovatiy-Kogan, Ruzmaikin, Syunyaev 1973.
  The other mechanisms: **Weibel** and **Kelvin-Helmholtz** instabilities. Production of magnetic field without pre-existing seed: **Resistive magnetic field generation** by Miniati and Bell.
  Shock may develop without magnetic field (Spitkovsky).

UHE NEUTRINOS from BRIGHT PHASE

V.B., Ozernoy 1981; Gao et al 2011, V.B., Blasi 2011.

At $z_b \sim 10-20$ CRs (mostly protons) are accelerated in Pop III SN. Cosmogenic neutrinos are produced in $p\gamma_{\rm cmb}$.



Energy losses of protons at z_b.

Neutrino flux has a maximum at:

$$E_\nu \sim 0.05 \frac{E_{\rm GZK}}{(1+z_b)^2} \approx 7.5 \times 10^{15}\ {\rm eV},$$

$$E_\nu^{\rm max} \sim 0.05 \frac{E_p^{\rm max}}{(1+z_b)} \approx 2.5 \times 10^{17}\ {\rm eV}.$$

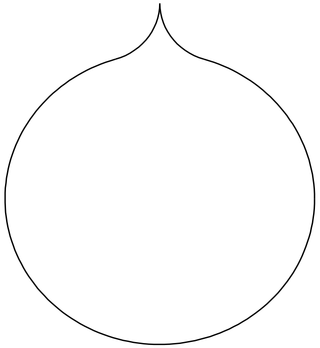
$$E_\nu^2 J_\nu(E) = 0.1 \frac{c}{4\pi} \frac{\boldsymbol{\omega_p(z_b)}}{\boldsymbol{(1+z_b)^4}} \frac{1}{\ln E_{\rm max}/E_{\rm min}}$$

The value of basic parameter $\frac{\omega_p(z_b)}{(1+z_b)^4} = 9.5 \times 10^{-7}$ eV/cm^3 corresponds to future IceCube sensitivity $E^2 J_\nu(E) = 3 \times 10^{-9}$ GeV/cm^2 s sr and respects the Fermi upper limit $\omega_{\rm cas}^{\rm max} = 5.8 \times 10^{-8}$ eV/cm^3.

TOPOLOGICAL DEFECTS

Symmetry breaking in early universe results in phase transitions (D.A. Kirzhnitz 1972), accompanied by TDs. Their common feature is production of HE particles.

Ordinary and superconducting strings



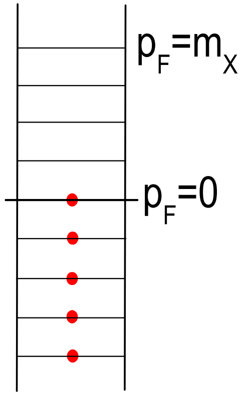
Produced at $U(1)$ symmetry breaking.
Particles are massless inside the string.
η is symmetry breaking scale, e.g. 10^9 GeV, and $\mu \sim \eta^2$ is tension.
Loop oscillates with periodically produced cusp ($v = c$) and with large Lorentz factors, e.g. above 10^{10}, at nearby points.
Particles escaping from cusp segment have energy $E \sim \Gamma m_X$, which can exceed the Planck scale.

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

$\frac{dp}{dt} = e\mathcal{E}, \;\; p_F = e\mathcal{E}t \sim m_X$ (exit)

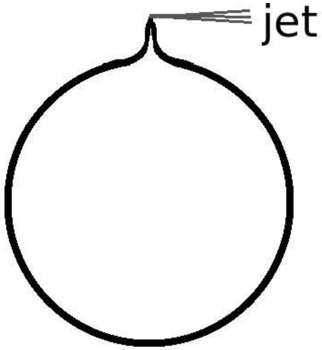
$n_X = \frac{p_F}{2\pi}, \;\; \frac{dJ}{dt} = e^2\mathcal{E}$ (superconductivity)

If a string moves through magnetic field the electric current is induced $J \sim e^2 vBt$



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 $\gamma_c \sim 1 \times 10^{12} i_c \eta_{10}^{-1} B_{\mu G}^{-1}$, $\mathbf{i_c} \lesssim 1$.

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

Clusters of galaxies dominate.

$I \sim e^2 B\ell, \quad I_{\rm cusp} \sim \gamma_c J, \quad I_{\rm cusp}^{\rm max} \sim i_c e\eta.$

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

Diffuse neutrino flux :

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

UHE neutrino flux is generated at $z \lesssim 4 - 5$.

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.**

UHE NEUTRINOS FROM ORDINARY STRINGS.

1. Ordinary strings with EW Higgs condensate. Vachaspati 2010

Interaction of EW Higgs ϕ with the string field Φ (κ is coupling constant):

$$S_{\rm int} = \kappa \int d^4x(\Phi^+\Phi - \eta^2)\phi^+\phi$$

After GUT symmetry breaking ($<\Phi>=\eta$):

$$S_{\rm int} = -\kappa\eta \int d^2\sigma\sqrt{-\gamma}\ \phi,$$

where $d^2\sigma$ is string world-sheet space, γ_{ab} is the world-sheet metric.
The higgses are emitted through the cusp.

1. UHE neutrinos emitted from ordinary strings via dilatons and moduli.
VB, Sabancilar, Vilenkin, 2011 following Damour and Vilenkin 1997.

$$S_{\rm int} = (\sqrt{4\pi}\alpha/M_{\rm Pl}) \int d^4x\ \phi\ T^{\nu}_{\nu},$$

$$T^{\nu}_{\nu}(x) = -2\eta^2 \int d^2\sigma\sqrt{-\gamma}\ \delta^4(x^\alpha - x^\alpha(\sigma))$$

is the trace of energy-momentum tensor of string.
Dilatons and moduli are produced as radiation quanta from the cusp.
In terms of the Fourier momenta k : $dN(k) = \alpha^2 G\eta^4\ell^{2/3}k^{-7/3}dk.$

CONCLUSIONS

- **Predicted fluxes of diffuse cosmogenic neutrinos strongly depend on the mass composition of UHECR measured by HiRes and Auger detectors. According to Auger data mass composition becomes steadily heavier with increasing energy, which dramatically decreases the predicted neutrino flux.**

- **HiRes data are compatible with pure proton composition and with large fluxes of cosmogenic neutrinos. However, these fluxes 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 in the extreme models.**

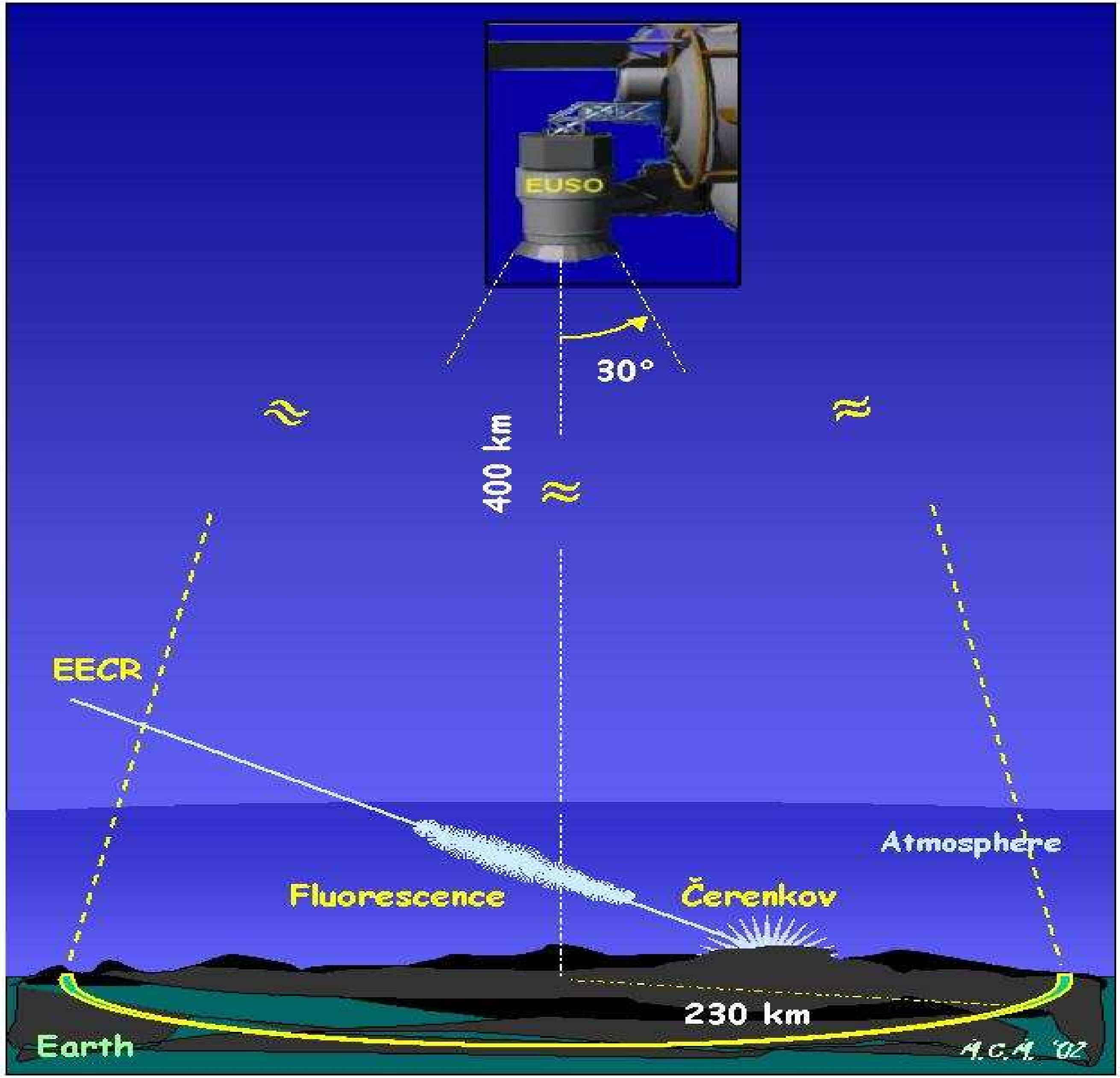
- **IceCube detector also can detect only marginally cosmogenic fluxes in case of extreme models with strong cosmological evolution and soft spectra (large $E_{\max}$ is not needed). However, IceCube can detect cosmogenic neutrinos from the bright phase. These fluxes are limited weaker by the cascade upper bound.**

- **IceCube is the first detector which crossed the cascade upper bound and entered the physically allowed domain of cosmogenic neutrino fluxes.**

- **In the light of new stronger limit on diffuse flux of cosmogenic neutrinos search for the sources becomes the priority goal of neutrino astronomy and JEM-EUSO and IceCube detectors. This task is viable even if protons constitute a small part of primary radiation. Discovery of HE neutrino radiation from SNR (in case of IceCube) will give the final proof of GCR SM, from AGN and GRB - proof of UHECR sources.**

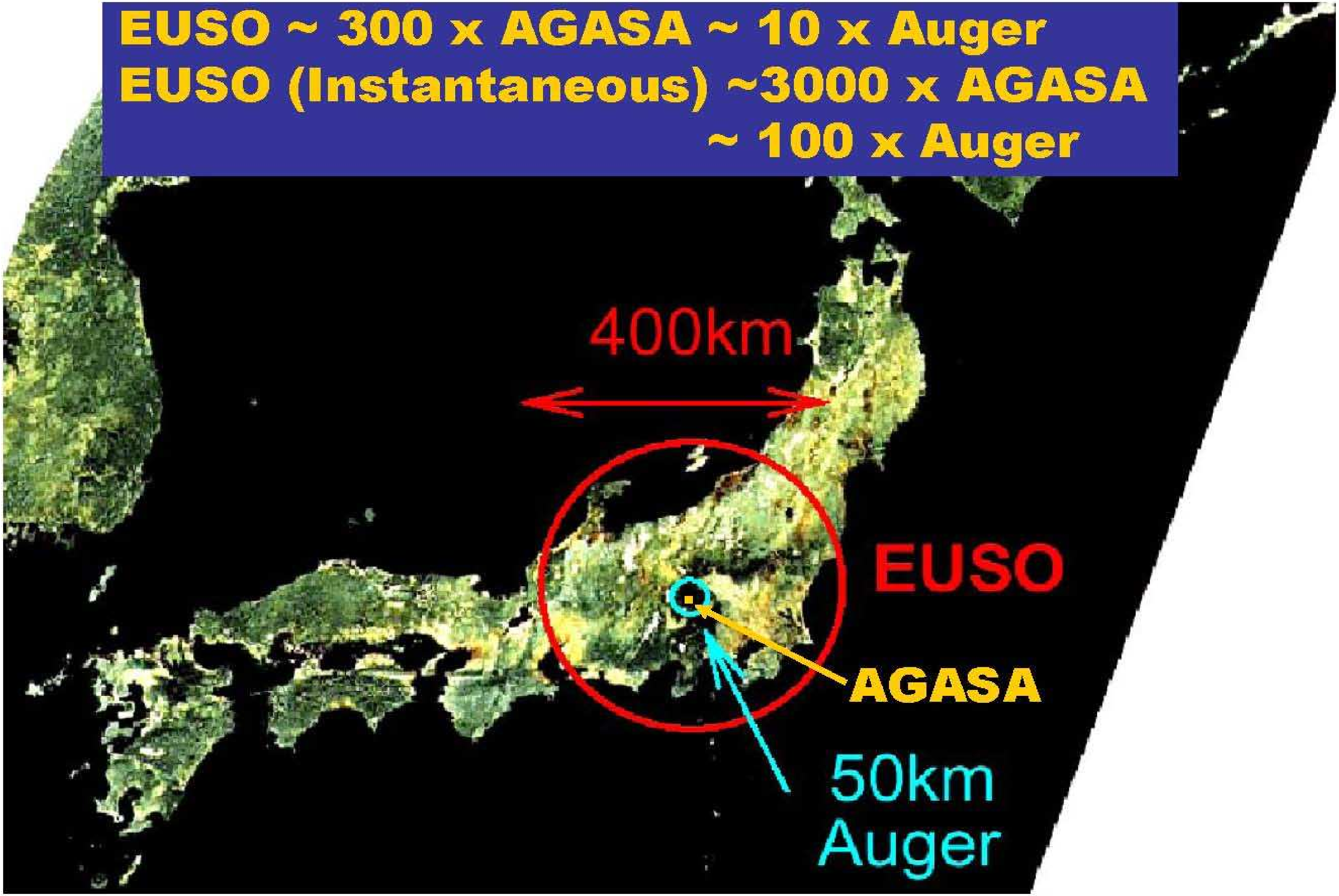
- **There is an impressive progress in theoretical study of TDs as UHE neutrino sources: The ordinary cosmic strings, which are the simplest TDs, can produce the large fluxes with extremely high $E_{\max}$. This prediction directly follows from fundamental properties of the strings: existence of cusp, gravitational interaction of intermediate particles (higgses, dilatons, moduli) with the string field Φ and basic string parameter $\eta^2 = \mu$, satisfying $G\mu \gtrsim 10^{-20}$, while observational limits are $G\mu \lesssim 10^{-6}$.**

PRINCIPLES OF EUSO OBSERVATIONS

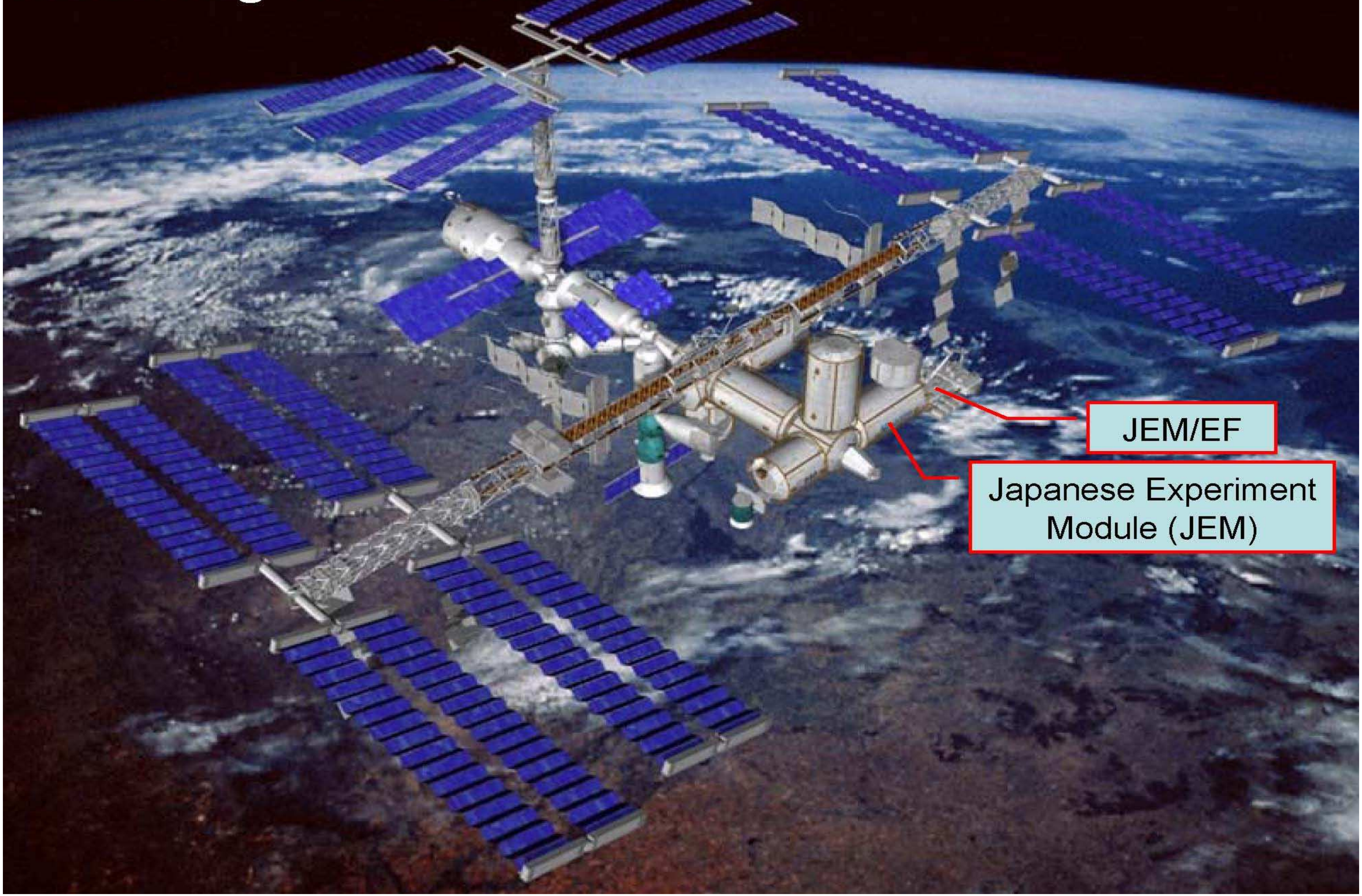


Field of View of EUSO

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



Rendering View of ISS



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.