

# **UHE COSMIC NEUTRINOS: failures and hopes**

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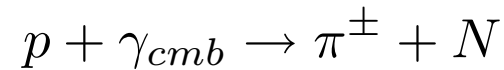
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# UHE NEUTRINOS: PRODUCTION and SOURCES

- **Astrophysical neutrinos** (produced by CRs)  
**pp:**  $p + N_{\text{tar}} \rightarrow \pi^{\pm} + \text{all}$ , **p $\gamma$ :**  $p + \gamma_{\text{tar}} \rightarrow \pi^{\pm} + \text{all}$
- **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  $z \sim 10 - 20$ ,  $z_{\text{reion}} = 11.0 \pm 0.14$  WMAP).  
**V.B., Ozerney 1981, V.B., Blasi 2012.**

## **UHECR and COSMOGENIC NEUTRINOS**

**UHE protons** propagating through CMB produce cosmogenic neutrinos:



**Proof of this process is detection of primary protons in UHECR.**

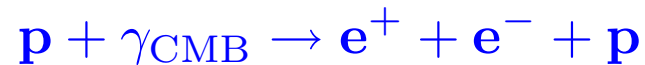
Spectral signatures of proton propagation through CMB are:

**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:



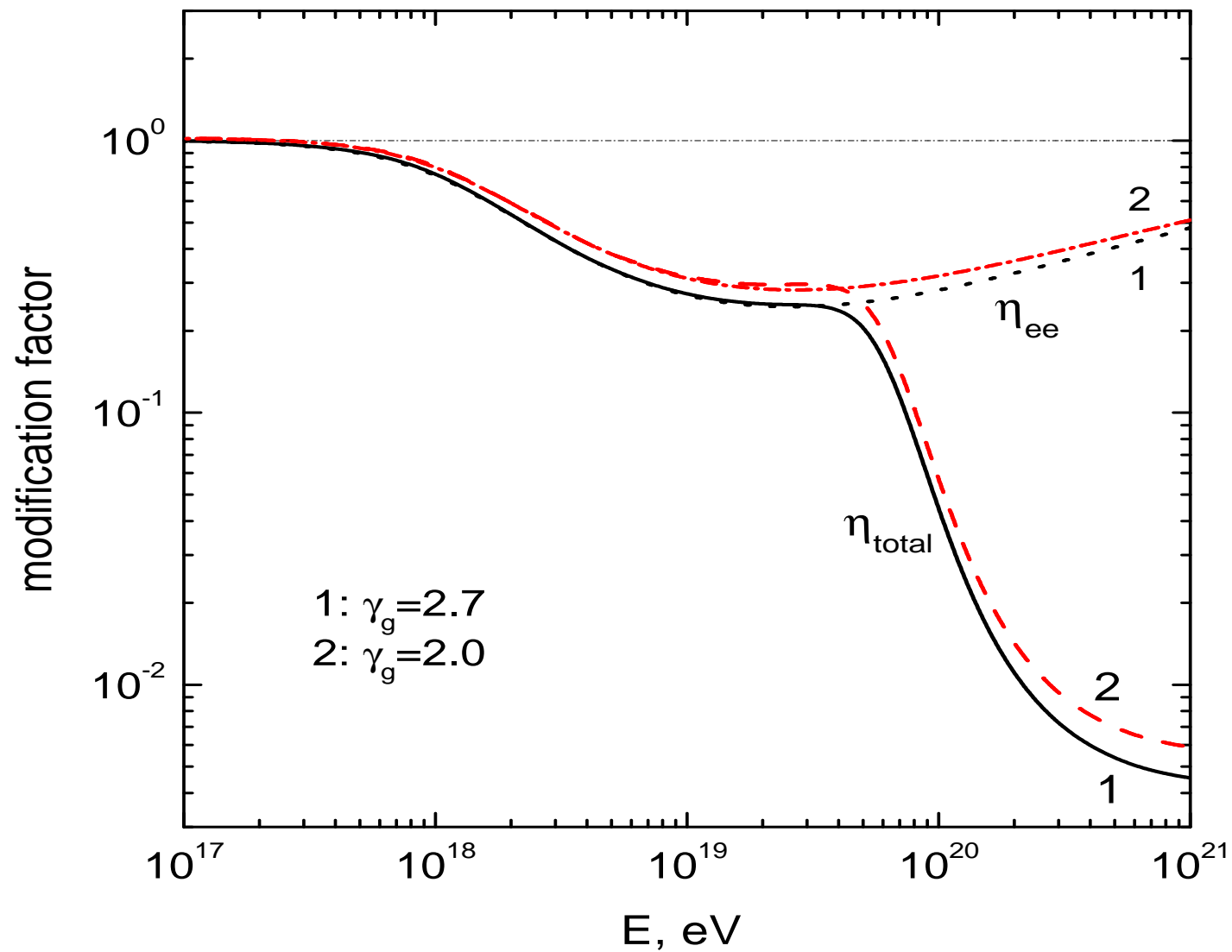
Dip is a faint spectral feature, seen better in terms of **modification factor**

$$\eta(\mathbf{E}) = \frac{\mathbf{J}_{\mathbf{p}}(\mathbf{E})}{\mathbf{J}_{\mathbf{p}}^{\text{unm}}(\mathbf{E})},$$

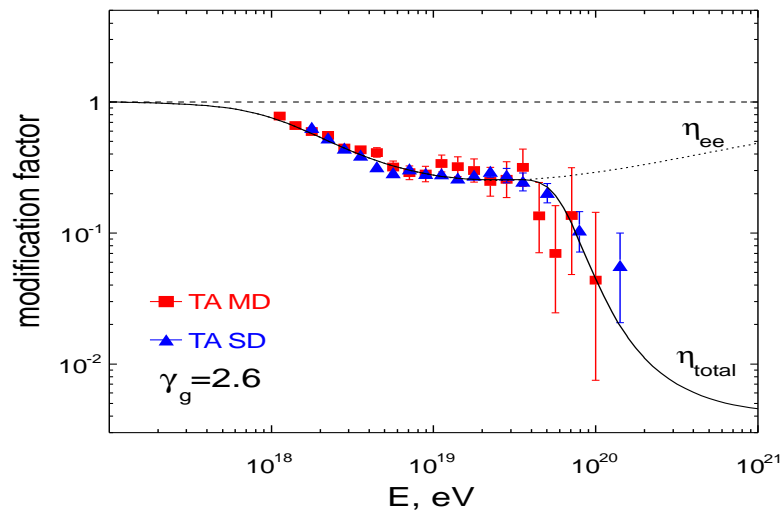
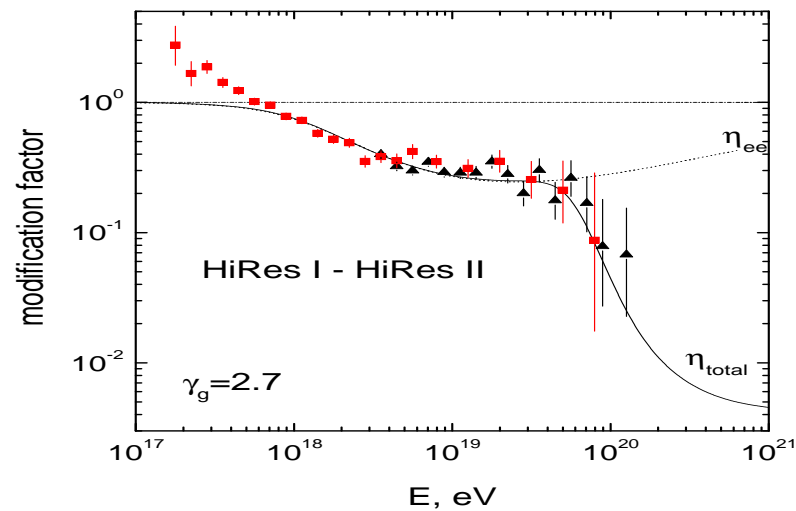
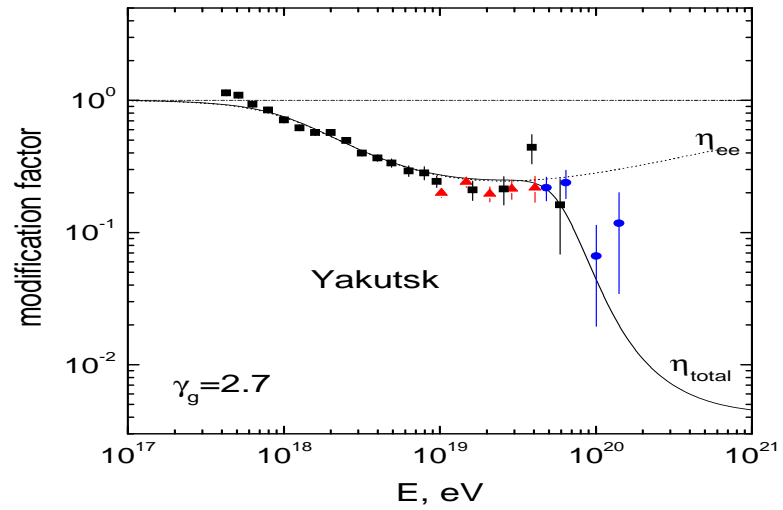
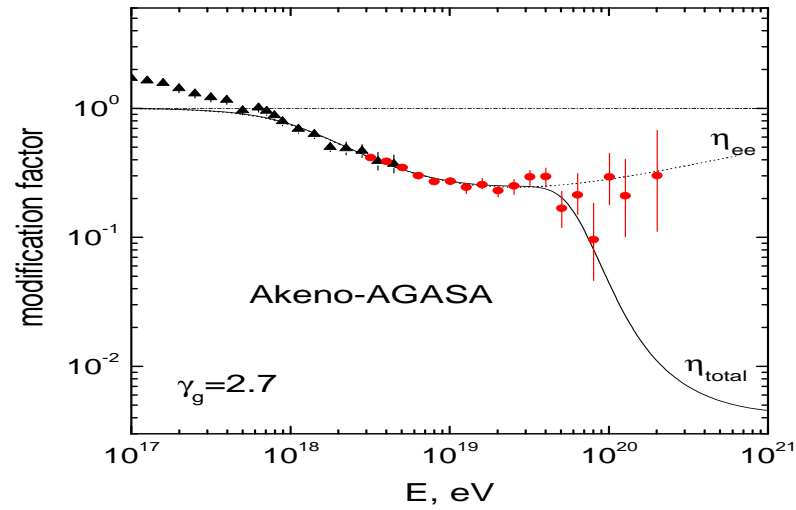
where  $J_p^{\text{unm}}(E) = K E^{-\gamma_g}$  includes only adiabatic energy losses (redshift),

and  $J_p(E)$  all energy losses.

# DIP AND GZK CUTOFF IN TERMS OF MODIFICATION FACTOR

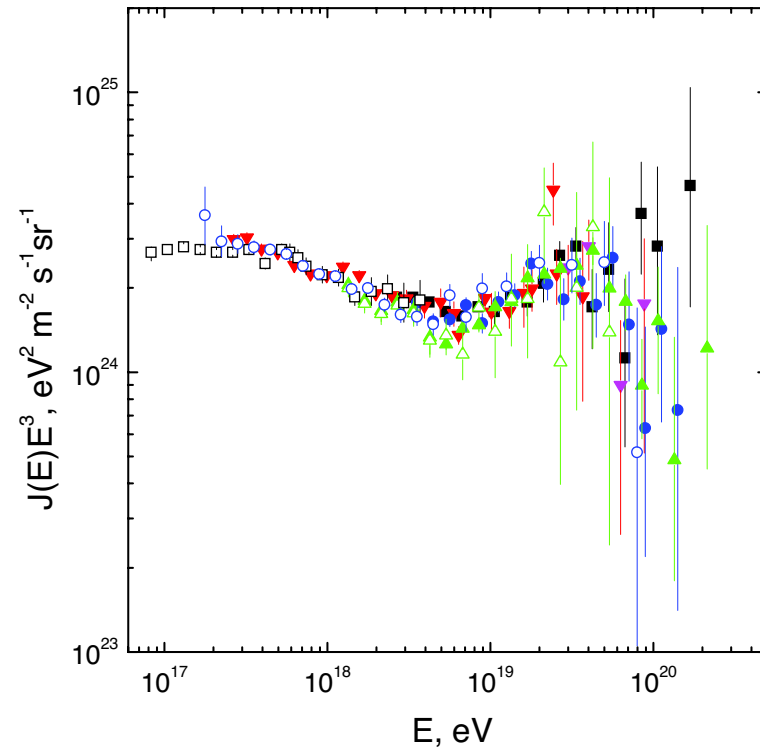
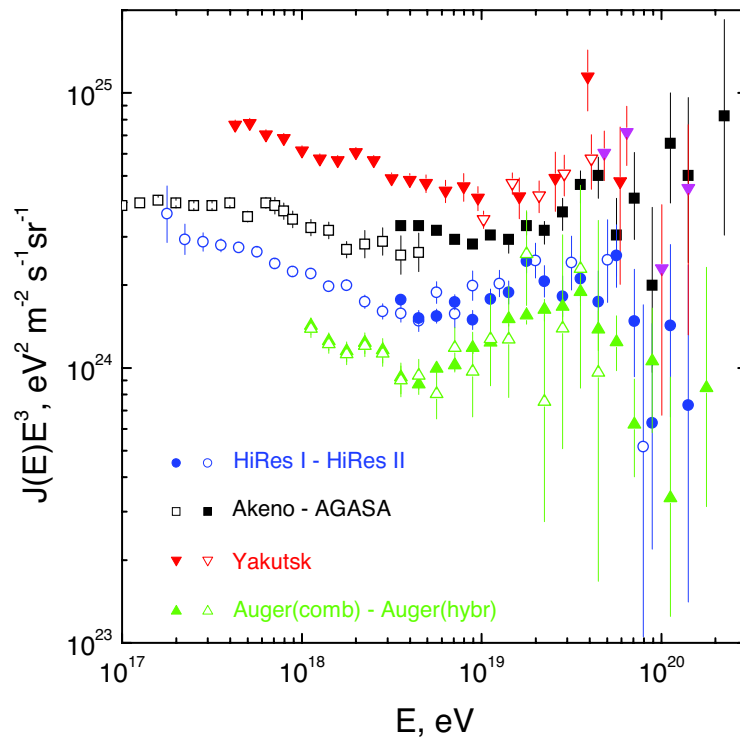


# COMPARISON OF PAIR-PRODUCTION DIP WITH OBSERVATIONS



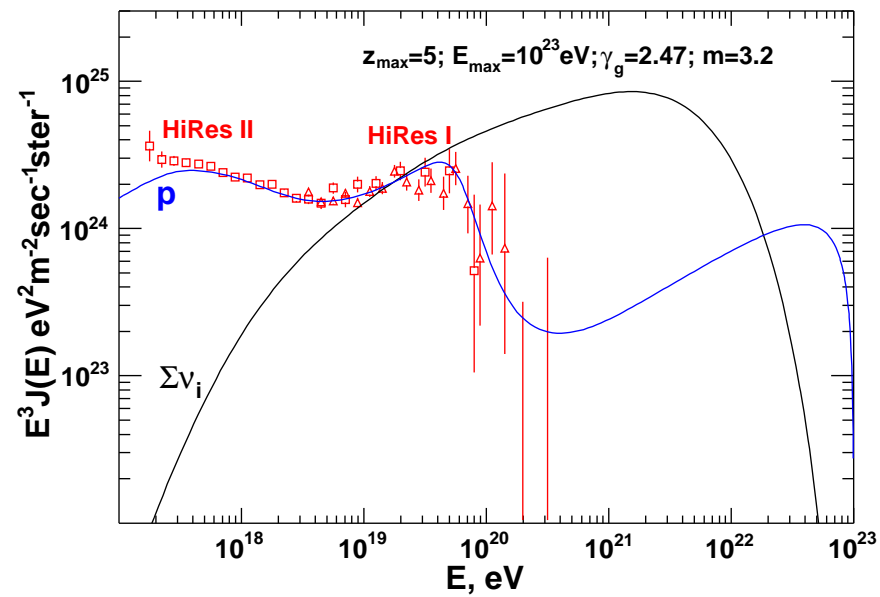
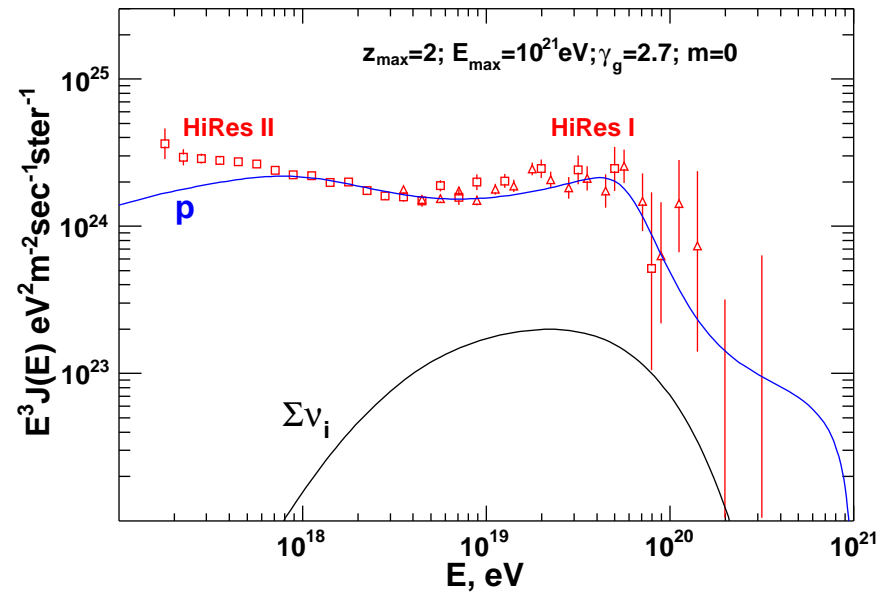
# RECALIBRATION of AUGER, HIRES, AGASA, YAKUTSK FLUXES

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



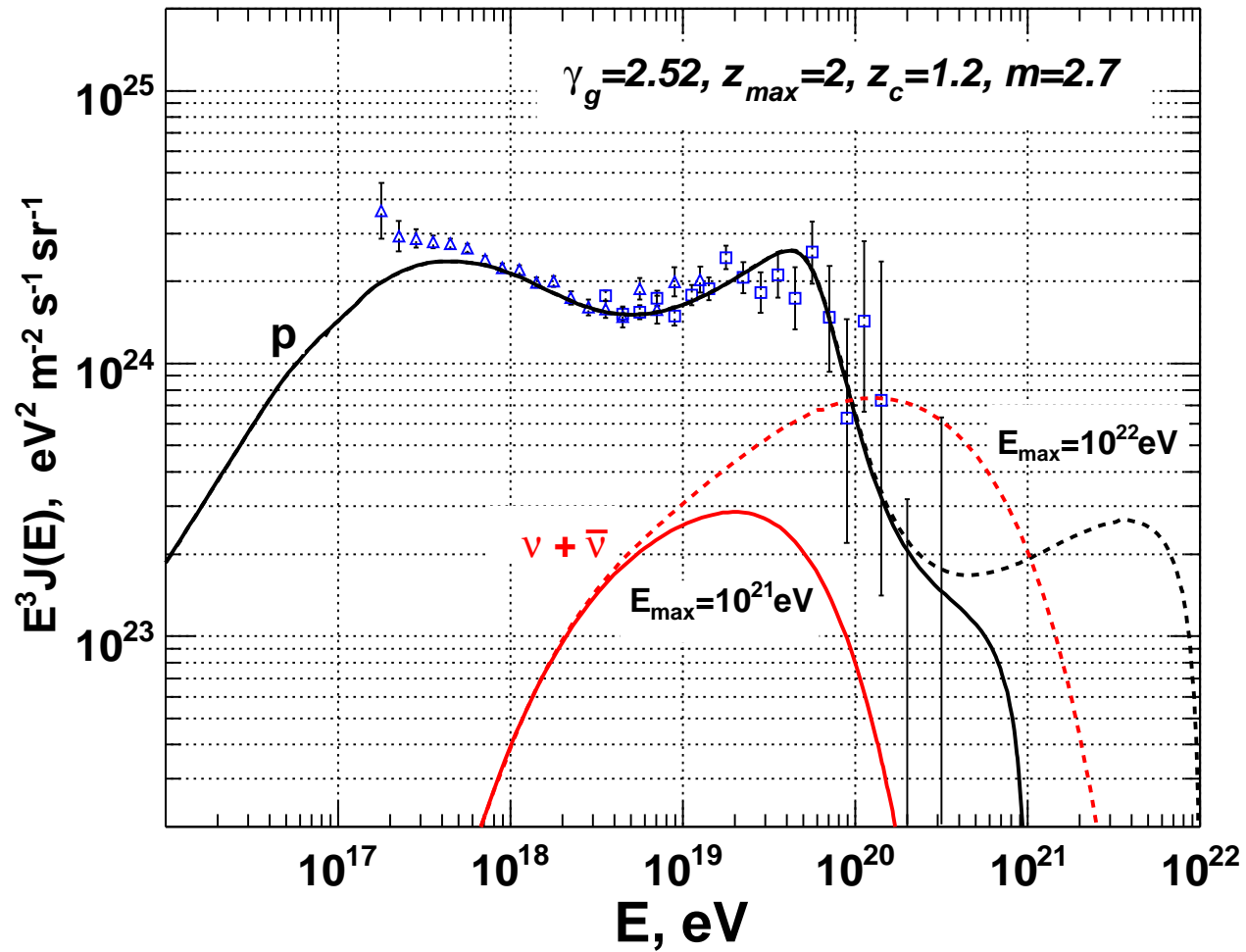
Recalibration factors:  $\lambda = 1.2$  (Auger),  $\lambda = 1.0$  (HiRes),  $\lambda = 0.75$  (AGASA),  $\lambda = 0.625$  (Yakutsk).

# COSMOGENIC NEUTRINO FLUXES IN THE DIP MODEL



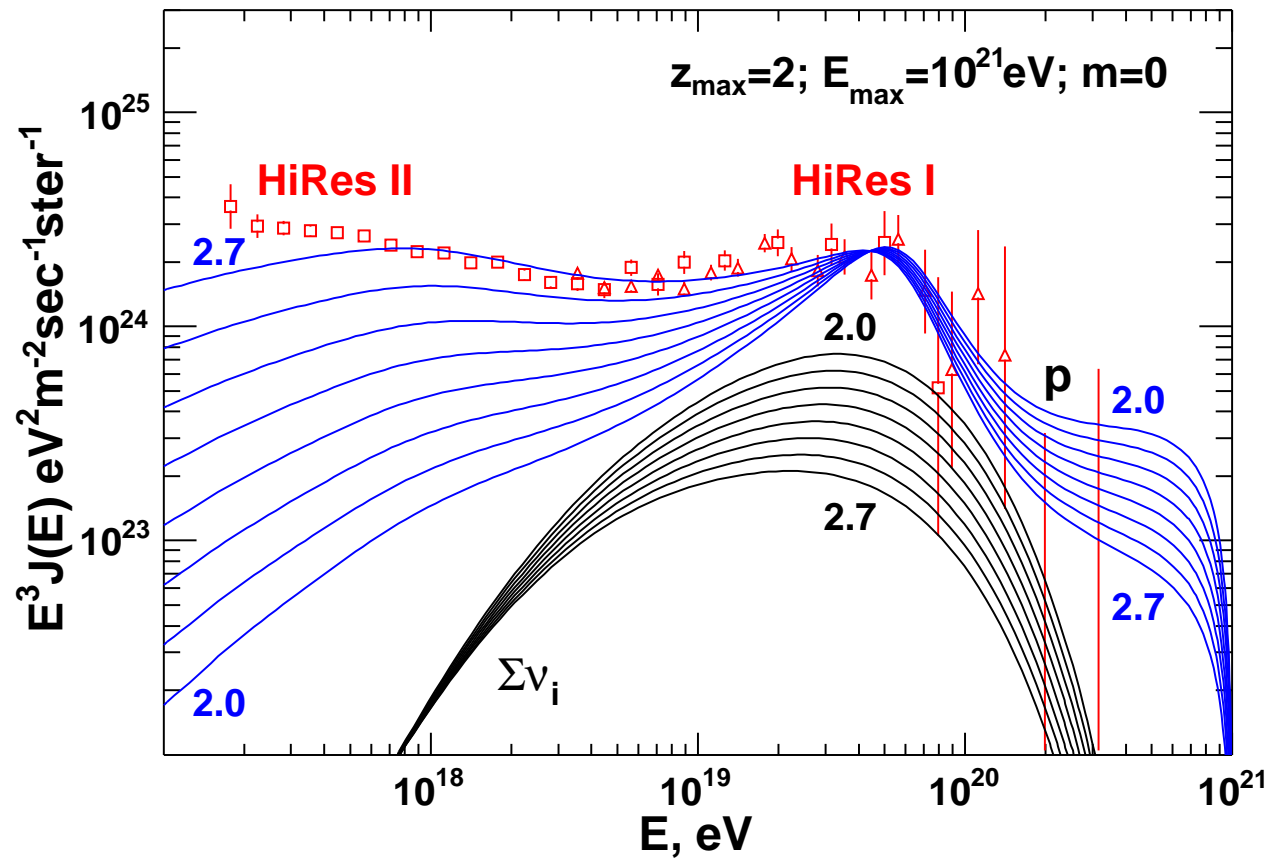


# COSMOGENIC NEUTRINO FLUXES FROM AGN



# LOWER LIMIT ON NEUTRINO FLUXES IN THE PROTON MODELS

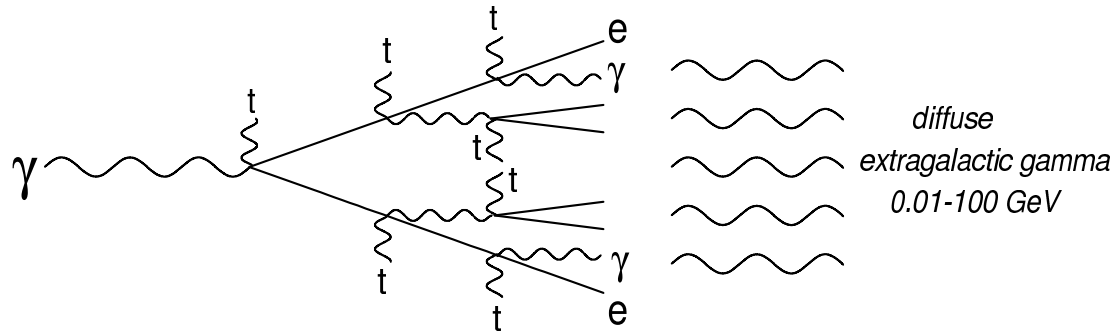
V.B. and A. Gazizov 2009



# CASCADE UPPER LIMIT

V.B. and A.Smirnov 1975

e – m cascade on target photons :  $\begin{cases} \gamma + \gamma_{\text{tar}} \rightarrow e^+ + e^- \\ e + \gamma_{\text{tar}} \rightarrow e' + \gamma' \end{cases}$



## Spectrum of cascade photons

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

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

**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:**

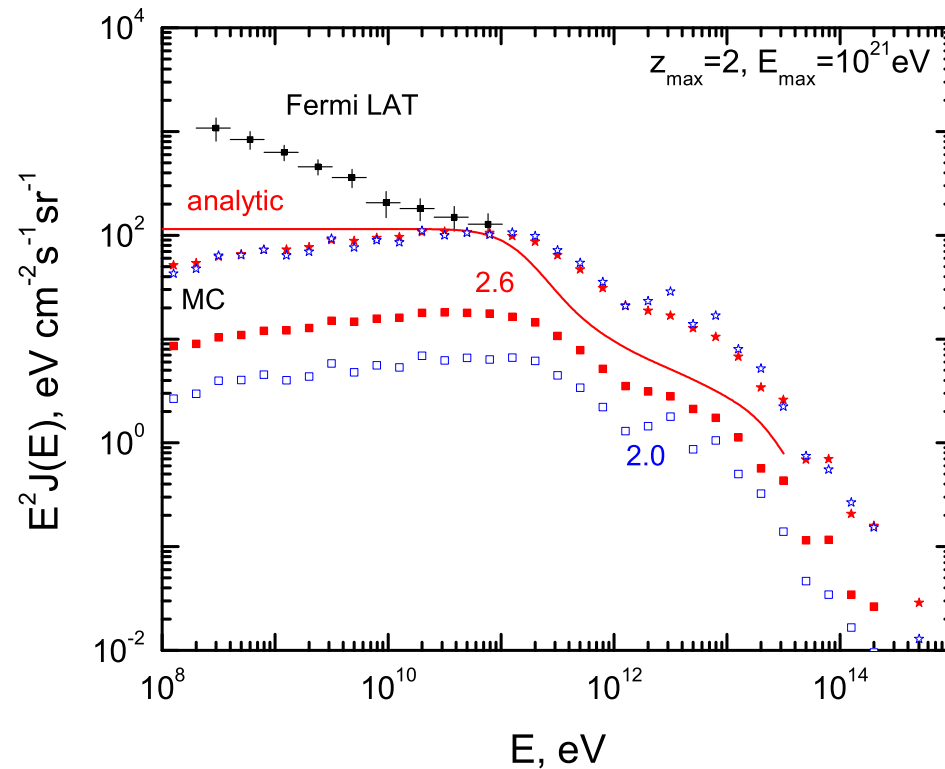
$$E^2 J_\nu(E) < \frac{c}{4\pi} \frac{\omega_{\text{cas}}}{\ln E_{\text{max}}/E_{\text{min}}}.$$

# 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.

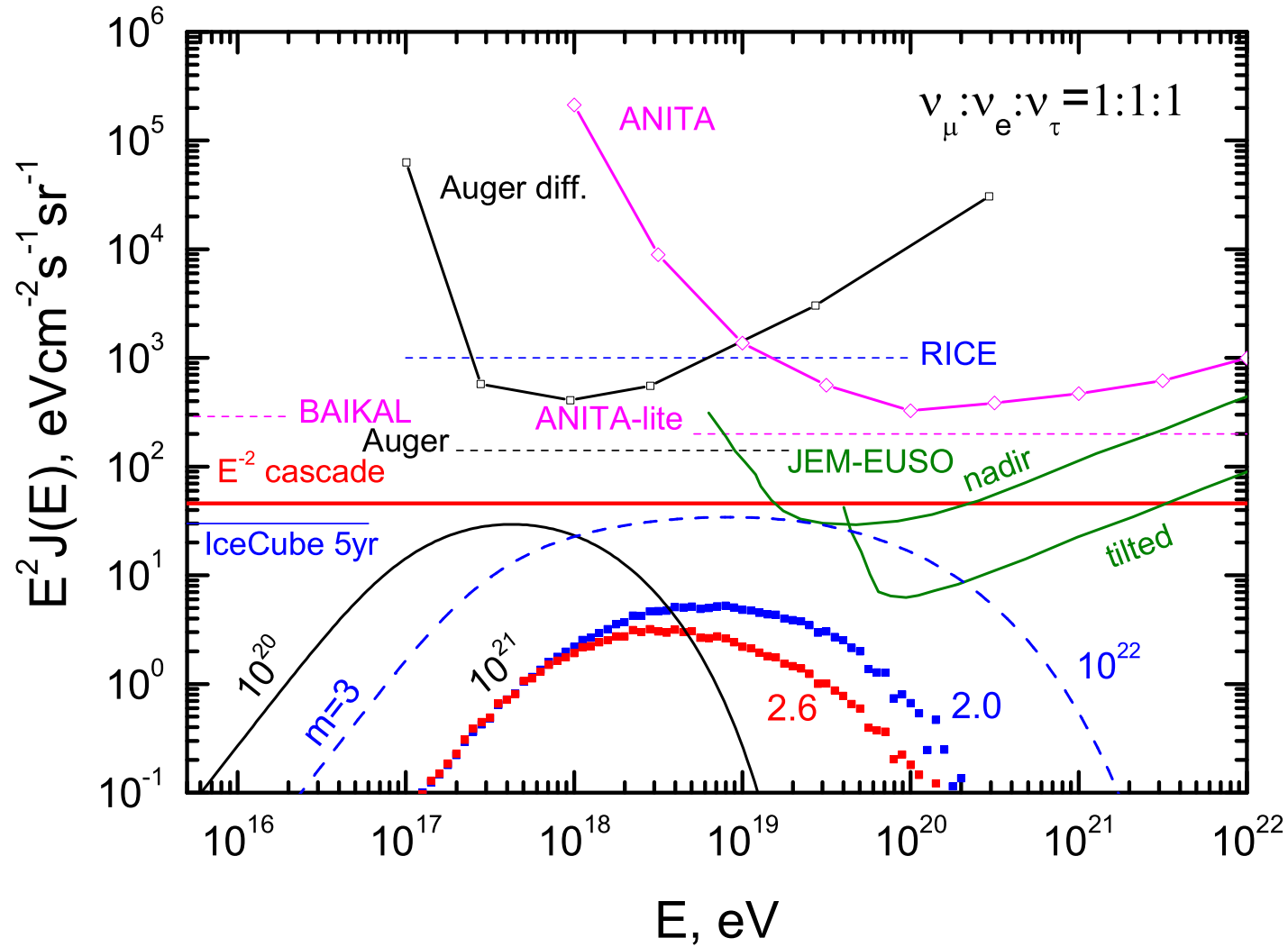
G. Gelmini, O. Kalashev, D. Semikoz arXiv:1107.1672



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

# 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  $T_{\text{dec}} \sim 3600$  K,  $z_{\text{dec}} \sim 1100$ .
- **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**  $z_{\text{reion}} = 11.0 \pm 1.4$  (WMAP).

## Pop III scenario fills in several blanks in astrophysics:

- Produces **metals** needed for evolution of normal stars.
- Produces **reionization** observed by WMAP.
- Produces **magnetic fields** in Universe.

Pioneering proposal: Bisnovatiy-Kogan, Ruzmaikin, Syunyaev 1973.

Magn. field production **without pre-existing magn. field:**

Collisionless shock without magn. field (e.g. Spitkovsky 2008).

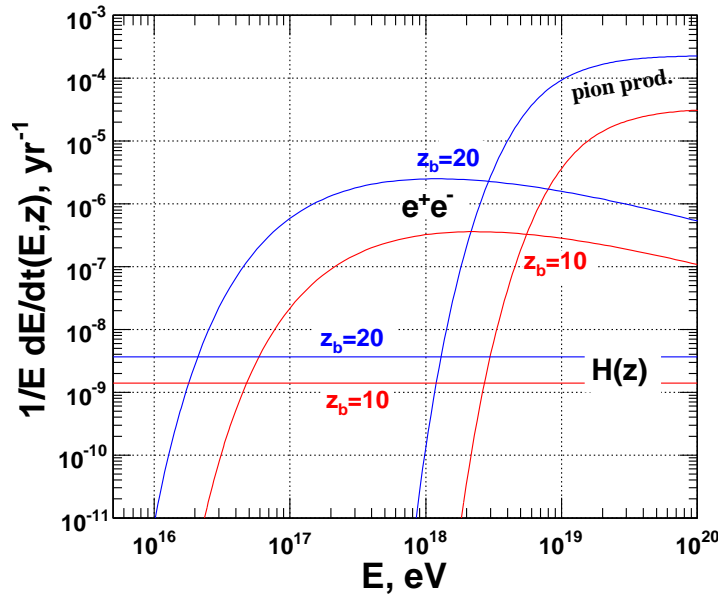
**Weibel instability** in shocks and winds (Medvedev et al 1999, 2006).

**Resistive mechanism** in shocks and winds (Miniati and Bell 2010).

# 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  $p\gamma_{\text{cmb}}$ .



Energy losses of protons at  $z_b$ .

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

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

**Neutrino flux** has a maximum at:

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

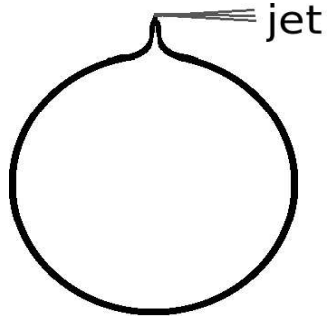
$$E_\nu^{\text{max}} \sim 0.05 \frac{E_p^{\text{max}}}{(1+z_b)} \approx 2.5 \times 10^{17} \text{ eV}.$$



# TOPOLOGICAL DEFECTS

Symmetry breaking in early universe results in **phase transitions** (D.A. Kirzhnits 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 and massive outside.

Loop oscillates with periodically produced cusp ( $v = c$ ) and with large Lorentz factors, e.g. above  $\Gamma \sim 10^{10}$ , at nearby points.

Particles escaping from cusp segment have energy  $E \sim \Gamma m_X$ ,

Particles are emitted as **jets** with  $\theta \sim 1/\Gamma_c$ .

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

## UHE neutrino jets from superconducting strings

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

**Electric current** is generated in magnetic fields ( $B, f_B$ ), dominated by clusters.

**Clusters of galaxies** dominate.

**Lorentz factor** of cusp  $\Gamma_c \sim 1 \times 10^{12}$ .

**Diffuse neutrino flux :**

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

# UHE NEUTRINOS FROM ORDINARY STRINGS.

## 1. Ordinary strings with EW Higgs condensate. Vachaspati 2010

Interaction of EW Higgs  $\phi$  with the string field  $\Phi$  ( $\kappa$  is coupling constant):

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

After GUT symmetry breaking ( $\langle \Phi \rangle = \eta$ ):

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

where  $d^2\sigma$  is string world-sheet space,  $\gamma_{ab}$  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.

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

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

is the trace of energy-momentum tensor of string.

**Dilatons and moduli** are produced as radiation quanta from the **cusp**.

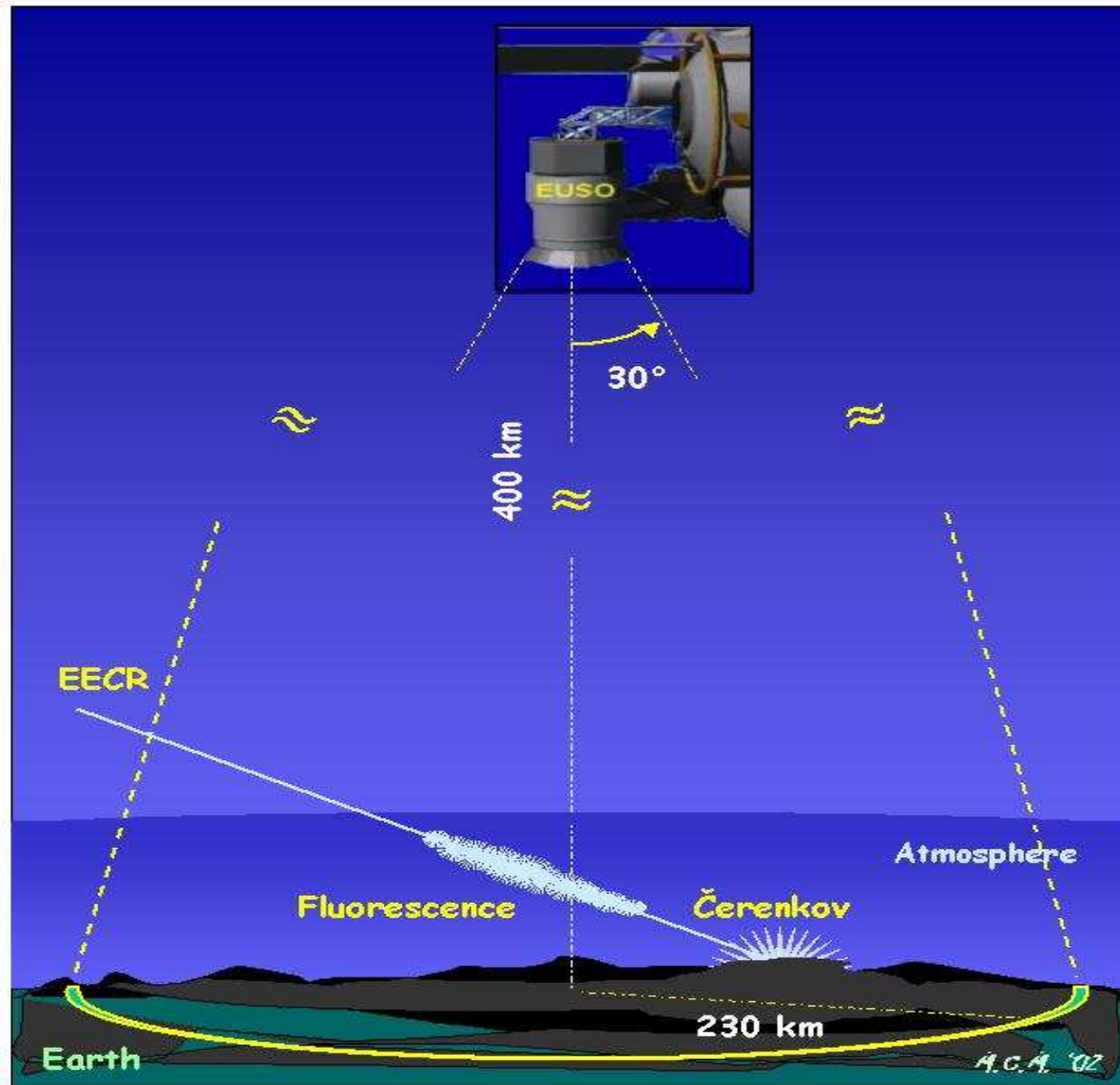
In terms of the Fourier momenta  $k$ :  $dN(k) = \alpha^2 G \eta^4 \ell^{2/3} k^{-7/3} dk$ .

## CONCLUSIONS

- Fluxes of **diffuse cosmogenic neutrinos** strongly depend on the mass composition of UHECR. According to **Auger data** mass composition becomes **heavy** at highest energy, which dramatically decreases the predicted neutrino flux.
- **HiRes data** are compatible with pure **proton composition** and with much larger fluxes of cosmogenic neutrinos. However, these fluxes are strongly bounded by **the cascade upper limit** based on latest Fermi-LAT data. With this upper limit 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. 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  $\Phi$  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

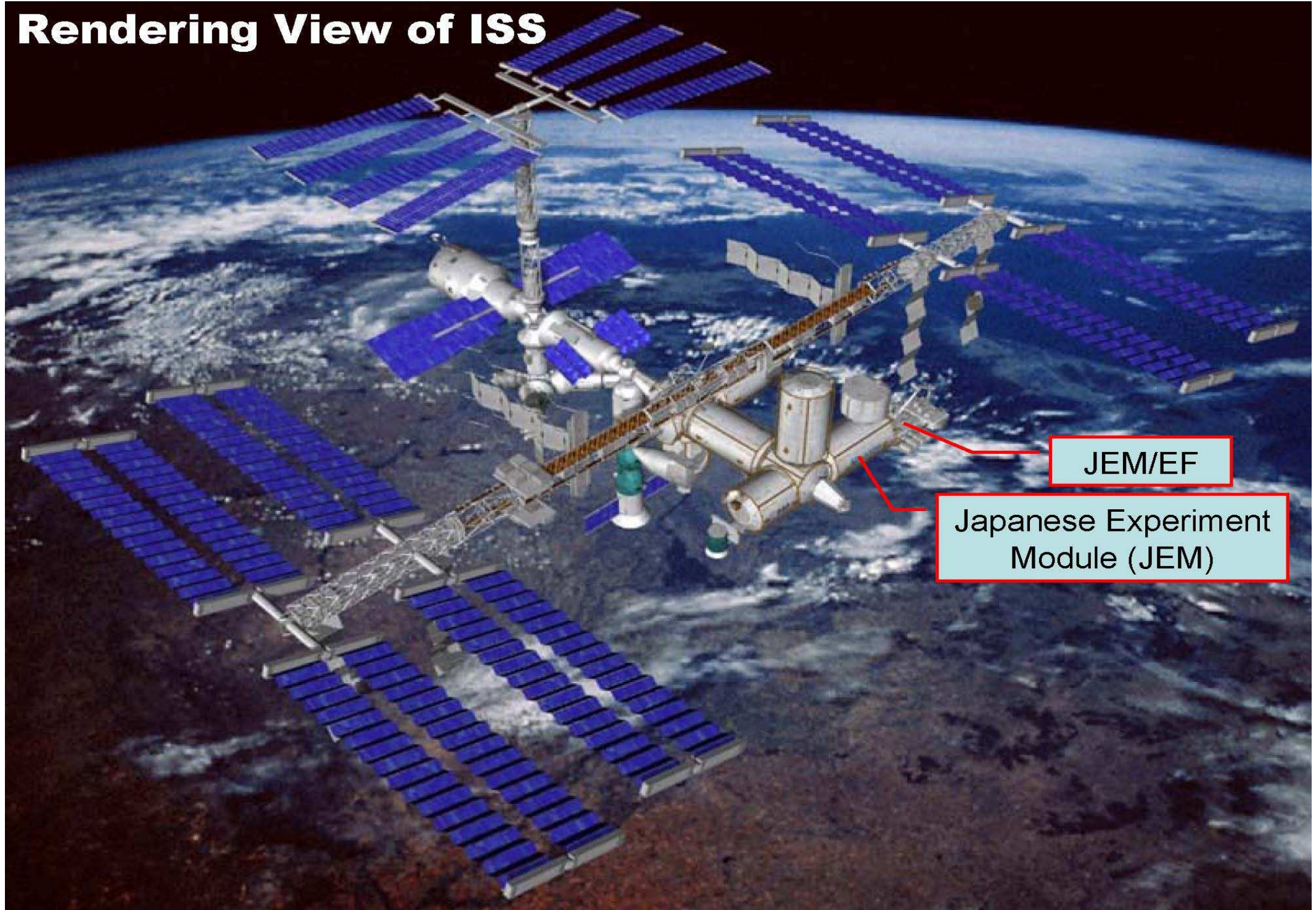


# Field of View of EUSO

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



# Rendering View of ISS



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.**