Cosmogenic Neutrinos

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Overview:

- *Acceleration of UHECR in astrophysical sources*
- *UHECR spectrum and GZK cutoff*
- *Theoretical models and composition*
- *Constraints on gamma-ray flux*
- *Predictions for the neutrino flux*

Pion production

$$N + \gamma_b \Rightarrow N' + \sum \pi^i$$

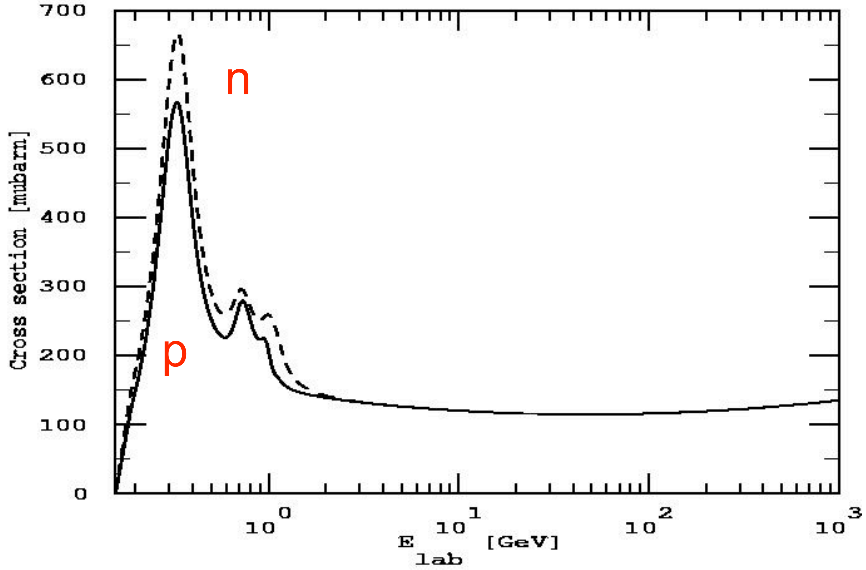
$$P + P_b \Rightarrow \sum \pi^i + \ldots$$

$$\pi^0 \Rightarrow 2\gamma$$

$$\pi^\pm \Rightarrow \mu^\pm + \nu_\mu$$

$$\mu^\pm \Rightarrow e^\pm + \bar{\nu}_e + \nu_\mu$$

$$n \Rightarrow p + e^- + \bar{\nu}_e$$

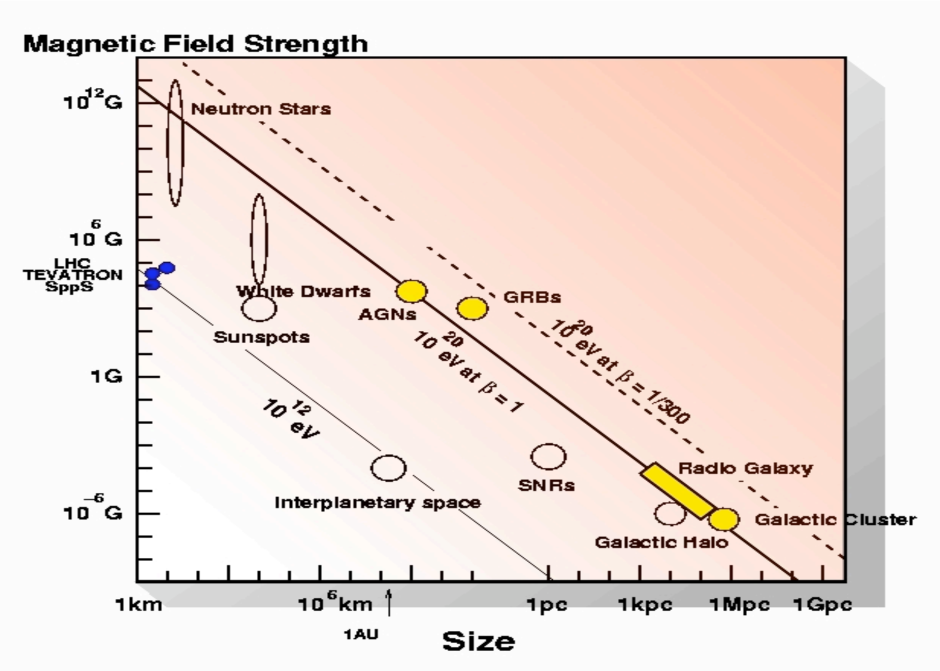


Conclusion: proton, photon and neutrino fluxes are connected in well-defined way.

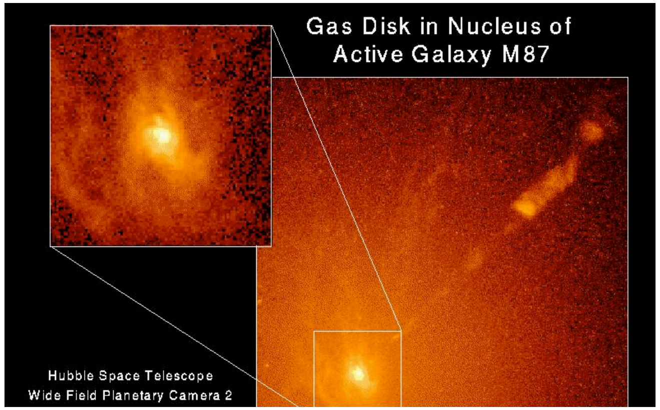
$$E_\gamma^{tot} \sim E_\nu^{tot}$$

Acceleration of UHECR

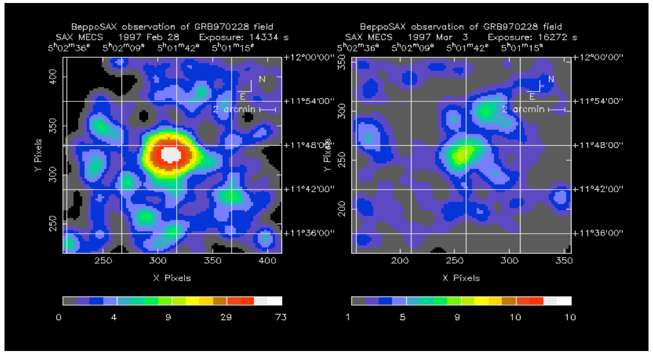
Acceleration of UHECR



A.G.N.

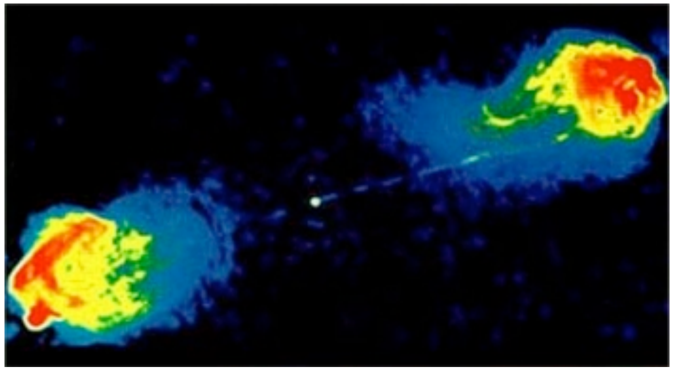


GRB

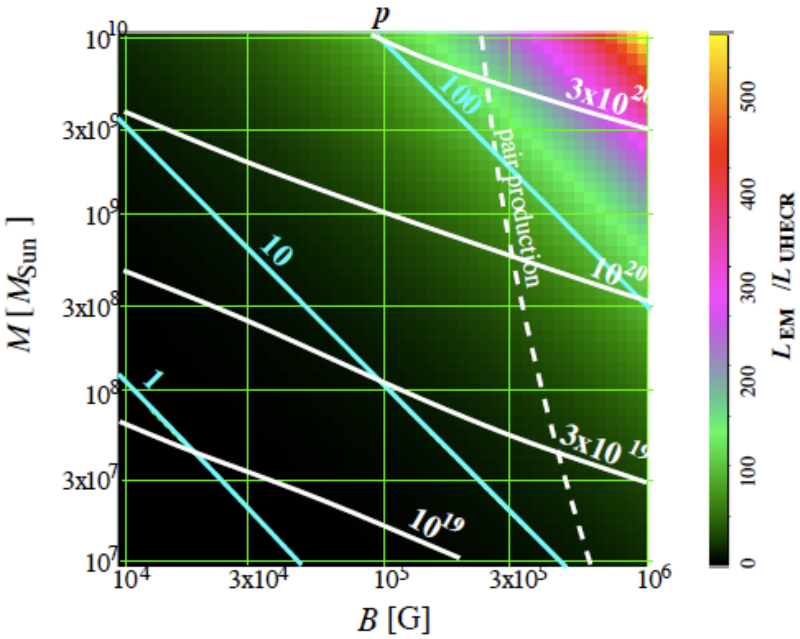


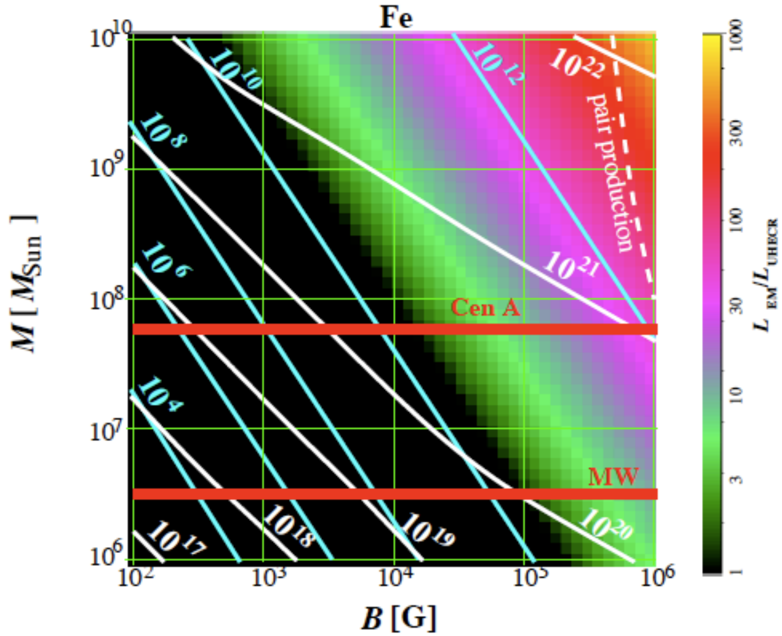
- Shock acceleration $1/E^{\alpha}$ $\alpha >= 2$
- Electric field acceleration line at E_{max}
- Converter acceleration can be both

Radio Galaxy Lobe



Acceleration in polar cap of Black Hole by the electric field



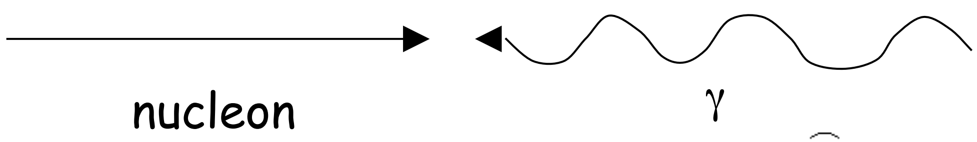


A.Neronov, D.Semikoz and I.Tkachev astro-ph/0712.1737

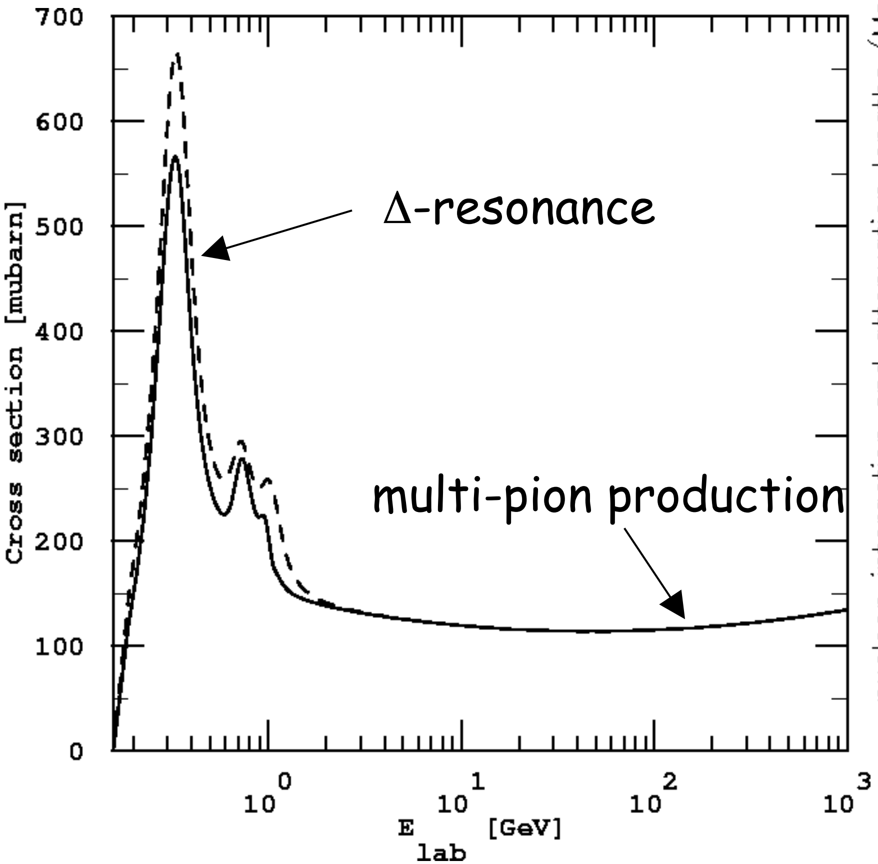
UHECR spectrum and GZK cutoff

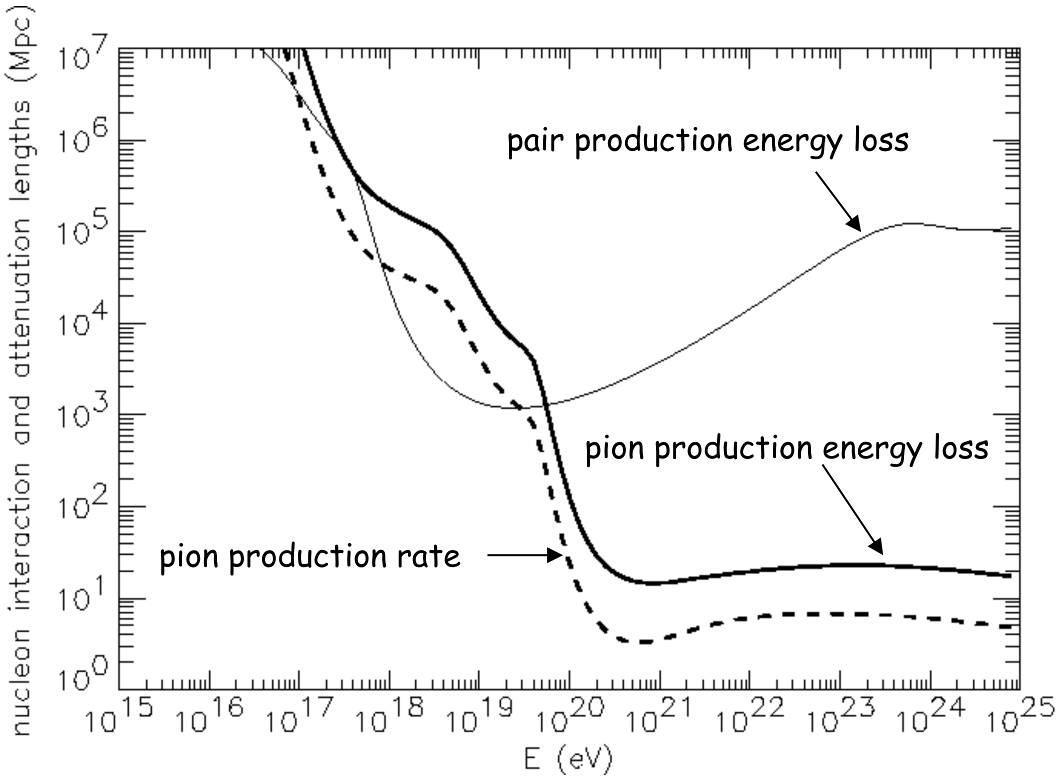
The Greisen-Zatsepin-Kuzmin (GZK) effect

Nucleons can produce pions on the cosmic microwave background



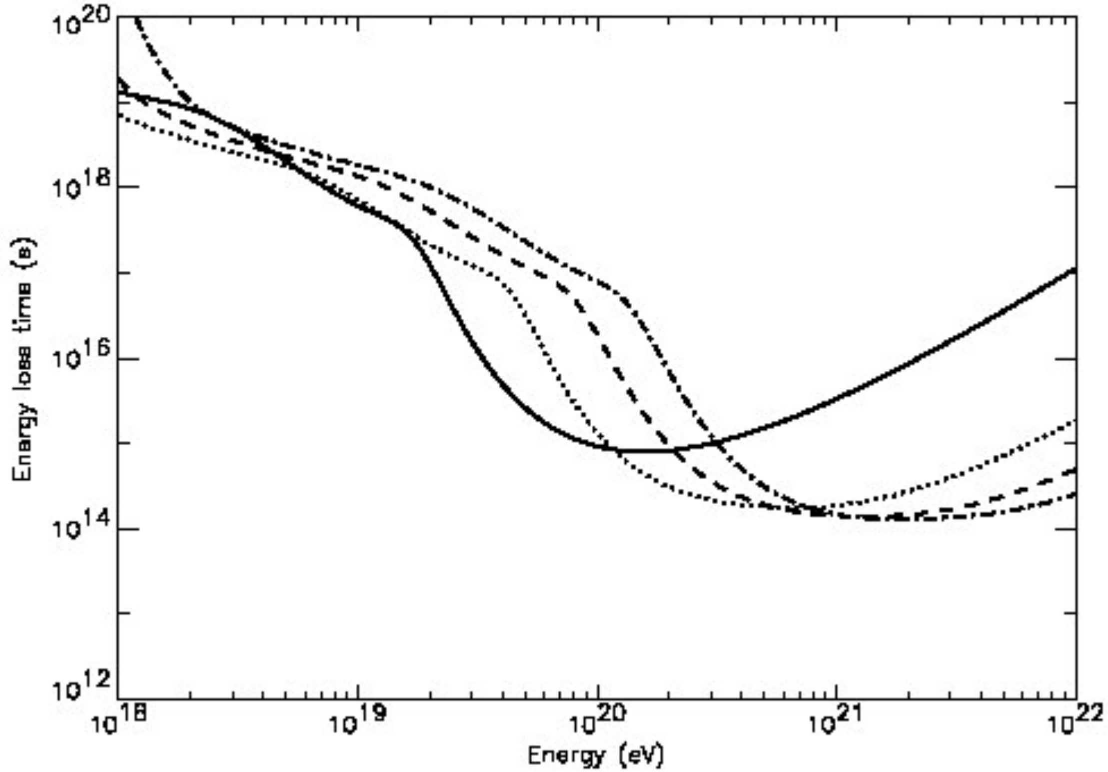
$$E_{th} = \frac{2m_N m_\pi + m_\pi^2}{4\varepsilon} \approx 4\cdot 10^{19}\,\mathrm{eV}$$





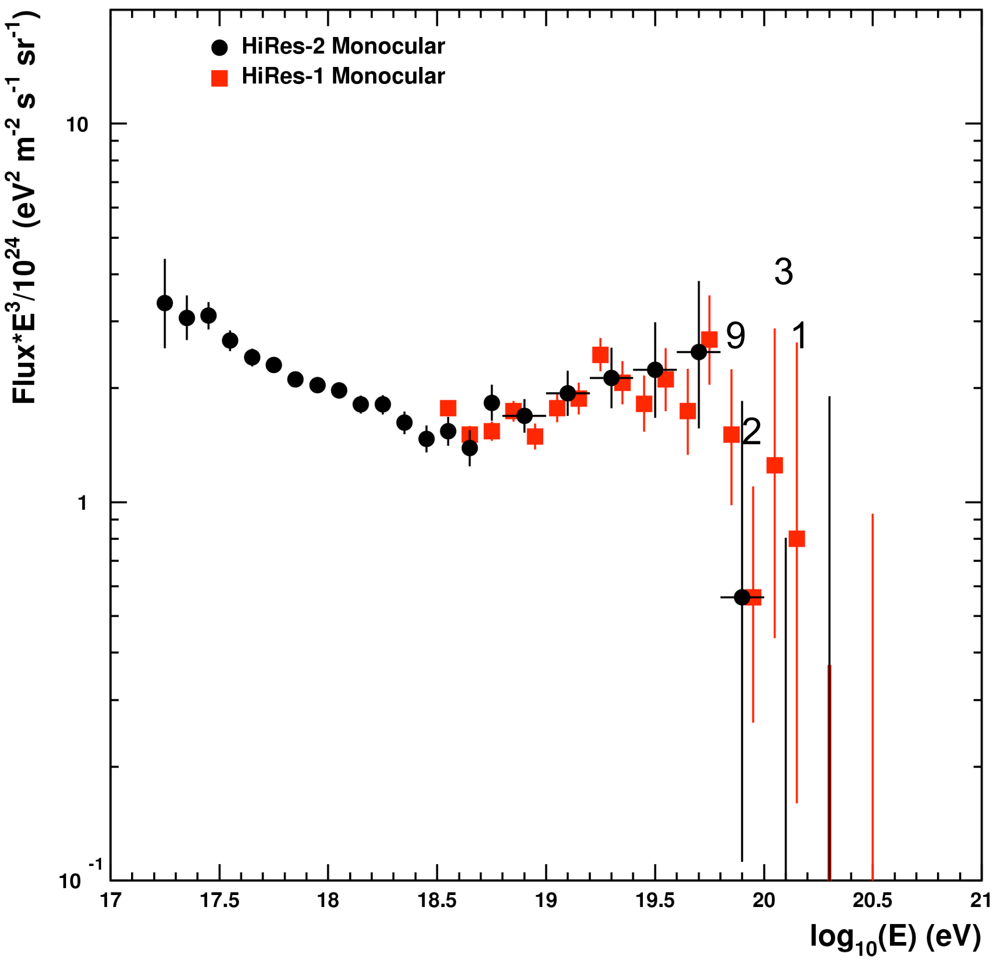
⇒sources must be in cosmological backyard within 50-100 Mpc from Earth (compare to the Universe size ~ 5000 Mpc)

Same true for heavy nuclei: Fe



Simulation by D.Allard

HiRes: cutoff in the spectrum

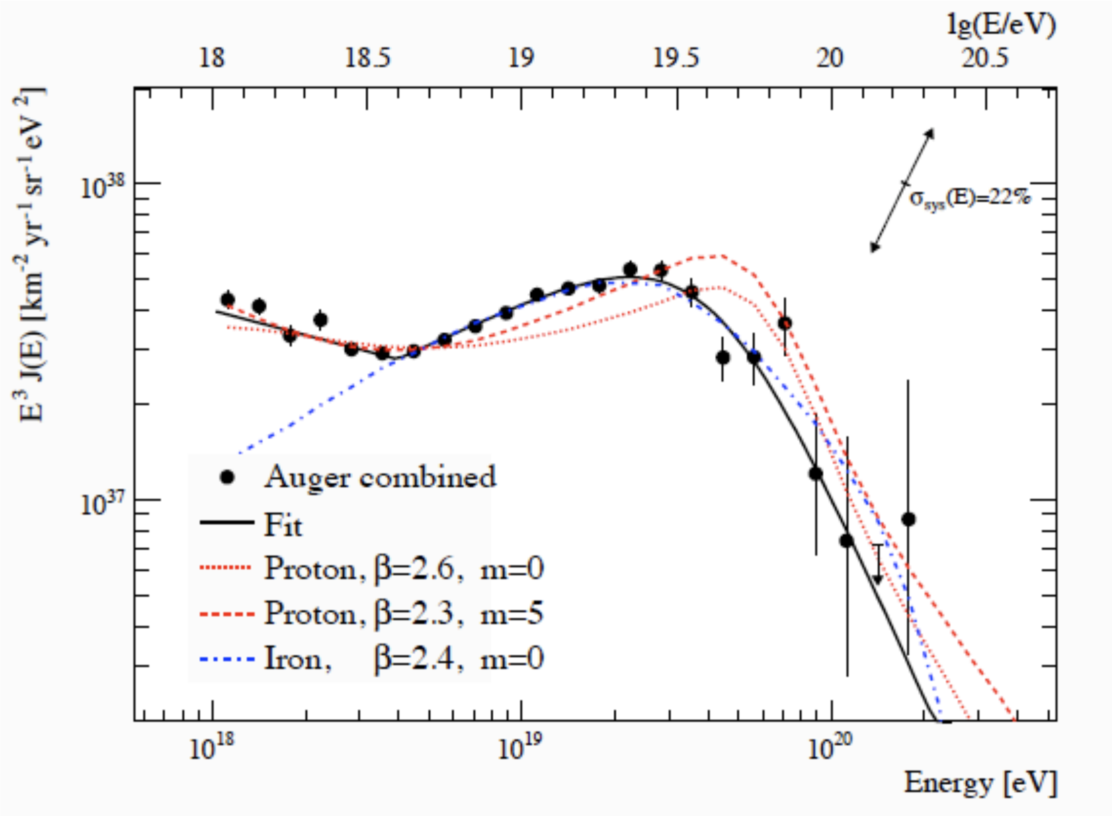


"GZK" Statistics

- Expect 42.8 events
- Observe 15 events
- ~ 5 σ

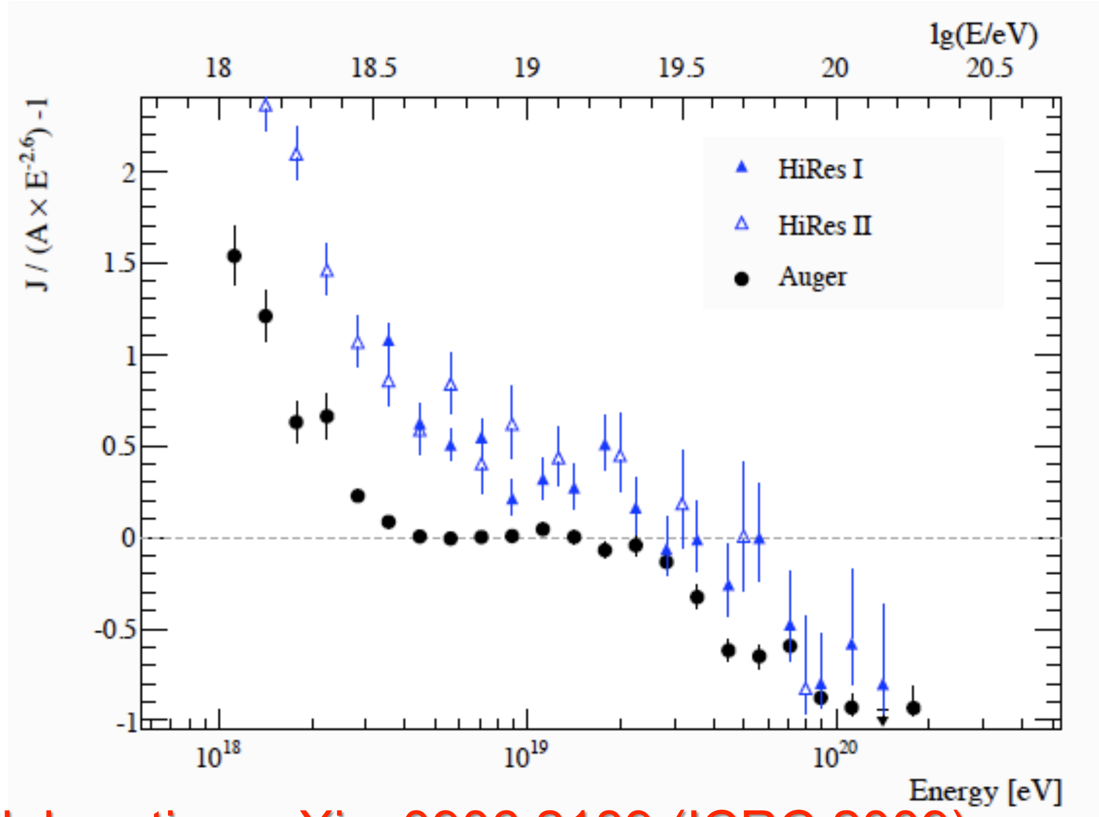
Bergman (ICRC-2005)

Auger Energy Spectrum 2009



Auger collaboration arXiv: 0906.2189 (ICRC 2009)

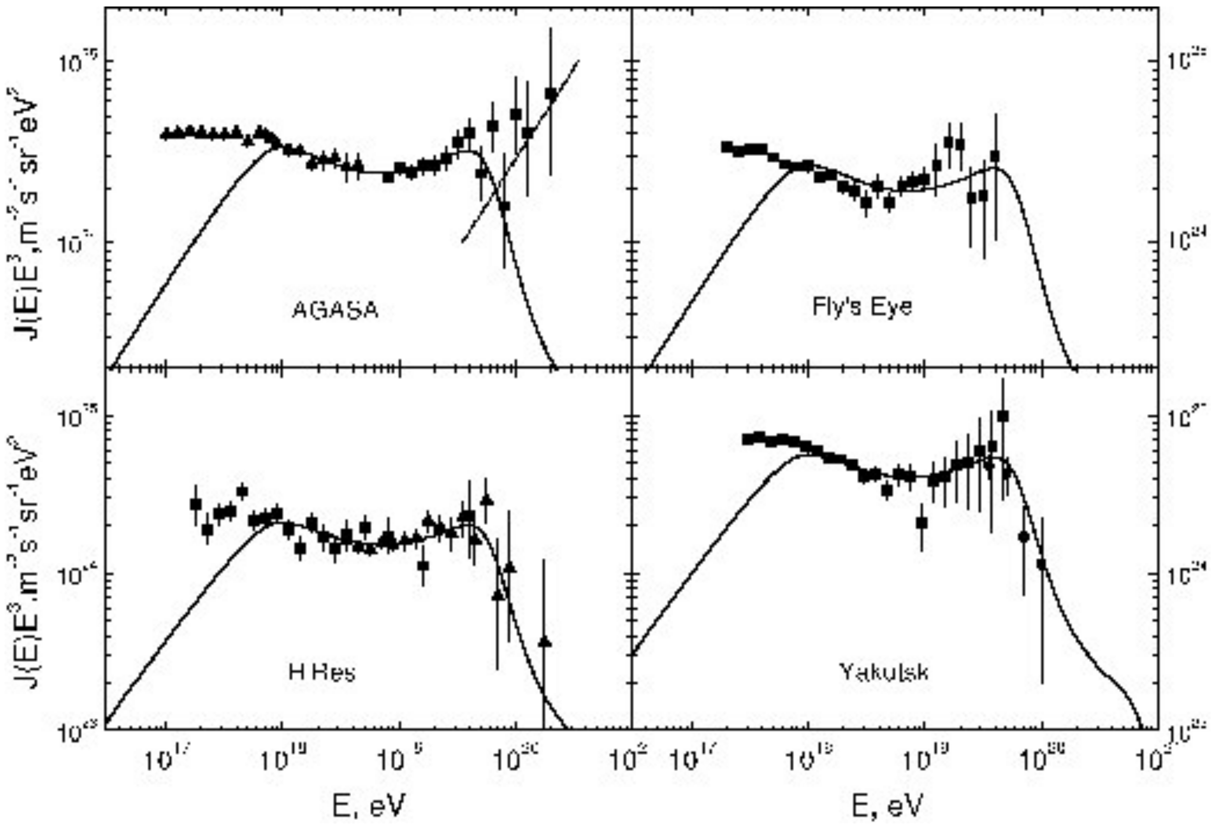
Auger Energy Spectrum 2009



Auger collaboration arXiv: 0906.2189 (ICRC 2009)

Theoretical models and composition

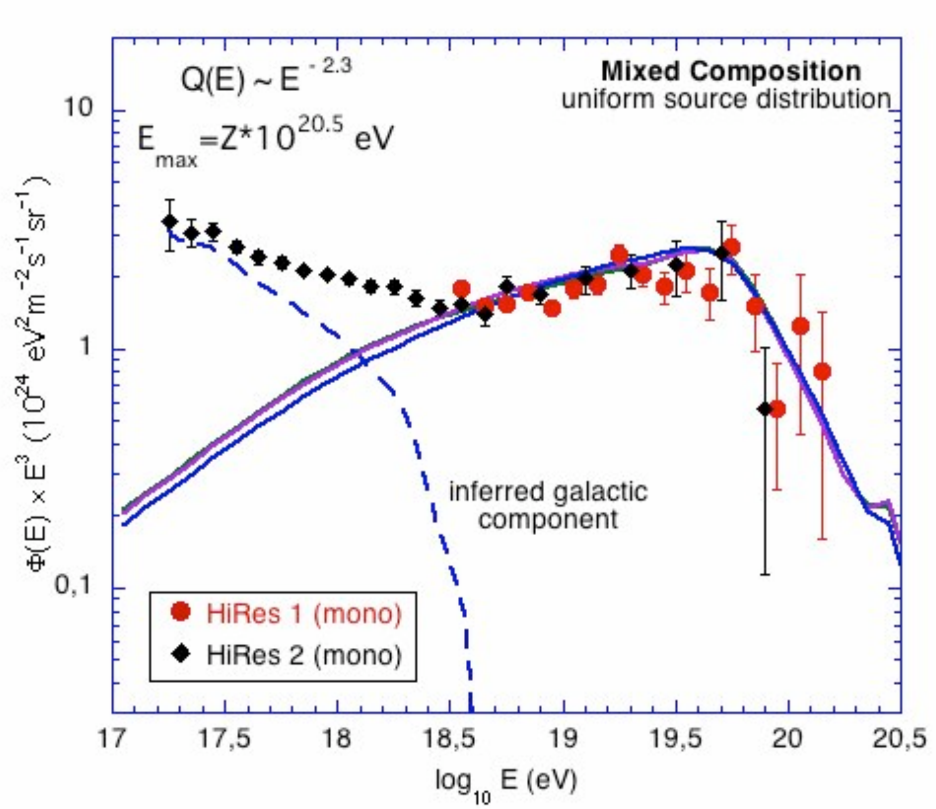
Protons can fit UHECR data



V.Berezinsky , astro-ph/0509069

problem: composition

Mixed composition model

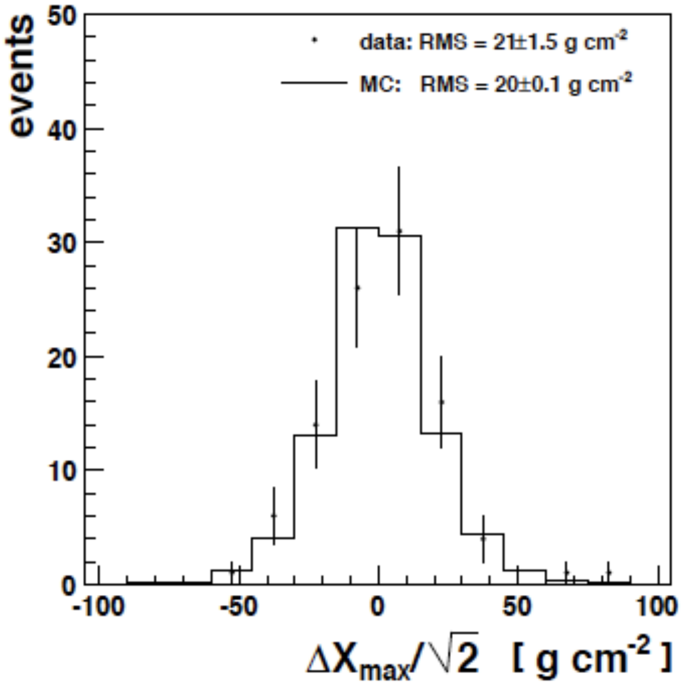


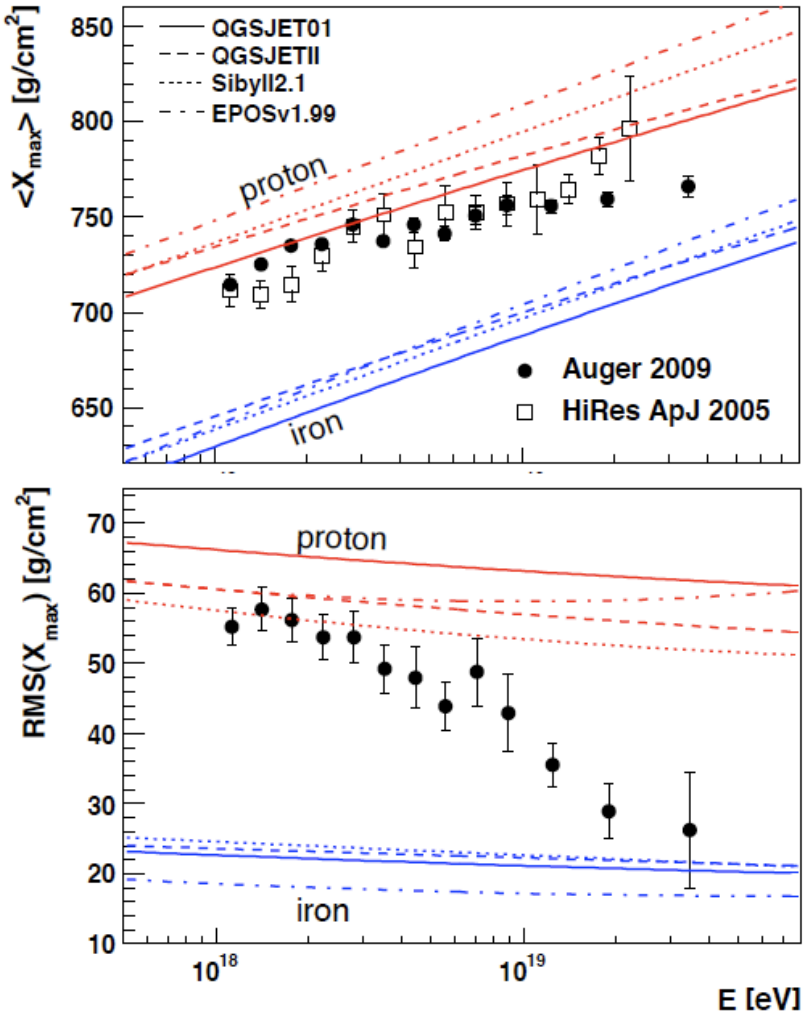
D.Allard, E.Parizot and A.Olinto, astro-ph/0512345

Problems: 1) escape of the nuclei from the source

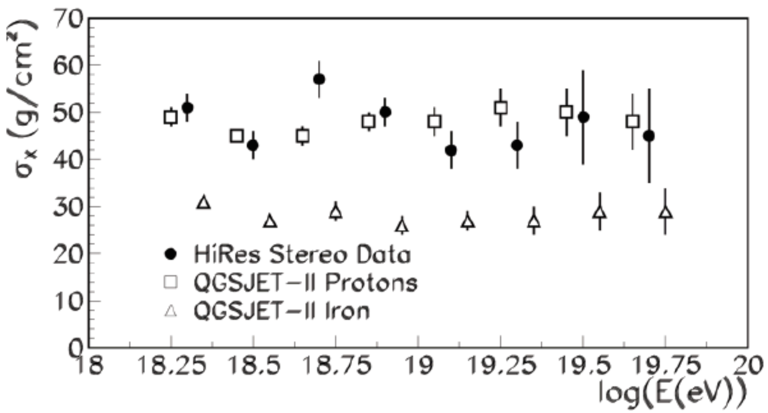
2) How to accelerate Fe in our Galaxy

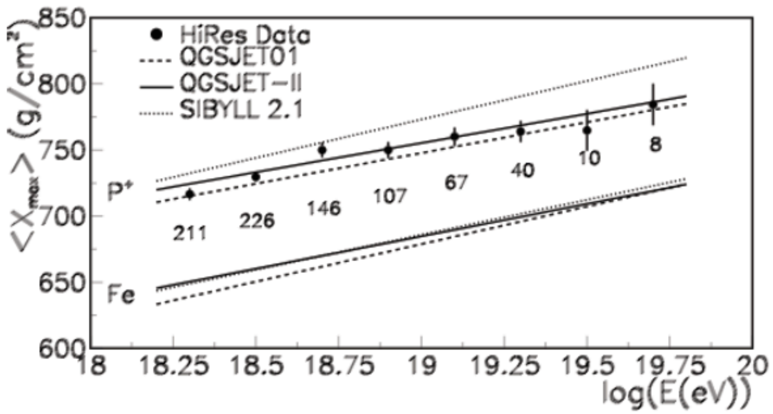
Auger composition 2009: nuclei!





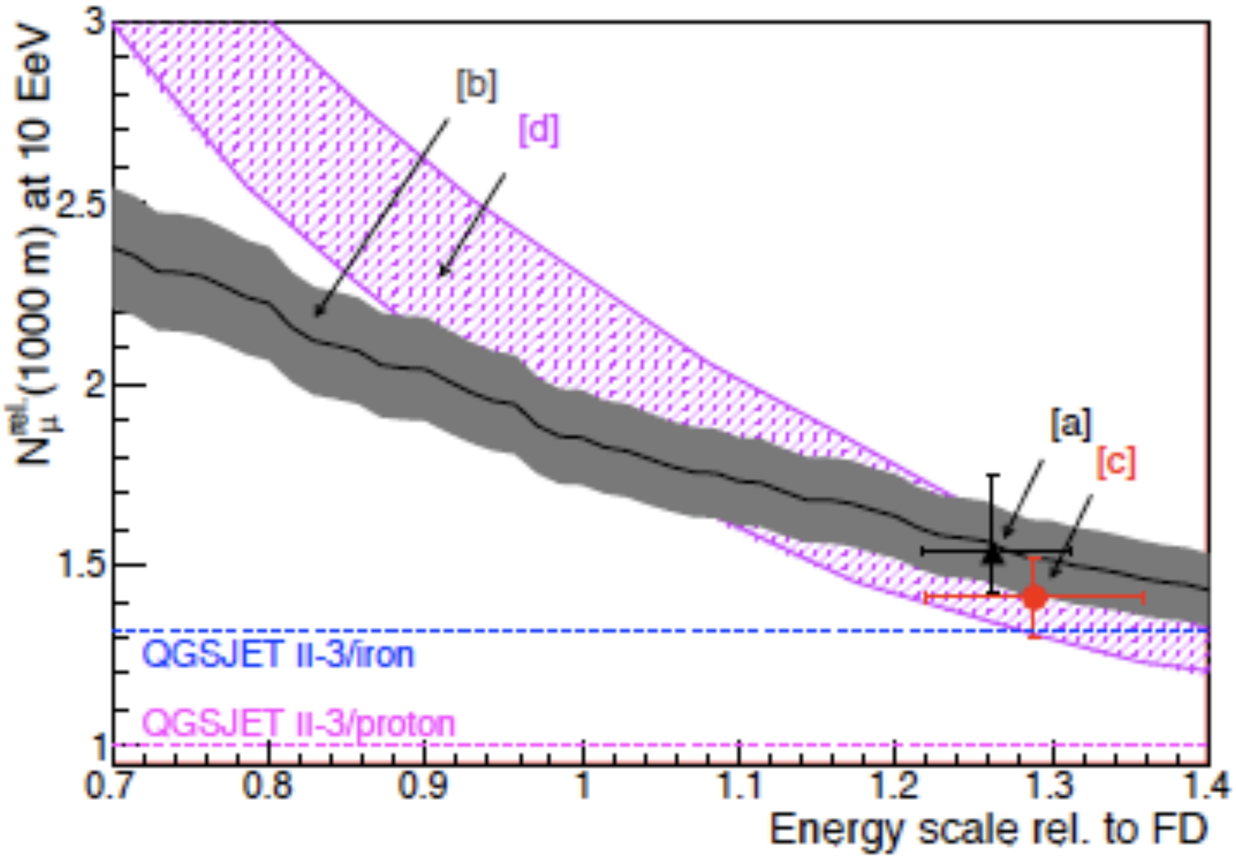
HiRes composition



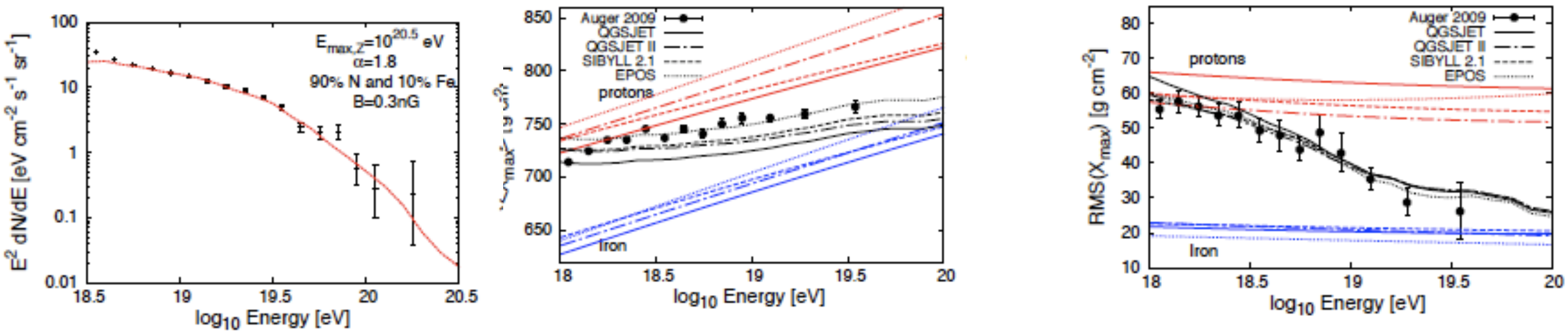


From 1010.2690

Muon number in Auger



Can one explain nuclei + cutoff?



D.Hooper and A.Taylor 0910.1842

Secondary photons and neutrinos from UHECR

Pion production

$$N + \gamma_b \Rightarrow N' + \sum \pi^i$$

$$P + P_b \Rightarrow \sum \pi^i + \ldots$$

$$\pi^0 \Rightarrow 2\gamma$$

$$\pi^\pm \Rightarrow \mu^\pm + \nu_\mu$$

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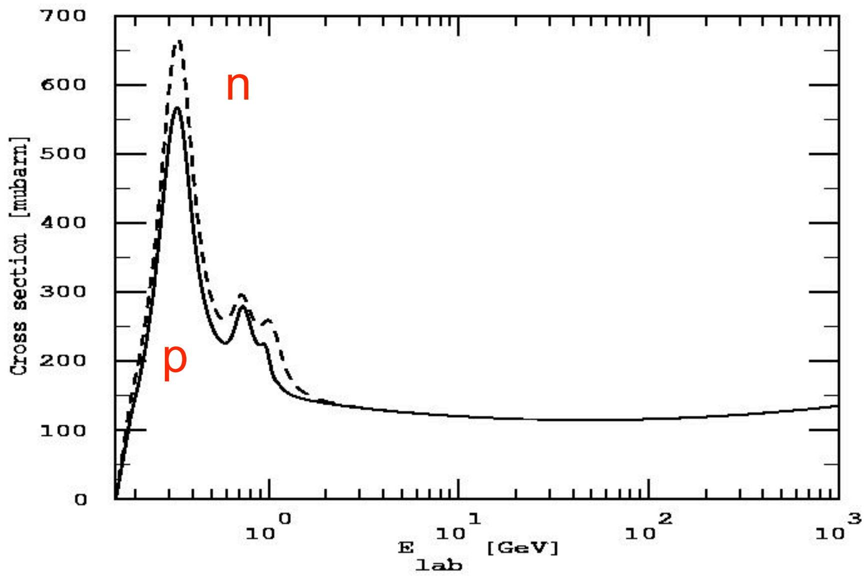
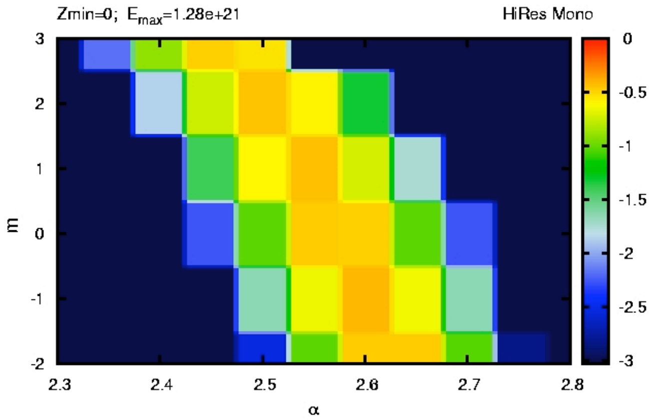
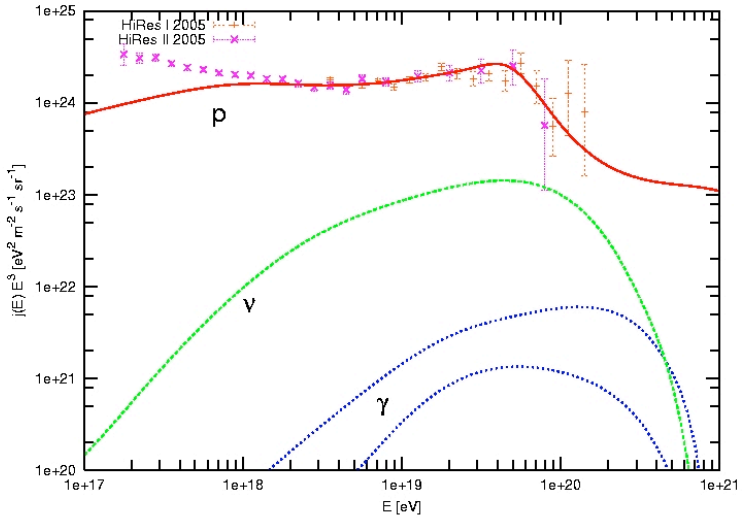


Conclusion: proton, photon and neutrino fluxes are connected in well-defined way. If we know one of them we can predict other ones: $E_\gamma^{tot} \sim E_\nu^{tot}$

GZK photons with E>10 EeV

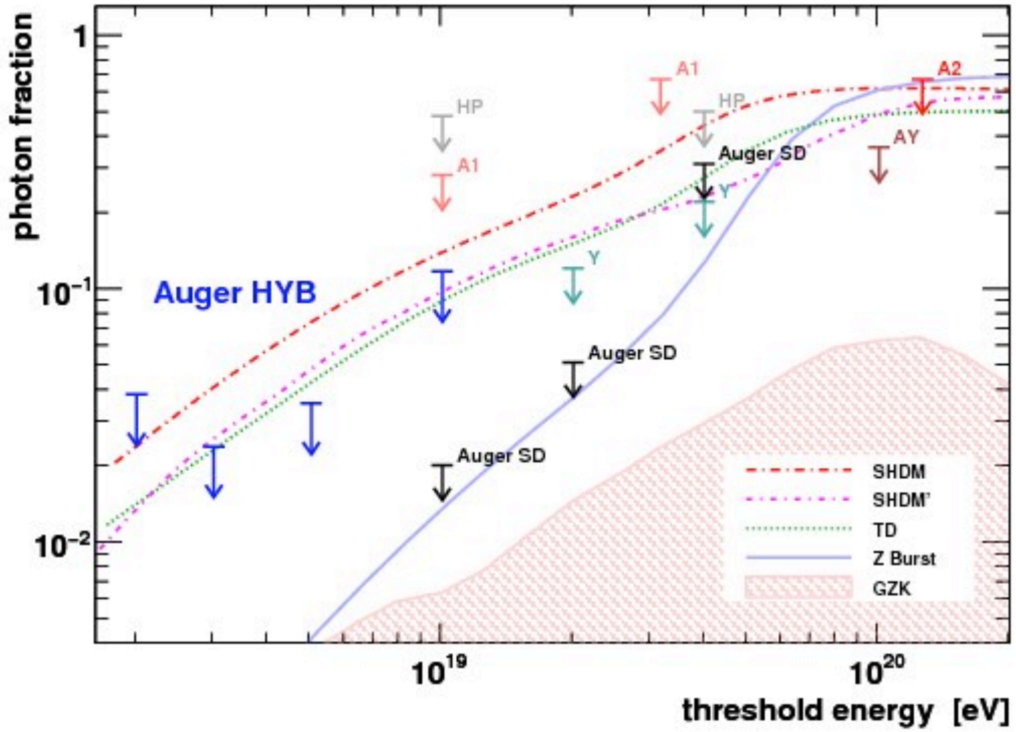
Secondary photons and neutrinos





G.Gelmini et al, astro-ph/0702464

Search for secondary photons



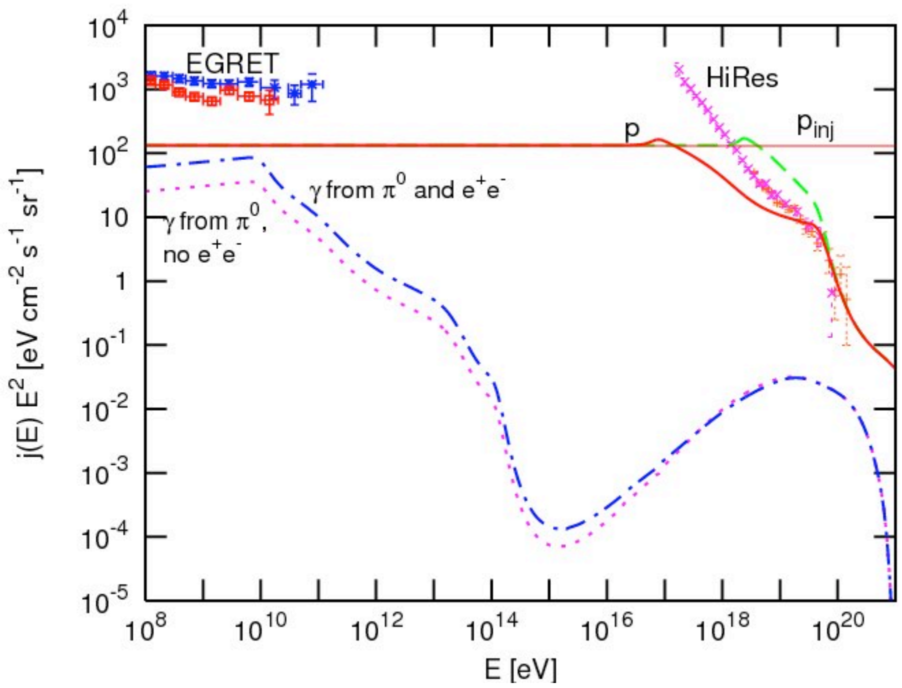
Cascade photons with GeV - TeV energies

Cascade photons for 1/E^2.

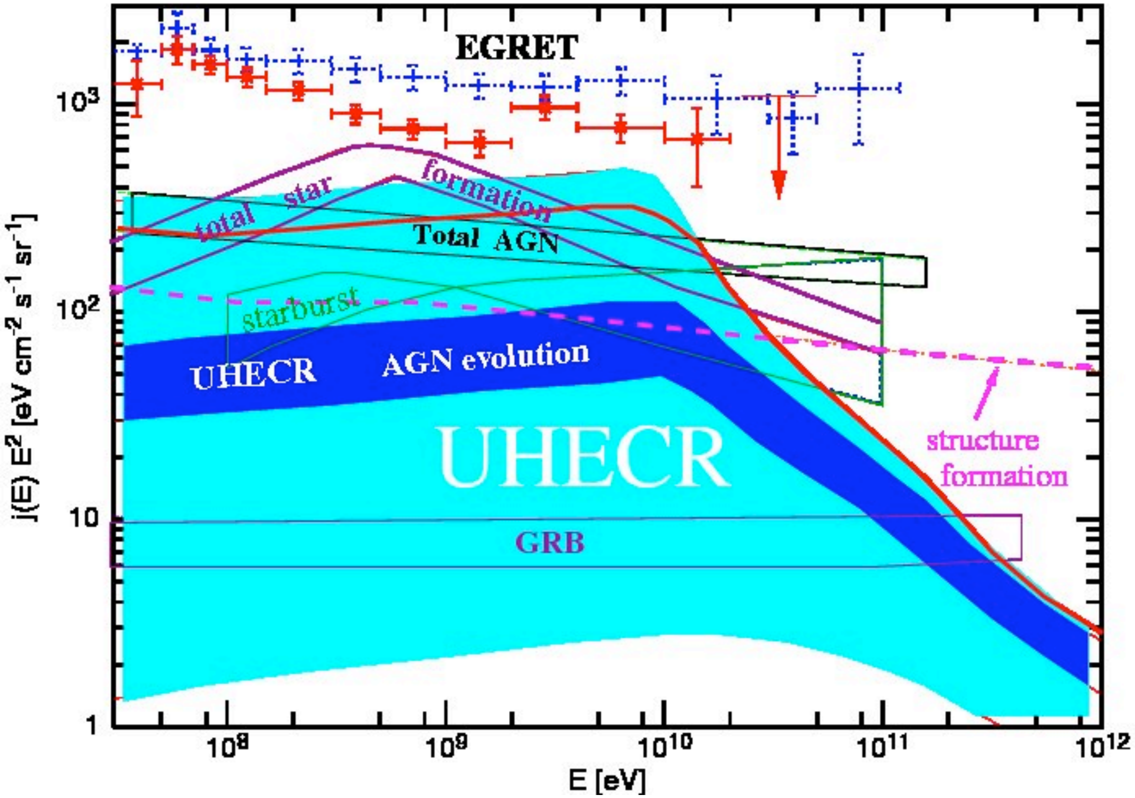
$$\gamma + \gamma_{CMB} \Rightarrow e^- + e^+$$

$$e^\pm + \gamma_{CMB} \Rightarrow e^\pm + \gamma$$

$$e^\pm + B \Rightarrow e^\pm + \gamma_{synch}$$



Contribution of UHECR to diffuse gamma-ray flux



O.Kalashev , D.S. and G.Sigl, astro-ph/0704.2463

UHE neutrinos.

Parameters which define diffuse neutrino flux

- Proton spectrum from one source:

$$F(E) = \frac{A}{E^{\alpha}} \qquad E_{\min} < E < E_{\max}$$

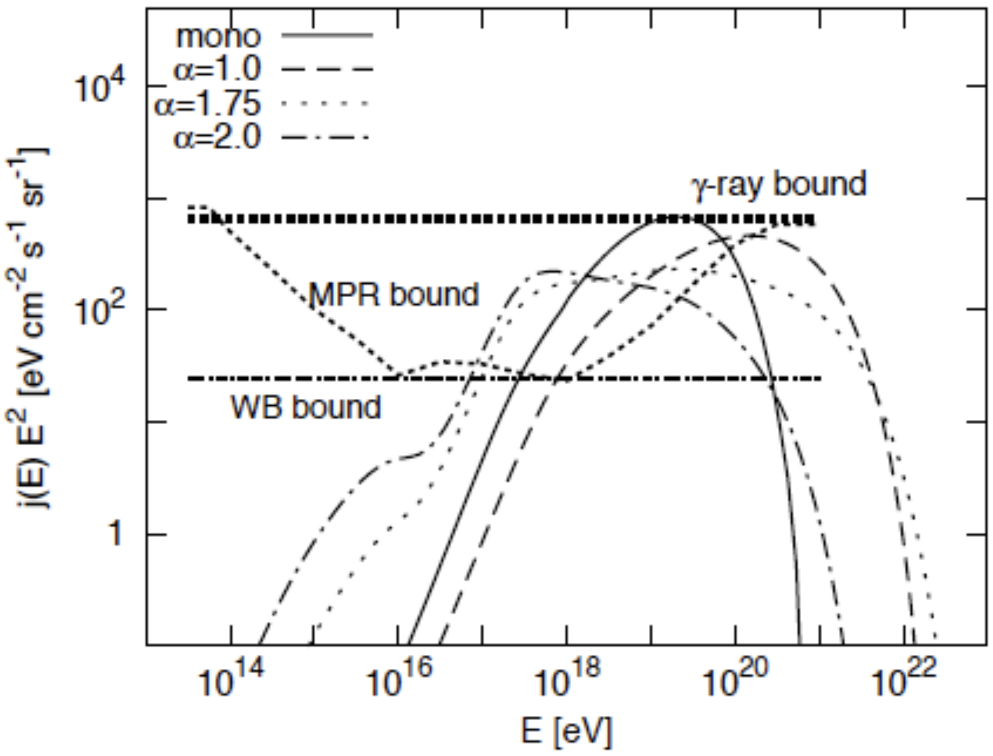
- Distribution of maximum energy of sources:

$$F(E_{\max}) = \frac{B}{E_{\max}{}^{\beta}} \qquad \beta = \alpha_0 - \alpha + 1$$

- Distribution of sources:

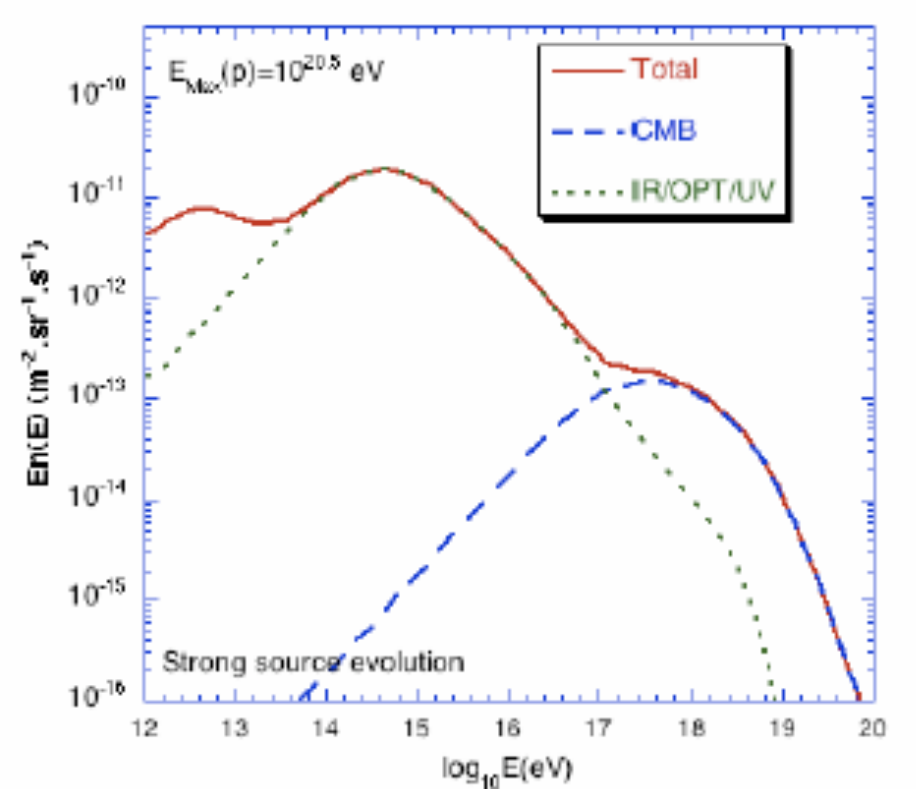
$$D = (1+z)^{m+3} \qquad z_{\min} < z < z_{\max}$$

High neutrino fluxes



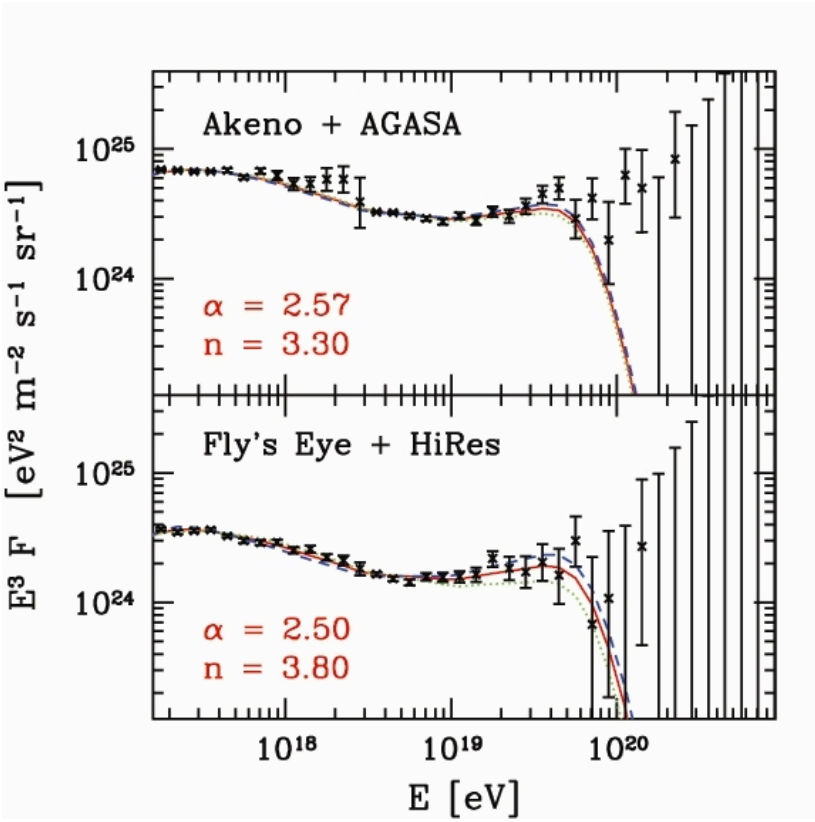
O.Kalashev et al astro-ph/0205050

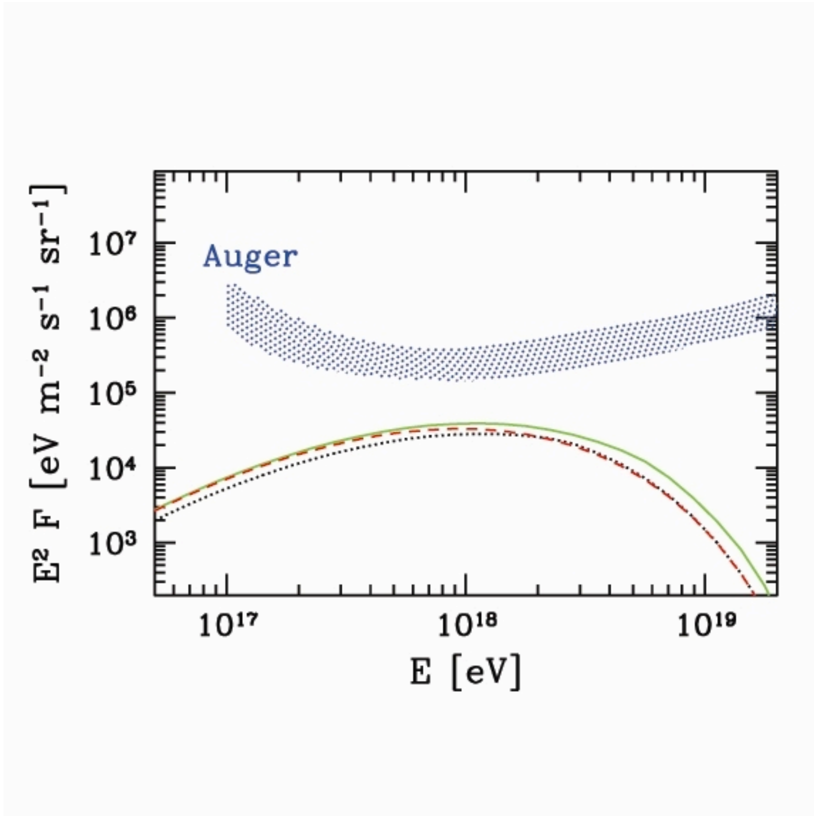
High neutrino fluxes: IR



D.Alard et al astro-ph/0605327

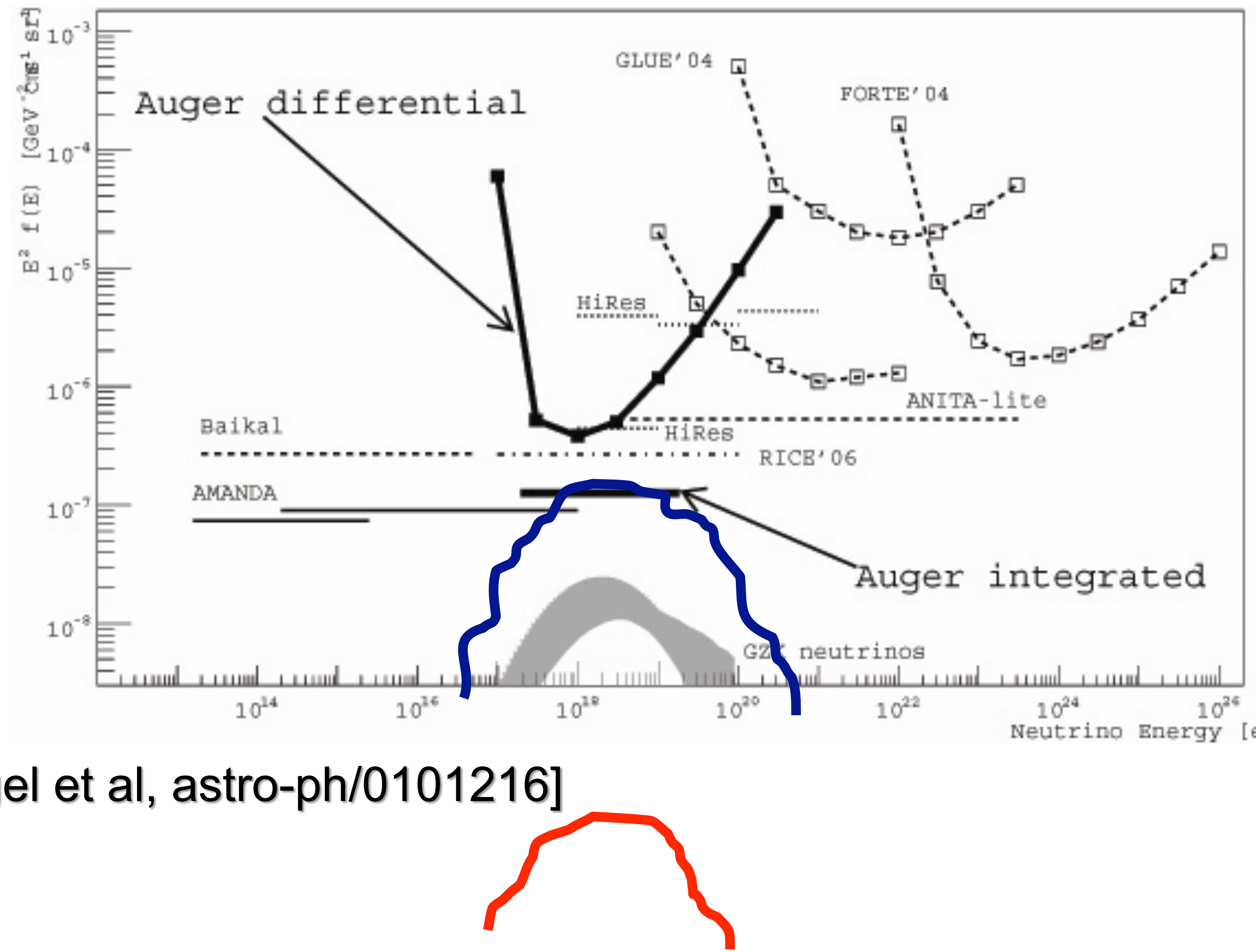
Low flux of neutrino





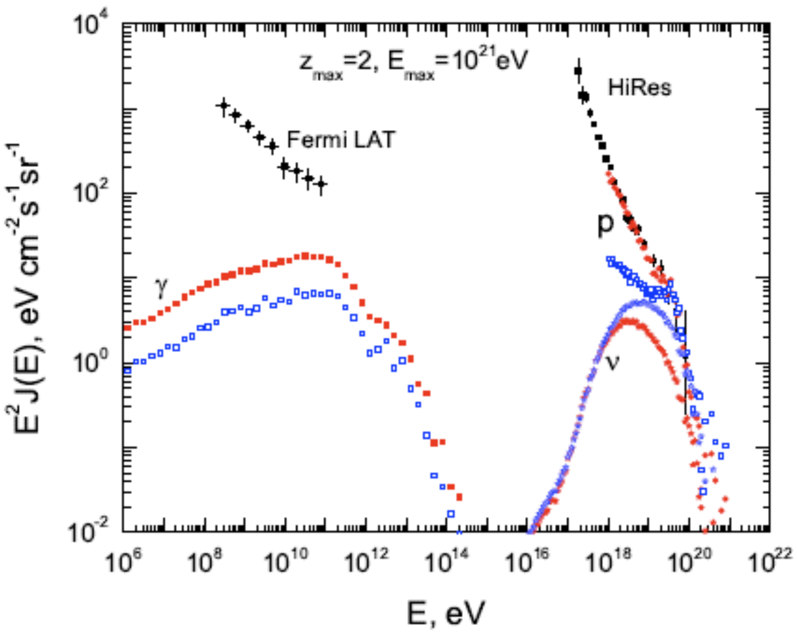
- Z.Fodor et al, **hep-ph/ 0309171**

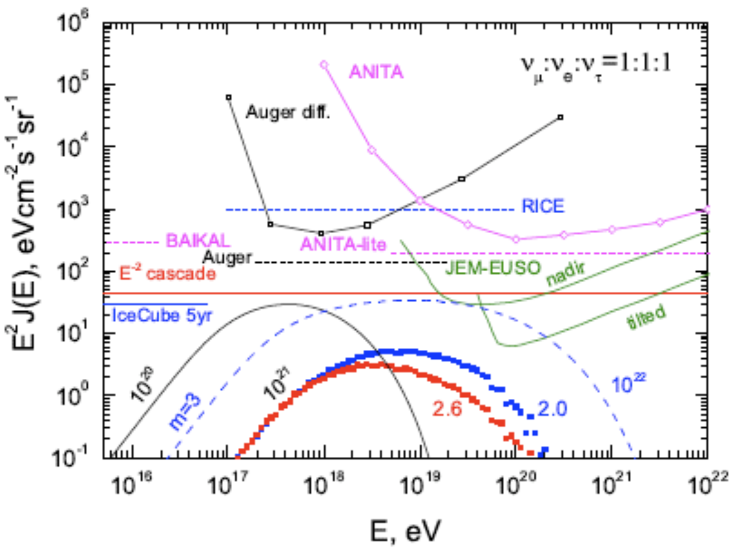
Neutrino limits constrain most optimistic models



R.Engel et al, astro-ph/0101216]

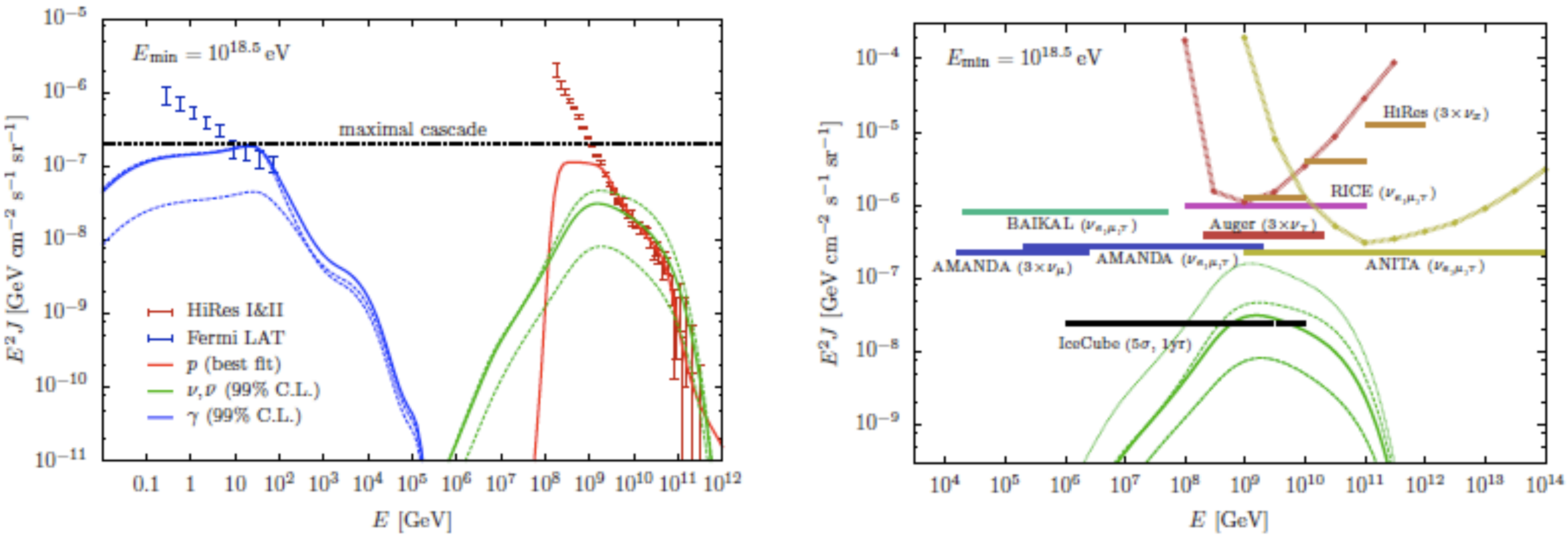
Fermi diffuse gamma-ray flux





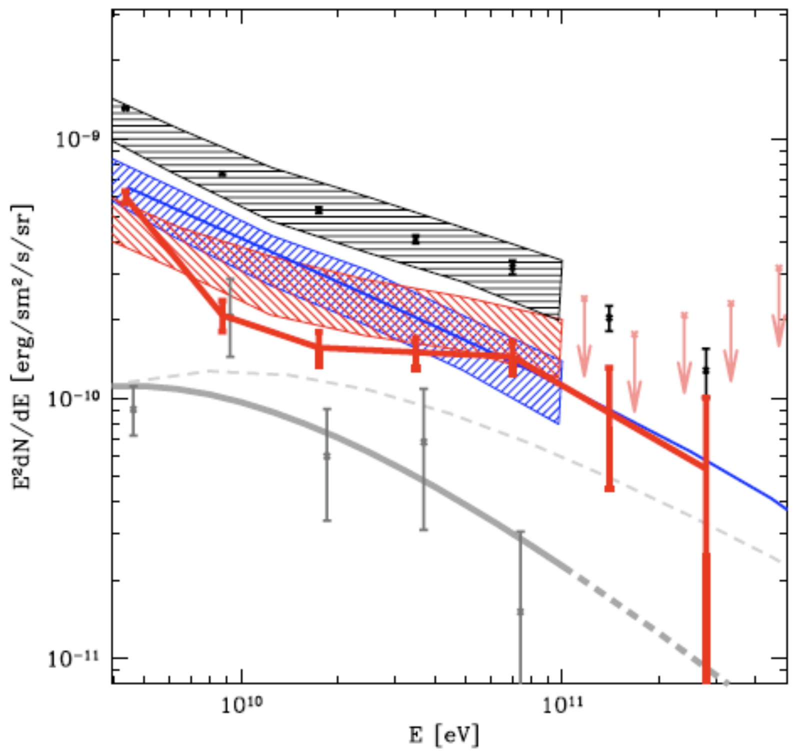
V.Berezinsky et al. 1003.1496

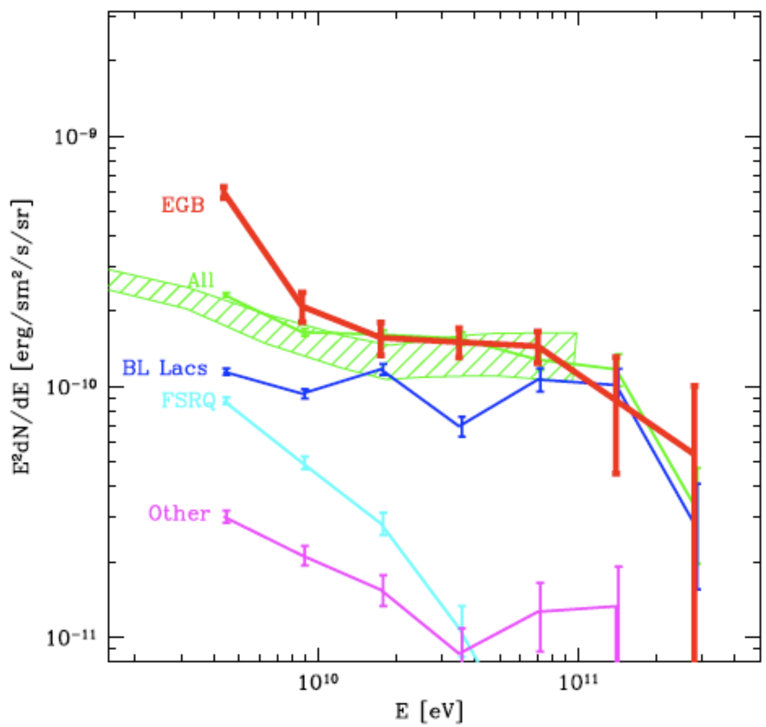
Maximum contribution to Fermi diffuse gamma-ray flux



M.Ahlers et al 1005.2620

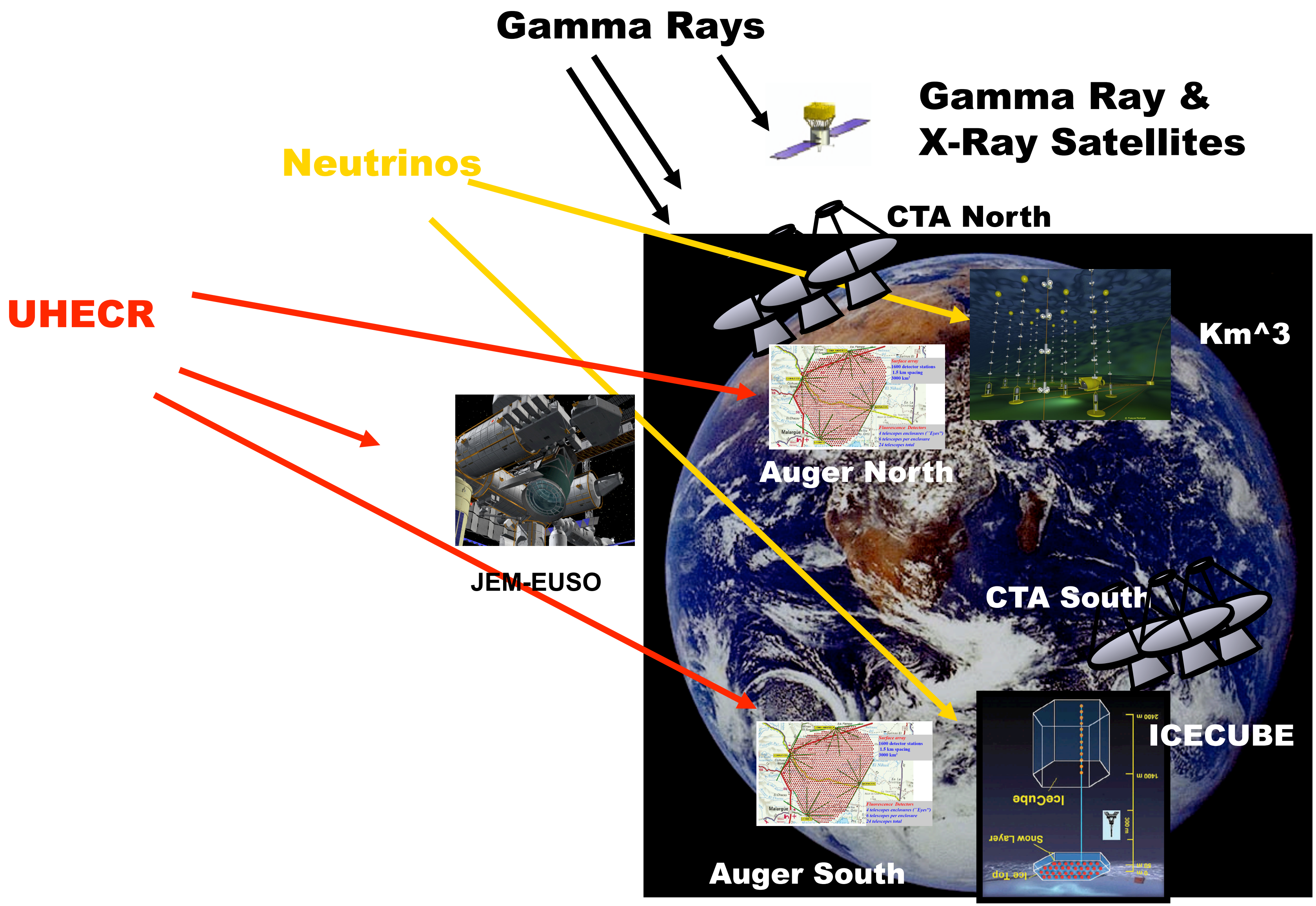
Contribution of BL Lacs to diffuse gamma-ray flux





A.Neronov, D.S, astro-ph/1103.3884

Multi-Messenger observation all-sky



Conclusions

- Cutoff in UHECR spectrum exist. UHECR come from astrophysical sources. Open questions:
  - Cutoff from acceleration or/and cutoff from propagation.
  - Composition: protons or/and nuclei? Input from LHC needed to reduce uncertainty in hadronic models: energy determination and composition of UHECR
- If nuclei dominate at highest energies, flux of cosmogenic neutrinos is tiny
- Fermi data on diffuse gamma-ray background constrain most optimistic models of cosmogenic neutrinos.