UniverseNet: Activities on the Origin of Cosmic Rays

- **Oxford**: Propagation of UHE heavy nuclei (interpretation of Auger results
  dependence of high energy neutrino fluxes on cosmic ray composition

- **Paris**: Secondary photon fluxes at GeV and EeV energies, acceleration
  in cluster shocks, constraints on LI violation from photon fraction

Annecy: Galactic positron and anti-proton fluxes from dark matter annihilation

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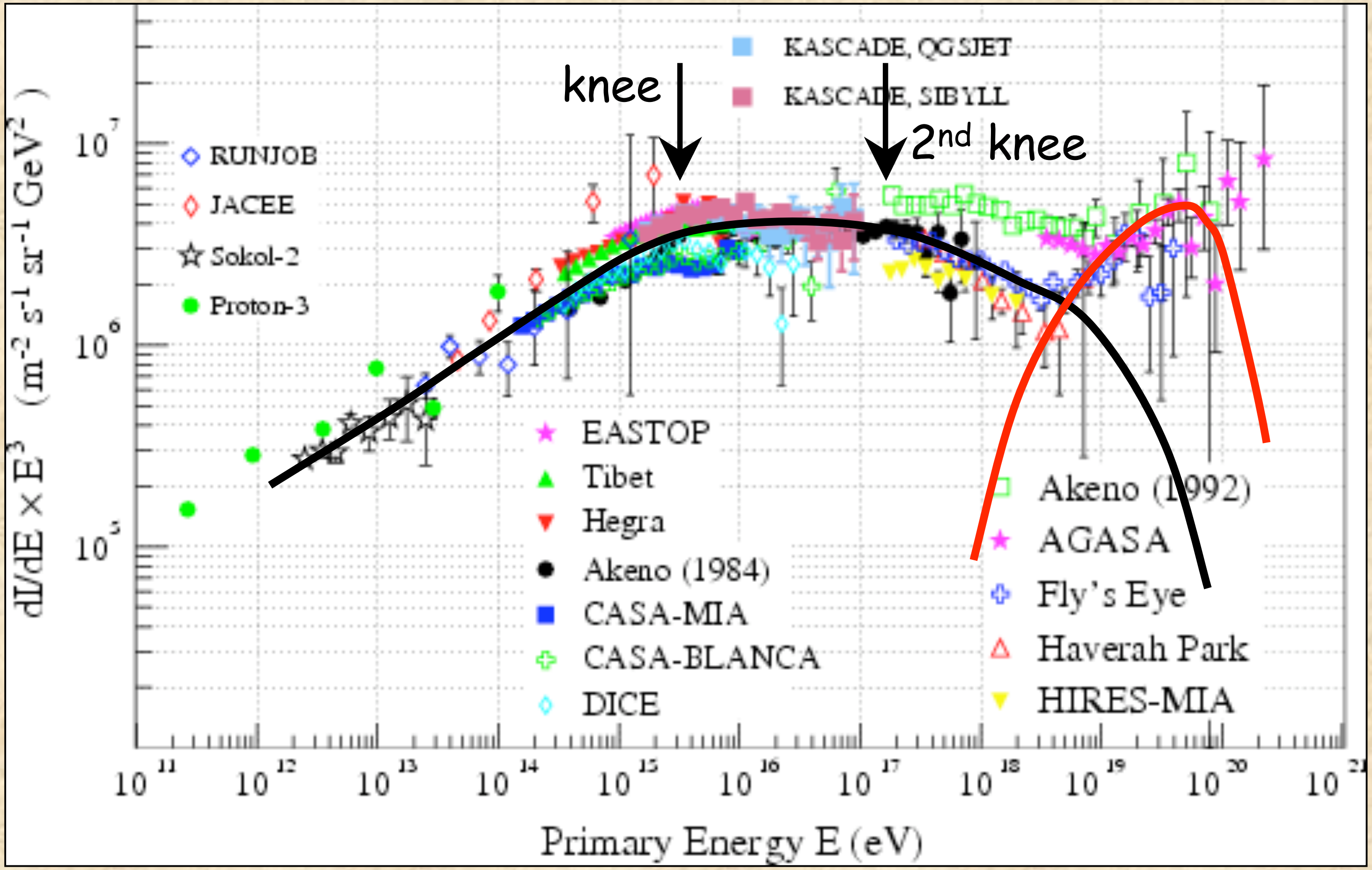
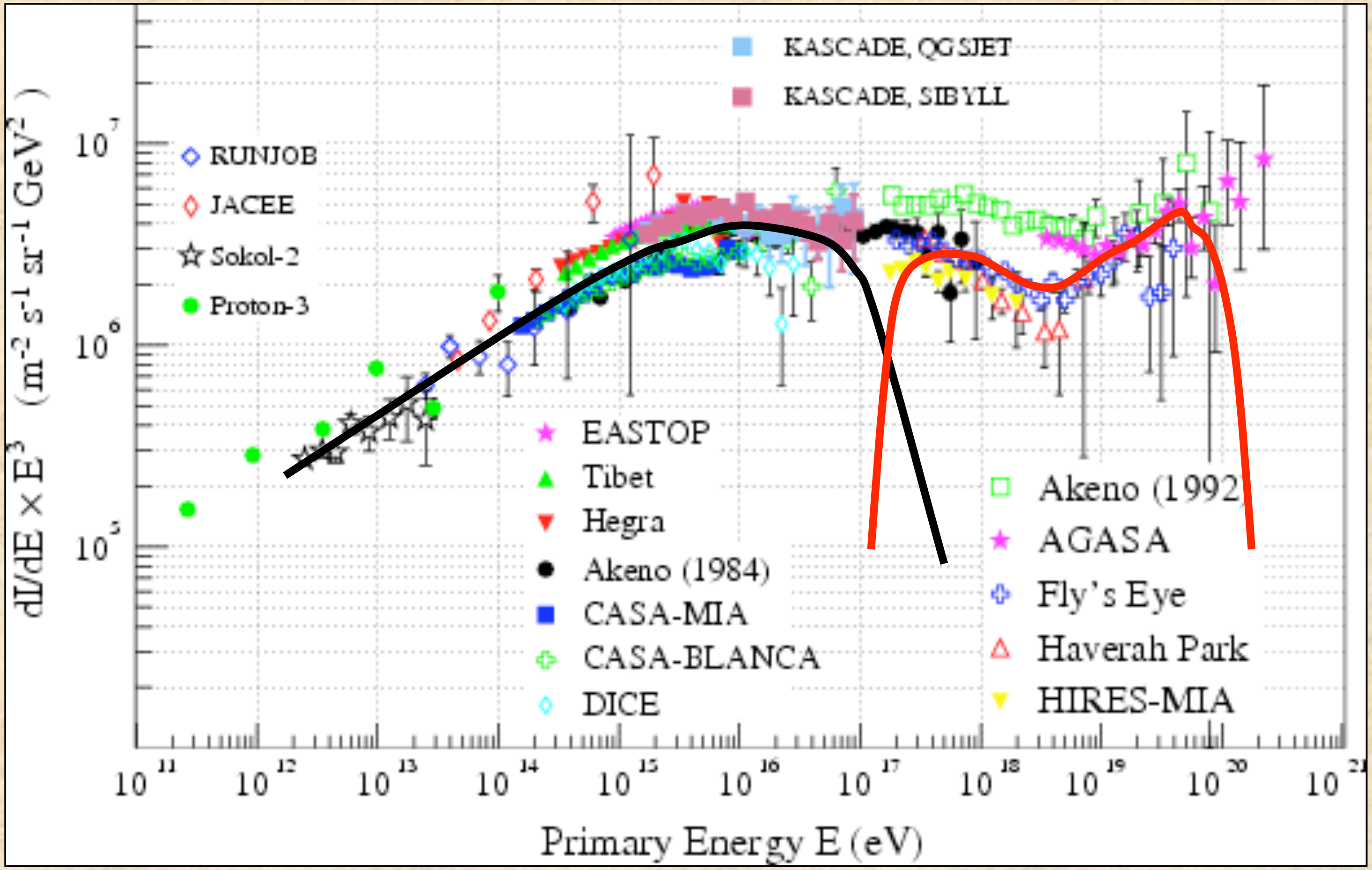
http://www2.iap.fr/users/sigl/homepage.html

Chemical Composition, Magnetic Fields, Nature of the Ankle



"Conventional Scenario":
The ankle at ~5×10^{18} eV is a cross-over from a heavy Galactic to a light extragalactic component. Best fit injection spectrum $E^{-2.3}$

Chemical Composition, Magnetic Fields, Nature of the Ankle

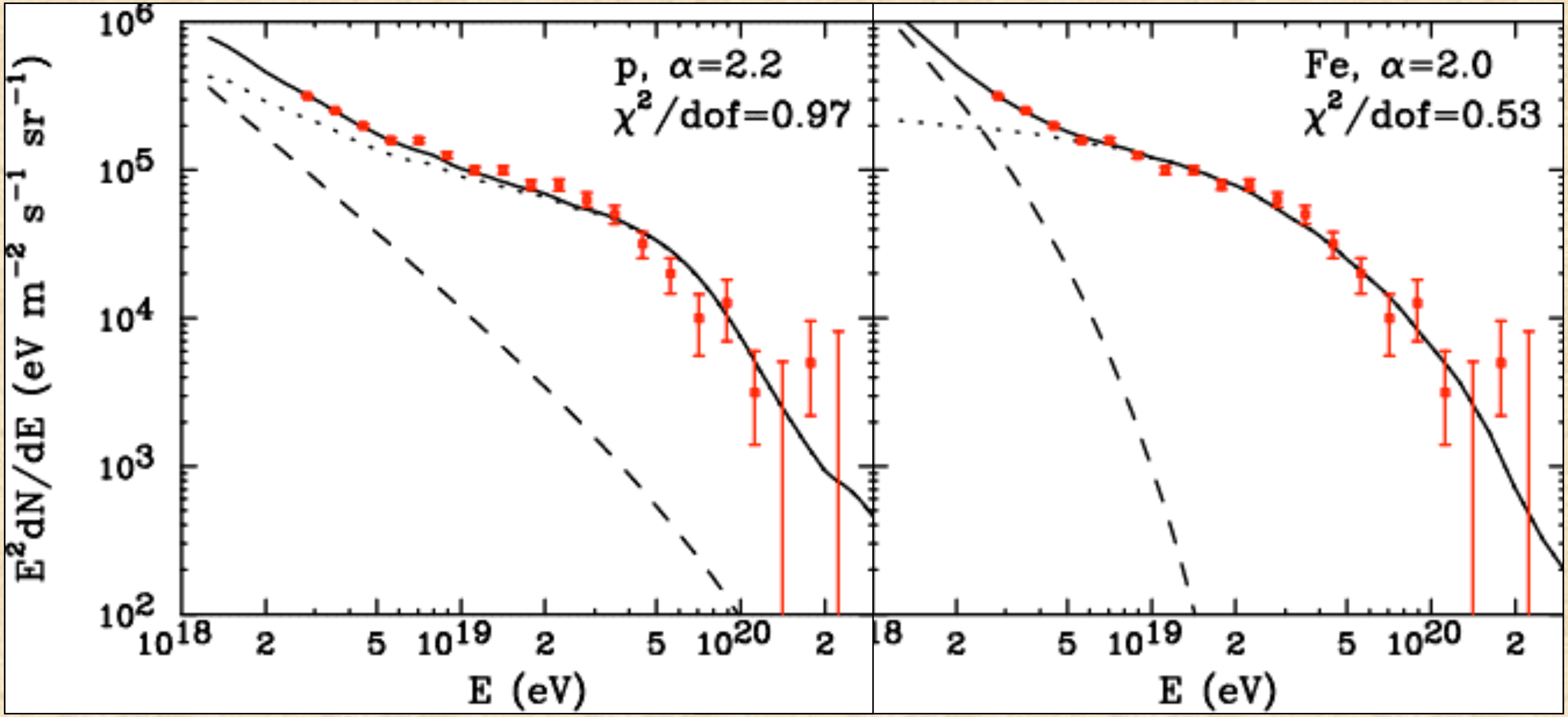


Scenario of Berezinsky et al.:

Galactic cosmic rays level out at the 2nd knee at ~4x10^{17} eV where dominated by heavy nuclei..

The ankle at ~5x10^{18} eV is due to pair production of extragalactic protons on the CMB. Requires >85% protons at the ankle and $E^{-2.6}$ injection.

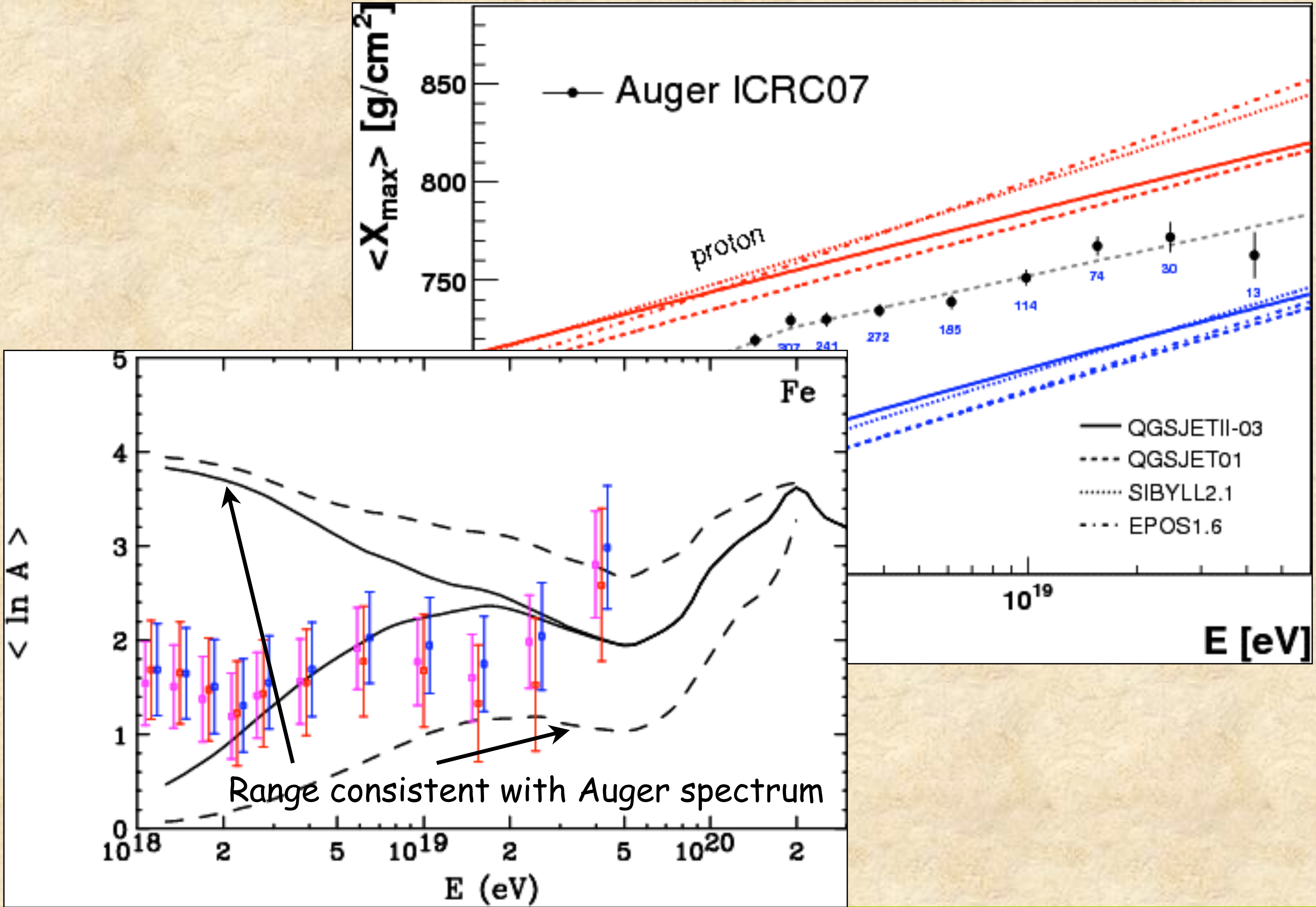
Chemical Composition and Cosmogenic Neutrino Flux



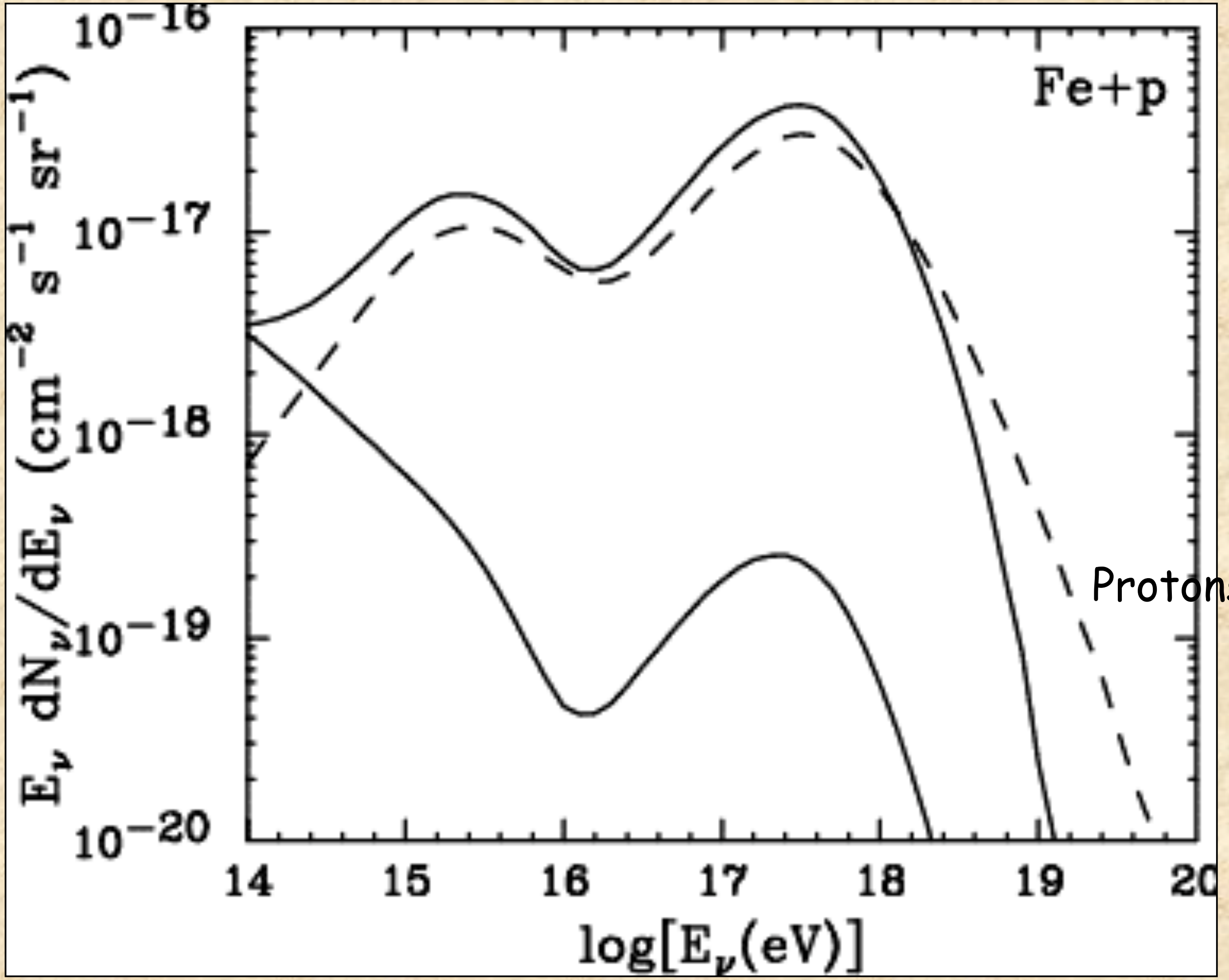
Best fits to Auger spectrum for proton and iron injection with E_{max}=(Z/26)10^{22} eV

Anchordoqui, Hooper, Sarkar, Taylor, astro-ph/0703001

Composition



Range of cosmogenic neutrino fluxes consistent with PAO spectrum and composition

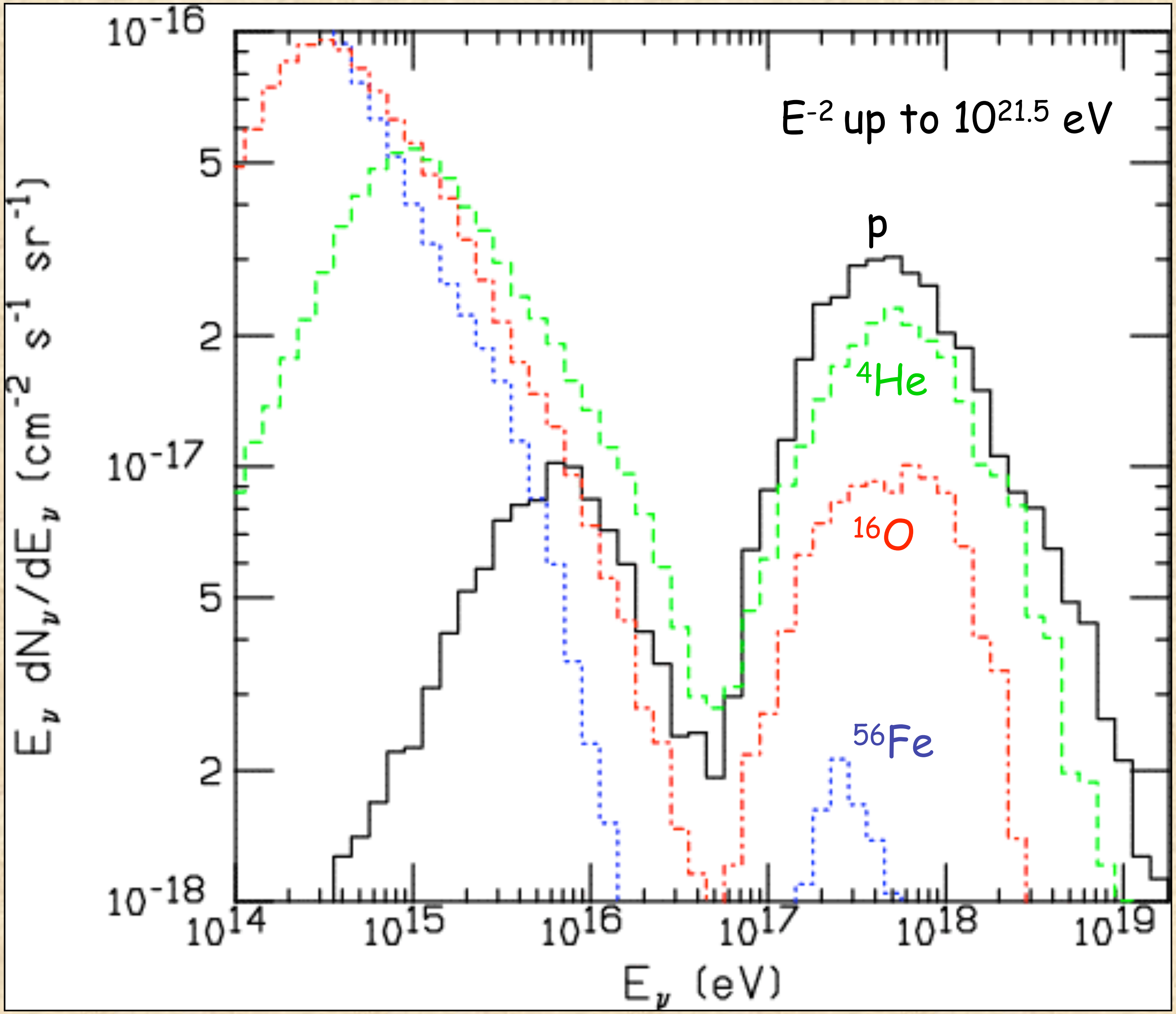


Protons only

Influence of Composition on Cosmogenic Neutrinos

The highest rates are 1 event/year in ICECUBE for protons, but suggests rates 10-30 times lower for iron.

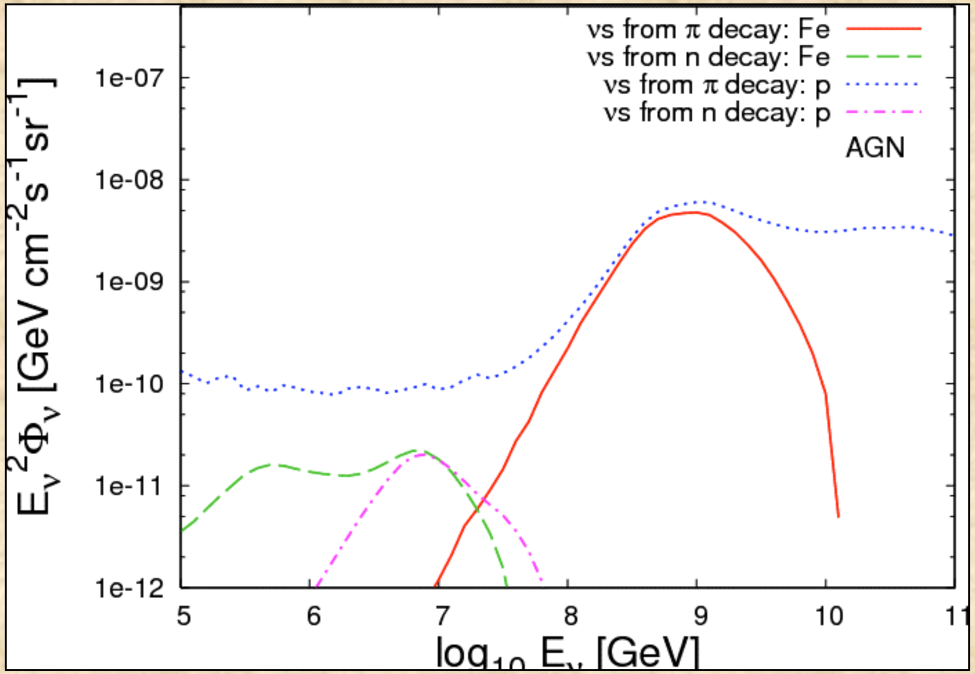
See, however, results by Ave et al. Astropart. Phys.23 (2005) 19

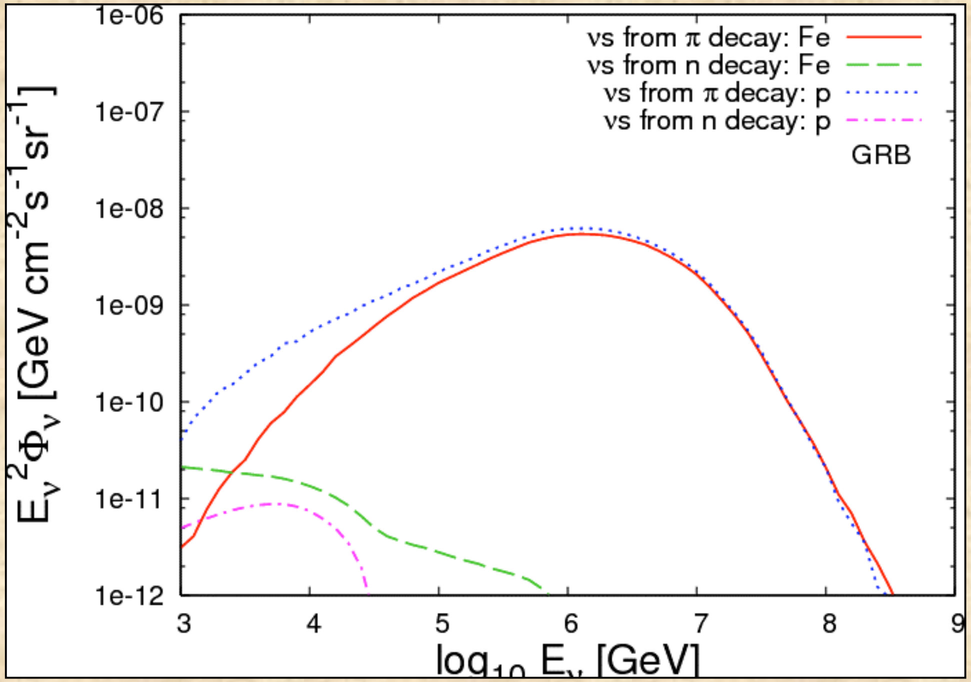


D.Hooper, A.Taylor, S.Sarkar, Astropart.Phys.23 (2005) 11

Chemical Composition and Source Contributions to the Ultra-High Energy Neutrino Flux

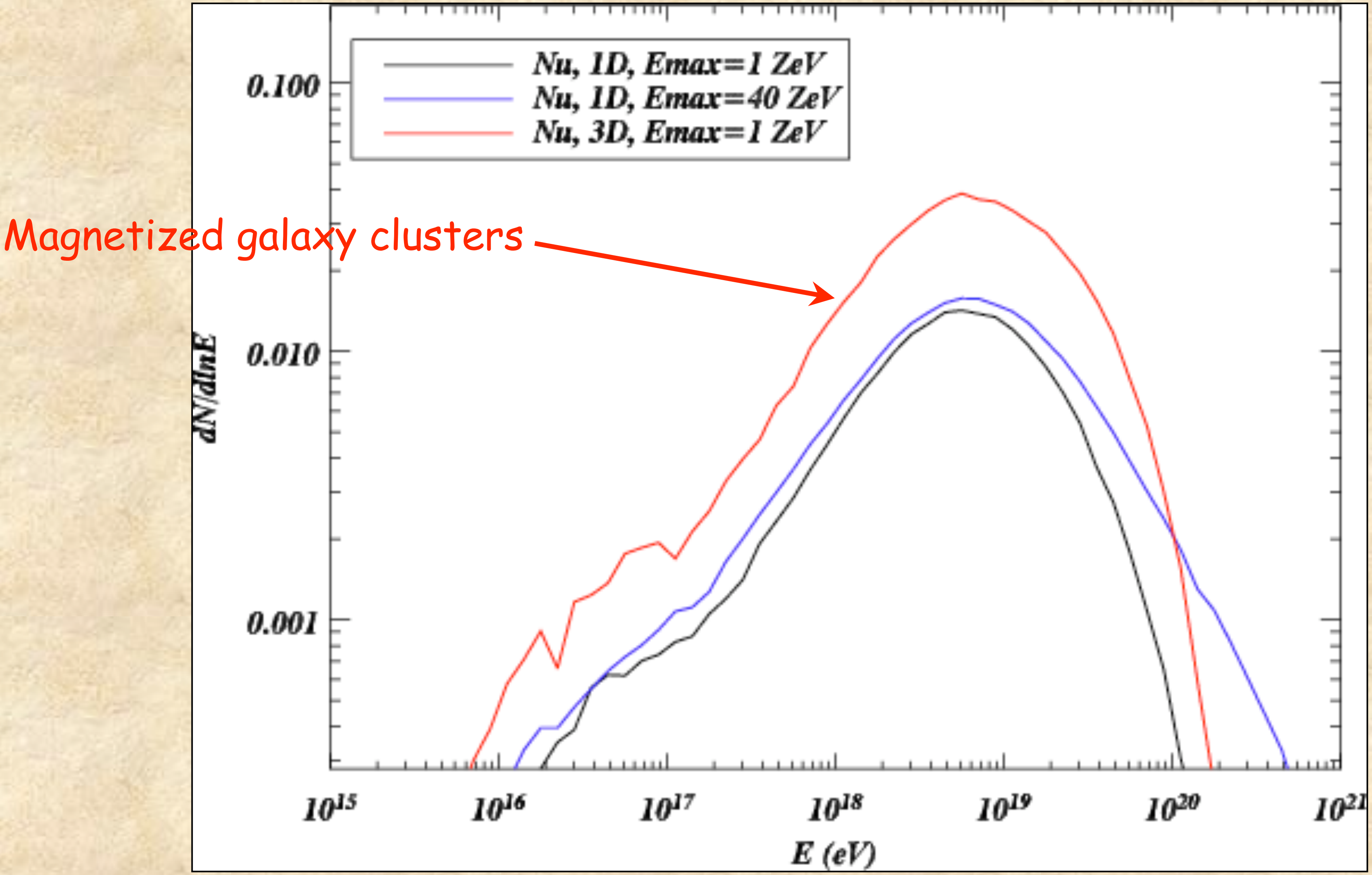
In AGN sources, nuclei are disintegrated above ~10^{19} eV
In GRB sources, all nuclei are practically disintegrated (compact source)
In starburst galaxy sources, very few nuclei are disintegrated





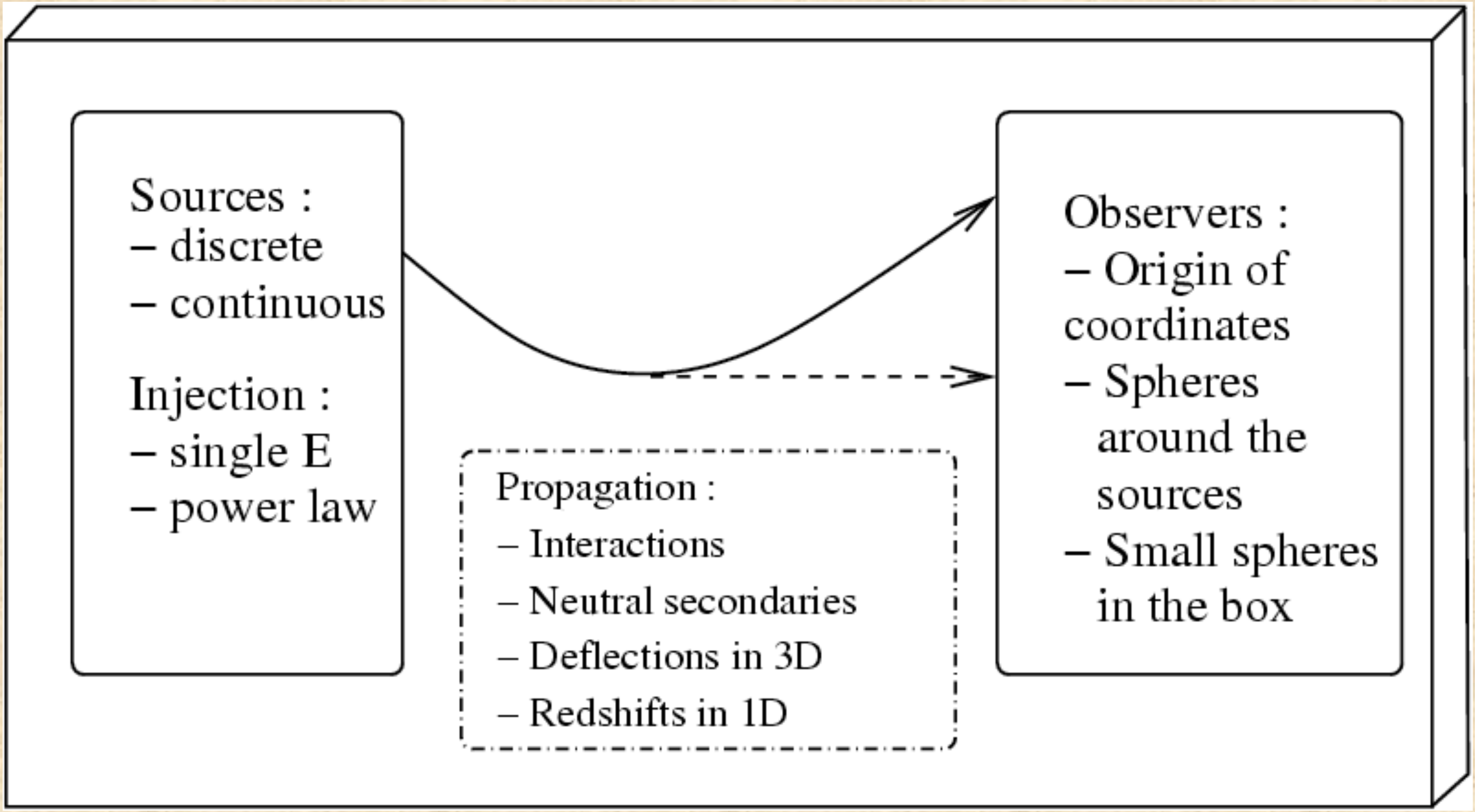
Anchordoqui, Goldberg, Hooper, Sarkar, Taylor, arXiv:0709.0734

The GZK neutrino flux can also be enhanced by magnetic fields surrounding the sources



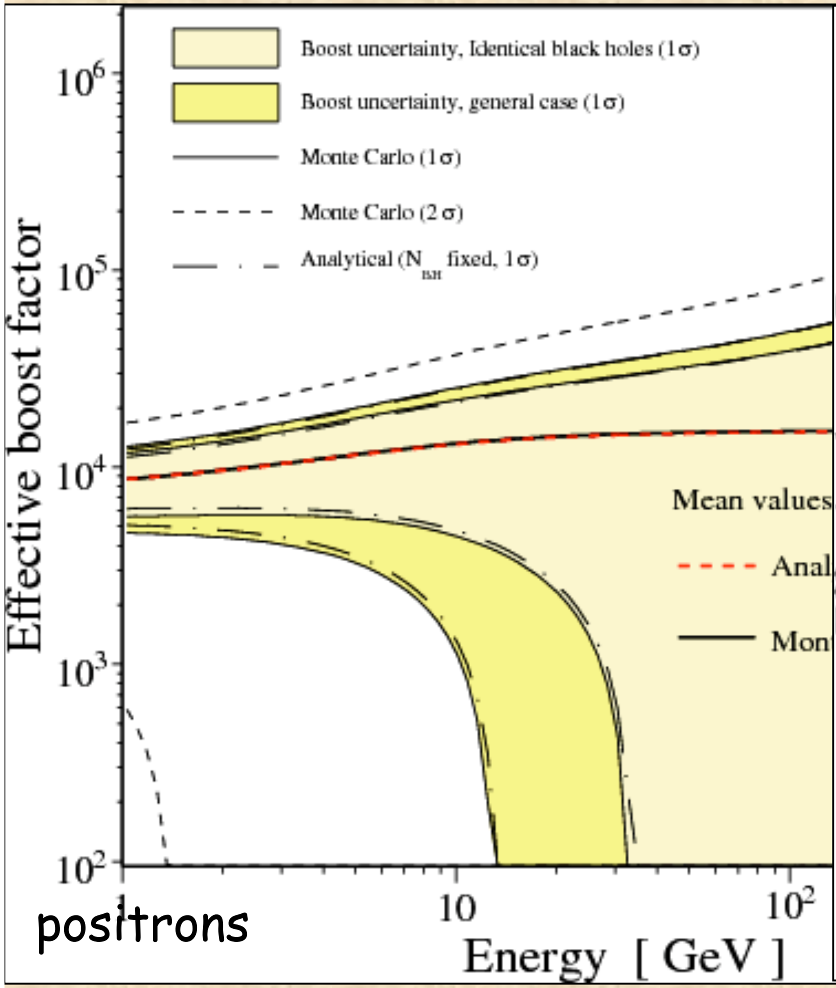
Armengaud and Sigl

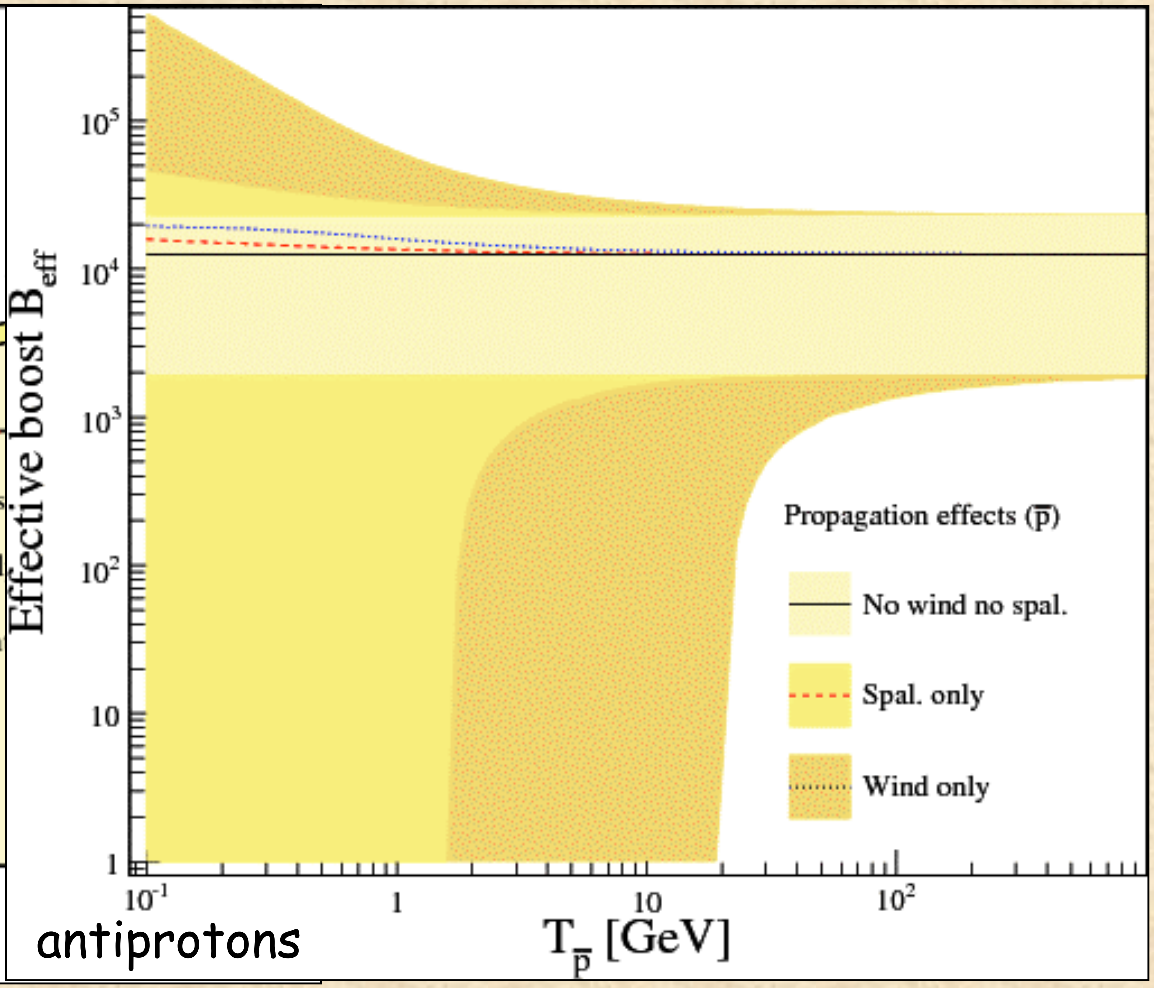
Short Advertisement: CRPropa a public code for UHE cosmic rays, Neutrinos and γ-Rays



Eric Armengaud, Tristan Beau, Günter Sigl, Francesco Miniati,
astro-ph/0603675, to appear in Astroparticle Physics

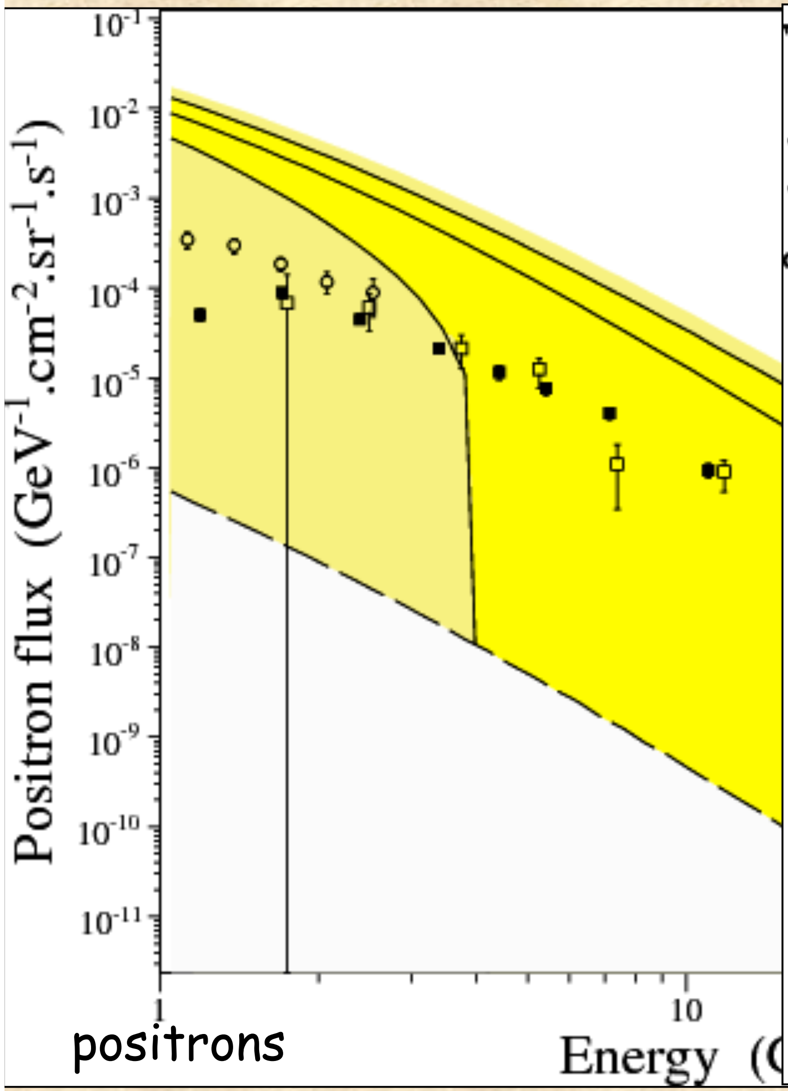
Boost Factors for Galactic Positron and Antiproton Fluxes from Dark Matter Spikes around intermediate mass black holes

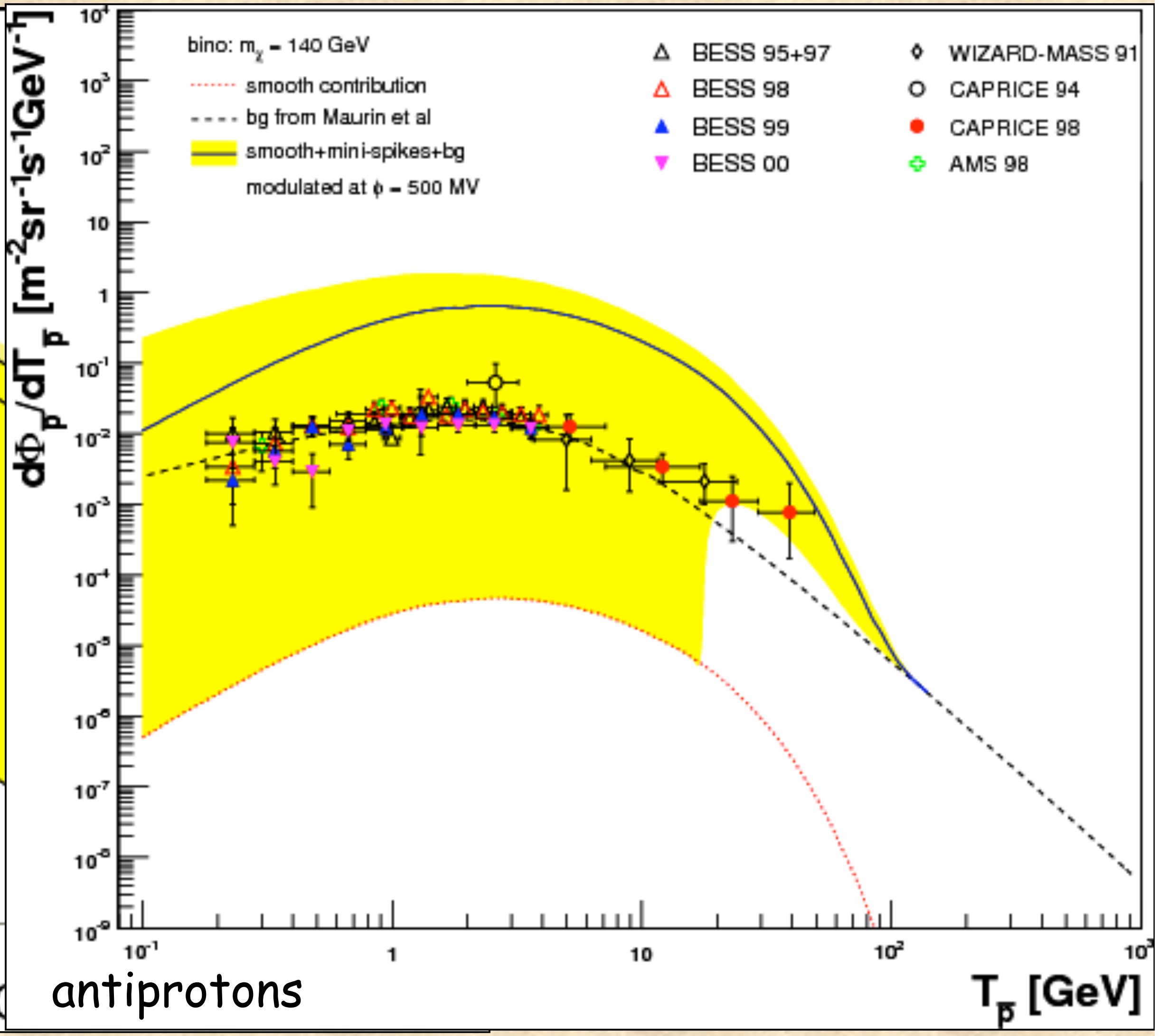




Brun, Bertone, Lavalle, Salati, Taillet, arXiv:0704.2543

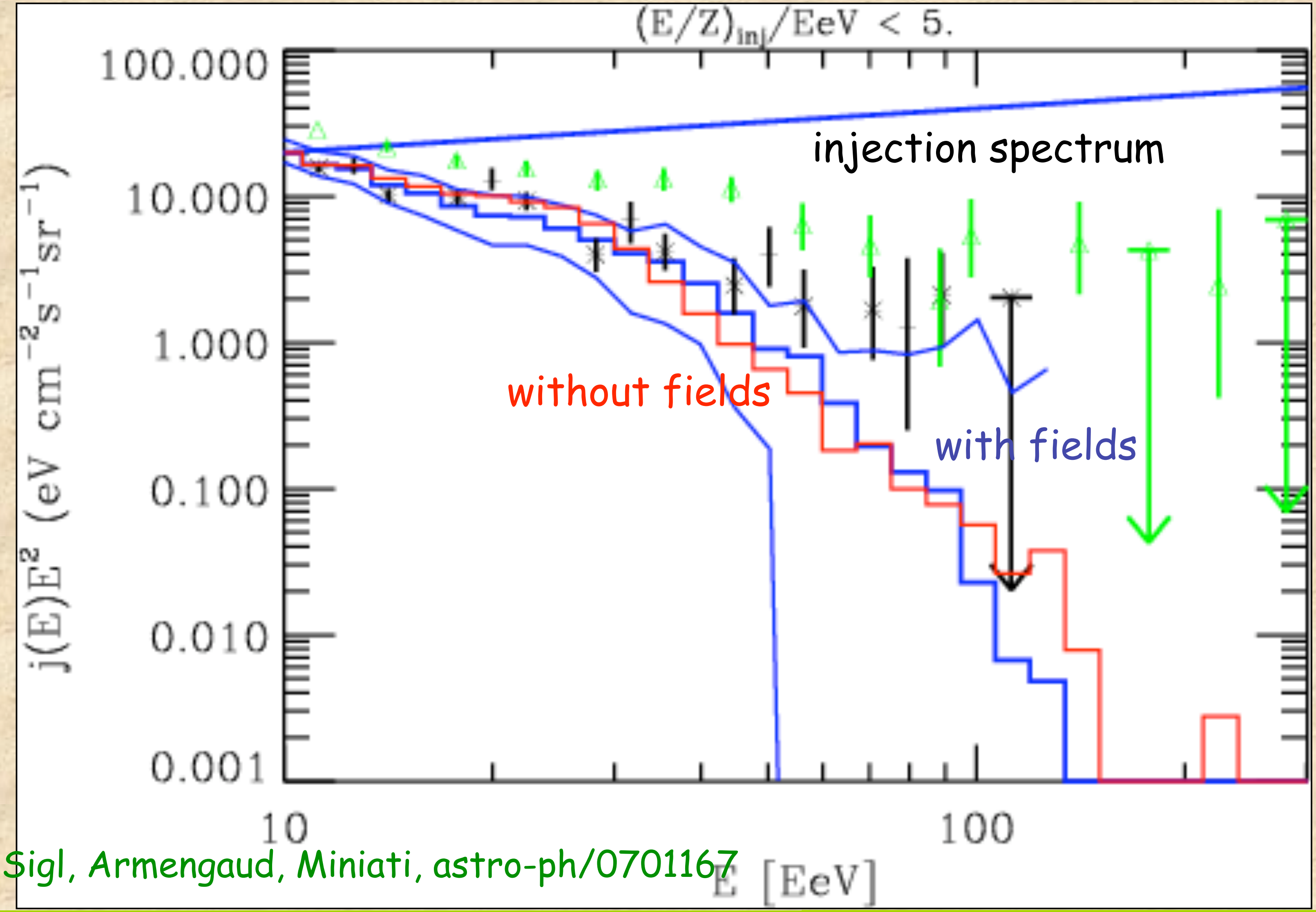
Resulting antimatter spectra



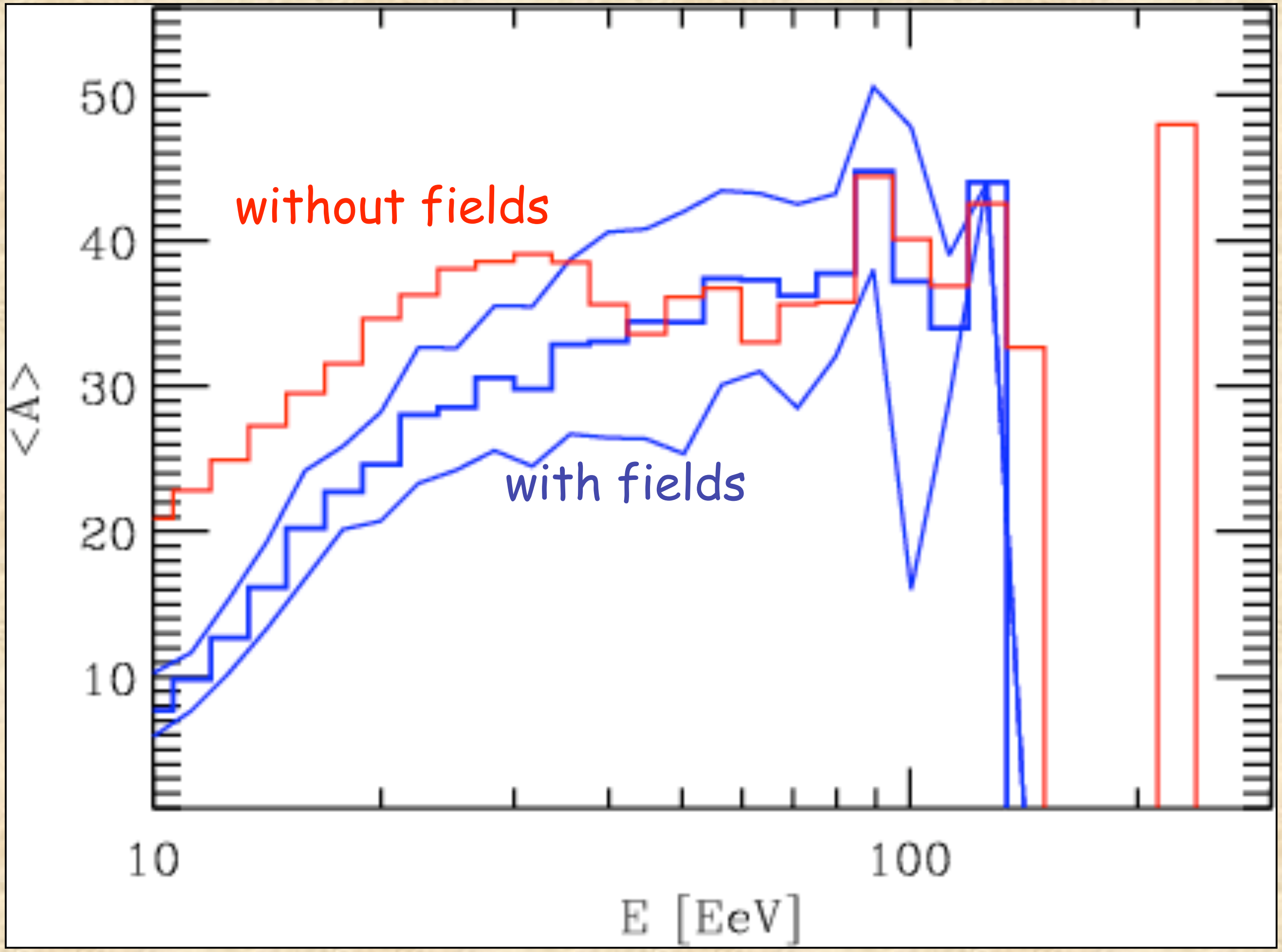


Acceleration of Mixed Composition at Cluster Accretion Shocks

Injection spectrum $E^{-1.7}$ with rigidity $E/Z < 5\times10^{18}$ eV (consistent with cluster shock properties) and a source density ~ 2.4×10^{-6} Mpc^{-3}.



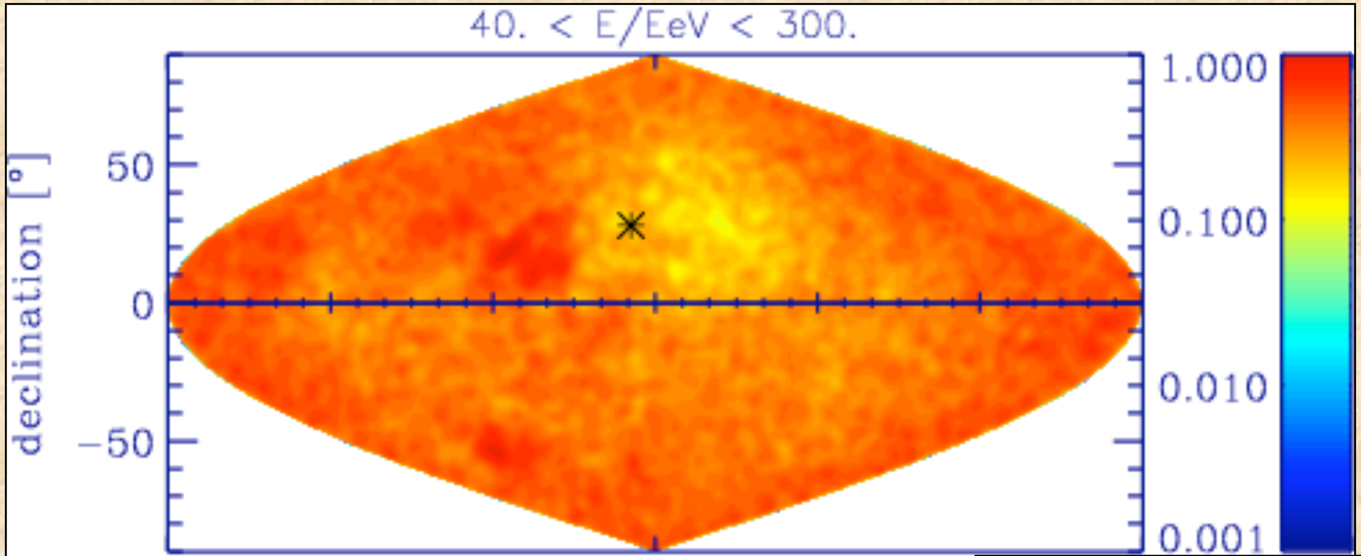
Inoue, Sigl, Armengaud, Miniati, astro-ph/0701167



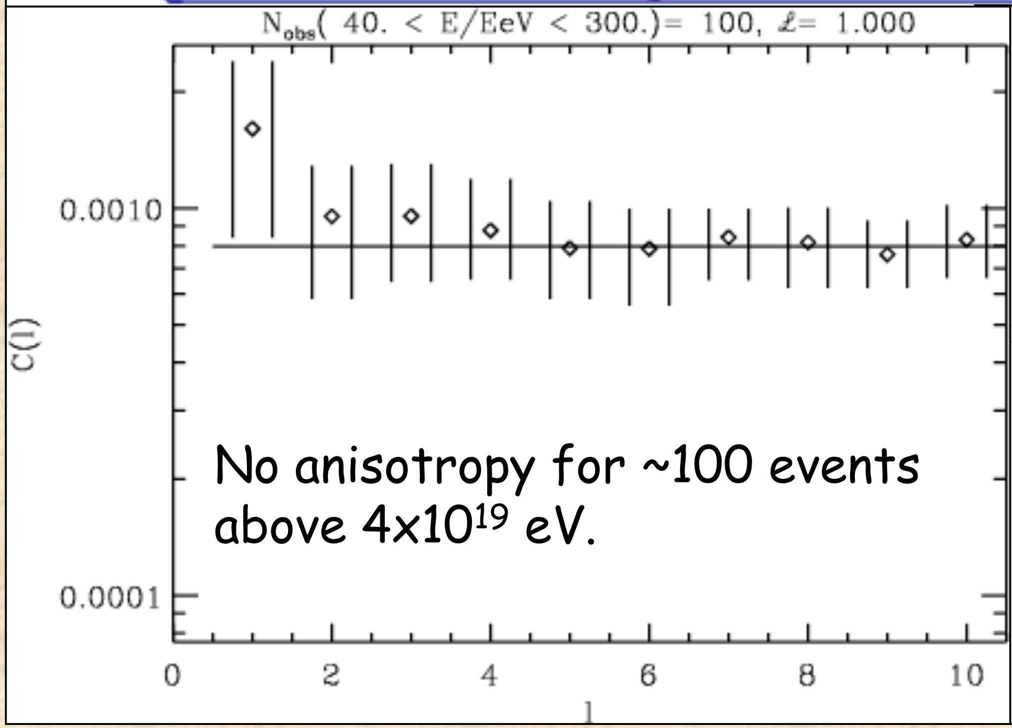
This scenario predicts an increasingly heavy composition at the highest energies.

Interestingly, the propagated spectrum depends very little on the injection spectrum because a steeper injection spectrum $E^{-\alpha}$ is compensated by the factor $A^{\alpha-1}$ which is roughly proprotional to $E^{\alpha-1}$ at the highest energies.

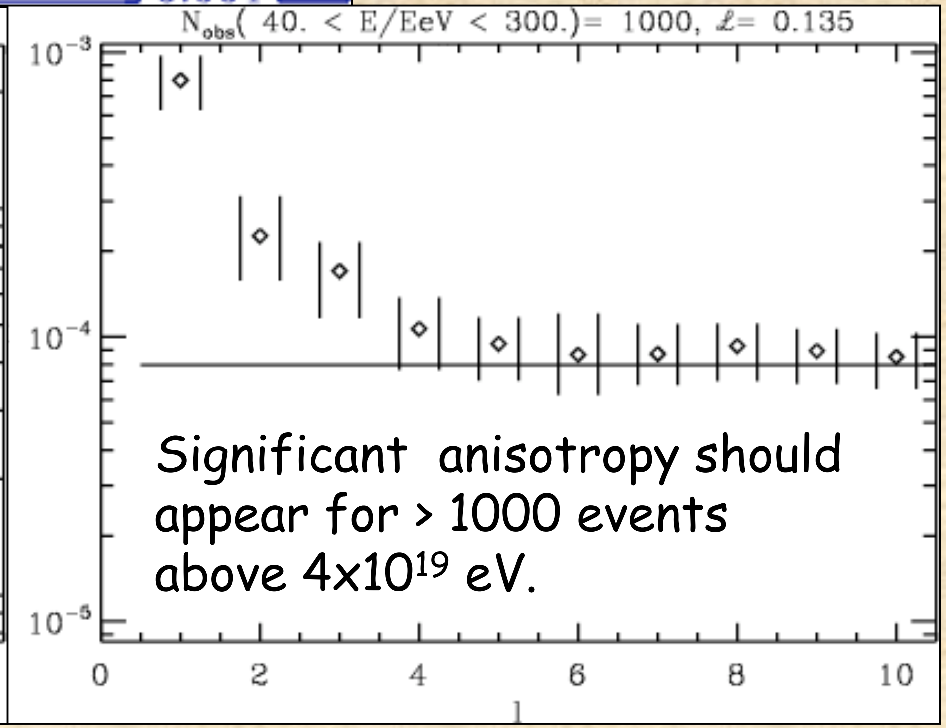
A particular instance of the Mixed Composition Cluster Accretion Shocks Scenario



With field:
Isotropy consistent with current statistics

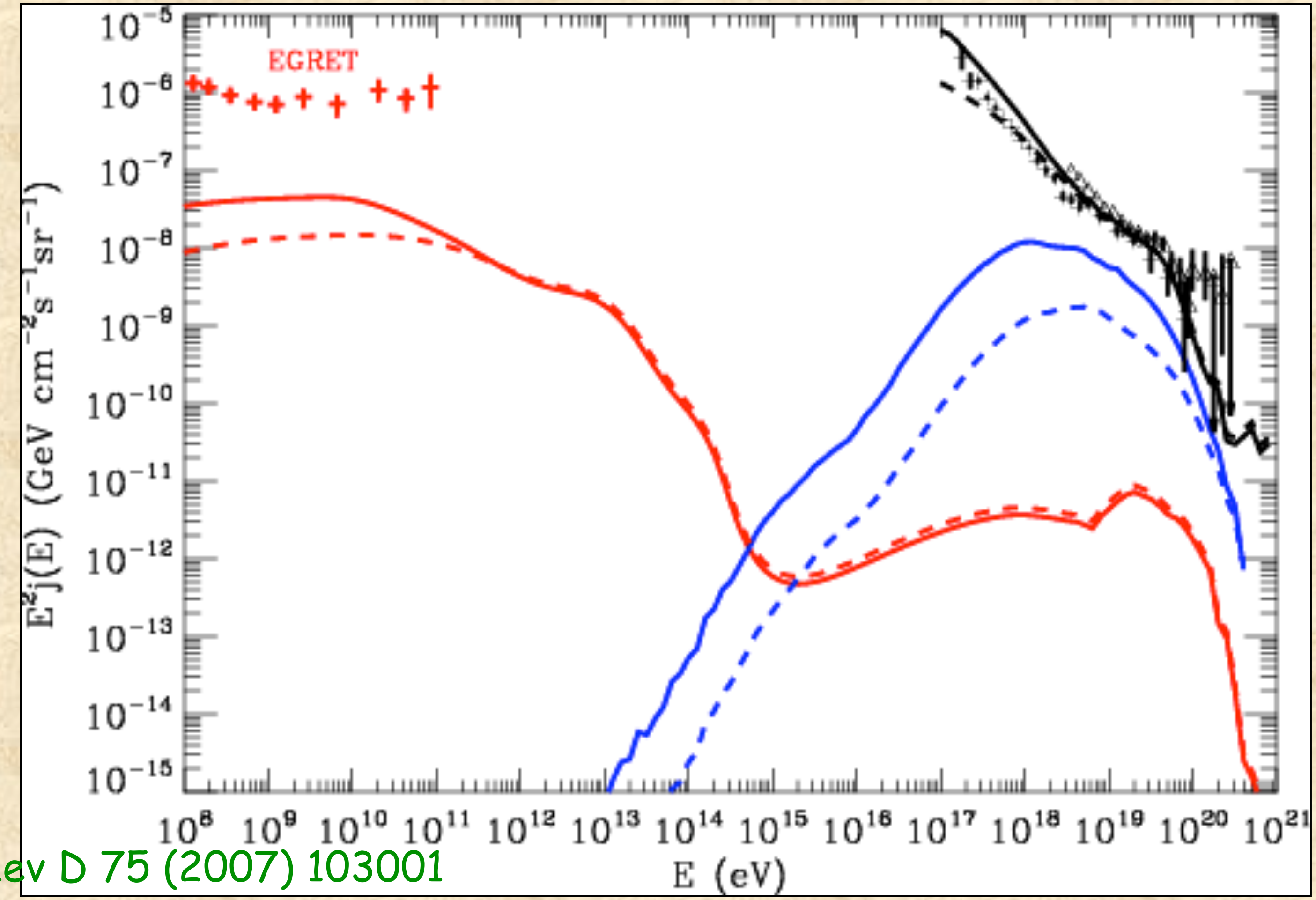


No anisotropy for ~100 events above 4×10^{19} eV.



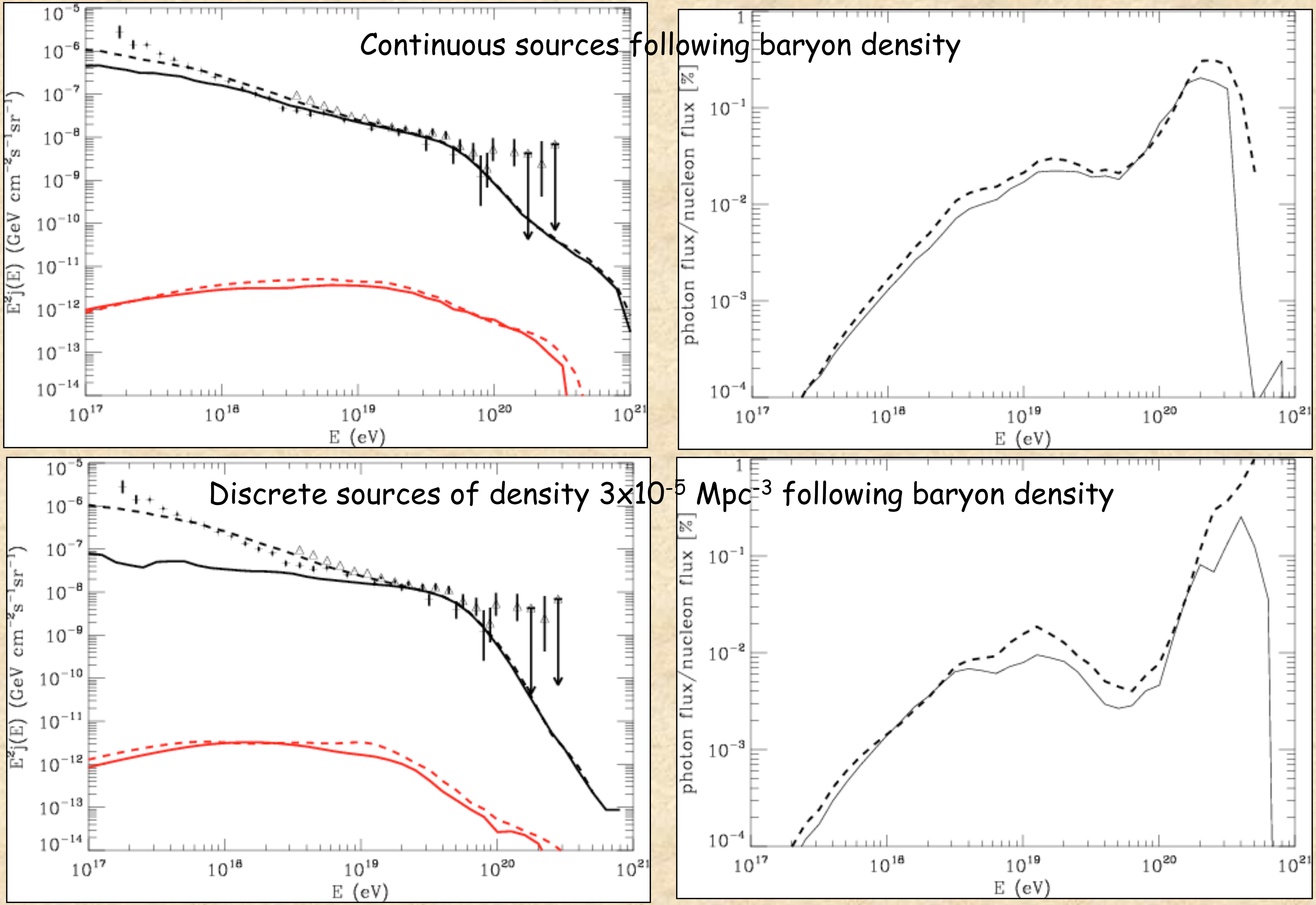
Significant anisotropy should appear for > 1000 events above 4×10^{19} eV.

Non-Universal Spectra of Ultra-High Energy Cosmic Ray Primaries and Secondaries in a Structured Universe



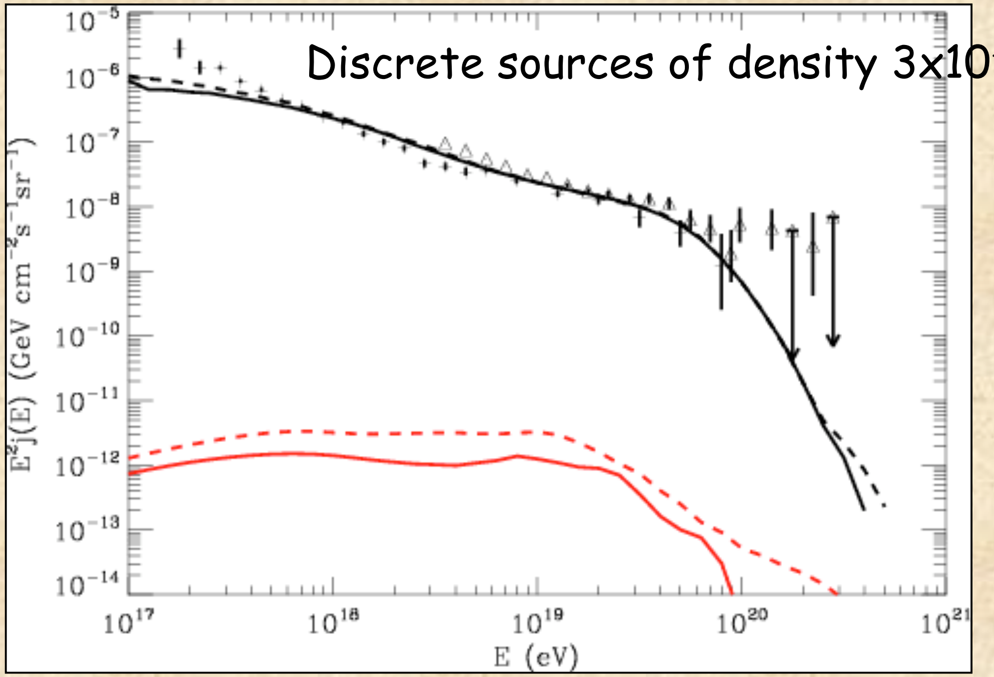
Sigl, Phys.Rev D 75 (2007) 103001

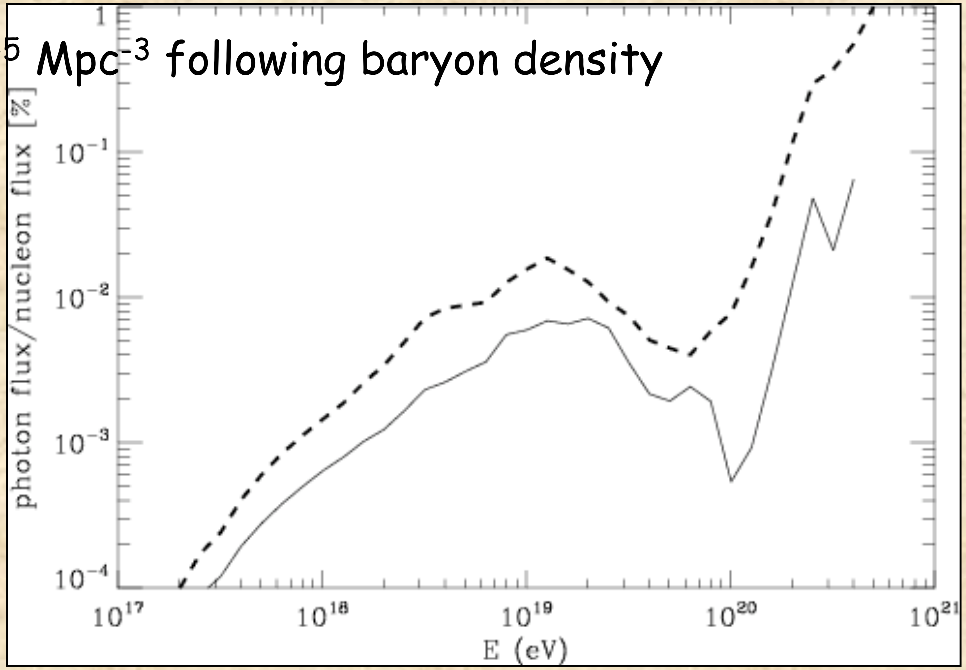
Unstructured, homogeneous sources: $E^{-2.6}$ proton injection for 10^{17} eV < E < 10^{21} eV with constant injection power (dashed) and injection power $\propto (1+z)^3$ (solid).



Dashed = without field; solid = with structured field

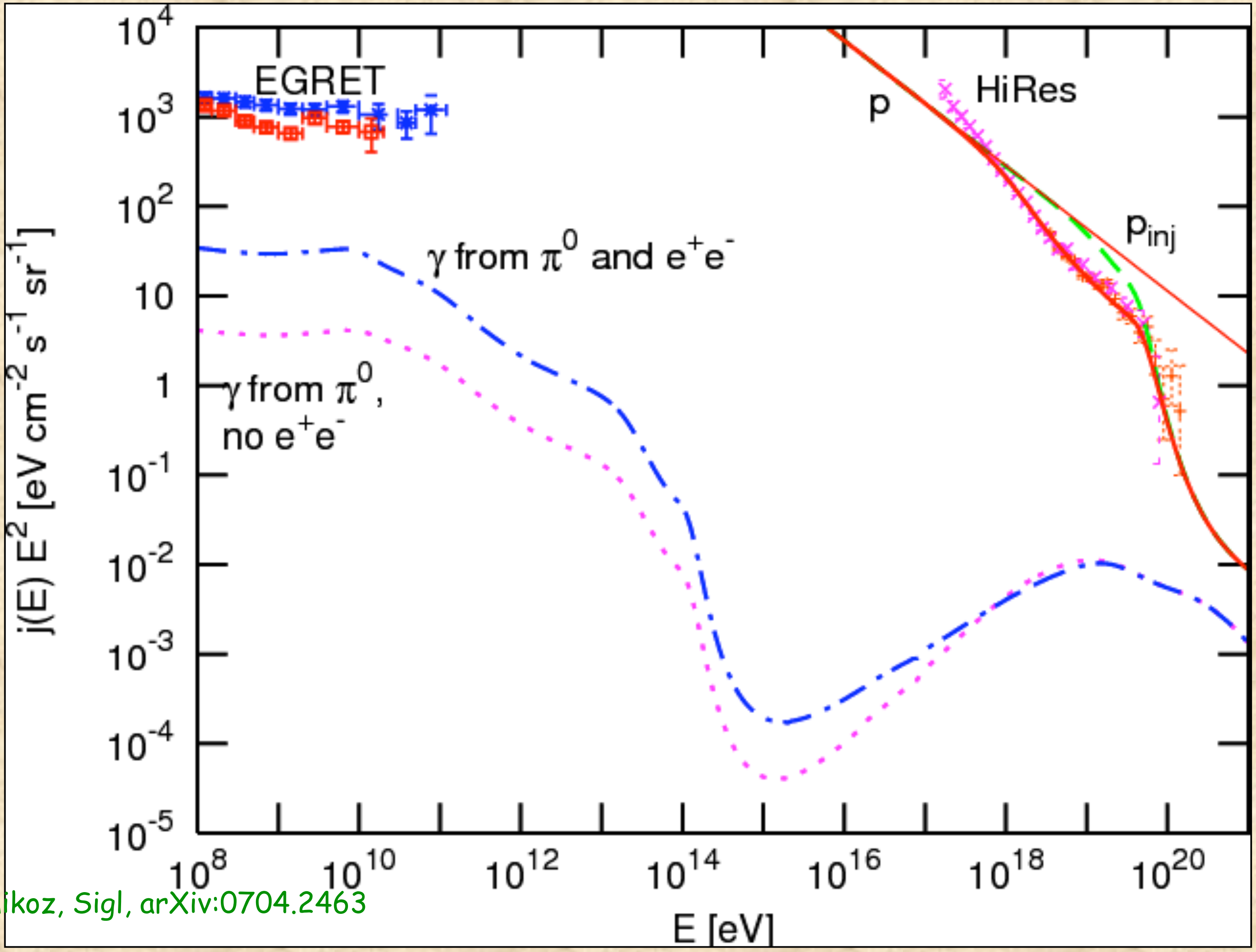
Discrete sources of density 3×10^{-5} Mpc^{-3} following baryon density





Dashed = without field; solid = with unstructured field 10^{-9} G, coherence length 1Mpc

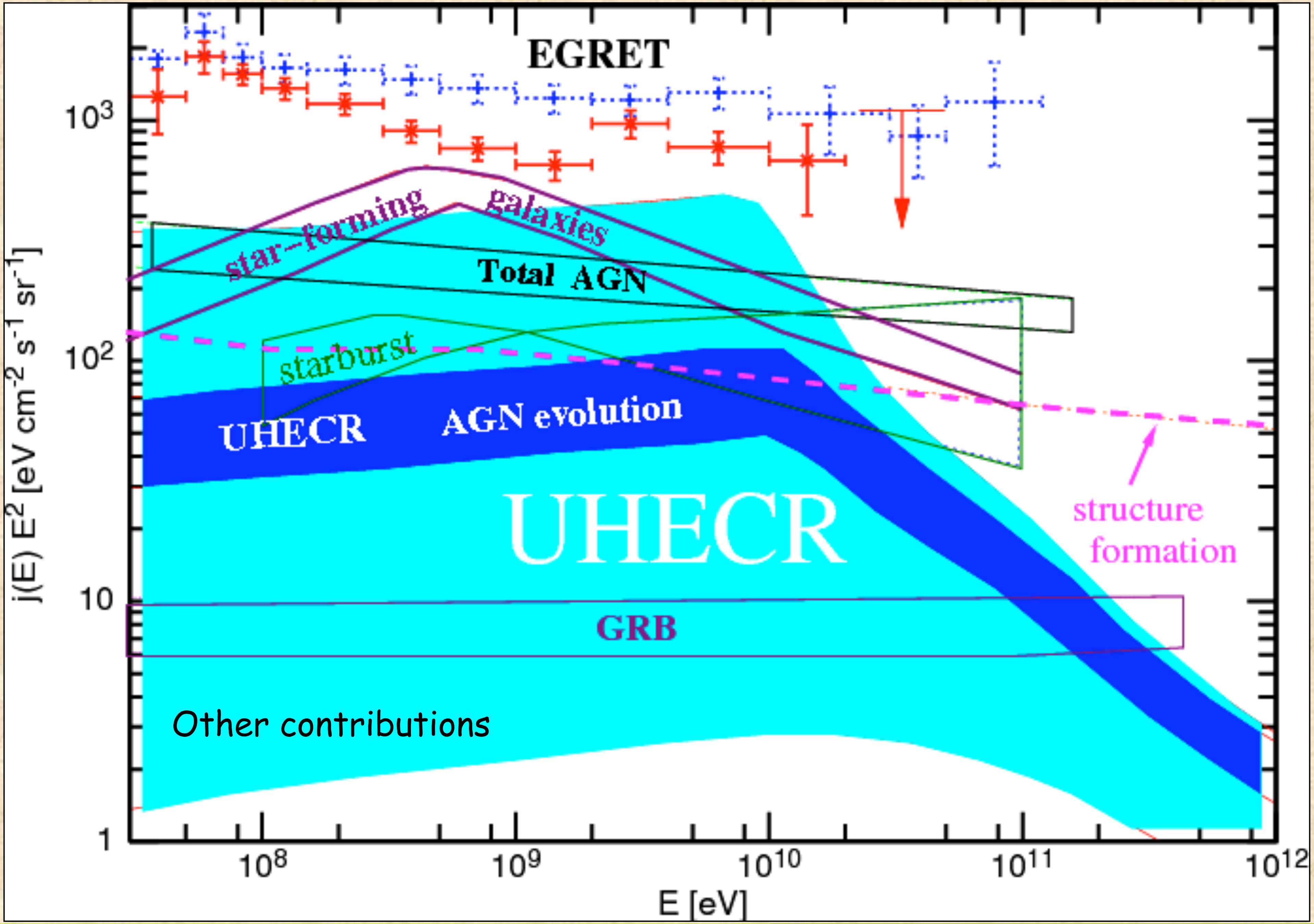
Ultra-High Energy Cosmic Ray Contributions to the MeV-TeV γ-ray background



Kalashev, Semikoz, Sigl, arXiv:0704.2463

Unstructured, homogeneous sources: $E^{-2.6}$ proton injection for 10^{16} eV < E < 10^{21} eV with constant comoving injection power.

Other Contributions to the MeV-TeV γ-ray background



Lorentz Symmetry Violation in the Photon Sector

For photons we assume the dispersion relation

$$\omega^2 = k^2 \pm \xi_n k^2 \left(\frac{k}{M_{\rm pl}}\right)^n \quad \text{with} \quad n \geq 1$$

with only one term present, whereas dispersion relations for other particles are unchanged.

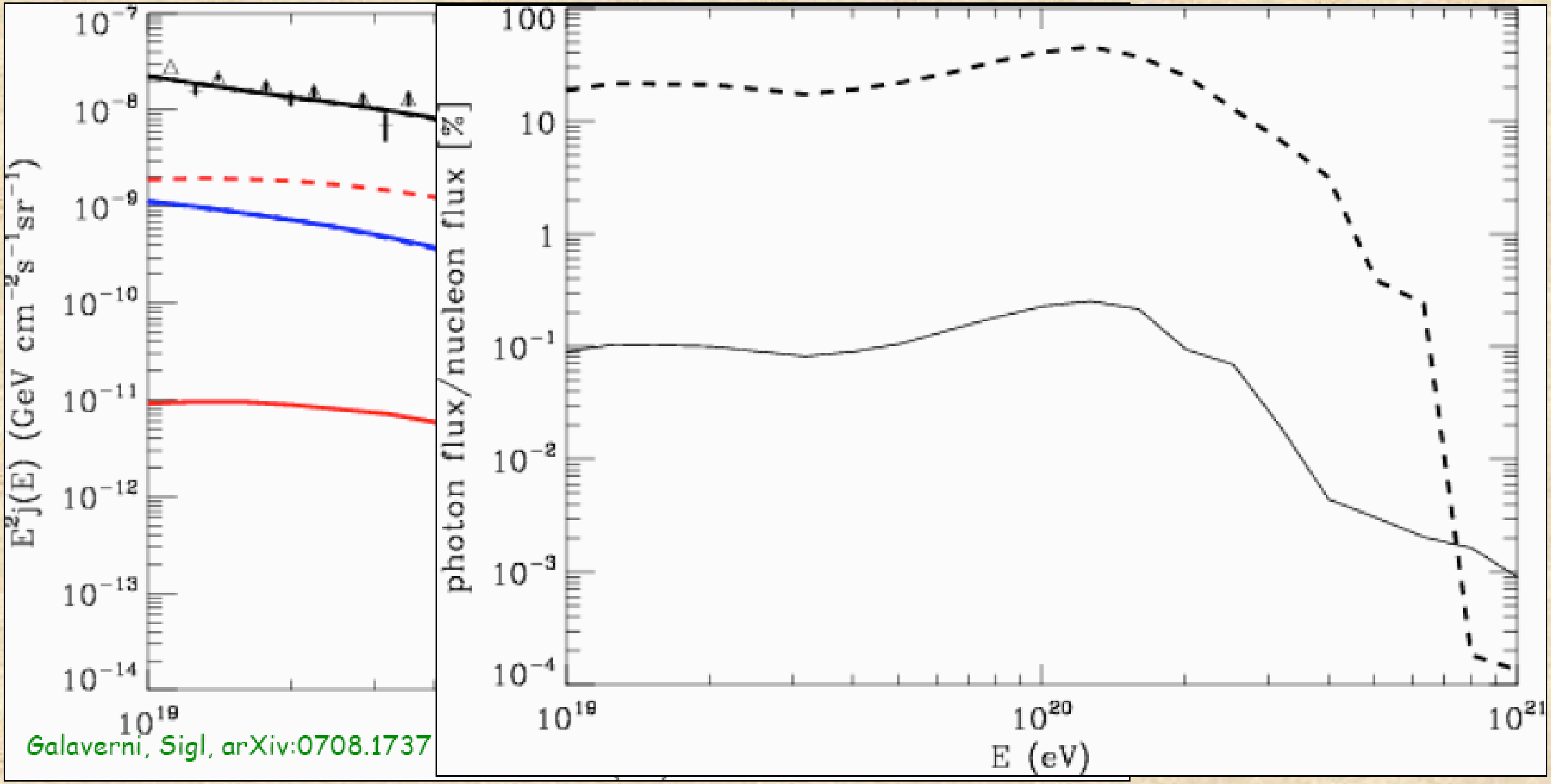
Consider pair production $\gamma\gamma \to e^+e^-$, on a background photon of energy ω_b. Scaled to the threshold in absence of Lorentz invariance (LI) breaking, $k_{LI} \equiv m_e^2/\omega_b$, the threshold condition is

$$\pm\alpha_n x^{n+2} + x - 1 \geq 0\,,$$

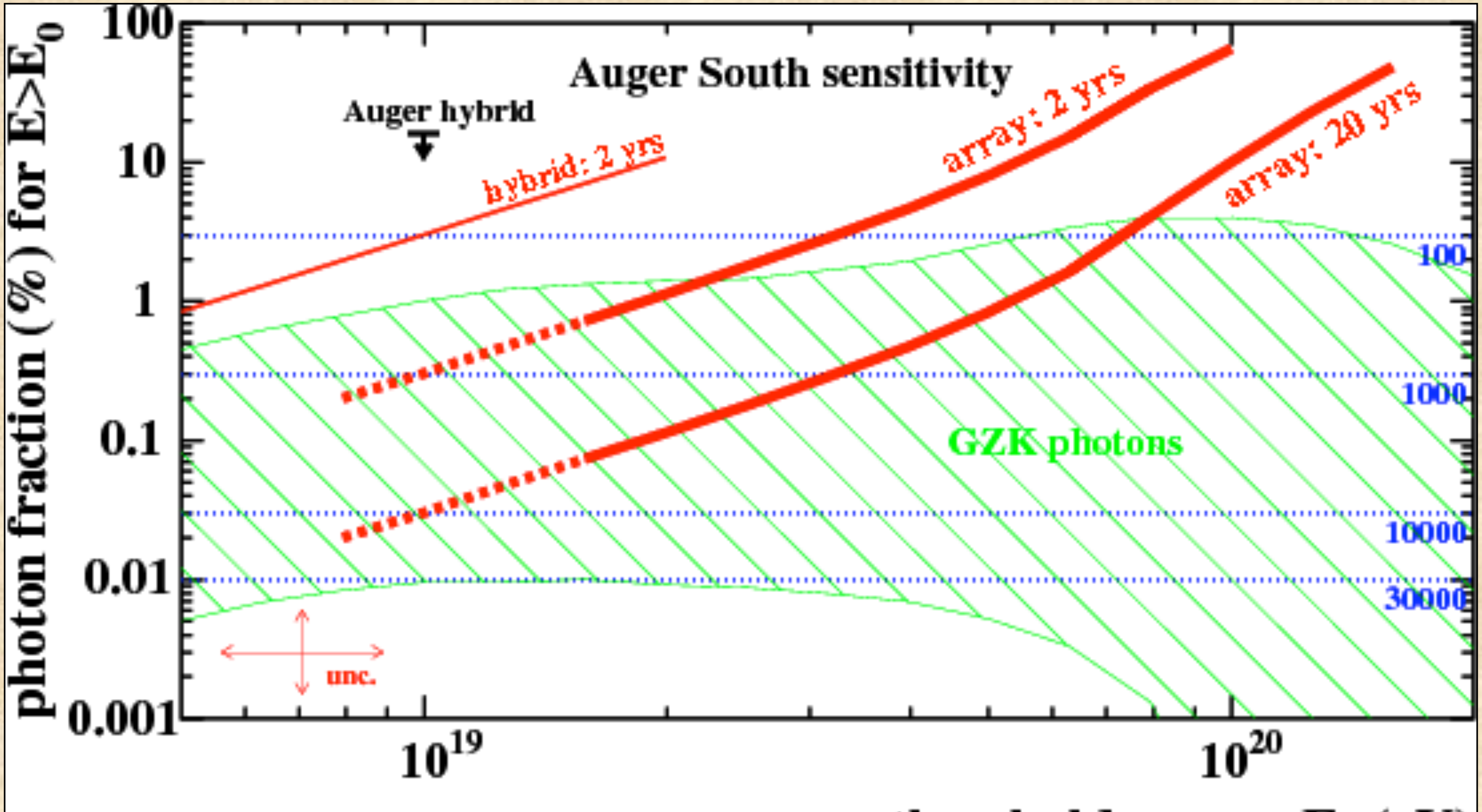
where

$$\alpha_n \equiv \xi_n \frac{k_{LI}^2}{4m_e^2}\left(\frac{k_{LI}}{M_{\rm pl}}\right)^n\,.$$

Since photon interaction length above 10^{19} eV is below a few Mpc, the fraction of secondary photons is expected to be $\lesssim 1\%$ above 10^{19} eV and $\lesssim 10\%$ above 10^{20} eV. But without pair production for $10^{19}\,\text{eV} \lesssim \omega \lesssim 10^{20}$ eV the photon fraction would be $\simeq 20\%$:



Current upper limits on the photon fraction are of order 2% above 10^{19} eV from latest results of the Pierre Auger experiments (ICRC) and order 30% above 10^{20} eV.



Risse, Homola, Mod.Phys.Lett. A22 (2007) 749.

Absence of pair production between 10^{19} eV and 10^{20} eV would thus violate experimental constraints.

Since a typical CMB photon energy is $\omega_b \sim 6 \times 10^{-4}\,\mathrm{eV}$, pair production should be allowed for

$$2.3 \times 10^4 \lesssim x \lesssim 2.3 \times 10^5 \lesssim x_n^u(\alpha_n)\,.$$

For $n = 1$ this yields

$$\alpha_1 \lesssim \frac{1}{(2.5 \times 10^5)^2} \simeq 1.9 \times 10^{-11}\,; \quad \xi_1 \lesssim 2.4 \times 10^{-15}\,.$$

For $n = 2$ this yields

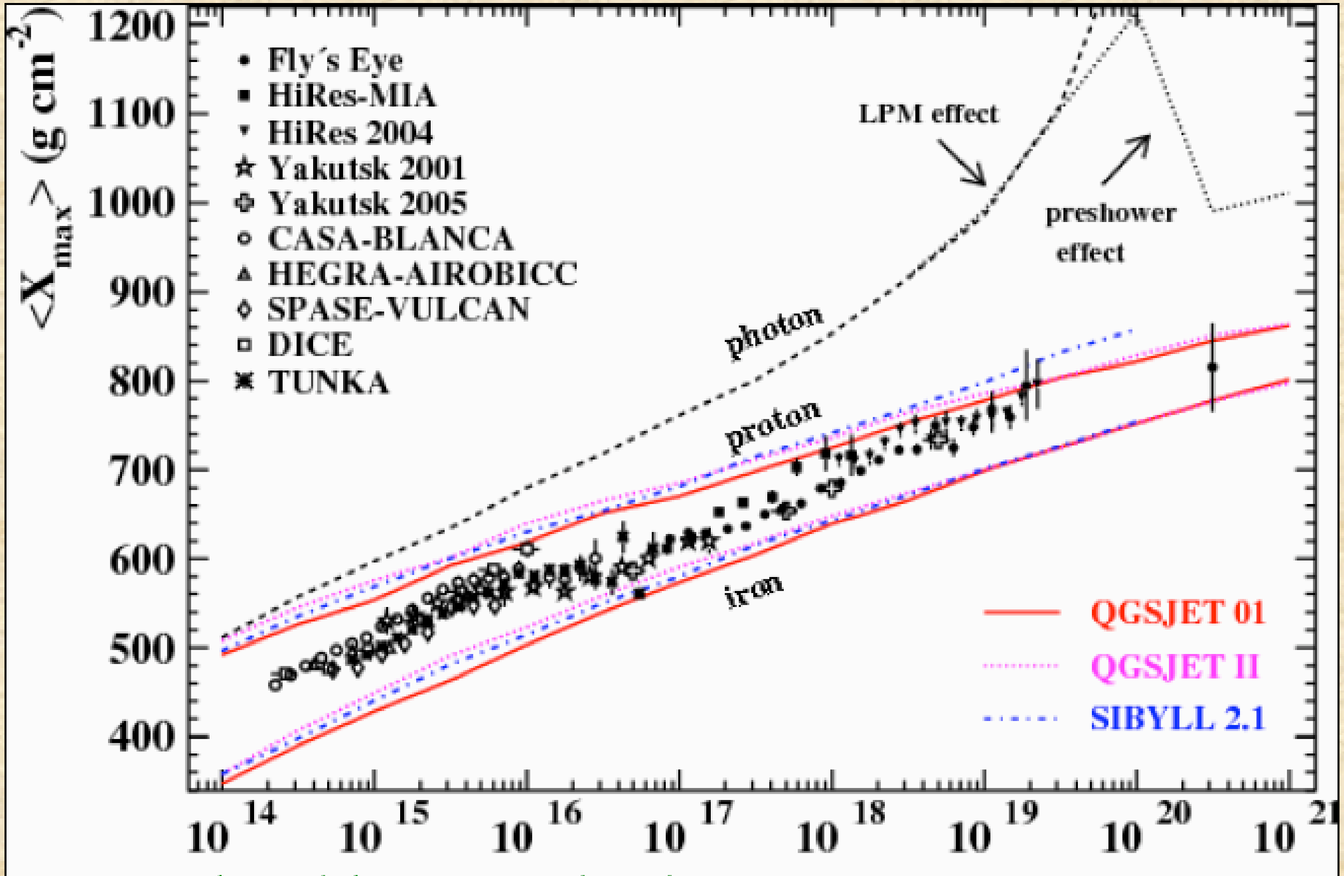
$$\alpha_2 \gtrsim -\frac{1}{(2.5 \times 10^5)^3} \simeq -8.2 \times 10^{-17}\,; \quad \xi_2 \gtrsim -2.4 \times 10^{-7}\,.$$

Only for $n \geq 3$ the limits on ξ_n become larger than unity.

Galaverni, Sigl, arXiv:0708.1737

Possible Caveats

1.) Air shower physics of photon primaries not well understood ?



Risse, Homola, Mod.Phys.Lett. A22 (2007) 749.

2.) LI violation in the electron sector can enable pair production if corresponding dimensionless parameters are considerably larger than in the photon sector.

3.) Our constraints do not apply to supersymmetric QED which implies LI violating terms suppressed by the electron mass, $\xi_n m^2 (k/M_{\rm Pl})^n$.

Conclusions

1.) Many activities on the origin of cosmic rays and related topics at several participant labs (APC Paris and Oxford are members of the Pierre Auger Collaboration and Oxford is also member of the IceCube collaboration).

2.) So far, no dedicated ERs or ESRs funded by UniverseNet yet working on this topic.