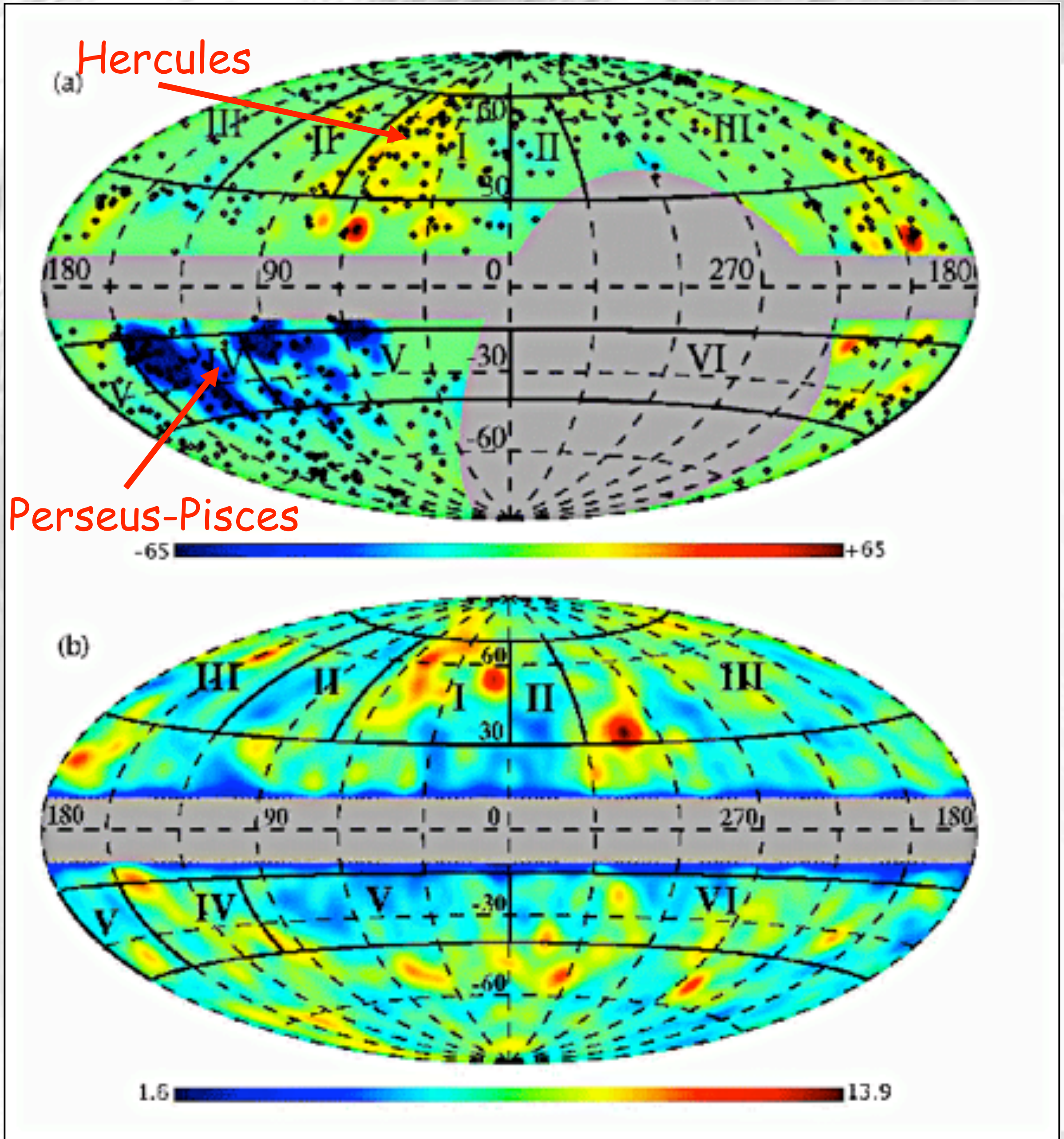


Smoothed rotation measure:
Possible signatures of ~0.1μG level on super-cluster scales!

Theoretical motivations from the Weibel instability which tends to drive field to fraction of thermal energy density

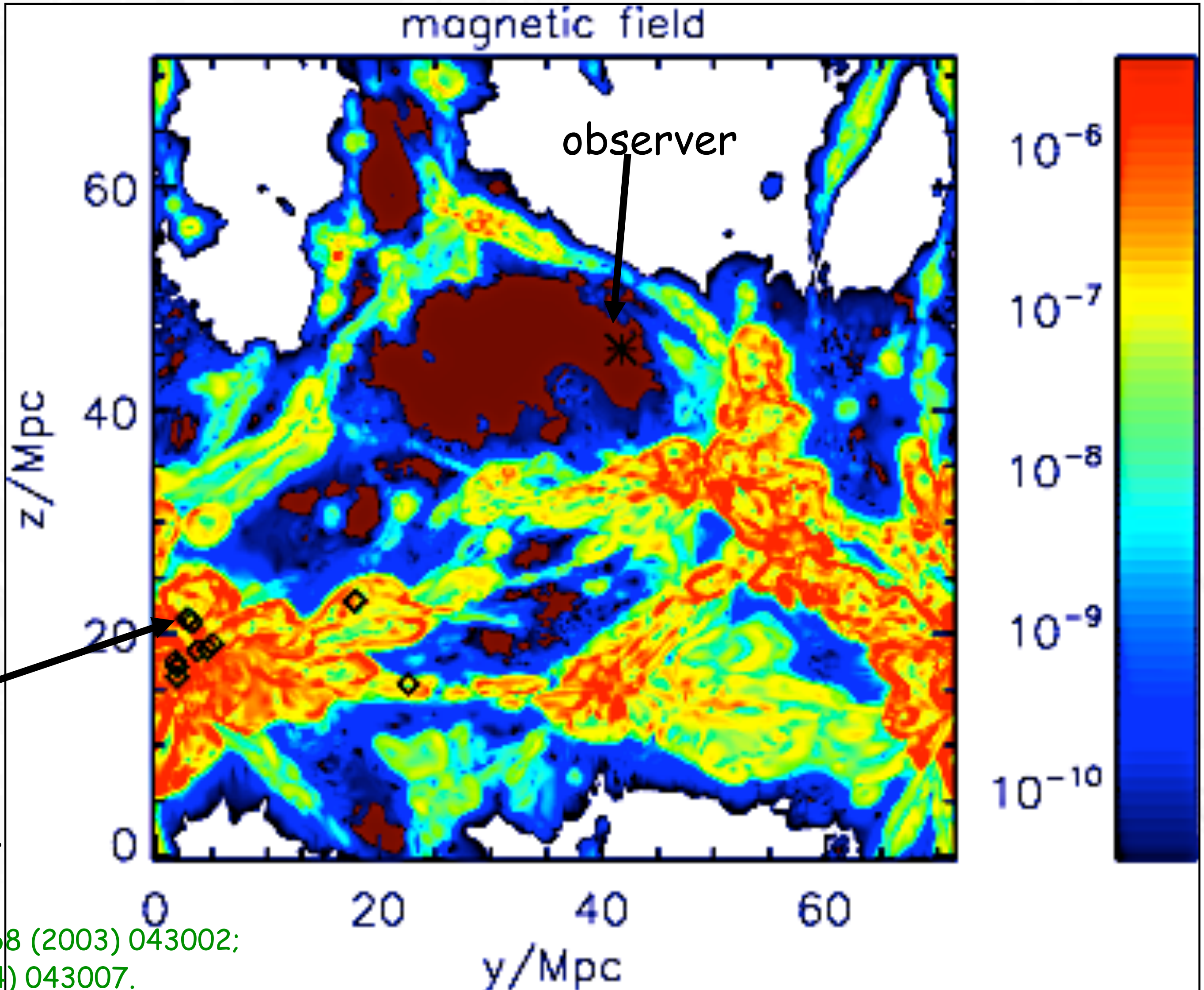
But need much more data from radio astronomy, e.g. Lofar, SKA

2MASS galaxy column density

Xu et al., astro-ph/0509826

Propagation in structured extragalactic magnetic fields

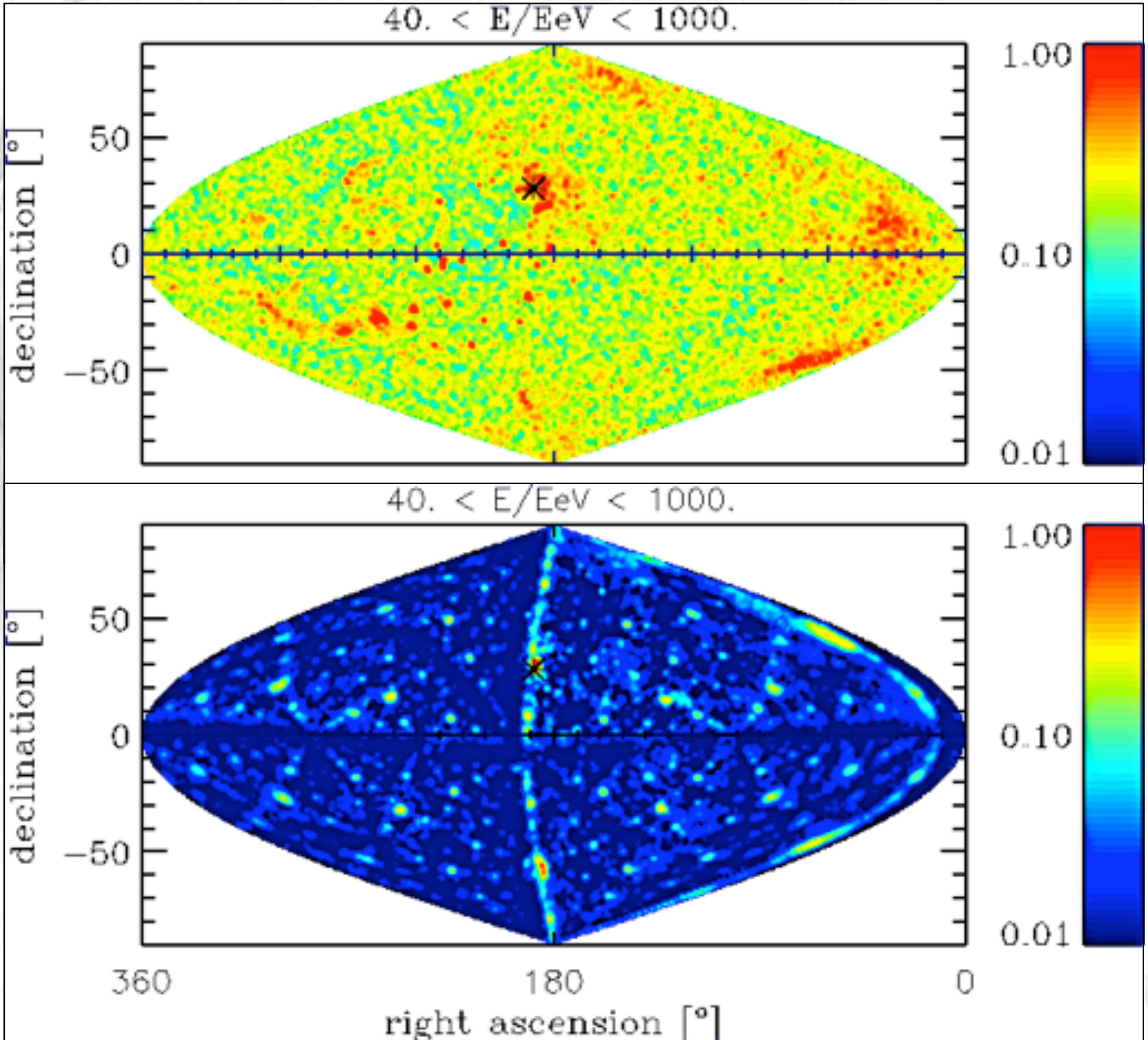
Scenarios of extragalactic magnetic fields using large scale structure simulations with magnetic fields reaching few micro Gauss in galaxy clusters.



Discrete sources of density ~10^{-5} Mpc^{-3} follow baryon density, field at Earth ~10^{-11} G.

Sigl, Miniati, Ensslin, Phys.Rev.D 68 (2003) 043002; astro-ph/0309695; PRD 70 (2004) 043007.

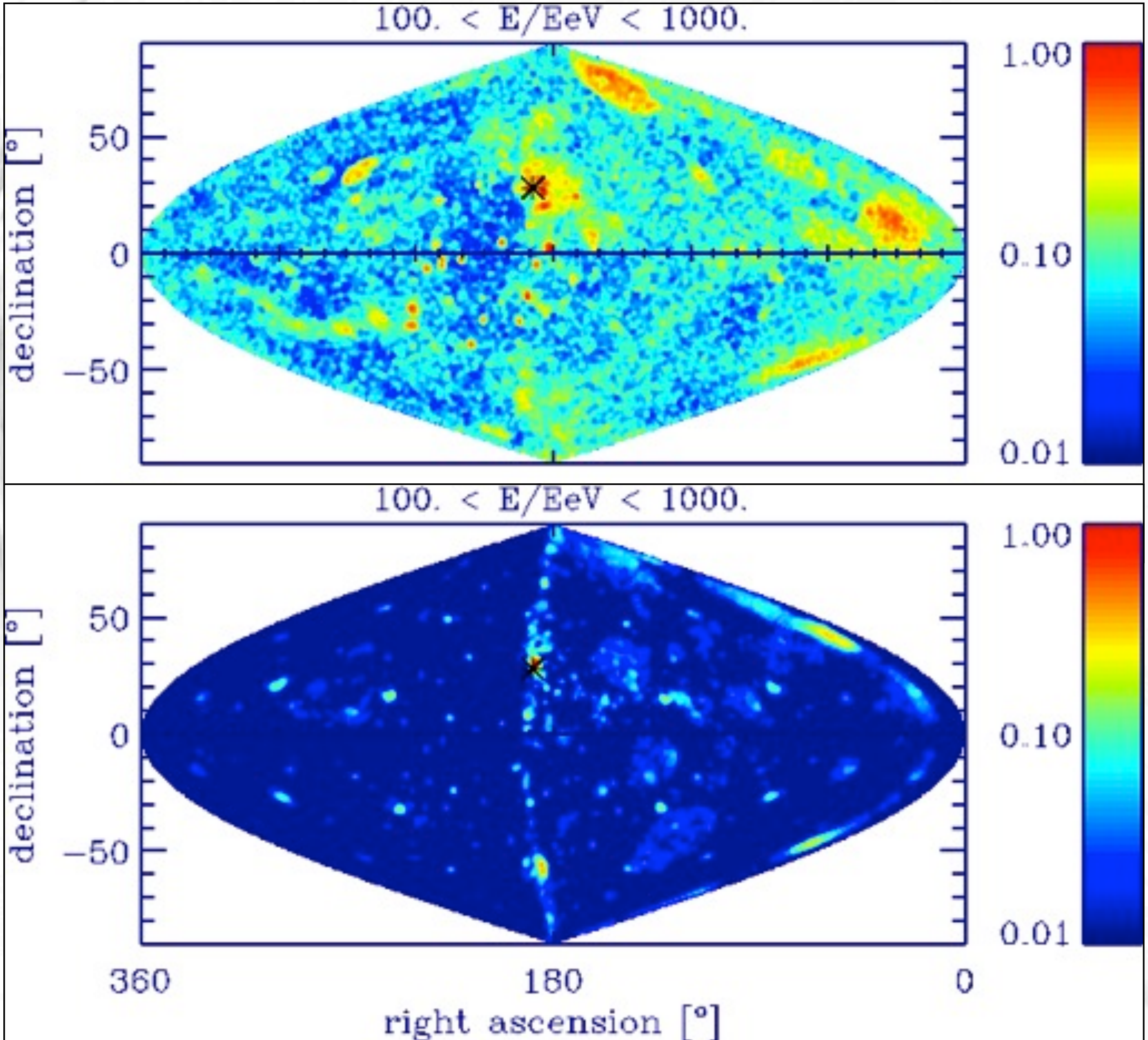
The simulated sky above $4x10^{19}$ eV with structured sources of density $2.4x10^{-5}$ Mpc^{-3} : ~$2x10^5$ simulated trajectories above $4x10^{19}$ eV.



With field

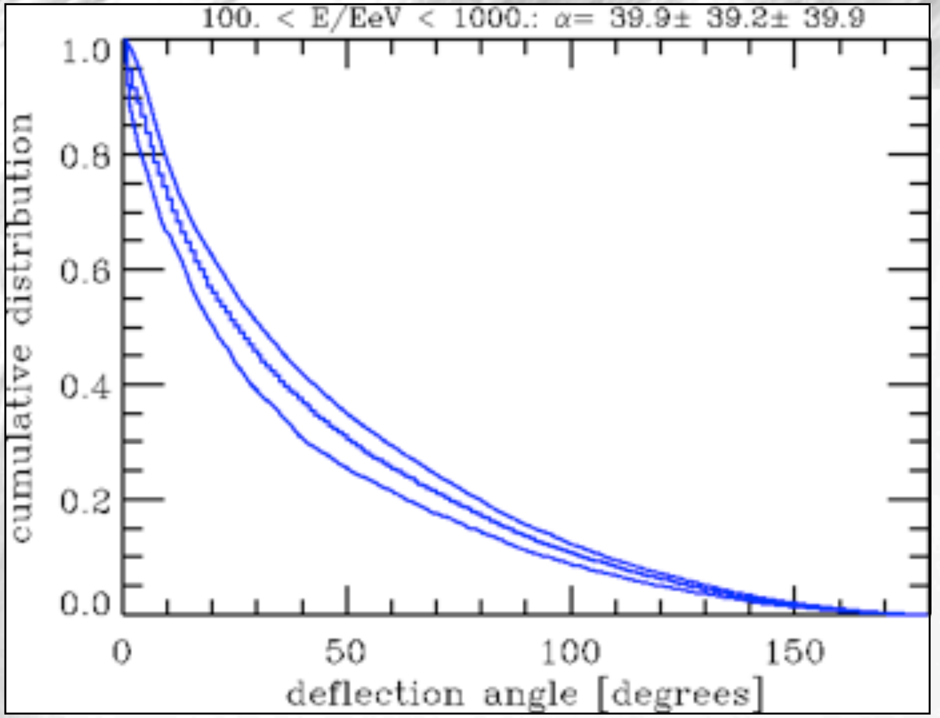
Without field

The simulated sky above 10^{20} eV with structured sources of density 2.4×10^{-5} Mpc^{-3} : ~2×10^5 simulated trajectories above 10^{20} eV.



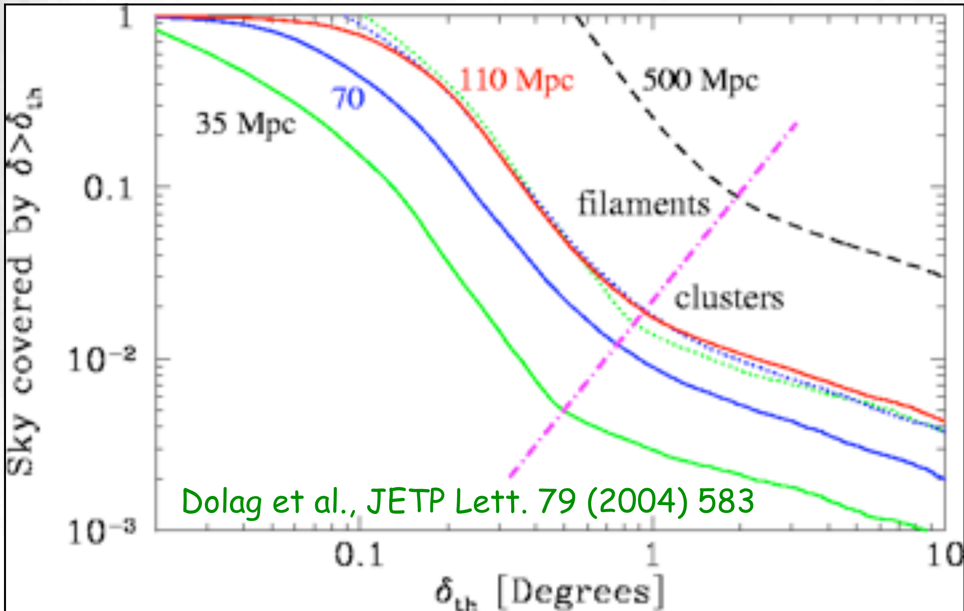
With field

Without field



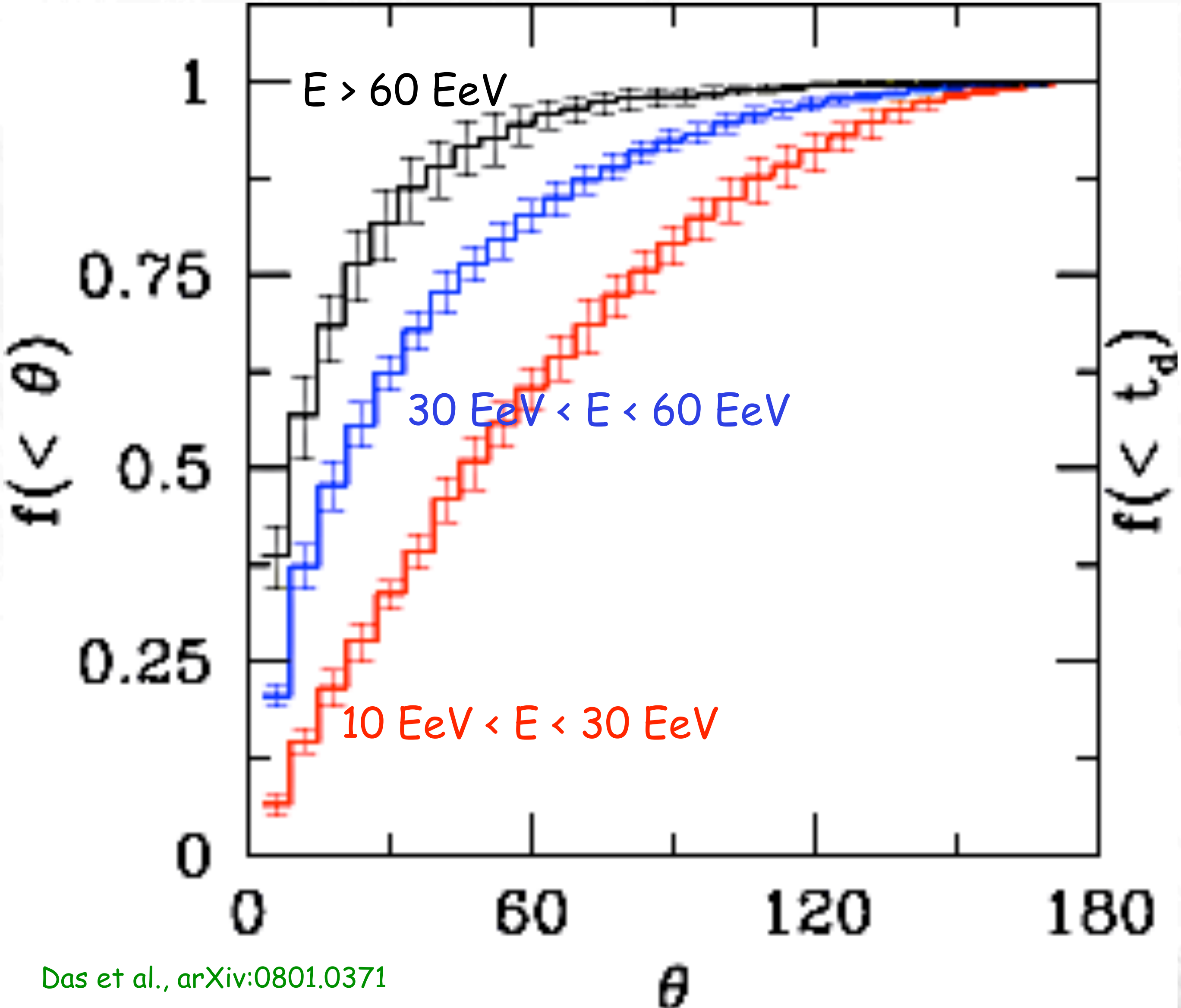
Deflection in magnetized structures surrounding the sources lead to off-sets of arrival direction from source direction up to >10 degrees up to 10^{20} eV in our simulations. This is contrast to Dolag et al., JETP Lett. 79 (2004) 583.

Particle astronomy not necessarily possible, especially for nuclei !

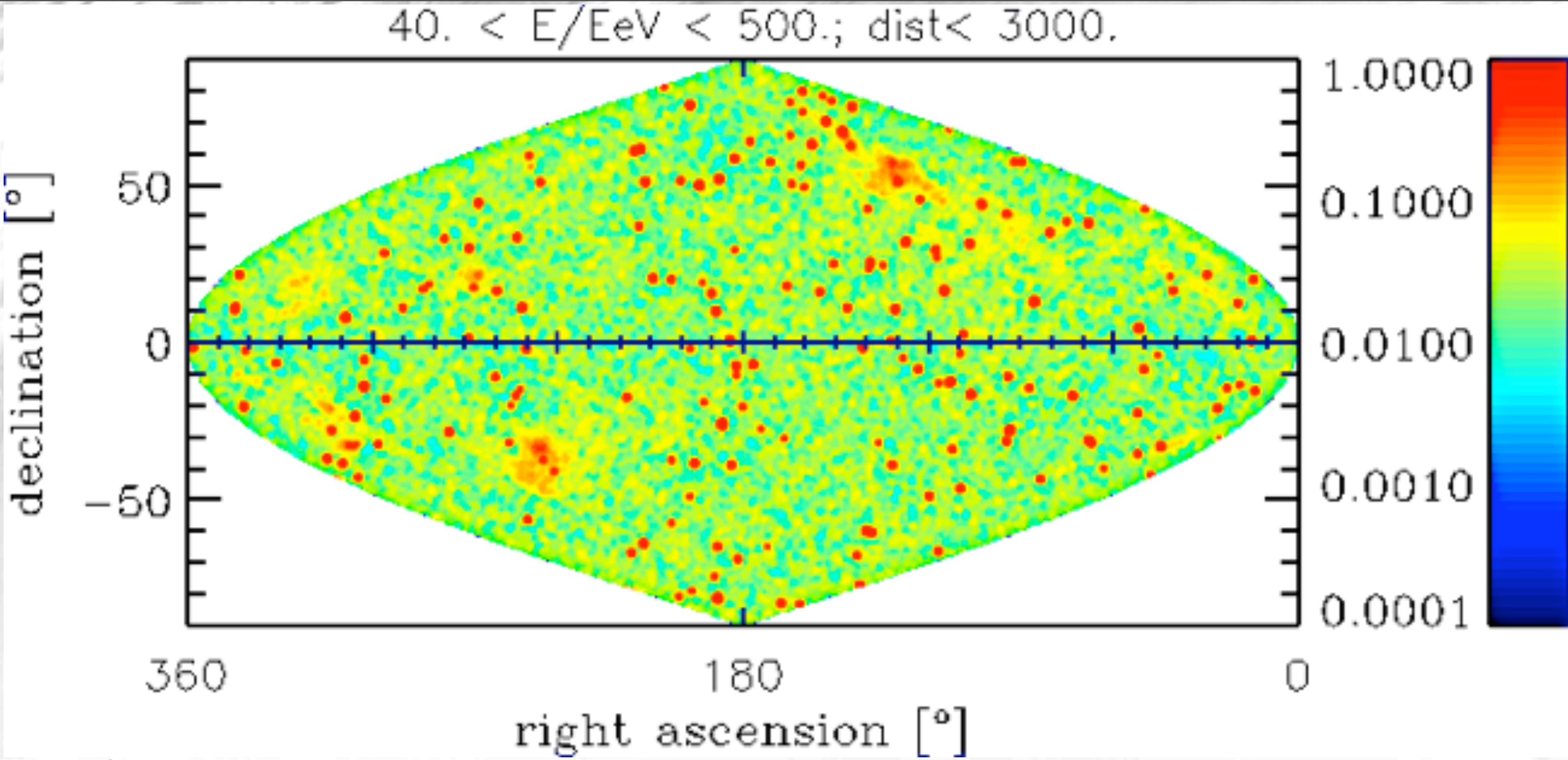


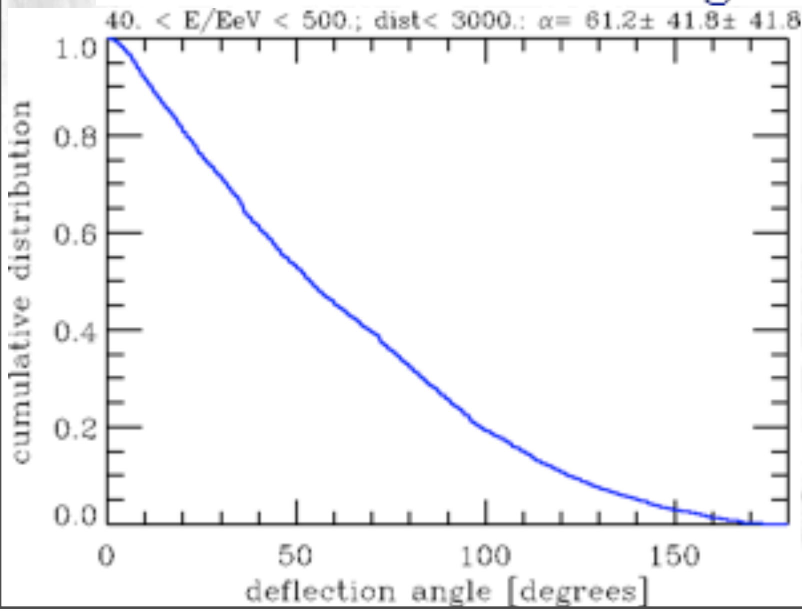
Cumulative deflection angle distributions for proton primaries

Recent results give intermediate and still significant deflections for proton primaries:

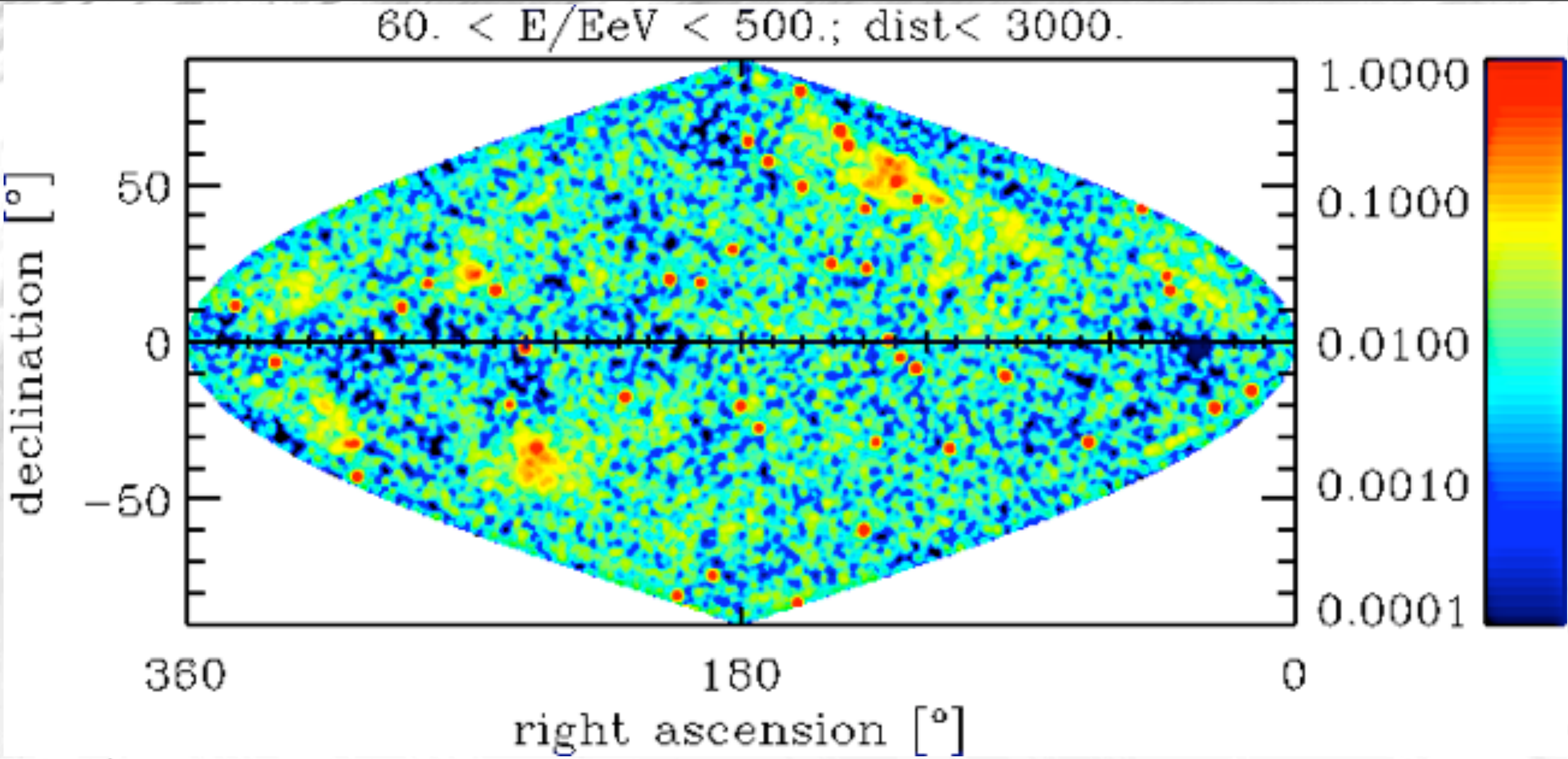


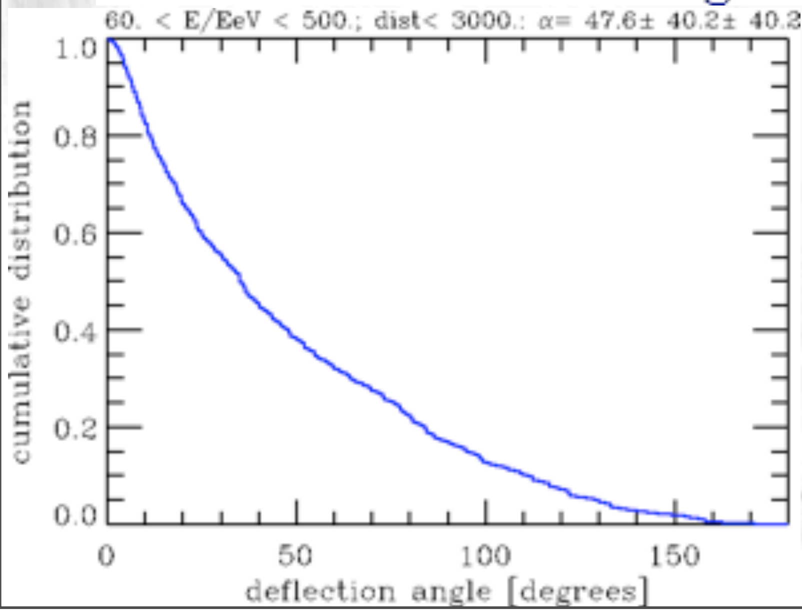
Das et al., arXiv:0801.0371



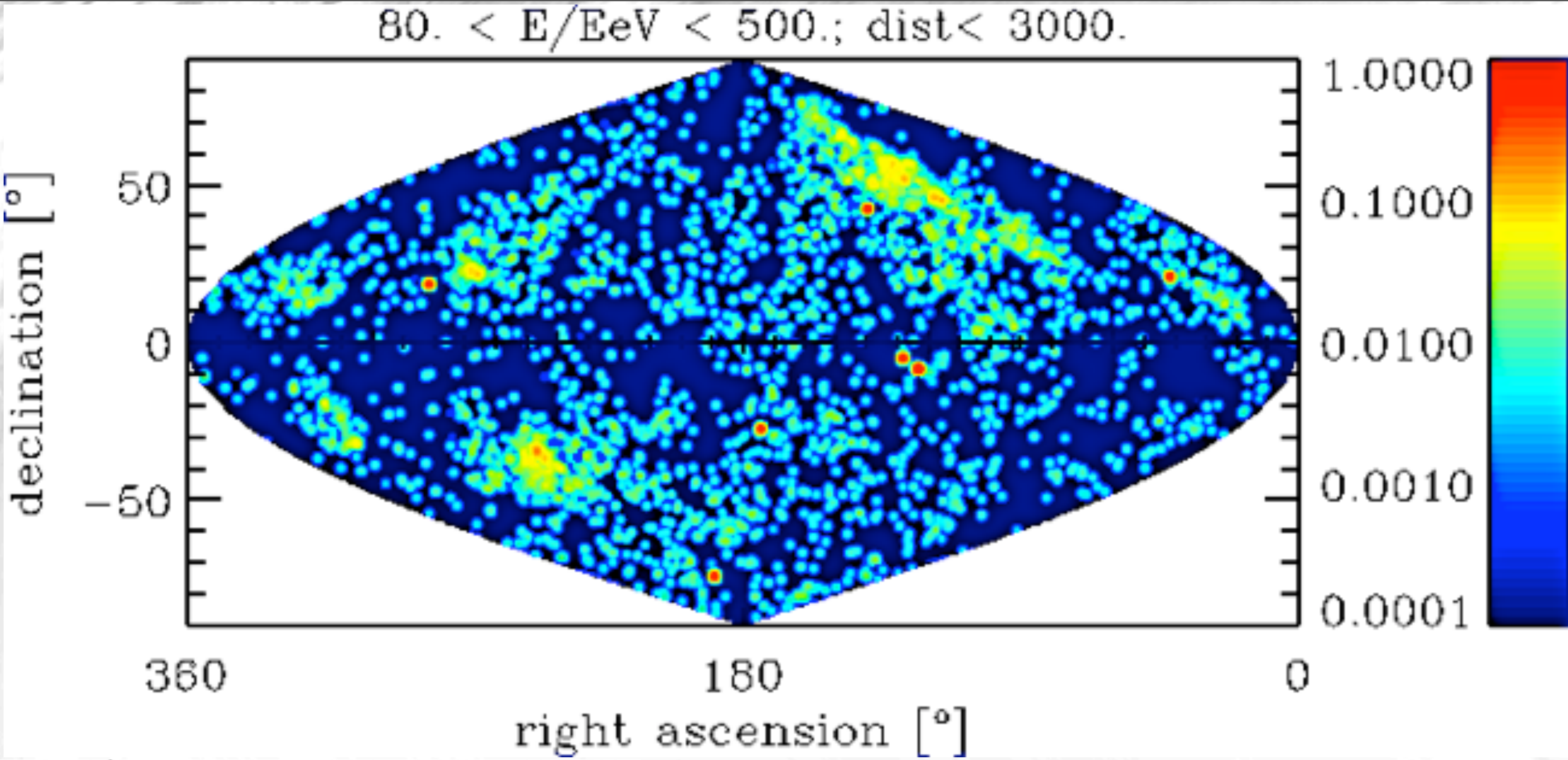


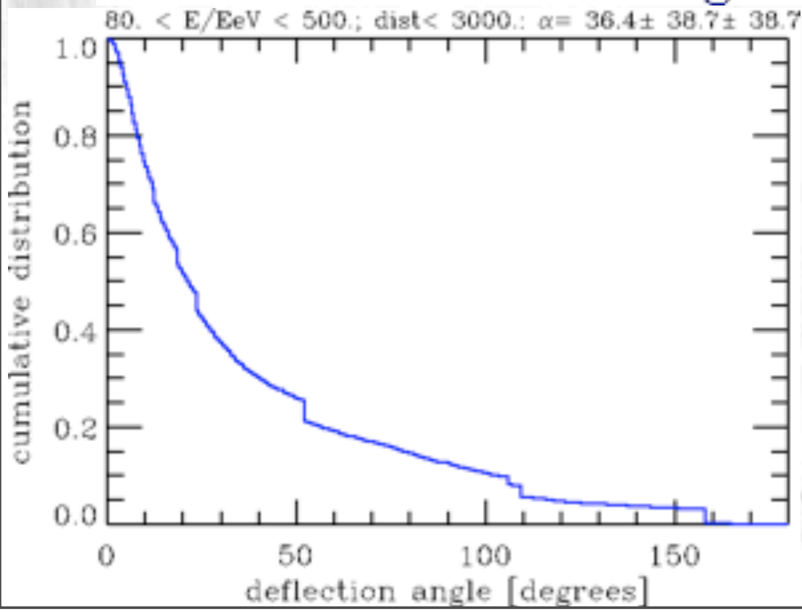
Sky distributions for iron primaries above 40 EeV, $E^{-2.2}$ injection up to 10^{22} eV



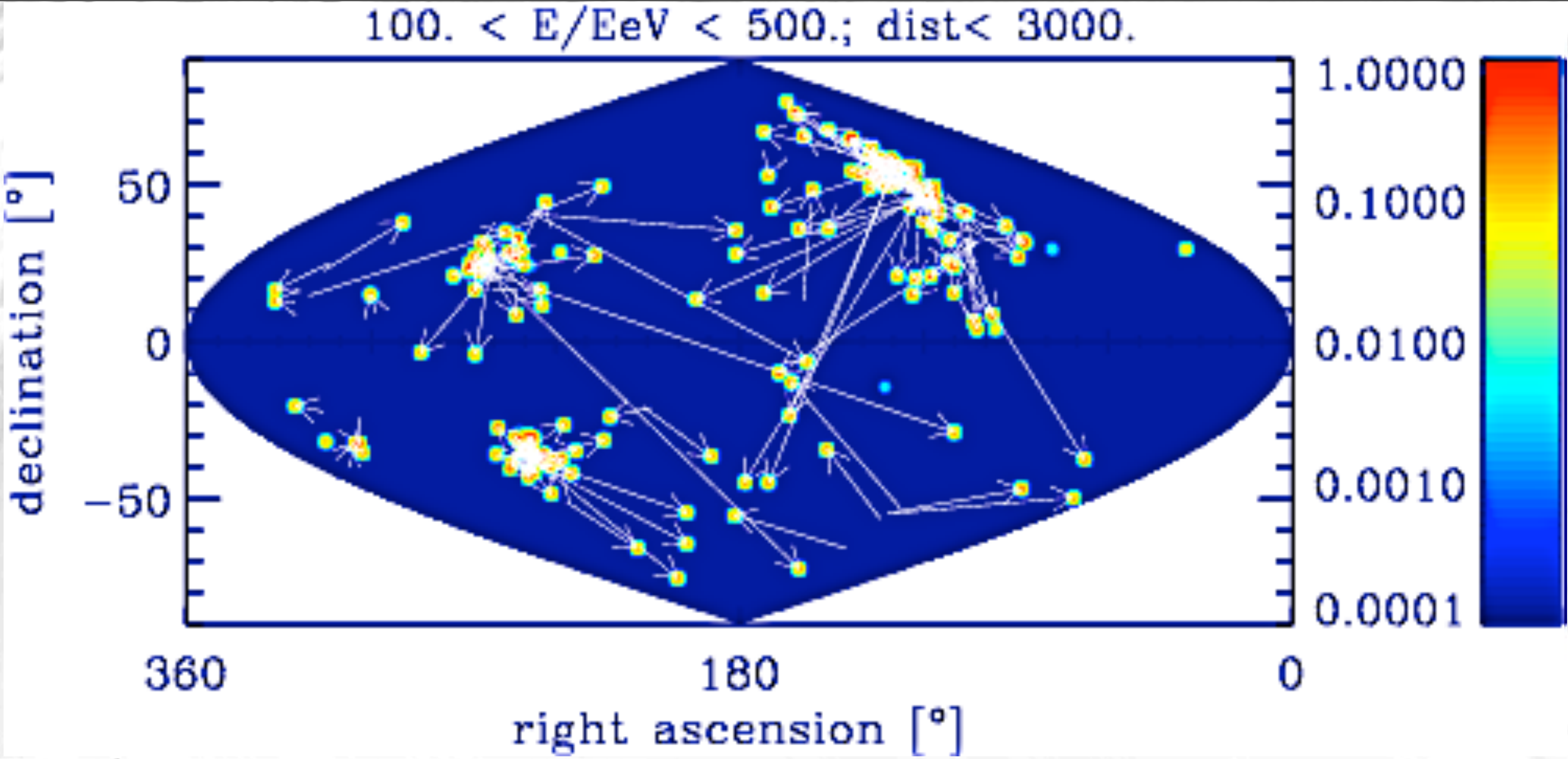


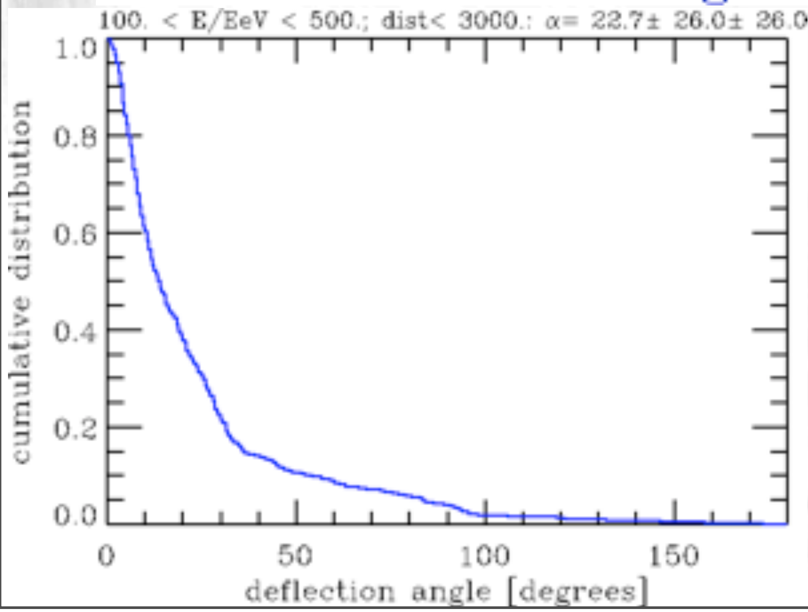
Sky distributions for iron primaries above 60 EeV, $E^{-2.2}$ injection up to 10^{22} eV





Sky distributions for iron primaries above 80 EeV, $E^{-2.2}$ injection up to 10^{22} eV





Sky distributions for iron primaries above 100 EeV, $E^{-2.2}$ injection up to 10^{22} eV

Conclusion:

A correleation with the local large scale structure is not necessarily destroyed by relatively large deflection, not even for iron, provided the field correlates with the large scale structure and deflection is mainly within that structure

It would mean that any correlation with specific sources does not identify particular sources, but only a source class that is distributed as the large scale structure

Instead of AGN it could be e.g. due to GRBs or magnetars

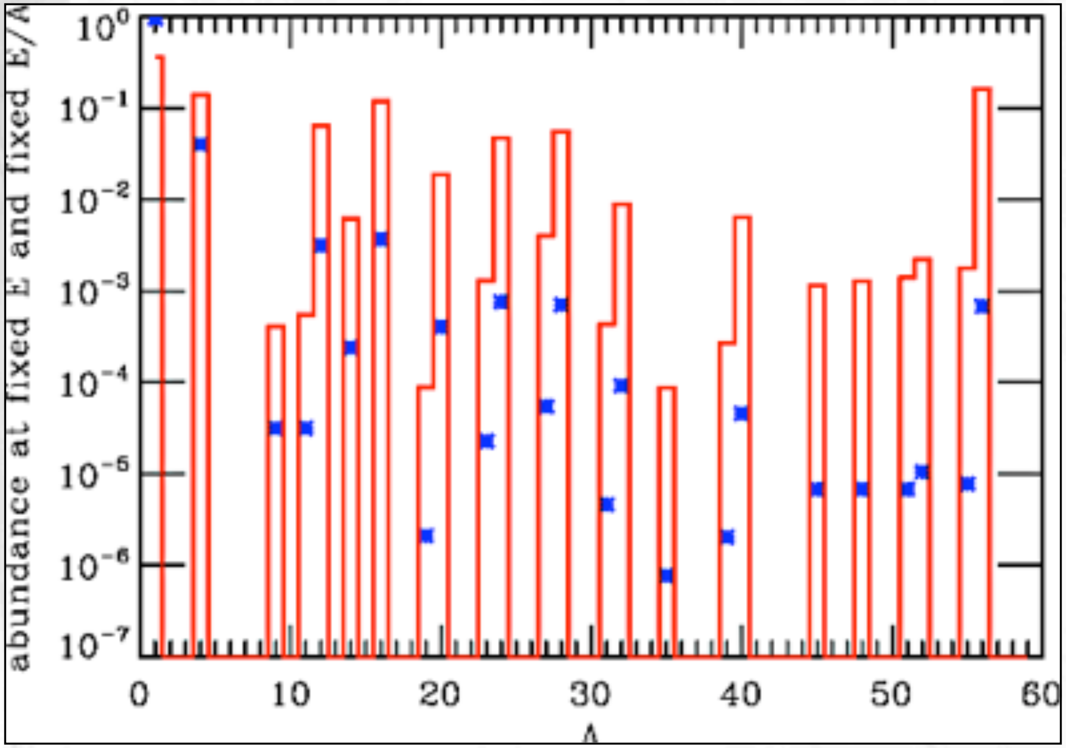
But galactic deflection is also large and in general does not align with with supergalactic plane

Injection of Solar Abundances for Magnetized Sources

For an injection spectrum $E^{-\alpha}$ elemental abundance at given energy E is modified to

$$\frac{dn_A}{dE}(E) = N\, x_A\, A^{\alpha-1}\, E^{-\alpha}$$

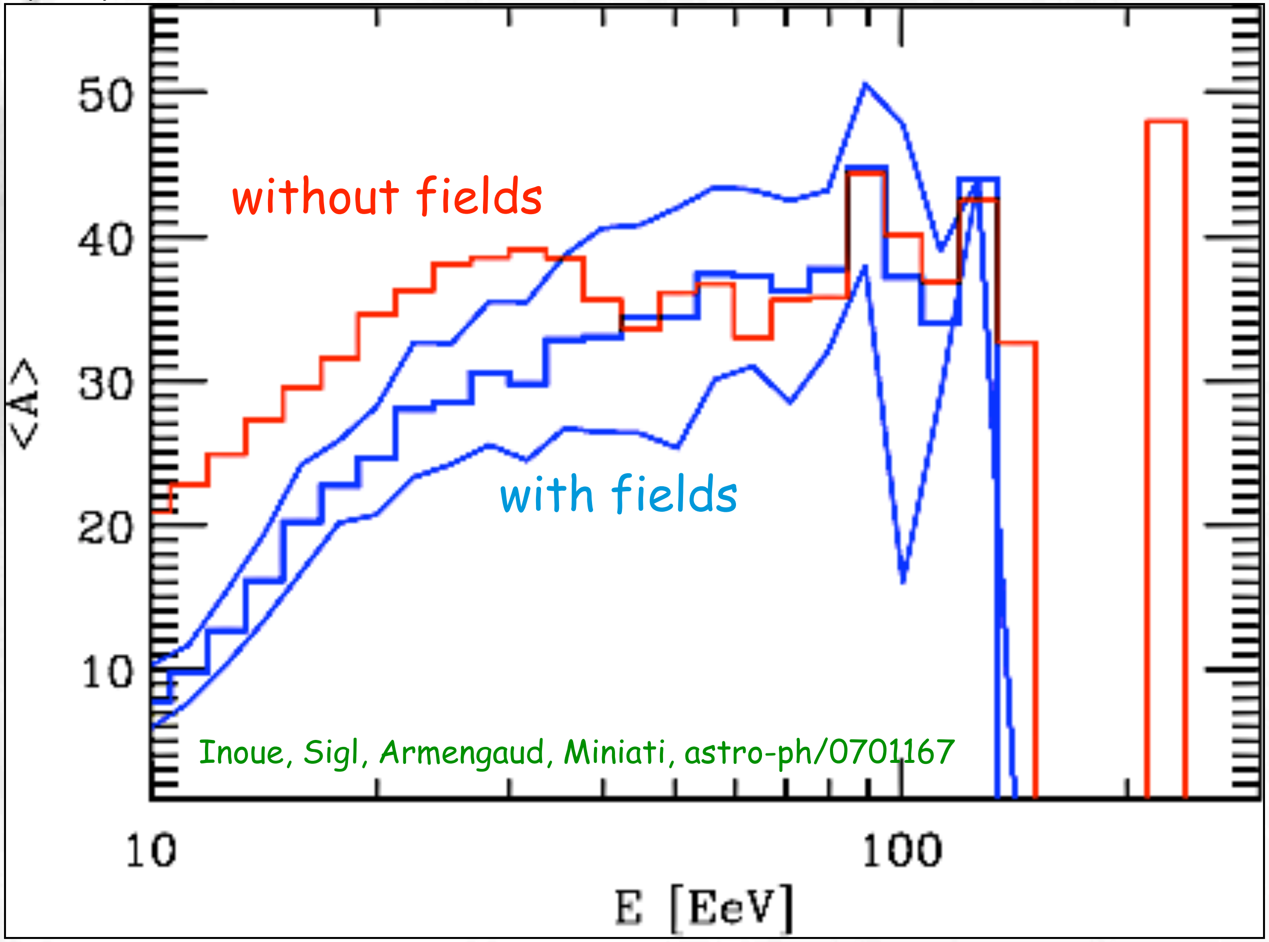
where x_A is the abundance at given energy per nucleon E/A.



Composition at given E/A (blue), Composition at given E for an $E^{-2.6}$ injection spectrum (red).

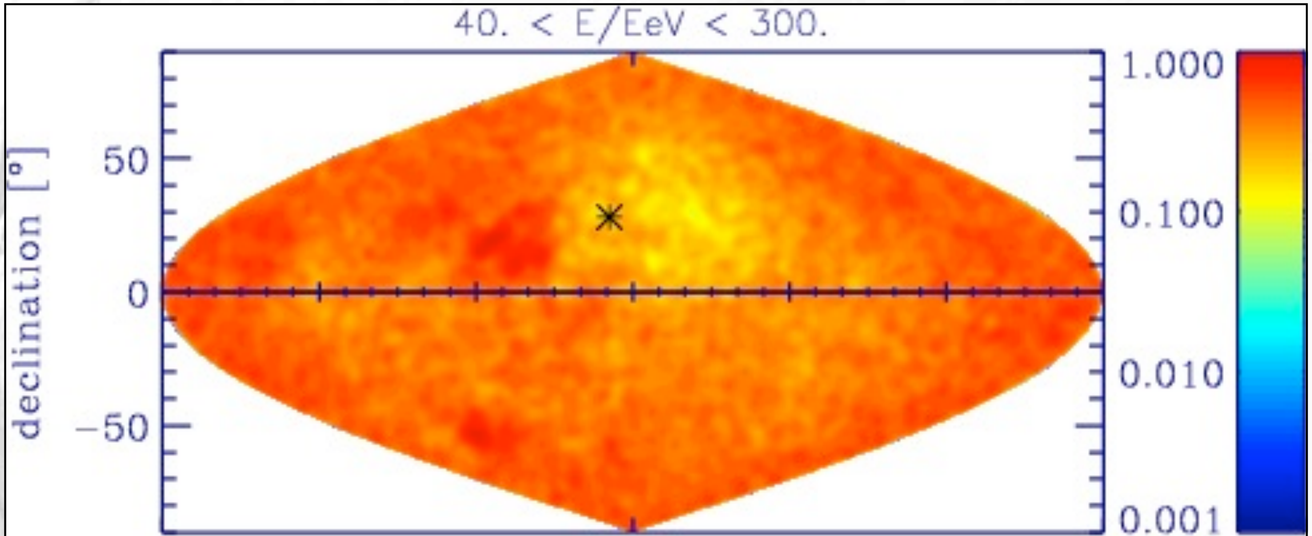
Example: Acceleration of Mixed (Solar Metallicity) Composition at Cluster Accretion Shocks

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



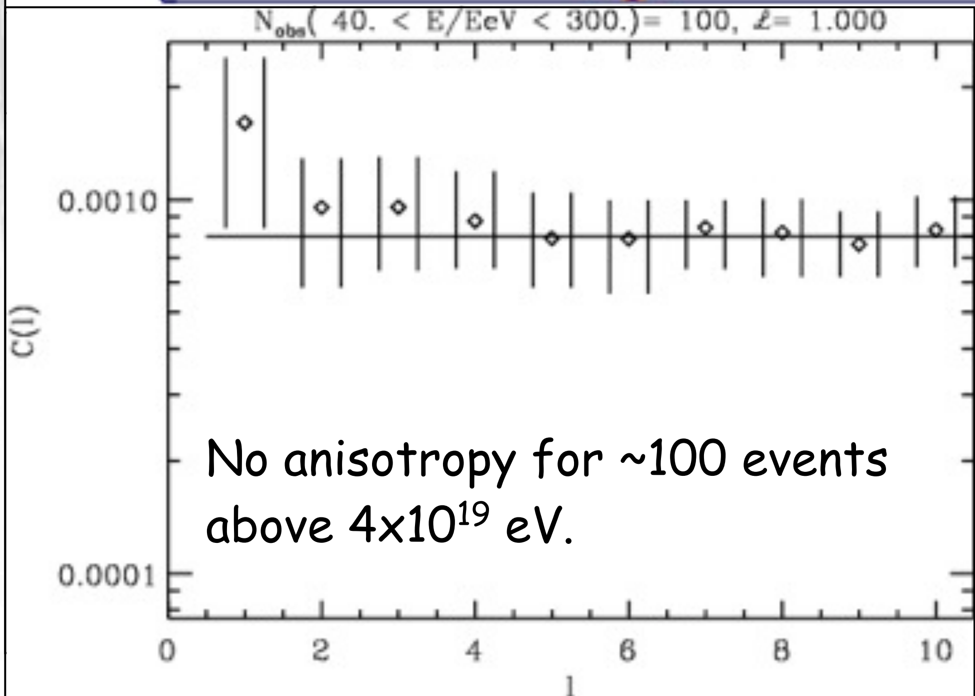
This scenario predicts an increasingly heavy composition at the highest energies.

A particular instance of the
Mixed Composition Cluster Accretion Shocks Scenario

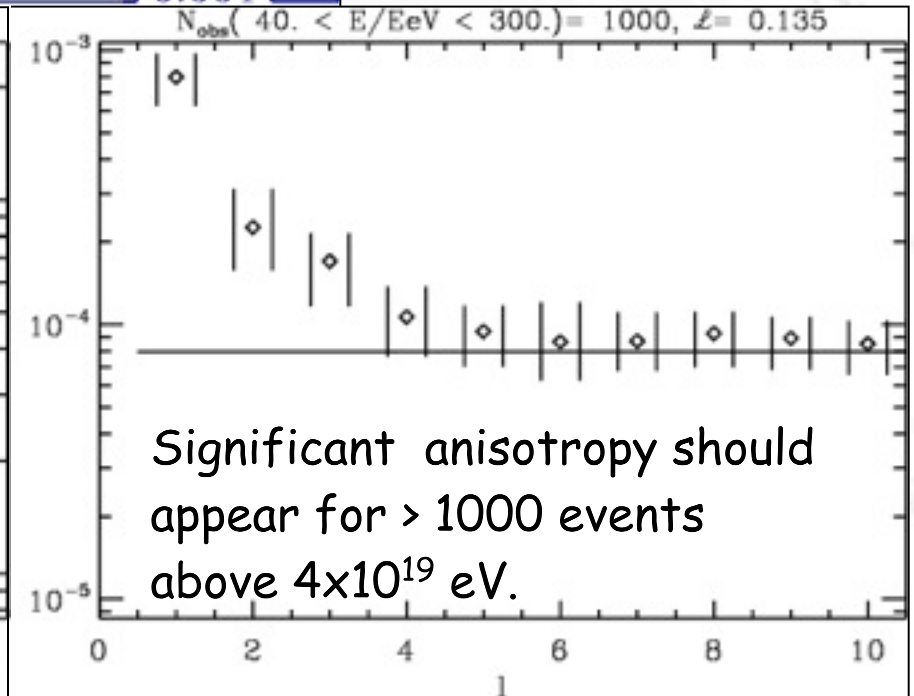


With field:

Almost isotropic; would be consistent with HiRes observations !



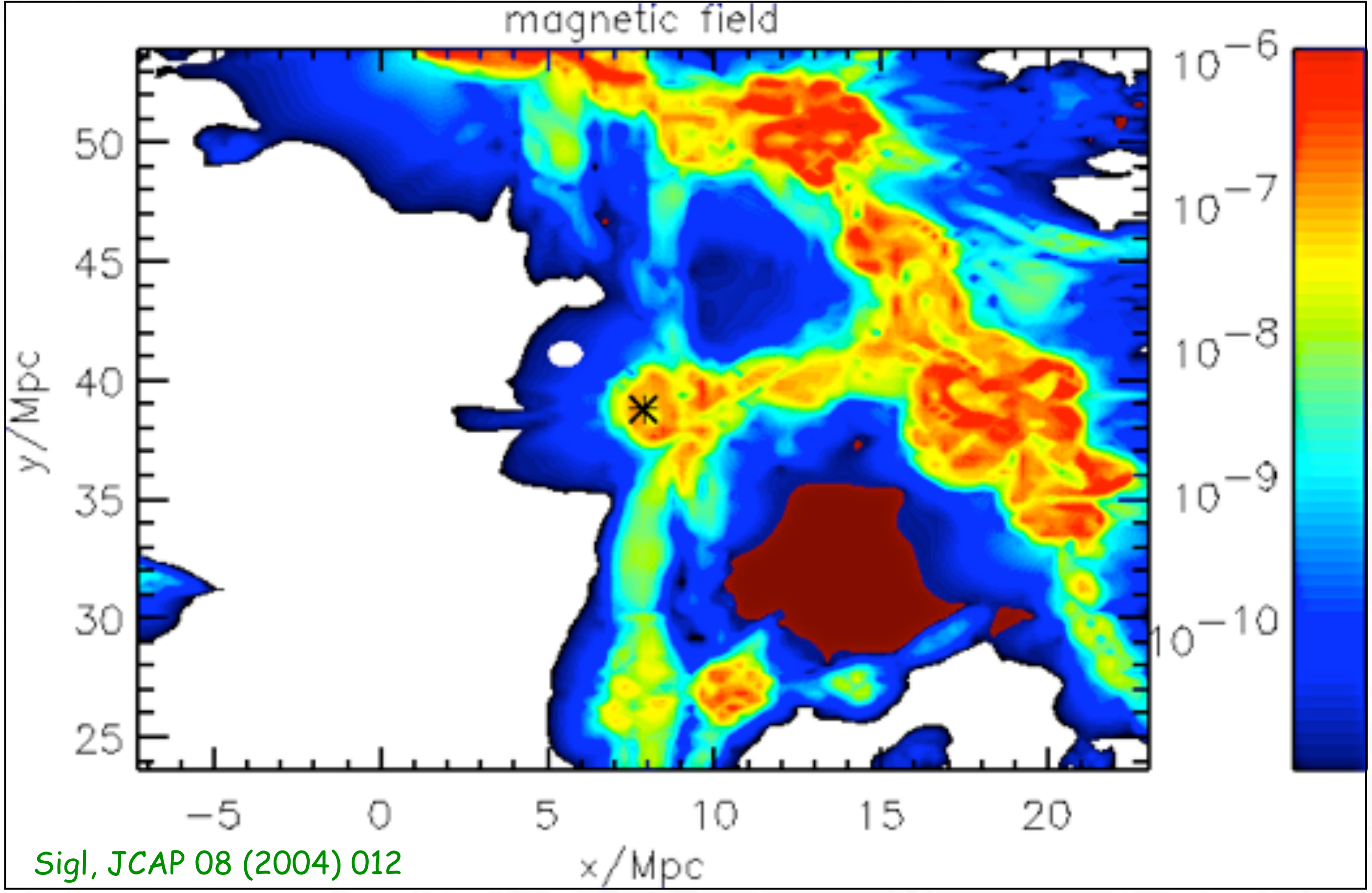
No anisotropy for ~100 events above 4×10^{19} eV.



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

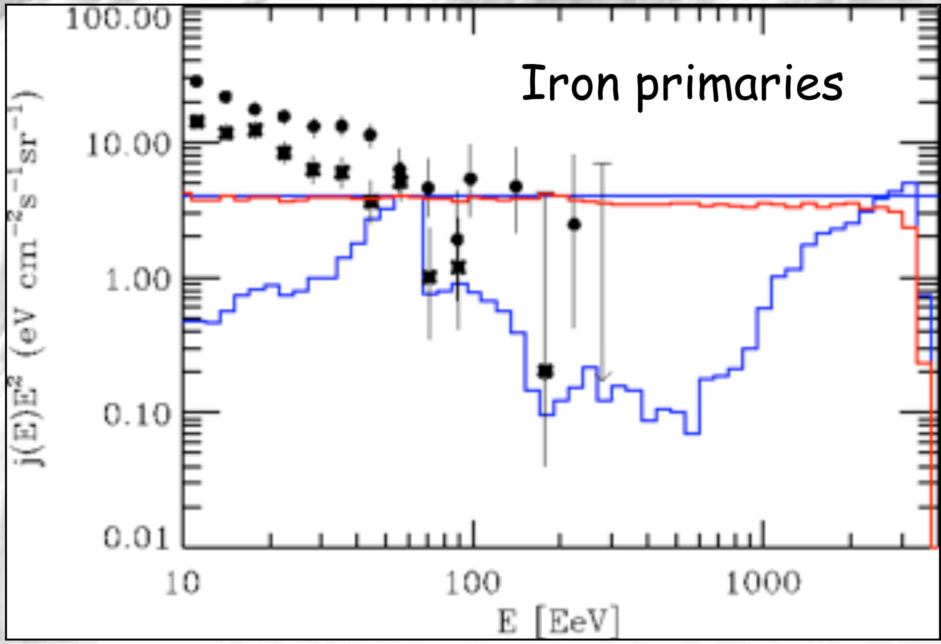
Heavy Nuclei: Structured Fields and Individual Sources

Spectra and Composition of Fluxes from Single Discrete Sources considerably depend on Source Magnetization, especially for Sources within a few Mpc.



Sigl, JCAP 08 (2004) 012

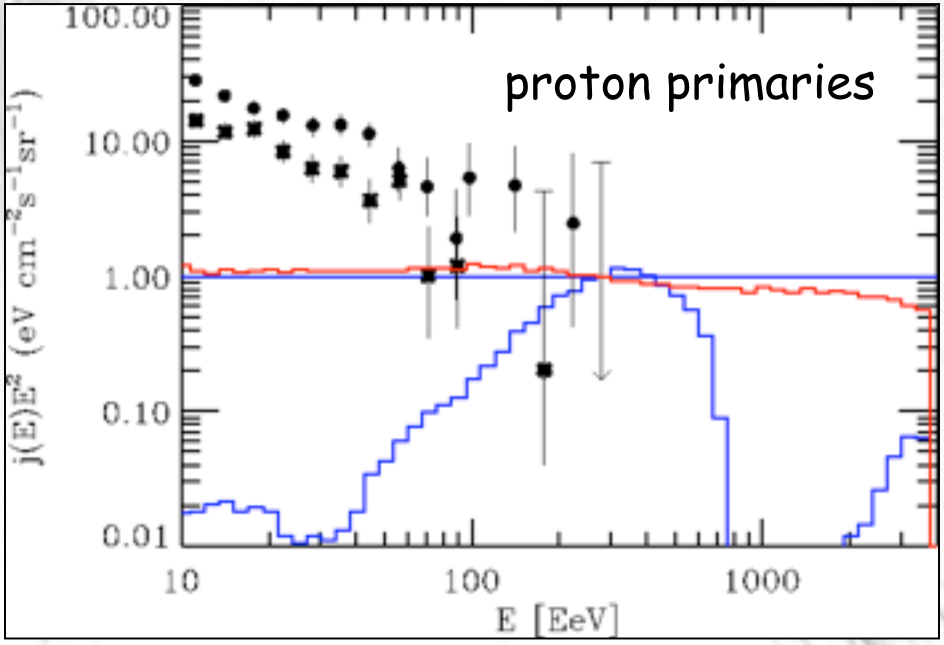
Source in the center; weakly magnetized observer modelled as a sphere shown in white at 3.3 Mpc distance.

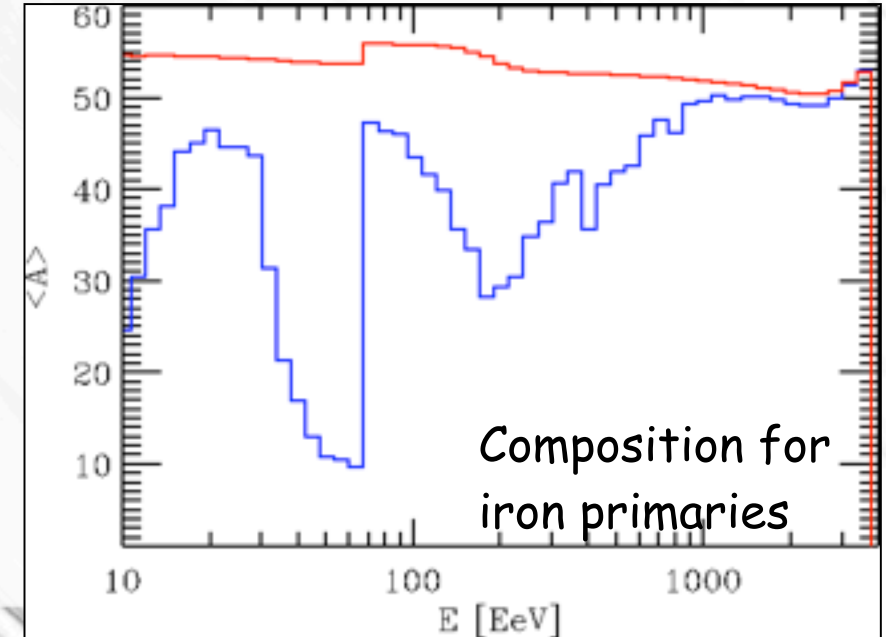


With field = blue

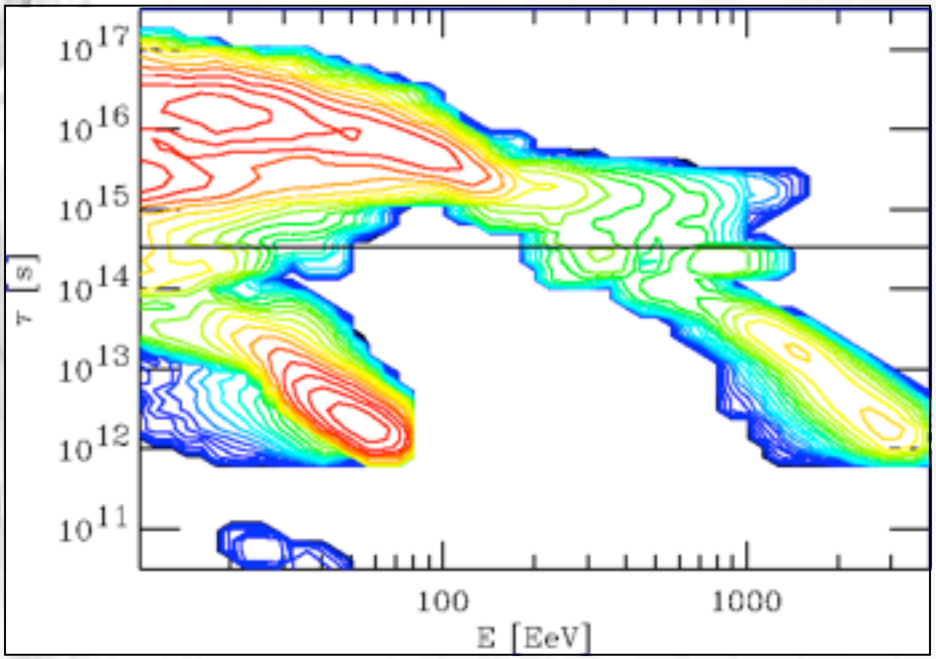
Without field = red

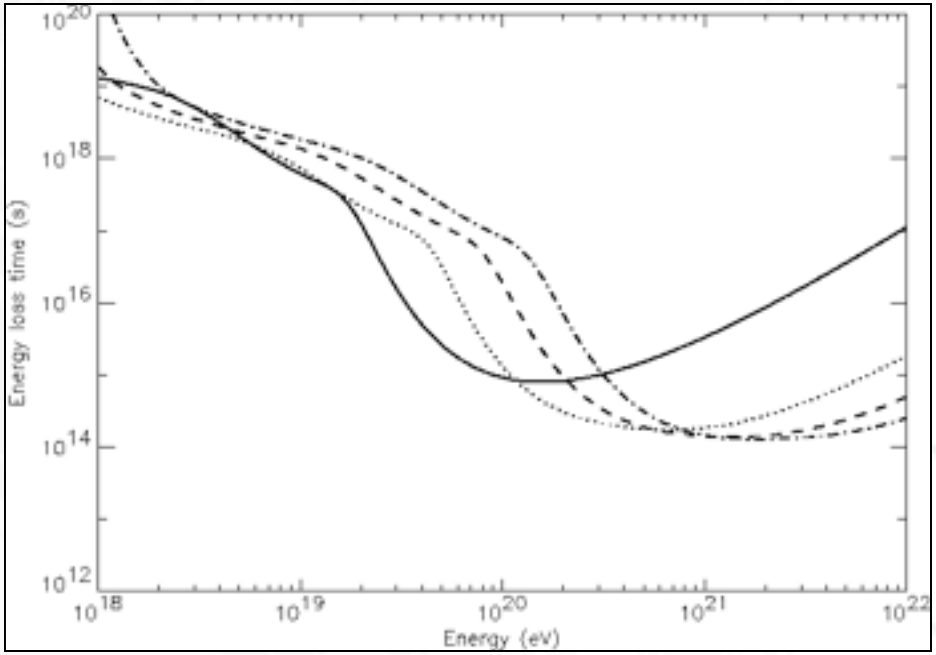
Injection spectrum = horizontal line





Importance of deflection obvious from comparing energy loss/spallation time scales with delay times





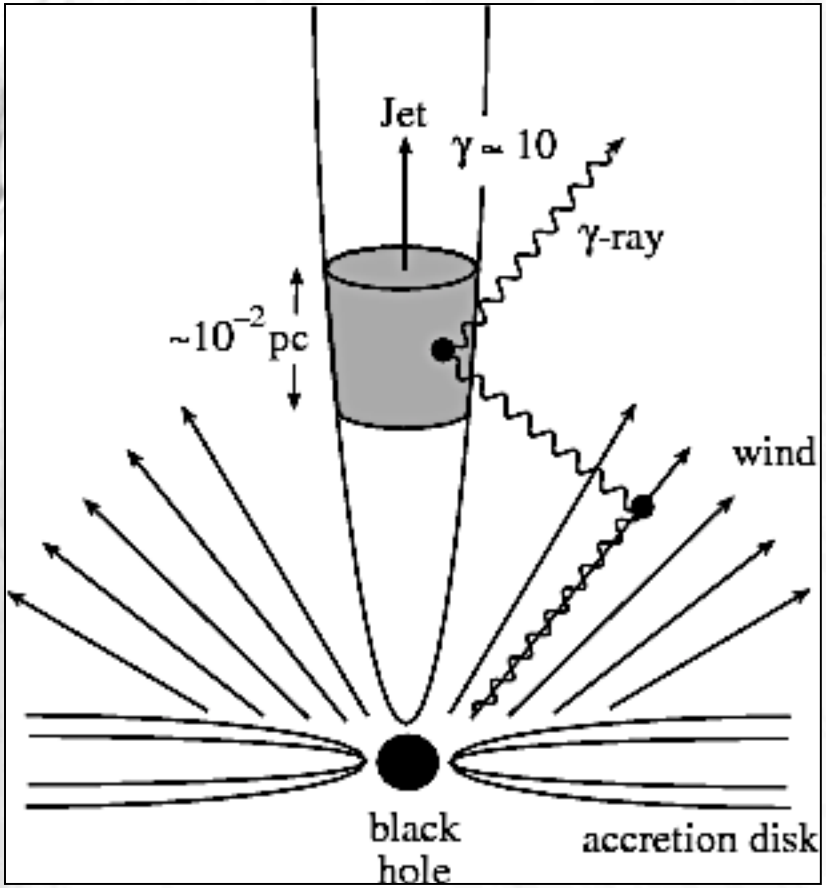
horizontal line=straight line propagation time

low delay-time spike at ~50 EeV due to spallation nucleons produced outside source field.

Energy loss times for helium (solid), carbon (dotted), silicon (dashed), and iron (dash-dotted).

Discrete Extragalactic High Energy Neutrino Sources

Rough estimate of neutrino flux from hadronic AGN jets: The “proton blazar”



Following
Halzen and Zas, Astrophys.J. 488 (1997) 669

1. Size of accelerators $R \sim \Gamma T$, where jet boost factor $\Gamma \sim 10$ and duration of observed bursts $T \sim 1$ day

2. Magnetic field strength in jet $B^2 \sim \rho_{electron} \sim 1$ erg cm^{-3} (equipartition)

3. "Hillas condition" on maximal proton energy $E_{max} \sim eBR$ and from $p\gamma \rightarrow N\pi$ kinematics $E_{max,\nu} \sim 0.1\, E_{max} \sim 10^{18}$ eV.

4. Neutrino luminosity related to γ-ray luminosity by $L_\nu \sim 3L_\gamma/13$ from $p\gamma \rightarrow N\pi$ kinematics

5. Assume proton spectrum $dN_p/dE_p \propto E_p^{-2-\epsilon}$; γ–ray spectrum $dN_\gamma/d\epsilon \propto \epsilon^{-2-\alpha}$.
If jet is optically thin against $p\gamma$ then

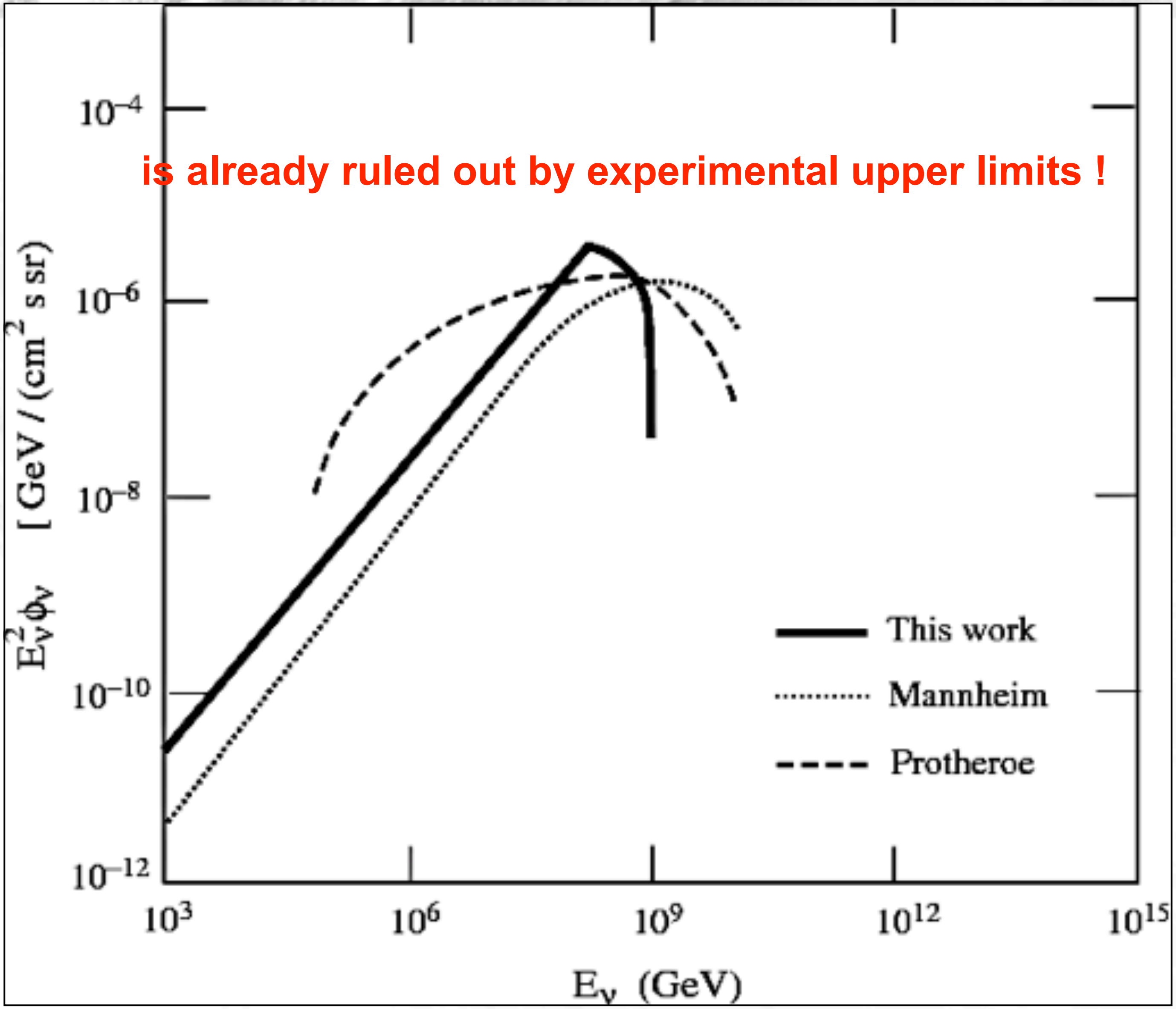
$$\frac{dN_\nu}{dE_\nu} \propto \frac{dN_p}{dE_p}(10\,E_\nu)\int_{\epsilon_\gamma^{\rm thr}} d\epsilon_\gamma \frac{dN_\gamma}{d\epsilon_\gamma} \propto E_\nu^{-2-\epsilon}(\epsilon_\gamma^{\rm thr})^{-1-\alpha} \propto E_\nu^{-1-\epsilon+\alpha}\,,$$

6. Combine with normalization:

$$\frac{dN_\nu}{dE_\nu} \sim \frac{3}{13}\frac{L_\gamma}{E_{\max,\nu}}\frac{1-\epsilon+\alpha}{E_\nu}\left(\frac{E_\nu}{E_{\max,\nu}}\right)^{-\epsilon+\alpha}.$$

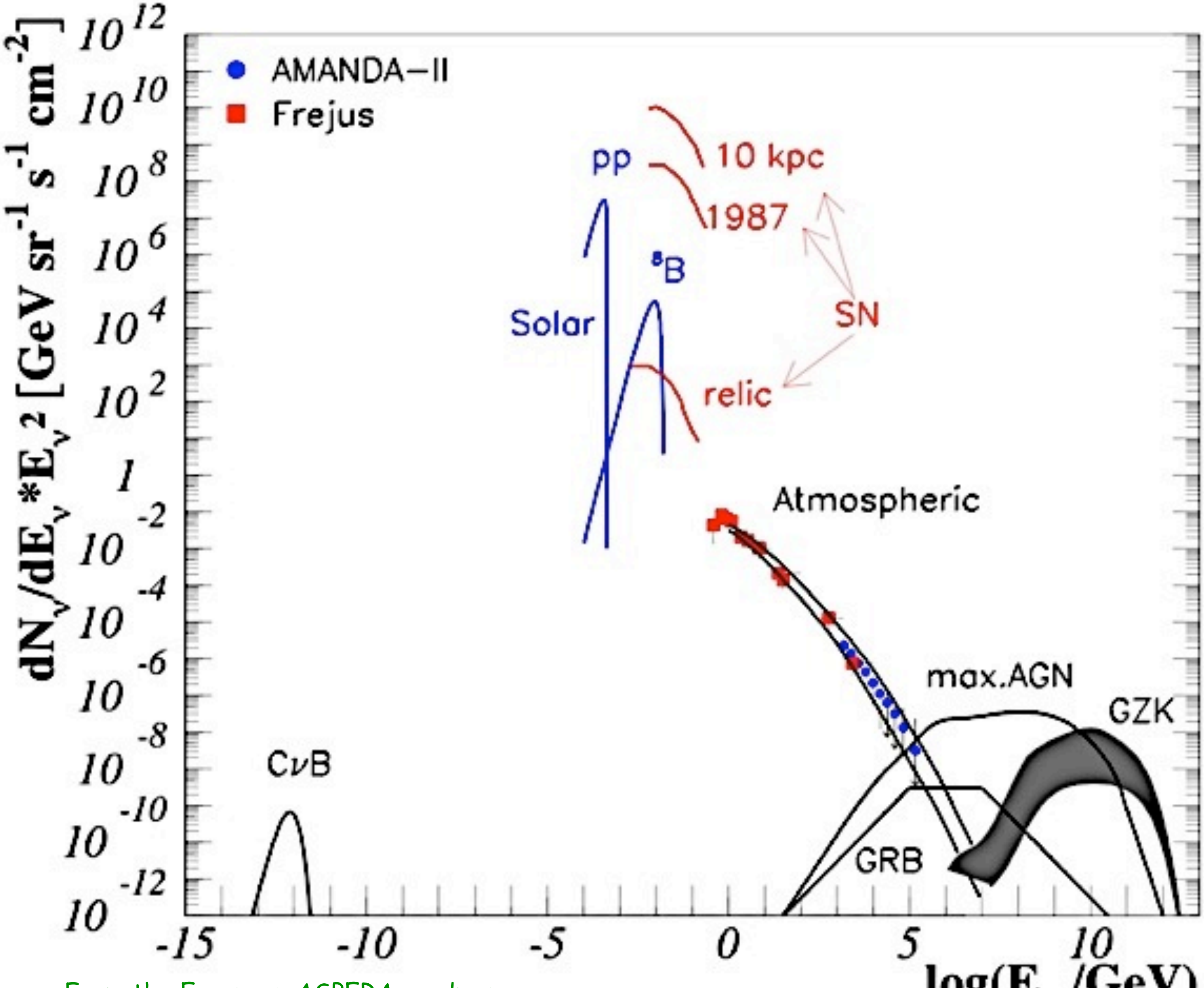
7. Fold with luminosity function of AGNs in GeV γ-rays.

Diffuse Neutrino fluxes from AGN jets



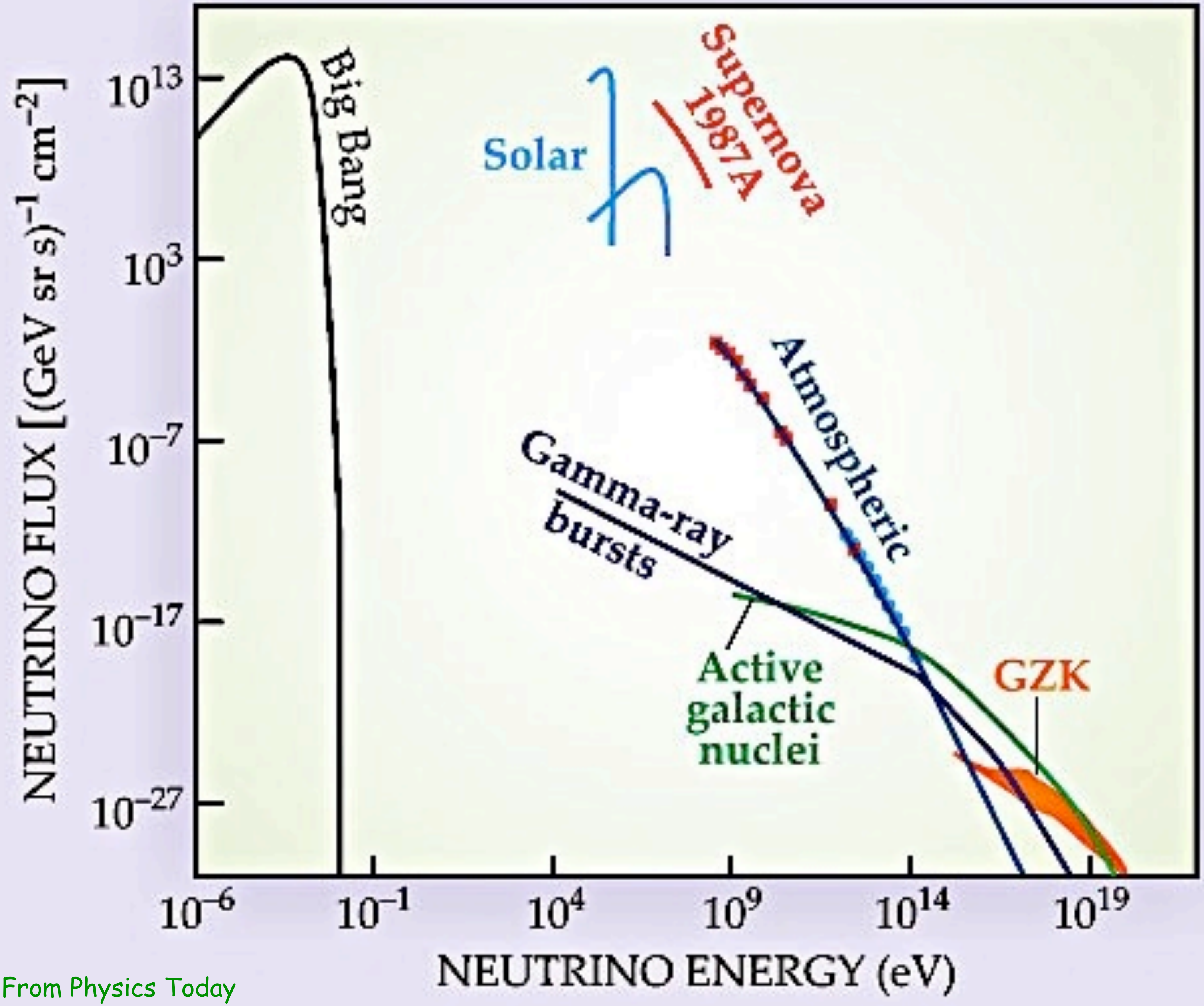
Halzen and Zas, Astrophys.J. 488 (1997) 669

The „grand unified“ neutrino energy flux spectrum



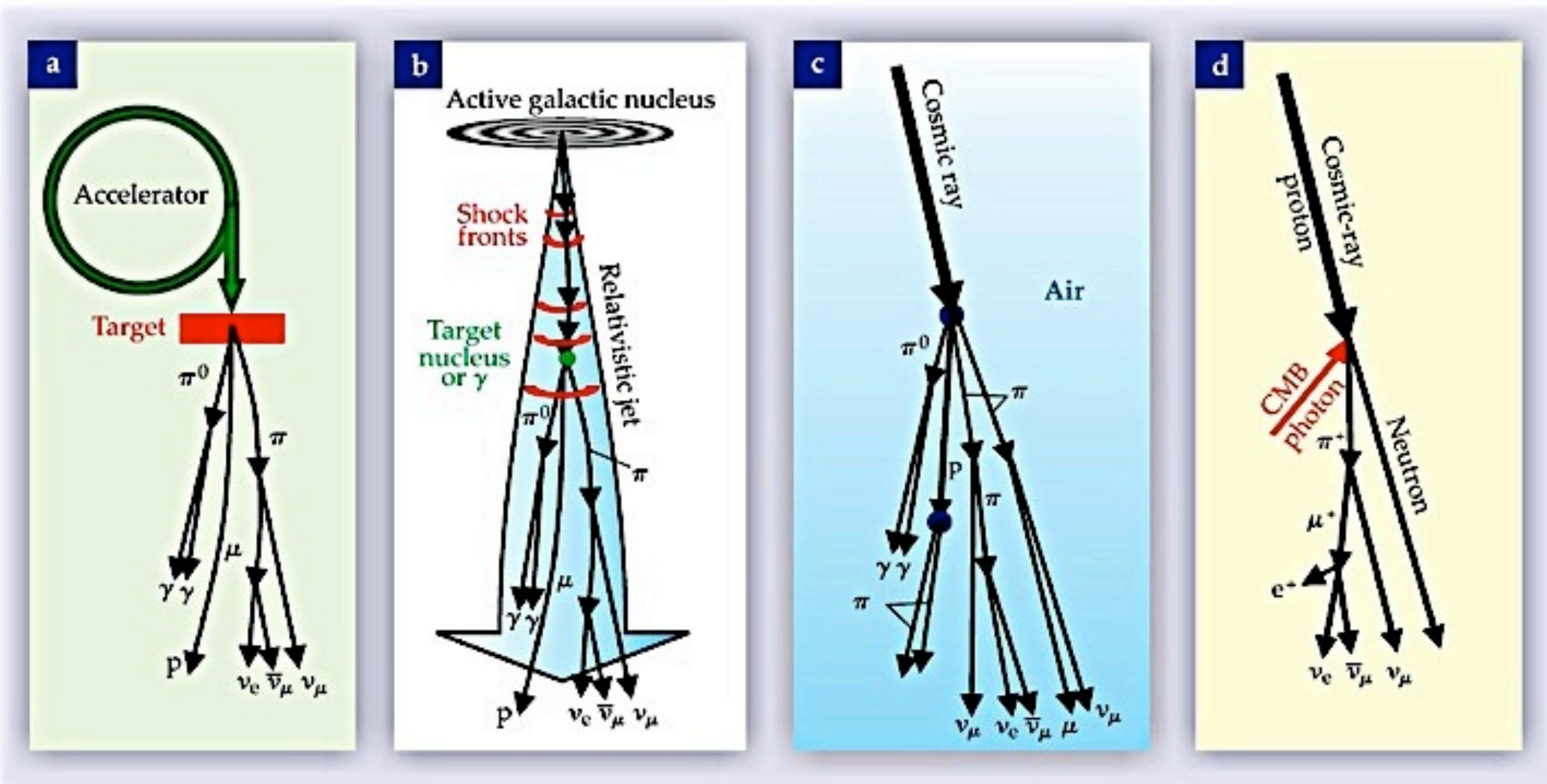
From the European ASPERA roadmap

The „grand unified“ differential neutrino number spectrum



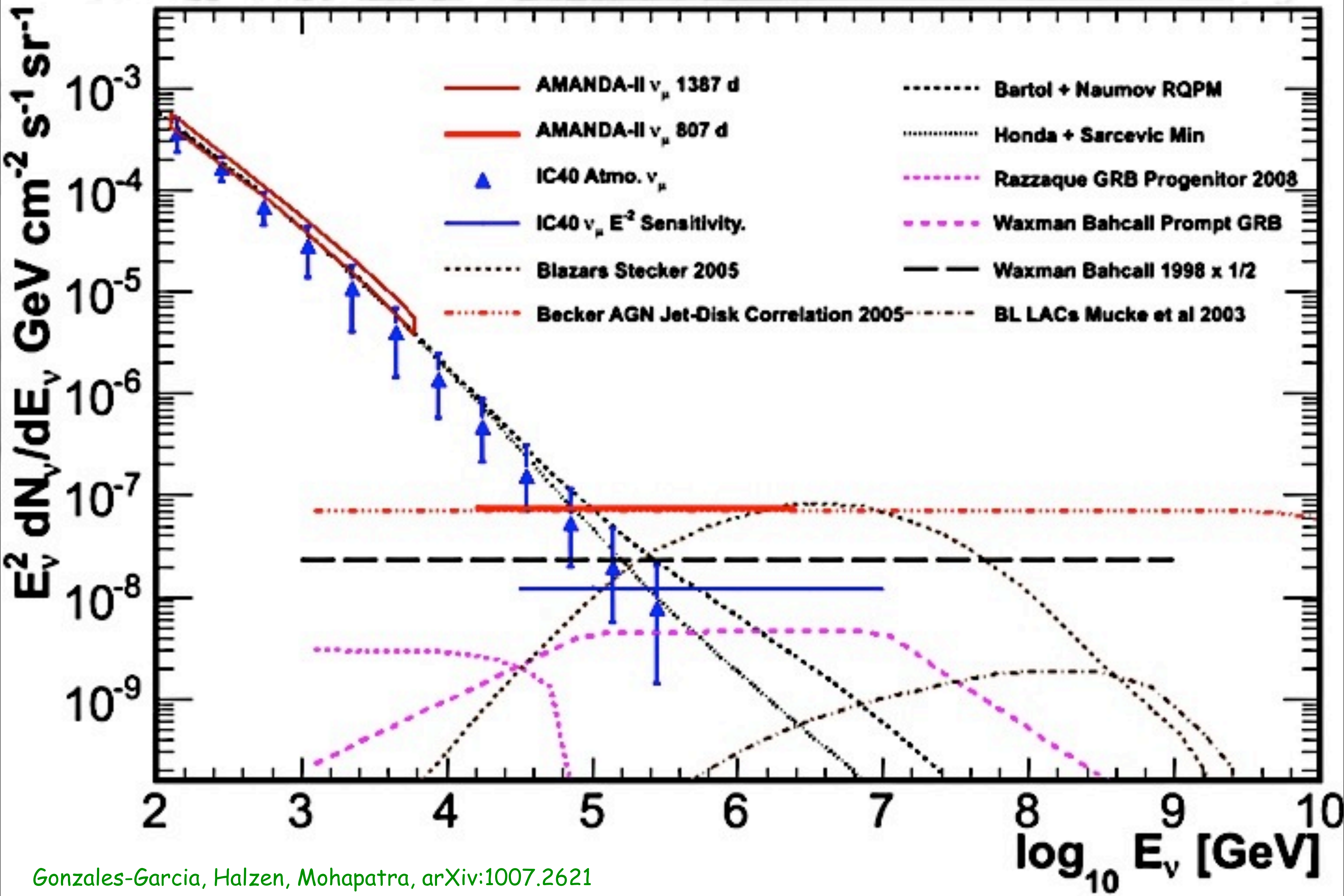
From Physics Today

Summary of neutrino production modes



From Physics Today

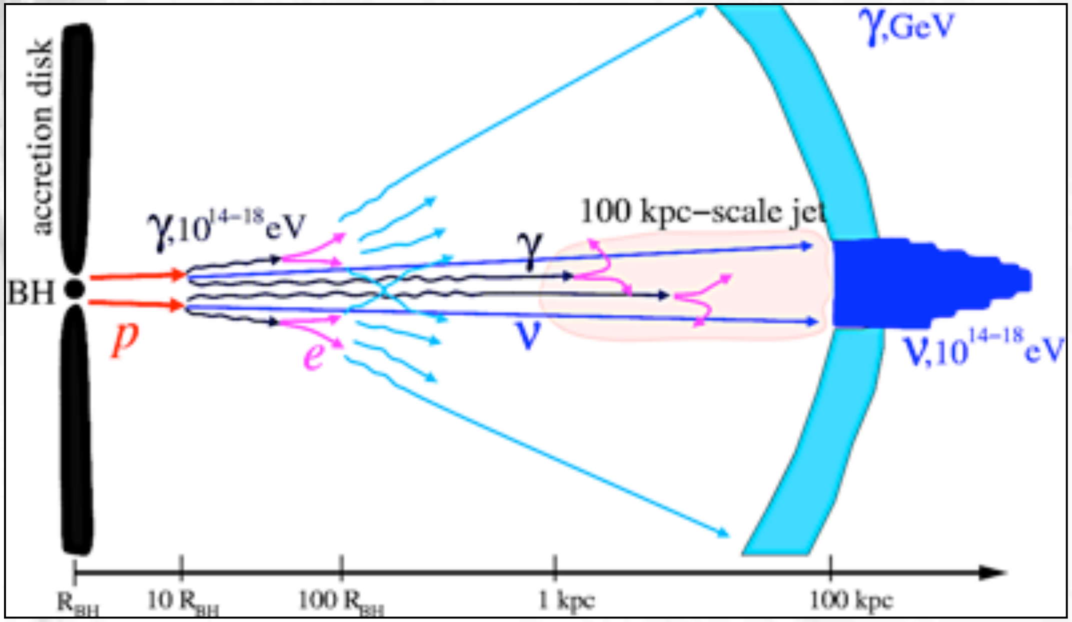
Current Upper Limits at TeV-EeV energies

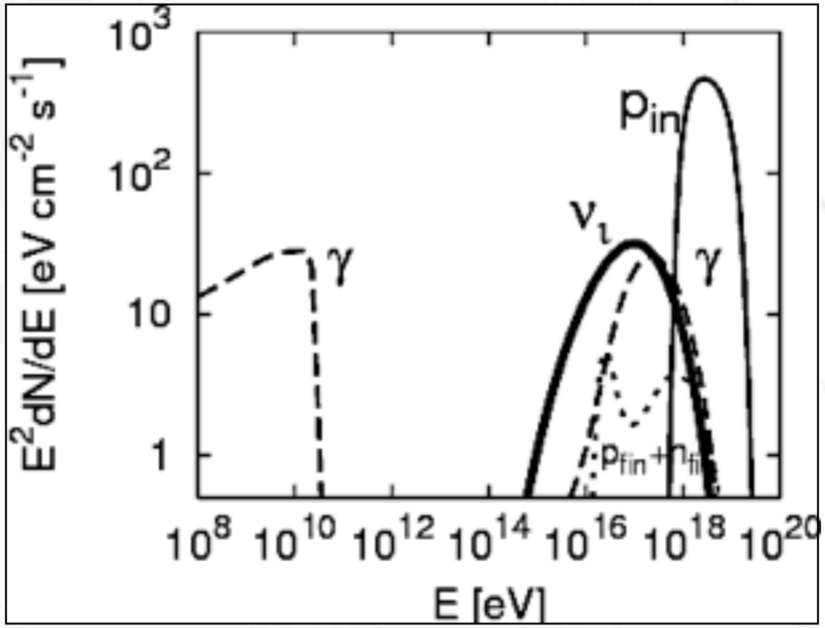


Gonzales-Garcia, Halzen, Mohapatra, arXiv:1007.2621

Note, however, that blazars promising as neutrino sources should be loud in GeV γ-rays, but NOT in γ-rays above TeV.

This is because such γ-rays pair produce with "blue bump" photons of ~10 eV energy with a cross section $\sim\sigma_{Th} \sim 1$ b about a factor 10^4 larger than the pγ cross section that produces the neutrinos => If loud in > TeV γ-rays, optical depth for neutrino production would be very small.



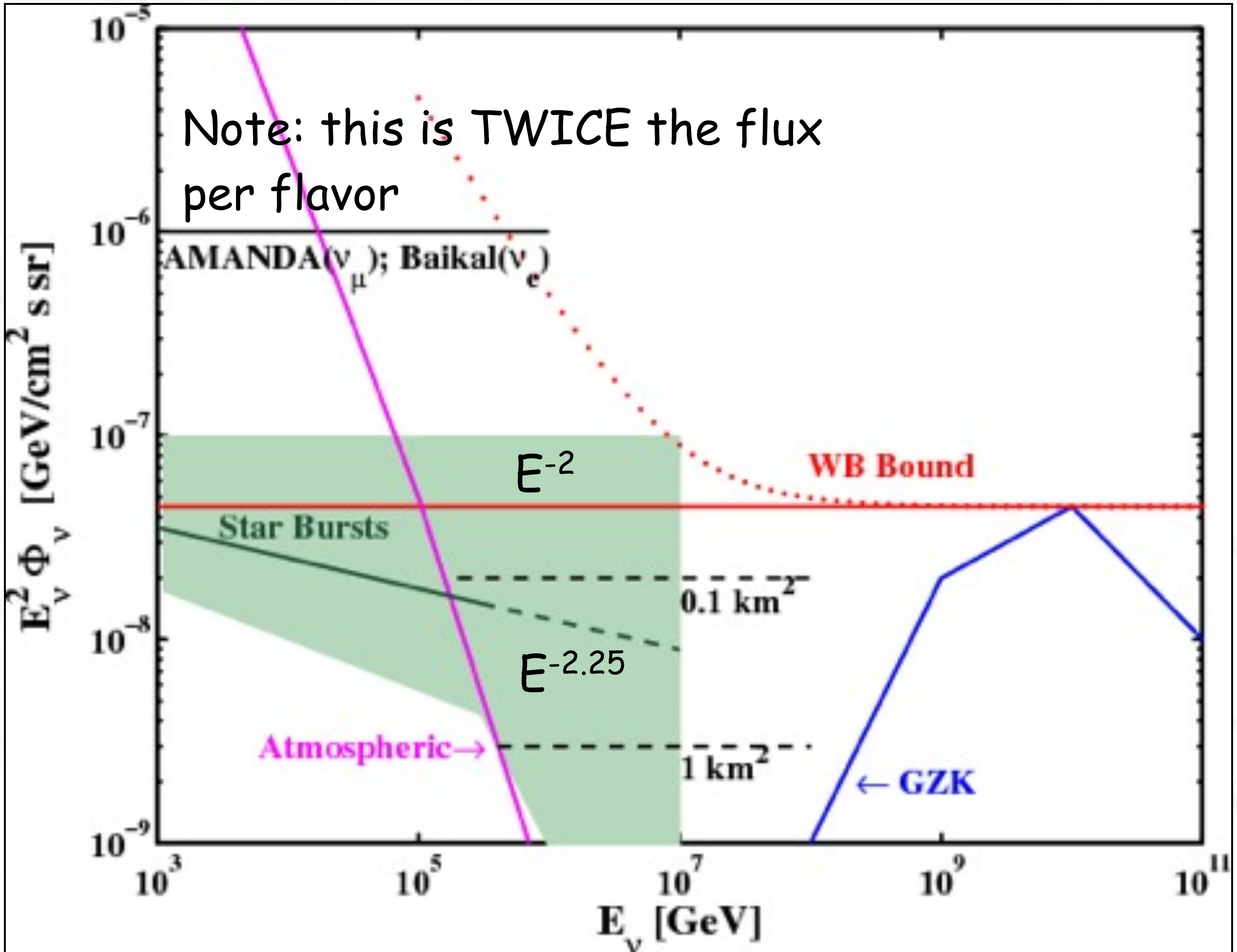


Neronov and Semikoz, Phys.Rev.D66 (2002) 123003

A "guaranteed" flux from starburst galaxies:

Idea: protons loose most of their energy in form of pions => secondary electrons produce radio synchrotron => can be related to secondary neutrinos

$$E_\nu \frac{dL}{dE_\nu}(E_\nu \simeq \mathrm{GeV}) \simeq 4\nu L_\nu(\nu \simeq \mathrm{GeV})$$



Loeb and Waxman, astro-ph/0601695

Another estimate of neutrino fluxes from continuous UHECR sources

If f is the ratio of cosmic rays interacting within the source to the cosmic ray flux leaving the source and $x_\nu \sim 0.05$ the average neutrino energy in units of primary energy, then

$$E^2 j_\nu^{\rm diff}(E) \simeq \frac{1}{6\pi H_0} f\, x_\nu^{\alpha-1}(\alpha-2) Q_{\rm UHE} \left(\frac{E}{10^{20}\,{\rm eV}}\right)^{2-\alpha}$$

In a water/ice detector the detection rate is

$$R_\nu(>E) \sim 2.3 \left(\frac{E}{10^{16}\,{\rm eV}}\right)^{-0.637} \left(\frac{V_{\rm eff}}{{\rm km}^3}\right) \left(\frac{E^2\, j_\nu^{\rm diff}(E)}{100\,{\rm eV\,cm^{-2}\,sr^{-1}\,s^{-1}}}\right) {\rm yr}^{-1}$$

If the ankle marks the transition from galactic to extragalactic cosmic rays then $\alpha \sim 2.2$ and the neutrino spectrum goes down to $\sim 10^{17}$ eV, with

$$R_\nu \sim 2\times 10^{-2} f\,{\rm yr}^{-1}\,{\rm km}^{-3} < 20\, Z^{-2} \left(\frac{L_{\rm tot}}{L_{\rm min}}\right) {\rm yr}^{-1}\,{\rm km}^{-3}$$

G.Sigl arXiv:0803.3800

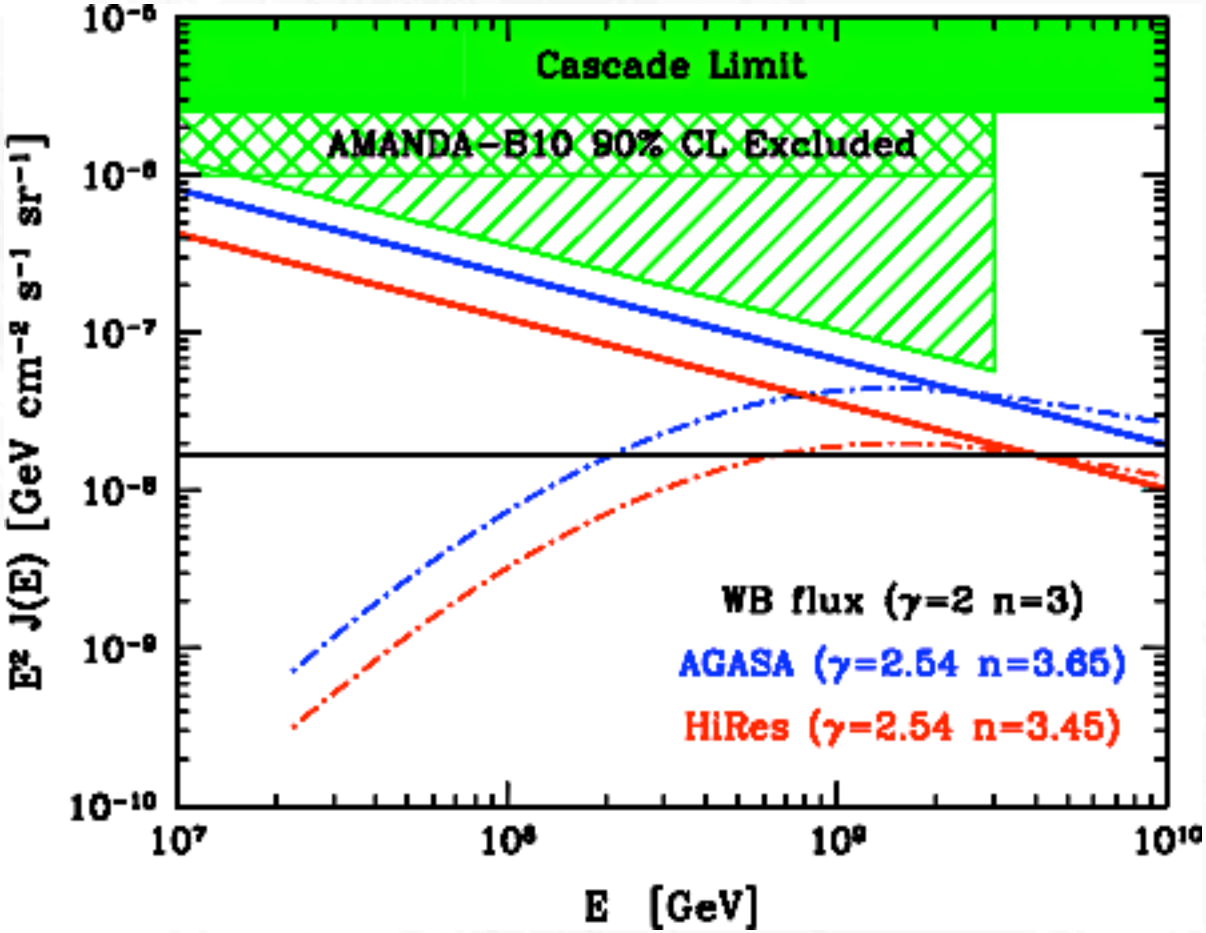
where L_{tot} is the bolometric luminosity.

If the ankle is due to pair production of extragalactic cosmic rays, then $\alpha \sim 2.6$ and the neutrino spectrum goes down to $\sim 10^{16}$ eV, with

$$R_\nu \sim 5.5 f \,\mathrm{yr}^{-1}\,\mathrm{km}^{-3} < 180\, Z^{-2} \left(\frac{L_{\mathrm{tot}}}{L_{\mathrm{min}}}\right) \mathrm{yr}^{-1}\,\mathrm{km}^{-3}$$

The low cross-over scenario where flux is dominated by extragalactic protons above 4×10^{17} eV may be close to be ruled out by AMANDA.

This, however, assumes transparent sources which cosmic rays have to leave as neutrons which each come with one π^+ decaying into neutrinos.



Ahlers et al., Phys.Rev. D72 (2005) 023001