Escape Model for Galactic Cosmic Rays

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+

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Giacinti, Kachelriess & Semikoz, PRD 90, 041302(R) (2014);
Giacinti, Kachelriess & Semikoz, PRD 91, 083009 (2015);
Giacinti, Kachelriess, Kalashev, Neronov & Semikoz,
arXiv:1507.07534

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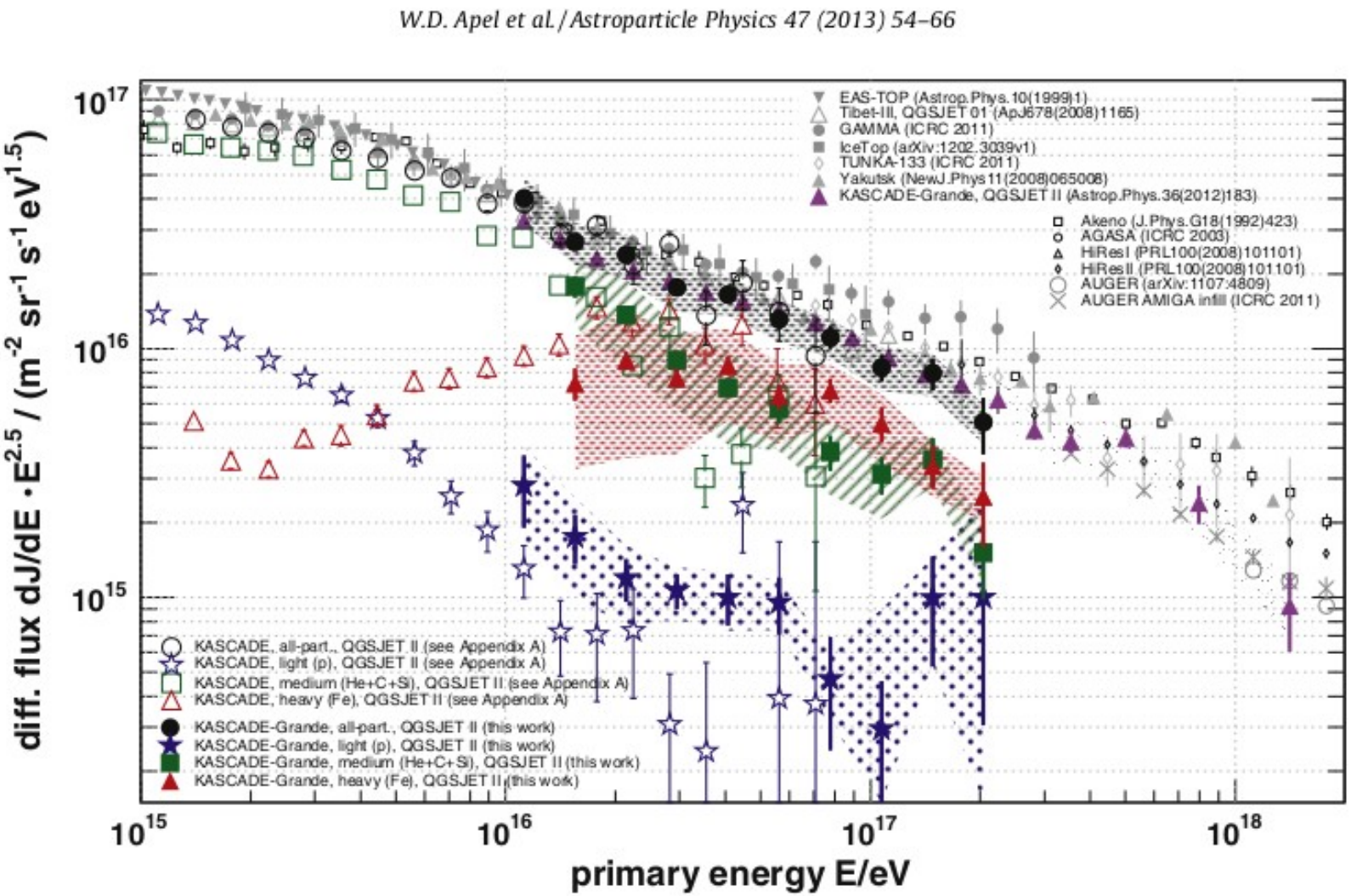
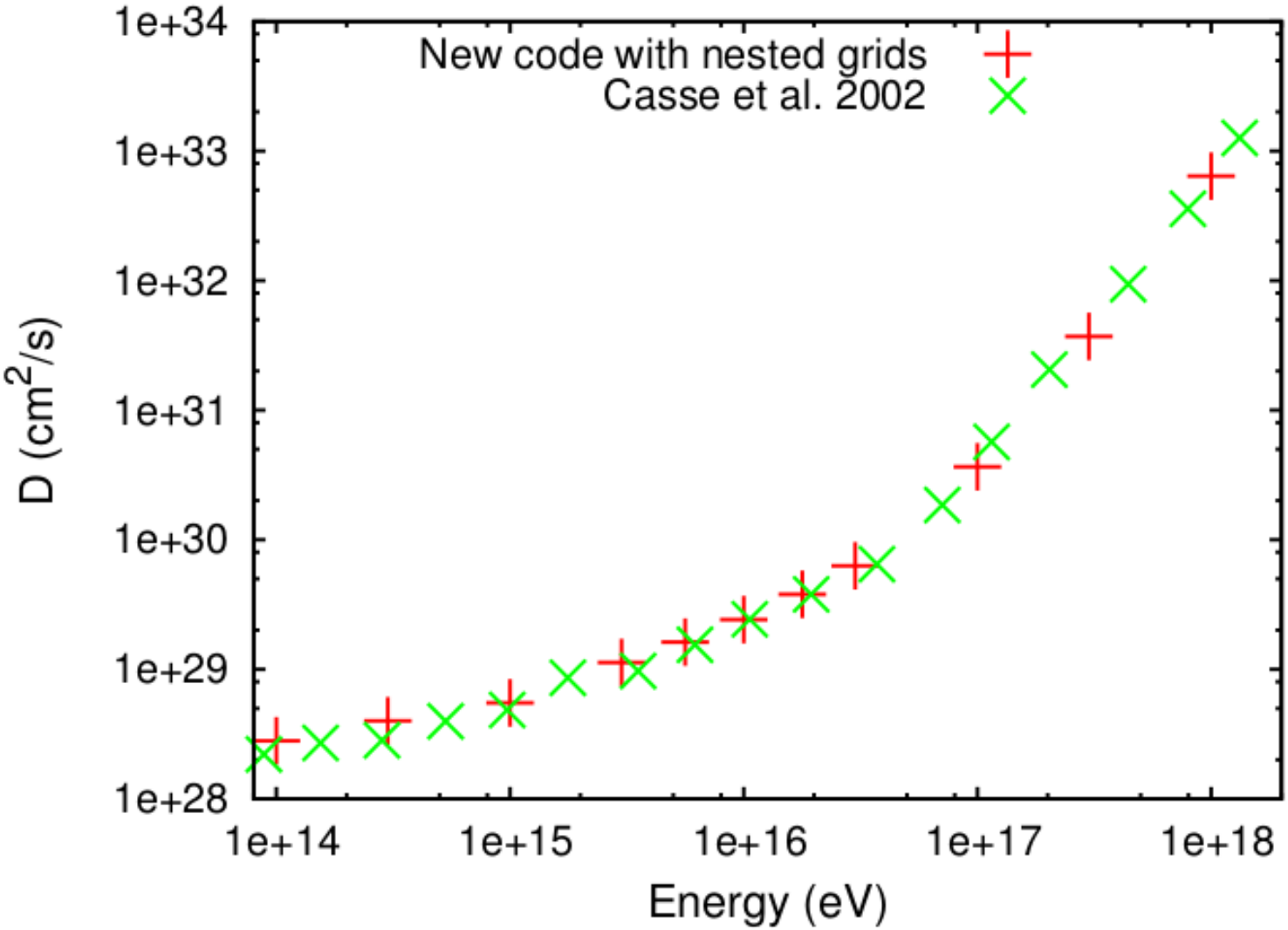
Origin of the knee ?



E_{max} sources vs Energy at which $r_L = L_c$

Ginzburg & Syrovatski '64 ; Ptuskin et al. '93

Diffusion coefficient versus energy



Giacinti et al., JCAP, 2012

4 μG L_{max} = 150 pc

A&A 558, A72 (2013)
DOI: 10.1051/0004-6361/201322013

Astronomy & Astrophysics

Studying Galactic interstellar turbulence through fluctuations in synchrotron emission

First LOFAR Galactic foreground detection

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a variation of the ratio of random to ordered field as a function of Galactic coordinates, supporting different turbulent regimes.
Conclusions. We present the first LOFAR detection and imaging of the Galactic diffuse synchrotron emission around 160 MHz from the highly polarized Fan region. The power spectrum of the foreground synchrotron fluctuations is approximately a power law with a slope $\alpha \approx -1.84$ up to angular multipoles of $\lesssim 1300$, corresponding to an angular scale of ~8 arcmin. We use power spectra fluctuations from LOFAR as well as earlier GMRT and WSRT observations to constrain the outer scale of turbulence (L_{out}) of the Galactic synchrotron foreground, finding a range of plausible values of 10–20 pc. Then, we use this information to deduce lower limits of the ratio of ordered to random magnetic field strength. These are found to be 0.3, 0.3, and 0.5 for the LOFAR, WSRT and GMRT fields considered respectively. Both these constraints are in agreement with previous estimates.

Outline

I – Individual elements around the knee

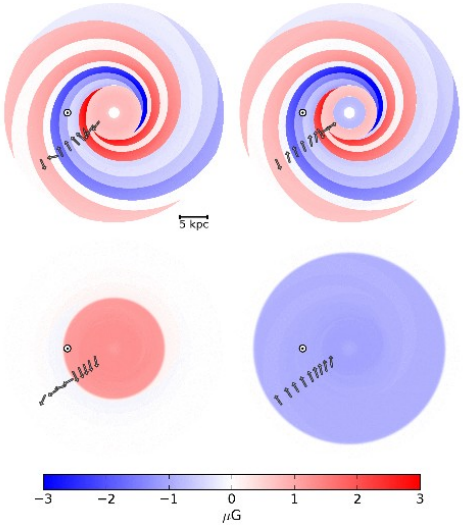
II – Transition Gal. → Extragal. ?

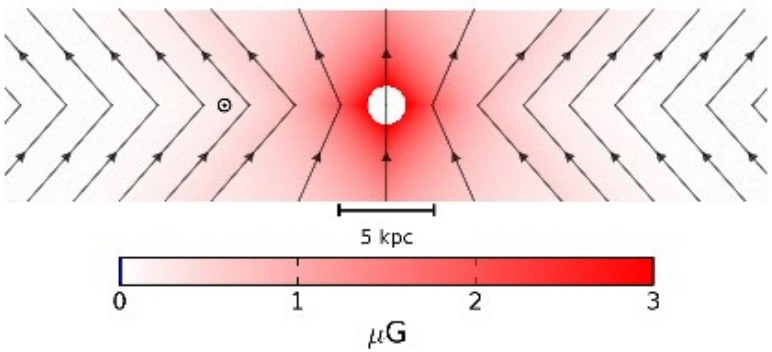
III – Extragalactic CRs / Diffuse gamma and neutrino fluxes

(Recent) Galactic magnetic field model

Jansson & Farrar

Jansson & Farrar, ApJ 757, 14 (2012)





Regular

Halo component	$\breve{B}_0 = 4.68 \pm 1.39\,\mu$G	field strength
	$r_0 = 10.97 \pm 3.80$ kpc	exponential scale length
	$z_0 = 2.84 \pm 1.30$ kpc	Gaussian scale height
Striation	$\beta = 1.36 \pm 0.36$	striated field $B^2_{\rm stri} \equiv \beta B^2_{\rm reg}$

ApJ 761, L11 (2012)

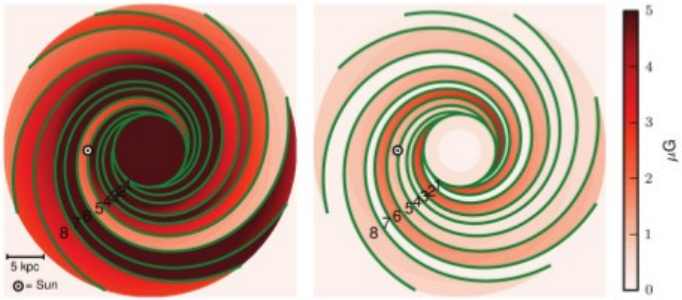
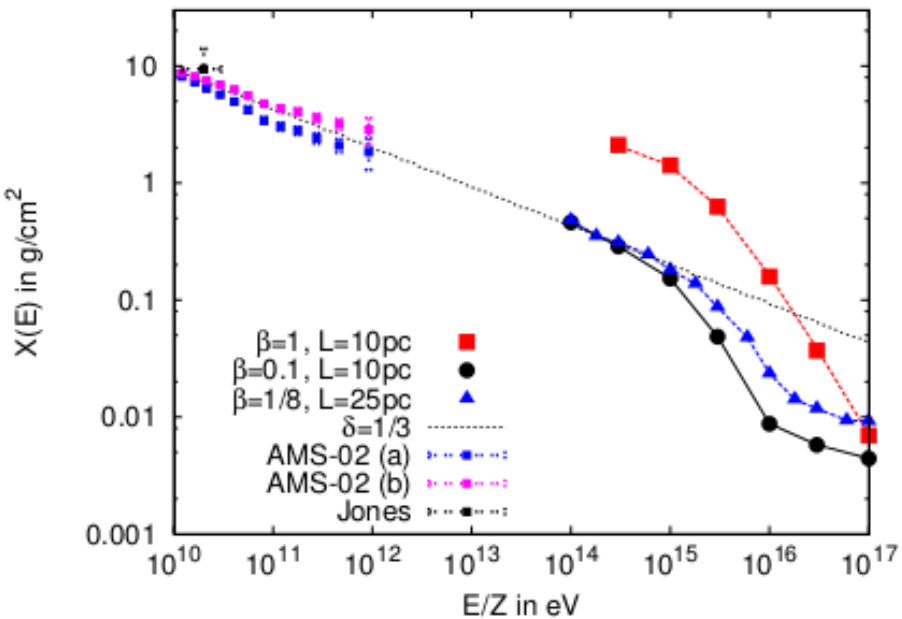


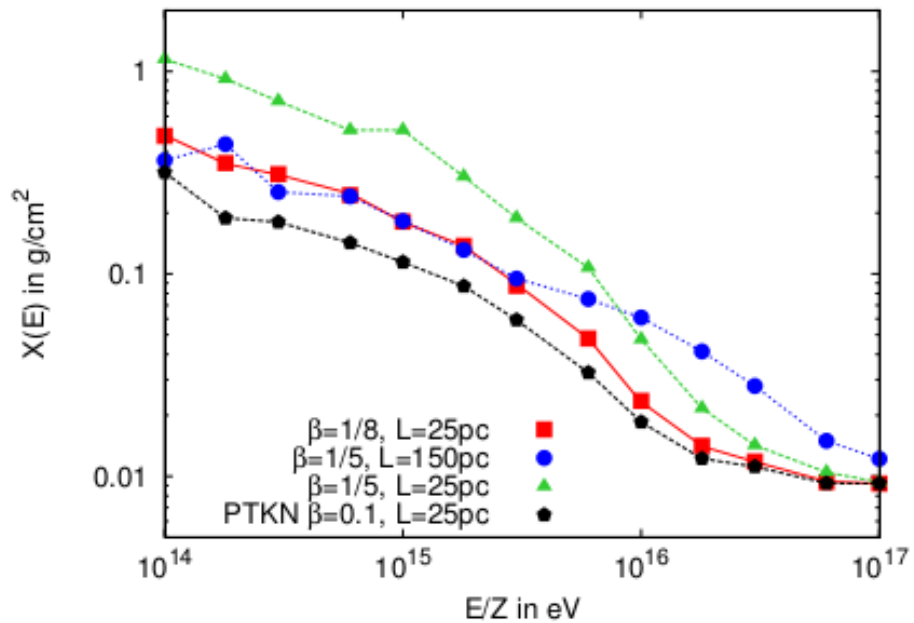
Figure 3. *Left panel:* The random field in the disk. *Right panel:* The disk component of the JF12 coherent field model for comparison; it is clockwise in rings 3-6 and counterclockwise in 1,2,7, and 8.

Turbulent

The knee

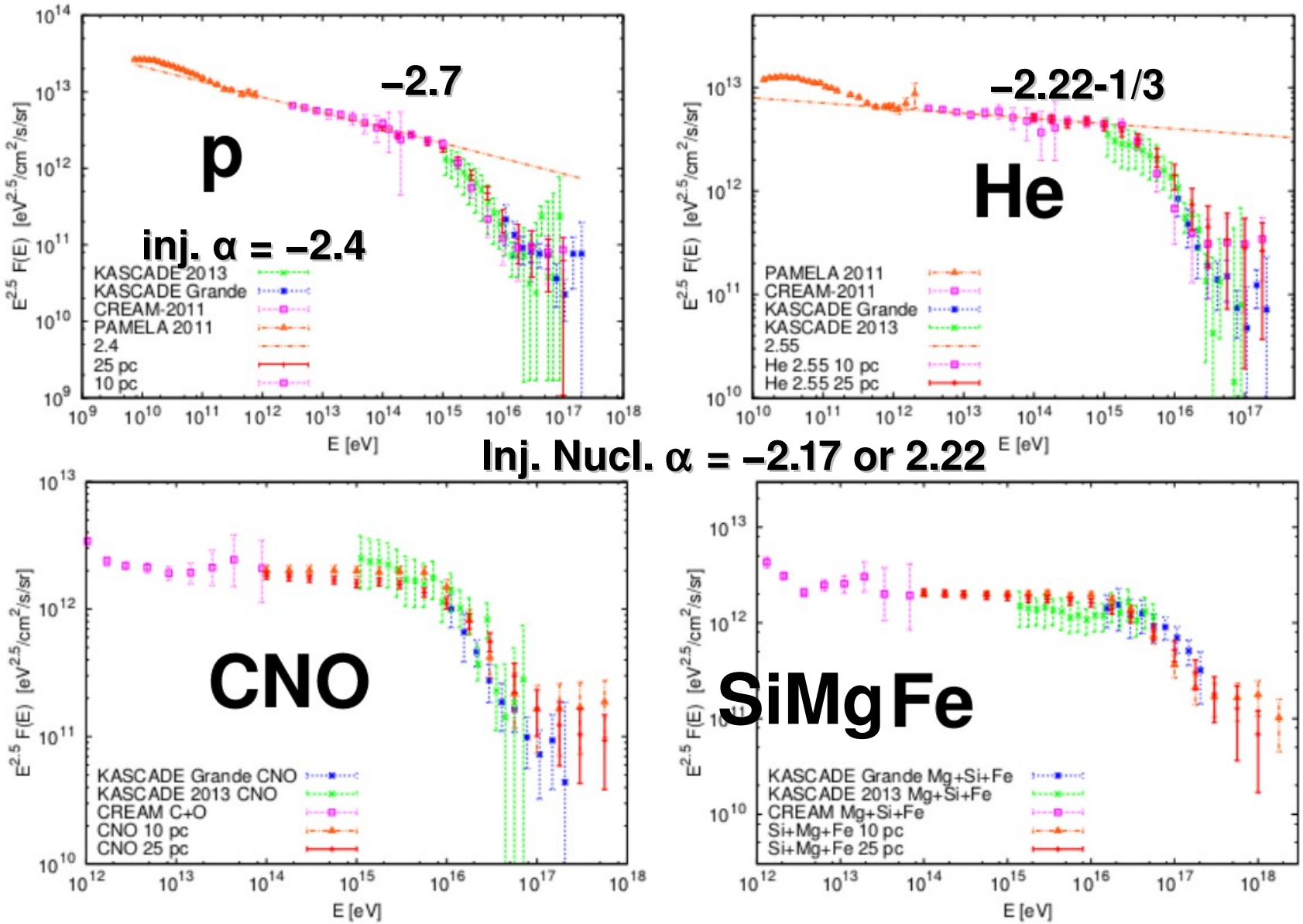


Grammage for different coherence lengths l_c and turbulent fields: red squares $L_{max} = 10$ pc and $\beta = 1$, black dots $L_{max} = 10$ pc and $\beta = 0.1$, and blue triangles $L_{max} = 25$ pc and $\beta = 0.125$; all cases for the JF GMF model



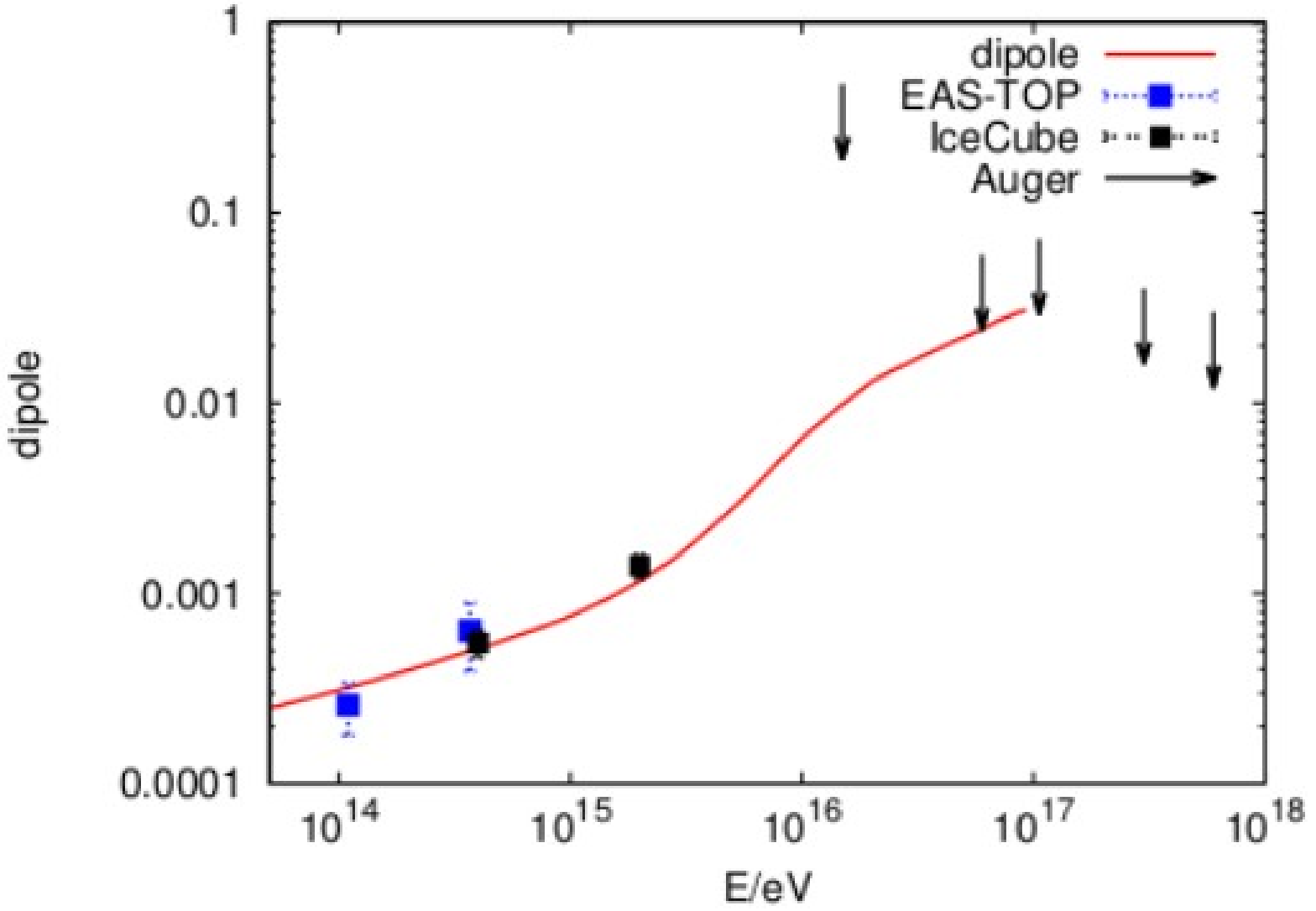
Grammage for different coherence lengths l_c and turbulent fields: red squares $L_{max} = 25$ pc and $\beta = 1/8$, blue dots $L_{max} = 150$ pc and $\beta = 1/5$, and green triangles $L_{max} = 25$ pc and $\beta = 1/5$; all cases for the JF model Additionally we show the grammage for the PTKN model with $L_{max} = 25$ pc and $\beta = 0.1$ by black stars.

Composition - Fluxes

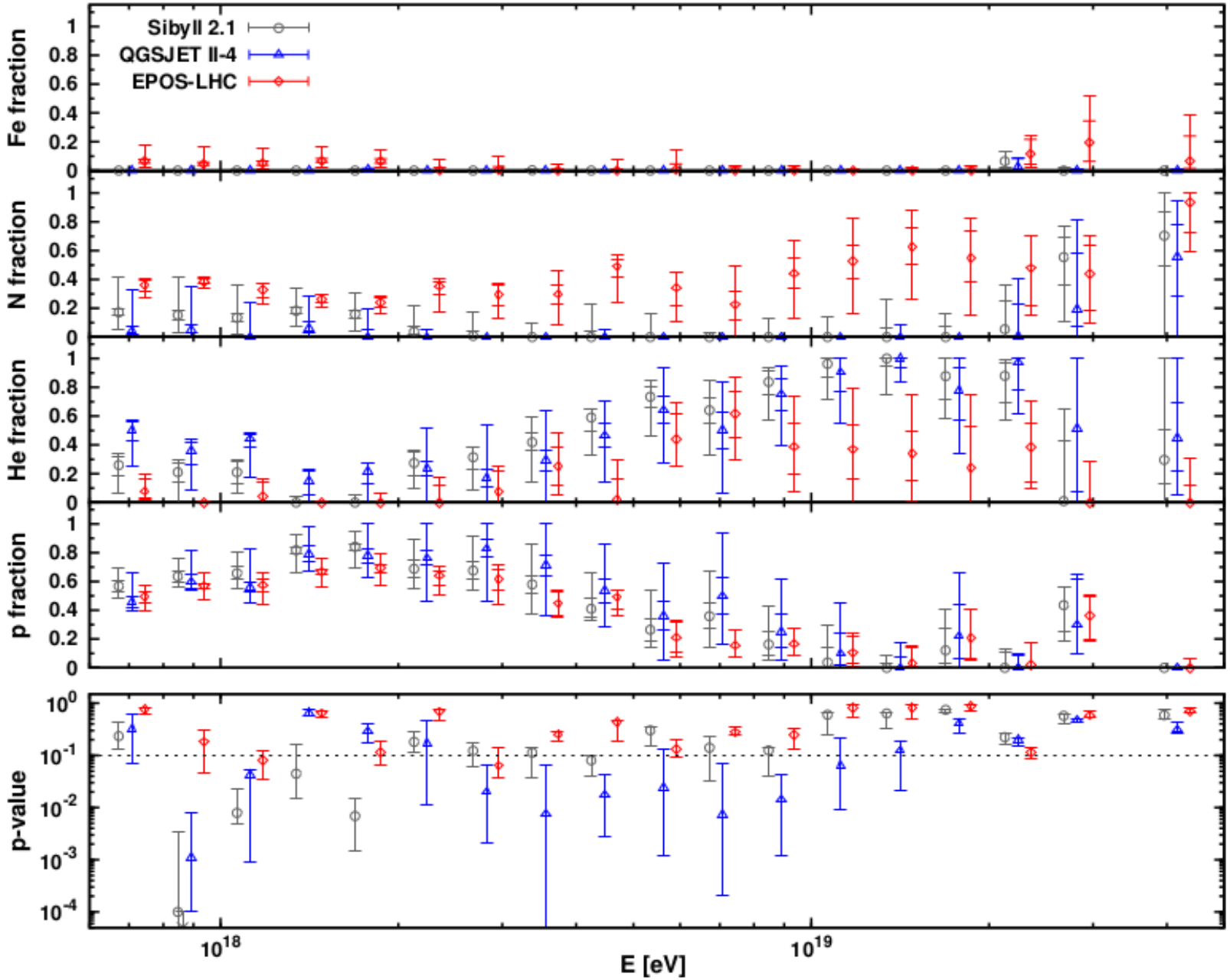


(10-30PeV : Reduced p flux of K-G by 40%, and added this diff. to the He flux)

Anisotropy

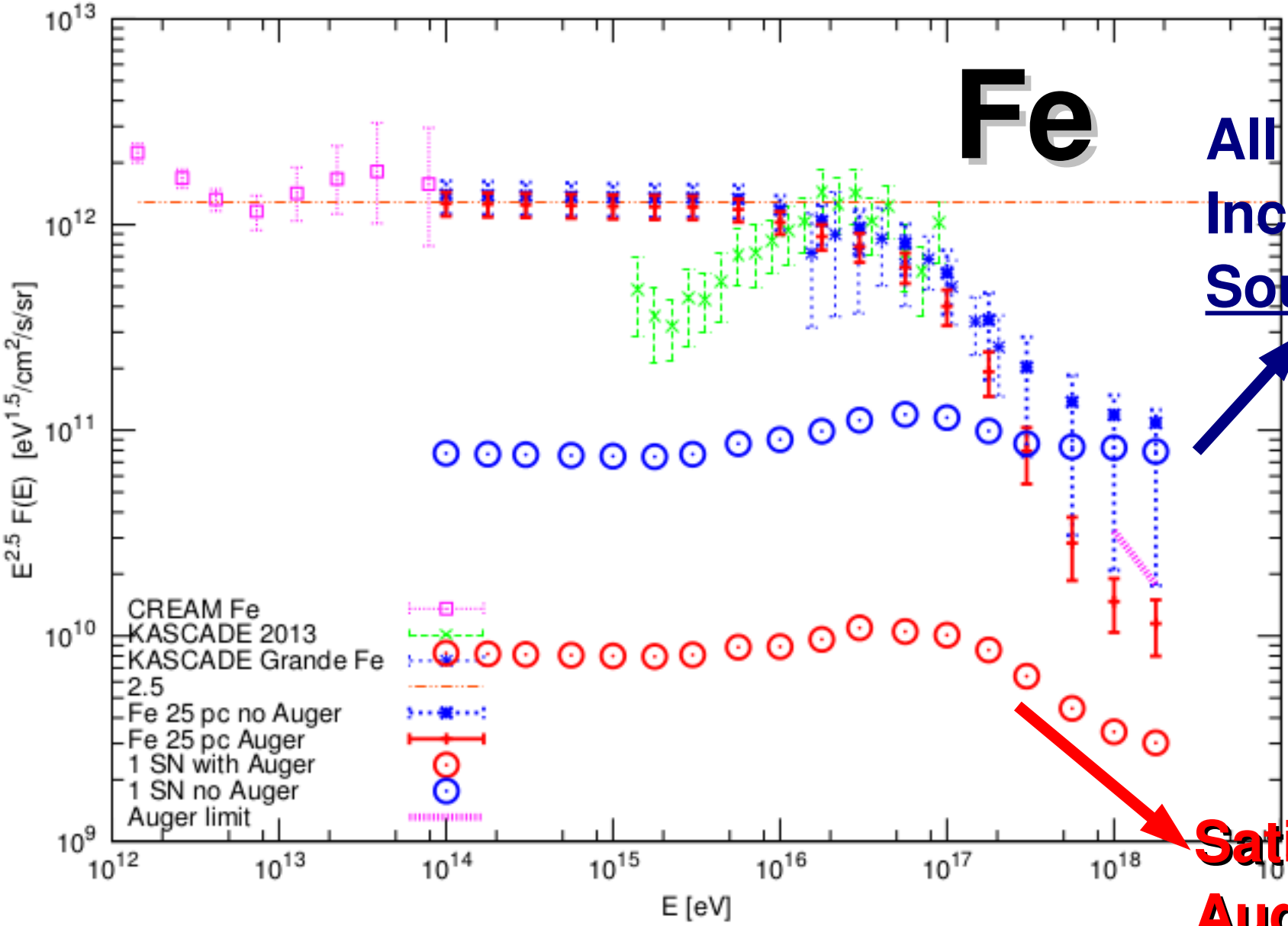

dipole
EAS-TOP
IceCube
Auger
1
0.1
0.01
0.001
0.0001
dipole
10^{14}
10^{15}
10^{16}
10^{17}
10^{18}
E/eV

Auger Limits



arXiv:1409.5083

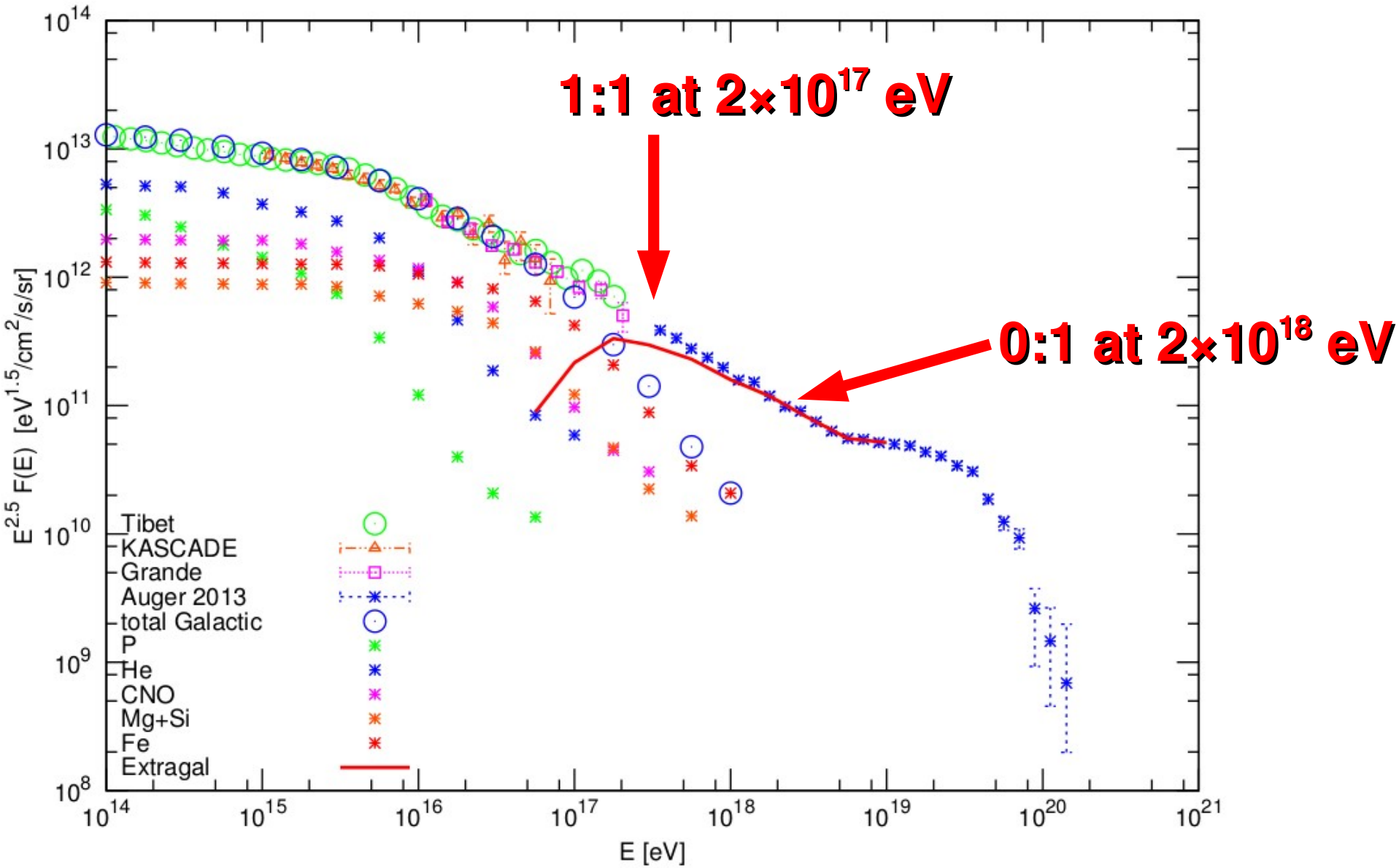
Auger Limits



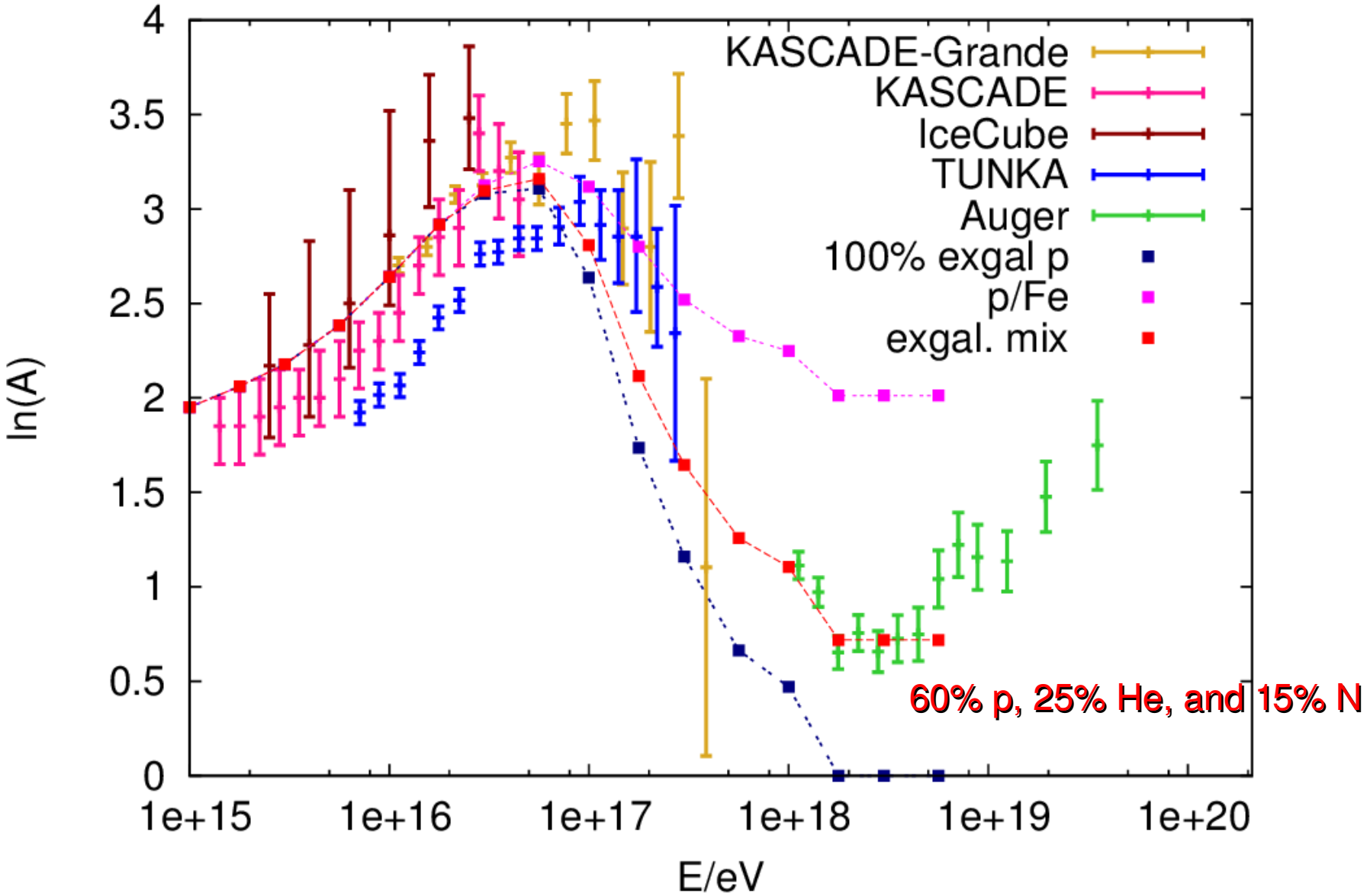
All configs Incl. Nearby Source

Satisfying Auger Limits

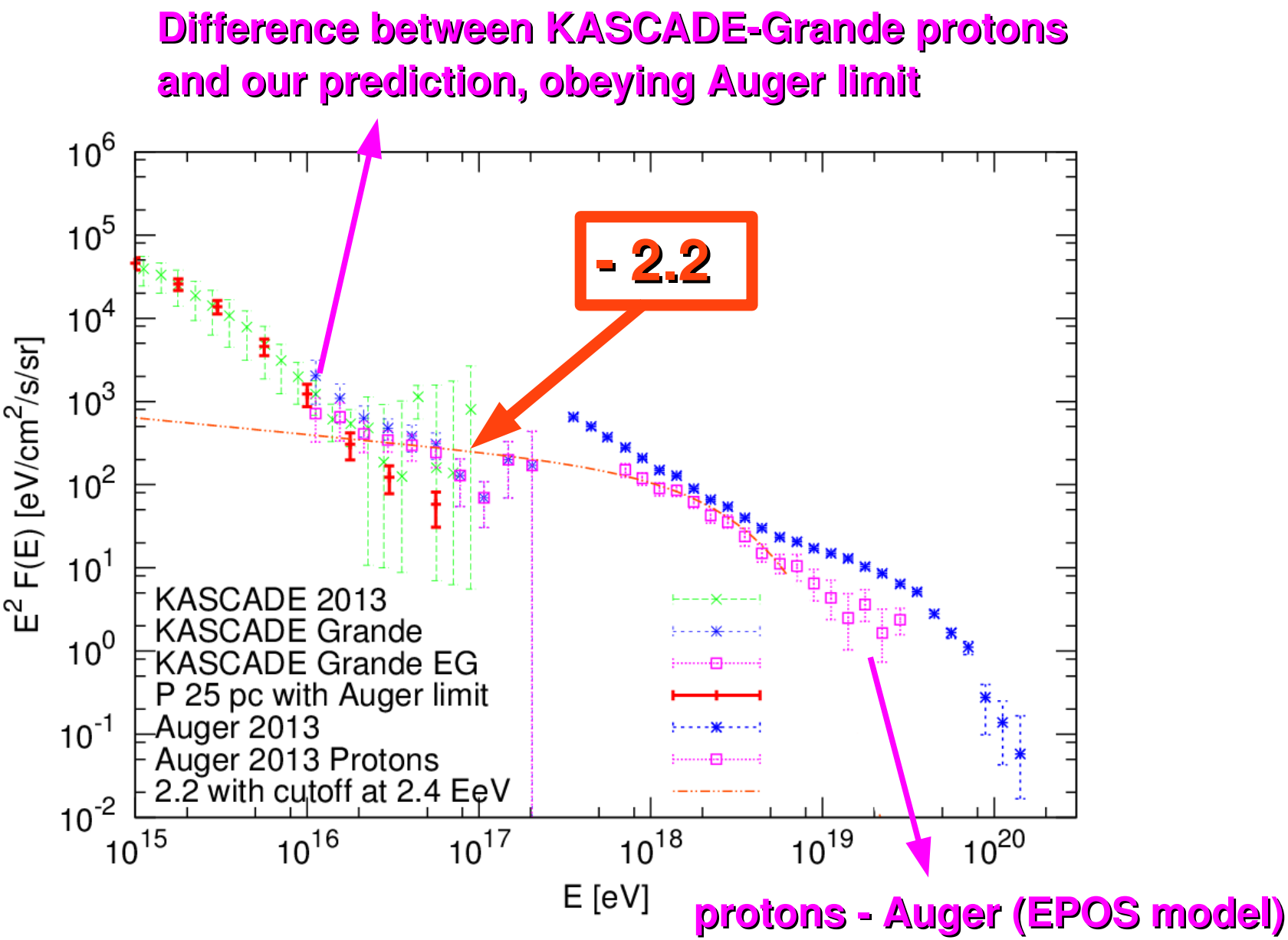
Galactic / Extragalactic CRs



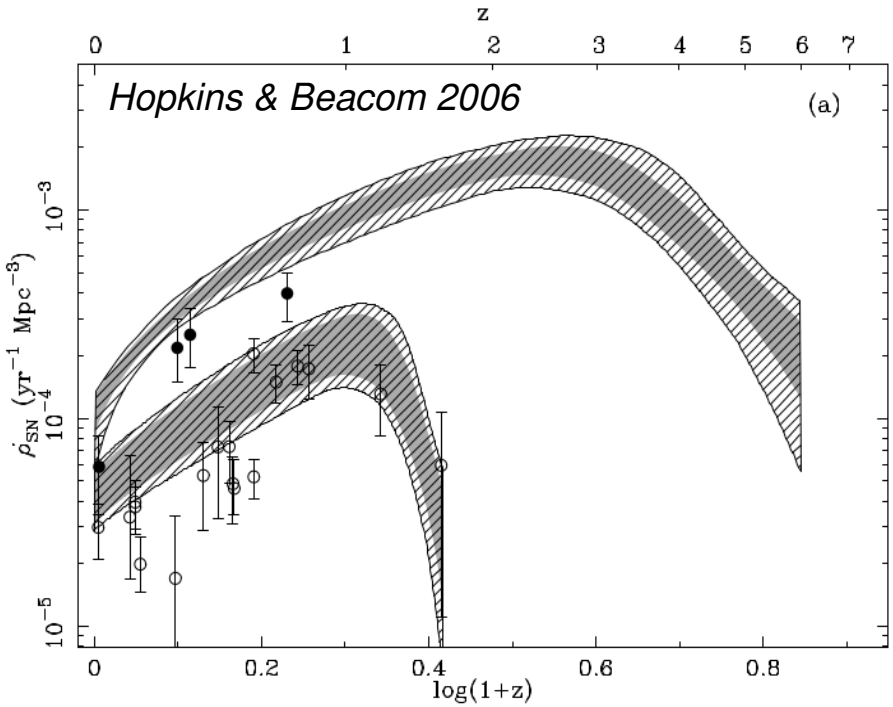
Composition - ln(A)

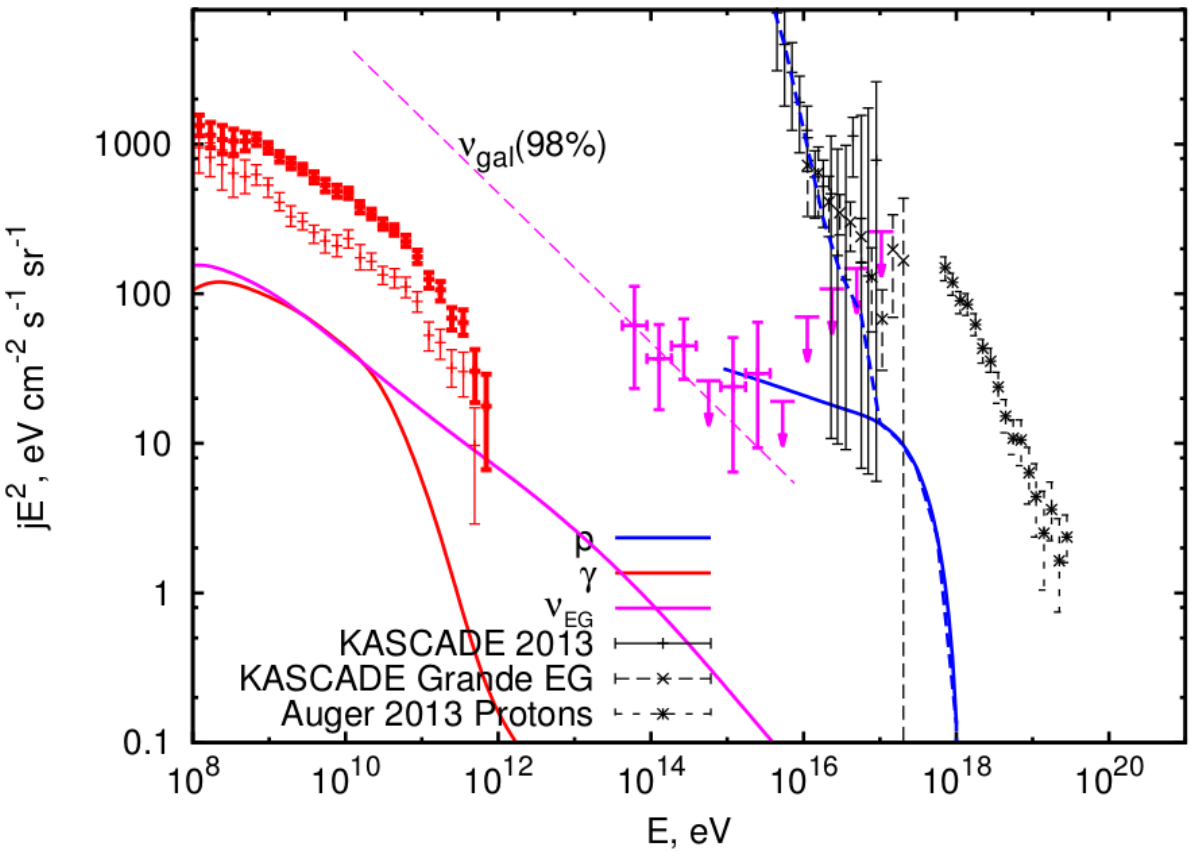


Slope extragalactic CRs below 1 EeV



Extragalactic CRs from spirals / starbursts ? NO

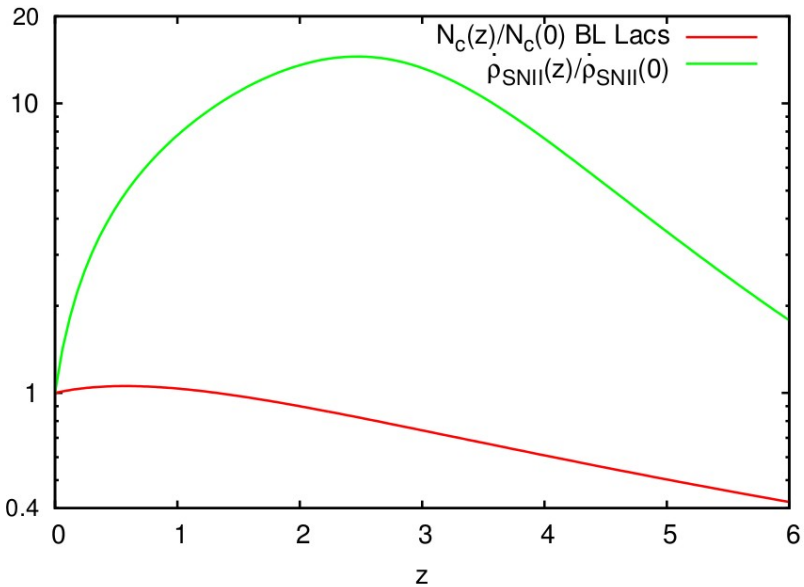




$$I(E) = \frac{c}{4\pi H_0} \int_0^{z_{\max}} \frac{dz}{(1+z)\omega}\, q_{\rm CR}(z, E')\, {\rm e}^{-\tau(E')} \,,$$

where $\omega = \sqrt{\Omega_\Lambda + \Omega_{\rm m}(1+z)^3}$.

Diffuse fluxes from BL Lacs / FR Is



BL Lac evol. from
Di Mauro et al. 2014

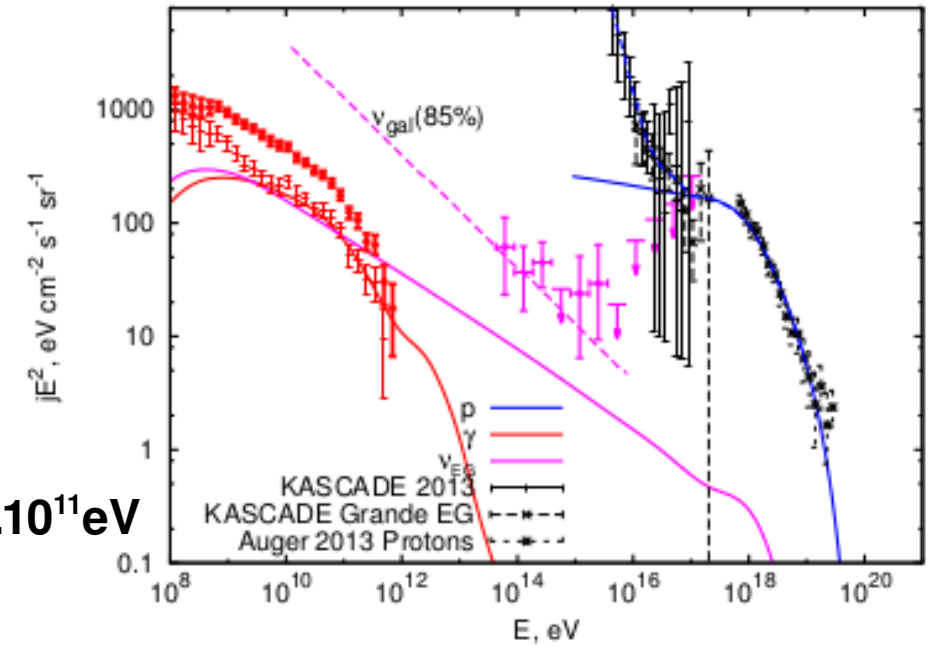
$R = 10^{14}$ cm

$B = 10^{4}$ G

$n = 10^{9}$ cm^{-3}

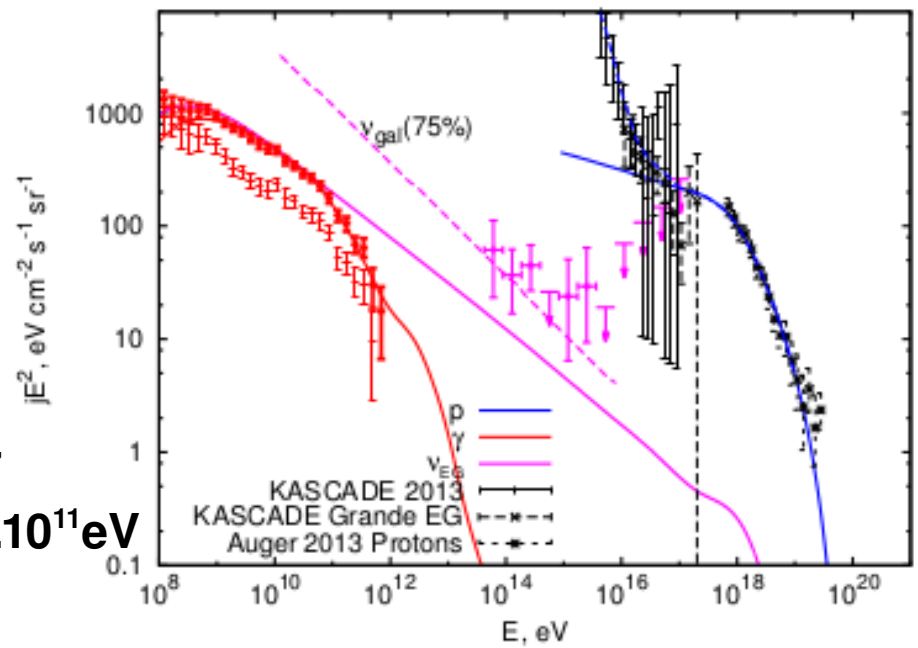
$\alpha = 2.11$

$E_{esc} = 3.10^{11}$eV

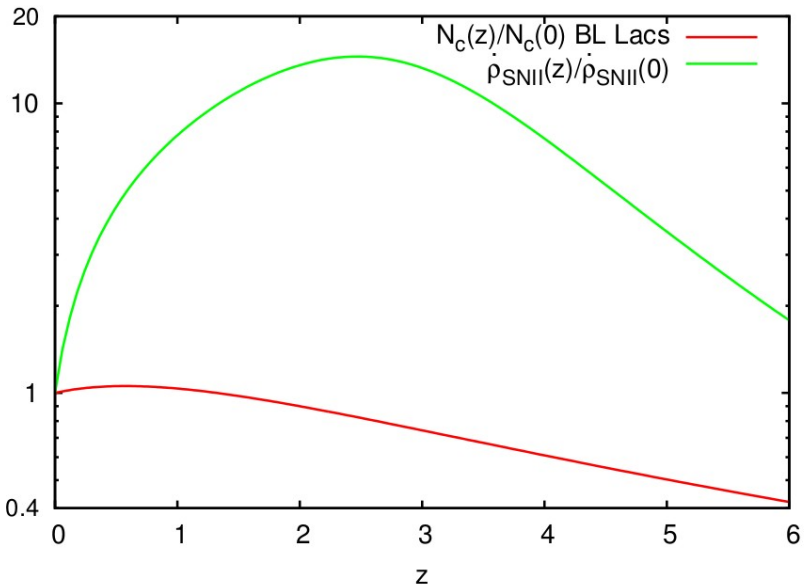


$\alpha = 2.17$

$E_{esc} = 3.10^{11}$eV



Diffuse fluxes from BL Lacs / FR Is



BL Lac evol. from
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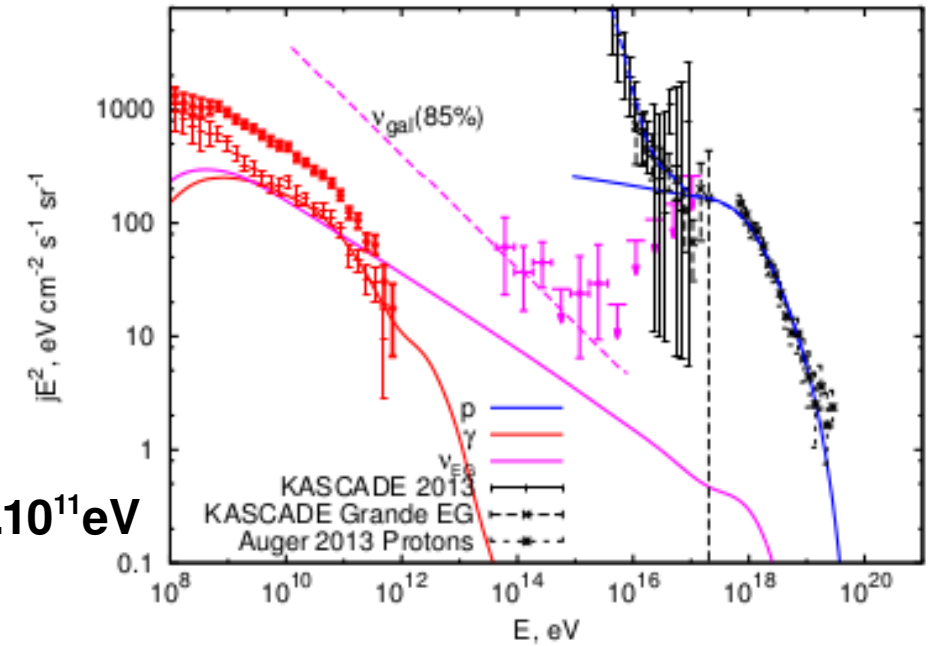
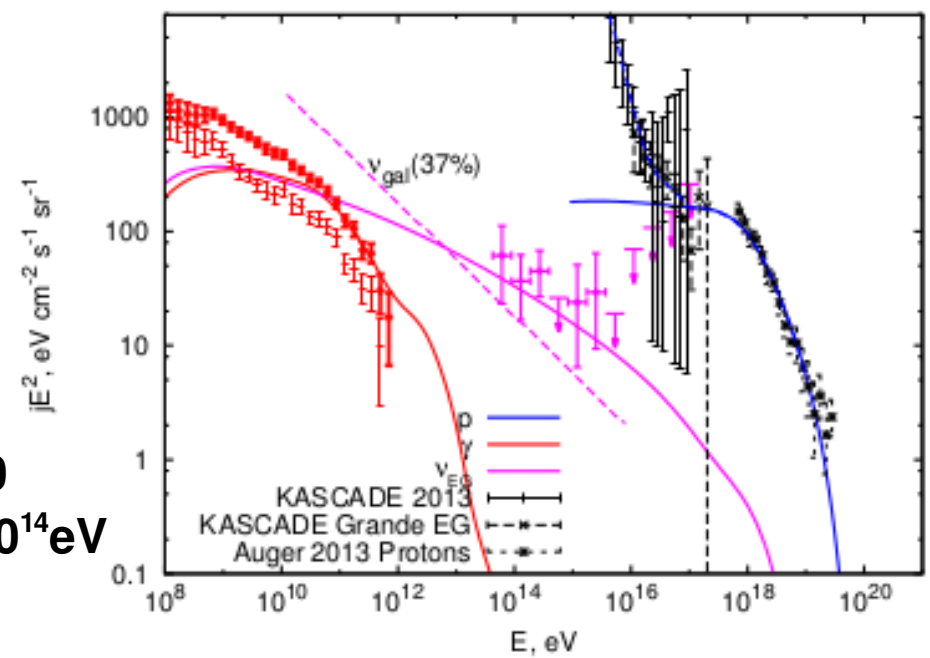


α = 2.11
E_{esc} = 3.10^{11}eV



α = 2.10
E_{esc} = 10^{14}eV

Conclusions

- 'Escape model' can fit all new CR data / observables, notably spectrum of individual elements around the knee
- Can be tested (e.g. Auger anisotropy at 'low' energies)

- Transition to extragal. CRs no later than at a few x 10^{17} eV

- BL Lacs / FR Is can explain deduced diffuse CR flux
- … + Diffuse gamma-ray / sizeable part of IC neutrino fluxes if grammage in sources sufficiently large.