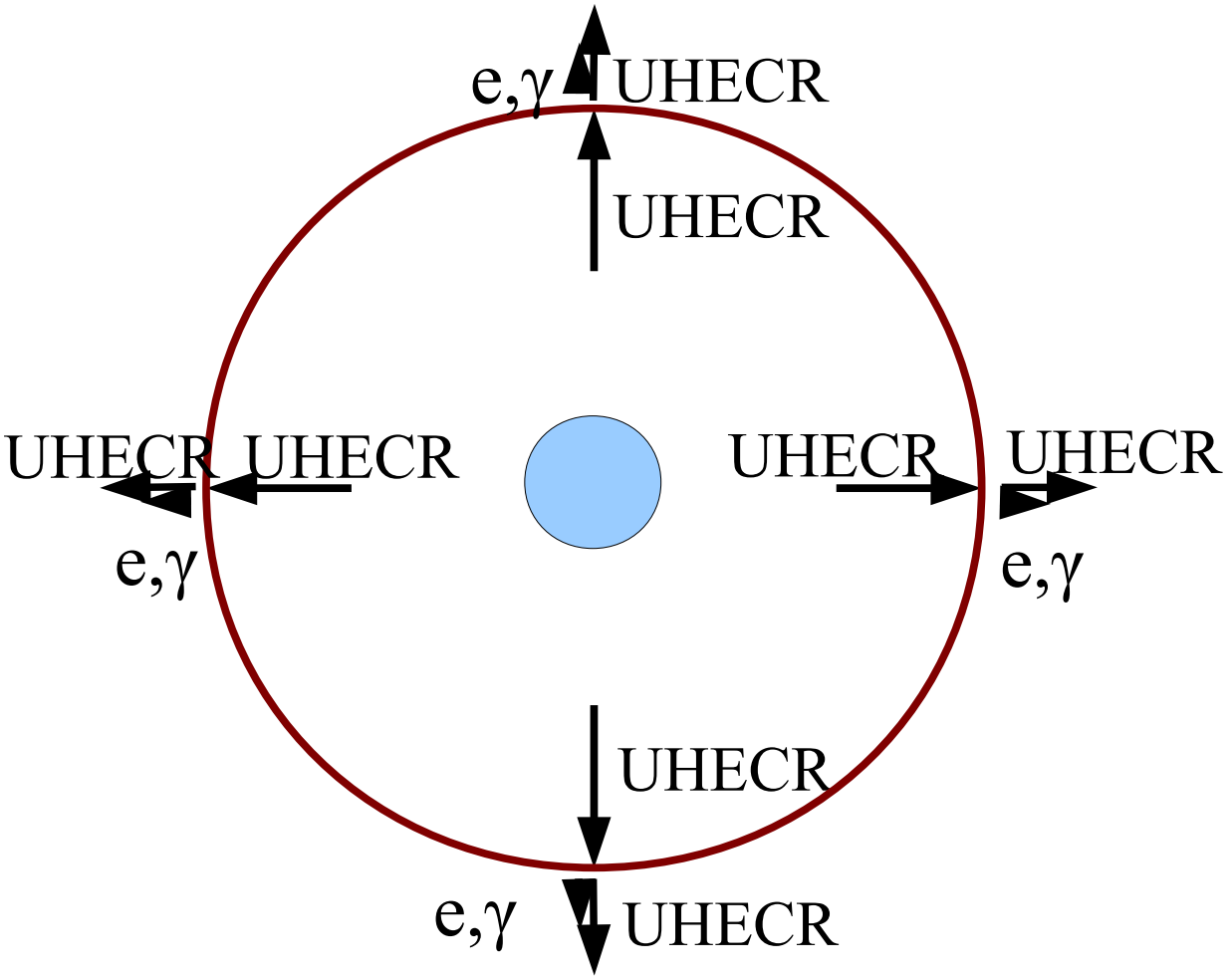
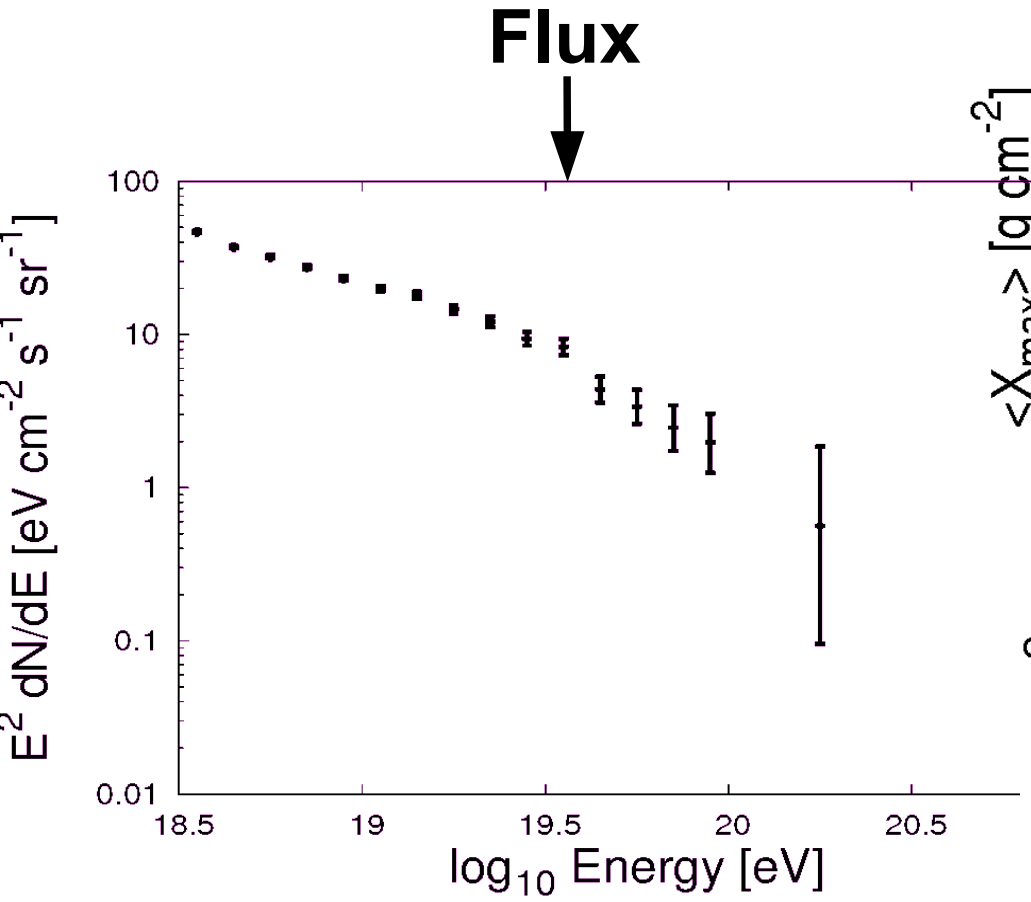
The Need For Hard Spectra Sources of Nearby Heavy Cosmic Rays

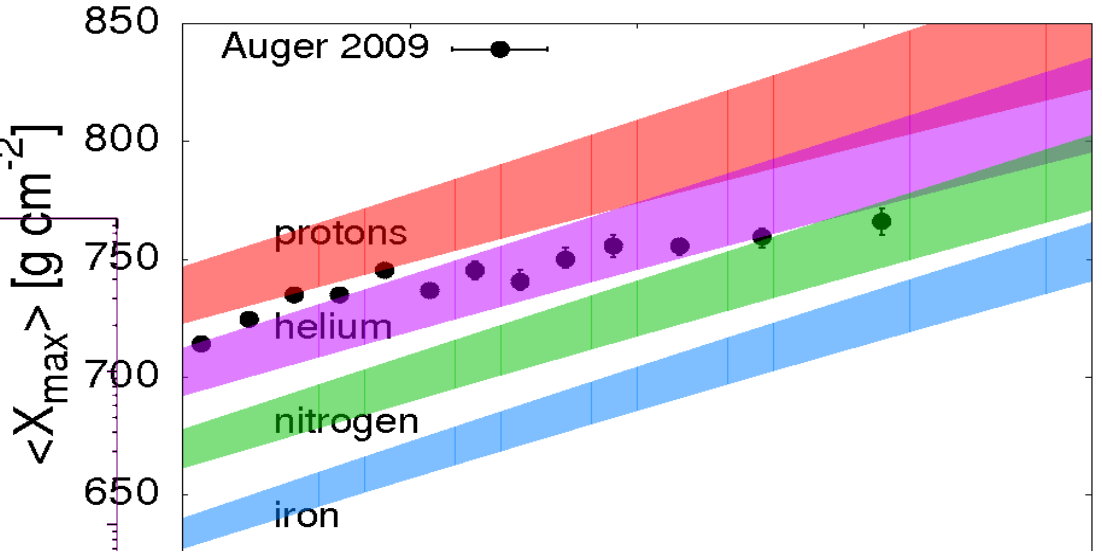


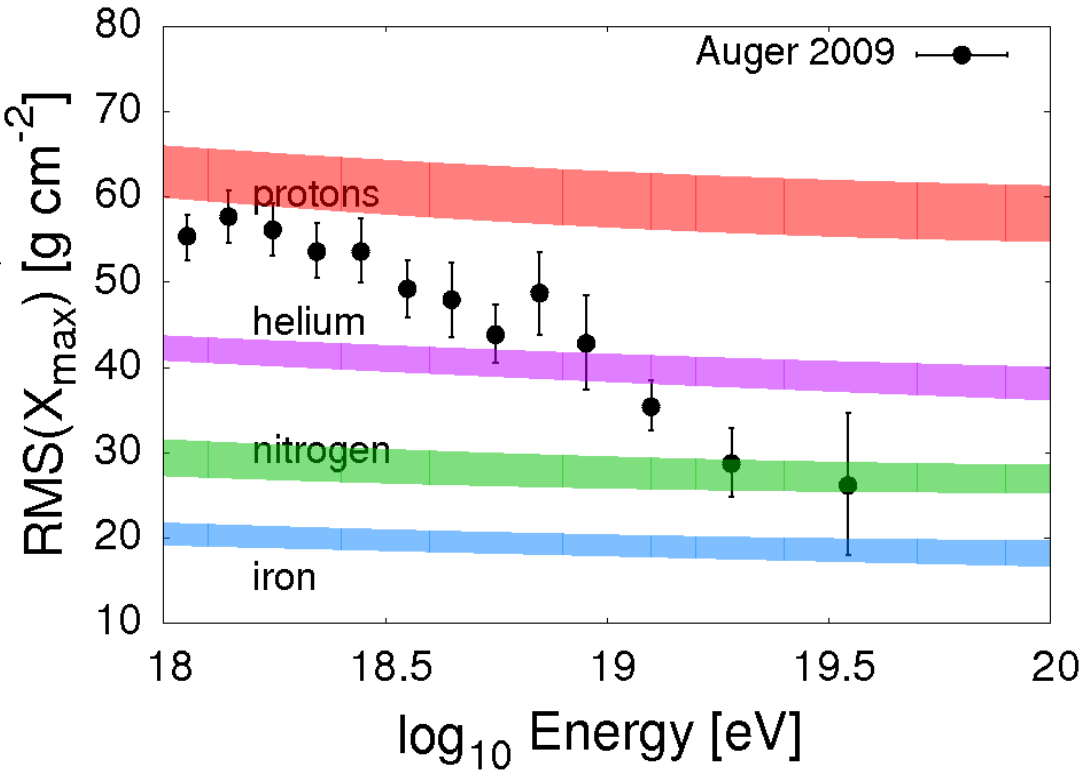
1) What source injection spectra + composition is consistent with Auger results?

2) What constraints do these fits place on the local source distribution?

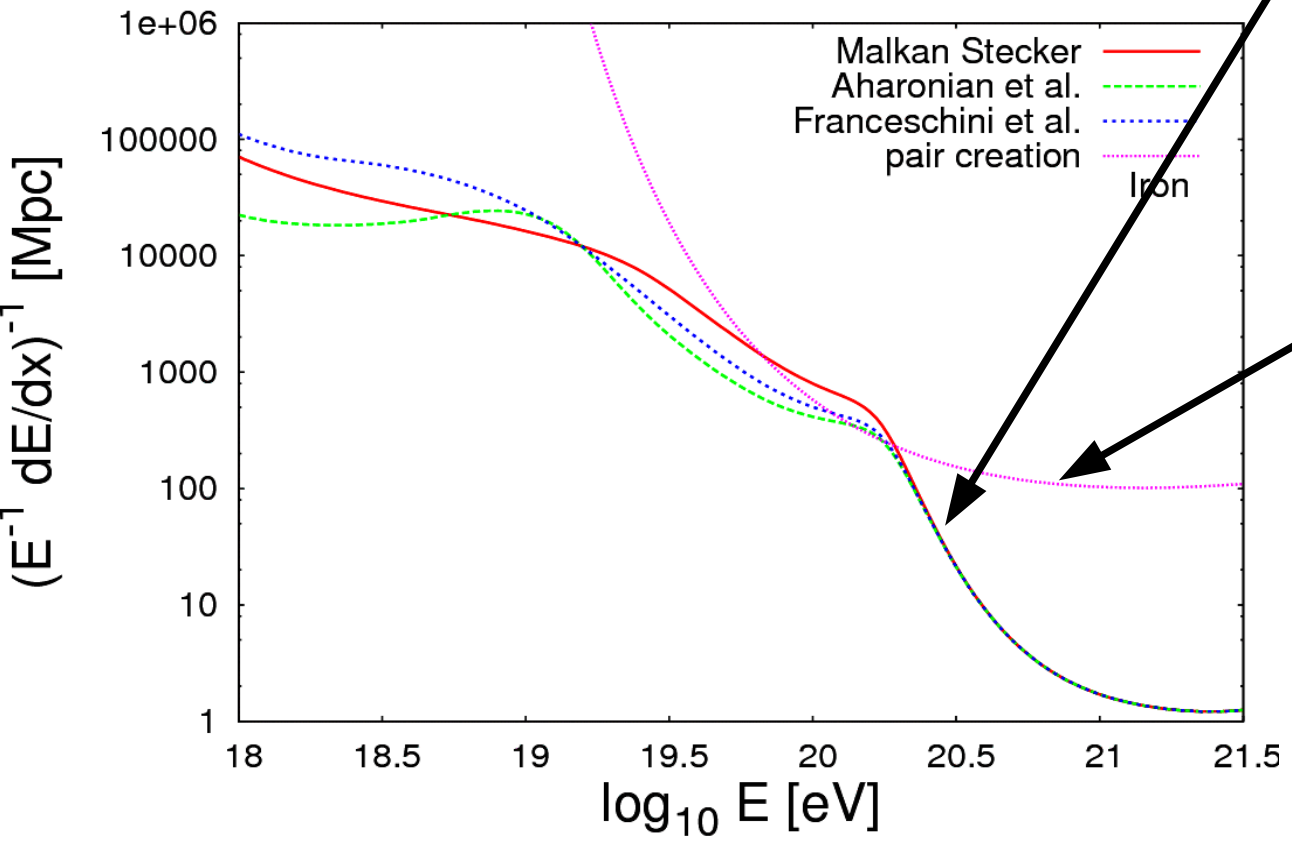
Reminder- The Composition that Arrives at Earth

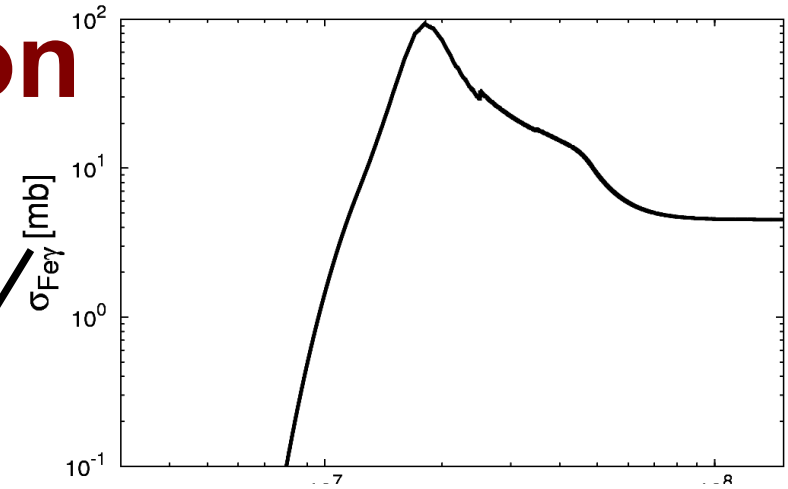


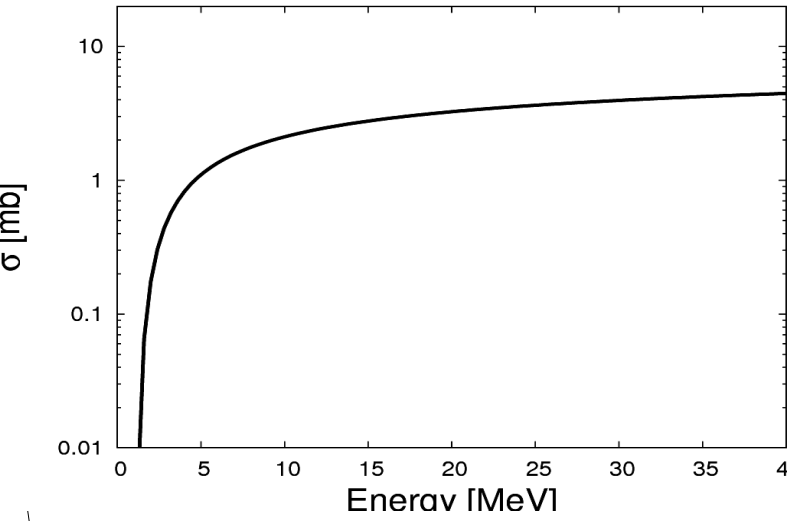


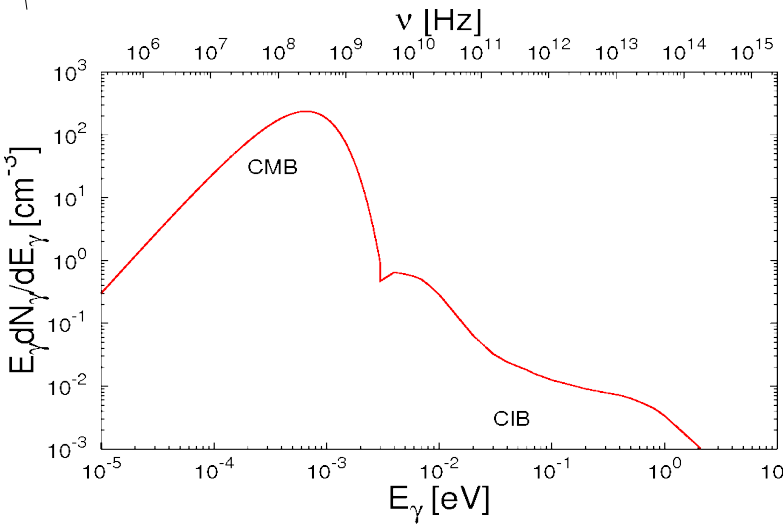


UHECR Nuclei Propagation From Source to Earth





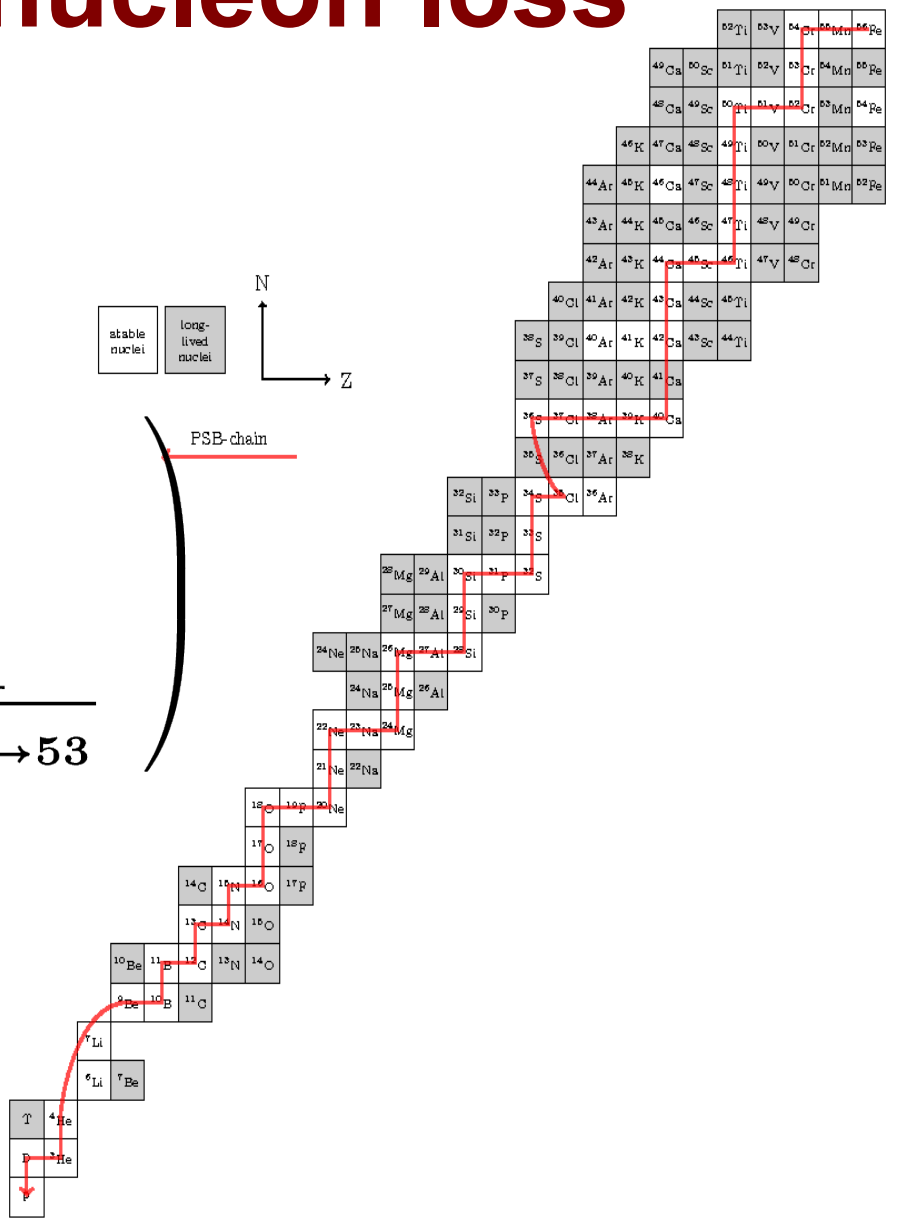




1st Order: Cascade of Nuclei Through Species- single nucleon loss

$$\frac{d}{dt}\begin{pmatrix} f_{56} \\ f_{55} \\ f_{54} \end{pmatrix} = \Lambda \begin{pmatrix} f_{56} \\ f_{55} \\ f_{54} \end{pmatrix}$$

$$\Lambda = \begin{pmatrix} -\frac{1}{\tau_{56\to 55}} & 0 & 0 \\ \frac{1}{\tau_{56\to 55}} & -\frac{1}{\tau_{55\to 54}} & 0 \\ 0 & \frac{1}{\tau_{55\to 54}} & -\frac{1}{\tau_{54\to 53}} \end{pmatrix}$$



Whose eigenvalues are

$$f_q = \sum_{n=q}^{56} \frac{\tau_q \tau_n^{56-q-1}}{\prod_{p=q}^{56}(\tau_n - \tau_p)} e^{-t/\tau_n}$$

Cascade of Nuclei Through Species- single nucleon loss

Since nuclei Lorentz factor remains ~conserved, and cross-section varies mildly with A (nuclear mass)

$$\tau_{56\rightarrow 55} \approx \tau_{55\rightarrow 54\cdots}$$

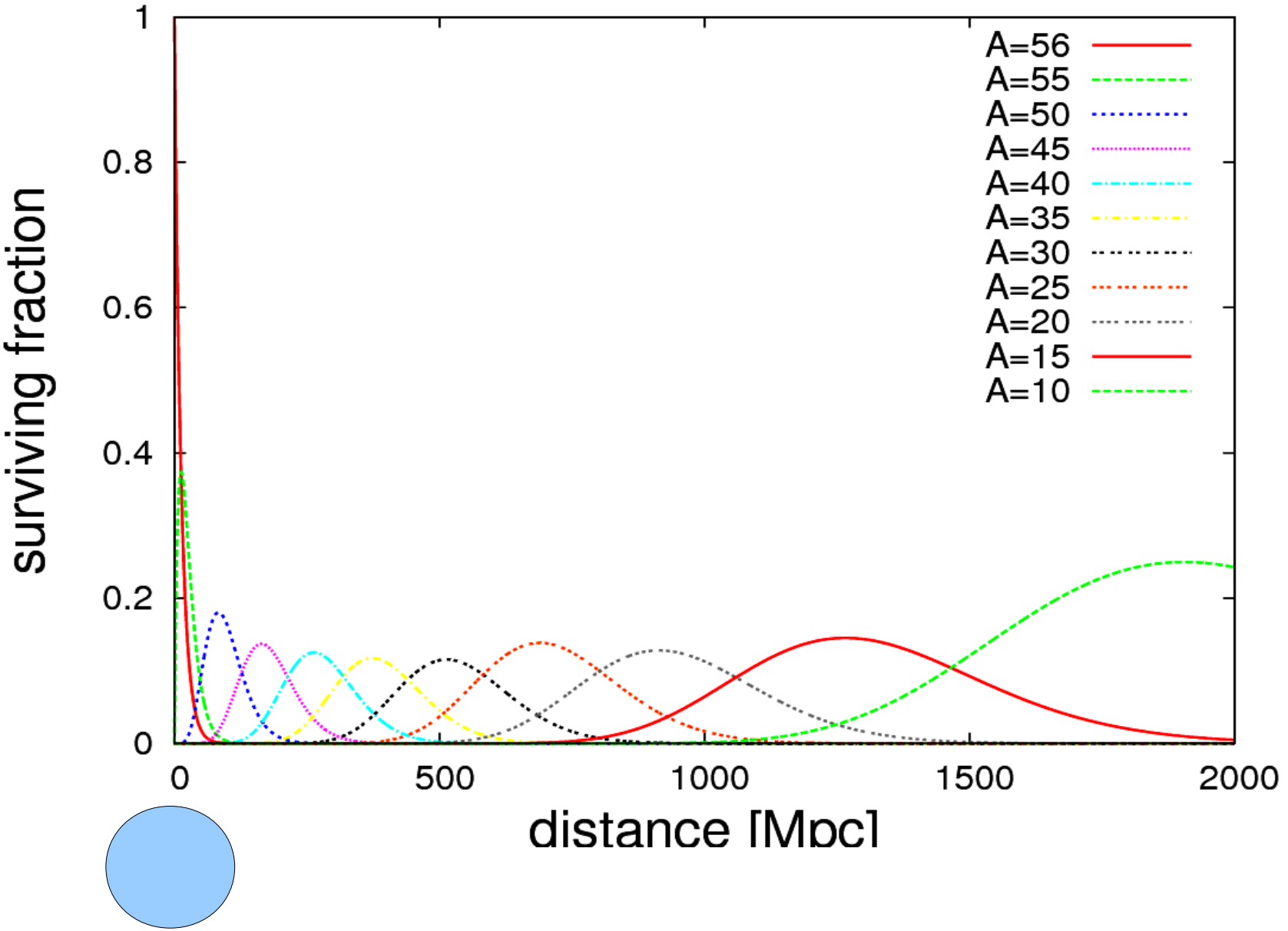
For the case $\tau_{56\rightarrow 55} = \tau_{55\rightarrow 54\cdots}$

$$f_q = \frac{t^{(q_{max}-q)}}{\tau_q (q_{max}-q)!} e^{-t/\tau_q}$$

ie. Gaisser-Hillas type function!
(used to describe air showers)

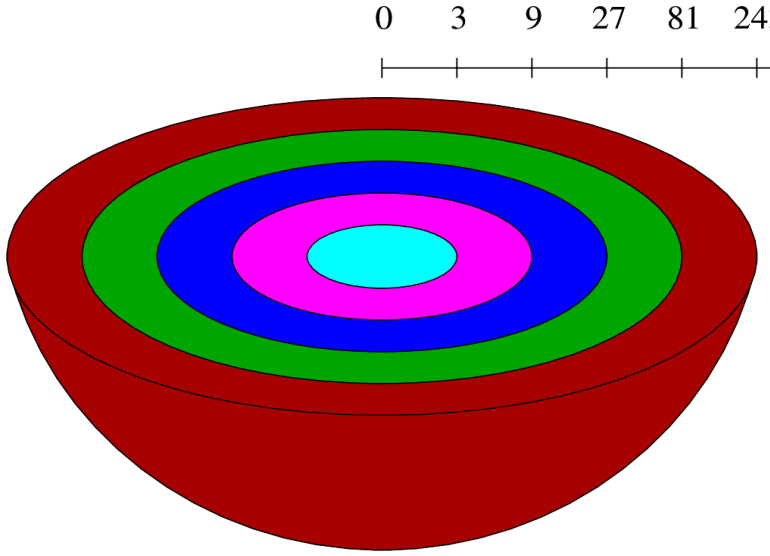
Nuclei Propagation Away from their Source + their Transmutation

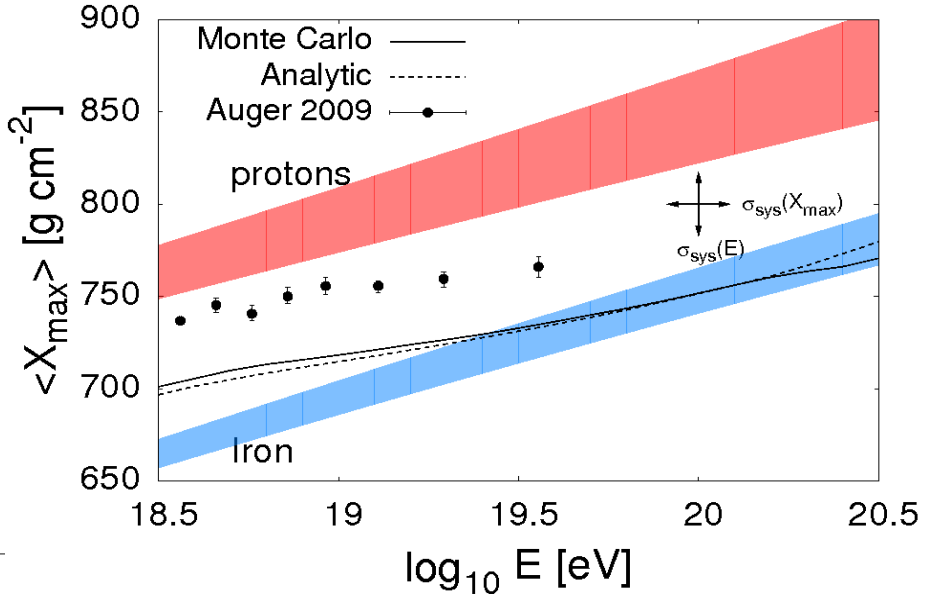
For 10^{20} eV Iron Nuclei at source-

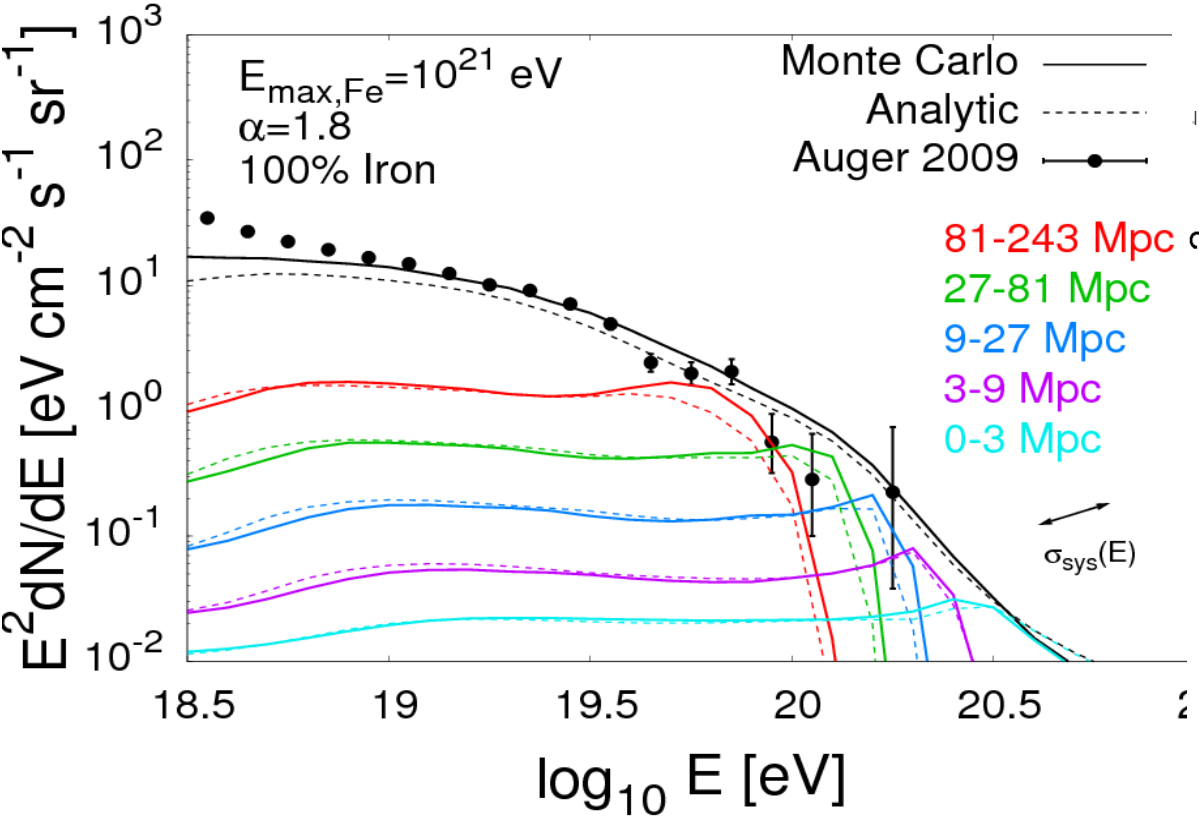


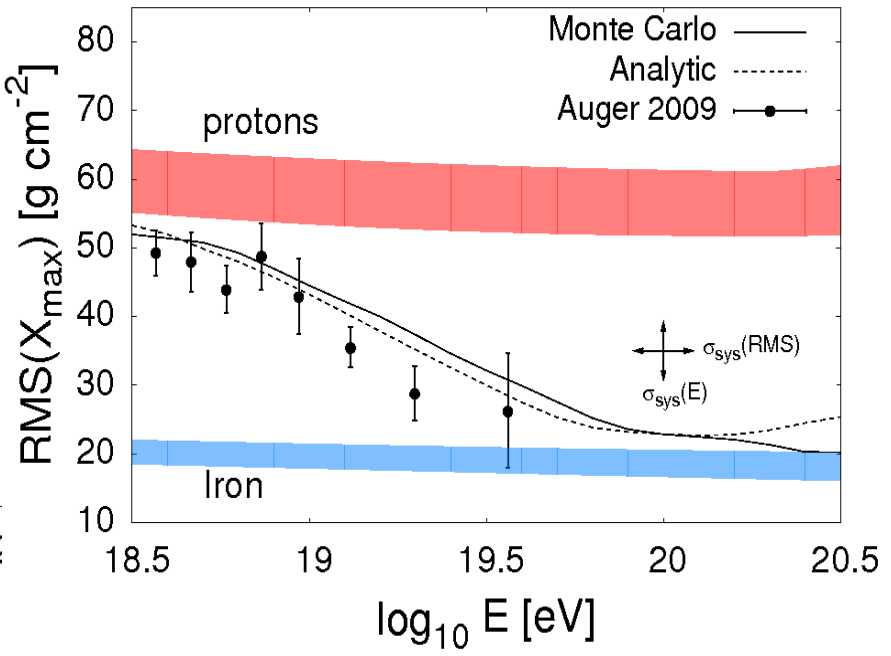
Local Scales Effect Highest Energies

(logarithmic scale)









What is the Source Composition?

Keep It Simple

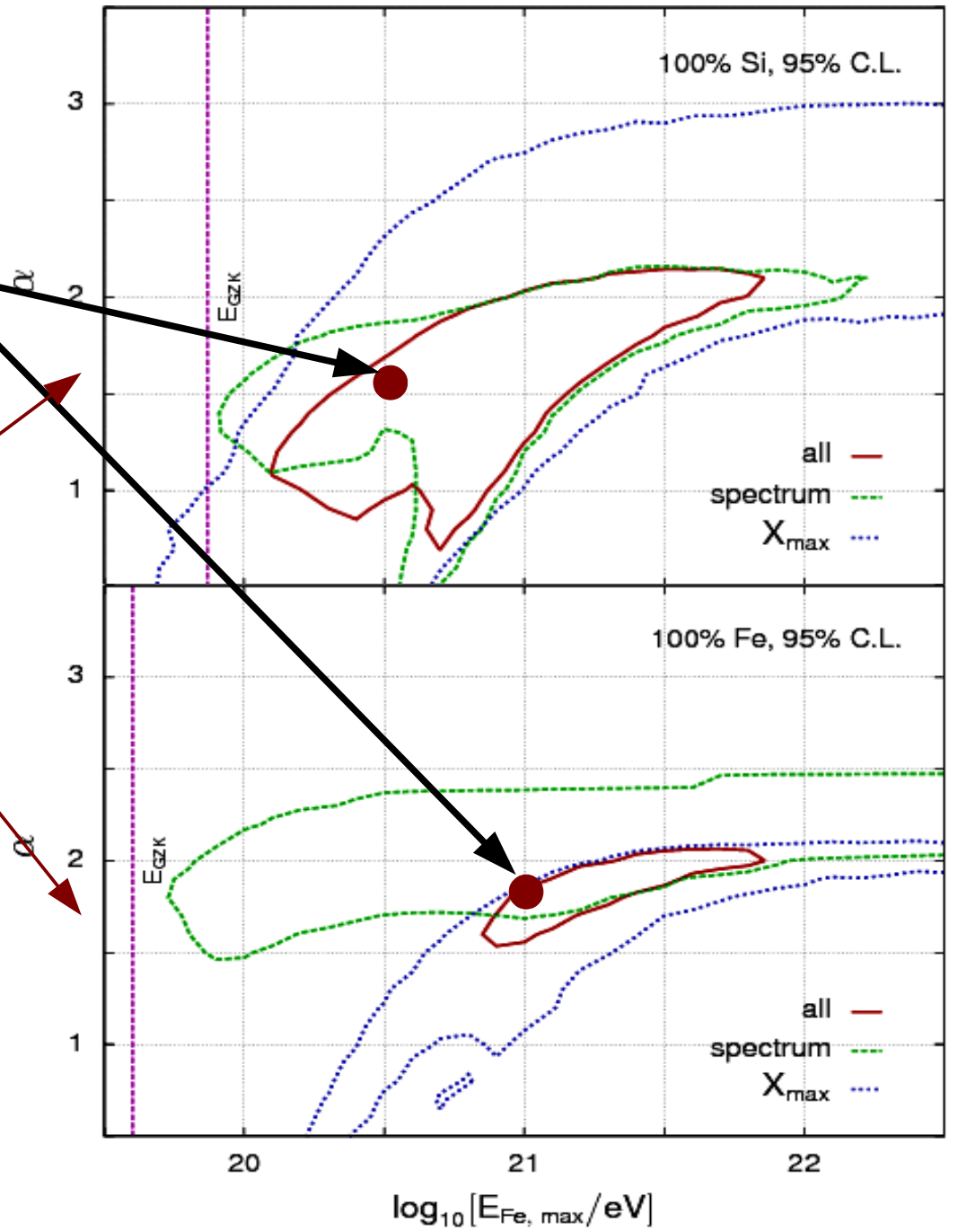
- Single Composition

Example Best-Fit Models

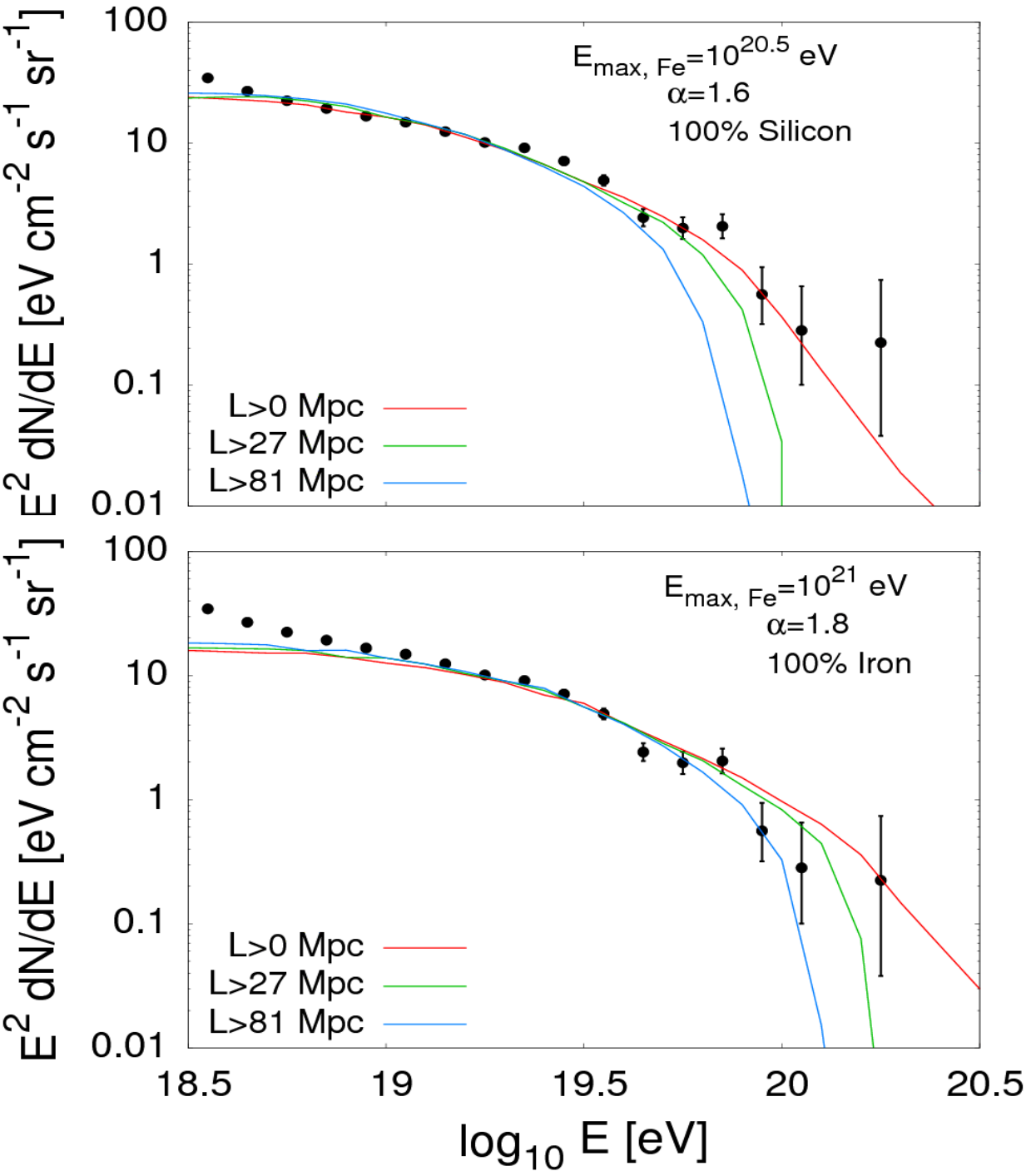
Silicon →

Hard Spectra preferred

Iron →



How Far is the Nearest Source?



L>0 Mpc

L>27 Mpc

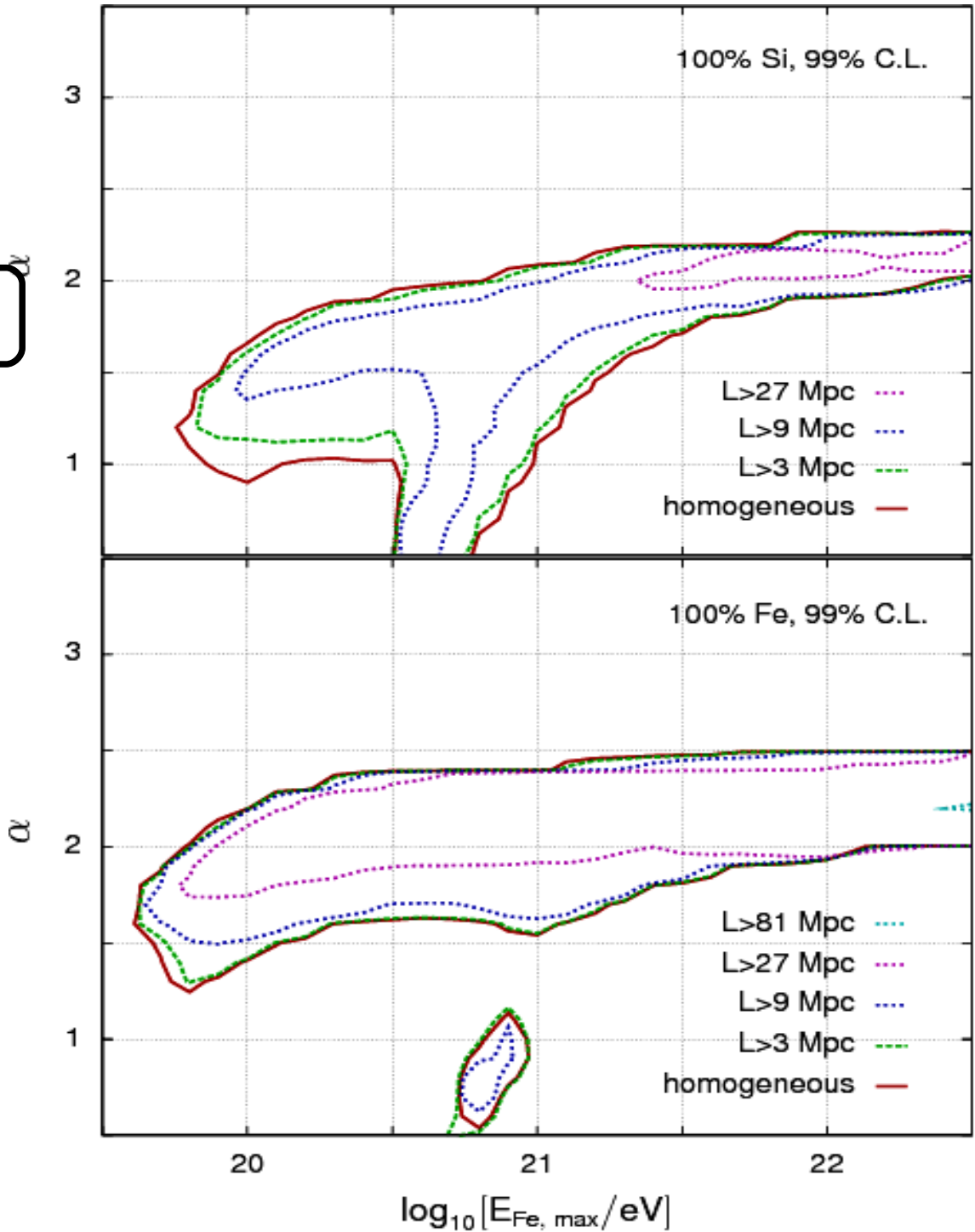
L>81 Mpc

How Far is the Nearest Source?

If $E_{max}<10^{22}$eV

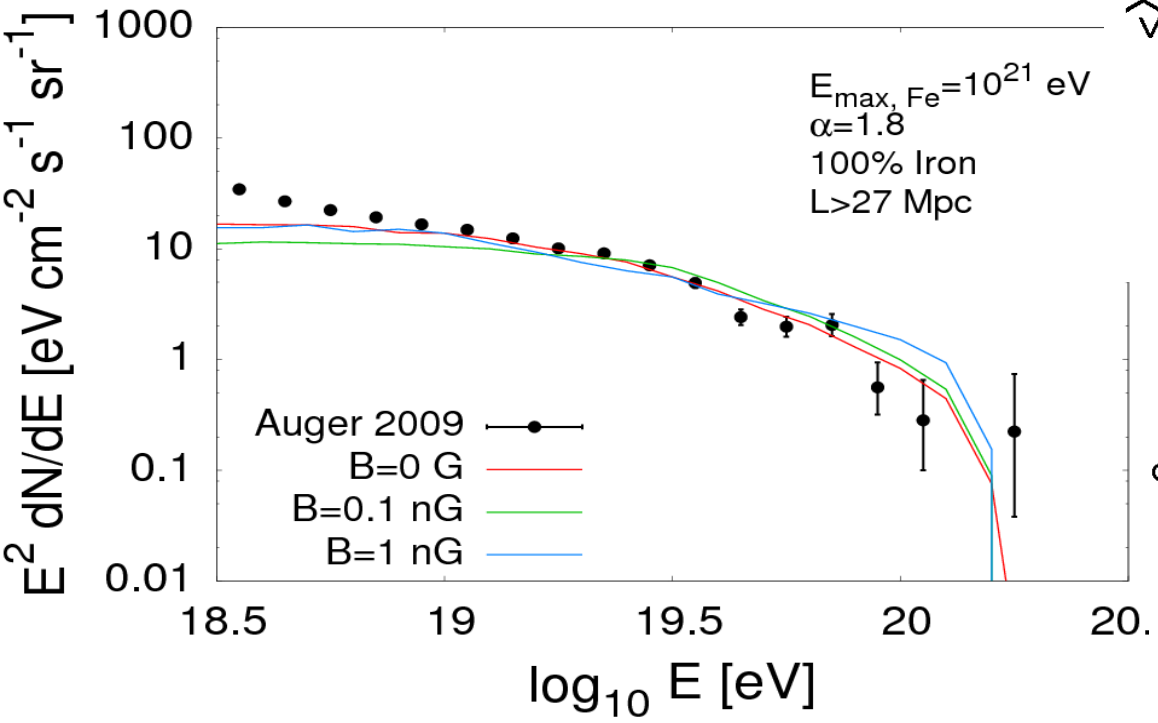
Silicon- D<60 Mpc

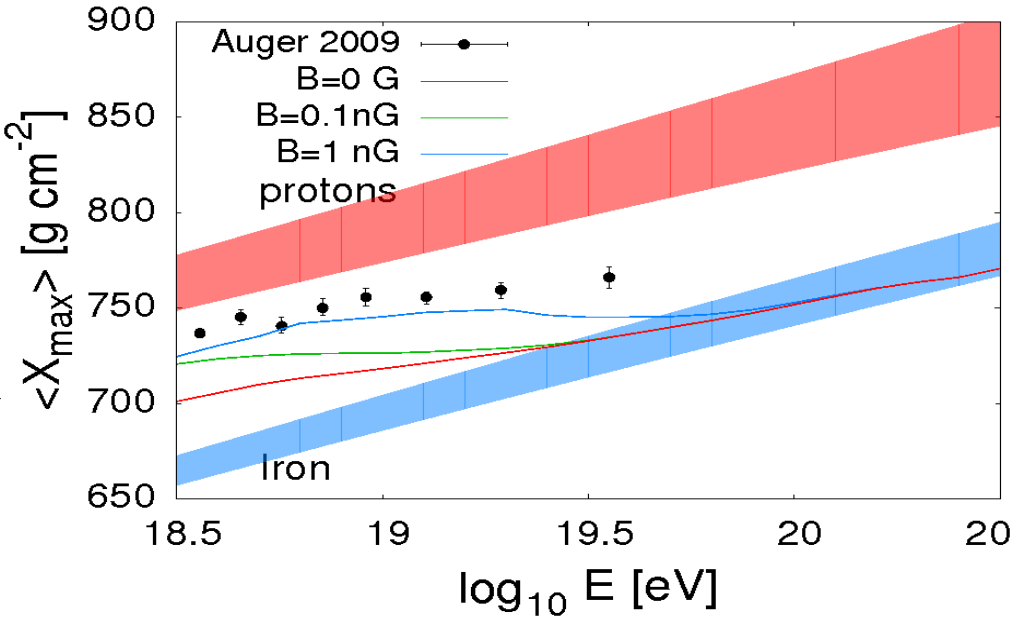
Iron- D<80 Mpc

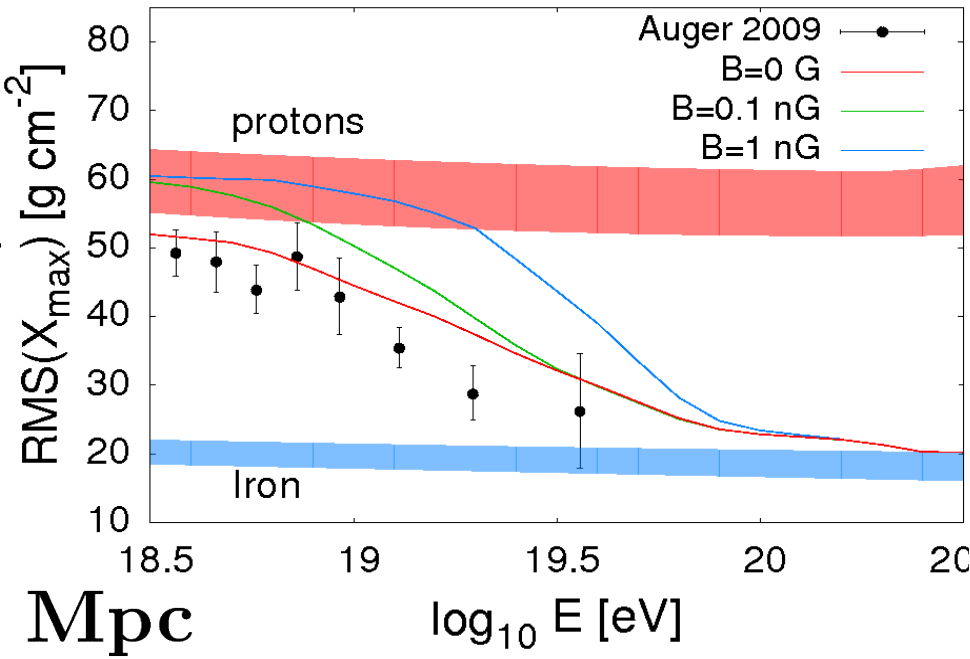


Extragalactic Magnetic Fields

L>27 Mpc







$$R_{\mathrm{Larmor}} \approx 4 \left(\frac{E}{10^{20}\ \mathrm{eV}}\right) \left(\frac{\mathrm{nG}}{B}\right) \left(\frac{26}{Z}\right)\ \mathrm{Mpc}$$

Conclusion

The dominance of nuclei at the high energies provides useful new information about the proximity of UHECR sources

Analytic calculations can be used to describe with reasonable accuracy the spectrum and the composition results

Agreement with both the spectral and composition information require that **local sources** exist which produce **hard spectra**