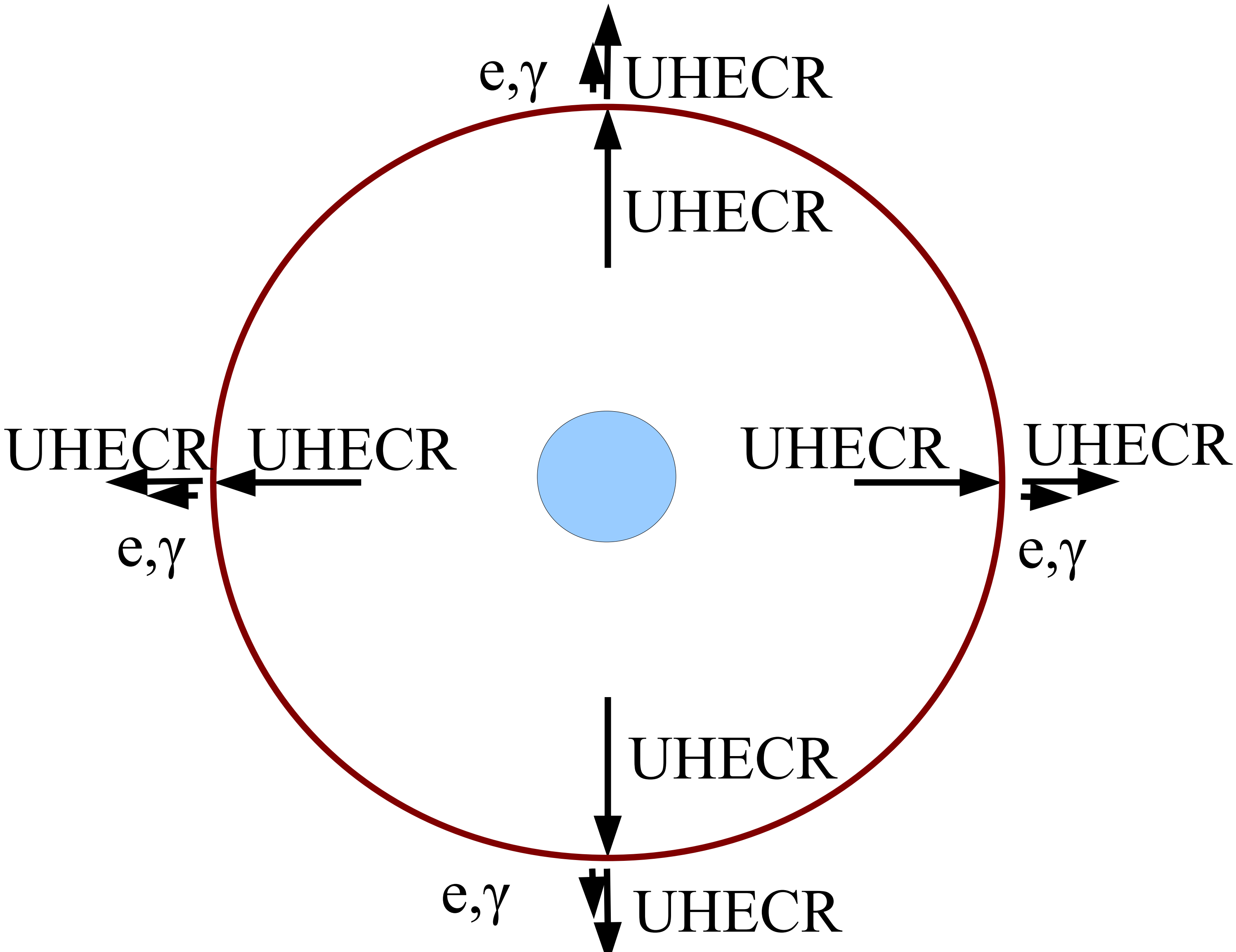
Probing Local UHECR Sources with Nuclei + Gamma-Rays



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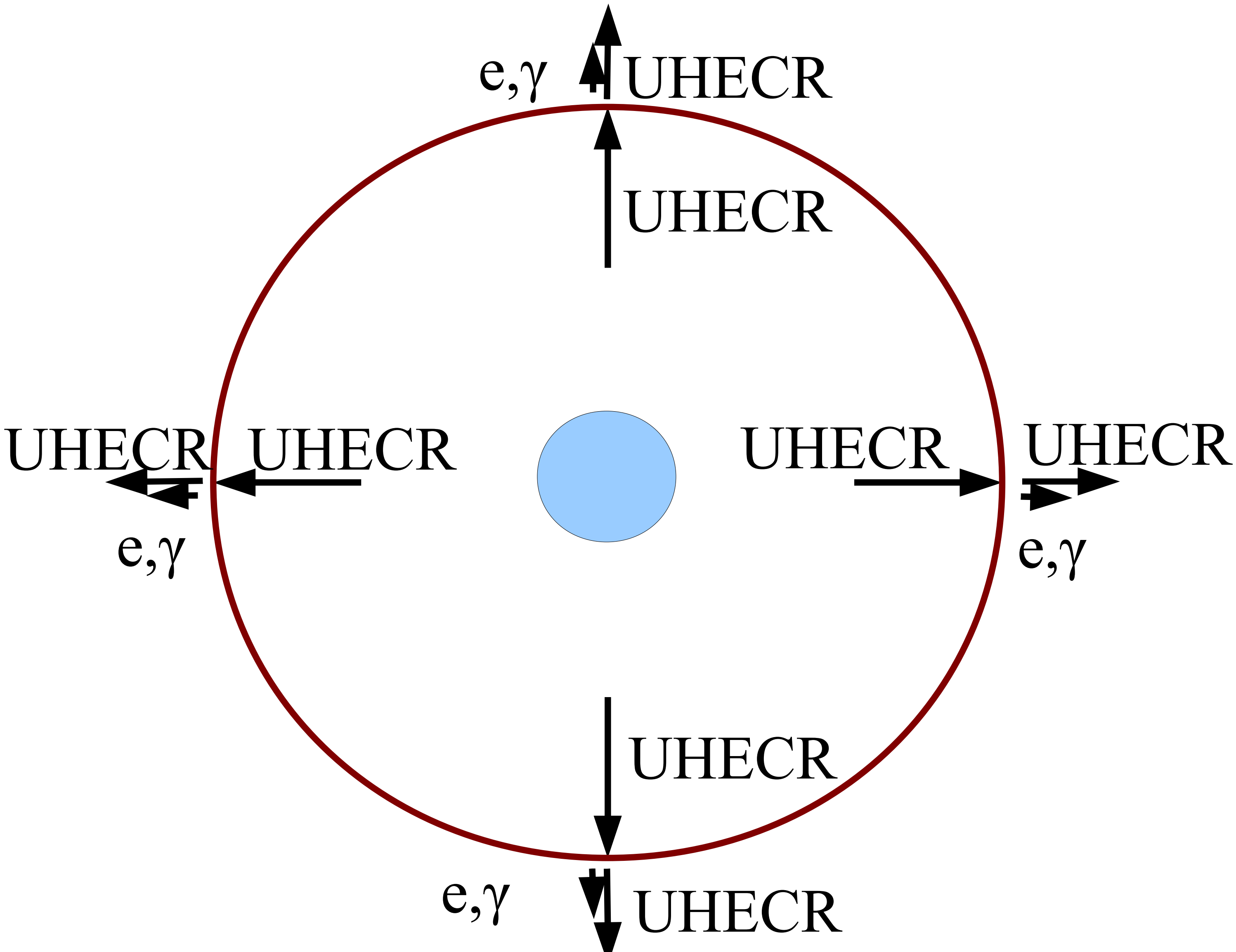

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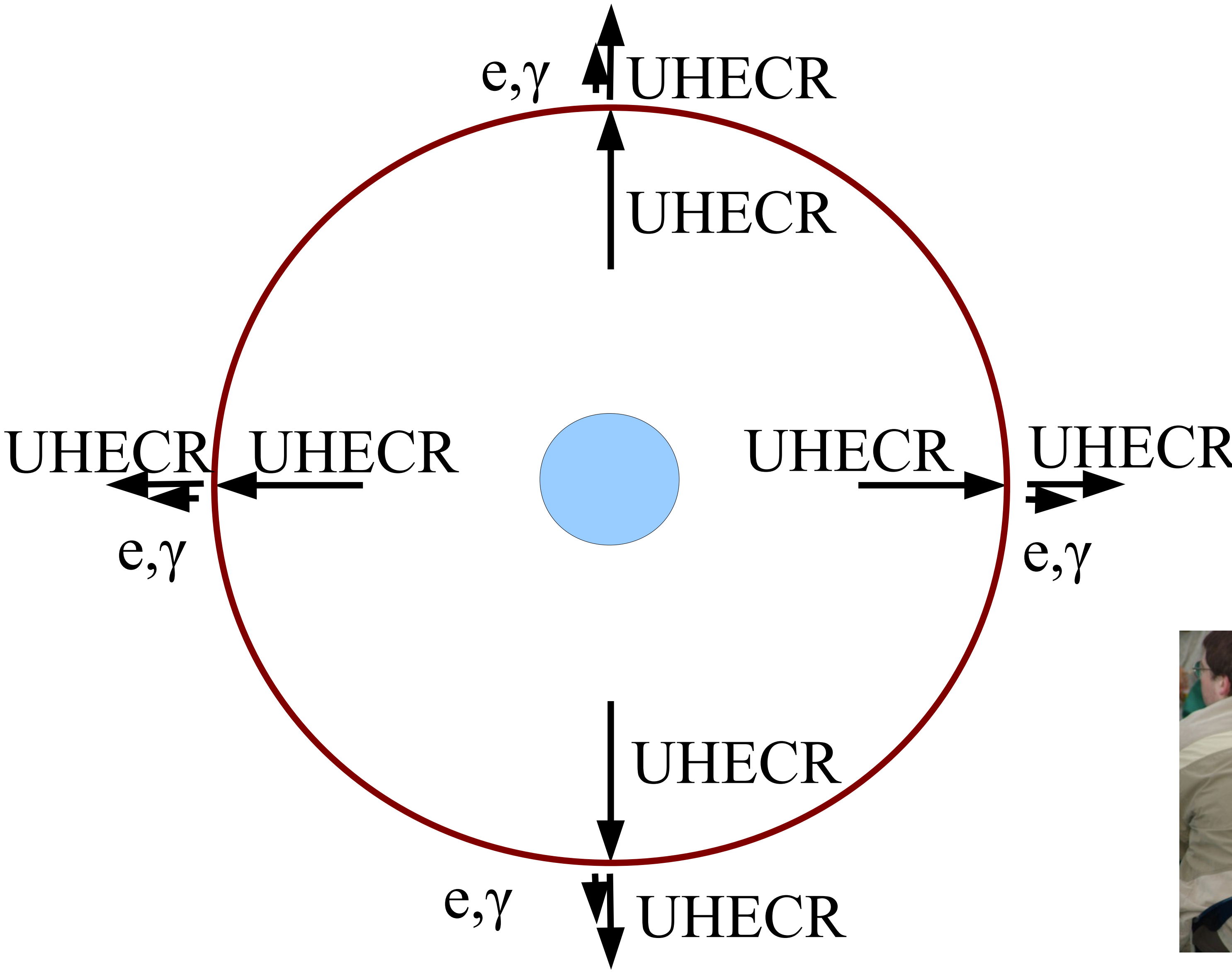

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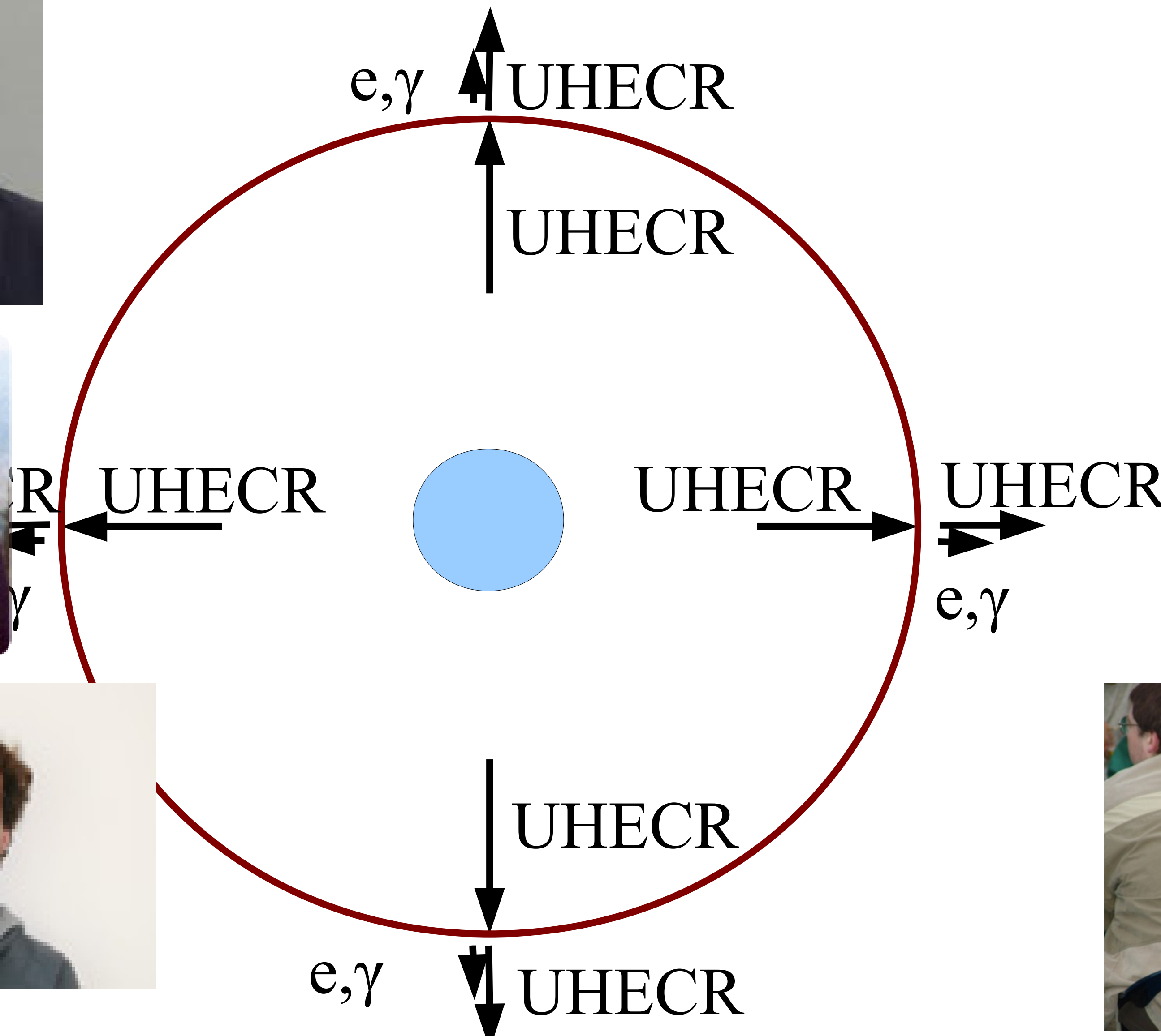
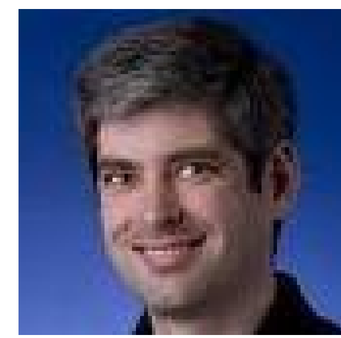




Talk Structure

Using Nuclei

1) Measurements of UHECR by the PAO

2) Implications for UHECR source requirements

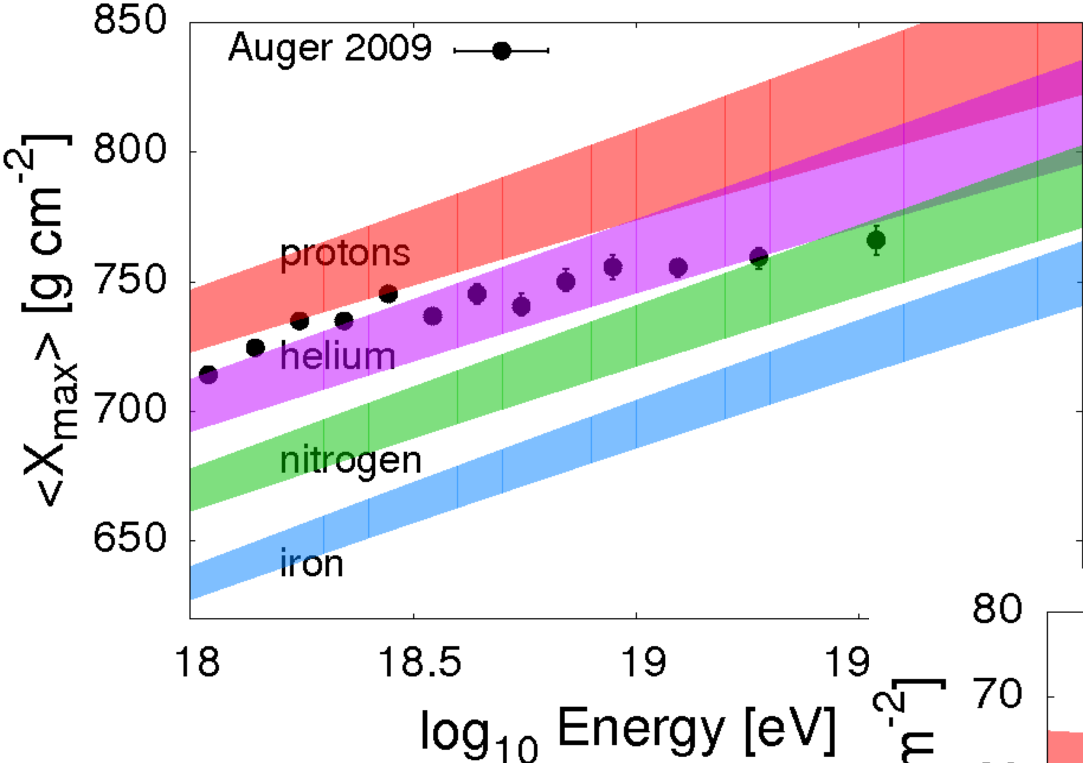
Using Gamma-Rays

3) Their birth + death in regions surrounding the source

4) What current PAO Gamma-Ray limits already tell us about the sources

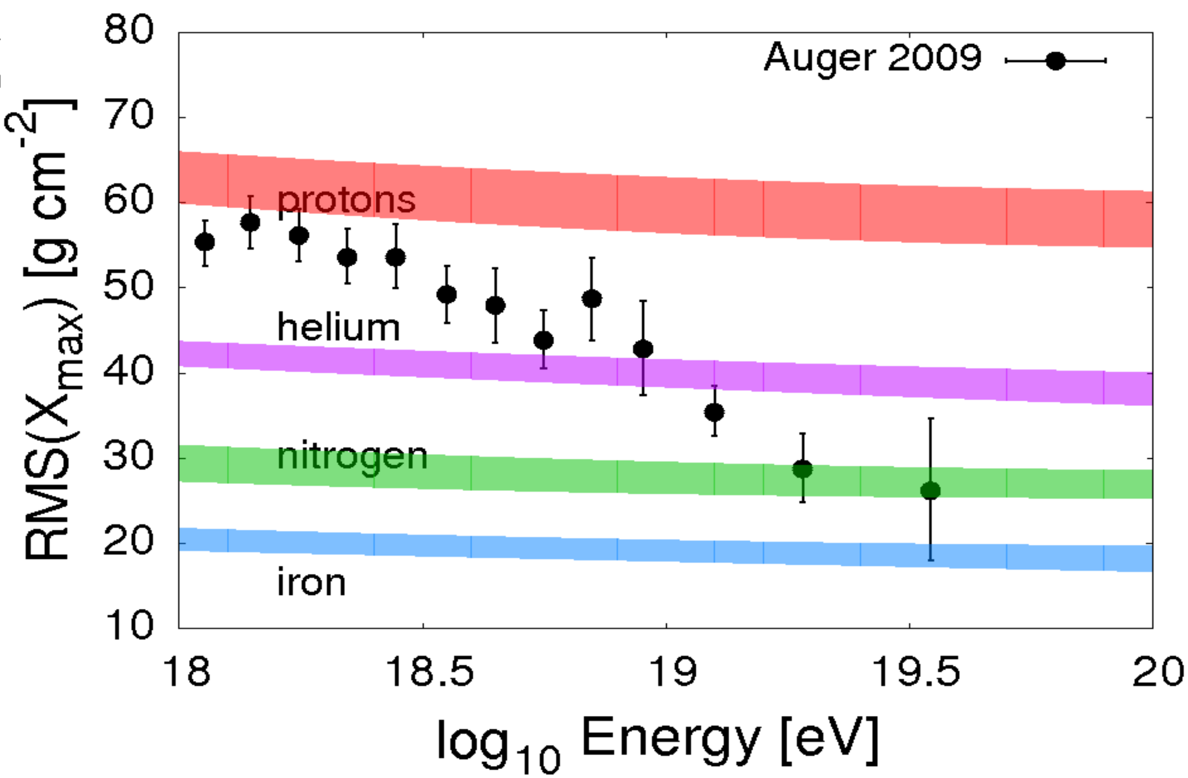
Part 1: Nuclei

MEASUREMENTS of UHECR by the PAO

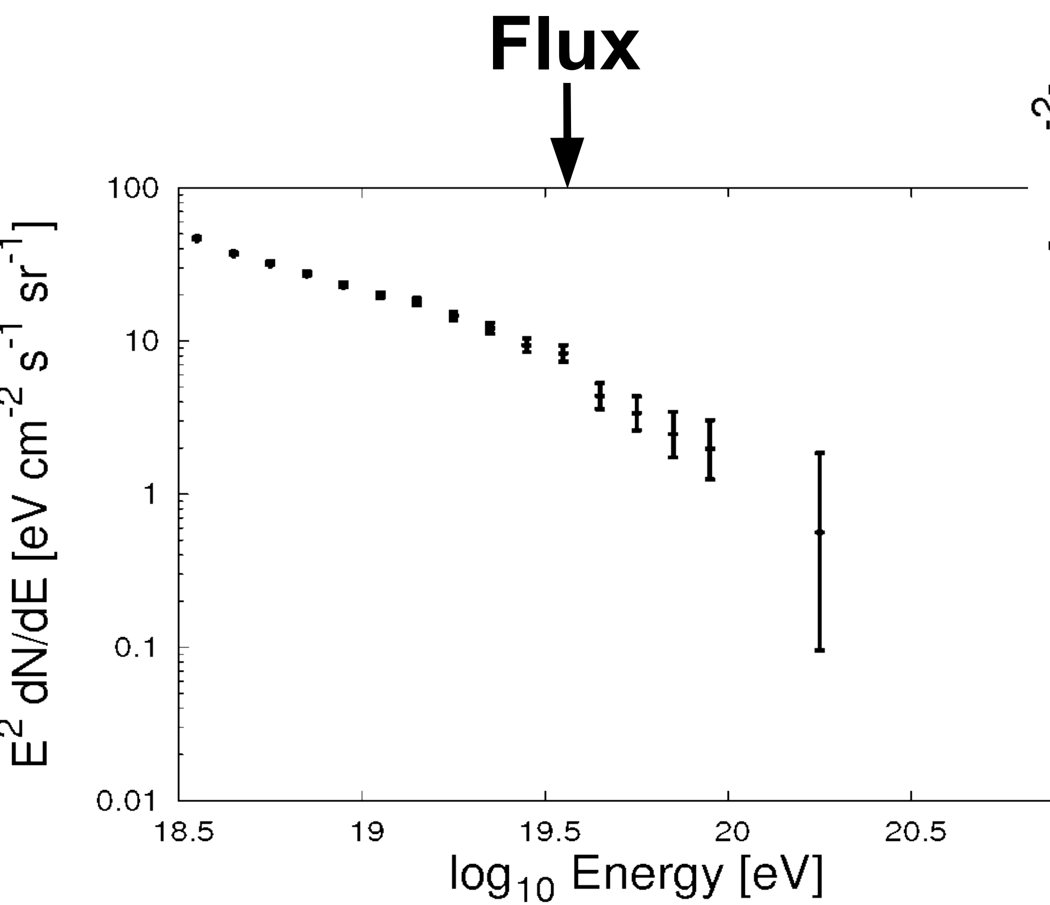


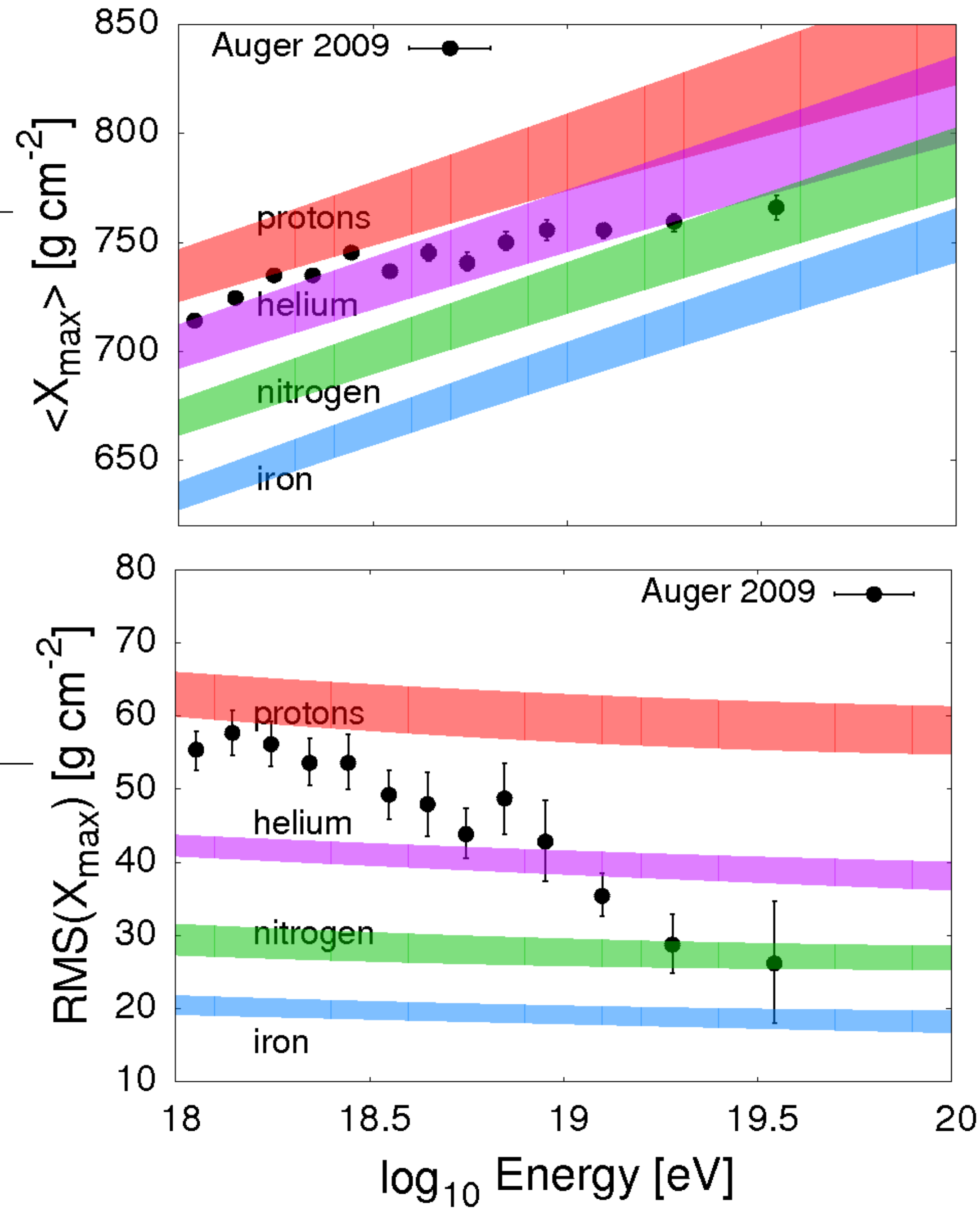
$\leftarrow \langle X_{\max} \rangle$

$\mathrm{RMS}(X_{\max})$

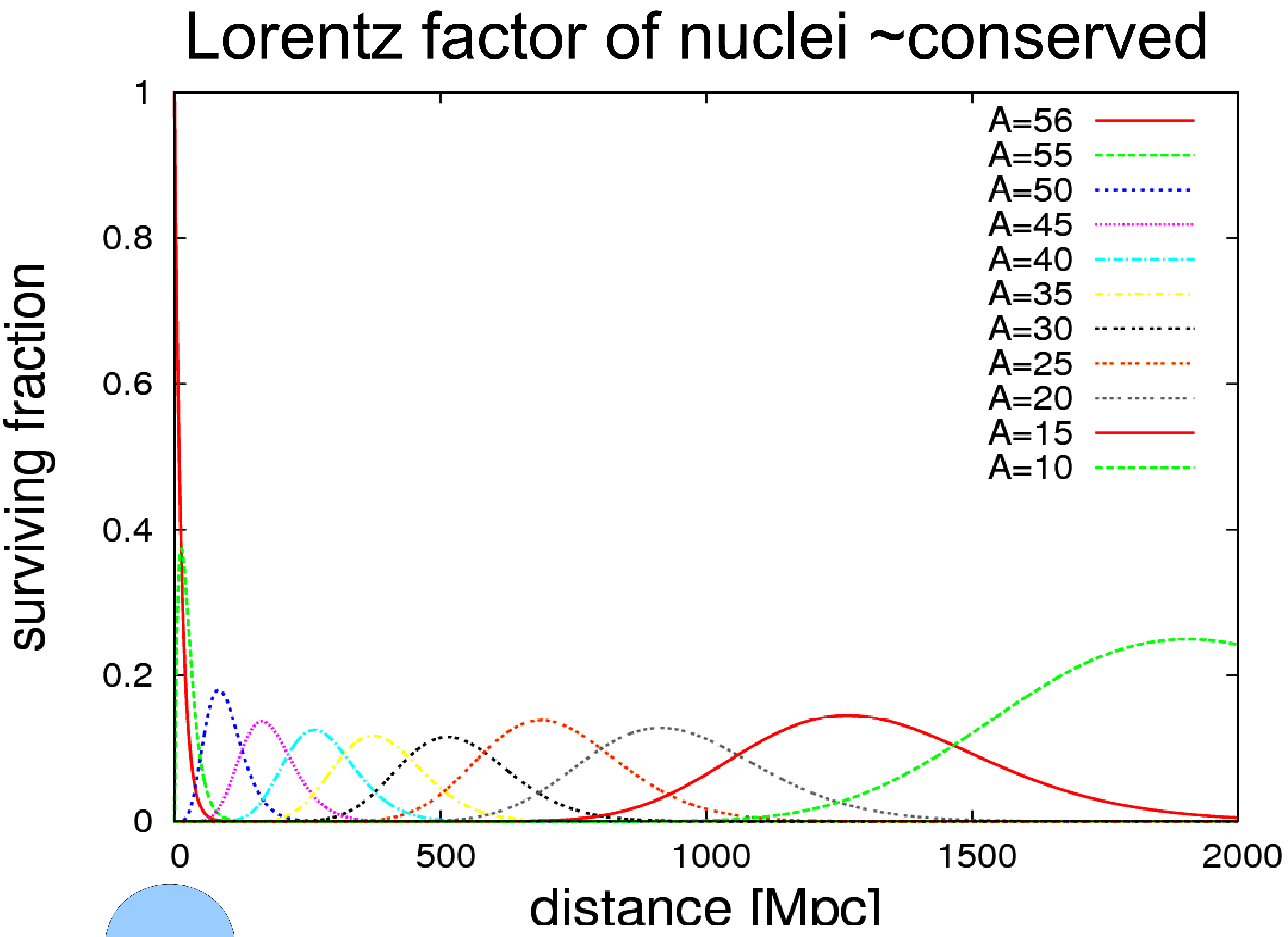


MEASUREMENTS of UHECR by the PAO



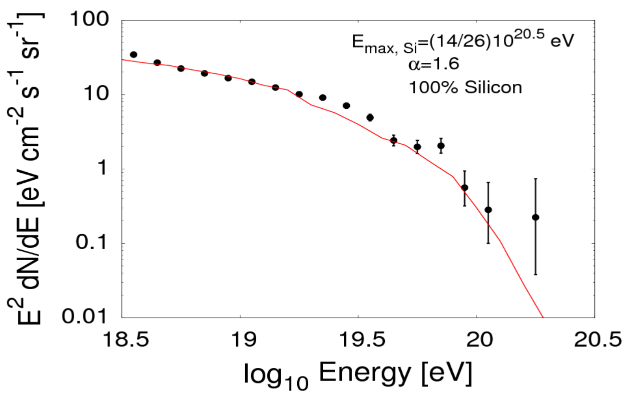


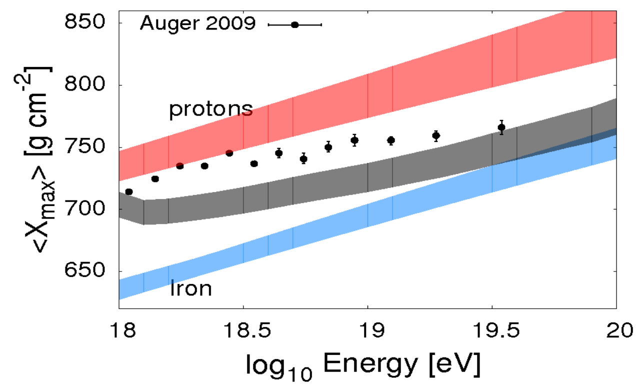
Nuclei Propagation Away from their Source + their Transmutation

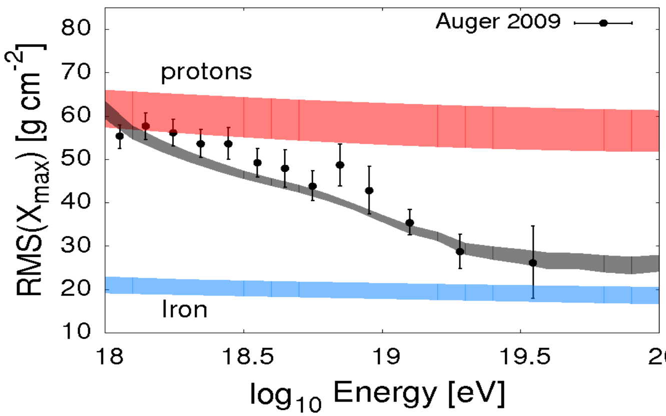


Nuclei Propagation Away from their Source + their Transmutation

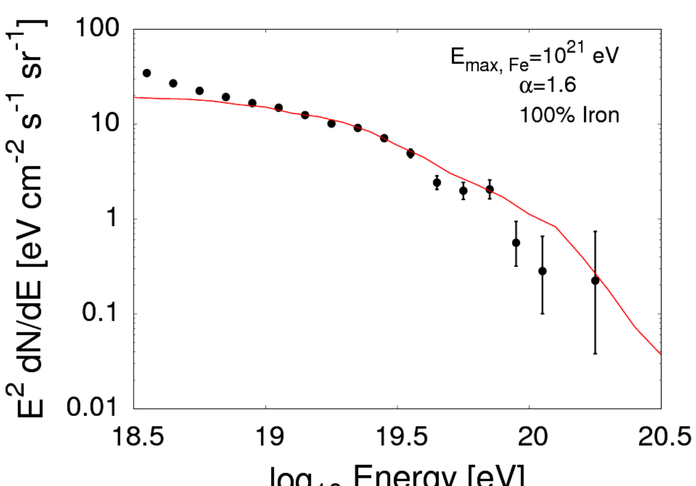
Silicon only?

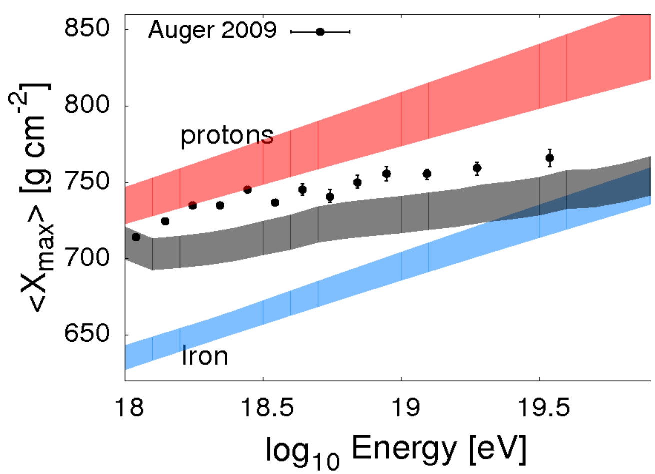


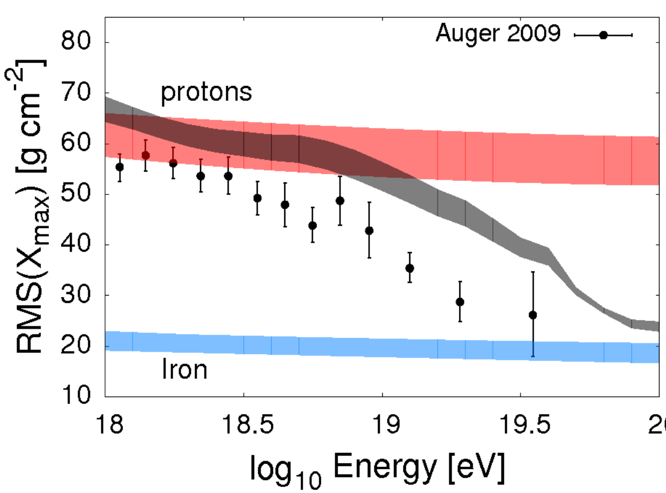




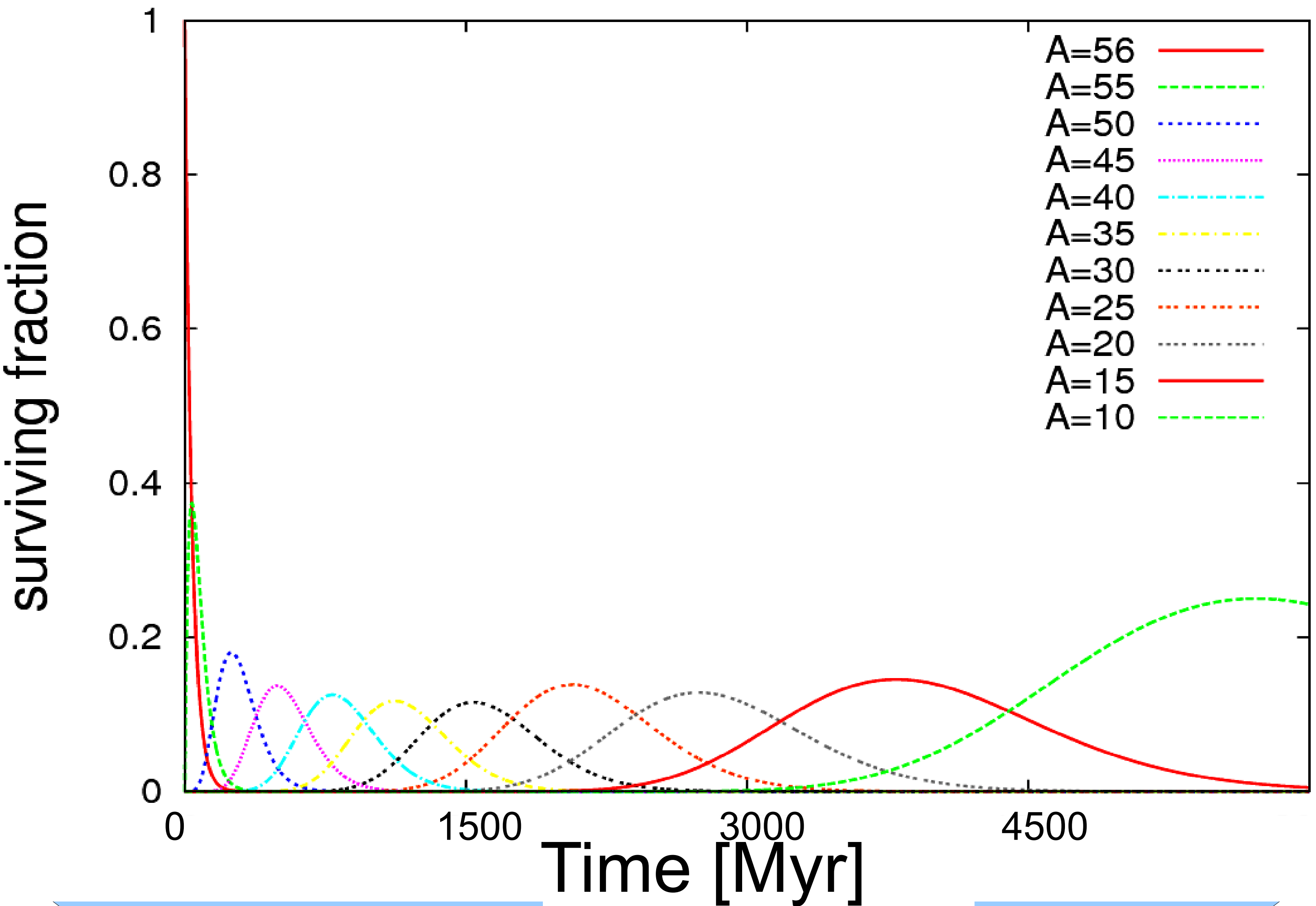
Iron only?





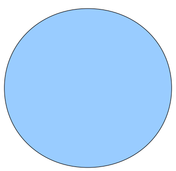


Nuclei Propagation Within their Source + their Transmutation



IMPLICATIONS for UHECR Sources

$$f = \frac{t_{\rm trap}}{t_{\rm int.}^{\rm CR\gamma}}$$



$$t_{\rm int.}^{\rm CR\gamma} \approx \frac{1}{n_\gamma \sigma_{\rm CR\gamma} c}$$

$$n_\gamma = \frac{L_\gamma}{c 4\pi R^2 \epsilon_\gamma}$$

$$t_{\rm trap} \approx \frac{R^2}{2D} = \frac{3R^2}{2R_{\rm Larmor}}$$

$$f^{\rm CR\gamma} = \frac{3 L_\gamma \sigma_{\rm CR\gamma} Z B}{8\pi \epsilon_\gamma E_{\rm CR}}$$

IMPLICATIONS for UHECR Sources

$$f^{\mathrm{CR}\gamma} = \frac{3L_\gamma \sigma_{\mathrm{CR}\gamma} Z B}{8\pi \epsilon_\gamma E_{\mathrm{CR}}} = \frac{s_1}{s_2}$$

Photo-disintegration threshold:

$2E_{\mathrm{CR}}\epsilon_\gamma > A m_p c^2 E_{\mathrm{bind.}}$, where $m_p c^2 E_{\mathrm{bind.}} = 10^{16}\ \mathrm{eV}^2$

Since,

$$L_\gamma[10^{40}\mathrm{erg\ s}^{-1}] = 2\times 10^{41}\mathrm{eV\ cm}^{-1}$$
$$\sigma_{\mathrm{CR}\gamma}[\mathrm{A\ mb}] = \mathrm{A}\times 10^{-27}\ \mathrm{cm}^2$$
$$B[1\ \mathrm{G}] = 300\ \mathrm{eV\ cm}^{-1}$$

$\frac{L_\gamma \sigma_{\mathrm{CR}\gamma} B}{A} = 6\times 10^{16}\ \mathrm{eV}^2$, ergo.... $f^{\mathrm{CR}\gamma} = 50\frac{Z}{26}$

IMPLICATIONS for UHECR Sources

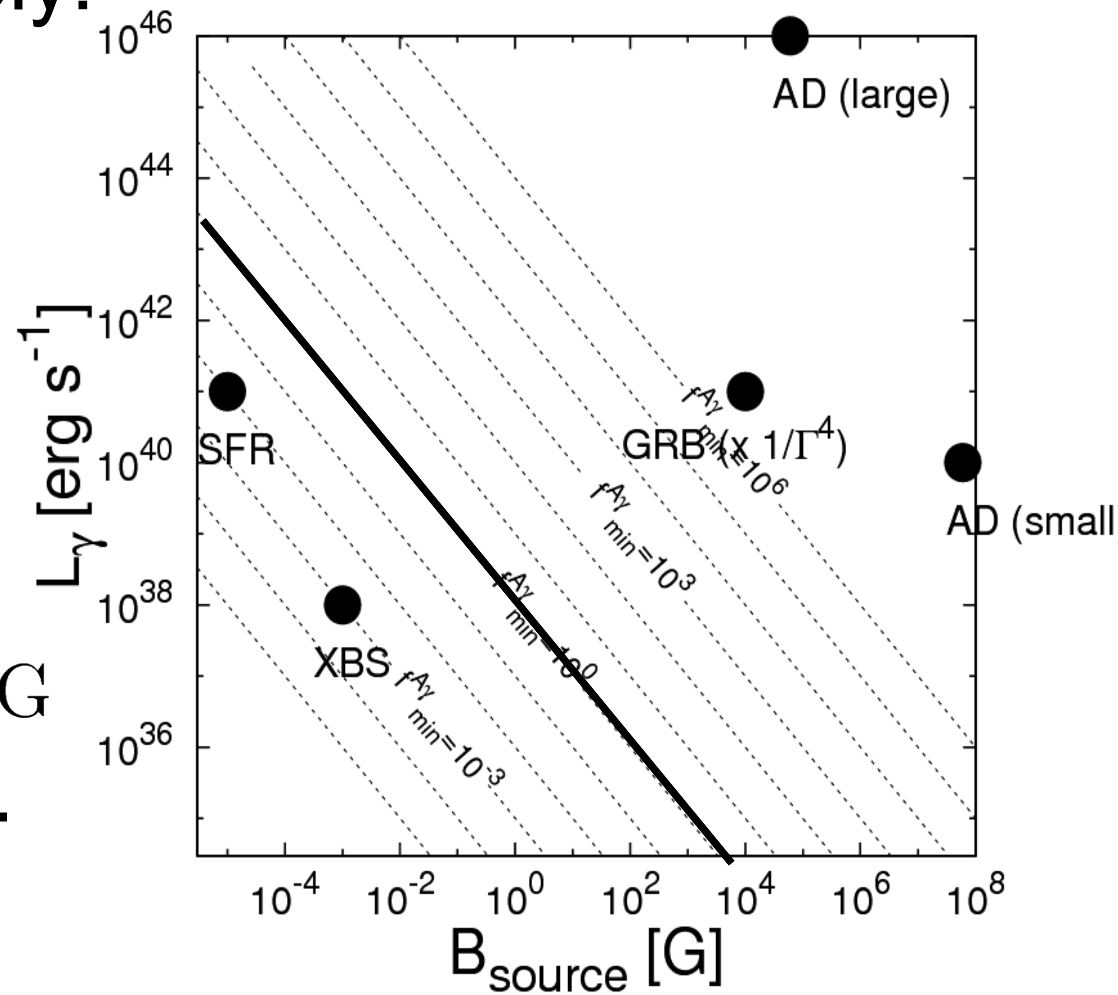
Since, $$\frac{L_\gamma^{\mathrm{Edd.}}\sigma_{\mathrm{CR}\gamma}B^{\mathrm{Edd.}}}{A} = 4\times 10^{23}\left(\frac{M}{M_\odot}\right)^{1/2}\ \mathrm{eV}^2$$

Only heavily sub-Eddington power objects need apply!

If magnetic + photon luminosity are in equipartition:

$$L_\gamma \approx \beta R^2 B^2$$

Requiring, $B < 4\times 10^{-5}$ G to ensure safe passage.



IMPLICATIONS for UHECR Sources

Since, $$\frac{L_\gamma^{\mathrm{Edd.}} \sigma_{\mathrm{CR}\gamma} B^{\mathrm{Edd.}}}{A} = 4 \times 10^{23} \left(\frac{M}{M_\odot}\right)^{1/2} \ \mathrm{eV}^2$$

Only heavily sub-Eddington power objects need apply!

If magnetic + photon luminosity are in equipartition:

$$L_\gamma \approx \beta R^2 B^2$$

WARNING:

$$R_{\mathrm{Larmor}}(10^{20}\ \mathrm{eV\ \ Fe}) \approx 0.1\ \mathrm{kpc}$$

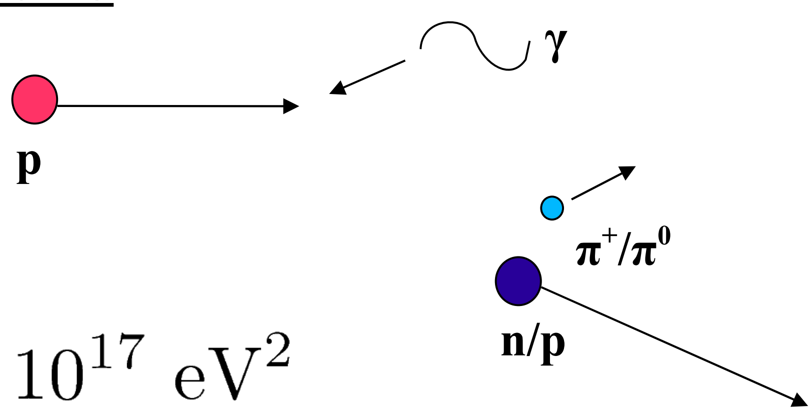
$$t_{\mathrm{acc}} \approx R_{\mathrm{Larmor}}/c\beta^2$$

Requiring, $$B < 4 \times 10^{-5}\ \mathrm{G}$$

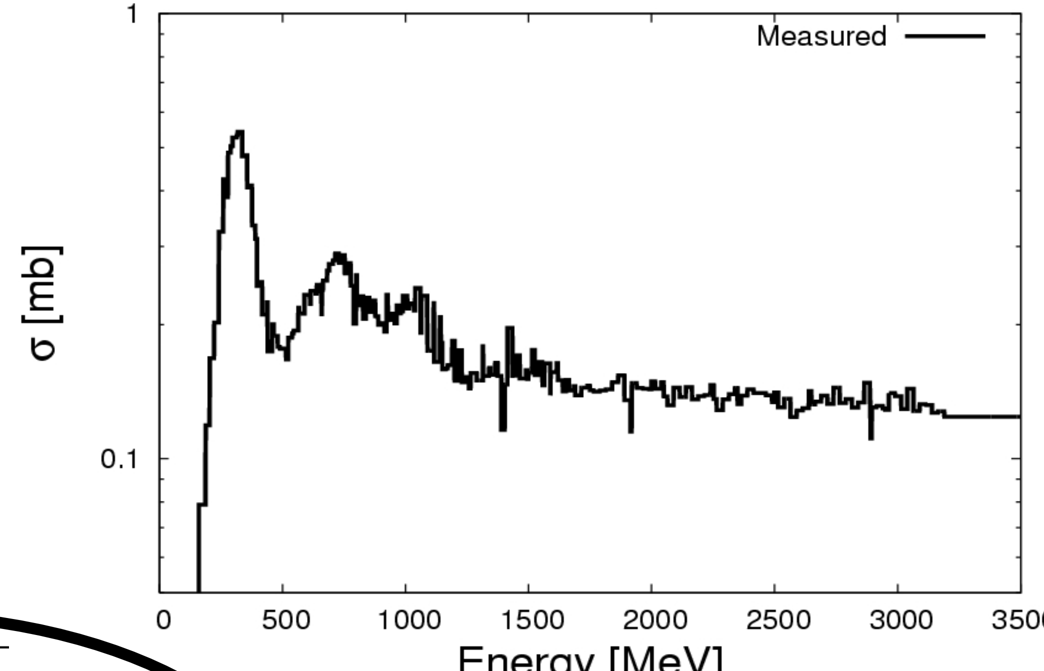
Part 2: Gamma-Rays

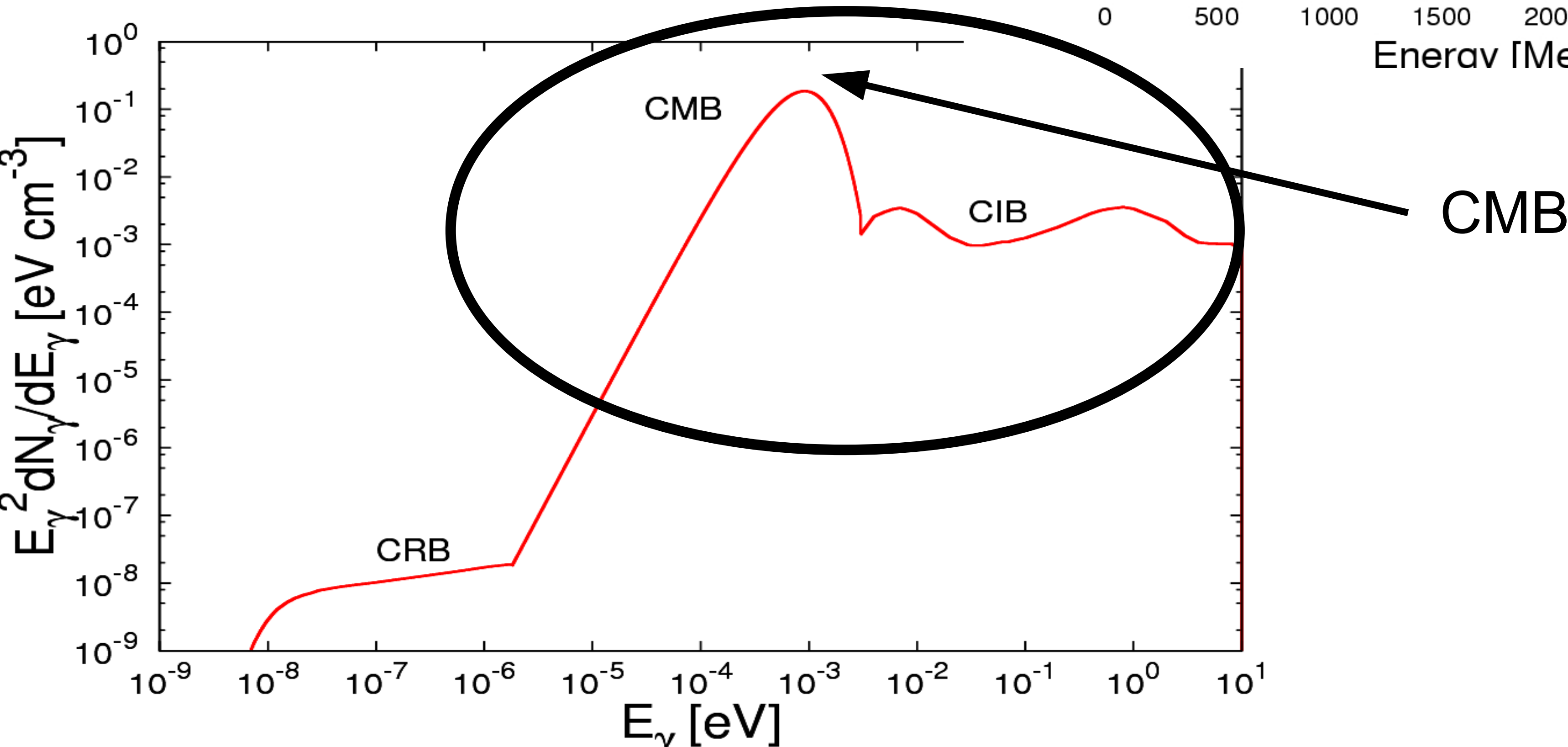
Gamma-Ray Production

protons

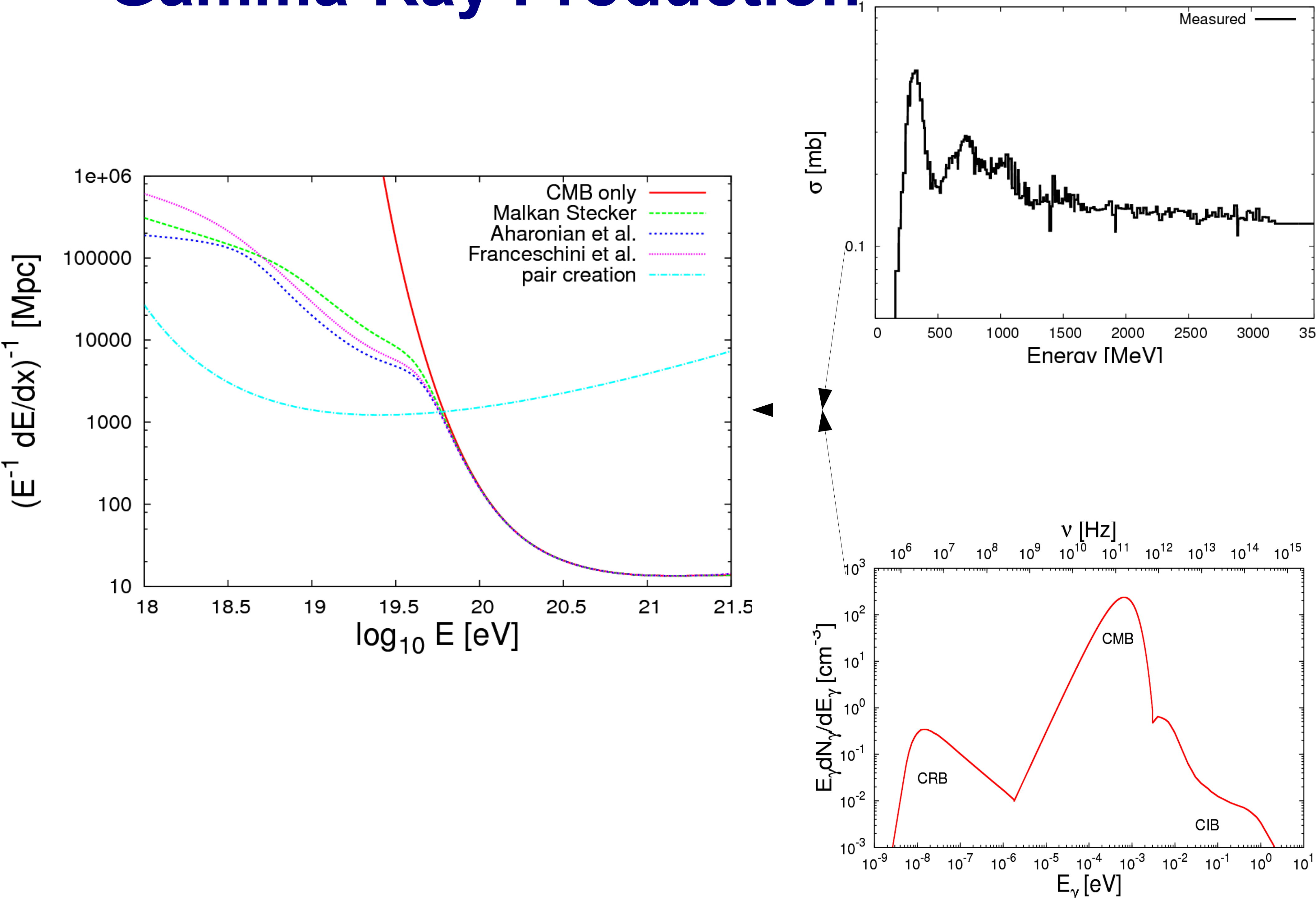


$$s \approx 10^{17}\ \mathrm{eV}^2$$

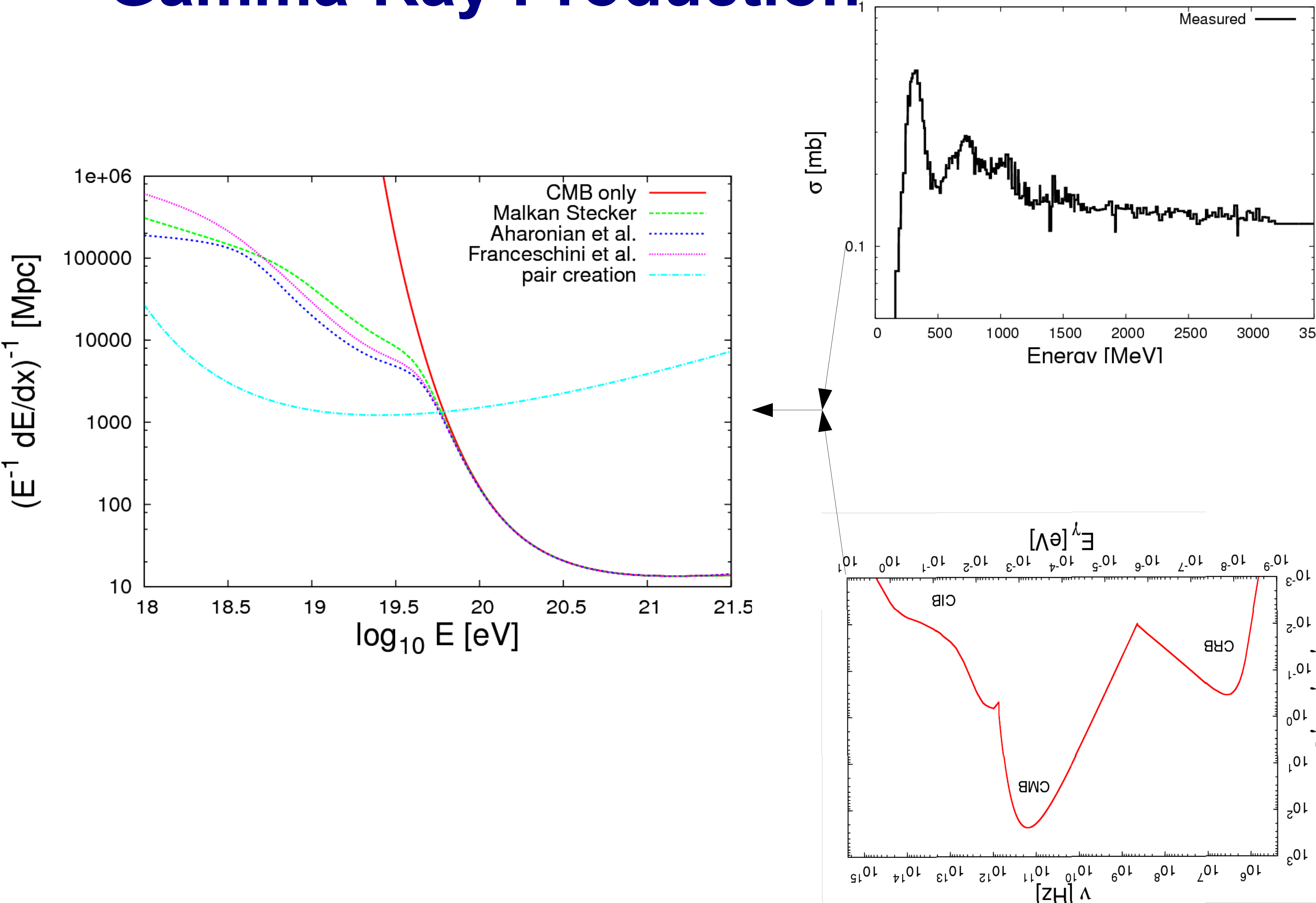




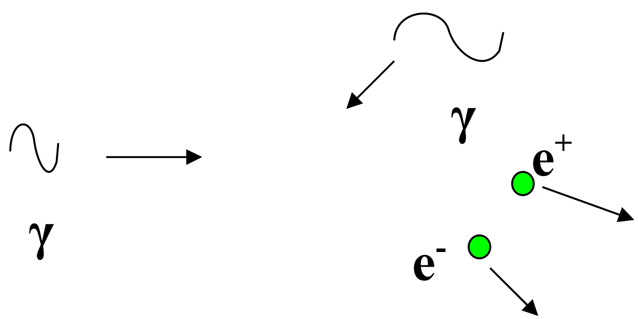
Gamma-Ray Production

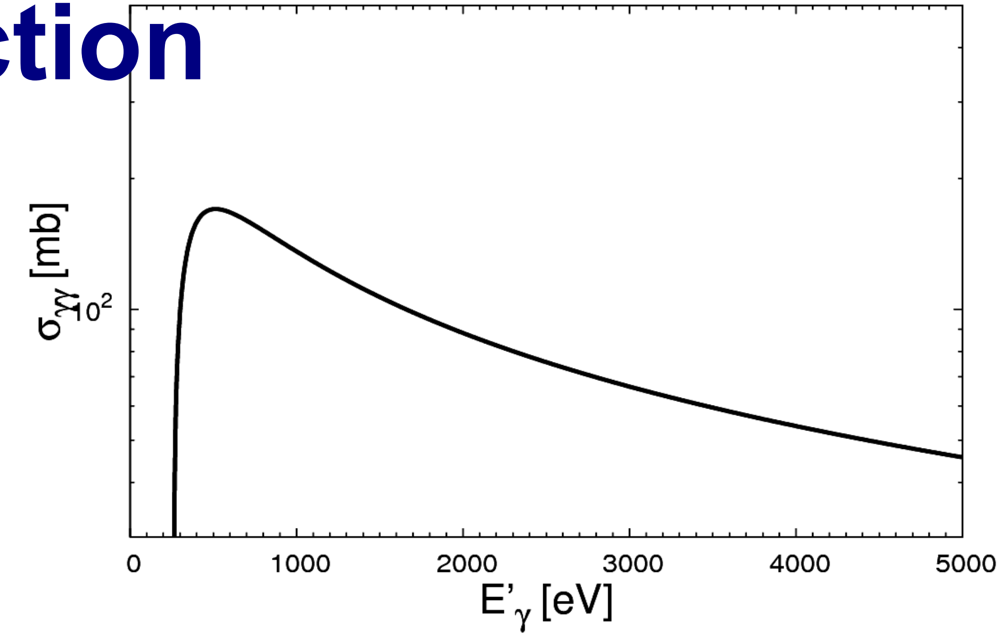


Gamma-Ray Production

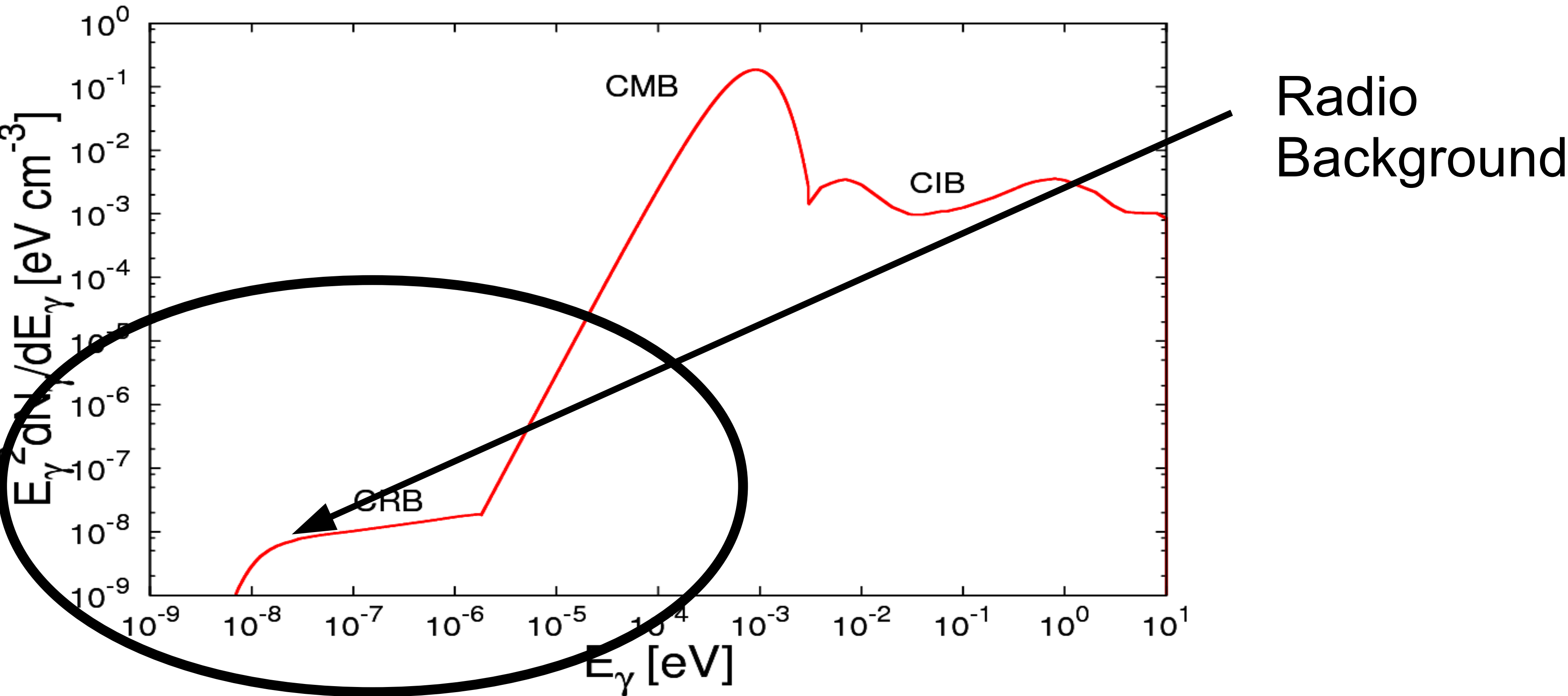


Gamma-Ray Interaction

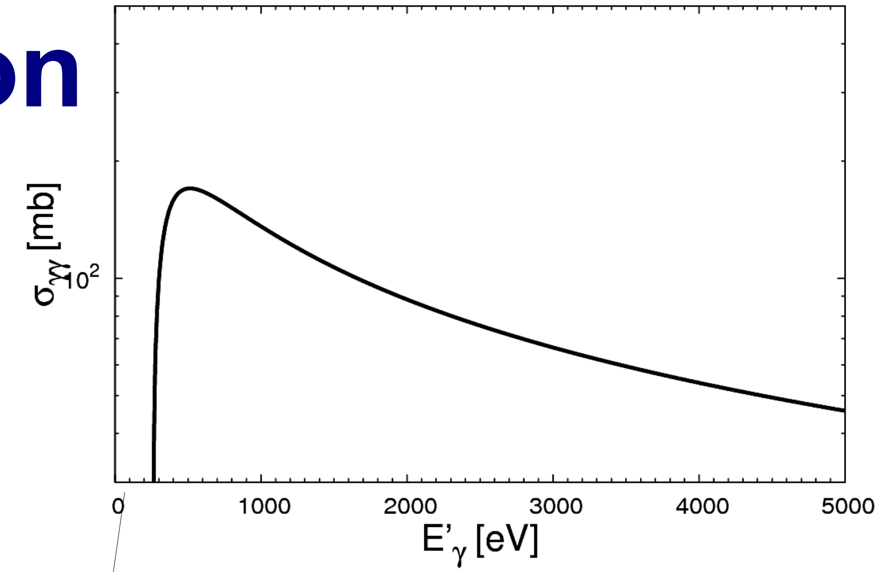


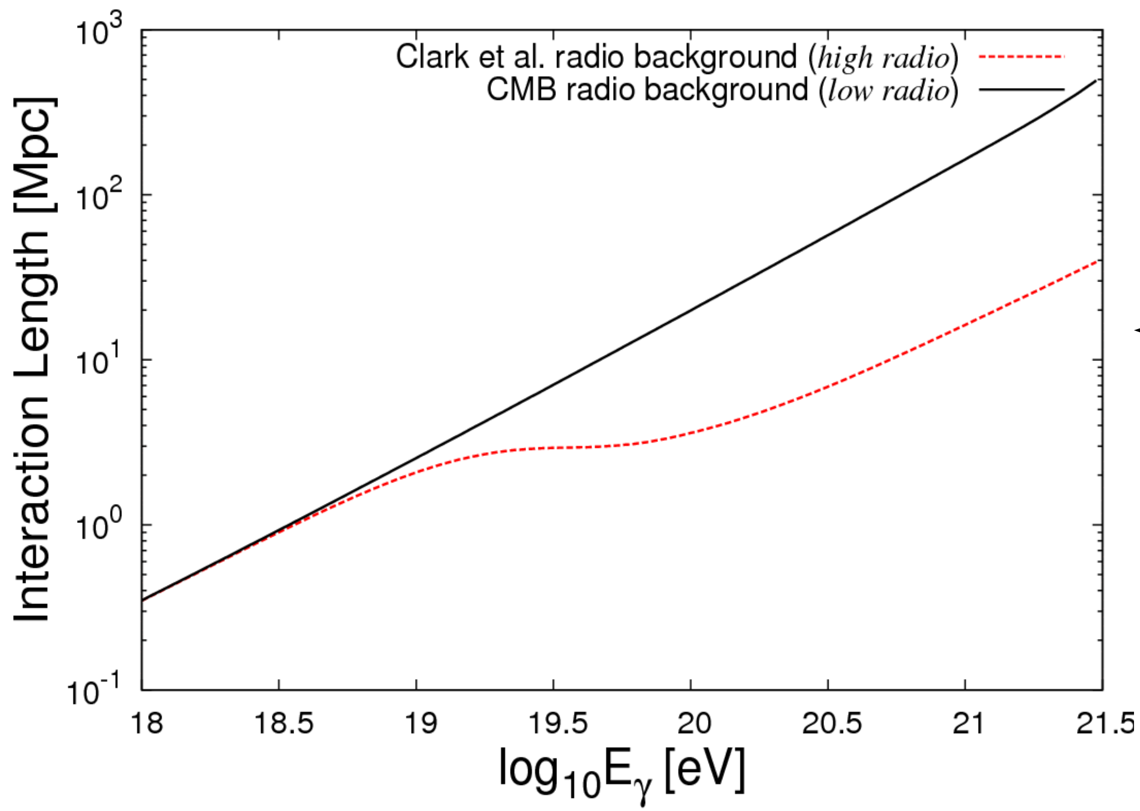


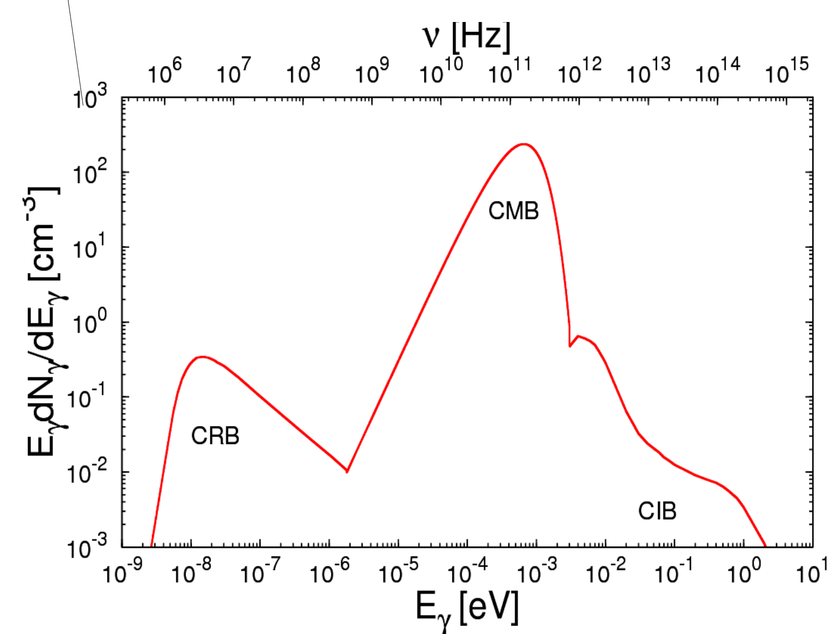
$$s \approx 10^{12}\ \mathrm{eV}^2$$



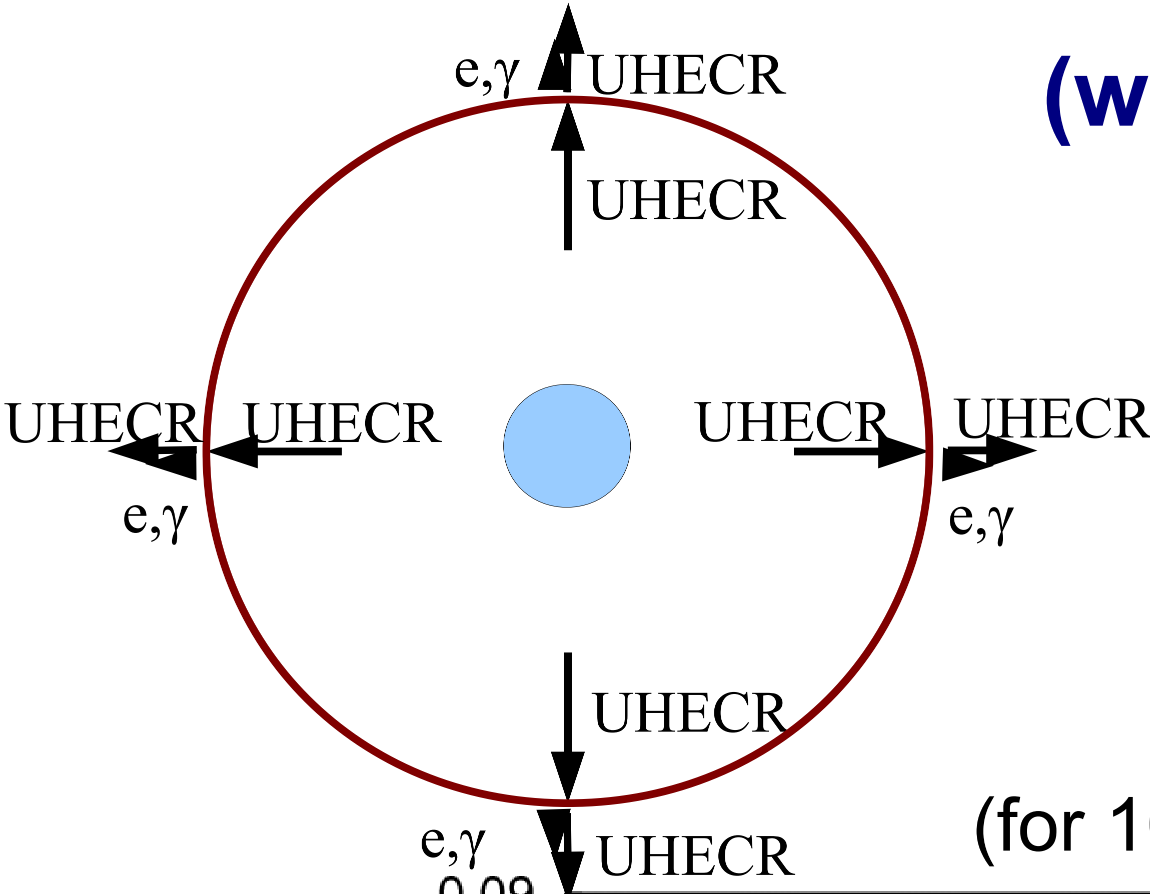
Gamma-Ray Interaction



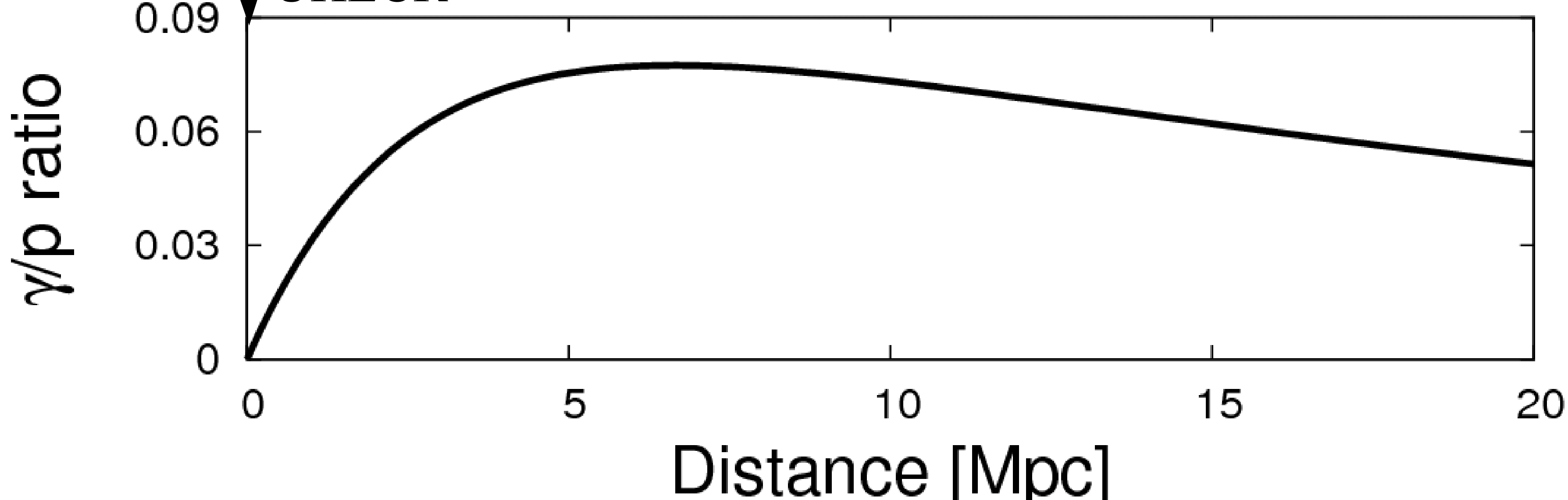




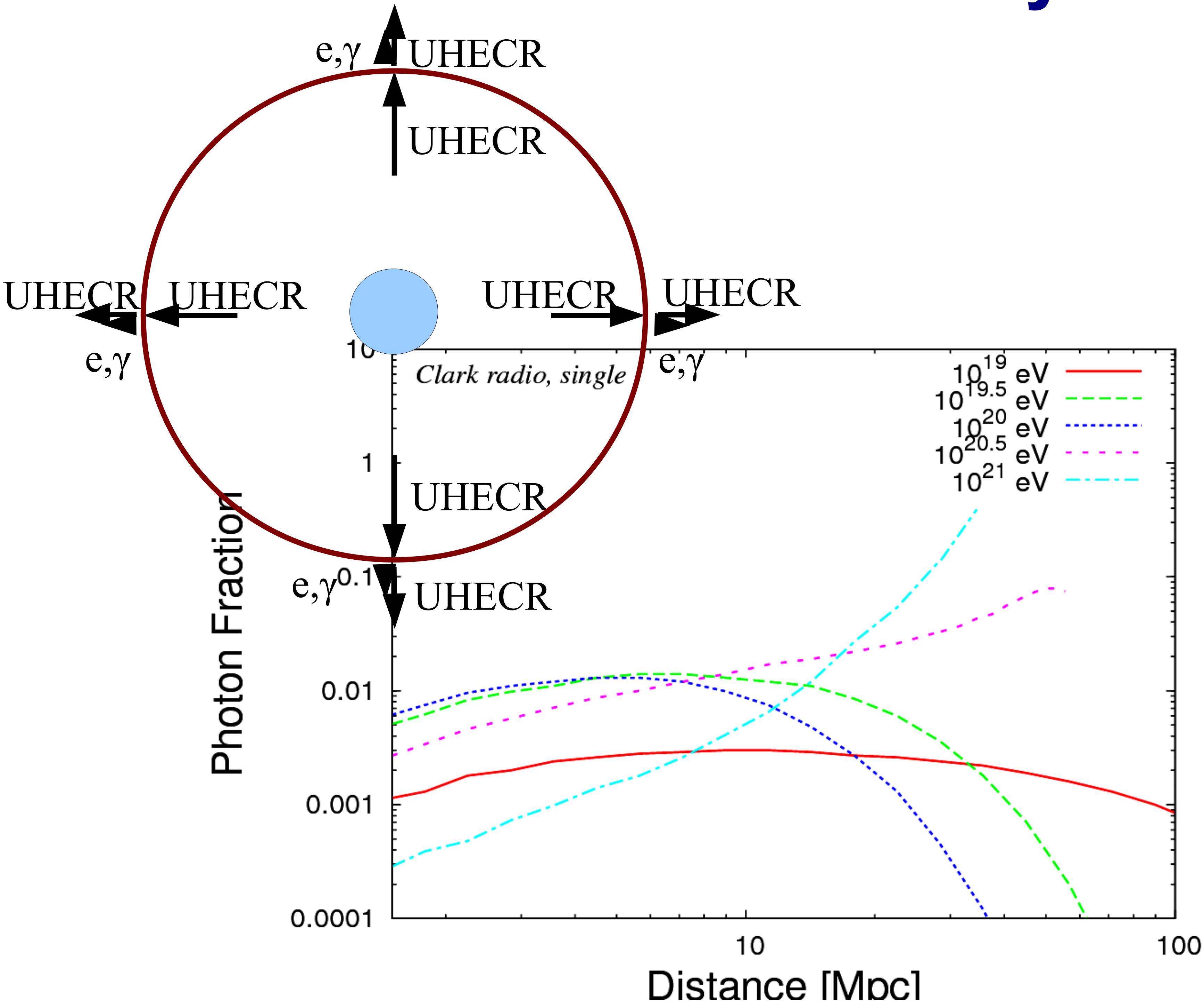
The Halo Around Heavenly Bodies (which acc. UHECR)



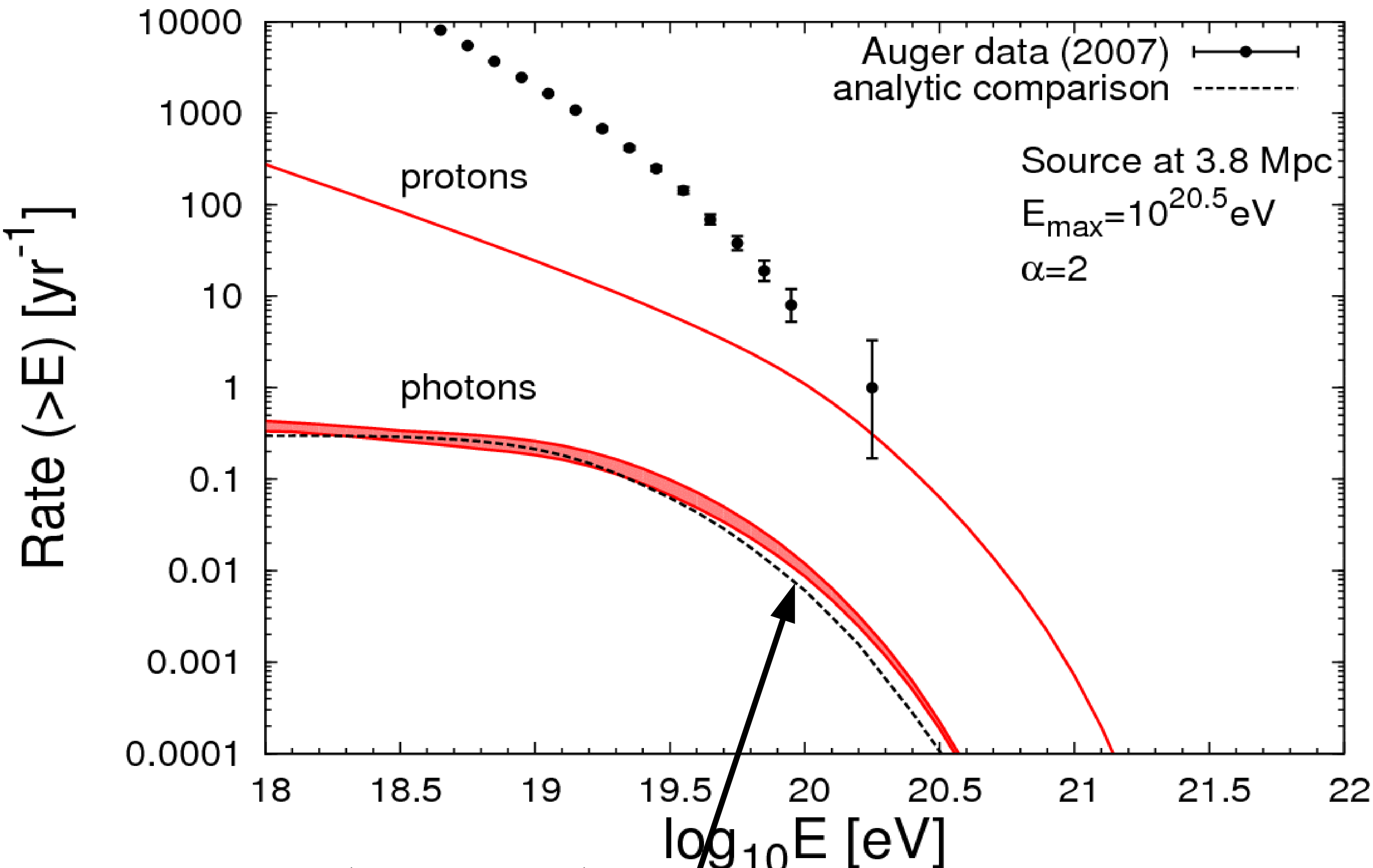
(for 10^{19}eV gamma-rays)



The Halo Around Heavenly Bodies



The Halo Around Cen A



$$\frac{N_\gamma(l)}{N_p(0)} = \frac{l_{\gamma\gamma}(e^{-l/l_{p\gamma}} - e^{-l/l_{\gamma\gamma}})}{(l_{p\gamma} - l_{\gamma\gamma})}$$

Conclusion

The dominance of nuclei at the highest energies provides useful new information about the nature of UHECR sources

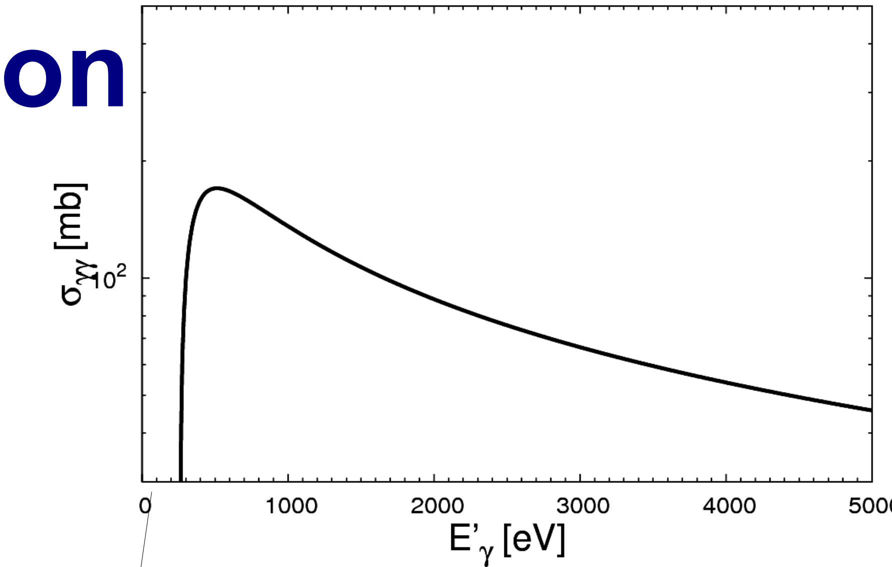
Regions close to luminous objects are excluded as UHECR sources, favouring slow acceleration scenarios

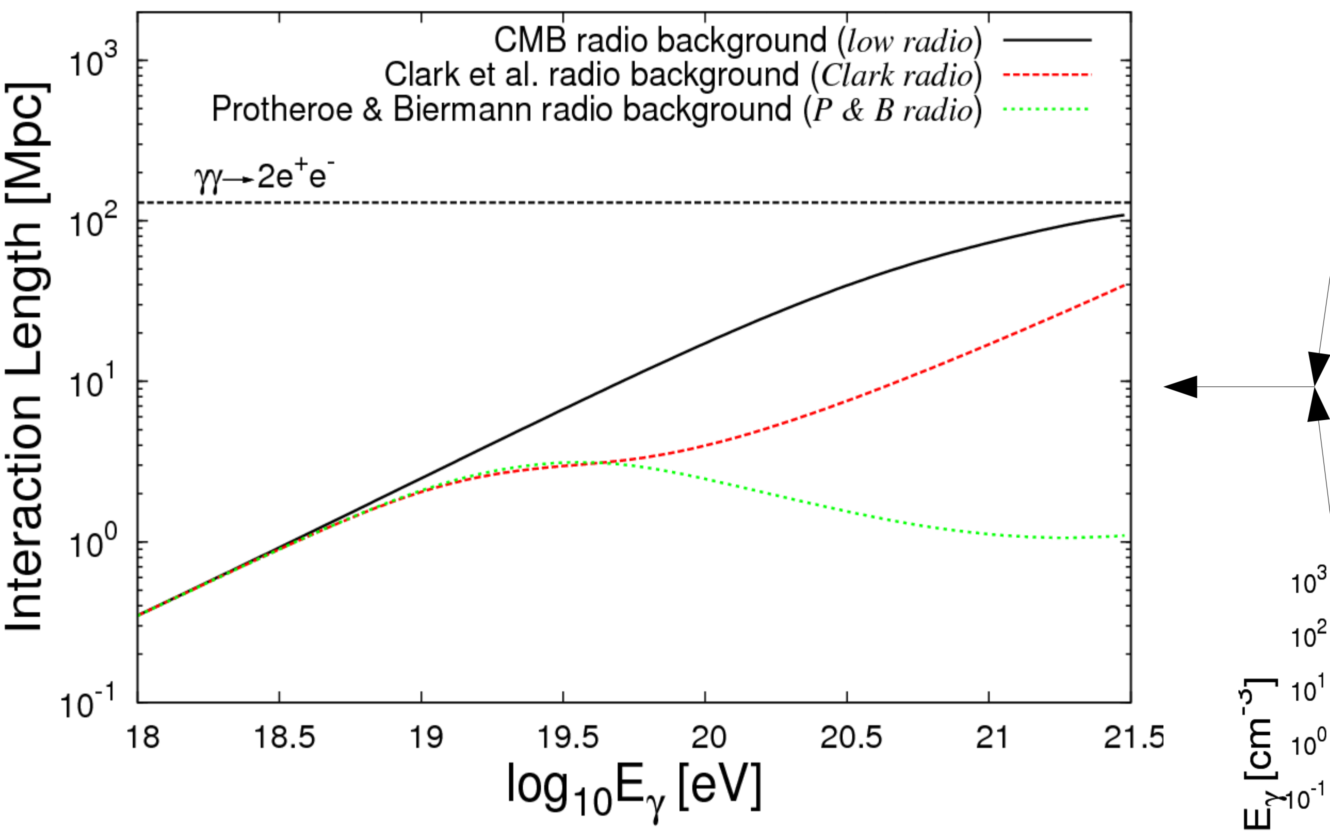
UHE photons can provide a useful probe of local sources

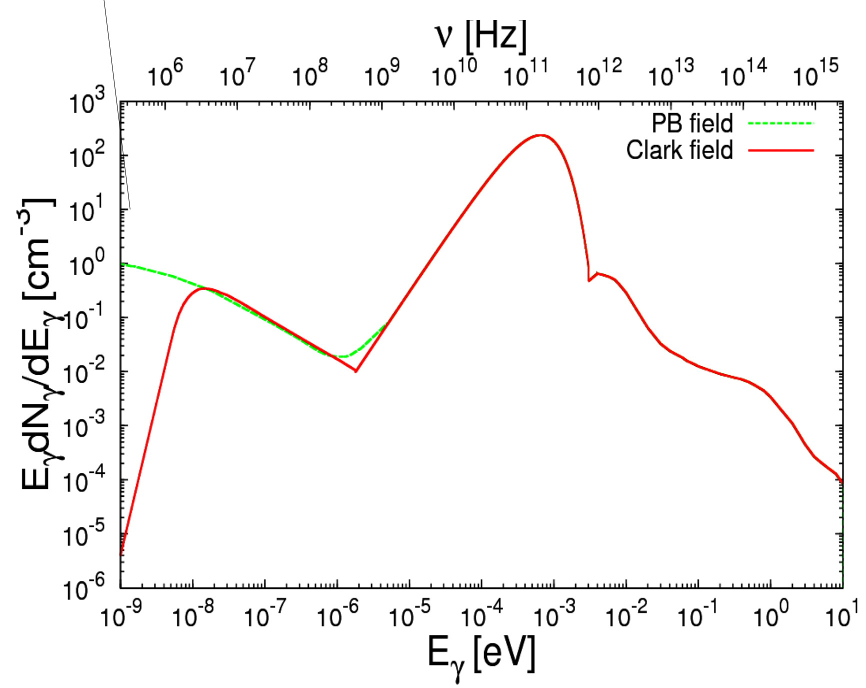
Applied to Cen A we expect an UHE photon in 5 years, if 2 UHECR in the PAO 57 UHECR set originated from Cen A.

Extra Slides

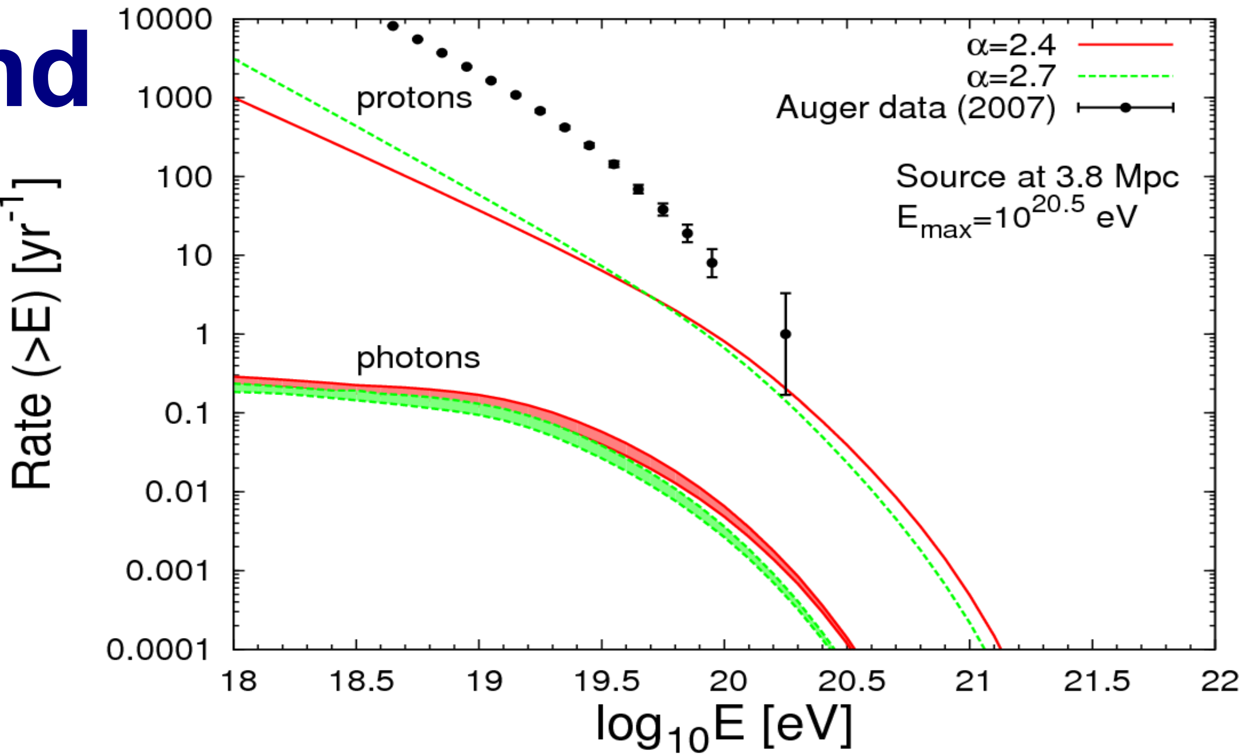
Gamma-Ray Interaction

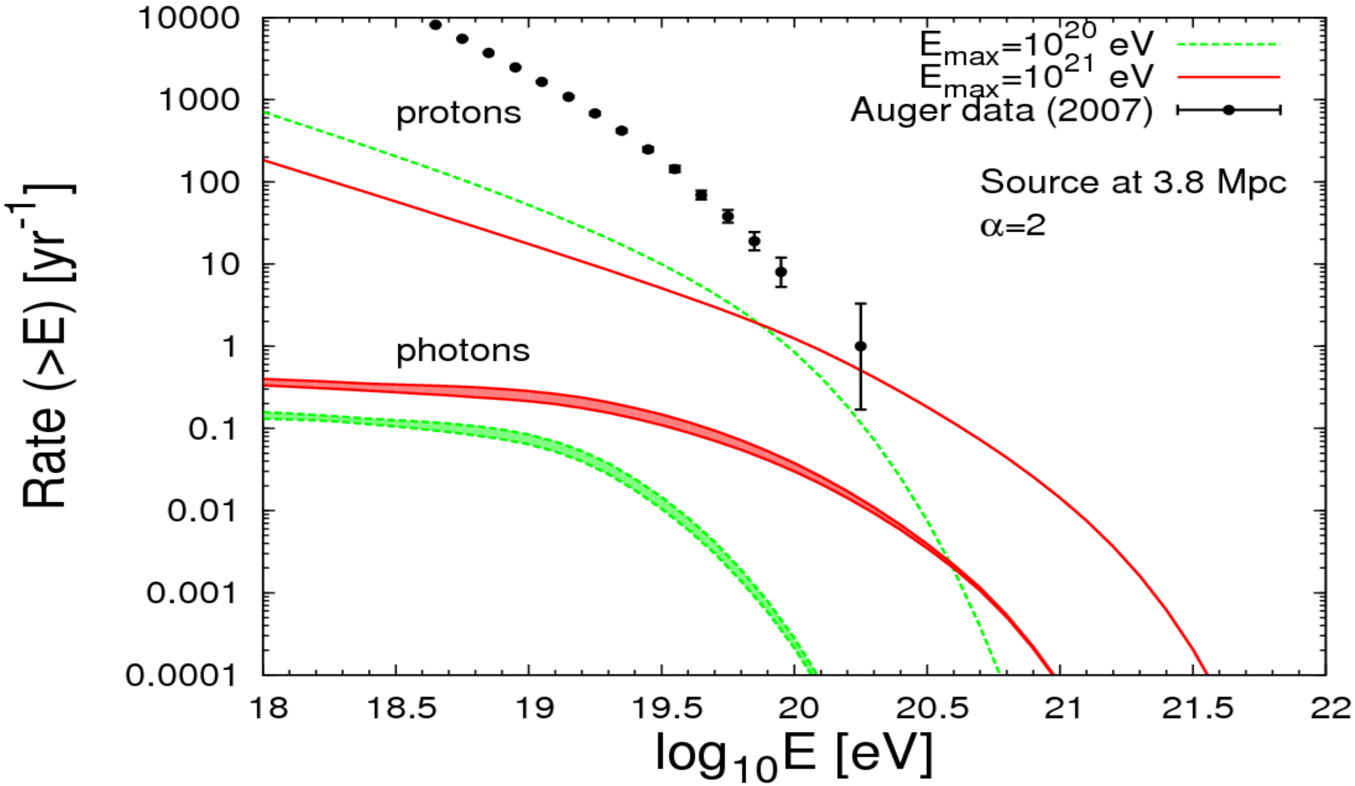






The Halo Around Cen A

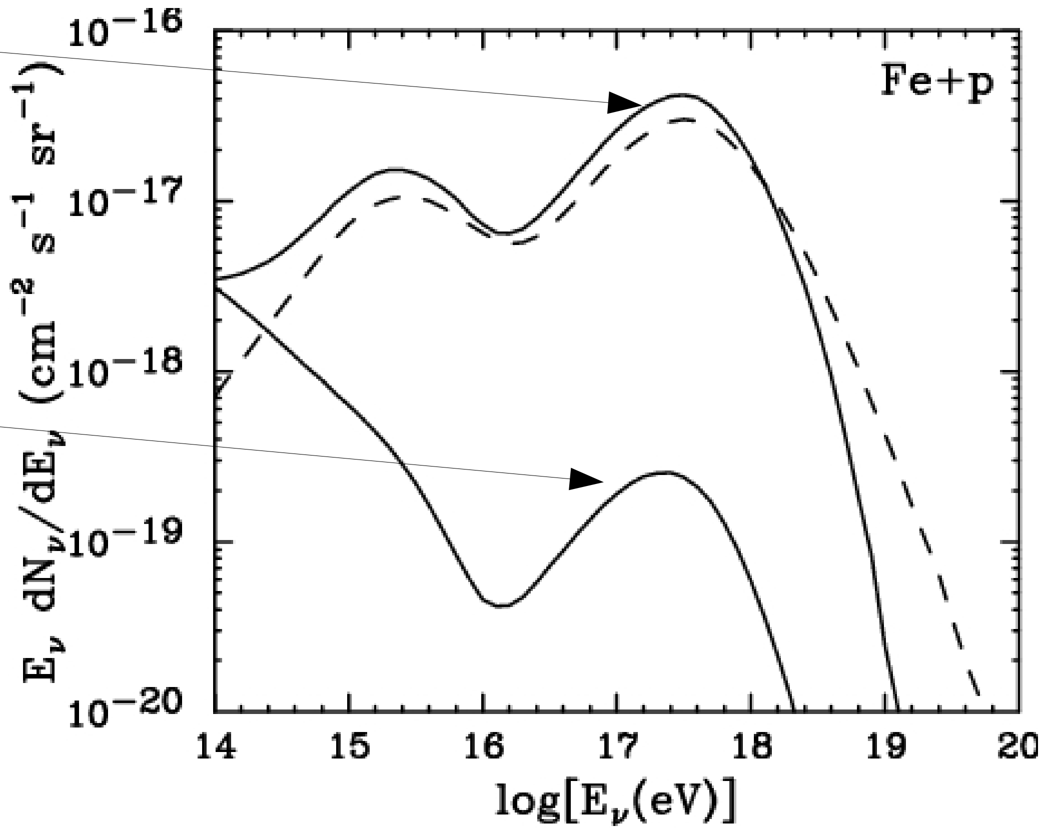




The Cosmogenic Neutrino Flux

The high energy (>10^{17} eV) flux quoted as the "Guaranteed flux" value

lowest value compatible with all the data



Smaller value obtained since best agreement found for a dominant Fe fraction with $\mathbf{E}_{max}=10^{21}$eV

Ratio Between Photo-Pion and Photo-Disintegration Rates (2)

with,

$$\sigma_{p,\gamma} = \text{٠.٥ mb}, \; E_{p,\gamma} = \text{٣١٠ MeV}, \; \Delta_{p,\gamma} = 100 \text{ MeV}$$

and

$$\sigma_{A_{56},\gamma} = 81 \text{ mb}, \; E_{A_{56},\gamma} = 18 \text{ MeV}, \; \Delta_{A_{56},\gamma} = 8 \text{ MeV}$$

therefore

$$R_{A_{56},\gamma}(\Gamma) \approx \frac{\sigma_{A_{56},\gamma}}{\sigma_{p,\gamma}} R_{p,\gamma}(15\,\Gamma) = 160\, R_{p,\gamma}(15\,\Gamma)$$