Probing the Intergalactic Magnetic Field Using Intensity Fluctuations in the Extragalactic Gamma-ray Background*

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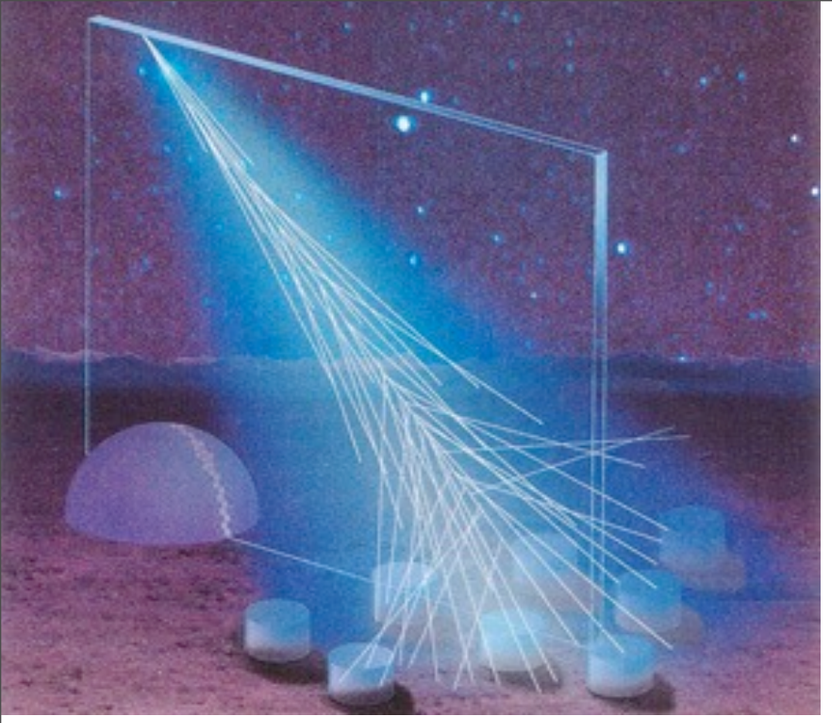
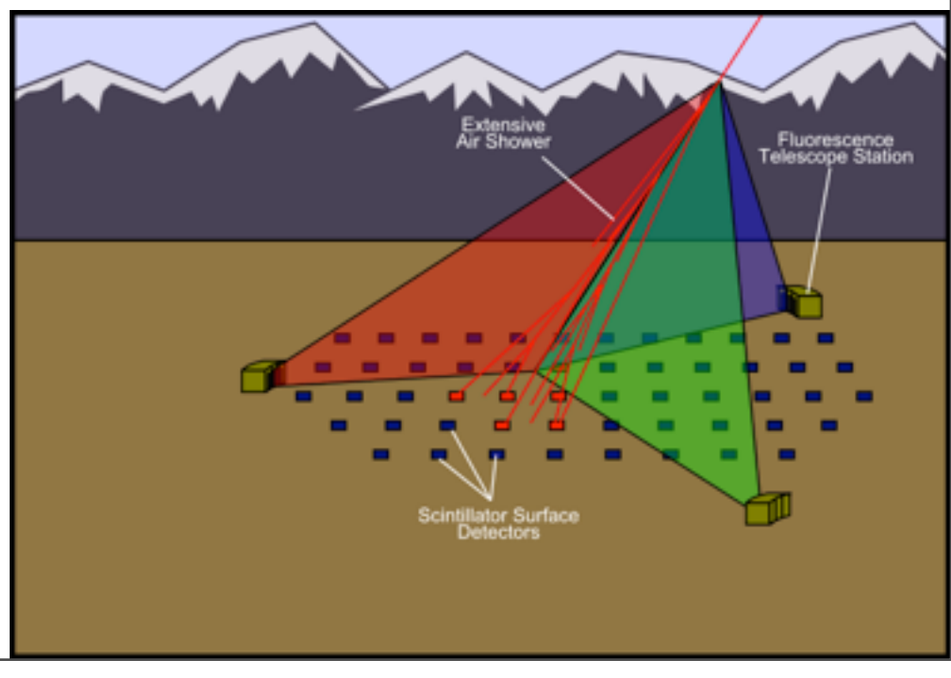
*based on Venters & Pavlidou 2013, MNRAS, 432, 3485

The Problem...



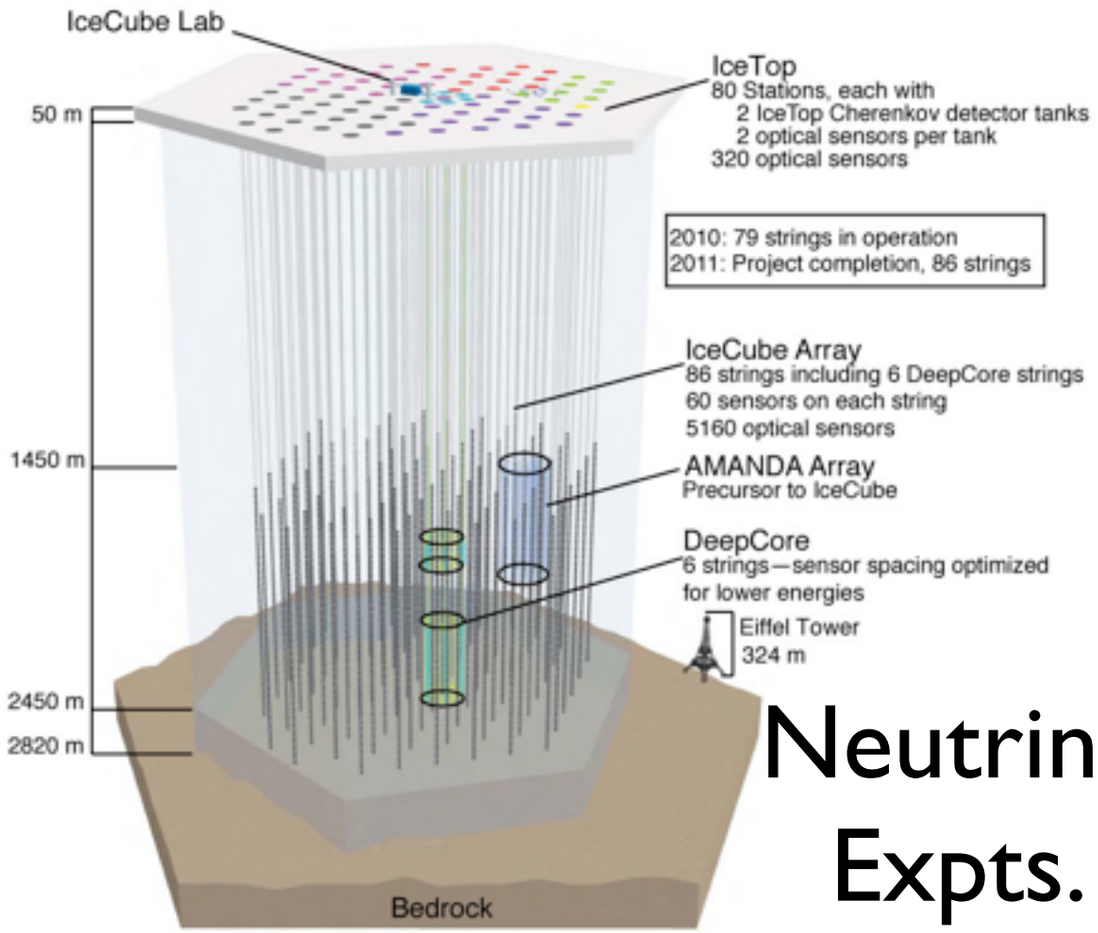
Pierre Auger (concept)



Telescope Array (concept)

Our Allies

Gamma-ray Satellites

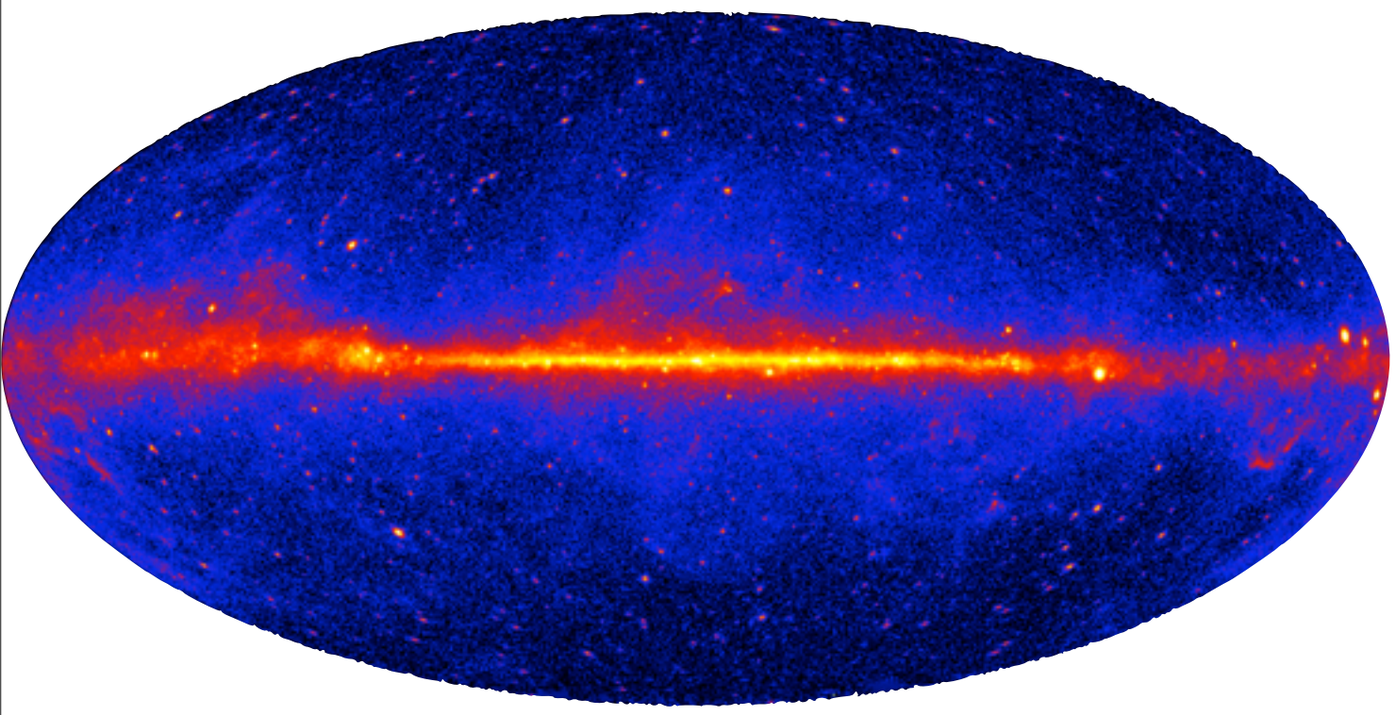


Neutrino Expts.

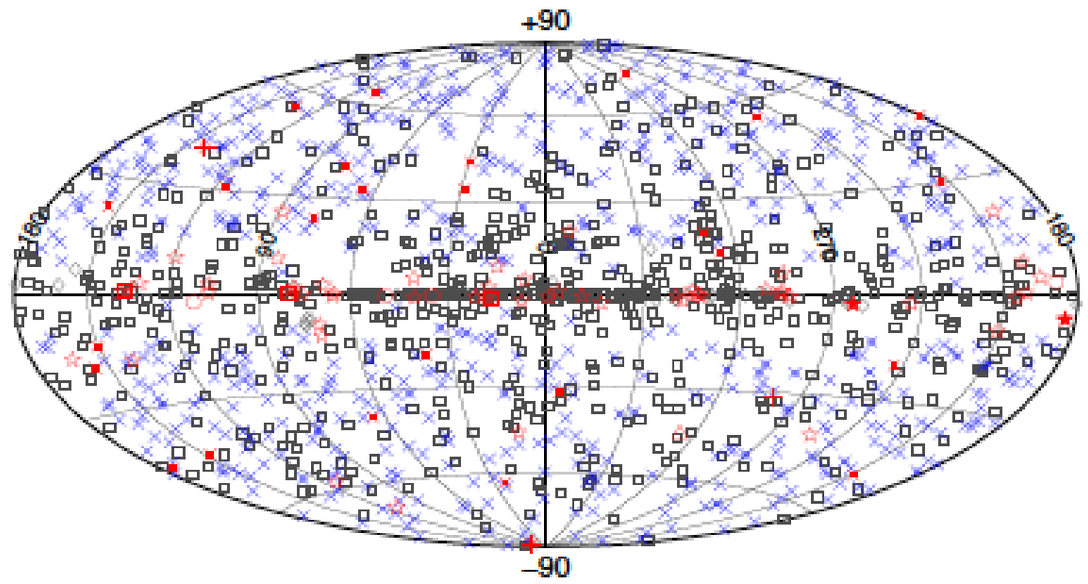
Air Shower Arrays

IACTs

The Gamma-ray Sky

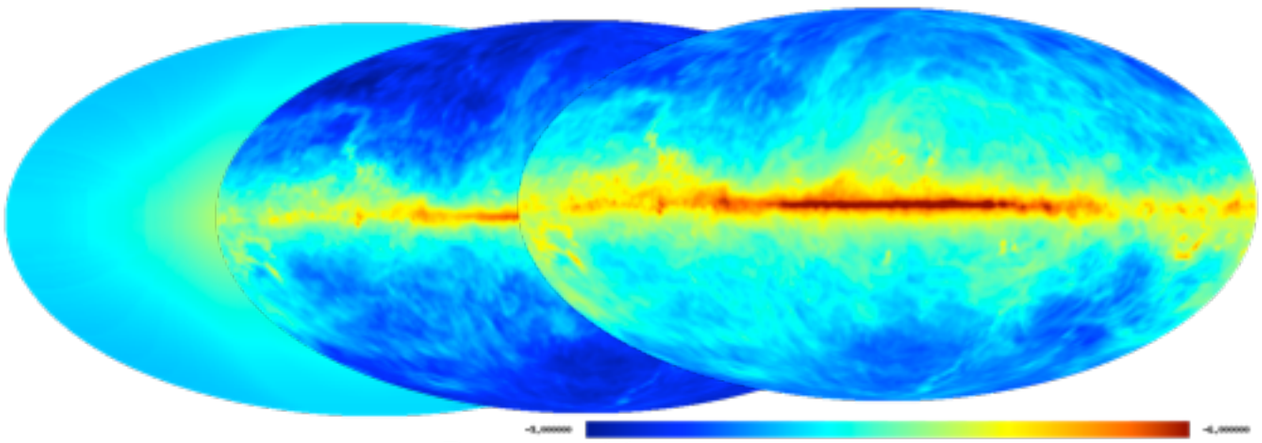


Resolved Point Sources



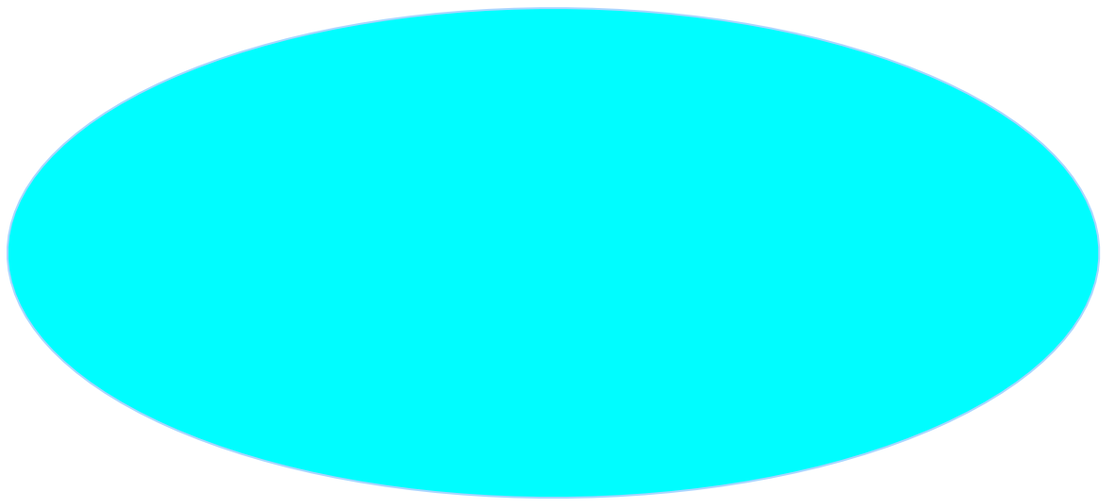
Inverse Compton

π^0-decay



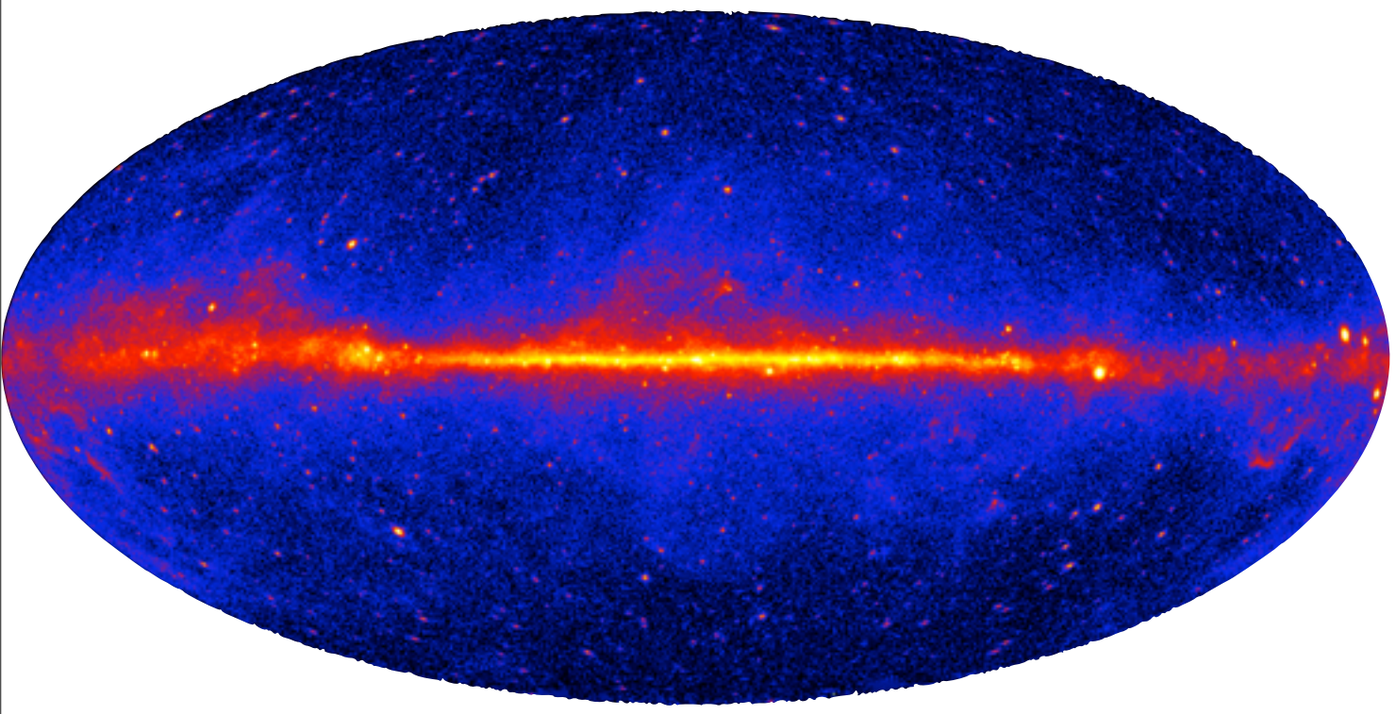
Bremsstrahlung

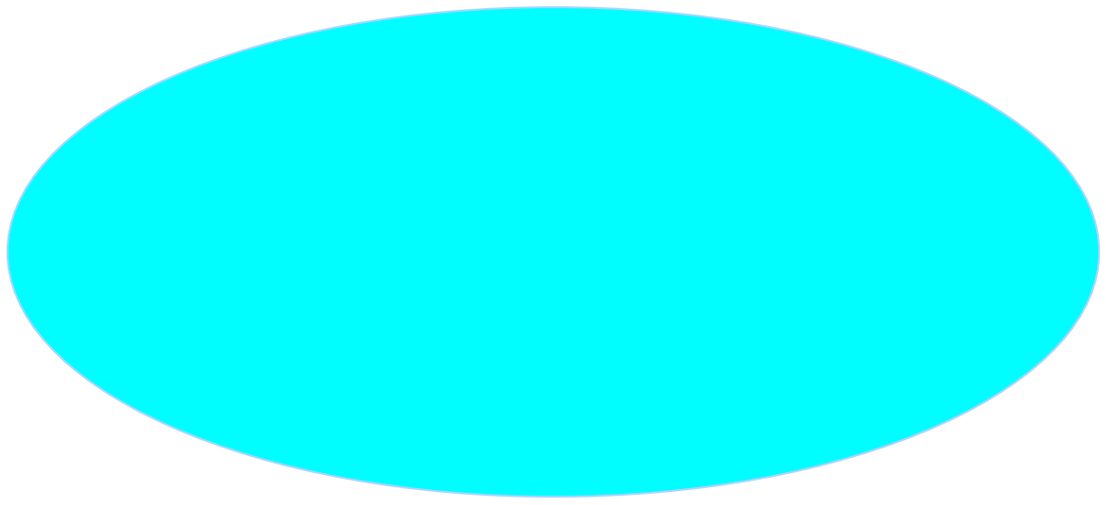
Galactic diffuse emission
(CR interactions with the interstellar medium)



Isotropic diffuse emission
(presumably extragalactic)

Gamma-ray Sky (after subtraction)

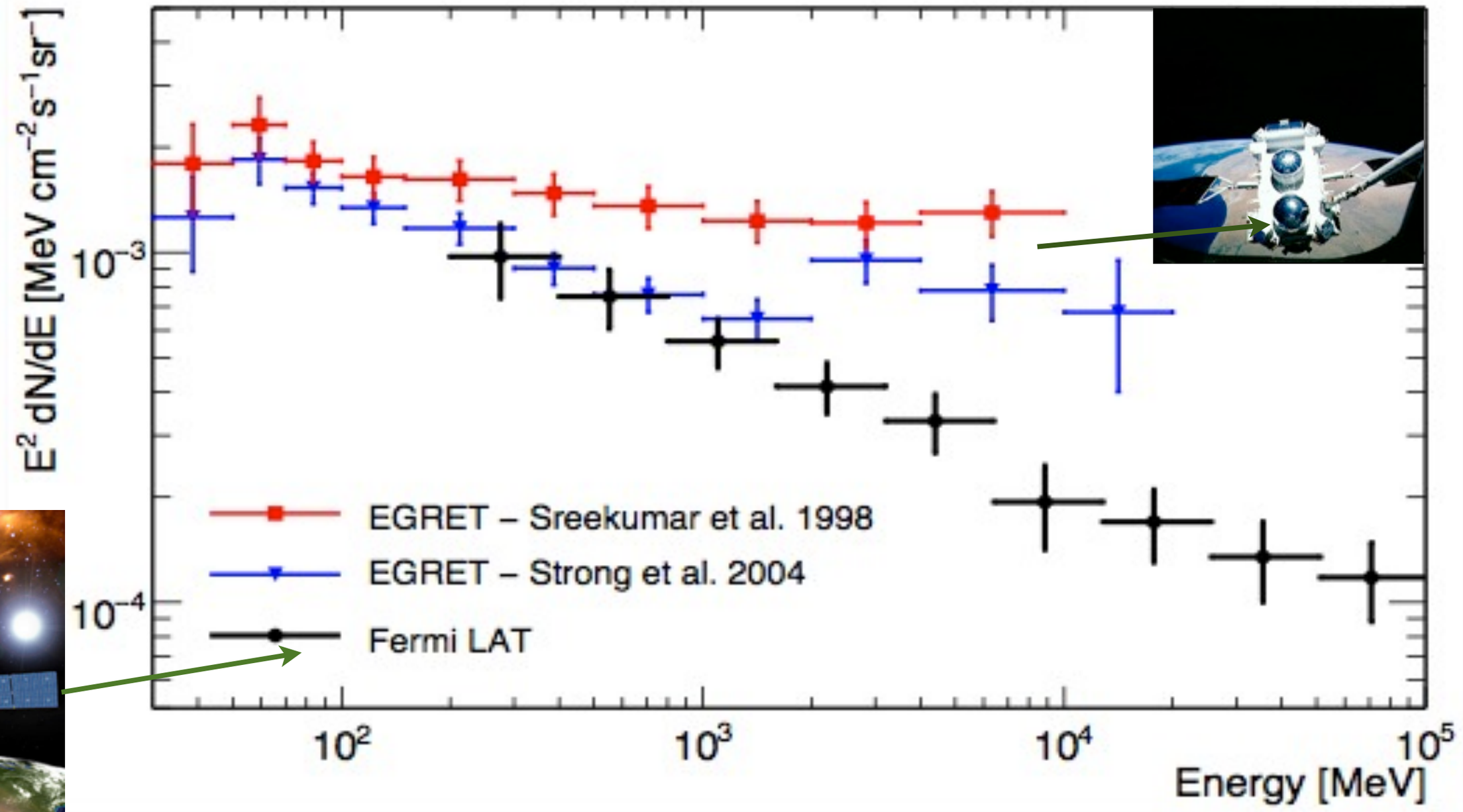




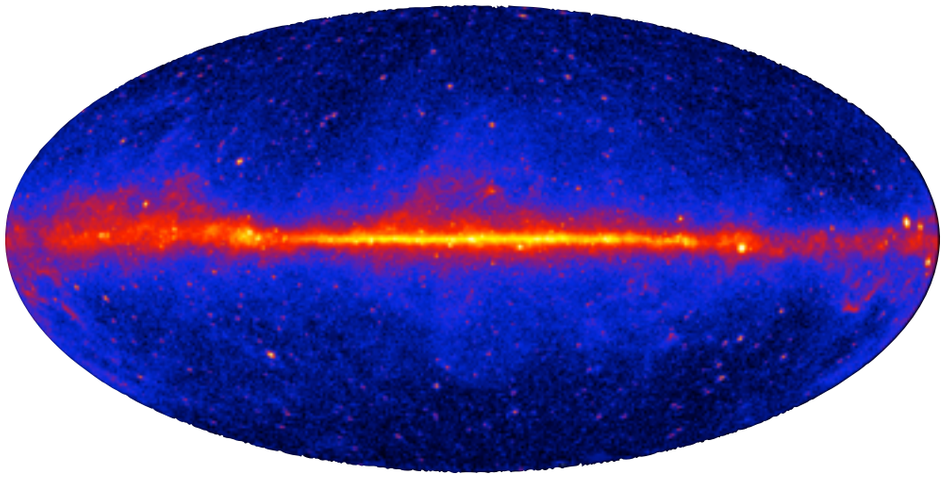
Isotropic diffuse emission
(presumably extragalactic)

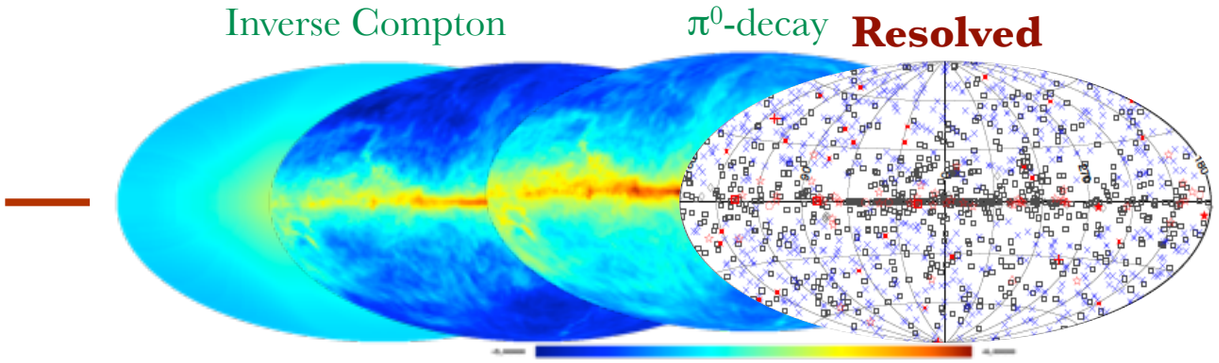
The Spectrum of the EGB

Isotropic diffuse emission
(presumably extragalactic)

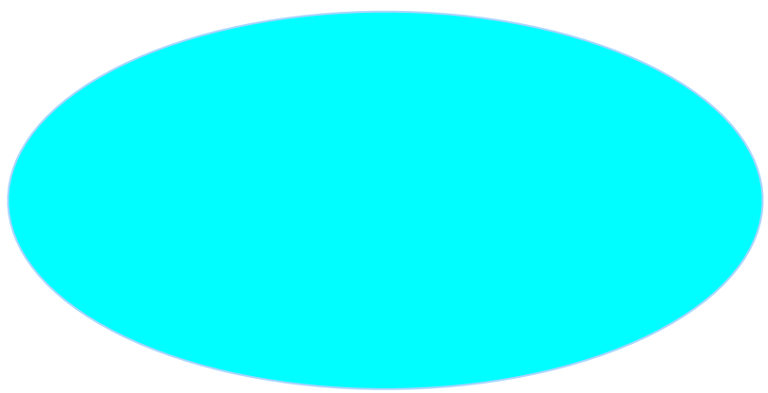


Components of the EGB





Galactic diffuse emission
(CR interactions with the interstellar medium)



Isotropic diffuse emission
(presumably extragalactic)

Known players:

- Star-forming galaxies
- Active galaxies (blazars, and maybe some from other types of radio galaxies)

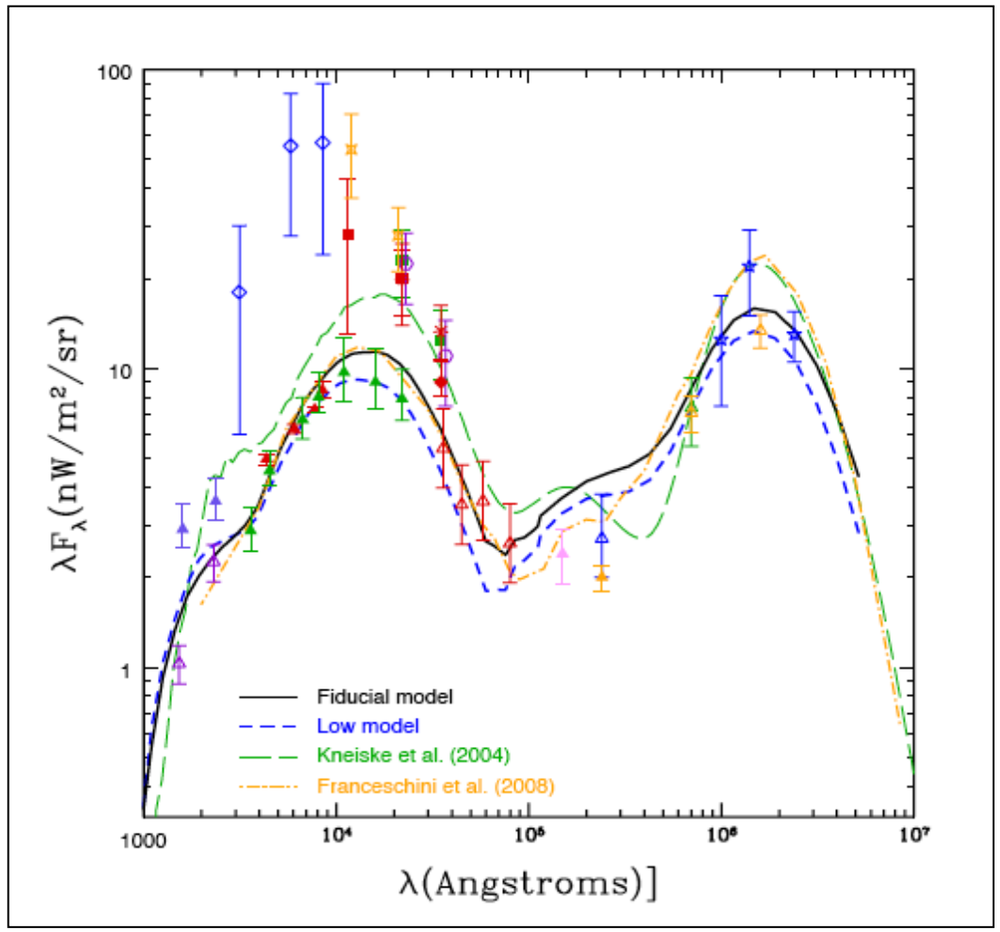
Suspected contributors:

- Truly diffuse emission - gamma rays produced in EM cascades of highly energetic particles

Players about which we like to speculate:

- Exotic physics (e.g., dark matter annihilation?)

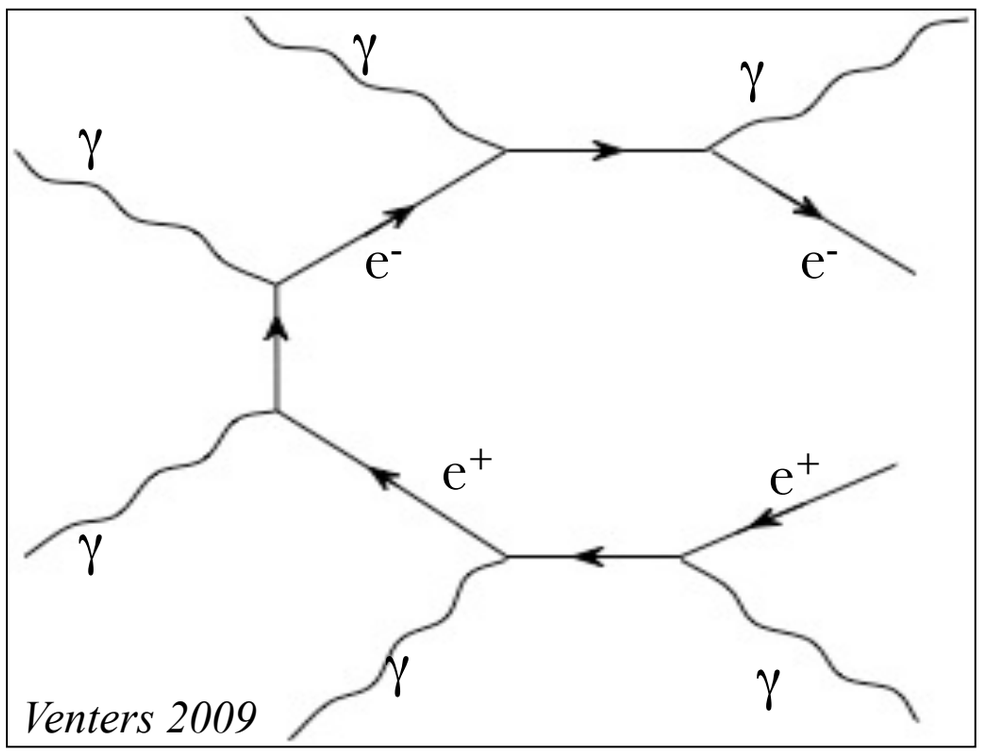
VHE Gamma Rays in the EBL



Gilmore et al. 2009

Extragalactic background light (EBL) consists of:

- Emission from starlight at NIR/Opt./UV wavelengths
- Reradiated thermal dust emission at FIR wavelengths



Venters 2009

Cascades -

- e^+e^- pair production
- inverse Compton scattering of cascade electrons

See also D. Williams' talk (tomorrow)

Magnetic Deflection of Cascades

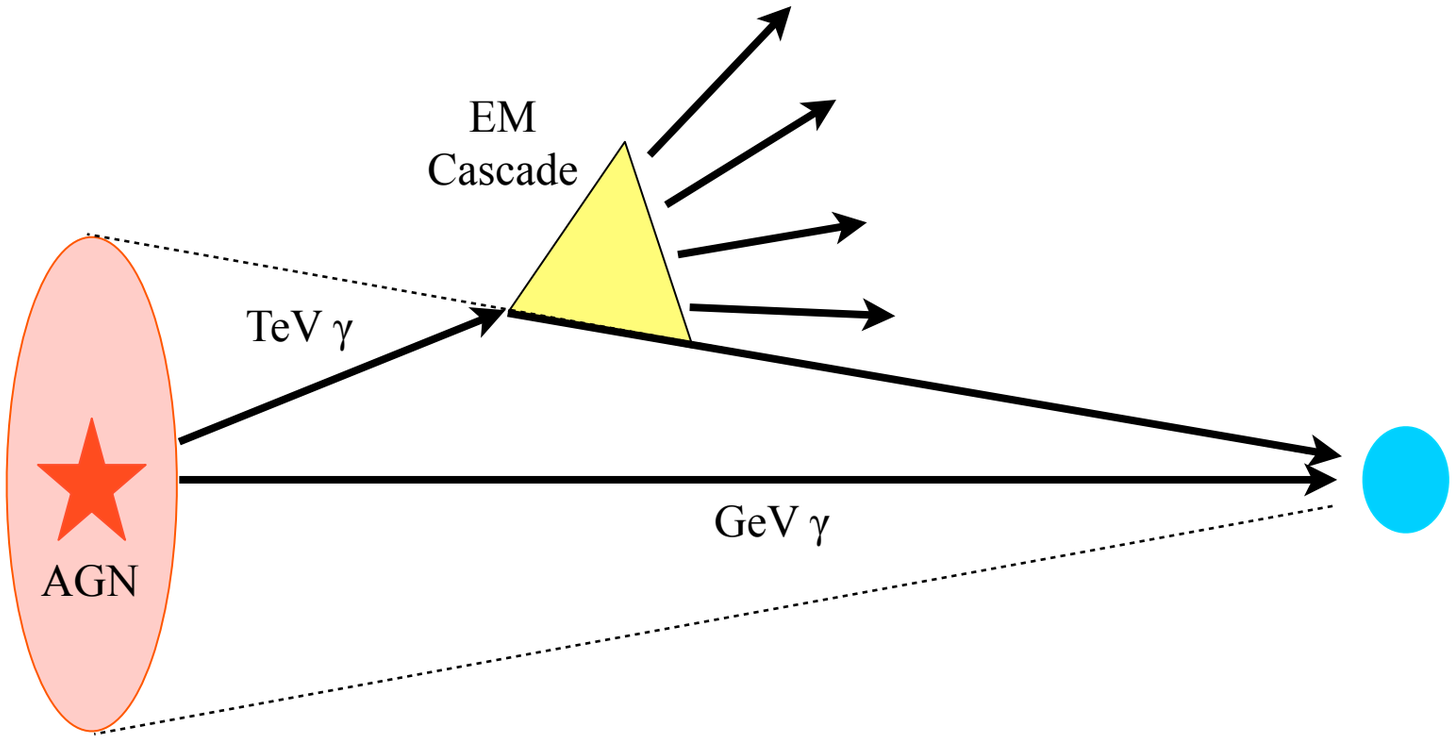


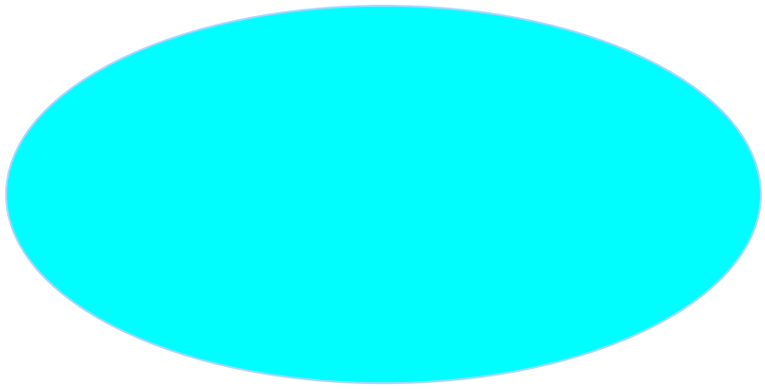
image credit: Ando 2009

- Gamma-rays initially emitted off observer's line-of-sight initiate cascades that are deflected in direction of observer.

- Deflected emission makes a halo around source.

See also W. Essey's talk (tomorrow)

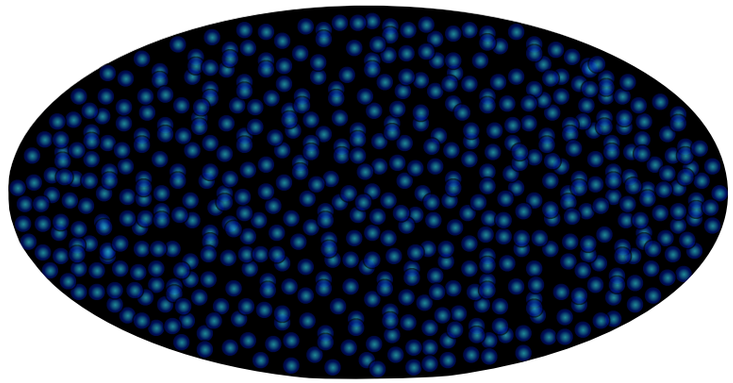
Anisotropy Studies



Isotropic diffuse emission
(presumably extragalactic)

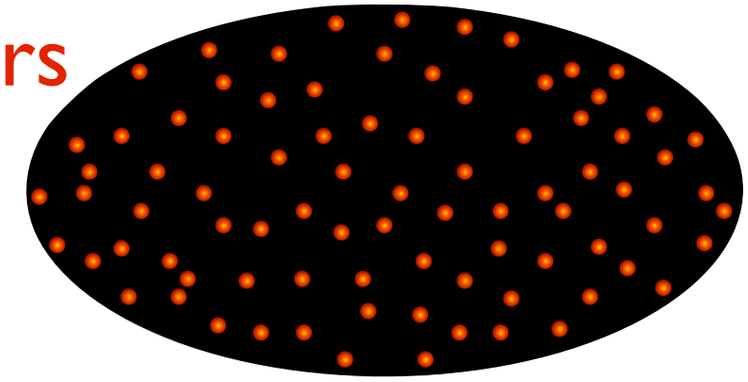
Star-forming Galaxies

$$\frac{\partial I}{I} = \sum_{l=1}^{\infty} \sum_{m=-l}^{l} a_{lm} Y_{lm}$$



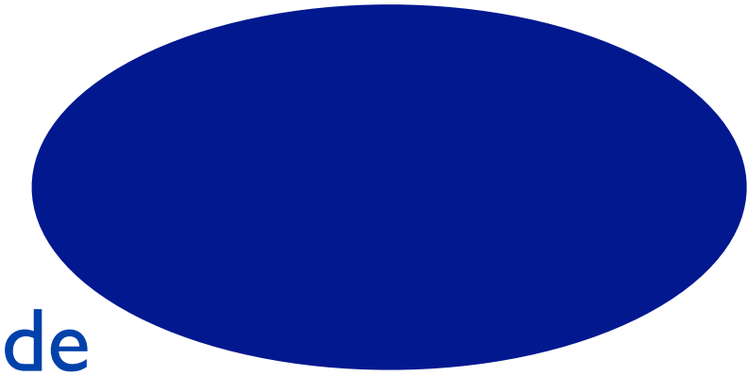
$$\langle a_{lm} a^*_{l'm'} \rangle = C_l$$

Blazars



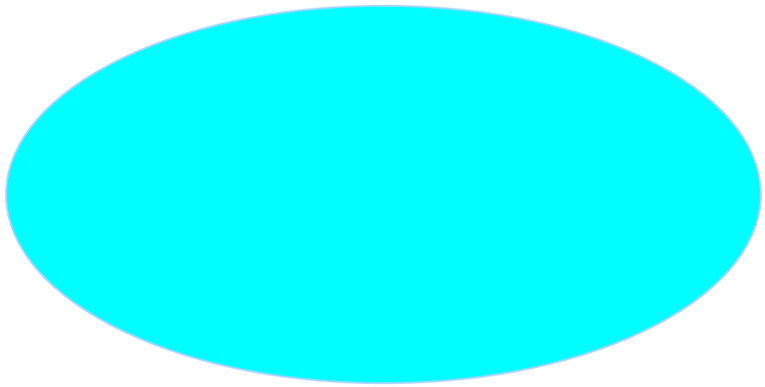
$$C_l^{\text{tot}}(E) = f_1{}^2(E) C_l^{(1)} + f_2{}^2(E) C_l^{(2)} + \text{cross terms},$$

$$\text{where } f_n(E) = I_n(E)/I_{\text{tot}}(E)$$



Deflected Cascade

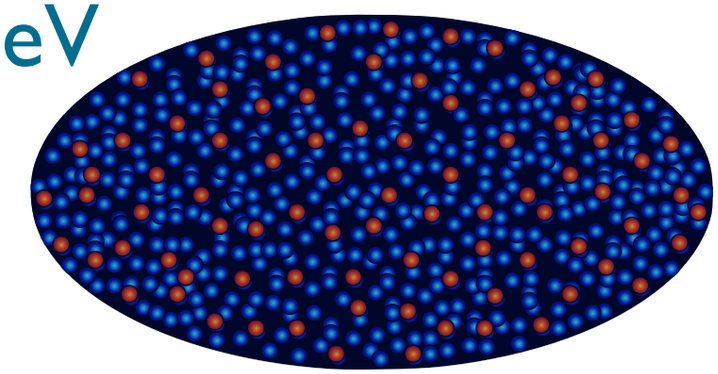
Anisotropy Studies



Isotropic diffuse emission
(presumably extragalactic)

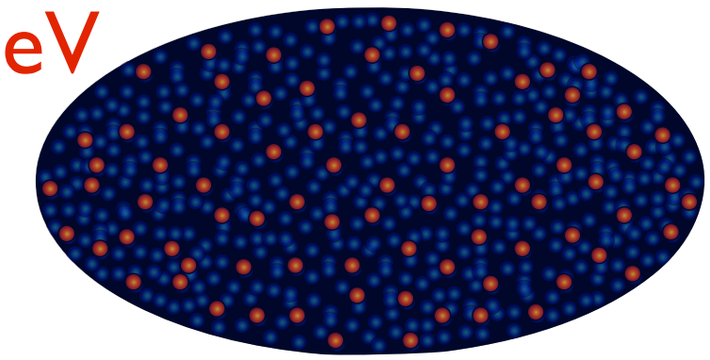
$$\frac{\partial I}{I} = \sum_{l=1}^{\infty} \sum_{m=-l}^{l} a_{lm} Y_{lm}$$

~ 1 GeV



$$\langle a_{lm} a^*_{l'm'} \rangle = C_l$$

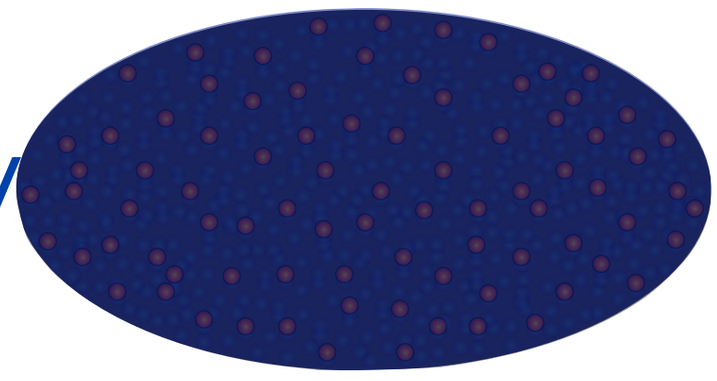
~ 10 GeV



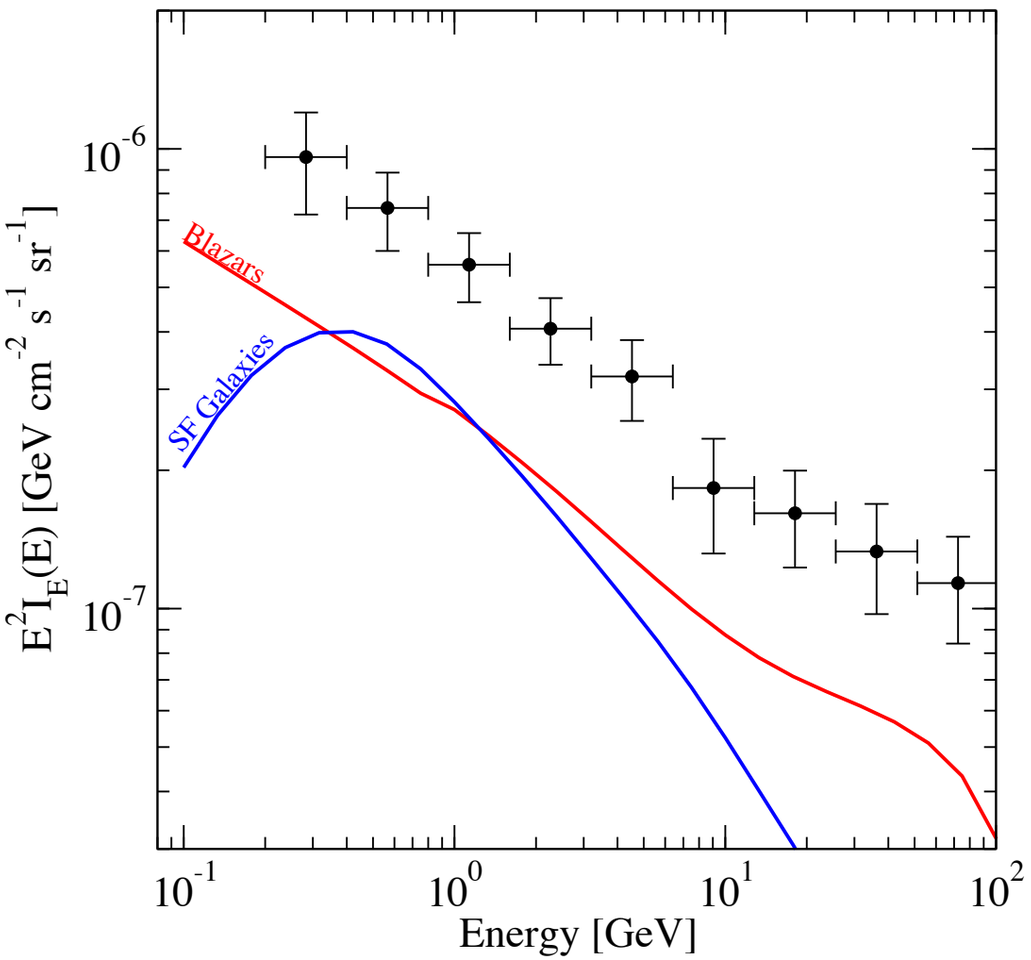
$$C_l^{\mathrm{tot}}(E) = f_1{}^2(E) C_l^{(1)} + f_2{}^2(E) C_l^{(2)} + \text{cross terms},$$

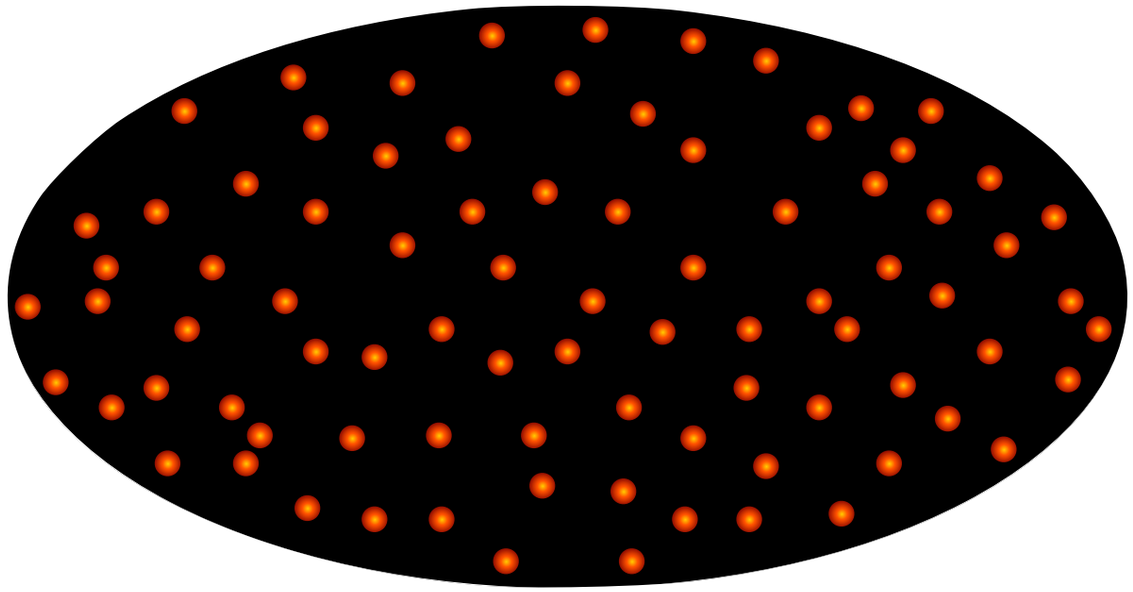
$$\text{where } f_{\mathrm{n}}(E) = I_{\mathrm{n}}(E) / I_{\mathrm{tot}}(E)$$

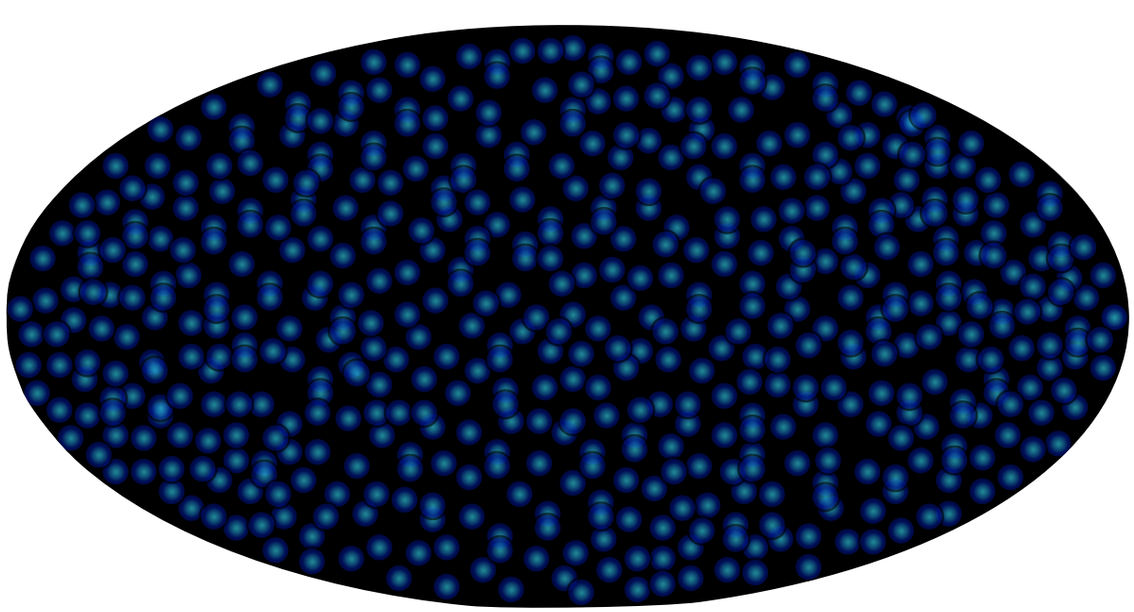
~100 GeV



Anisotropy as a Function of Energy







$$C_l^{\rm tot}(E) = {f_{\rm bl}}^2(E) C_l^{\rm bl} + {f_{\rm gal}}^2(E) C_l^{\rm gal}$$

Impact of Cascades (null B)

$$\frac{\partial I}{I} = \sum_{l=1}^{\infty} \sum_{m=-l}^{l} a_{lm} Y_{lm}$$

$$\langle a_{lm} a^*_{l'm'} \rangle = C_l$$

$$C_l^{\rm tot}(E) = {f_1}^2(E) C_l^{(1)} + {f_2}^2(E) C_l^{(2)} + \cancel{\text{cross terms}},$$
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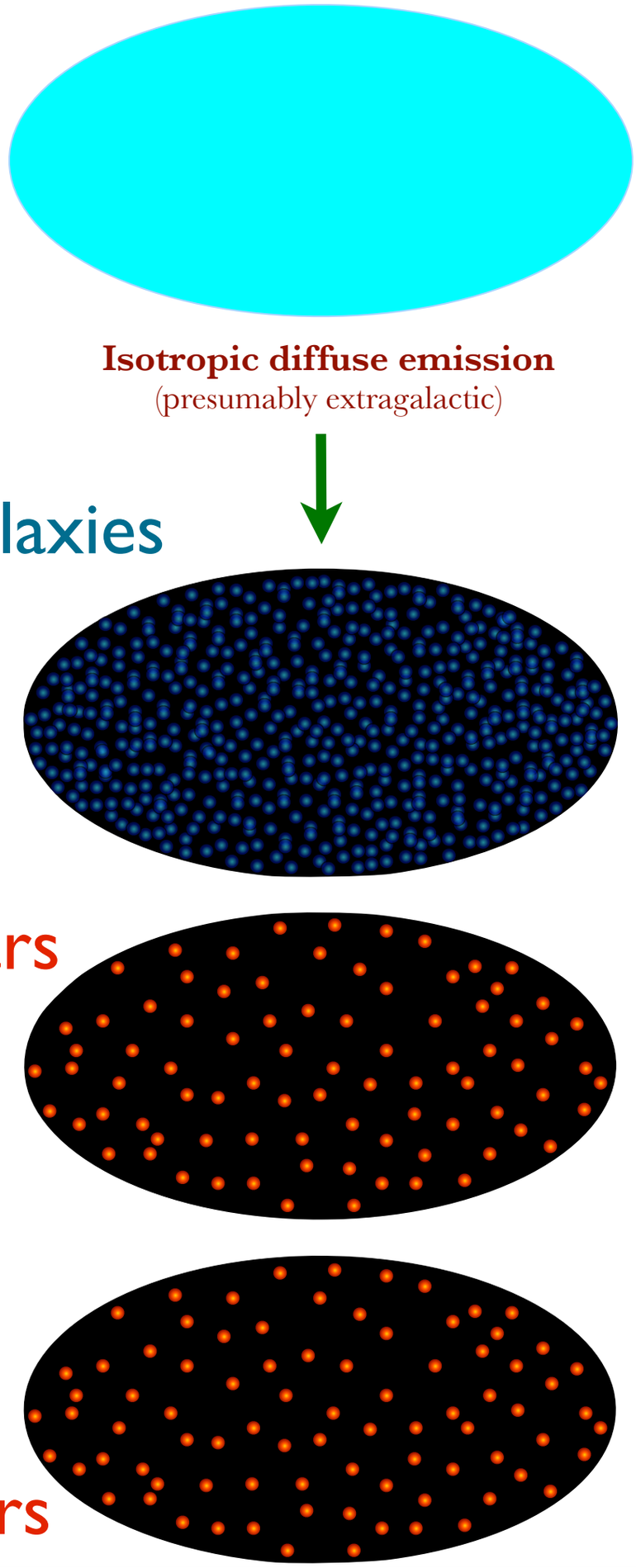
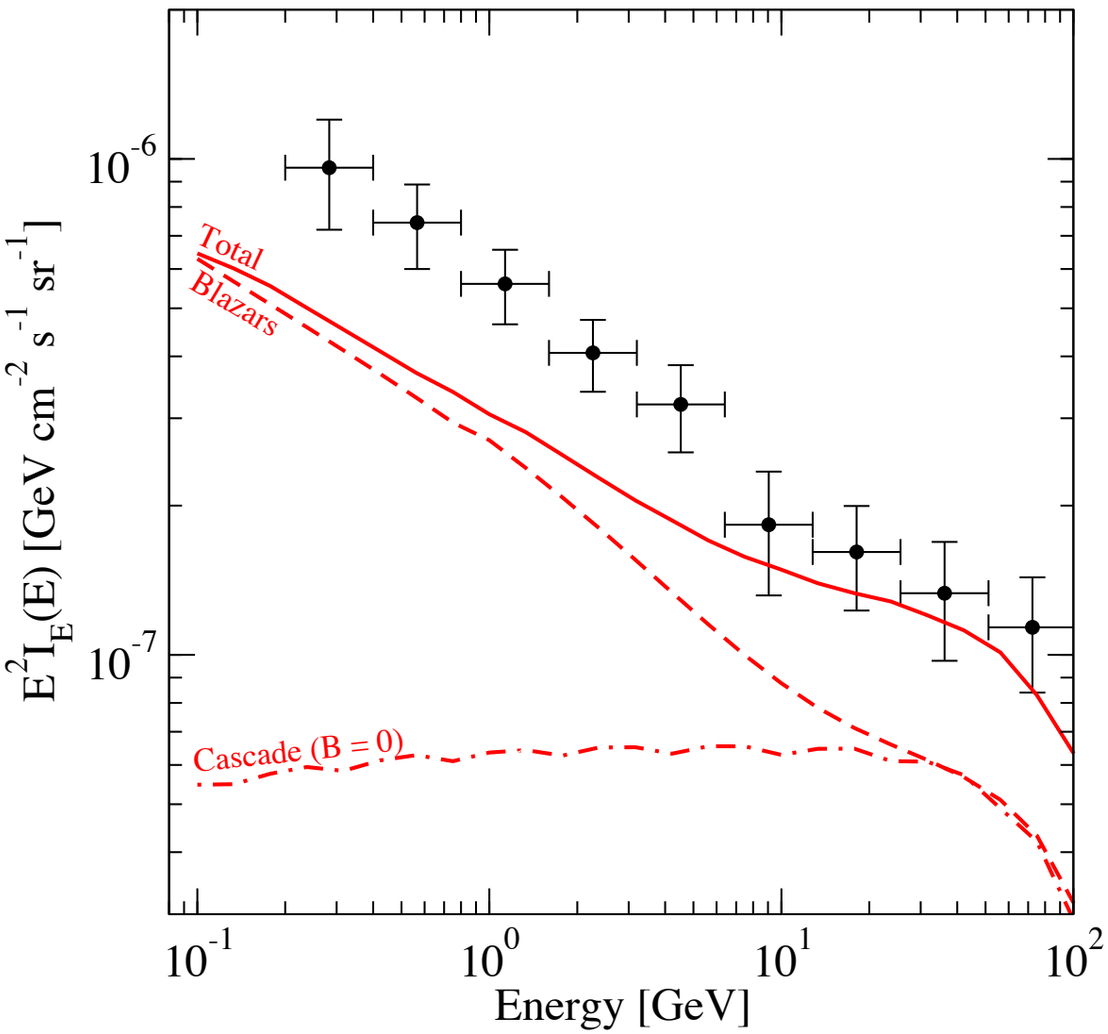
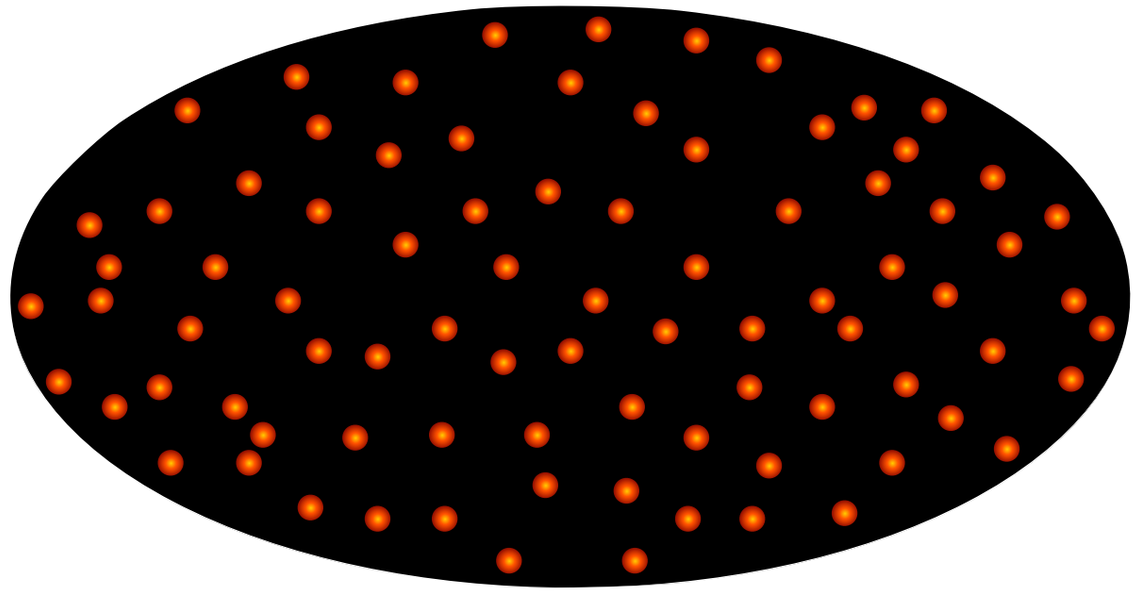


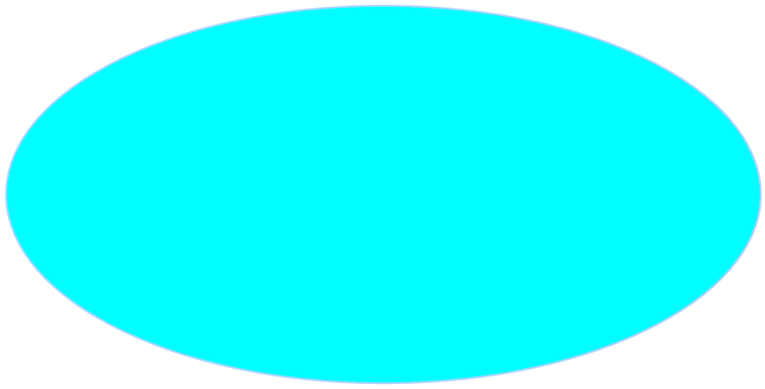
The Impact of Cascades (zero B)





$$C_l^{\rm tot}(E) = (f_{\rm bl}(E) + f_{\rm cas}(E))^2 C_l^{\rm bl}$$

Impact of Cascades (intermediate B)



Isotropic diffuse emission
(presumably extragalactic)

Star-forming Galaxies

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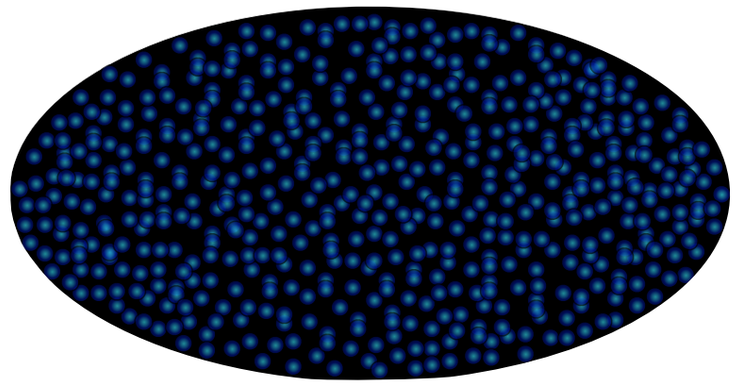
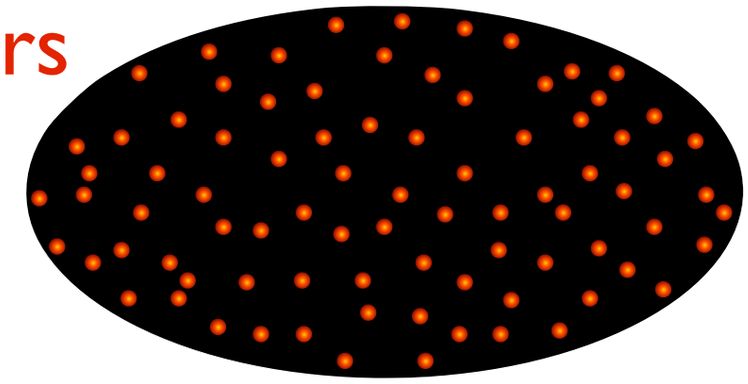
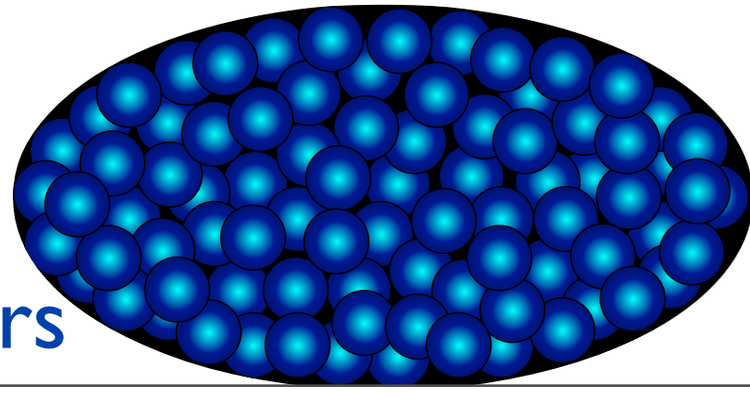


$$\langle a_{lm} a^*_{l'm'} \rangle = C_l$$

Blazars



$$C_l^{\rm tot}(E) = f_1{}^2(E) C_l^{(1)} + f_2{}^2(E) C_l^{(2)} + \text{cross terms},$$
$$\text{where } f_{\rm n}(E) = I_{\rm n}(E)/I_{\rm tot}(E)$$



Cascades from Blazars

Impact of Cascades (non-zero B)

$$\frac{\partial I}{I} = \sum_{l=1}^{\infty} \sum_{m=-l}^{l} a_{lm} Y_{lm}$$

$$\langle a_{lm} a^*_{l'm'} \rangle = C_l$$

$$C_l^{\rm tot}(E) = f_1{}^2(E) C_l^{(1)} + f_2{}^2(E) C_l^{(2)} + \cancel{\text{cross terms}},$$
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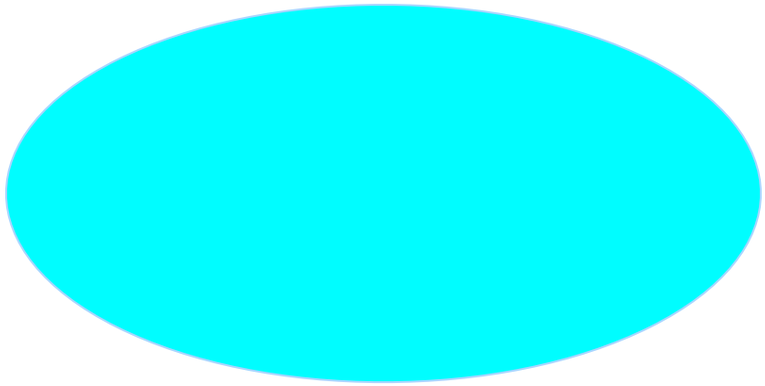

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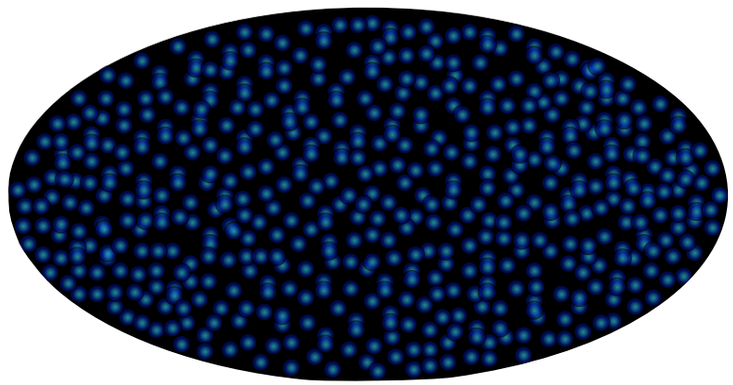
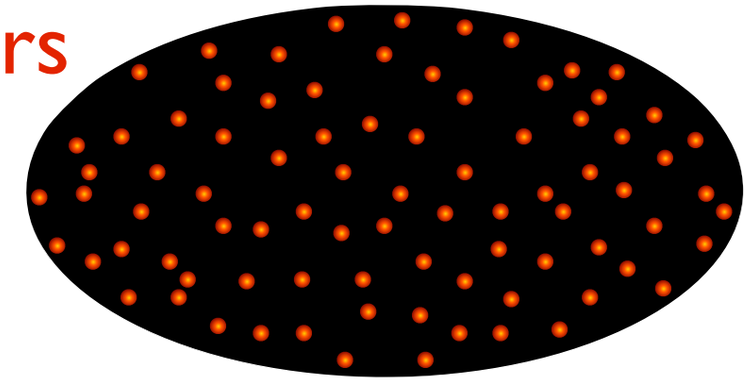
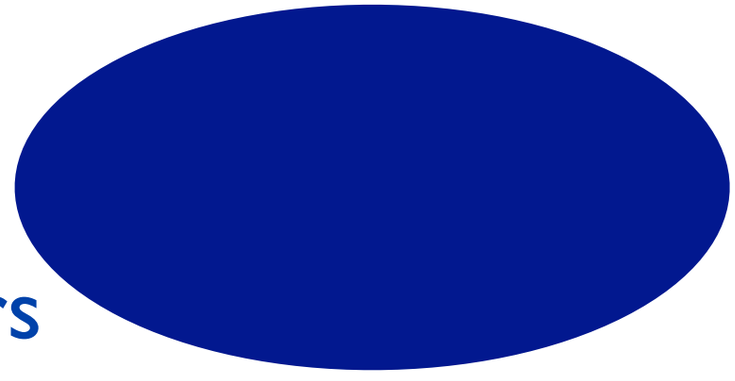


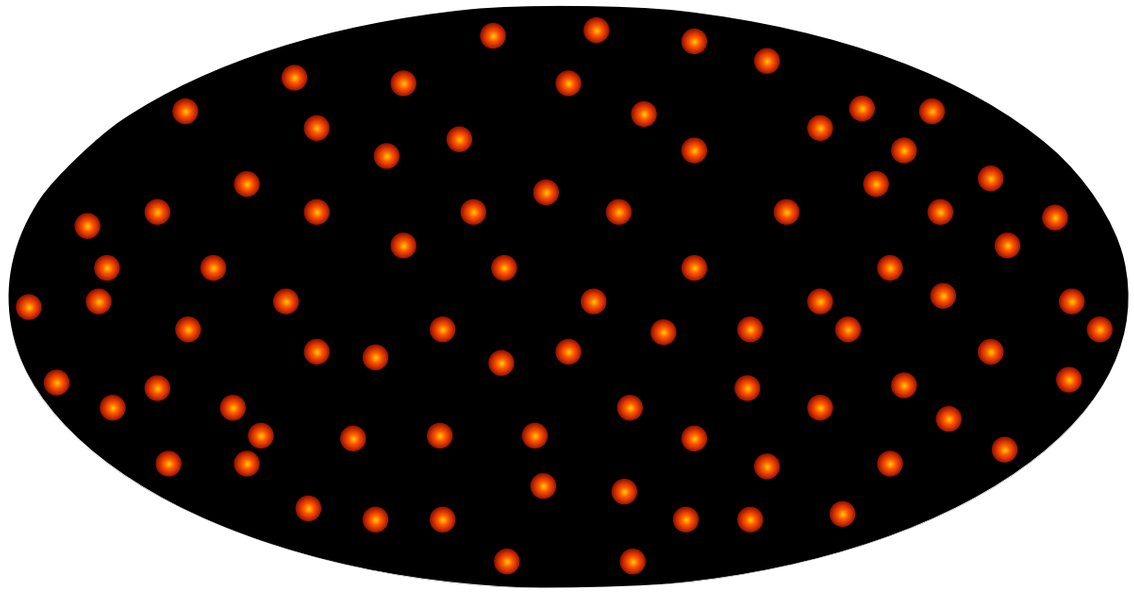
Blazars

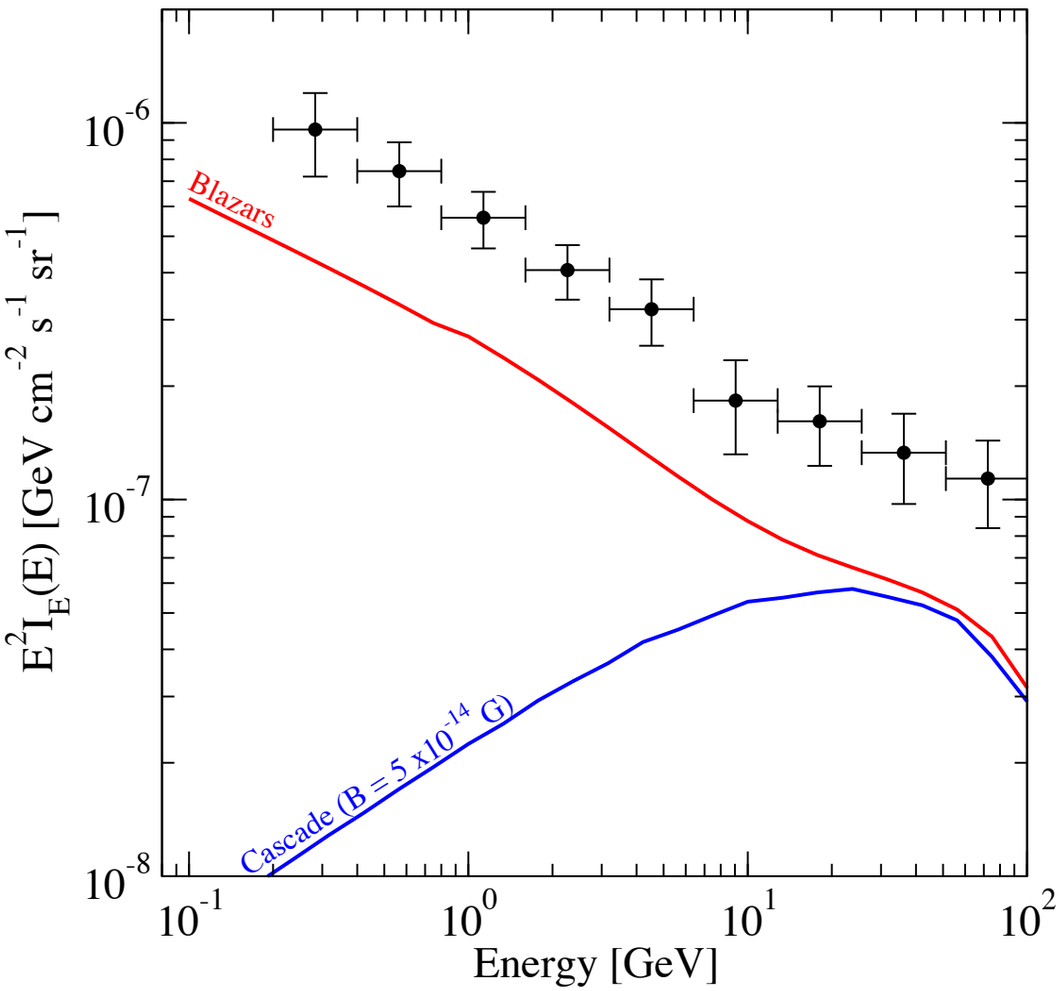


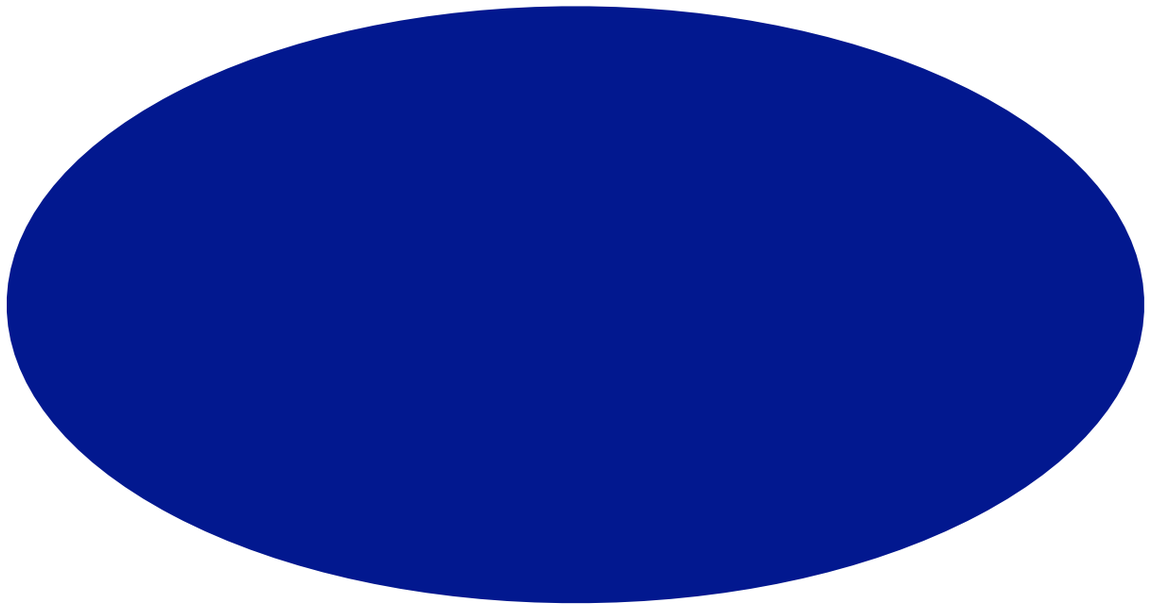
Cascades from Blazars



The Impact of Cascades (non-zero B)

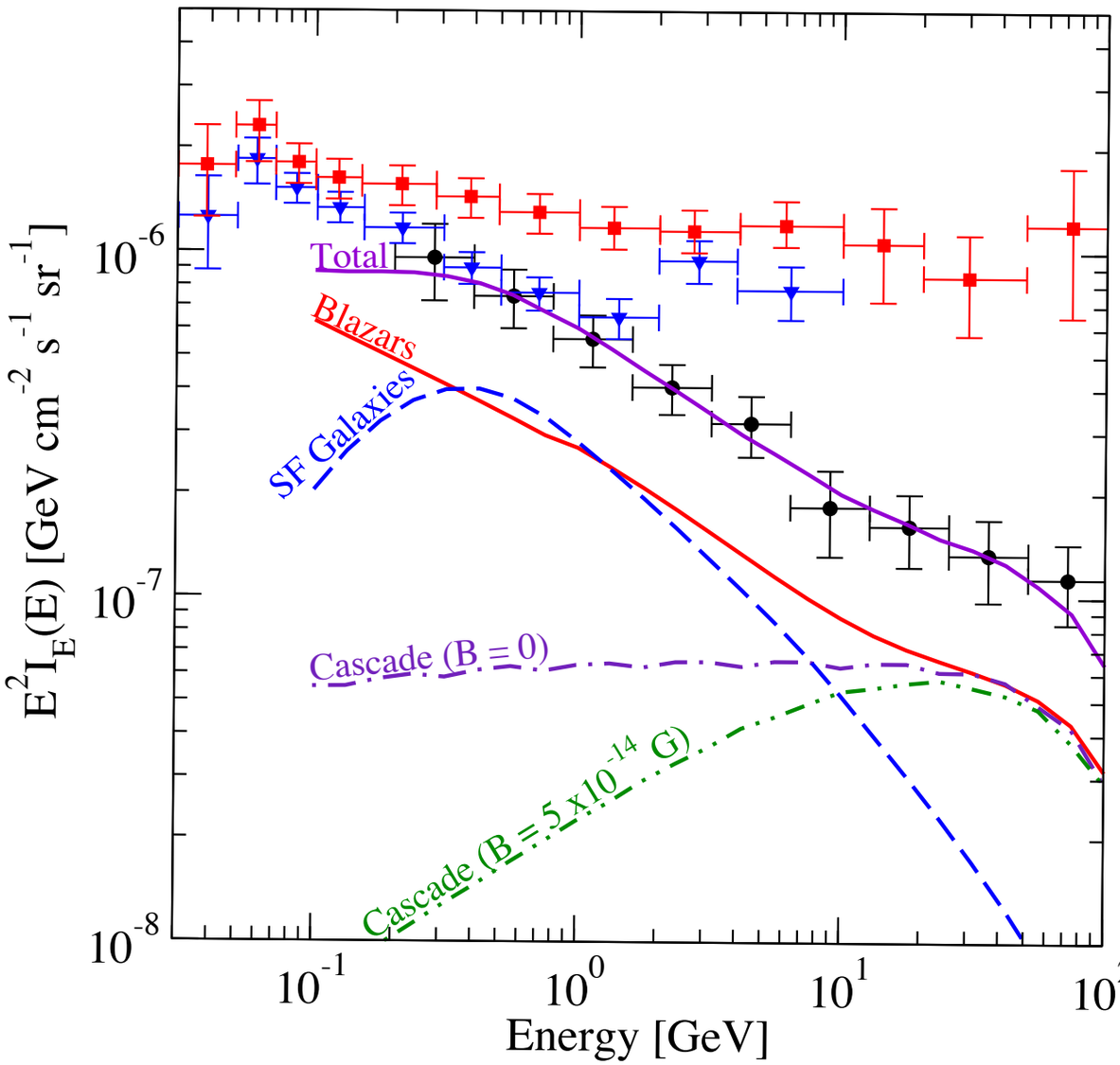


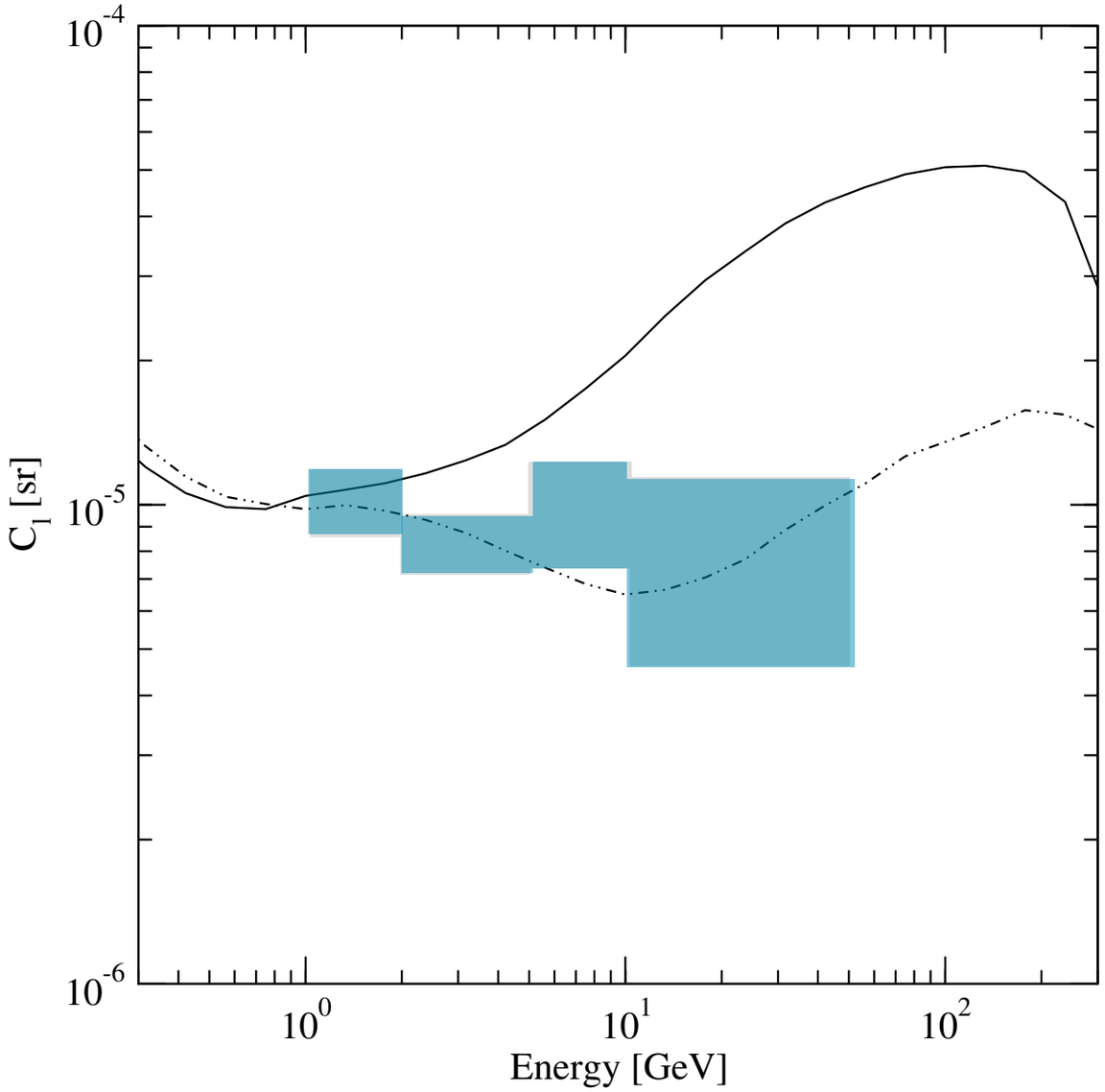




$$C_l^{\rm tot}(E) = f_{\rm bl}{}^2(E) C_l^{\rm bl} + \cancel{f_{\rm cas}{}^2(E) C_l^{\rm cas} + \text{cross terms}}$$

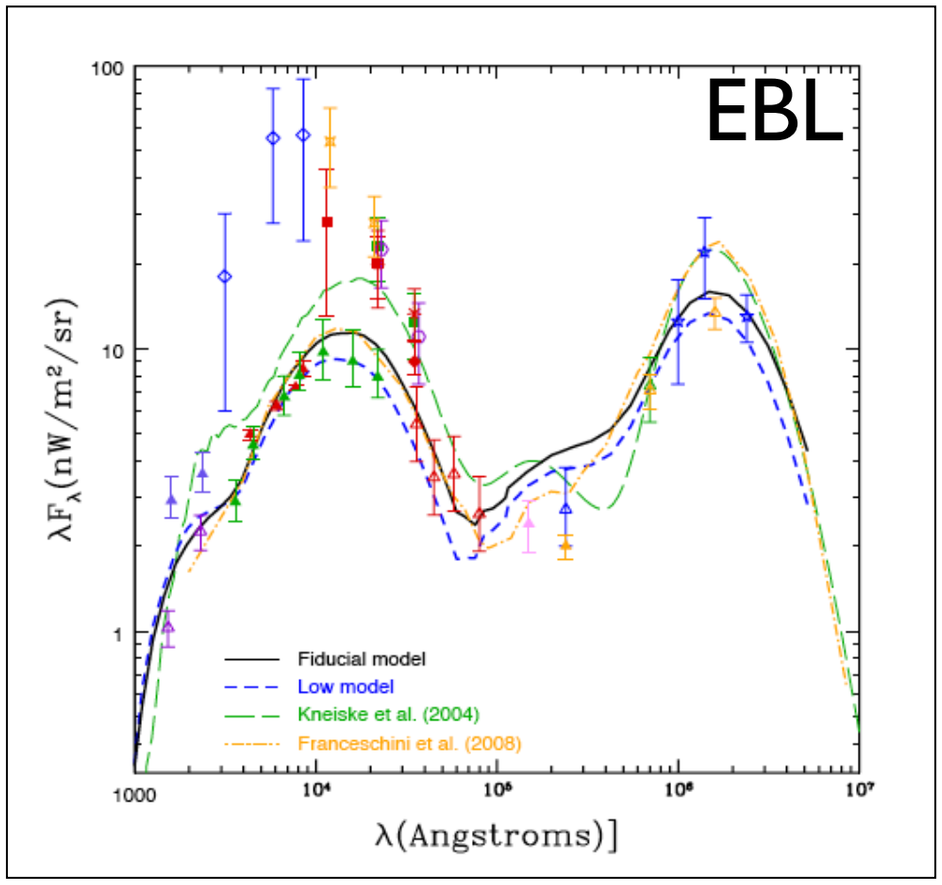
Cascades and EGB Anisotropy



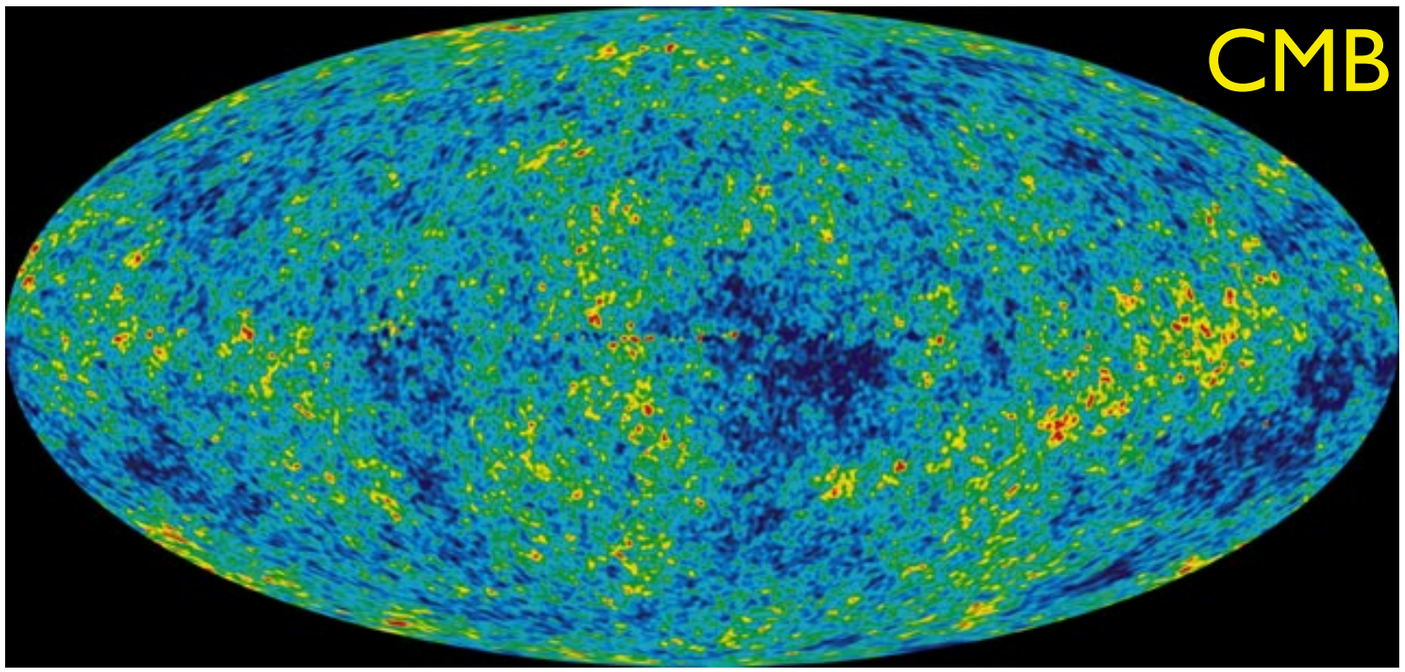


Venters & Pavlidou 2013

Interactions behind CR Propagation

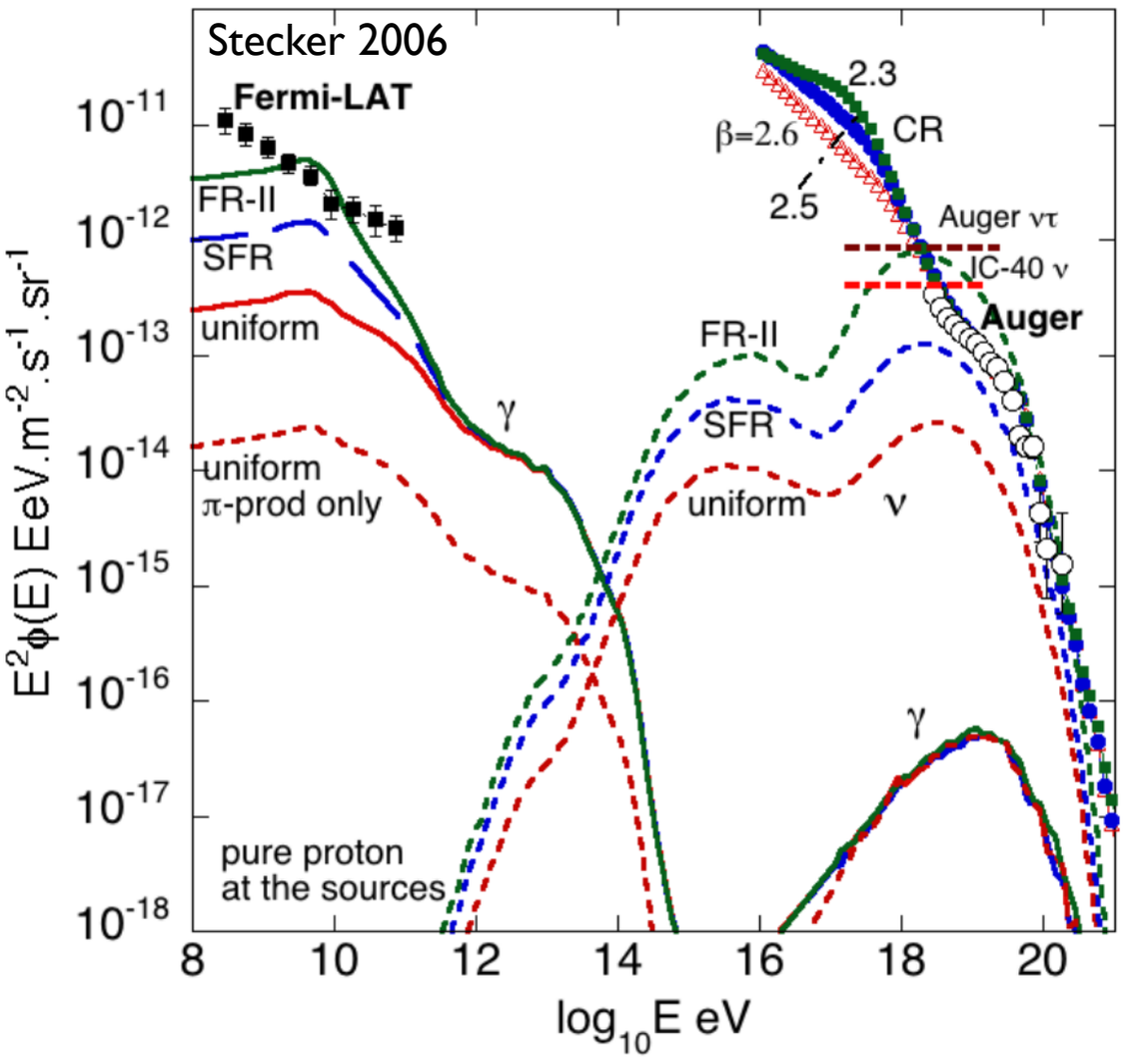


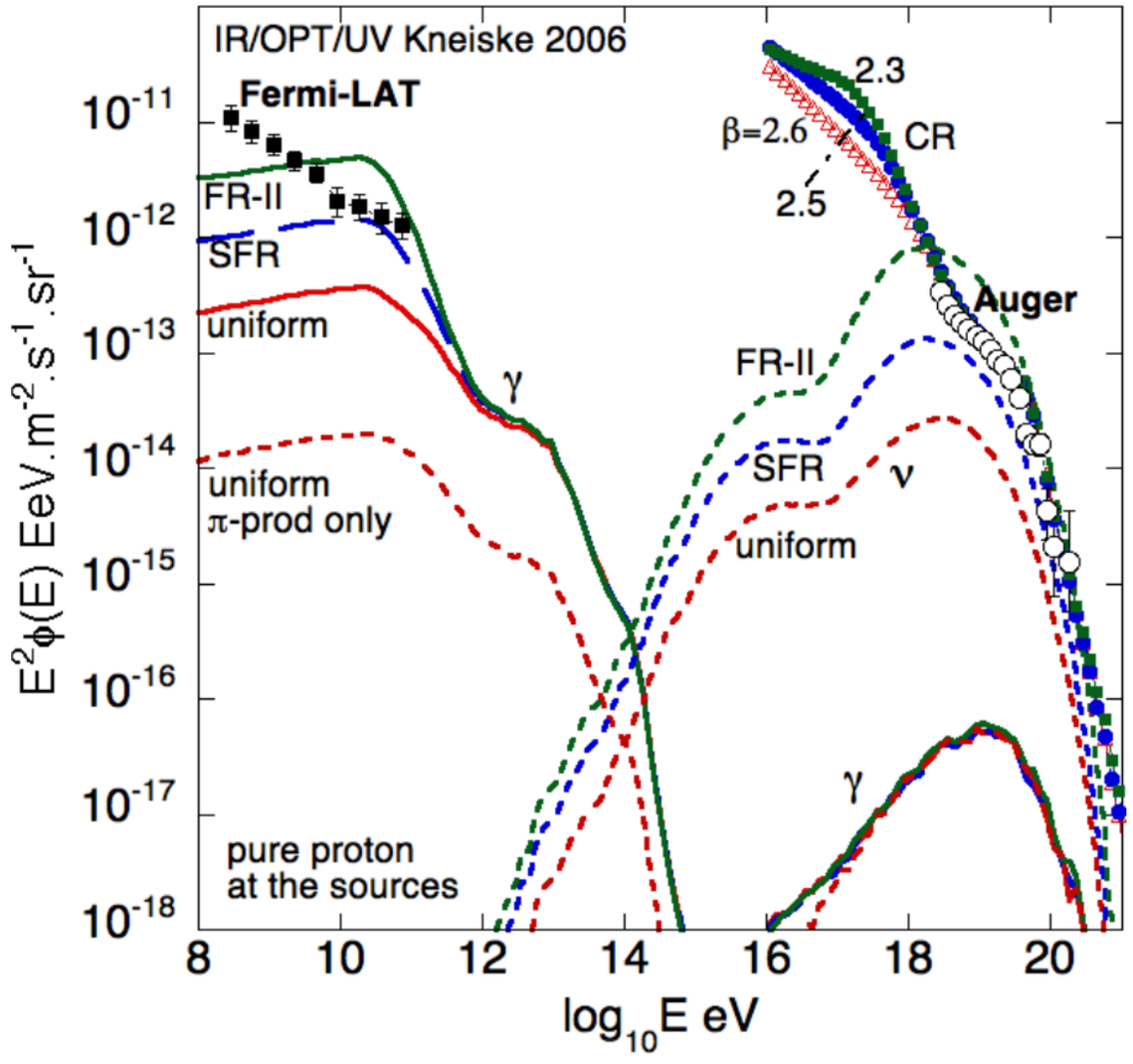
Gilmore et al. 2009



Protons and Nuclei	Bethe-Heitler pair production Photodisintegration (nuclei only) Photomeson Production	*e.g.*, $p^{\pm}\gamma \rightarrow p^{\pm}e^{-}e^{+}$ *e.g.*, ${}_{n}N\gamma \rightarrow {}_{n}N^{*} \rightarrow {}_{n-1}Np$ *e.g.*, $p\gamma \rightarrow \Delta(1232) \rightarrow p\pi^{0}$
Electrons	Inverse Compton Triple Pair Production Synchrotron	$e^{\pm}\gamma \rightarrow e^{\pm}\gamma$ $e^{\pm}\gamma \rightarrow e^{\pm}e^{+}e^{-}$ $e^{\pm}\tilde{\gamma} \rightarrow e^{\pm}\gamma$
Photons	Pair Production Double Pair Production	$\gamma\gamma \rightarrow e^{+}e^{-}$ $\gamma\gamma \rightarrow e^{+}e^{-}e^{+}e^{-}$
Mesons & Muons	Decay Synchrotron	*e.g.*, $\mu^{\pm} \rightarrow \bar{\nu}_{\mu}\,(\nu_{\mu})\,e^{\pm}\nu_{e}\,(\bar{\nu}_{e})$, $\pi^{0} \rightarrow \gamma\gamma$ $\mu^{\pm}\tilde{\gamma} \rightarrow \mu^{\pm}\gamma$

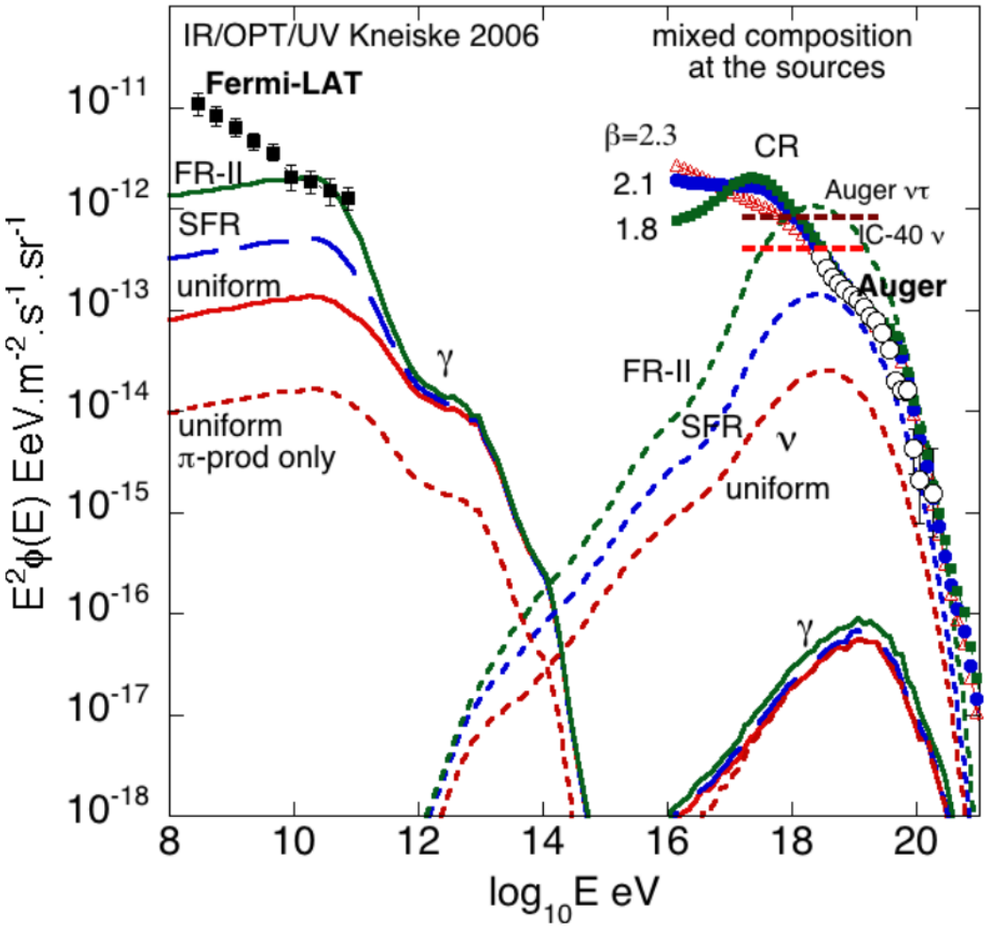
UHECR Propagation in Action

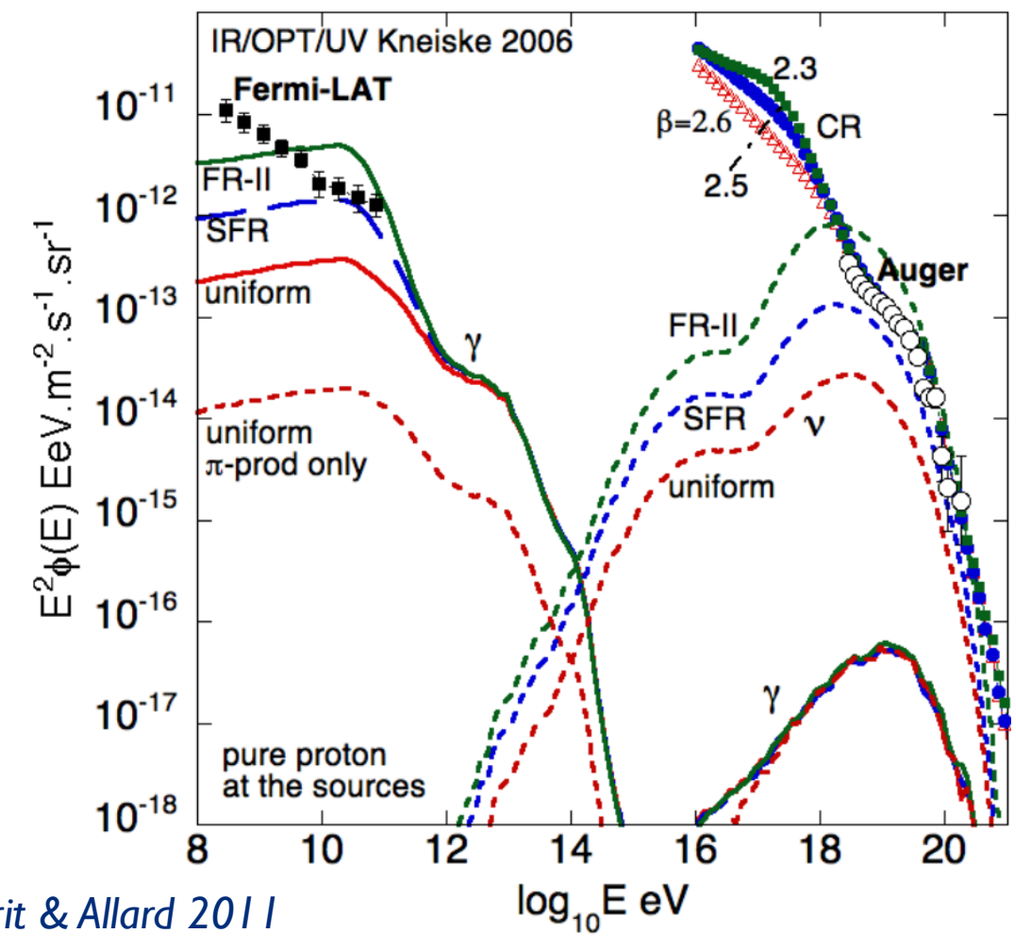


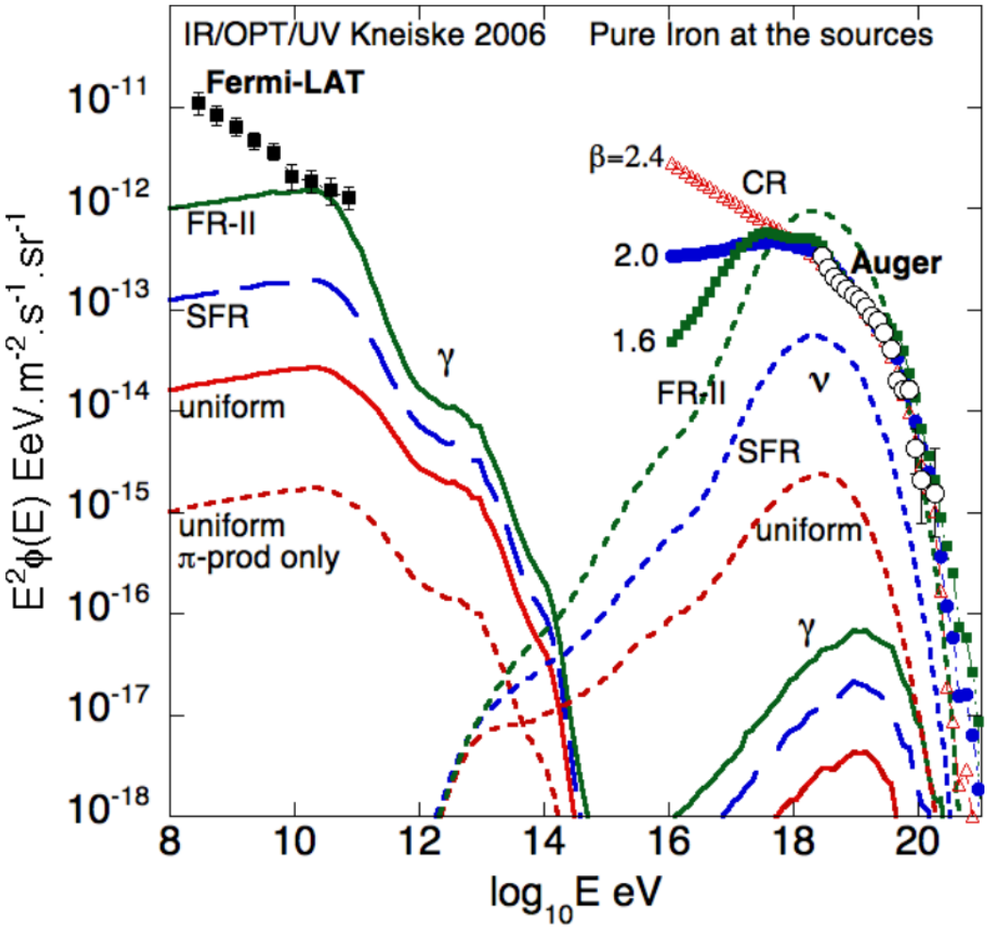


Decerprit & Allard 2011

UHECR Propagation in Action







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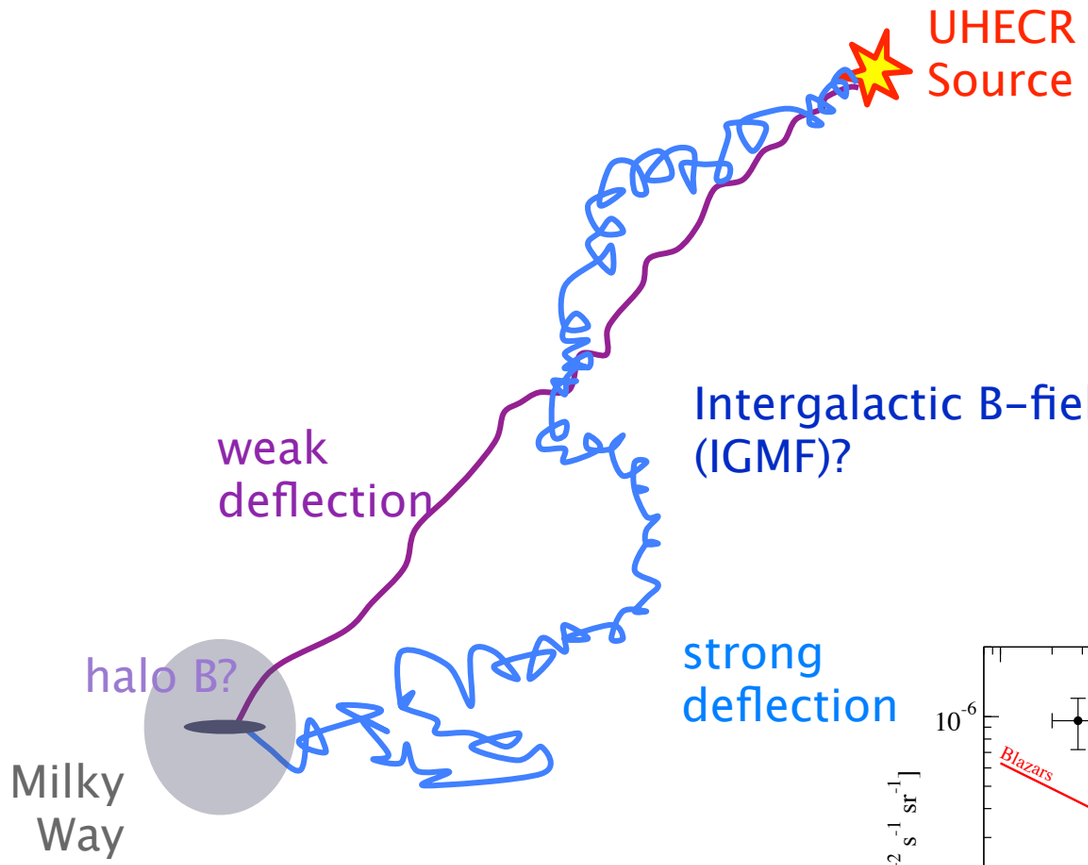
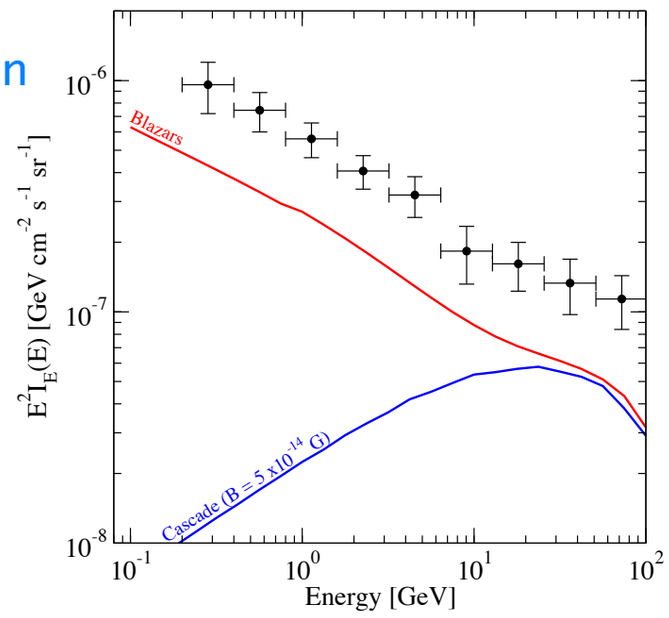
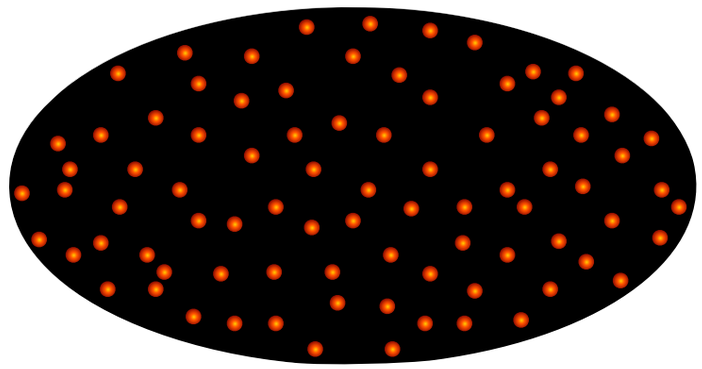
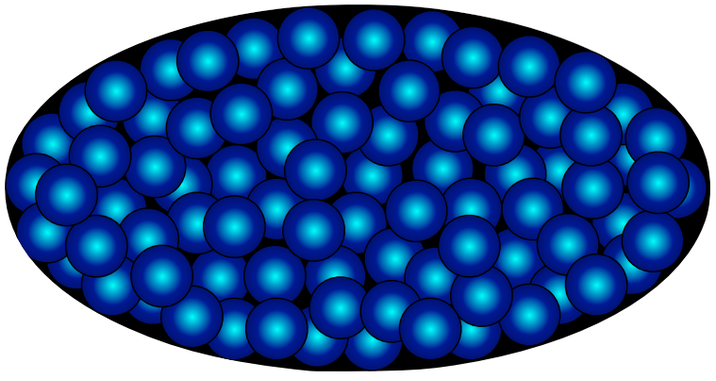
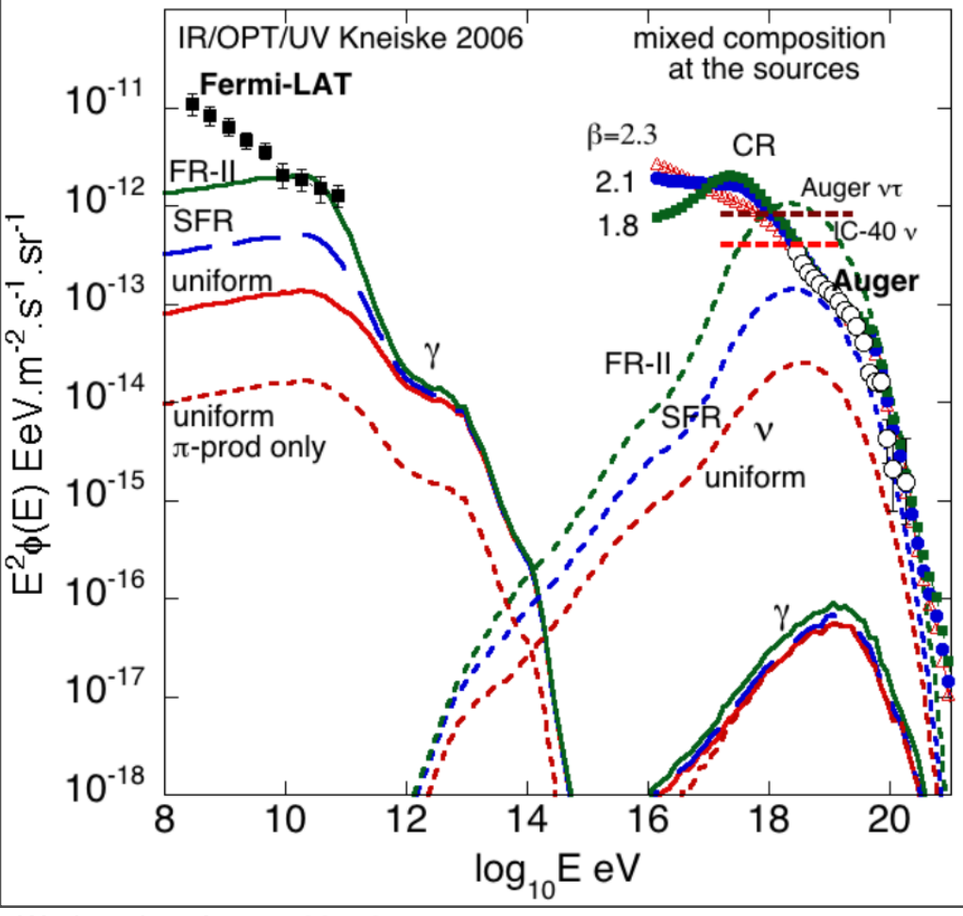


Stay Tuned!









$$C_l^{\rm tot}(E) = f_{\rm bl}{}^2(E) C_l^{\rm bl} + f_{\rm cas}{}^2(E) C_l^{\rm cas} \ + \text{cross terms}$$