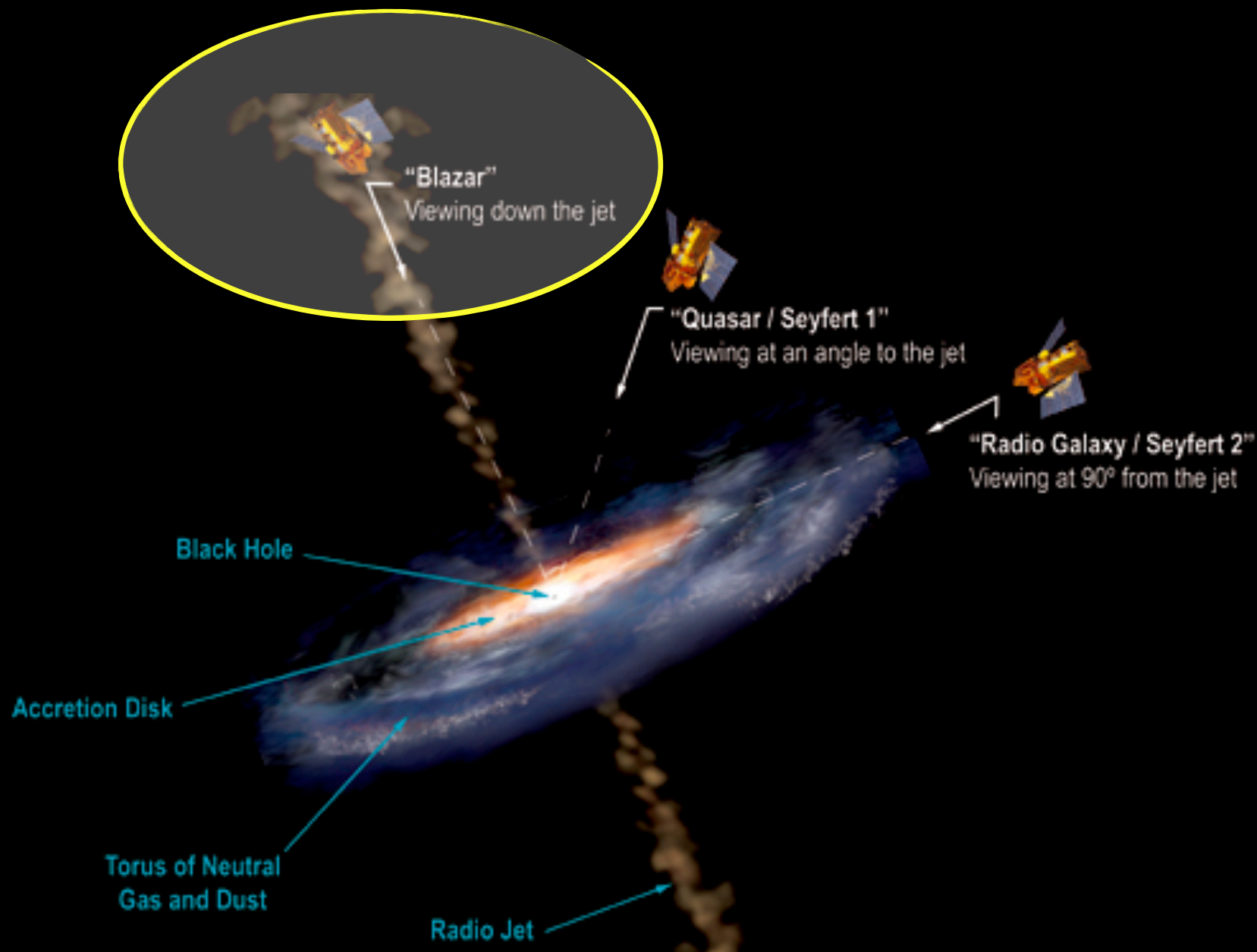


Explaining extreme TeV blazar observations with ultrahigh energy cosmic rays



Foteini Oikonomou
(Penn State)



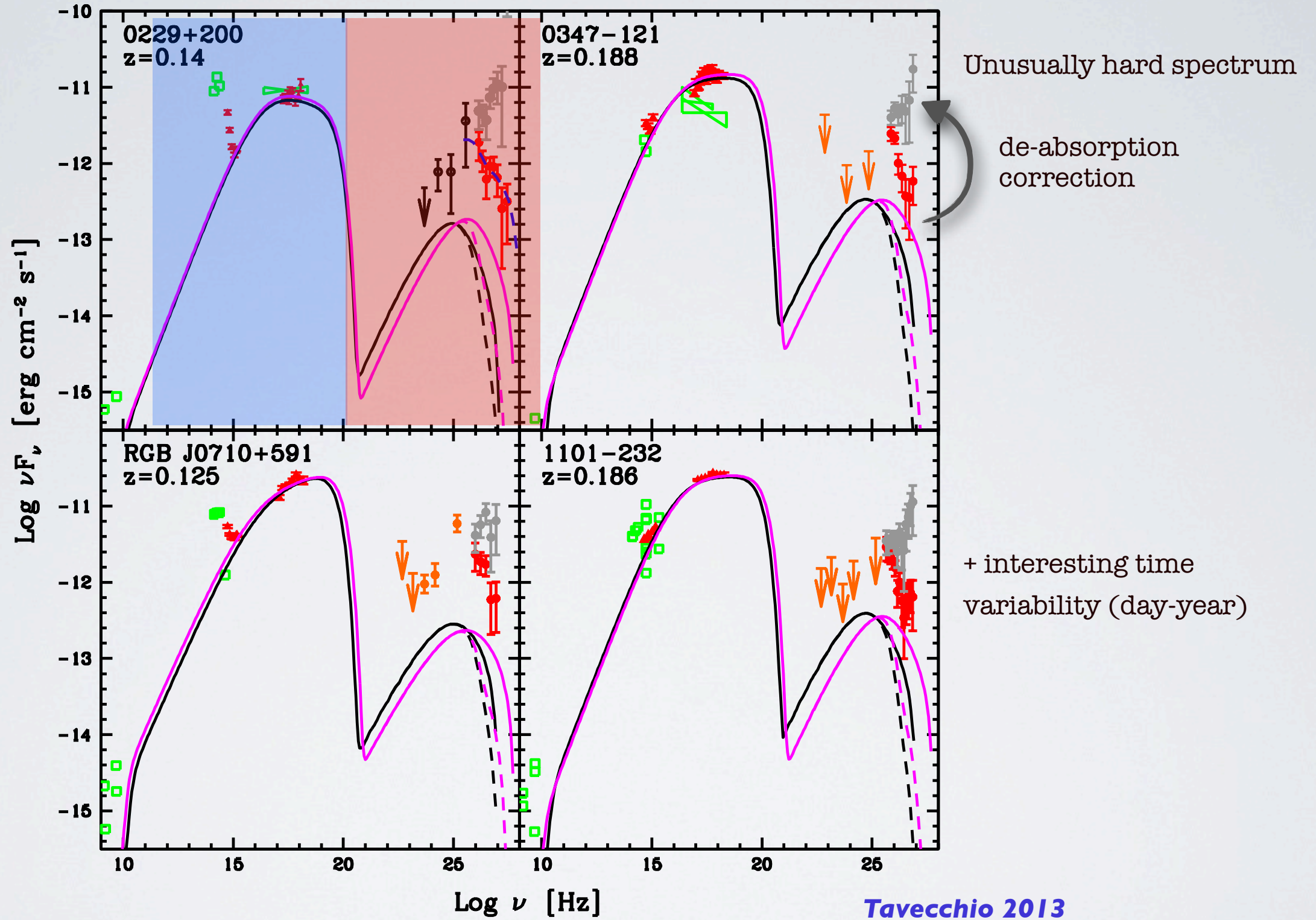
Oikonomou, Murase & KK,
submitted to A&A

IR/X-rays:

TeV gamma-rays: IC

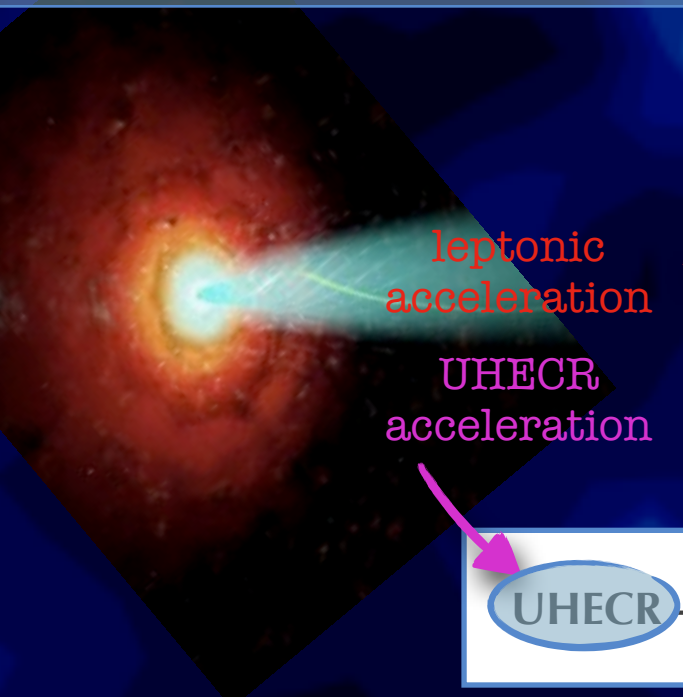
synchrotron from e^+e^-

on synchrotron?

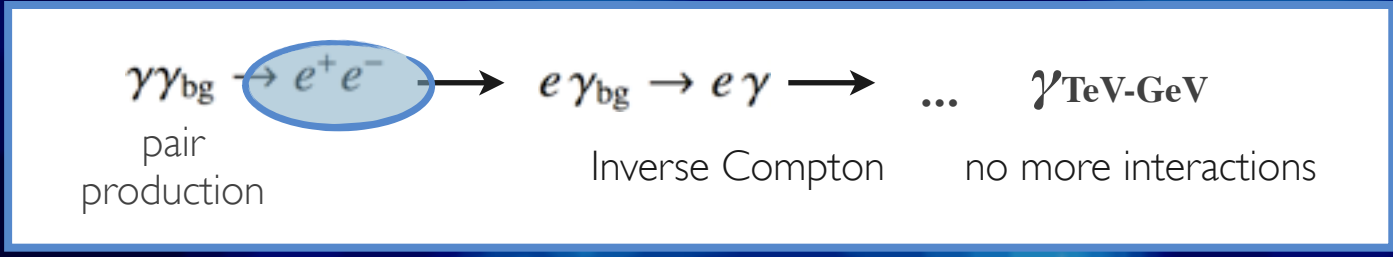


TeV emission from blazars

D. Giannios' & T. Venters' talk
 e.g., Aharonian et al. 94,, 06,
 Coppi & Aharonian 97, Tavecchio et al. 11...



Cascade in IGM



interactions with CMB/IR photons
 Essey & Kusenko 10, 13,
 Essey et al. 10, 11,
 Murase et al.

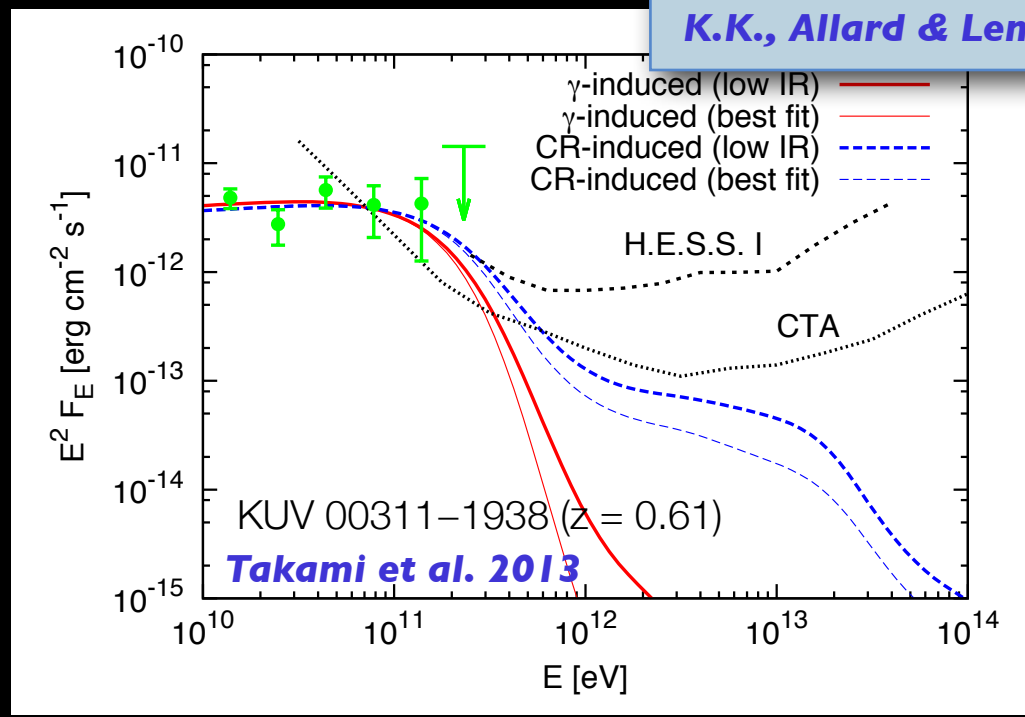
deflections
 dilution of signal

Cosmic Magnetic fields

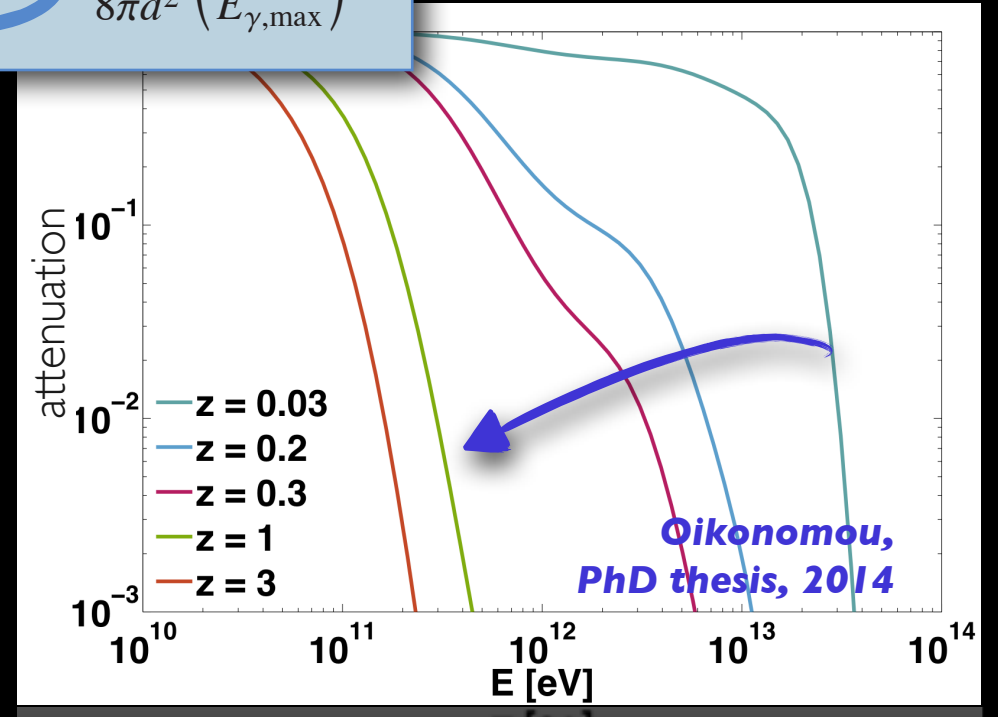
inhomogeneous B: flux dilution according to fraction of Universe where $B_{\text{IGM}} > 3 \times 10^{-11} \text{G}$
 K.K., Allard & Lemoine 2010

$$E_\gamma^2 \frac{dN_\gamma}{dE_\gamma} \approx f_{1d}(< B_\theta) \frac{L_{\text{cr}}}{8\pi d^2} \left(\frac{E_\gamma}{E_{\gamma, \text{max}}} \right)^{1/2}$$

UHECR vs leptonic cascade



attenuation

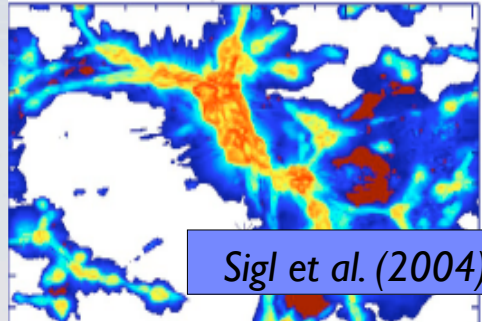


Uncertainties on the Intergalactic Magnetic Fields (IMF)

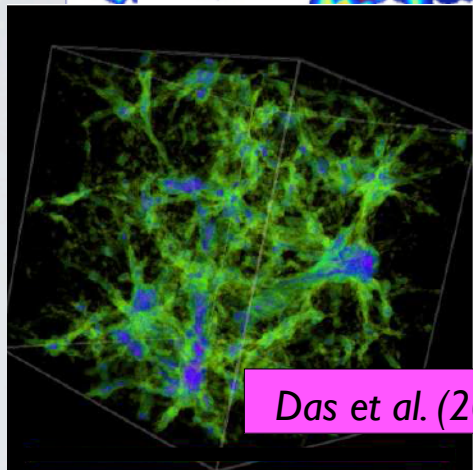
inhomogeneous **B**: flux dilution according to fraction of Universe where $B_{\text{IGM}} > 3 \times 10^{-11} \text{G}$

K.K., Allard & Lemoine 2010

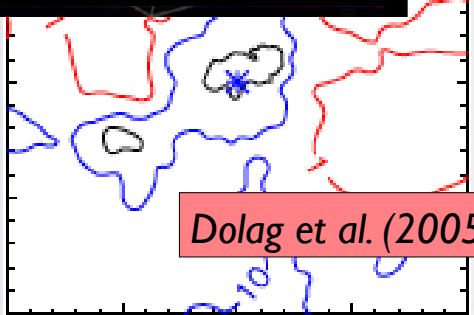
$$E_\gamma^2 \frac{dN_\gamma}{dE_\gamma} \approx f_{1d}(< B_\theta) \frac{L_{\text{cr}}}{8\pi d^2} \left(\frac{E_\gamma}{E_{\gamma, \text{max}}} \right)^{1/2}$$



Sigl et al. (2004)

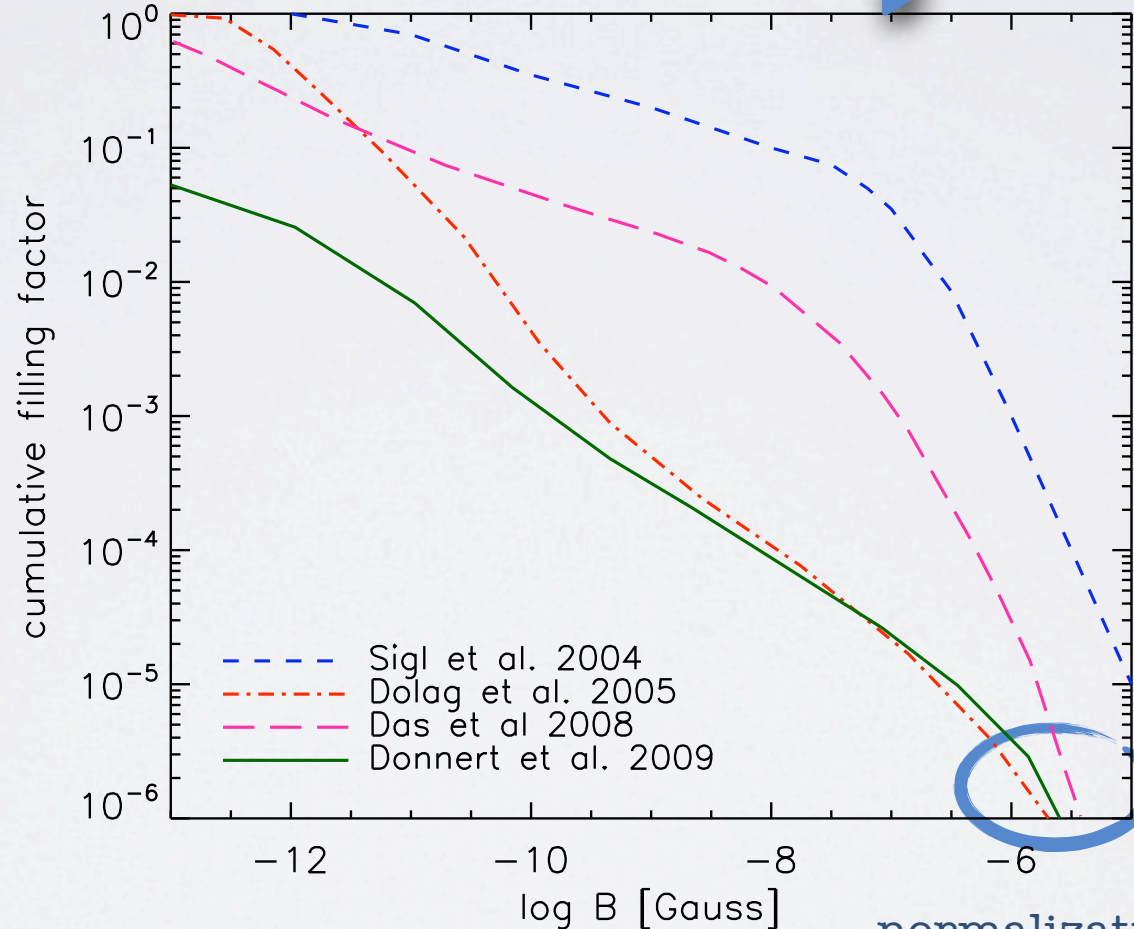


Das et al. (2008)



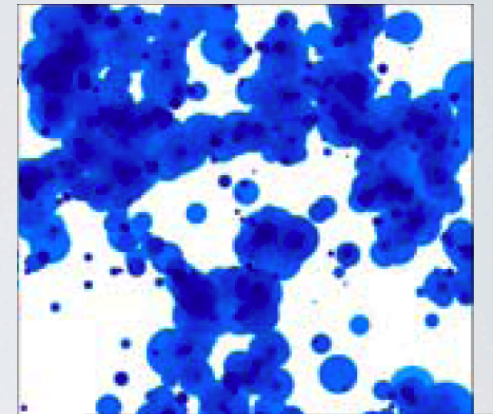
Dolag et al. (2005)

large uncertainties in underdense regions

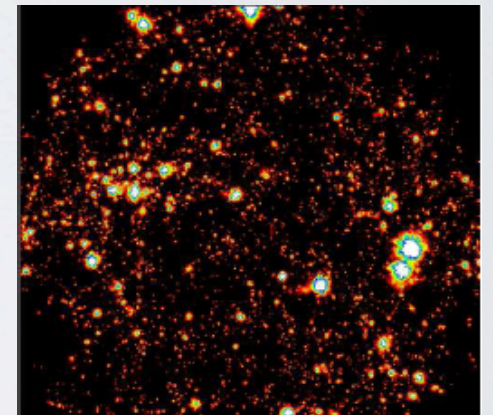


K.K. & Olinto 2011

normalization:
observations
of clusters of galaxies



Bertone et al. (2006)

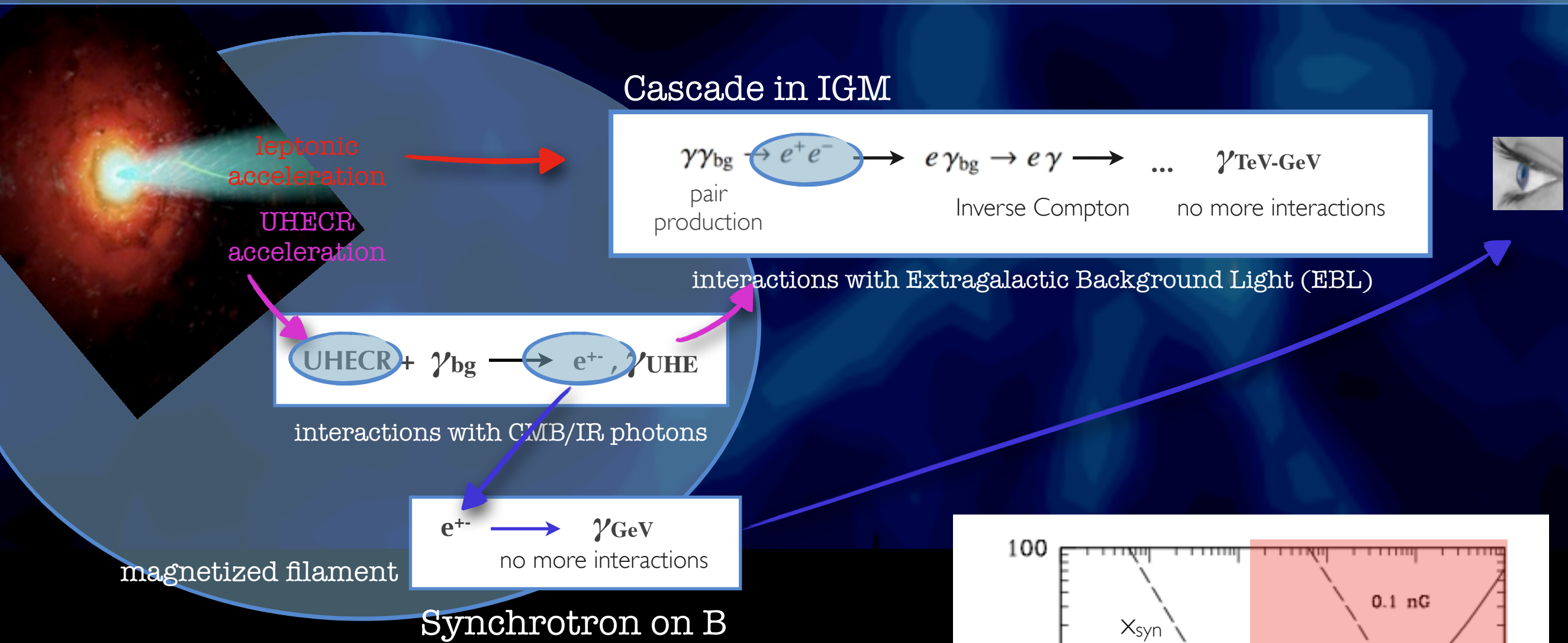


Donnert et al. (2008)

ad-hoc modeling of primordial origins
+ cosmological simulations
+ evolution of B field coupled to matter

tentative magnetic
pollution from
astrophysical sources

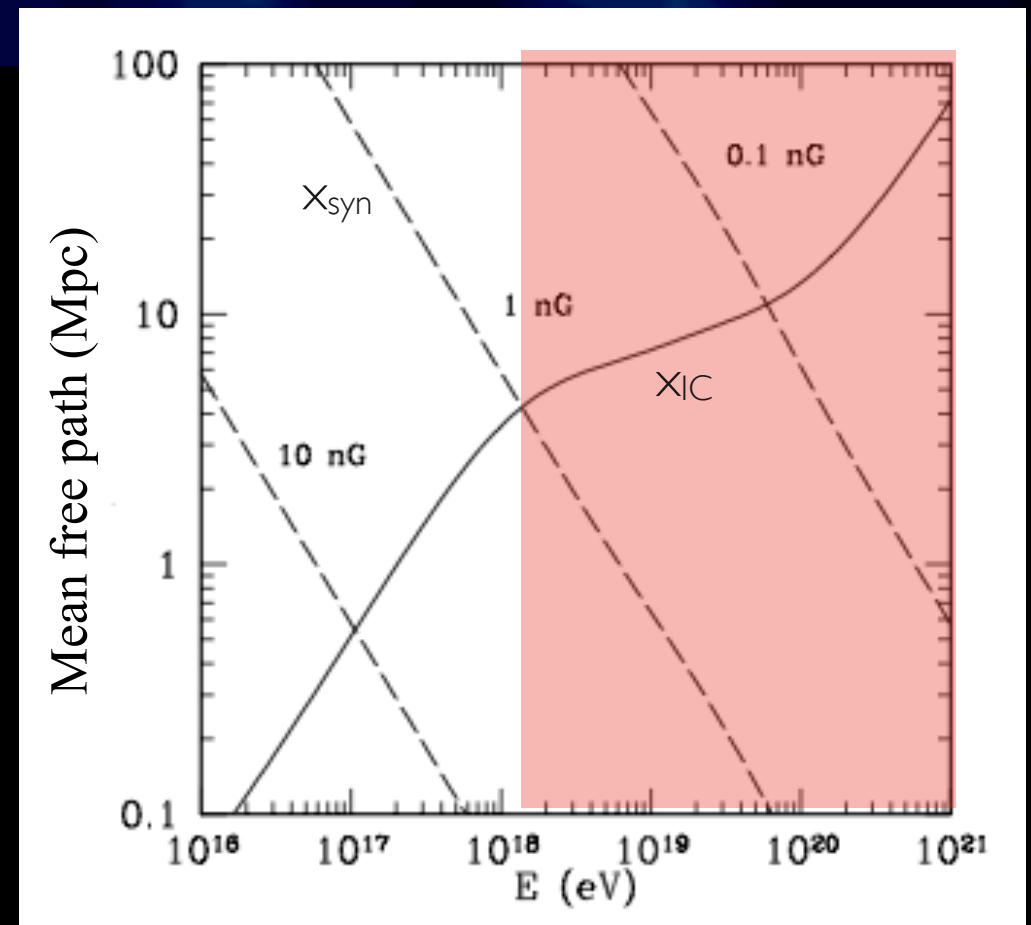
UHECR pair echo/halo



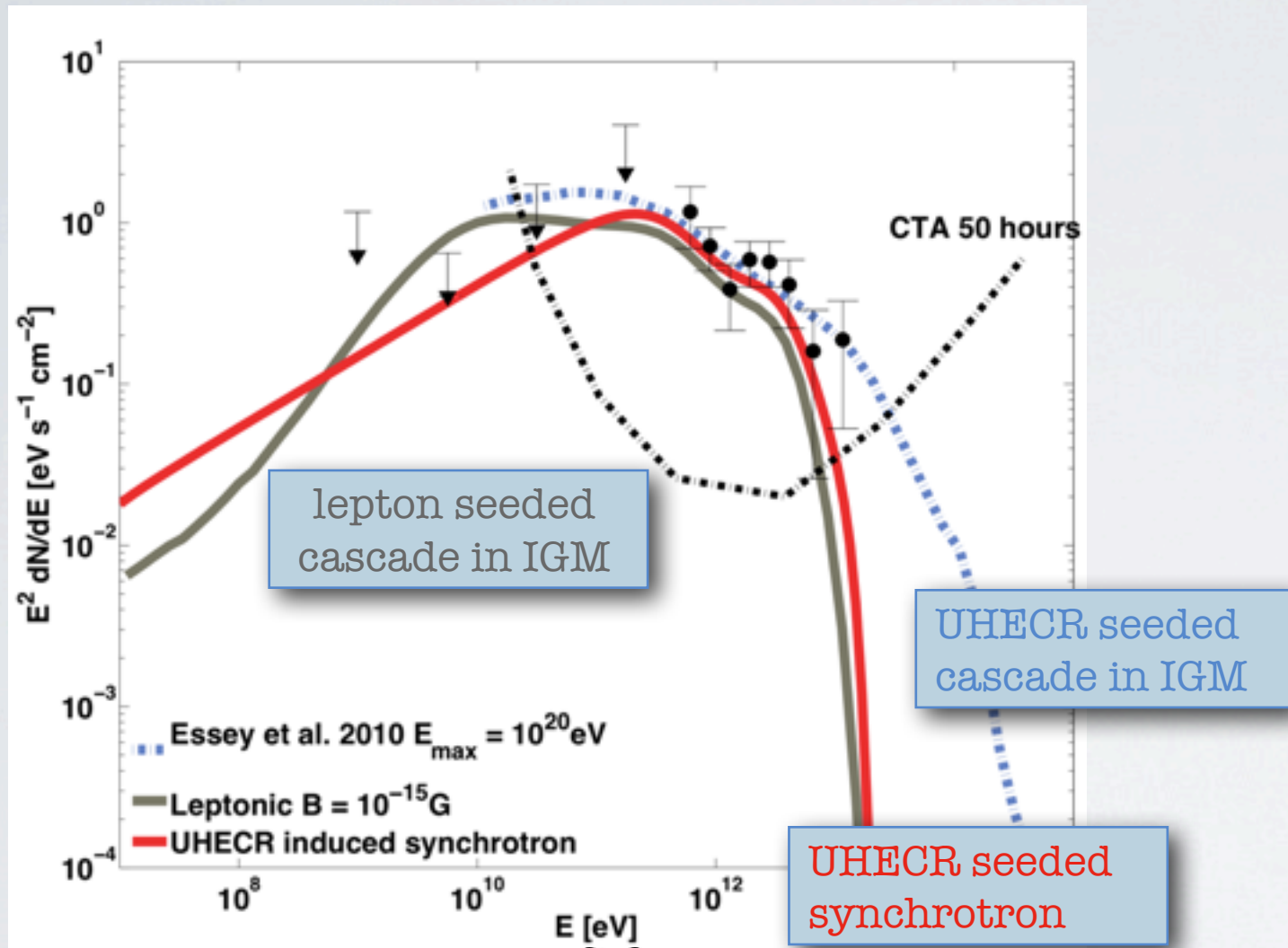
NB: Confined UHECRs should produce **UHE neutrals** (e.g, photons) at source
(Murase 2009, Murase 2012, Dermer et al. 2012)

guaranteed if $\chi_{syn} > \chi_{IC}$

Gabici & Aharonian 06

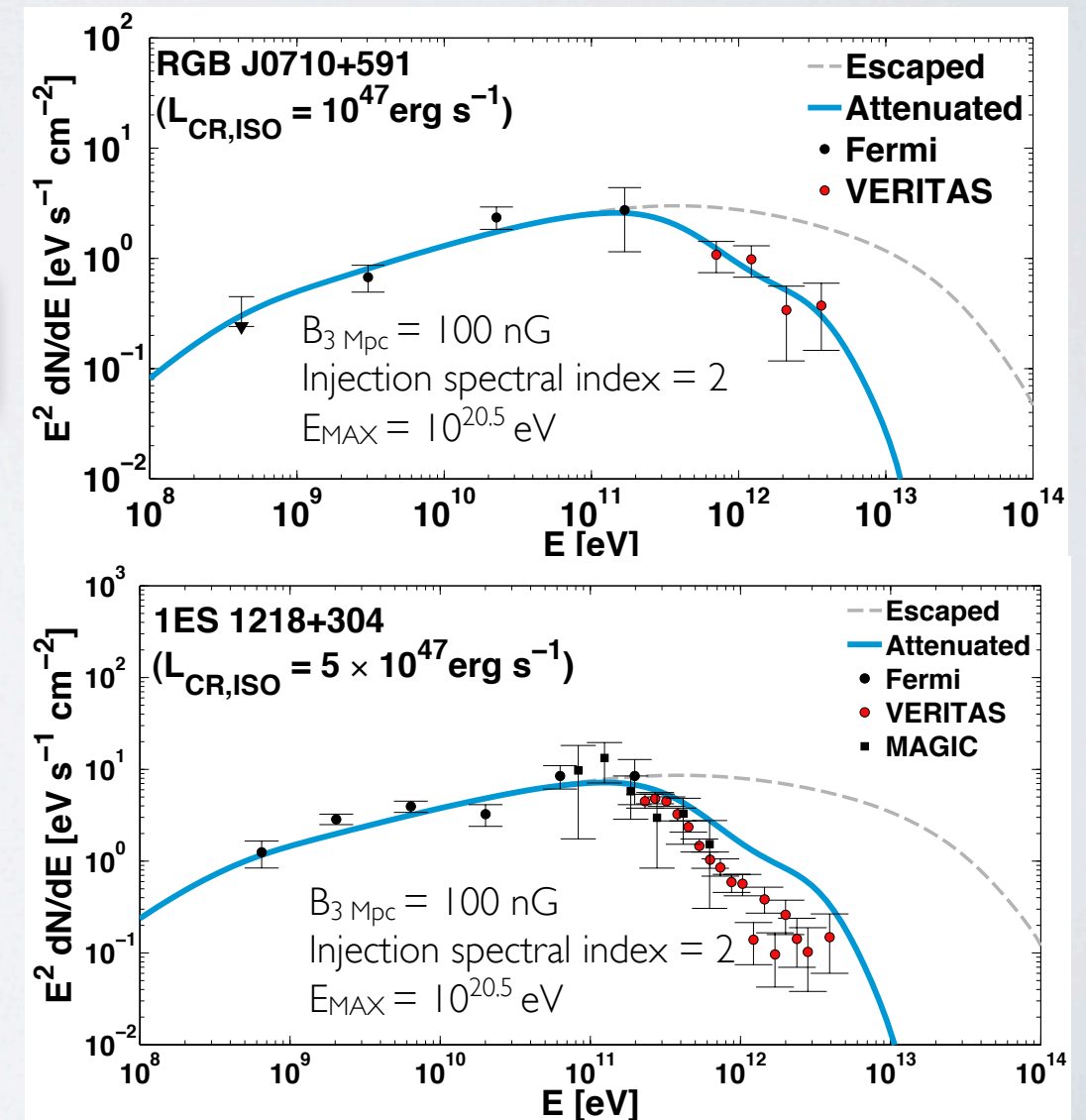


1ES 0229+200 (HESS Coll. 2007, VERITAS Coll. 2010, 2013)

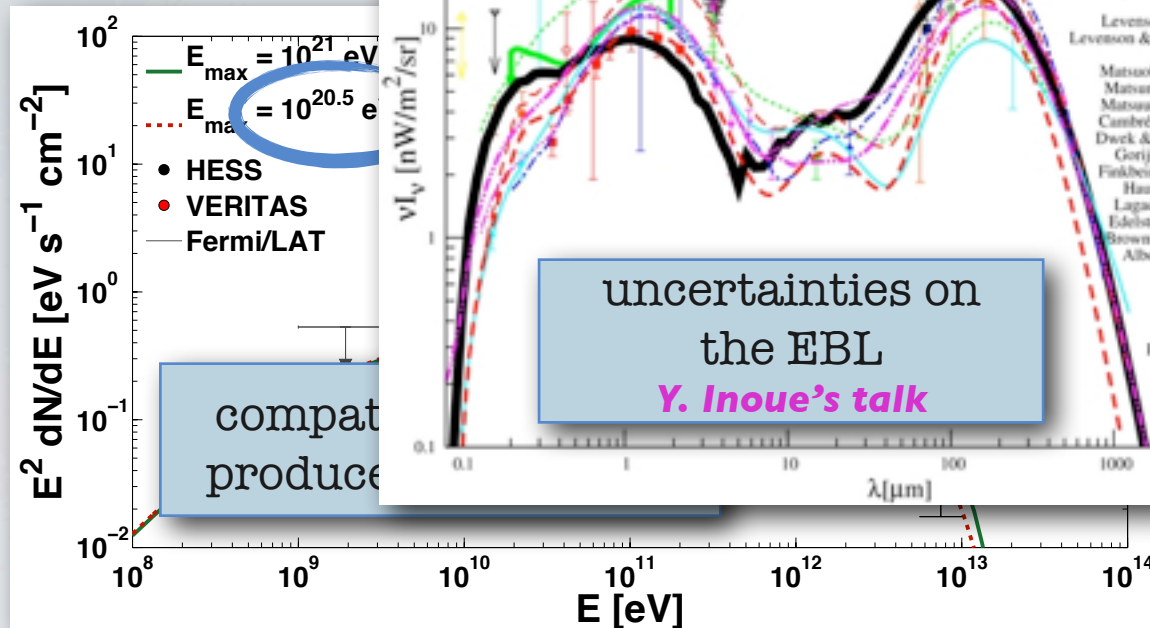


Proton UHECRs
 $B_{3 \text{ Mpc}} = 316 \text{ nG}$
 Injection spectral index = 2 $E_{\text{MAX}} = 10^{21} \text{ eV}$
 $L_{\text{CR},j} = 10^{44.5} \text{ erg s}^{-1}$

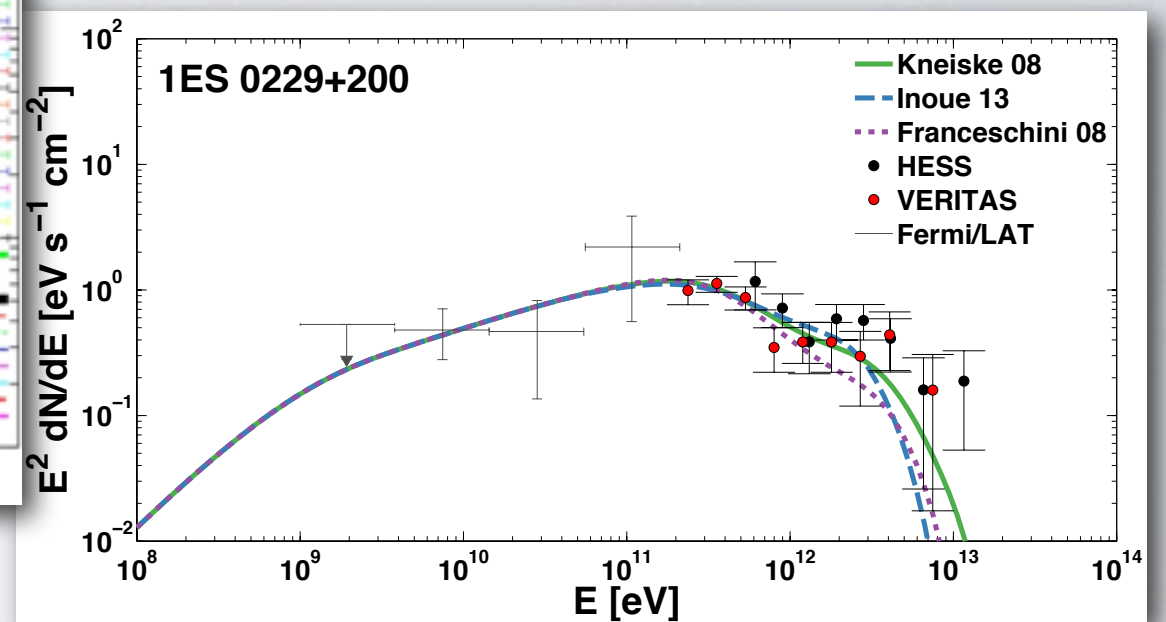
RGB J07010+591
 1ES 1218+304



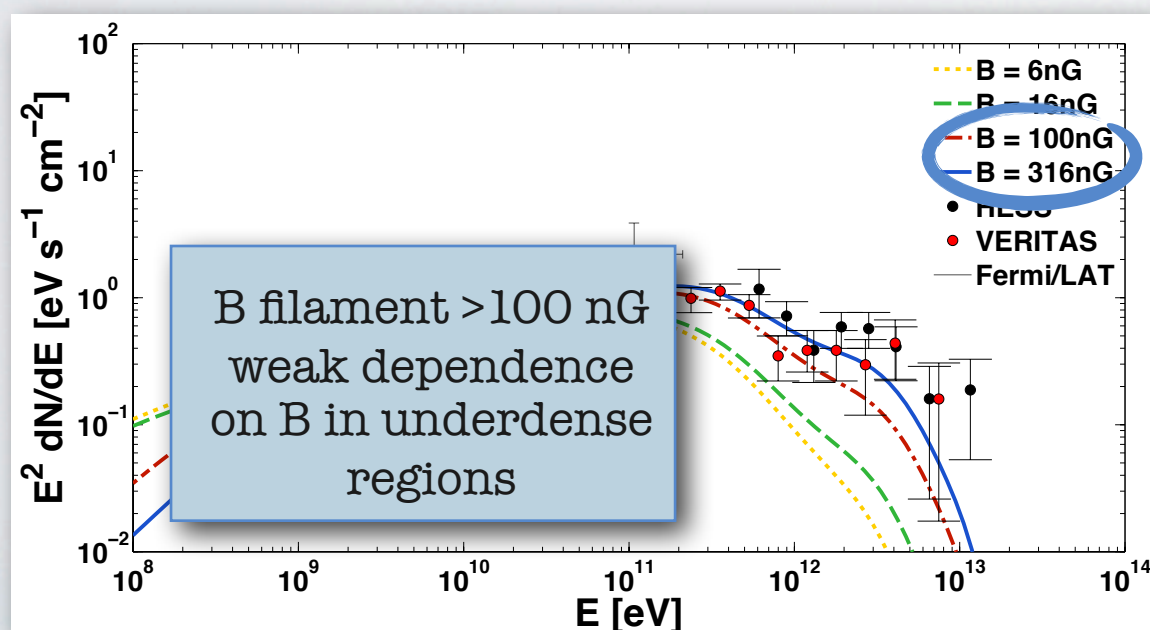
Robustness to



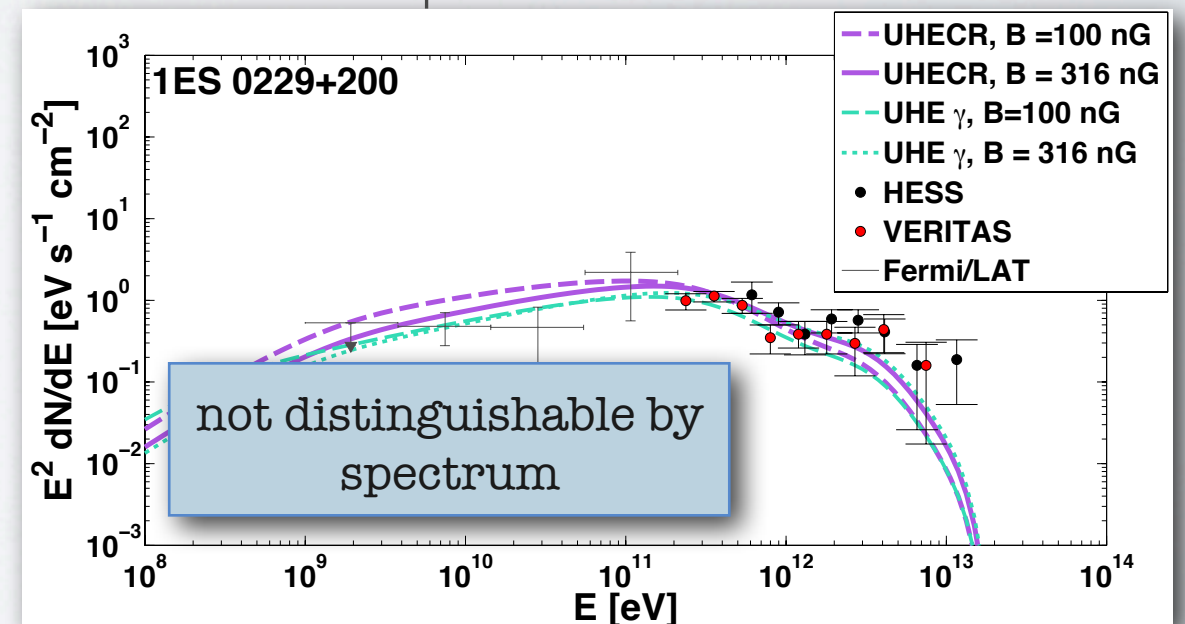
Robustness to particle EBL



Robustness to IGMF



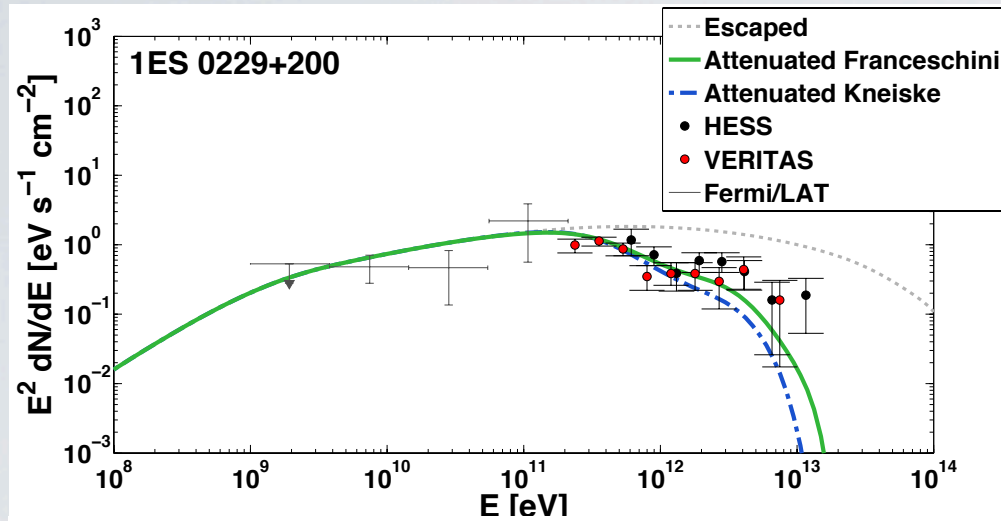
UHECR/UHE photons



$$\delta t \sim 2\theta_e^2 d / 2c \sim 0.3 \text{ yr } (E_{\text{syn}} / 10^{2.5} \text{ GeV}) (\min[d, \lambda_{\gamma\gamma}] / \text{Mpc})$$

deflection in B

$d =$ magnetised region \sim few Mpc, $\lambda_{\gamma\gamma} \sim 2$ Mpc



UHE photons

Injection spectral index = 1.5

$B_{3 \text{ Mpc}} = 316 \text{ nG}$

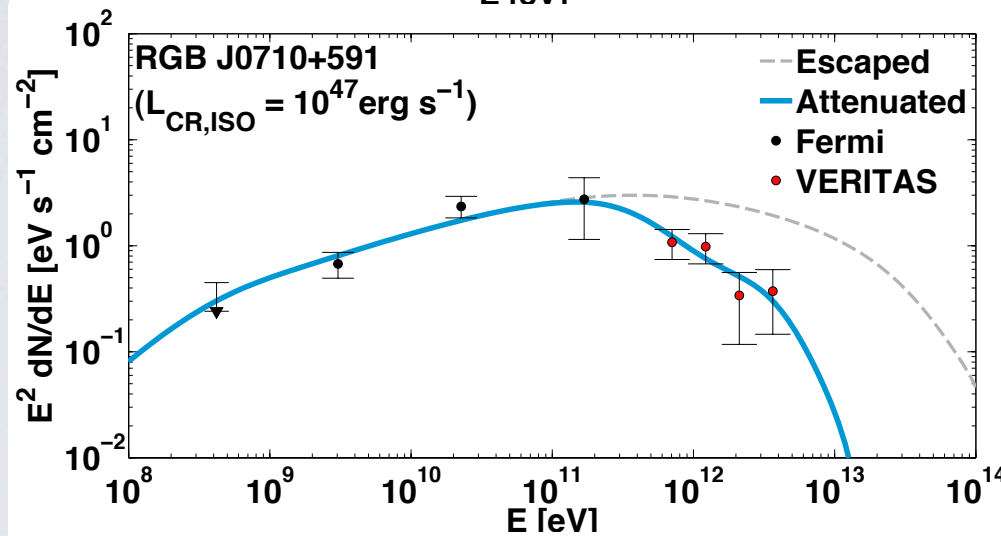
$E_{\gamma, \text{MAX}} = 10^{19.5} \text{ eV}$

$L_{\gamma} = 10^{45} \text{ erg s}^{-1}$

\sim year? *Aliu et al 2014*

If confirmed:

- disfavours UHECR synchrotron cascade
- rules out UHECR IC cascade



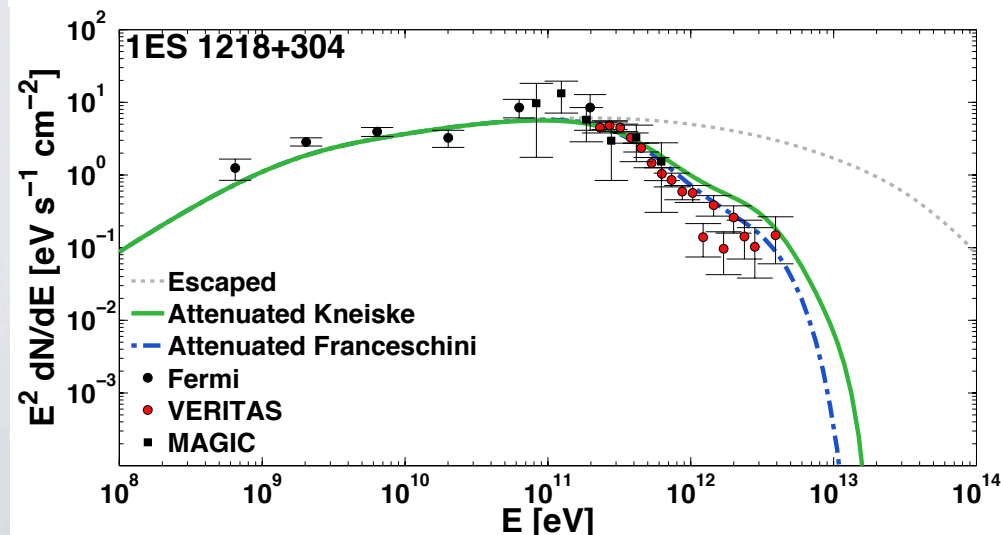
UHE protons

$B_{3 \text{ Mpc}} = 100 \text{ nG}$

Injection spectral index = 2

$E_{\text{MAX}} = 10^{20.5} \text{ eV}$

None



UHE photons

Injection spectral index = 1.5

$B_{3 \text{ Mpc}} = 100 \text{ nG}$

$E_{\gamma, \text{MAX}} = 10^{19.5} \text{ eV}$

$L_{\gamma} = 8 \times 10^{45} \text{ erg s}^{-1}$

\sim day *Acciari et al 2010*

UHE neutrals could account for \sim day variability if emission region $<$ pc size
detailed modeling needed

leptonic and UHECR Inverse Compton channels strongly subject to uncertainties on

- ▶ Extragalactic Background Light
- ▶ Intergalactic Magnetic fields

If blazar in mildly magnetized region (e.g. filament) and injects UHE protons

- ▶ robust synchrotron signal
- ▶ fits spectral shape

If UHE protons --> UHE photons inside source

- ▶ fits spectral shape
- ▶ time variability can be explained

Signatures:

- ▶ time variability
- ▶ extended halos around source

Fermi
CTA
HAWC

