Propagation of UHECRs in simulated Extra Galactic Magnetic Fields

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Overview

Cosmic Rays

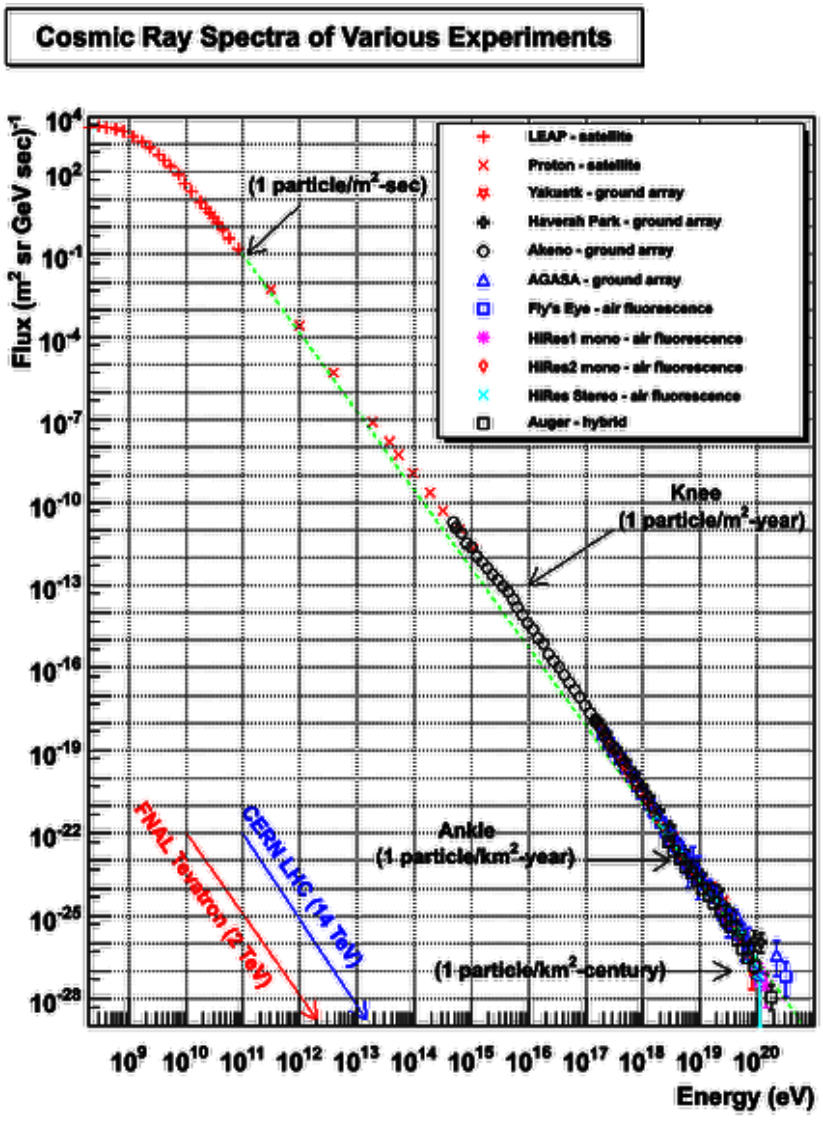
charged Nuclei

gyro radius $r_g = E/eZB$

low energy $E < 10^{18}\mathrm{eV}$

galactic origin

sources: remnants of SNe



W. Hanlon, Utah

Cosmic Rays

charged Nuclei

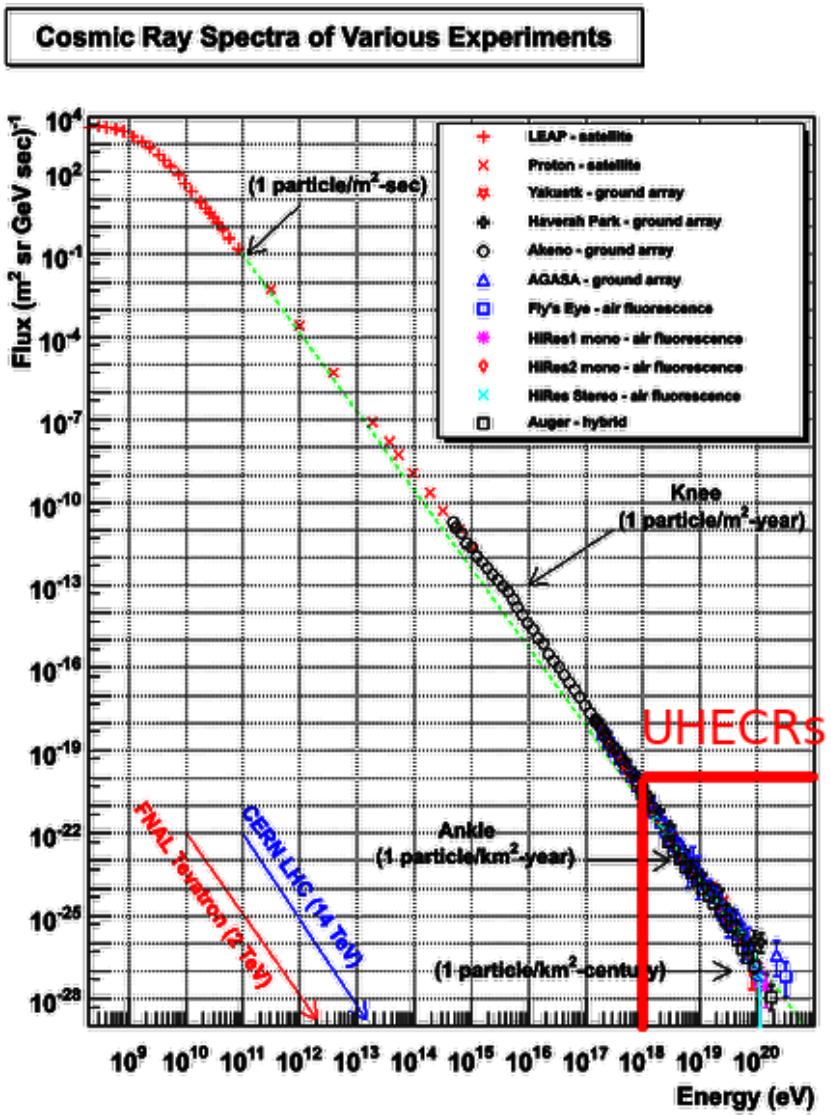
gyro radius $r_g = E/eZB$

low energy $E < 10^{18}\mathrm{eV}$

galactic origin
sources: remnants of SNe

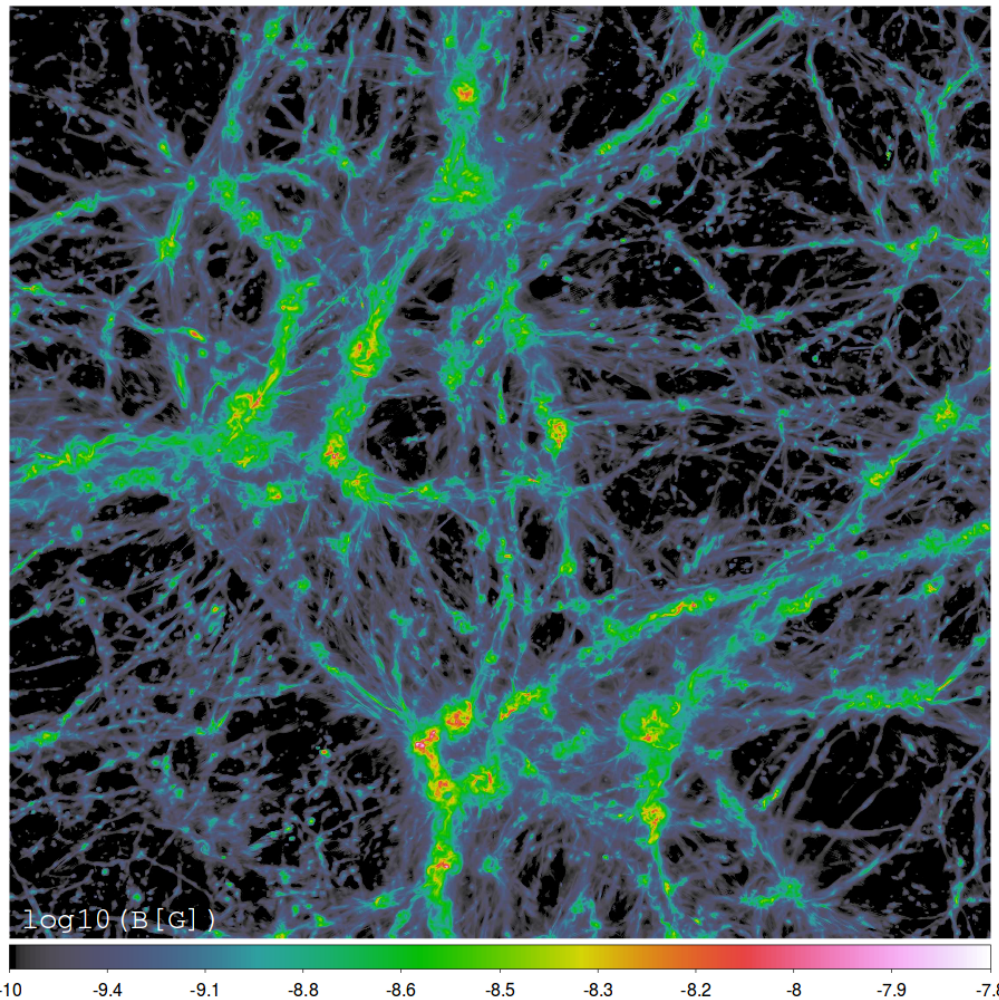
high energy $E > 10^{18}\mathrm{eV}$

extragalactic origin
sources: *unknown*



W. Hanlon, Utah

Extra-Galactic Magnetic Fields



F. Vazza, Bologna

Voids ($\approx 80\%$ of volume)

$B_0 \leq 0.55 - 5.6$ nG

$B_{\rm void} \geq 10^{-16}$G

LSS ($\approx$ 20% of volume)

galaxies $\sim 5 - 15\ \mu$G

clusters $\sim \mu$G

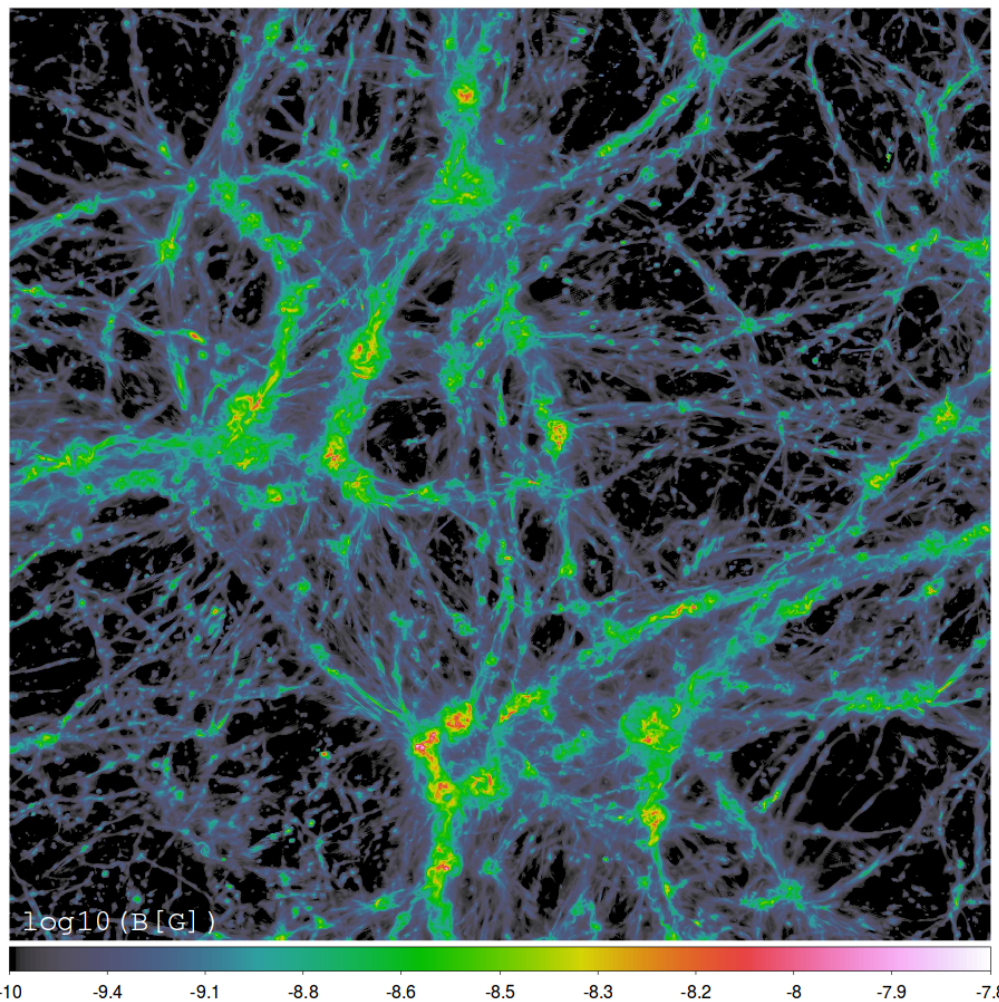
outskirts and filaments

unknown

Extra-Galactic Magnetic Fields

measure EGMFs with UHECRs?

constrain seeding processes?



Voids ($\approx$ 80% of volume)

$B_0 \leq 0.55 - 5.6$ nG

$B_{\rm void} \geq 10^{-16}$G

huge range of uncertainty

LSS ($\approx$ 20% of volume)

galaxies $\sim 5 - 15\ \mu$G

clusters $\sim \mu$G

outskirts and filaments

unknown

Combine ENZO

(state-of-the-art cosmic MHD simulations)

with CRPropa

(state-of-the-art simulation of UHECR propagation)

Magnetic Field Models

ENZO (cosmological grid MHD solver)

unconstrained

$B_0 = 10^{-14}$ G $- 10^{-8}$ G

18 observers

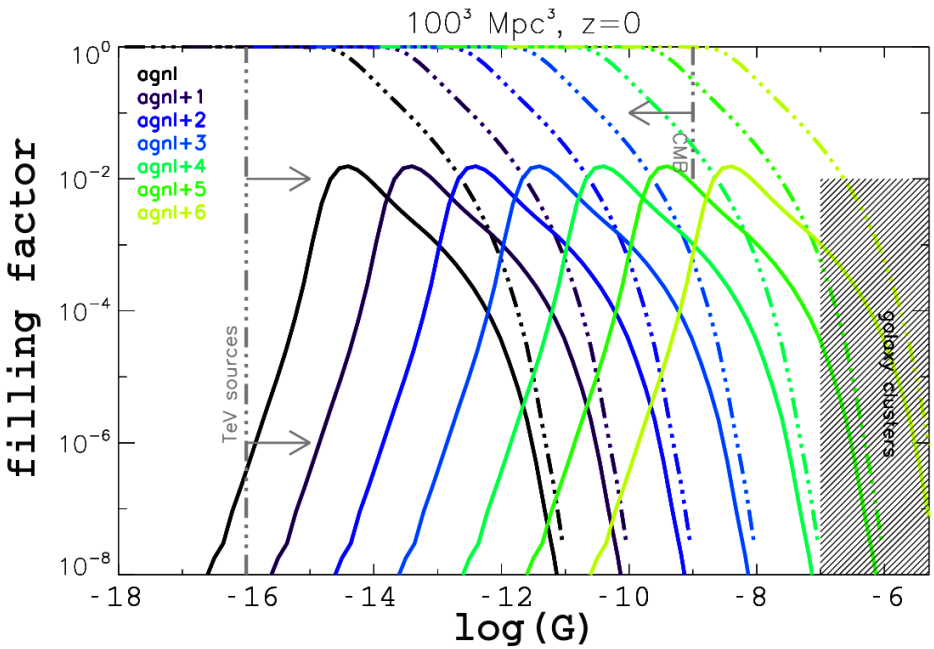
Protons: *Hackstein 2016*

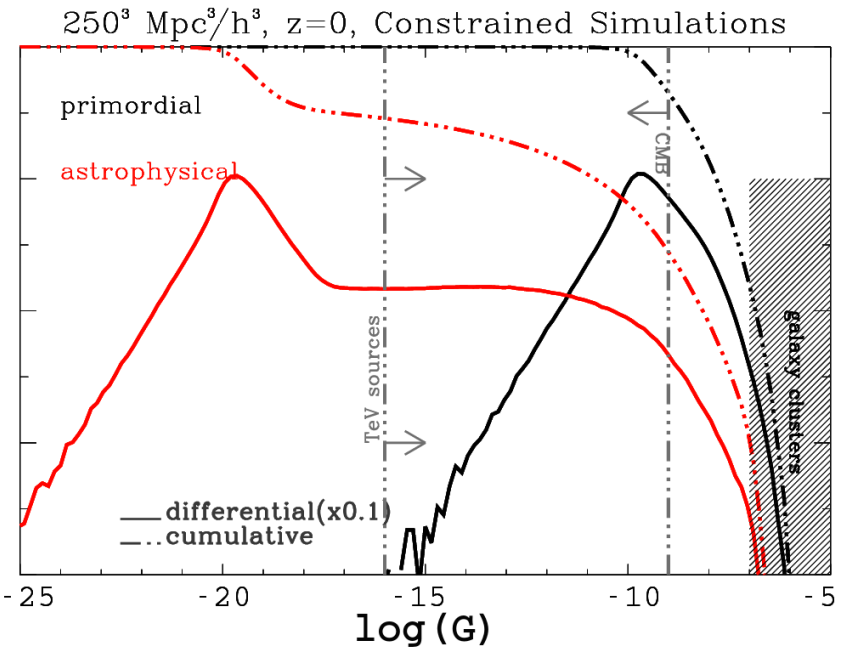
constrained *(Sorce 2015)*

primordial $B_0 = 10^{-9}$ G

astrophysical

magnetic feedback from AGN





Magnetic Field M

ENZO (cosmologi

unconstrained

$B_0 = 10^{-14}$ G $- 10^{-8}$ G

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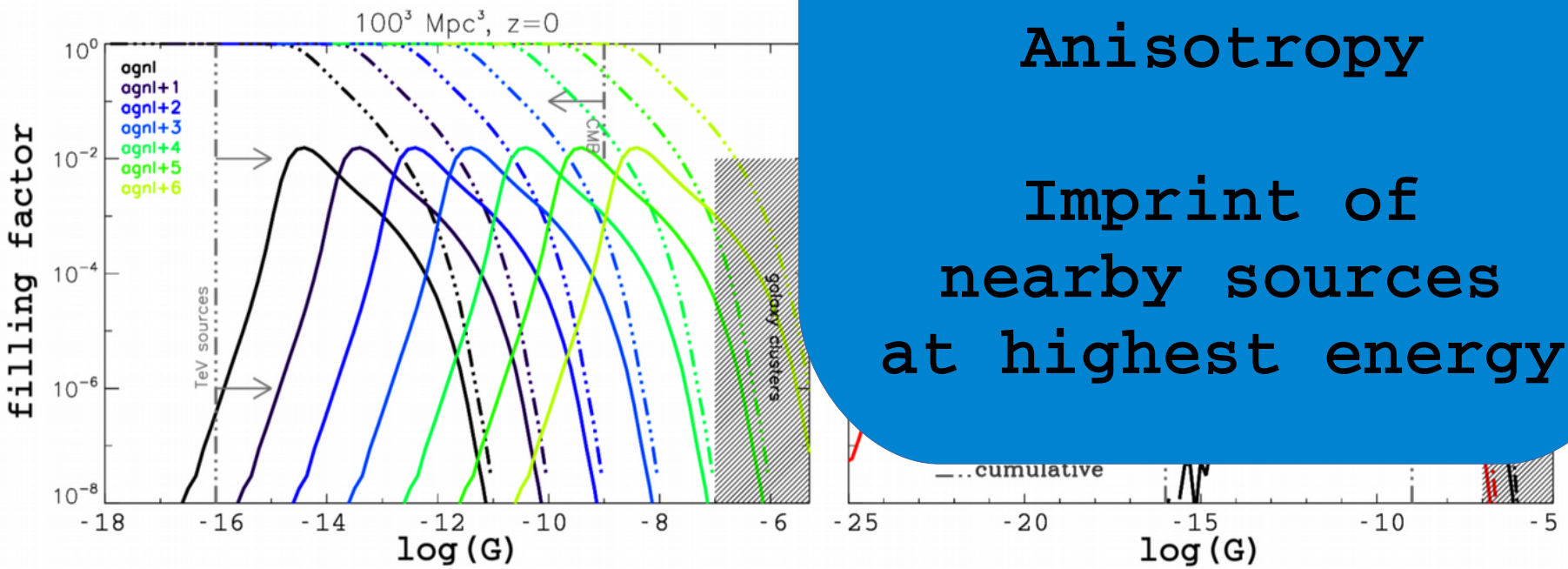
Protons: *Hackstein 2016*

Energy spectrum not affected by EGMFs

strong EGMFs increase Anisotropy

Imprint of nearby sources at highest energy



Magnetic Field M...

ENZO (cosmologi...

unconstrained

$B_0 = 10^{-14}$ G $- 10^{-8}$ G

18 observers

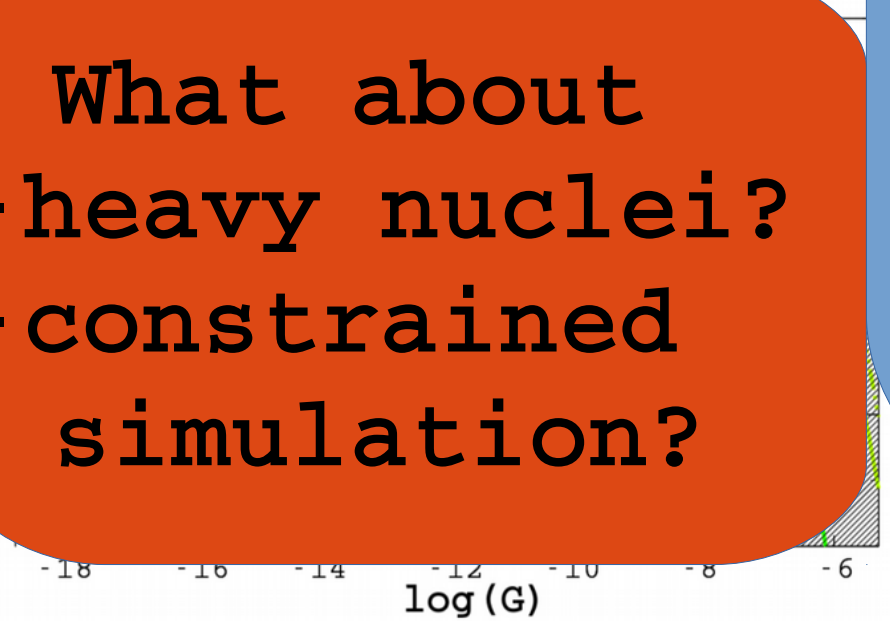
Protons: *Hackstein 2016*

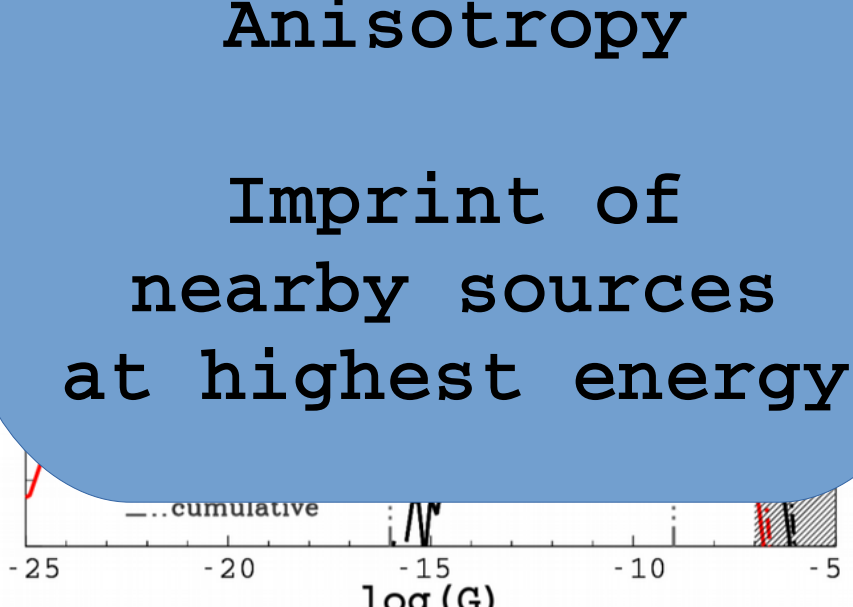
What about
-heavy nuclei?
-constrained
simulation?

Energy spectrum not affected by EGMFs

strong EGMFs increase Anisotropy

Imprint of nearby sources at highest energy





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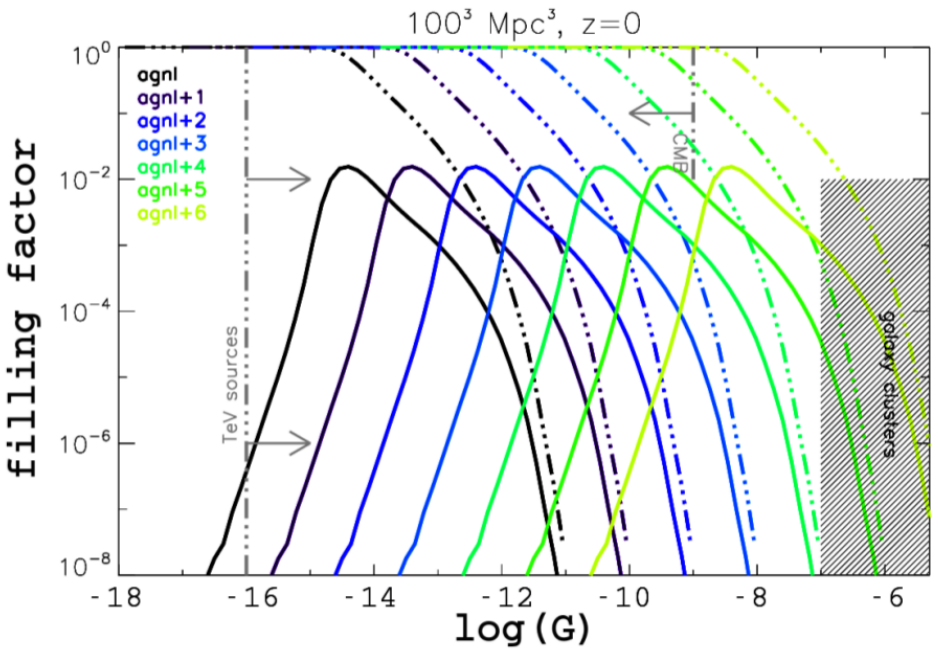
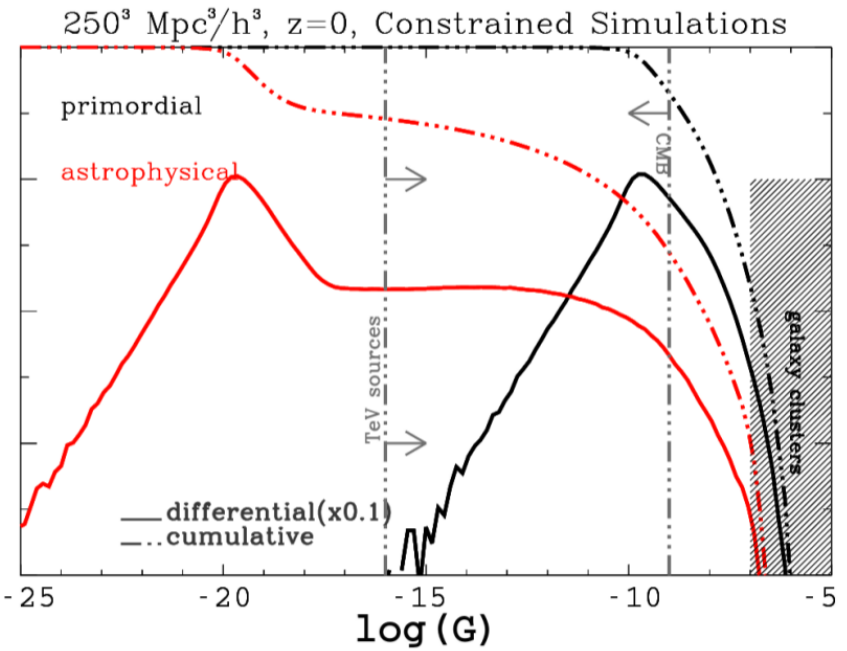
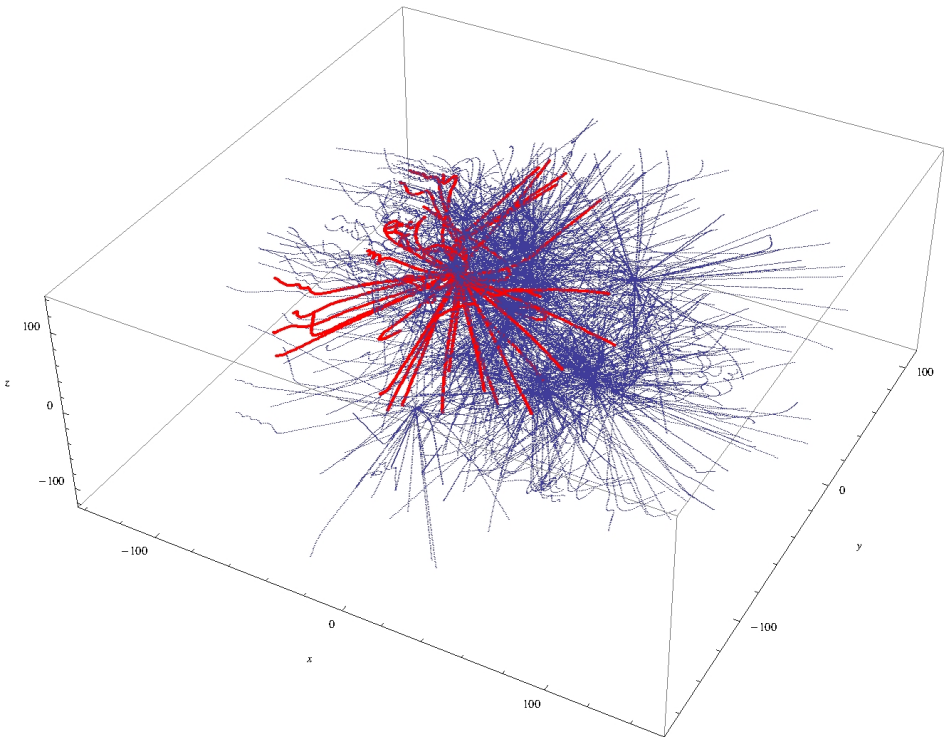




CRPropa



I. Dutan, L. I. Caramete et al. 2015

https://crpropa.desy.de/

Lorentz deflection

energy loss processes

- pair production
- pion production
  (GZK-effect, $E > 4 \cdot 10^{19}\mathrm{eV}$,
  $\Rightarrow$ distance limit $\sim 100\mathrm{Mpc}$)
- cosmic expansion

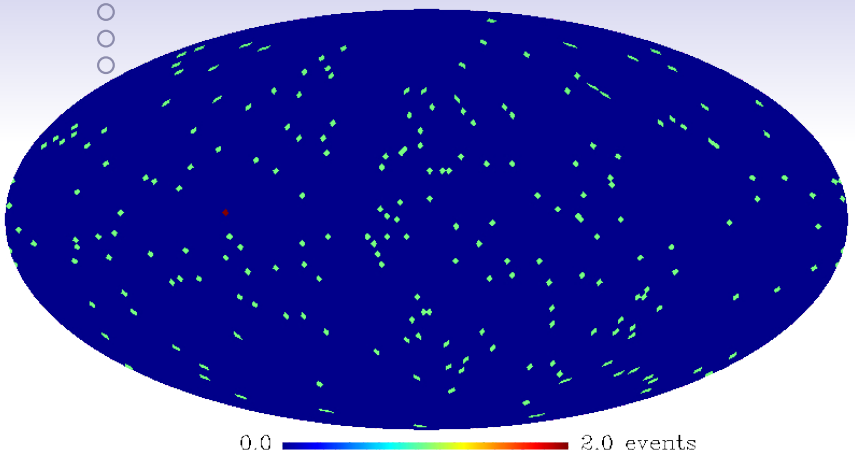
disintegration processes

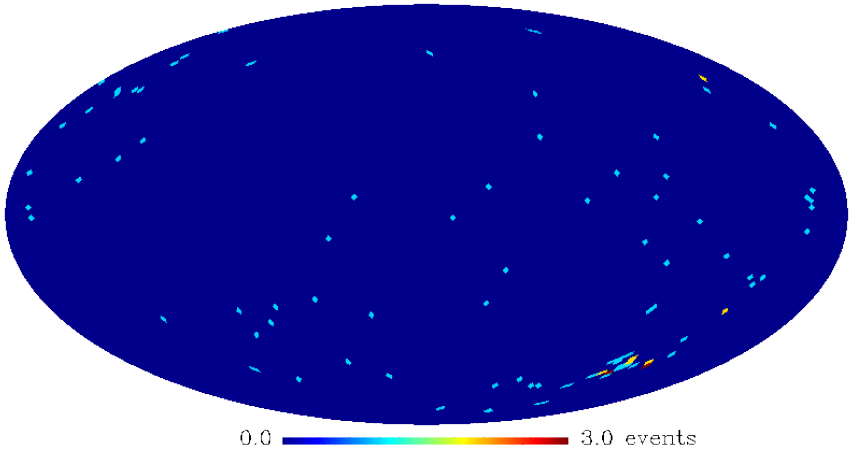
- photo disintegration
- nuclear decay

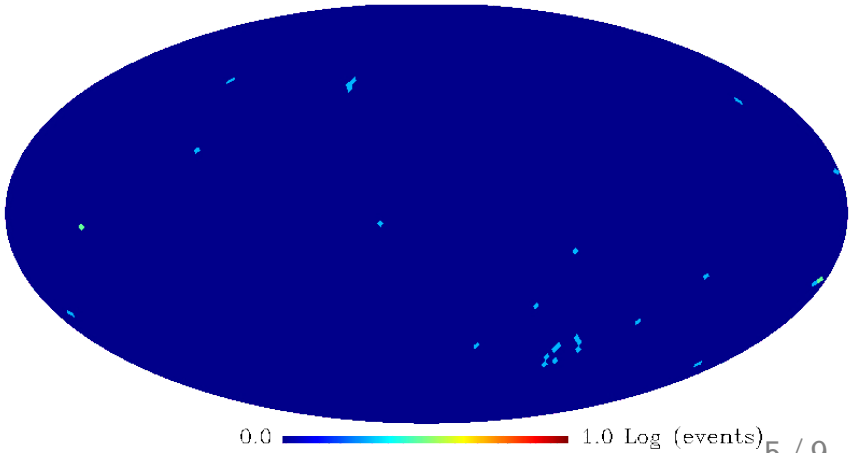
Sources

- **homogeneous** distribution
- follow gas **density** 1:1
- **mass halo**: overdensity $\rho > 20\rho_{\mathrm{mean}}$
- **vcv_velzen**: AGN & radio galaxies

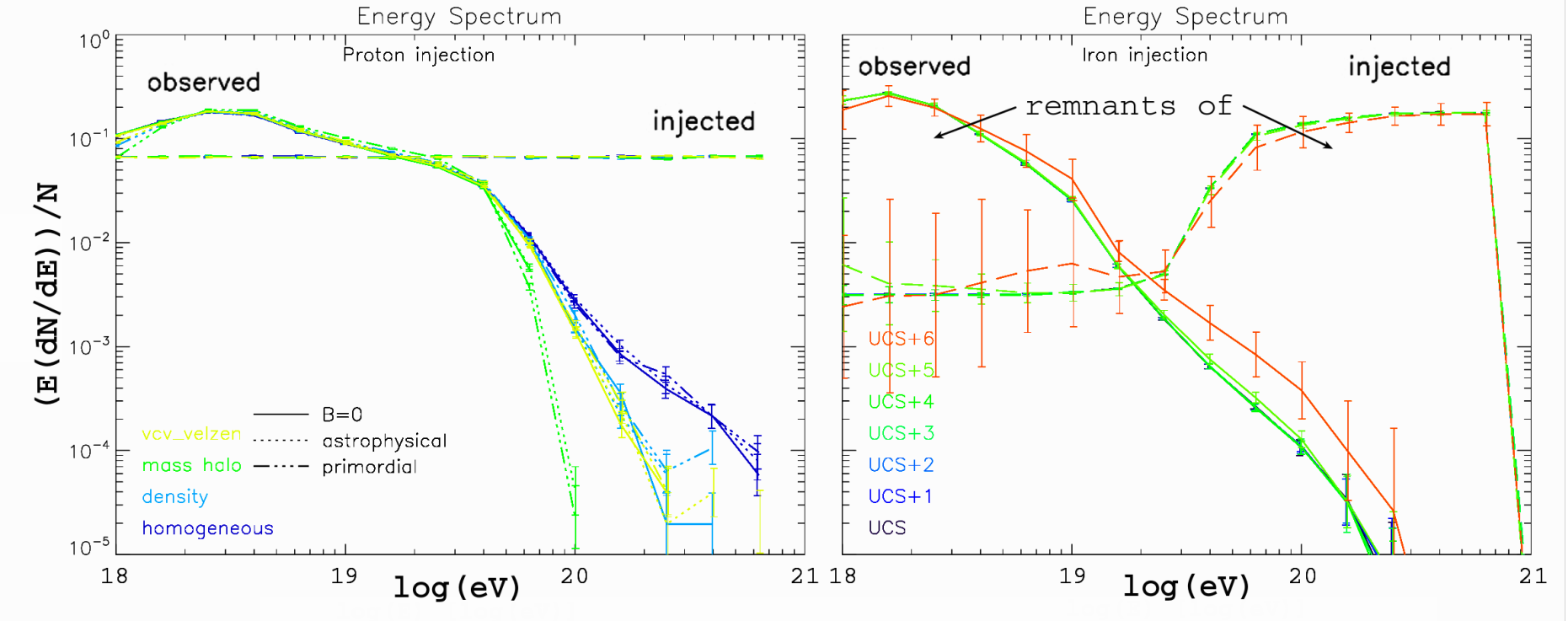
  (Véron-Cetty&Véron 2010, van Velzen 2012)





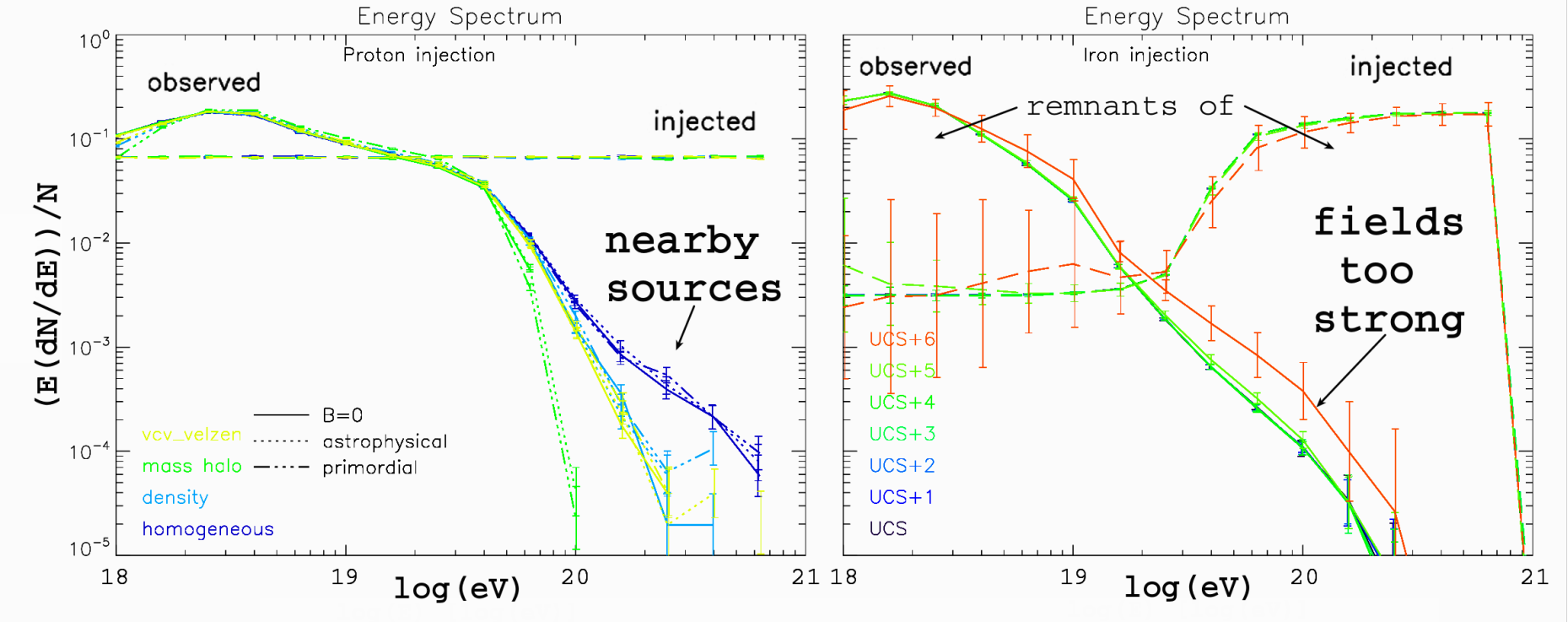


Energy Spectrum



- softer spectrum for heavy injection *(Allard 2012)*
  due to **shorter energy loss length** & remnant protons
- low energy: spectrum universal *(Aloisio 2004)*

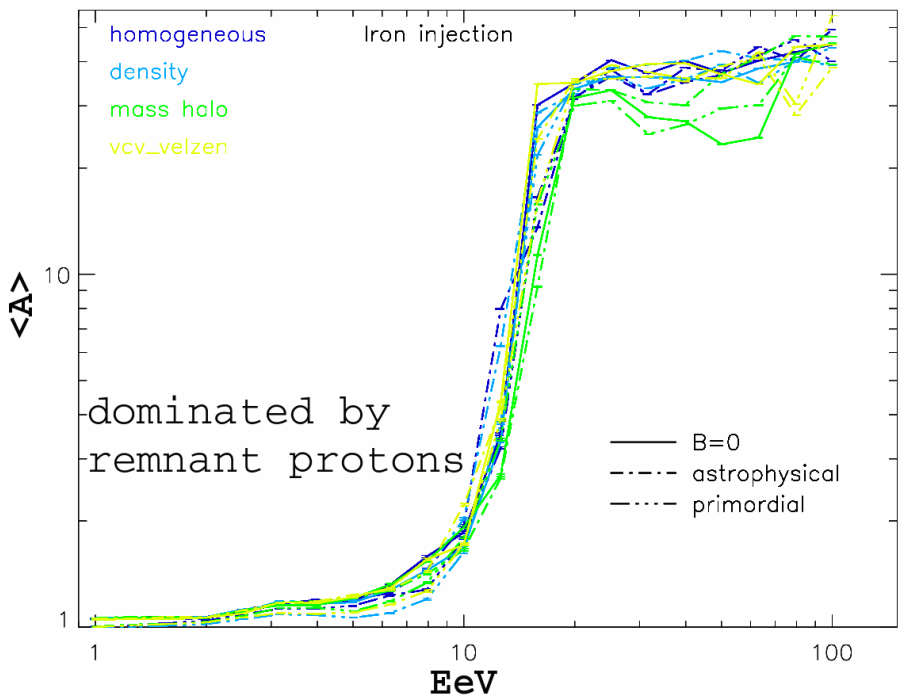
Energy Spectrum

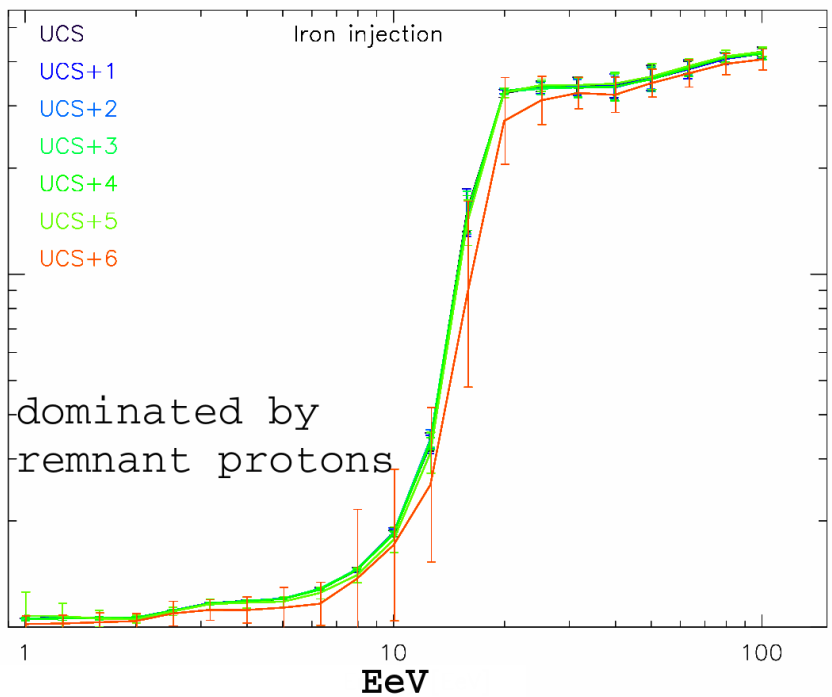


- softer spectrum for heavy injection *(Allard 2012)*
  due to **shorter energy loss length** & remnant protons
- low energy: spectrum universal *(Aloisio 2004)*
- **nearby sources** determine spectrum above GZK-limit
- no significant effect of EGMFs

Composition

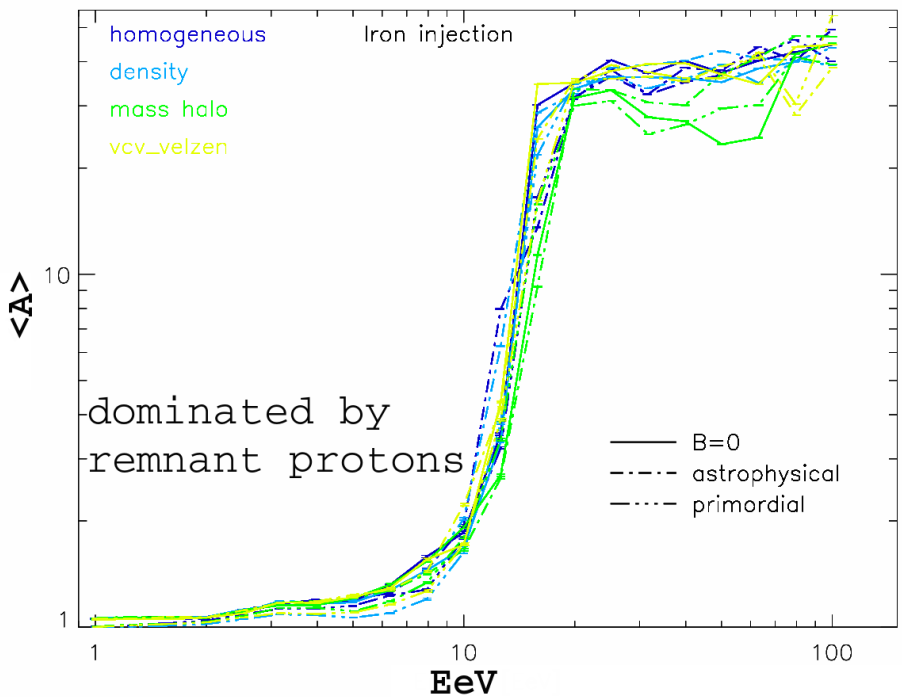
- not affected by choice of sources *(Globus 2007)*

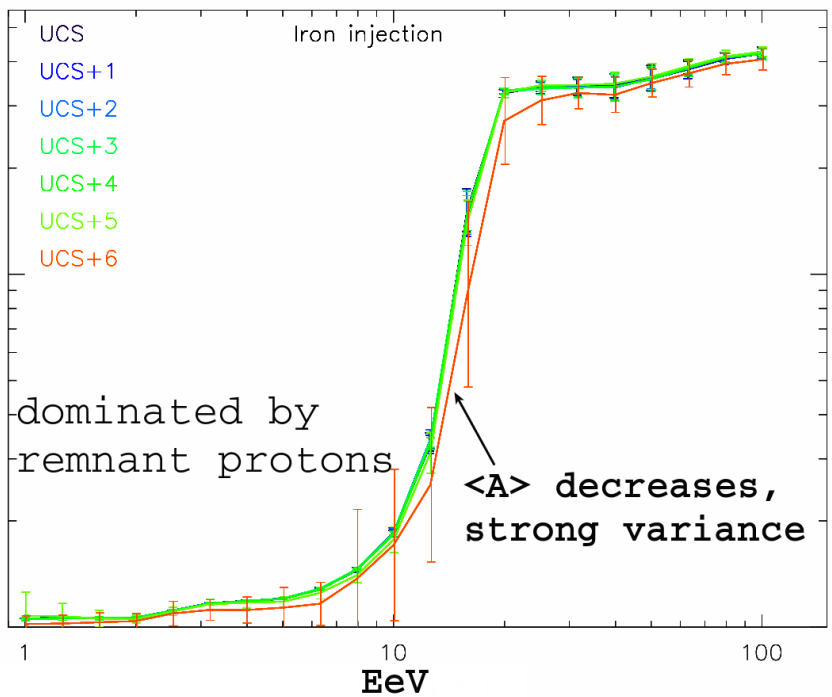




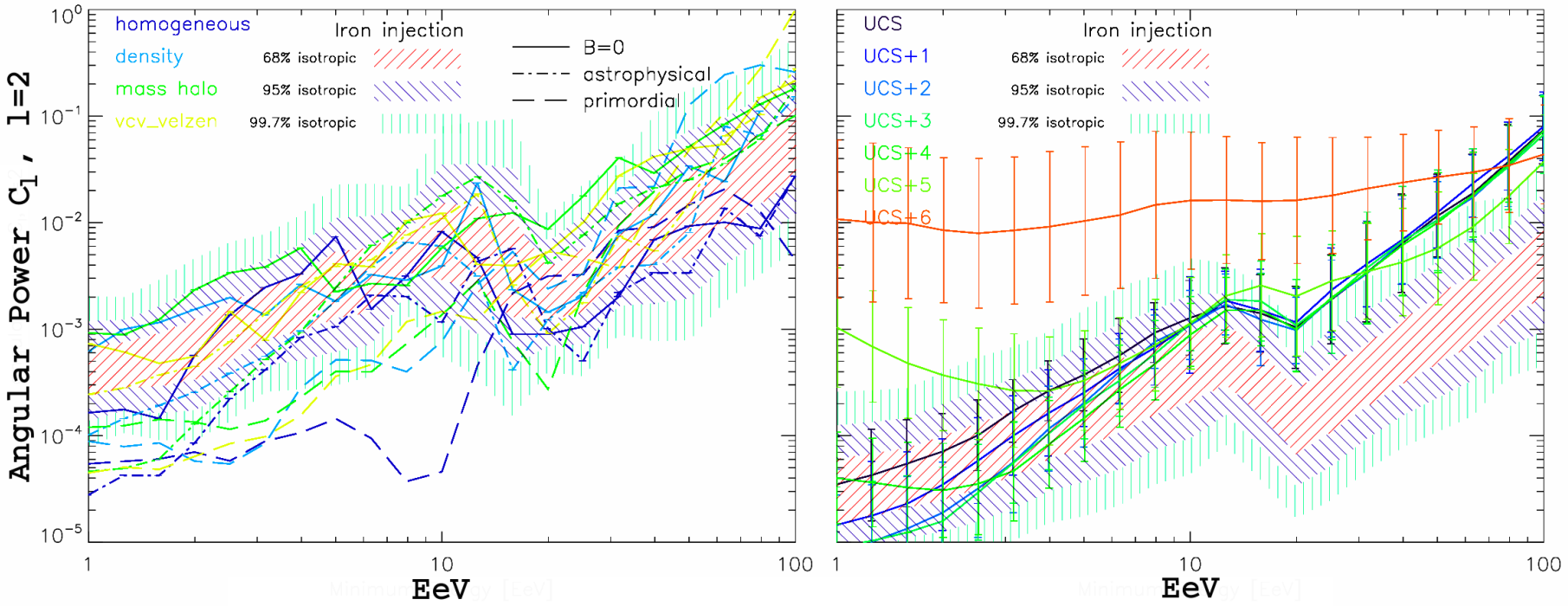
Composition

- not affected by choice of sources *(Globus 2007)*
- lighter composition in strongest models due to **longer travel** distance
- increased variance, independent of sources
  $\Rightarrow$ magnetization of observer favours effect





Angular Power $C_l = \frac{1}{2l+1} \sum_{m=-l}^{l} a_{lm} a_{lm}^{\star}$



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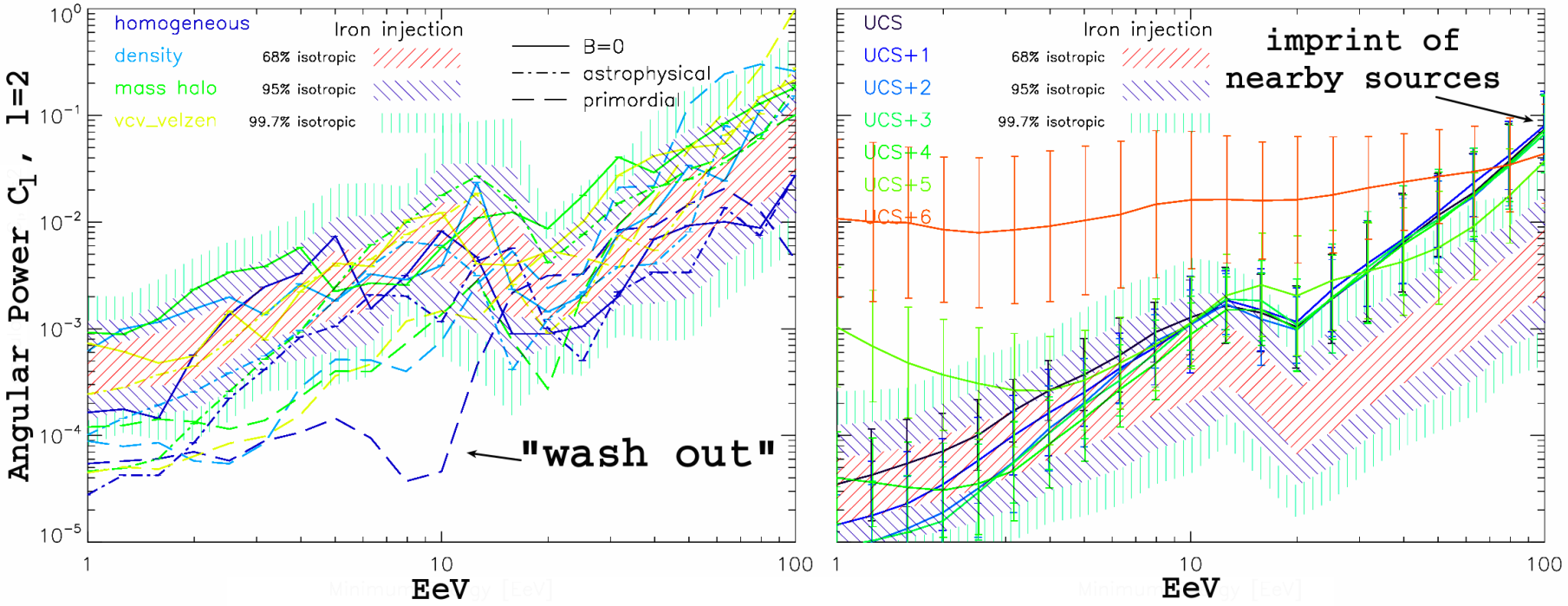

- source **imprint at highest Energy** in ALL models *(Harari 2013)*
- constrained: **wash out** anisotropy *(Takami 2012)*
- unconstrained: EGMFs **favour directions**
- **stronger deflection** of heavy nuclei

Conclusion

	Sources	**Strong CMFs**	**Heavy Nuclei**
spectrum	determine $E_{\max}$ & slope $> E_{\mathrm{GZK}}$	✗	softer spectrum
anisotropy	imprint at highest E	increase wash out	stronger deflection
observed composition	✗	✗	(obvious)

- UHECR astronomy possible at highest Energies ($\sim 10^{20}\mathrm{eV}$)
- chance to constrain magnetic seeding processes

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