Propagation of UHECRs in simulated Extra Galactic Magnetic Fields

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Overview

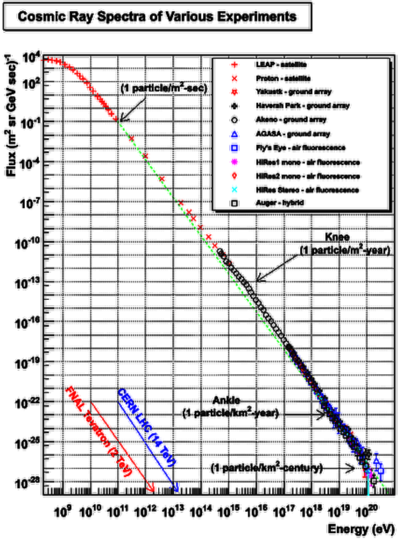
Cosmic Rays

charged Nuclei

gyro radius $r_g = E/eZB$

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

- galactic origin
- sources: remnants of SNe



Cosmic Rays

charged Nuclei

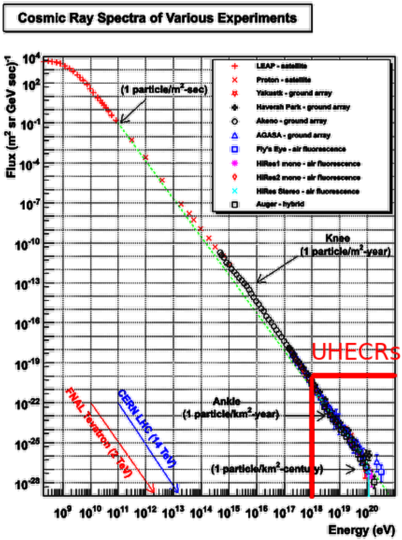
gyro radius $r_g = E/eZB$

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

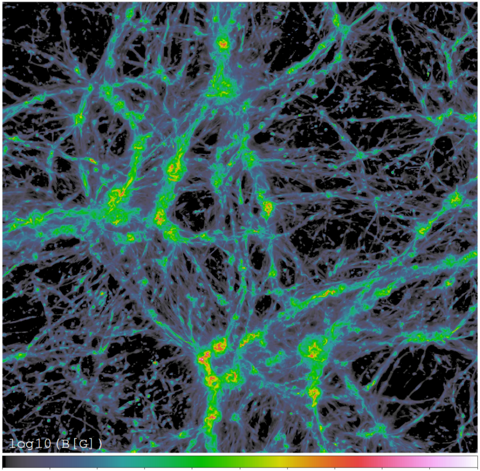
galactic origin
sources: remnants of SNe

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

extragalactic origin
sources: *unknown*



Extra-Galactic Magnetic Fields



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

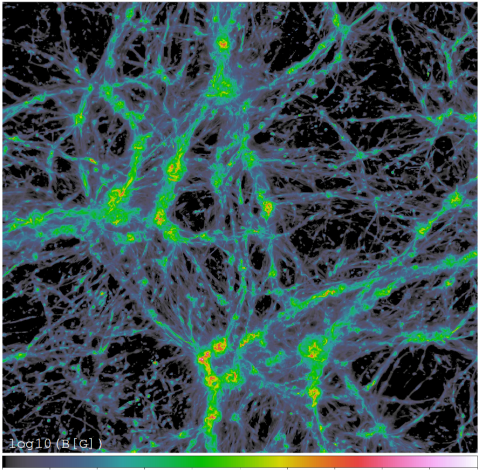
unknown

F. Vazza, Bologna

Extra-Galactic Magnetic Fields

measure EGMFs with UHECRs?

constrain seeding processes?



Voids ($\approx$ 80% of volume)

$B_0 \leq 0.55 - 5.6\ \mathrm{nG}$

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

huge range of uncertainty

LSS ($\approx$ 20% of volume)

galaxies $\sim 5 - 15\ \mu\mathrm{G}$

clusters $\sim \mu\mathrm{G}$

outskirts and filaments

unknown

F. Vazza, Bologna

Combine ENZO

(large MHD simulations on cosmic scale)

with CRPropa

(propagation of UHECRs in 3D models of EGMF)

Magnetic Field Models

ENZO (cosmological grid MHD solver)

unconstrained

$B_0 = 10^{-14}$ G – 10^{-8} G

18 observers

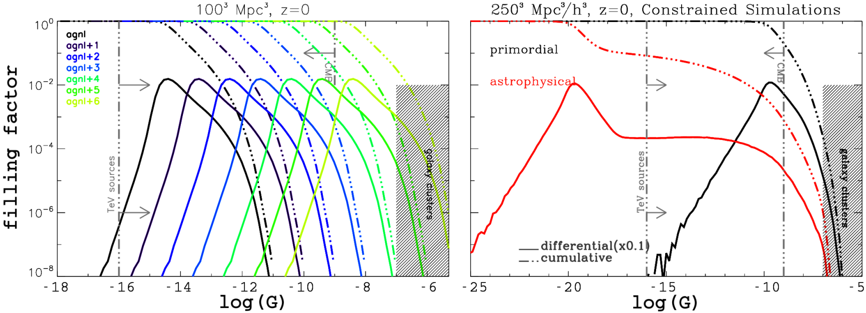
Hackstein et al. 2016 MNRAS

constrained *(Sorce 2015)*

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

astrophysical

magnetic feedback from AGN



Magnetic Fie

ENZO (cosmolog

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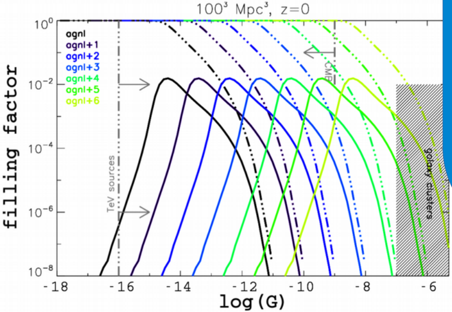
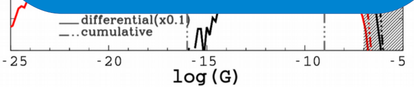
Energy spectrum not affected by EGMFs

strong EGMFs increase Anisotropy

Imprint of nearby sources at highest energy





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Energy spectrum
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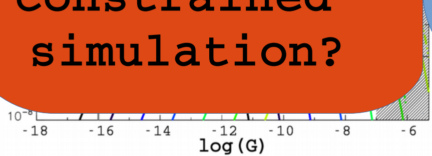
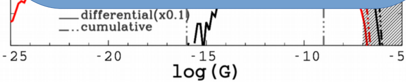
strong EGMFs
increase
Anisotropy

Imprint of
nearby sources
at highest energy

What about
-heavy nuclei?
-constrained
simulation?





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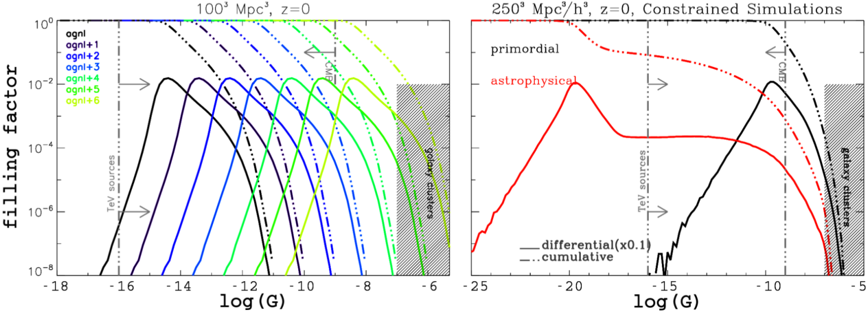
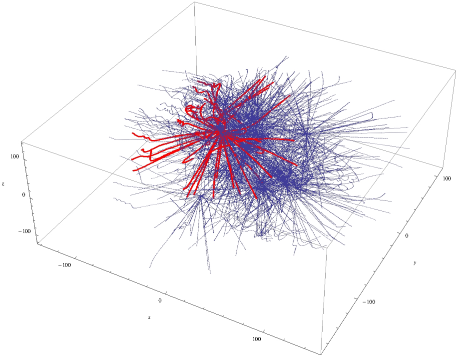


CRPropa



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

https://crpropa.desy.de/

Lorentz deflection

energy loss processes

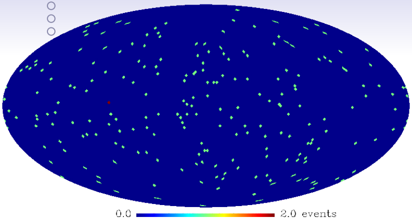
- pair production
- pion production (GZK-effect, $E > 4 \cdot 10^{19}\mathrm{eV}$, $\Rightarrow$ distance limit $\sim 100\mathrm{Mpc}$)
- cosmic expansion

disintegration processes

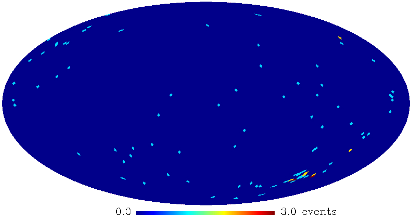
- photo disintegration
- nuclear decay

Sources

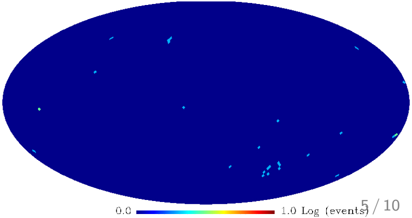
- **homogeneous** distribution



- follow gas **density** 1:1



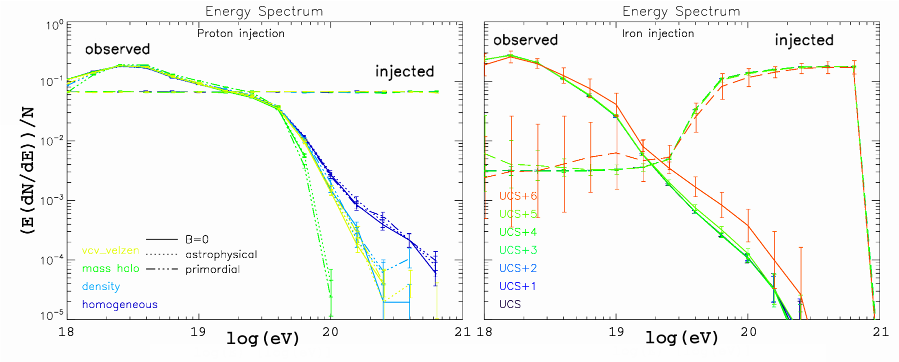
- **mass halo**: viral haloes



- **vcv_velzen**: AGN & radio galaxies

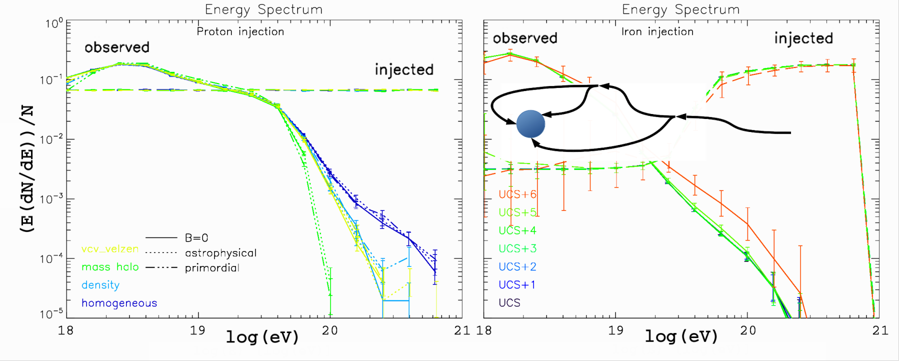
  (Véron-Cetty&Véron 2010, van Velzen 2012)

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



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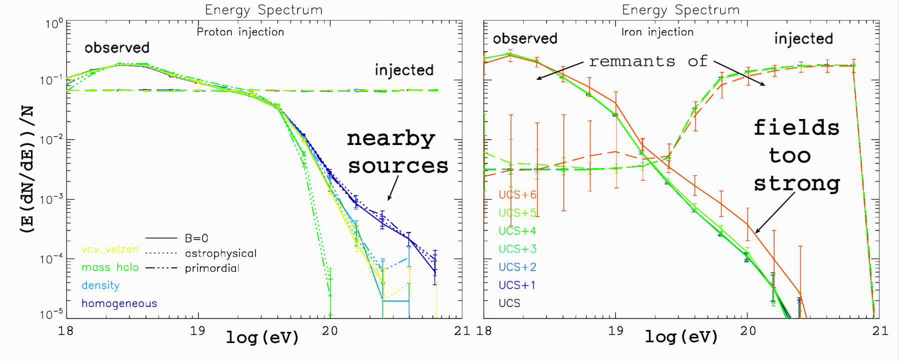
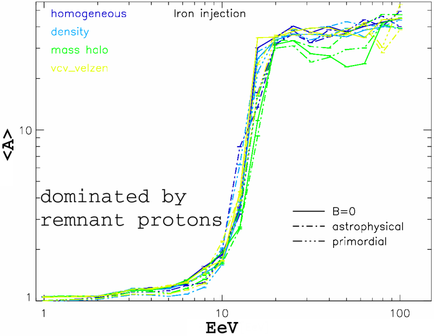
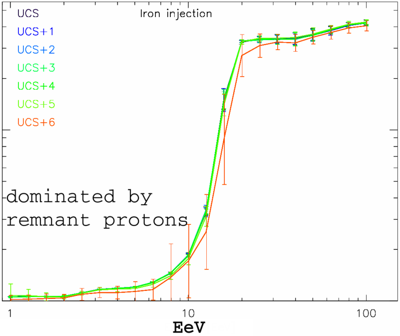


- softer spectrum for heavy injection *(Allard 2012)* due to **shorter energy loss length** & remnant protons
- low energy: spectrum universal *(Aloisio 2004)*
- **nearby sources** determine spectrum above GZK-limit
- no significant effect of EGMFs

Composition

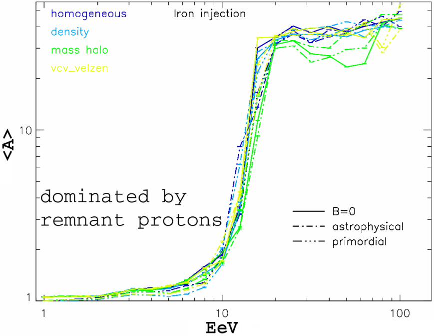
- not affected by choice of sources *(Globus 2007)*

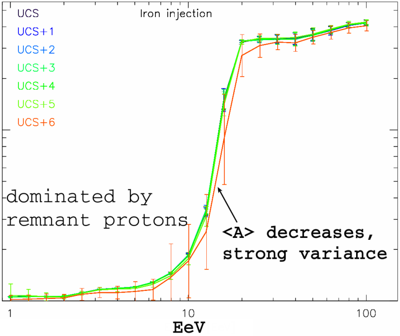




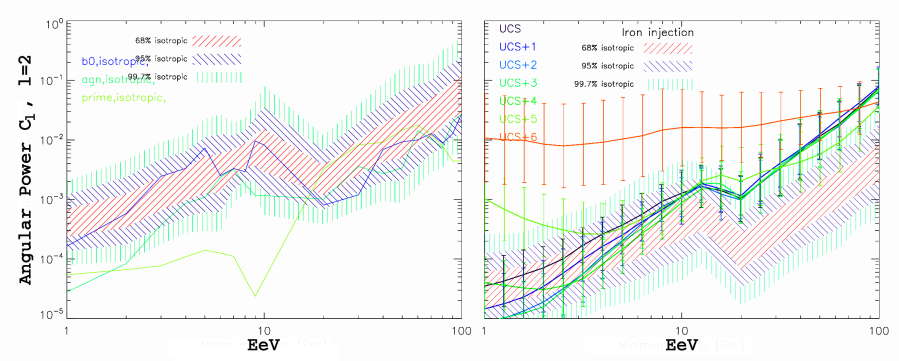
Composition

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



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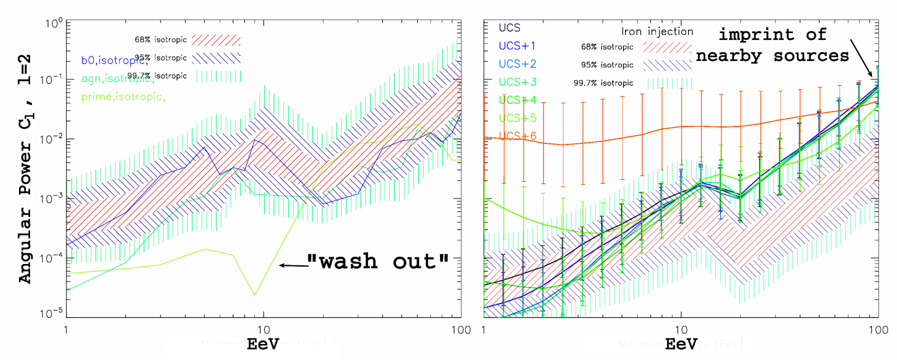
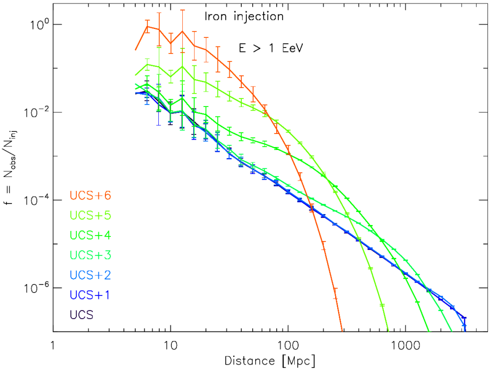


- source **imprint at highest Energy** in all models *(Harari 2013)*
- constrained: **wash out** anisotropy *(Takami 2012)*
- unconstrained: EGMFs **favour directions**
- **stronger deflection** of heavy nuclei

Contribution of Sources



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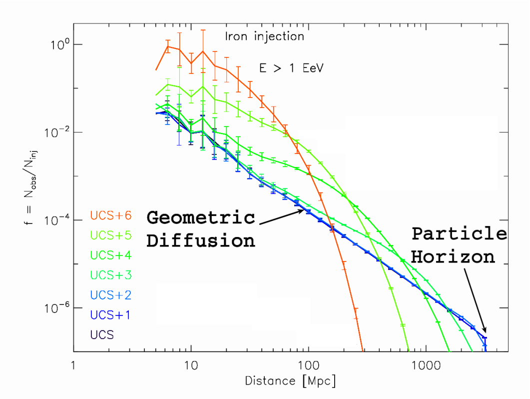
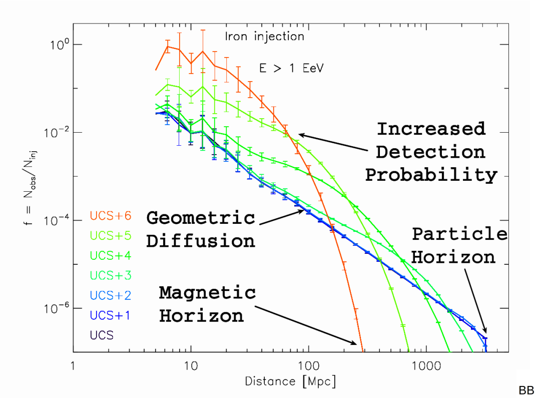


weak magnetic fields:

- geometric diffusion

Contribution of Sources

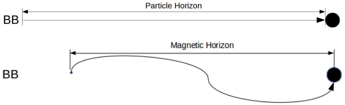


weak magnetic fields:

- geometric diffusion

strong magnetic fields:

- increased detection probability *(Harari 2013)*
- magnetic horizon *(Batista 2014)*



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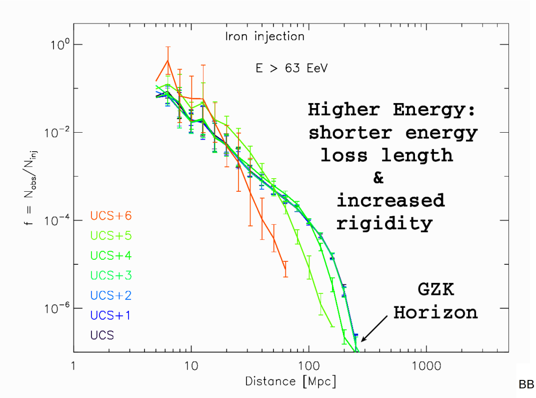

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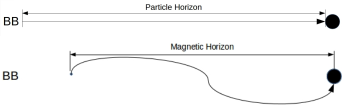


Conclusion

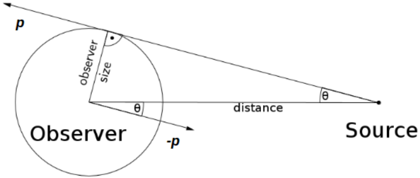
	Sources	**Strong CMFs**	**Heavy Nuclei**
spectrum	determine E_{max} & slope $> E_{\mathrm{GZK}}$	✗	softer spectrum
anisotropy	imprint at highest E	increase wash out	stronger deflection
observed composition	✗	✗	(obvious)

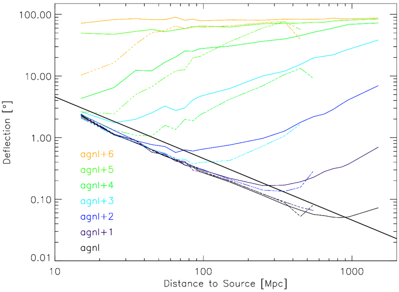
- UHECR astronomy possible at highest Energies ($\sim 10^{20}\mathrm{eV}$)
- chance to constrain magnetic seeding processes

Artefacts

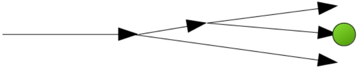
effect of finite observer

artificial deflection

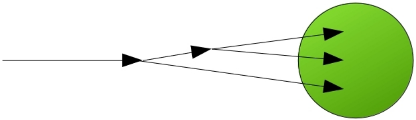




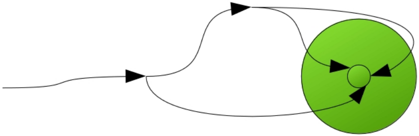
ideal observer



finite observer



magnetized observer



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