Ultra-high Energy Cosmic Rays and Cosmic Magnetic Fields

Stefan Hackstein

1st year PhD student @

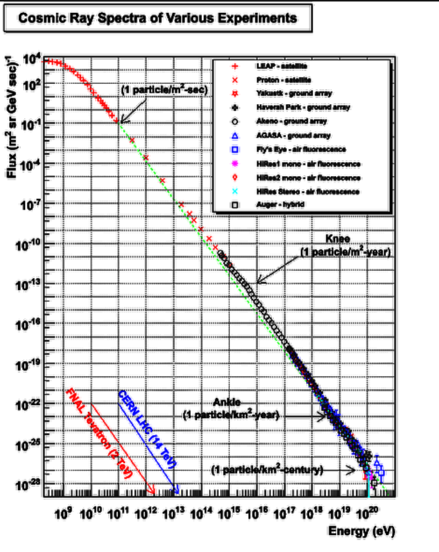
stefan.hackstein@hs.uni-hamburg.de

Supervisors: Marcus Brüggen, Franco Vazza

Collaborators: Günter Sigl, Andrej Dundovic, Jenny G. Sorce, Stefan Gottlöber

2018-3-7

Cosmic Rays



W. Hanlon

charged Nuclei

power law $10^9 - 10^{20}$ eV

knee at 10^{16} eV

E_{max} of galactic sources

SN remnants (*Blasi 2013*)

ankle at 10^{18}

sources extragalactic

unknown

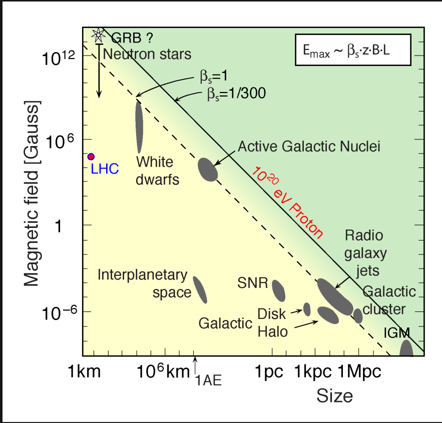
Hillas Criterion

Fermi acceleration

gyro radius $r_g = E/eZB$

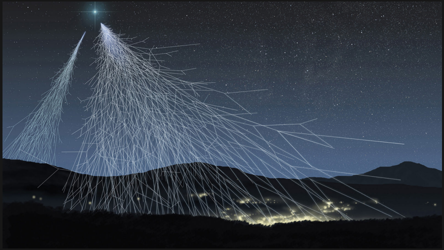
Hillas Criterion:
$R > r_g \Rightarrow E_{max} \propto B \cdot R$

Sources: GRB? AGN? RG? Cluster?



A. M. Hillas

Observation



ASPERA/Novapix/L.Bret

Extensive Air Shower
in earth's atmosphere

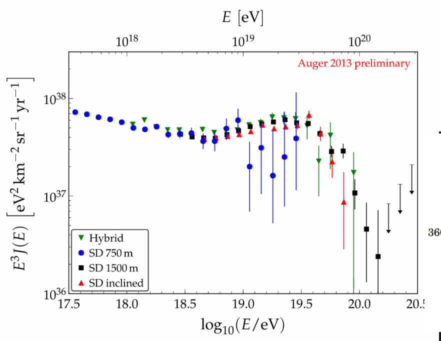
Array of:
Cherenkov telescopes &
Fluorescence light detector

Observables:

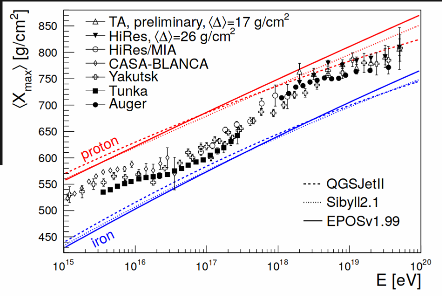
Energy (particle density)
Direction (delay)
Mass (Xmax, ρ_μ)

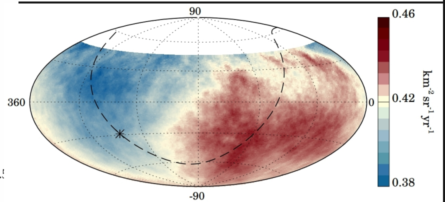
Combined Observables:

- Energy spectrum
- Composition
- Anisotropy



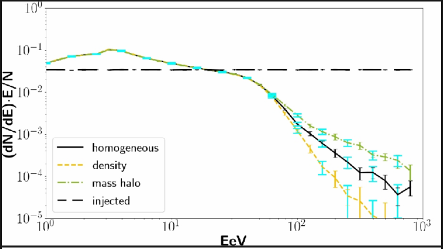
Letessier-Selvon

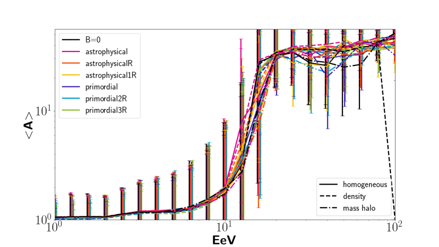




Pierre Auger Collaboration (Fall 2017)

Propagation





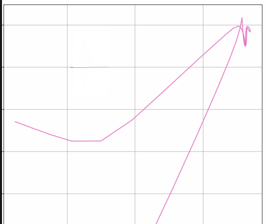
Hackstein et al. 2016 & 2018

energy losses
- pair production, GZK

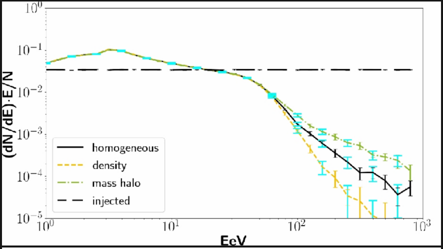
change in composition
- decay, disintegration

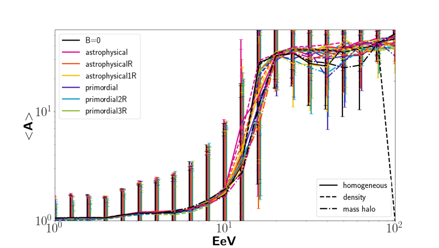
change in anisotropy
- deflection

UHECR astronomy not trivial



Propagation





Hackstein et al. 2016 & 2018

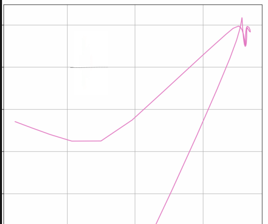
energy losses
- pair production, GZK

change in composition
- decay, disintegration

change in anisotropy
- deflection

UHECR astronomy not trivial

measure EGMFs?



ENZO

(large cosmological MHD)

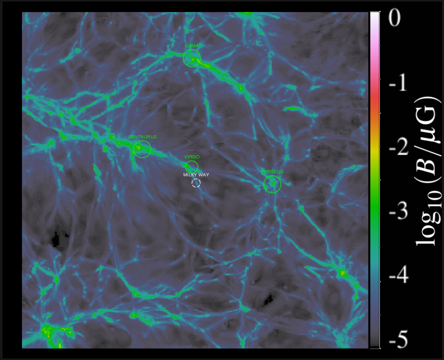
vary field strength
& magnetogenesis
(primordial vs. astrophysical)

&

CRPropa

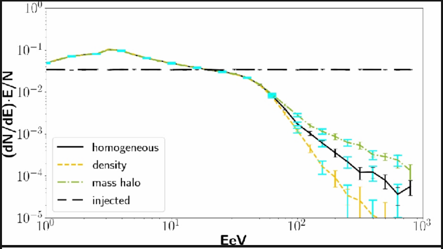
(CR propagation in CMFs)

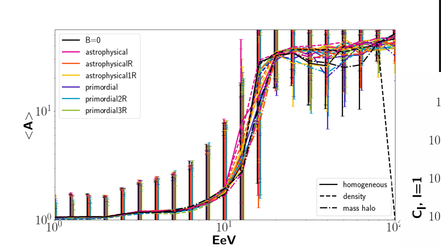
vary sources & composition



Franco Vazza, Bologna

Results

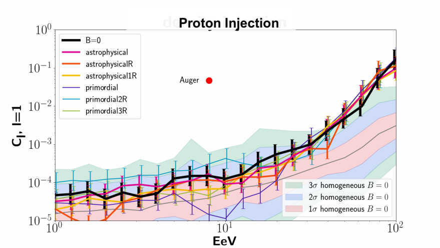




energy spectrum $\not\propto B$
(Propagation Theorem,
Aloisio & Berezinsky 2004)

composition $\not\propto B$

anisotropy source dominated,
UHECR astronomy at highest E



Hackstein et al. 2016 & 2018

Results

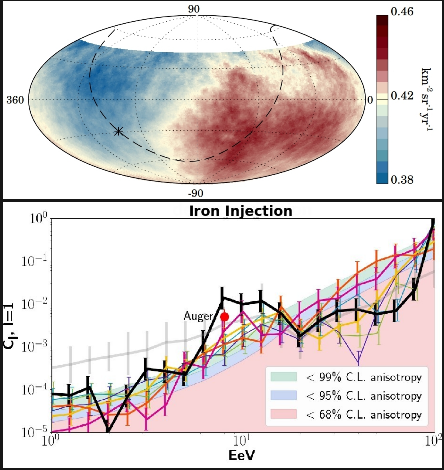
heavy injection spectrum

reproduces observed dipole with many source models,

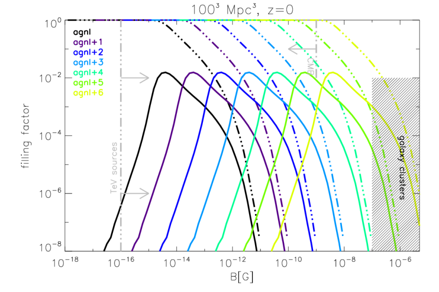
protons need extreme models

⇒ <u>heavy injection favoured</u>

Hackstein et al. 2018



Results

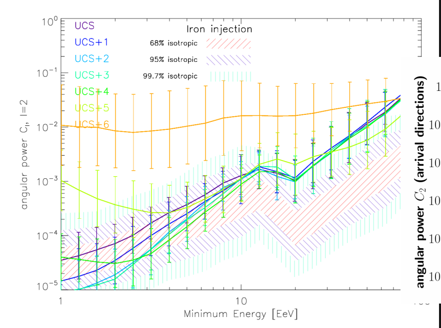


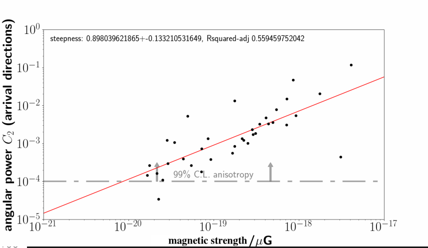
increase B

$\Rightarrow$ anisotropy at low energy

anisotropy $\propto B$

Hackstein et al. 2016





Liouville's Theorem

BUT

Theorem (Liouville's theorem on CRs)

isotropy of CR flux is preserved along line of force
i. e. magnetic deflection cannot create anisotropies

Parker 1967

Liouville's Theorem

BUT

Theorem (Liouville's theorem on CRs)

isotropy of CR flux is preserved along line of force
i. e. magnetic deflection cannot create anisotropies

Parker 1967

???

simulations too complex!

choose more basic models!

mono-energetic, constant composition

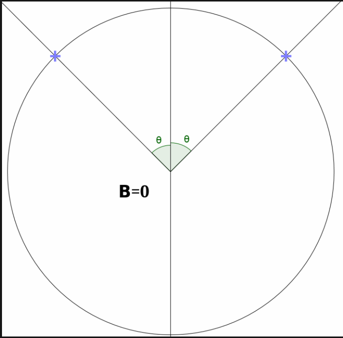
Uniform field

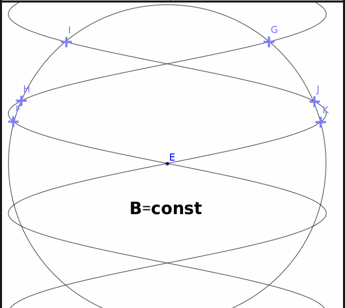
consider injection from sphere at distance d

most basic magnetic field: $B = const$

number of starting positions on injection sphere depends on Θ, B & d

Hackstein et al. *in proc.*





Uniform field

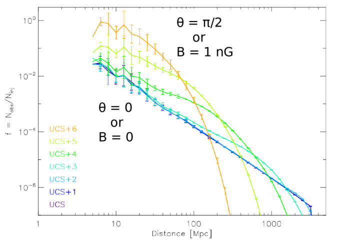
consider injection from sphere at distance d

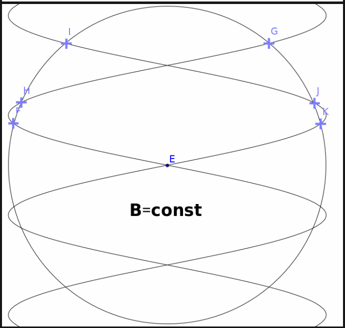
most basic magnetic field: $B = const$

number of starting positions on injection sphere depends on Θ, B & d

$\Rightarrow$ prefer nearby sources
$\Rightarrow$ shorter <trajectory>
$\Rightarrow$ heavier composition

Hackstein et al. *in proc.*





Uniform field

consider injection from sphere at distance d

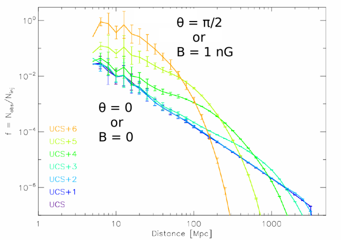
most basic magnetic field: $B = const$

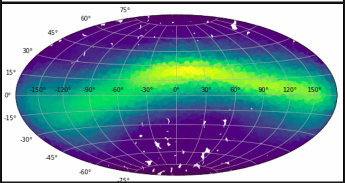
number of starting positions on injection sphere depends on Θ, B & d

$\Rightarrow$ prefer nearby sources
$\Rightarrow$ shorter <trajectory>
$\Rightarrow$ heavier composition

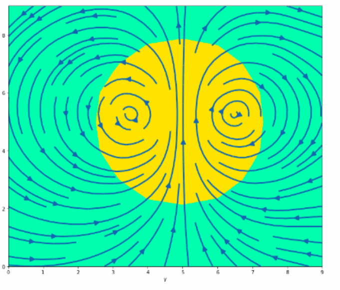
$\Rightarrow$ quadrupole anisotropy

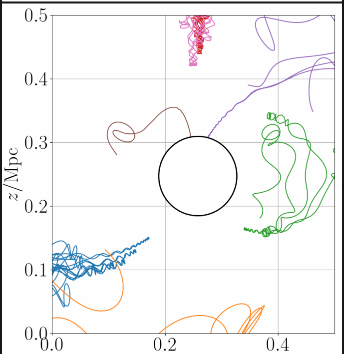
Hackstein et al. *in proc.*





Poloidal field





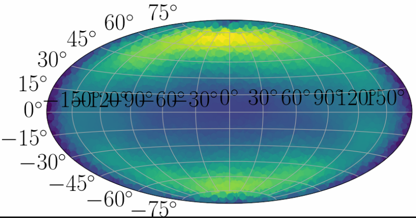
more realistic field: poloidal

shields at equator,
attracts at poles
(cf. earth's magnetosphere)

Parker, van Allen, Alfven, et al. 1960's

$\Rightarrow$ <u>quadrupole anisotropy</u>

Hackstein et al. *in proc.*



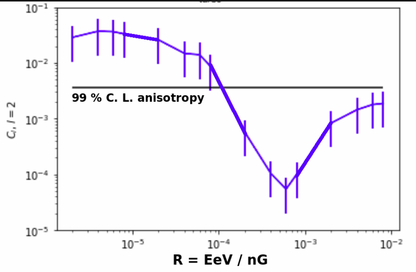
Constrain Magnetosphere of Milky Way

(quadrupole) anisotropy is not observed
$\rightarrow$ infer constraints on poloidal component of MW Magnetosphere

$R \overset{!}{>} 10^{-4} \Rightarrow$
$\underline{B_{\mathrm{Pol}} < \sim 10\ \mu\mathrm{G}}$

Hackstein et al. *in proc.*

predictions for influence of Magntosphere of Milky Way



Conclusions

ballistic propagation $\gtrsim 80\mathrm{EeV}$
$\Rightarrow$ **UHECR astronomy possible**

Different seeding models indistinguishable
$\Rightarrow$ **No info on magneto-genesis**

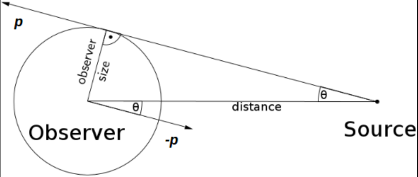
heavy injection composition more likely to reproduce observed anisotropy

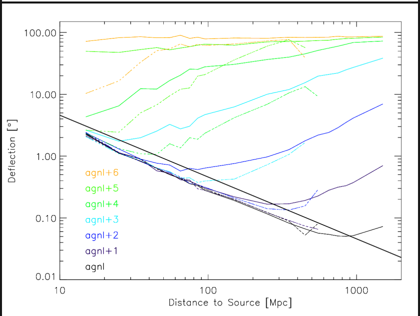
Extragalactic Magnetic fields can produce (quadrupole) anisotropy if particles are trapped
$\Rightarrow$ **constrain on poloidal component** in magnetosphere of MW of order $\sim 10\mu\mathrm{G}$,
uniform component of order $\sim 1\mathrm{nG}$

Artefacts

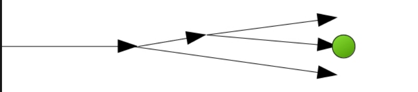
effect of finite observer

artificial deflection

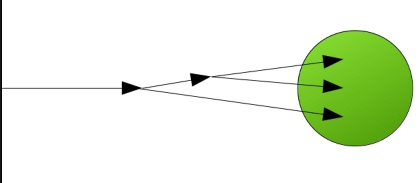




ideal observer



finite observer



magnetized observer