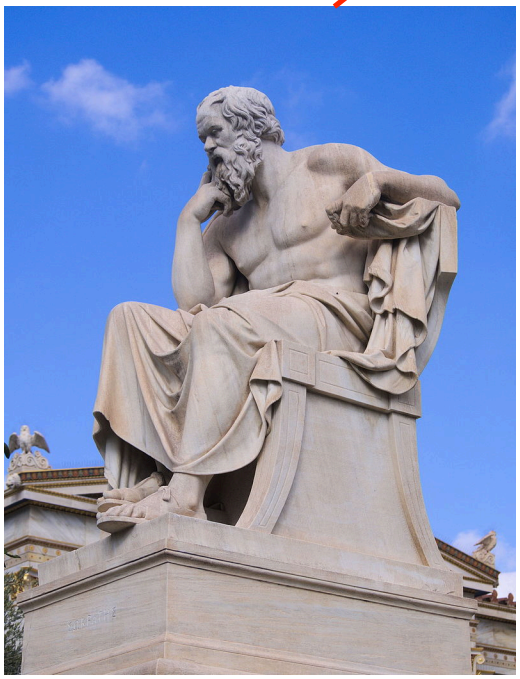
The Potential Effects of Galactic Magnetic Fields on UHECR from Local Sources

Know Thy~~self~~ Galaxy

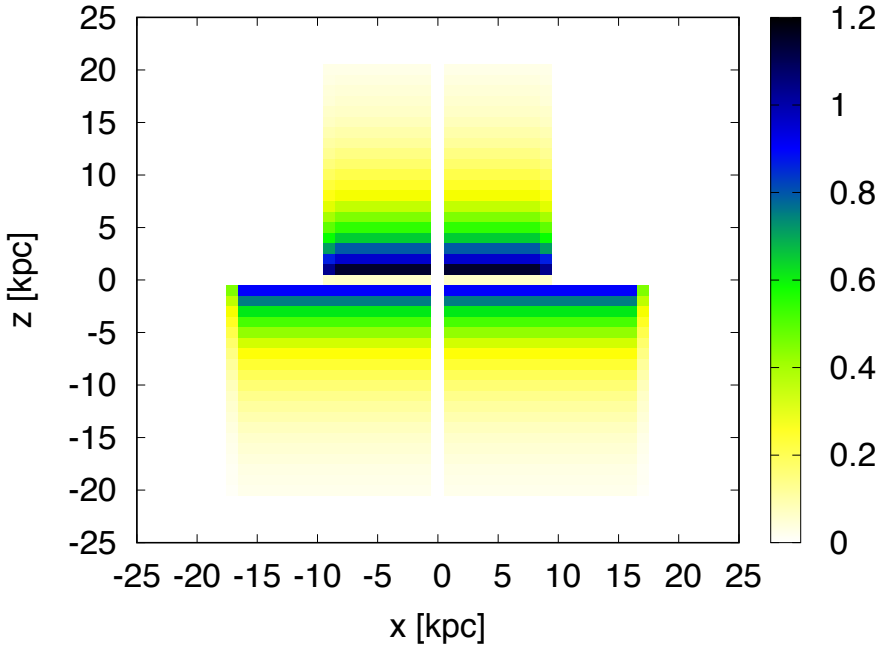


Andrew Taylor
&
Michael Hillas

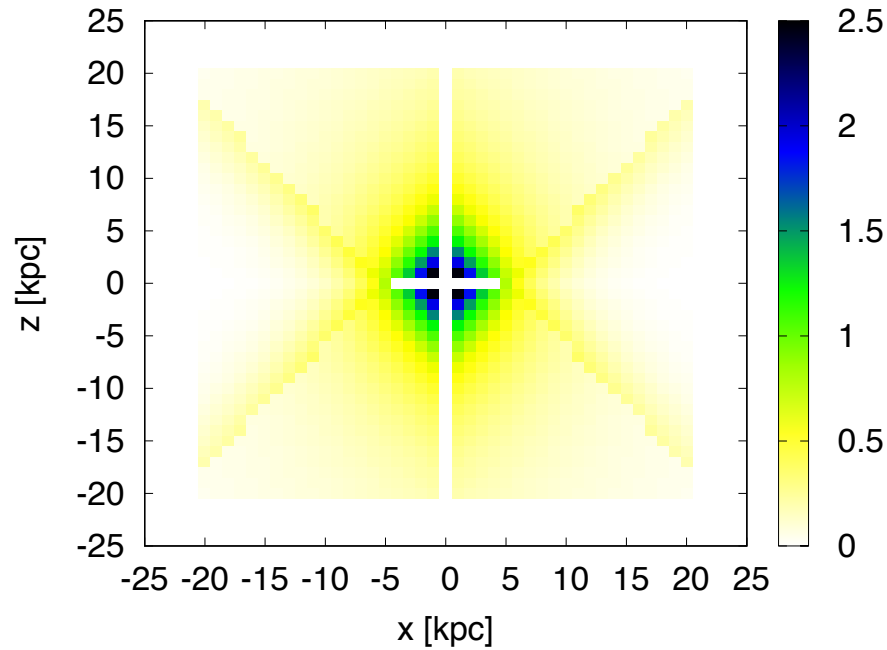
Galactic B-field Interaction with Cen A CR Flux

Jansson & Farrar (2012)

Toroidal field component



X-field component



Inferred indirectly from:

- Synchrotron Emission maps
- Rotation Measure maps

following the adoption of thermal and non-thermal particle models

Galactic Magnetic Field and Cosmic Ray Energy Content

$$\mathbf{U_B^{disk} = 8 \times 10^{53}\ erg}$$

$$\mathbf{U_B^{toroid} = 4 \times 10^{54}\ erg}$$

$$\mathbf{U_B^{X-field} = 3 \times 10^{54}\ erg}$$

$$\mathbf{U_{CR} \approx 3 \times 10^{55}\ erg}$$

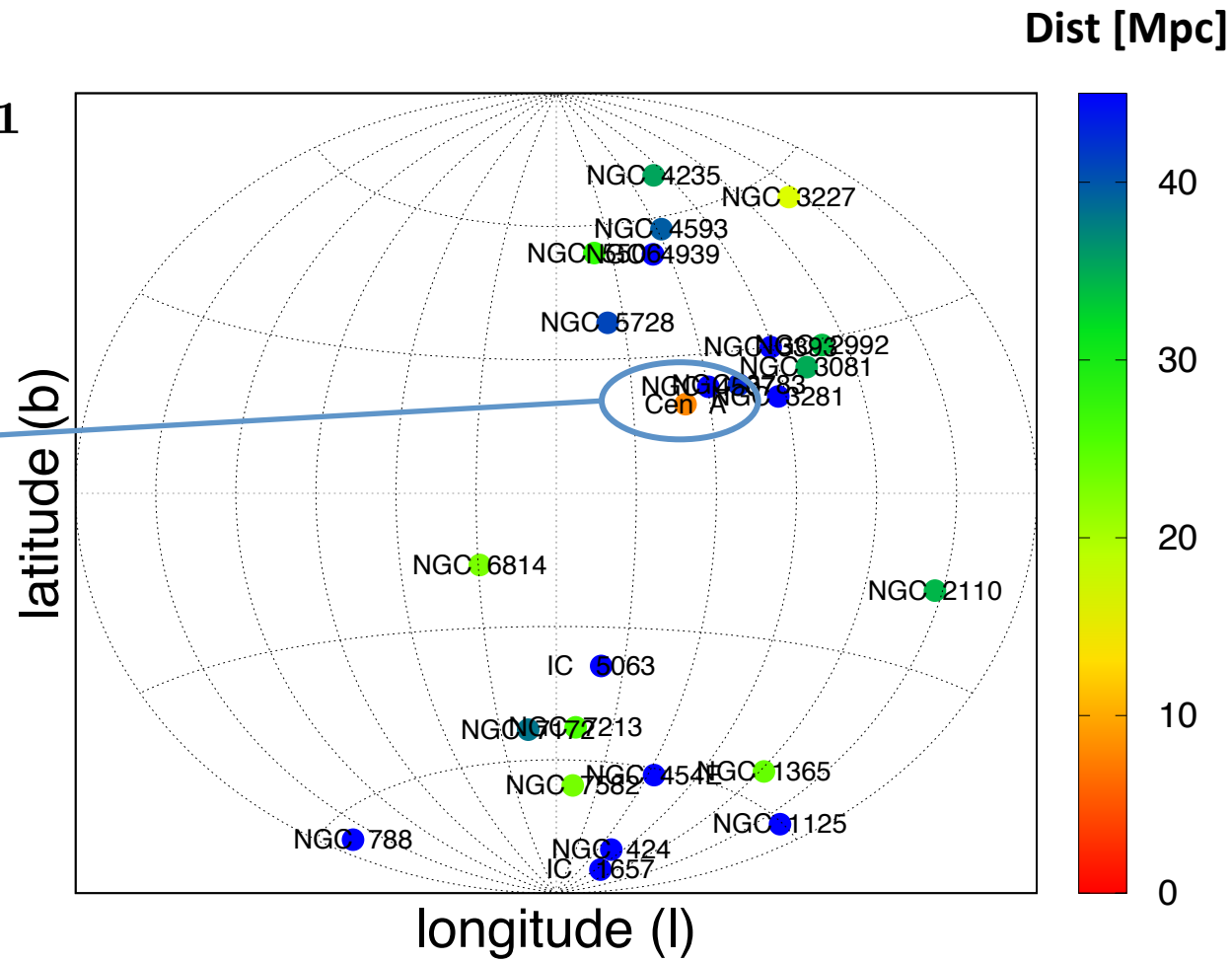
Deflections of CR From Local Sources

$$\mathbf{L} > \mathbf{3} \times \mathbf{10^{42}} \frac{\mathbf{1}}{\beta^{\mathbf{2}}} \left(\frac{\mathbf{E_p}}{\mathbf{3} \times \mathbf{10^{18}}\ \mathrm{eV}} \right)^{\mathbf{2}}\ \mathrm{erg\ s^{-1}}$$

Norman et al. (1995)
Pe'er et al. (2009), 0911.1776

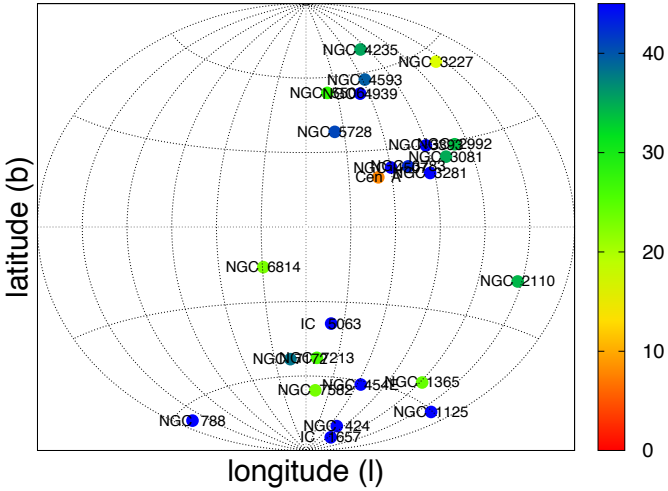
$$\mathbf{L_X} > \mathbf{10^{42.5}\ erg\ s^{-1}}$$

The locality of Cen A offers opportunity to use this candidate source to probe Galactic magnetic field effects

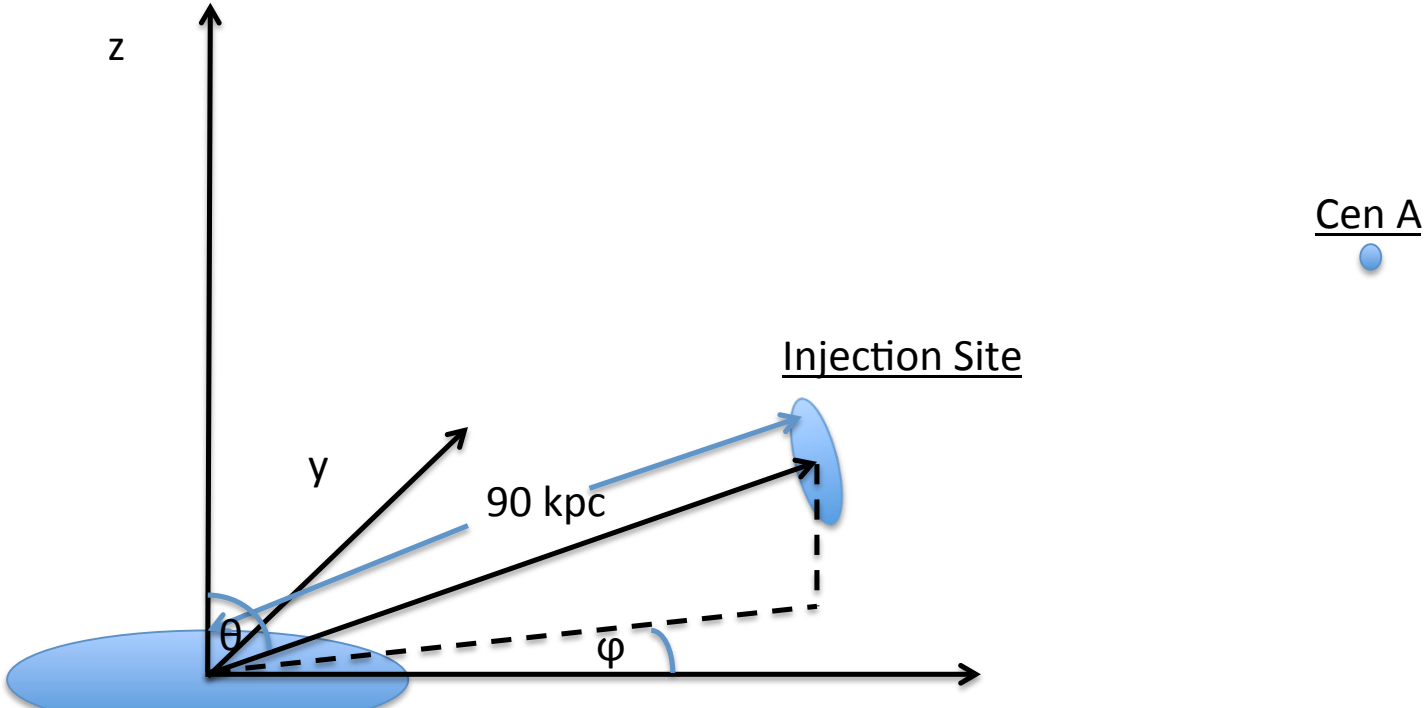


(Swift 58 month Hard X-Ray catalogue)

“Low Energy” Spectral Suppression of CR from Cen A



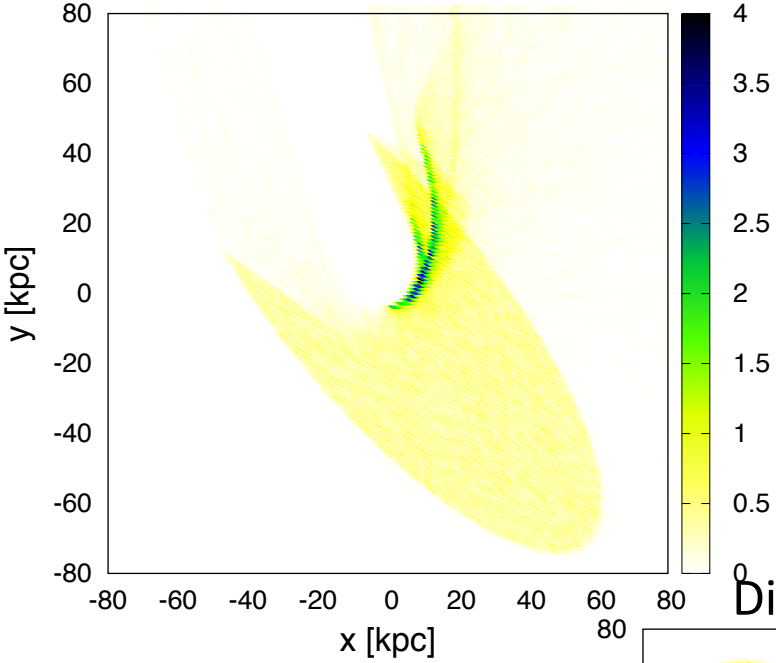
System Setup



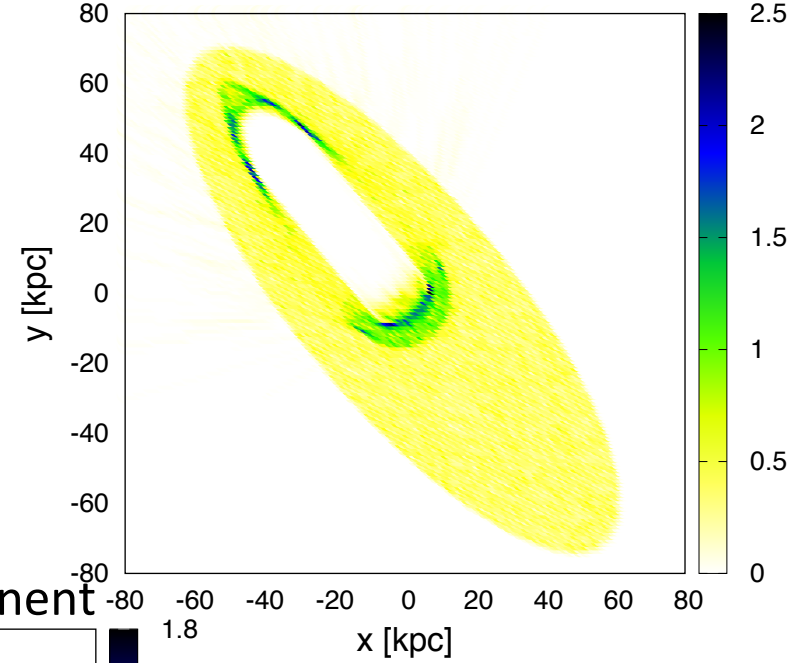
$\mathbf{E_p = 3 \times 10^{18}\ eV}$

"Shadowing"

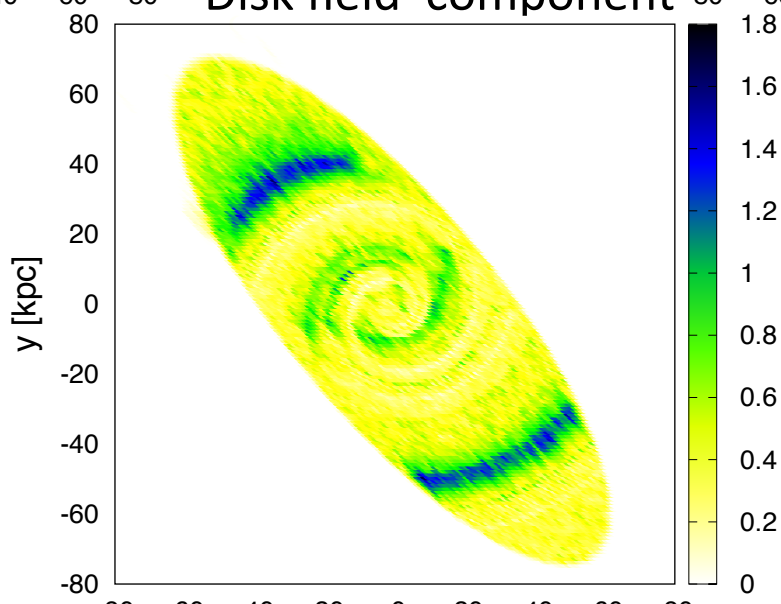
X-field component



Toroidal field component



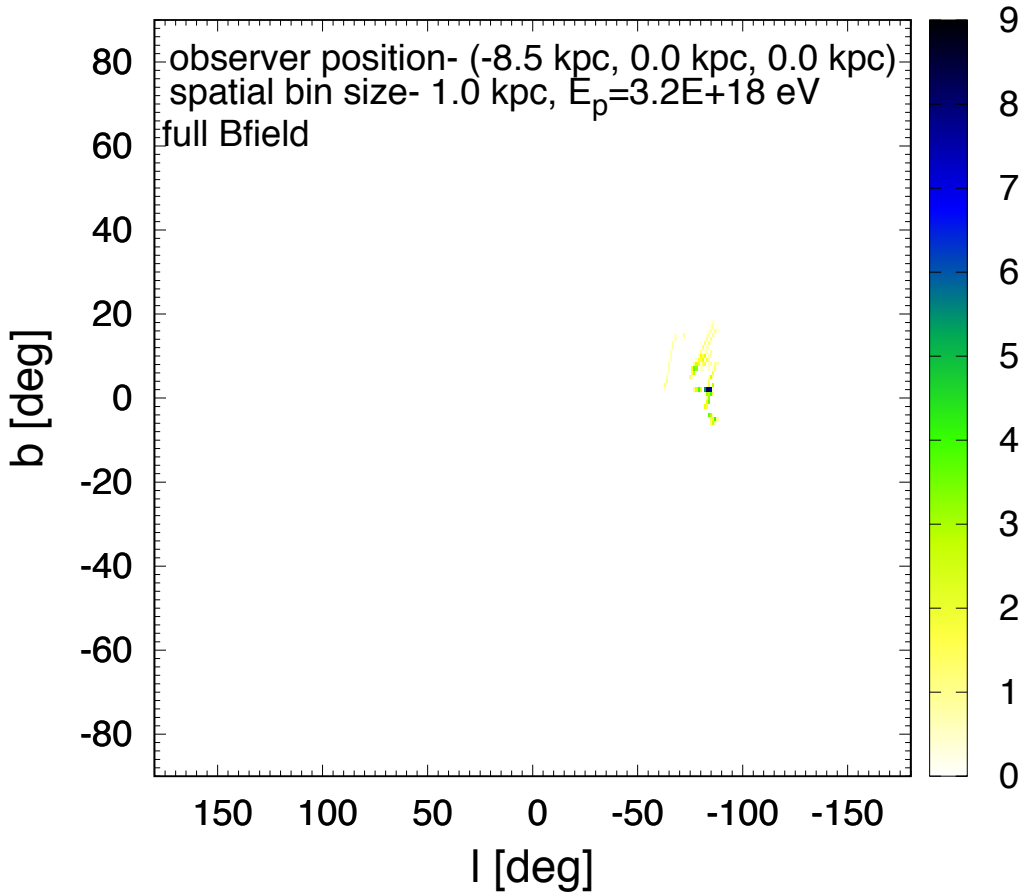
Disk field component



DESY.

Cosmic Ray Anisotropy from Cen A?

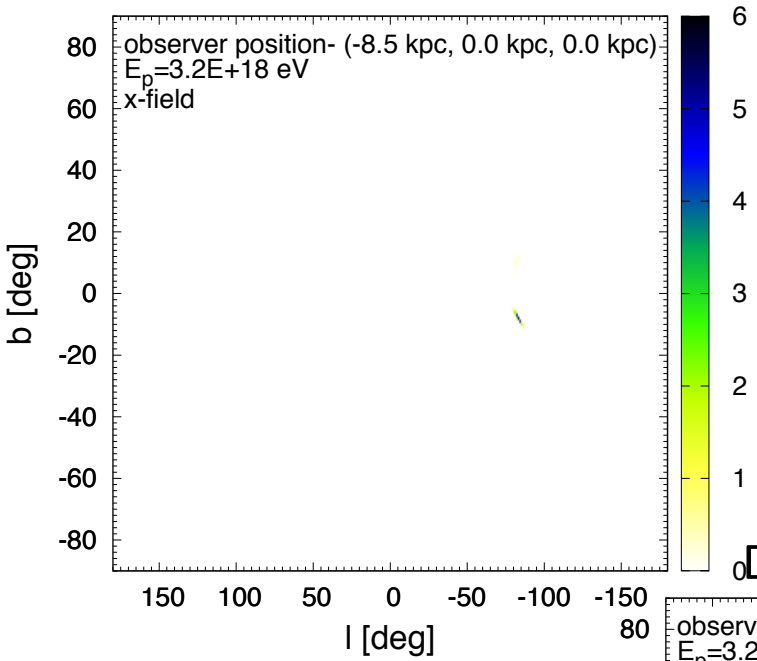
Angular arrival distribution of parallel beam from Cen A fired at Galactic magnetic field



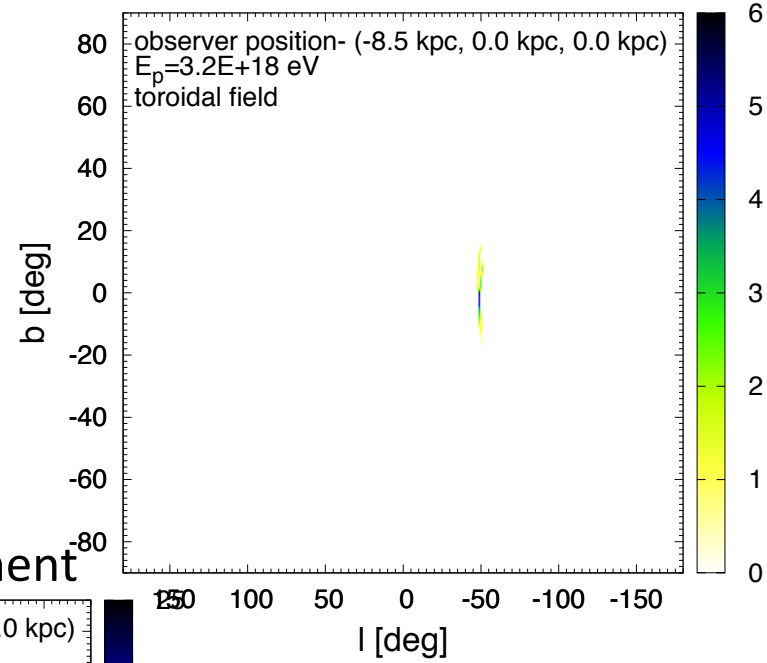
Can be compared to Keivani et al. (2015)

Cosmic Ray Anisotropy from Cen A?

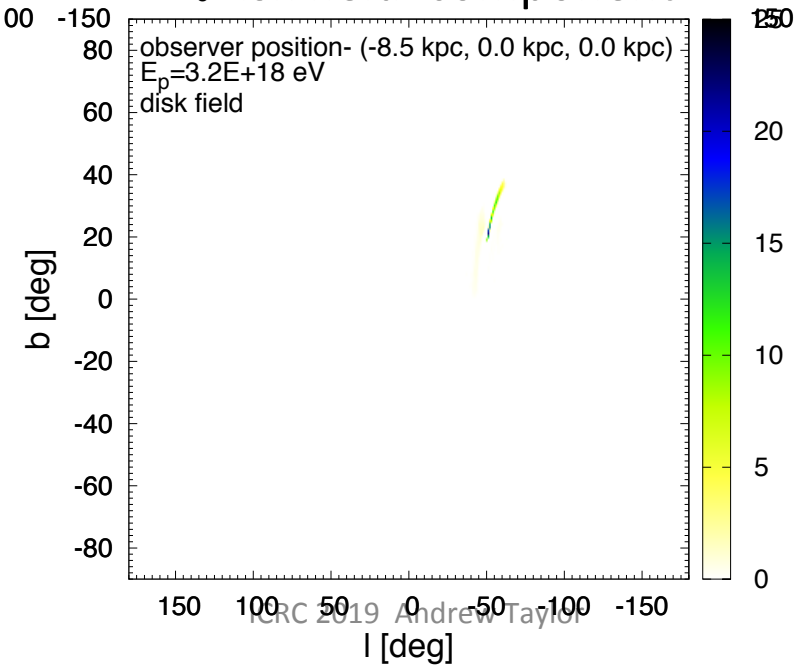
X-field component



Toroidal field component



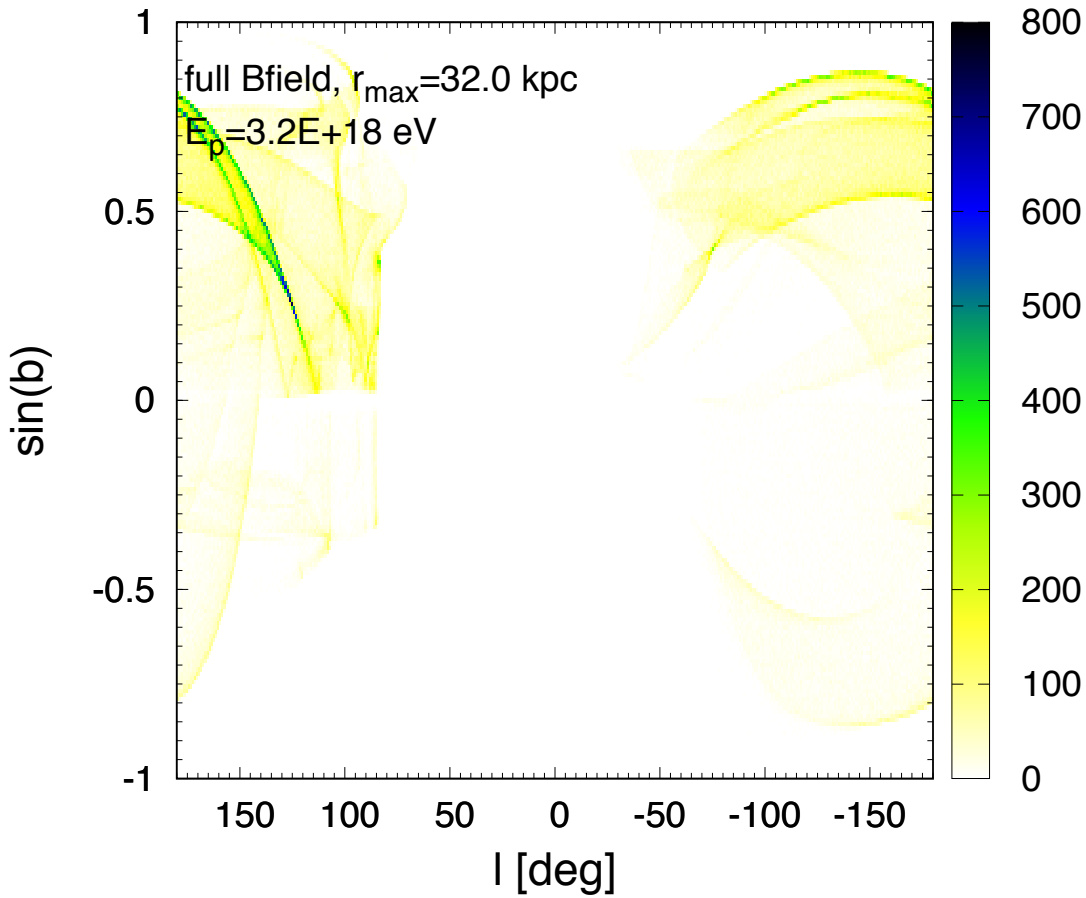
Disk field component



Importance in role of X-field component of the Galactic Magnetic in shifting position of Cen A in arriving flux from beam injected

Tunnel Vision- How Isotropic Cosmic Rays at Earth Sample the Isotropic Extragalactic Sky

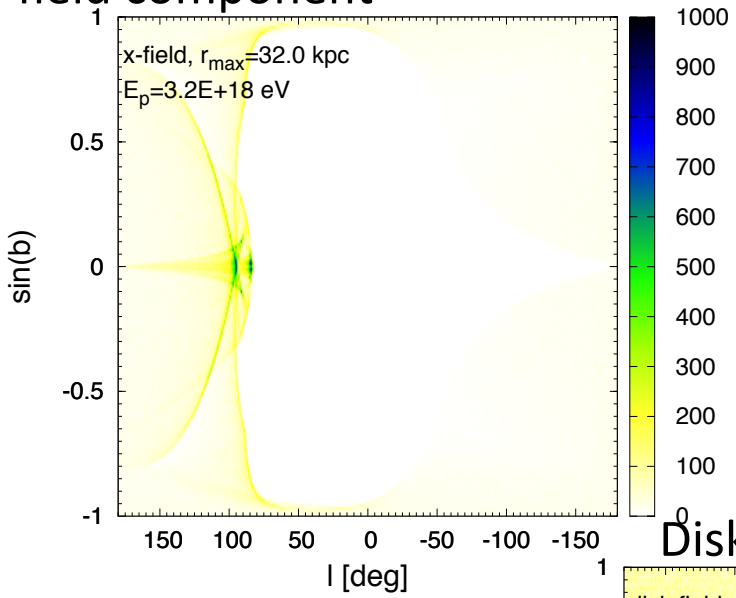
….and lastly, back-tracking isotropic particles from Earth to see which parts of extragalactic sky are preferentially sampled at these energies



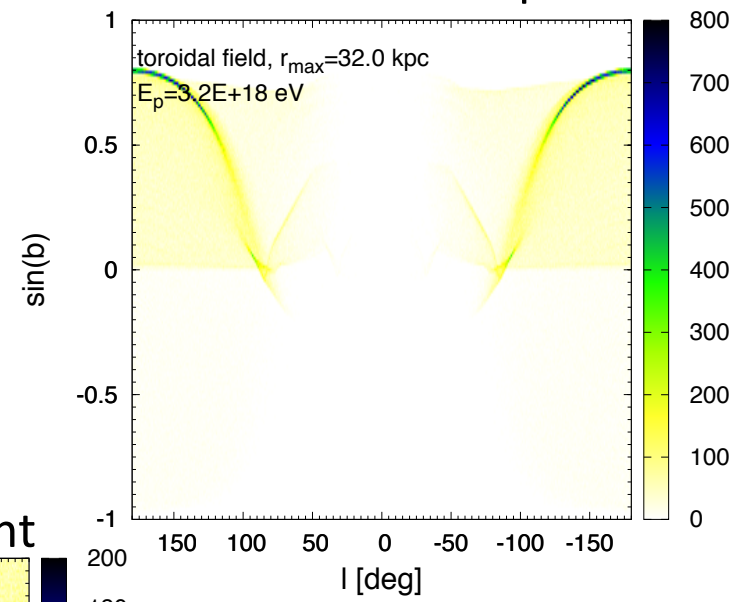
Michael named this effect "tunnel vision"!

Tunnel Vision- How Isotropic Cosmic Rays at Earth Sample the Isotropic Extragalactic Sky

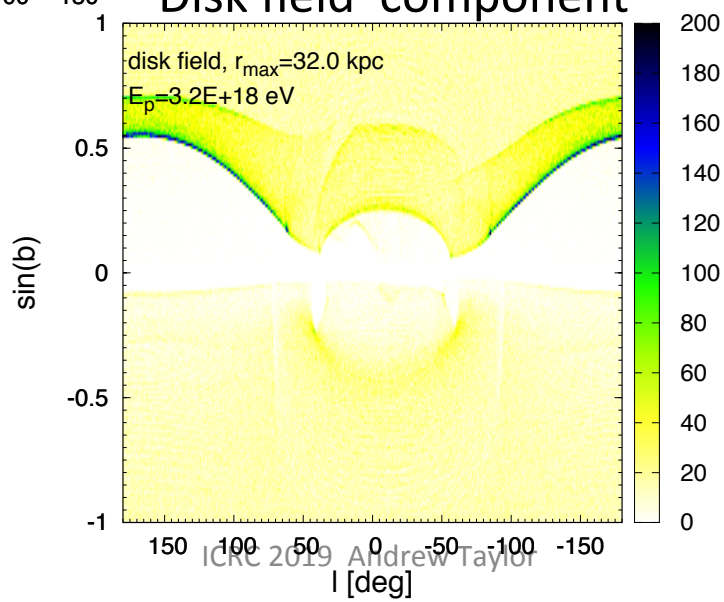
X-field component



Toroidal field component



Disk field component



Importance in role of Toroidal Field in Selecting Extragalactic Regions Probed

Turbulent B-field Effects

Turbulent B-fields introduce on top a Gaussian smearing of particle trajectories of size

Farrar et al. (2017)

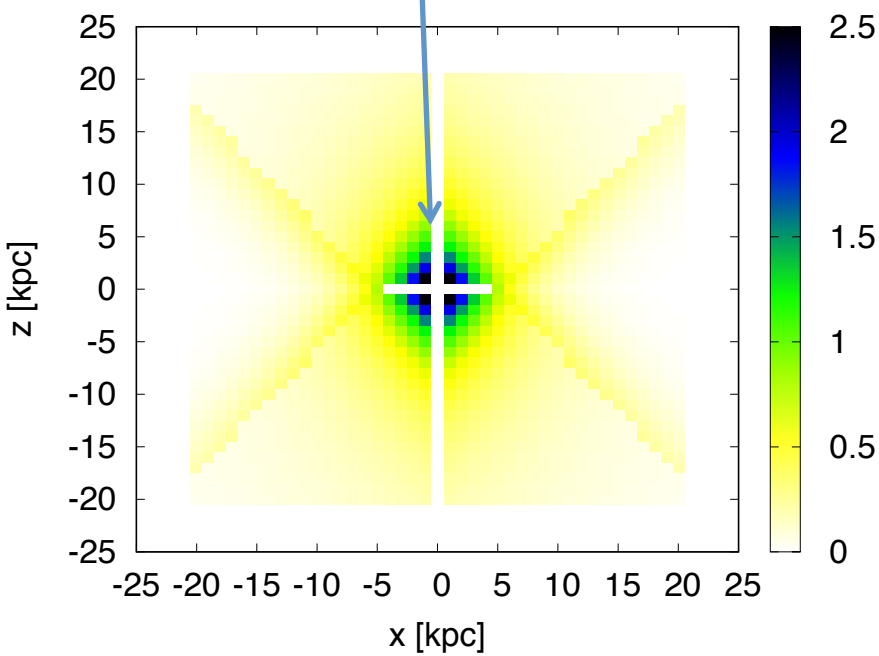
$$\mathbf{\Delta}\theta = \delta\theta \left(\frac{\mathbf{R}_{\mathrm{Gal}}}{\mathbf{l}_{\mathrm{coh}}}\right)^{\mathbf{1/2}}$$

$$\boxed{\delta\theta = \mathbf{0.6}^{\circ} \left(\frac{\mathbf{l_{coh}}}{\mathbf{10\ pc}}\right)\left(\frac{\mathbf{1\ kpc}}{\mathbf{R_{Lar}}}\right)}$$

Galactic B-field Interaction with Cen A CR Flux

Note weakness of this component at Galactic halo distances

This contrasts with radio bubbles- Carretti et al. (2013) Nat. Vol. 493



Note

$$\mathbf{U_{CR}^{FB} \approx 7 \times 10^{55}\ erg}$$

Crocker et al. 2015

Conclusions

The role 3 components (**disk**, **toroidal**, **x-field**) of the coherent magnetic field structure in the the Jansson and Farrar Galactic magnetic field model have on UHECR propagation from Cen A/extragalactic sky:

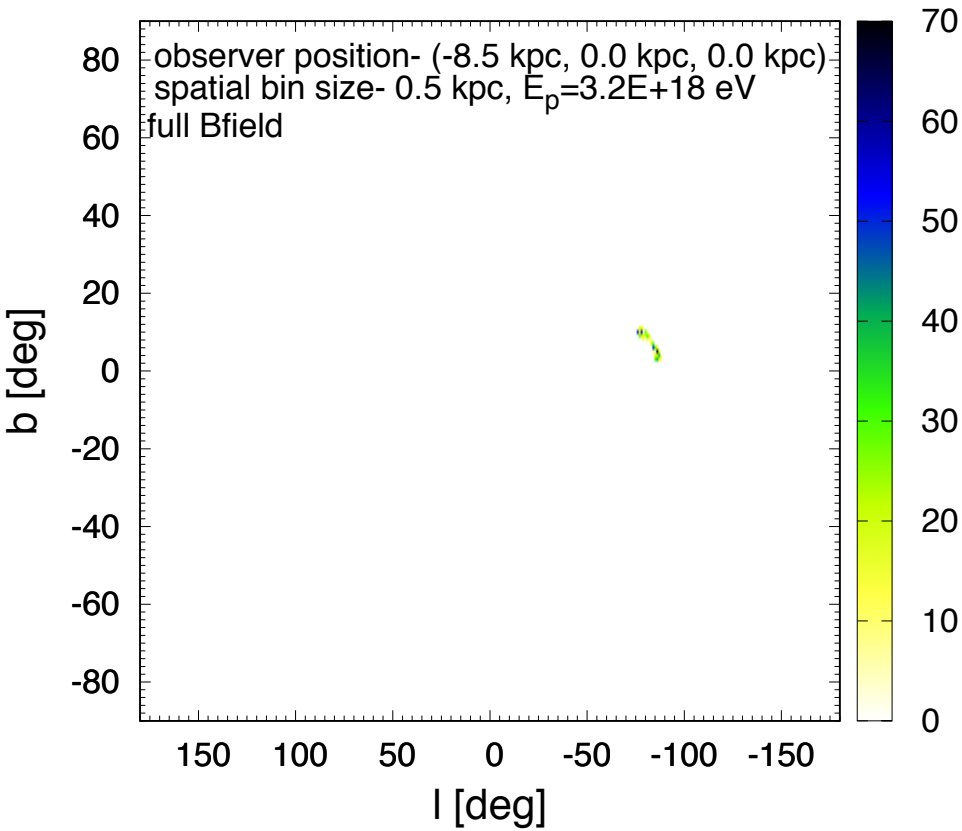
- Shadowing is dominated by **toroidal** B-field component
- Deflection of the source position is dominated by the **x-field** component
- Tunnel vision of the extragalactic sky is dominated by the **x-field** component

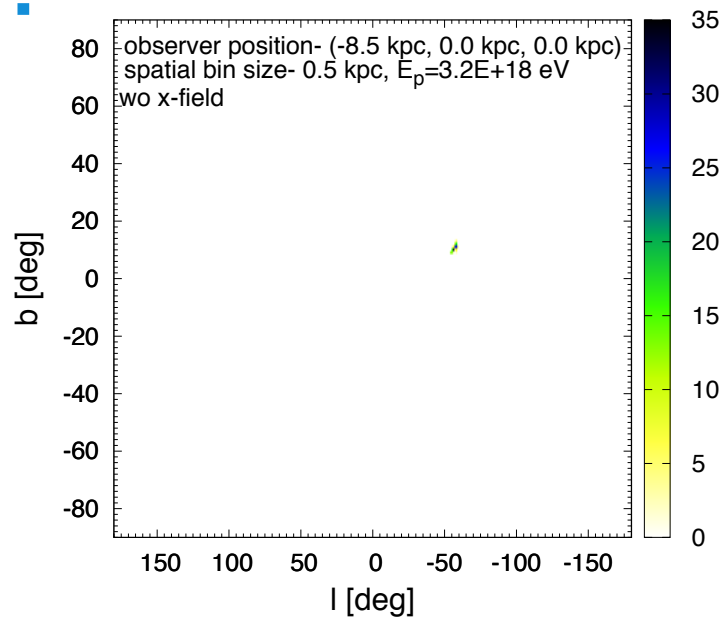
The presence of magnetic structures associated with the Fermi bubbles/ outflows may further hinder the arrival of UHECR into the Galactic magnetosphere.

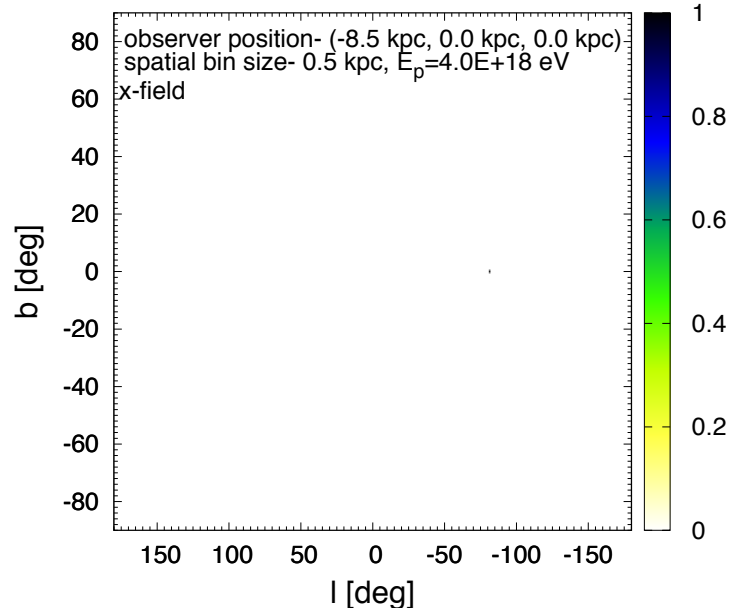
Indirect probes of the Galactic magnetic field are a limiting factor. Are more direct probes possible? (astro-ph/**1903.08675**)

Extra Slides

Injection from Source or Back-tracking from Earth?



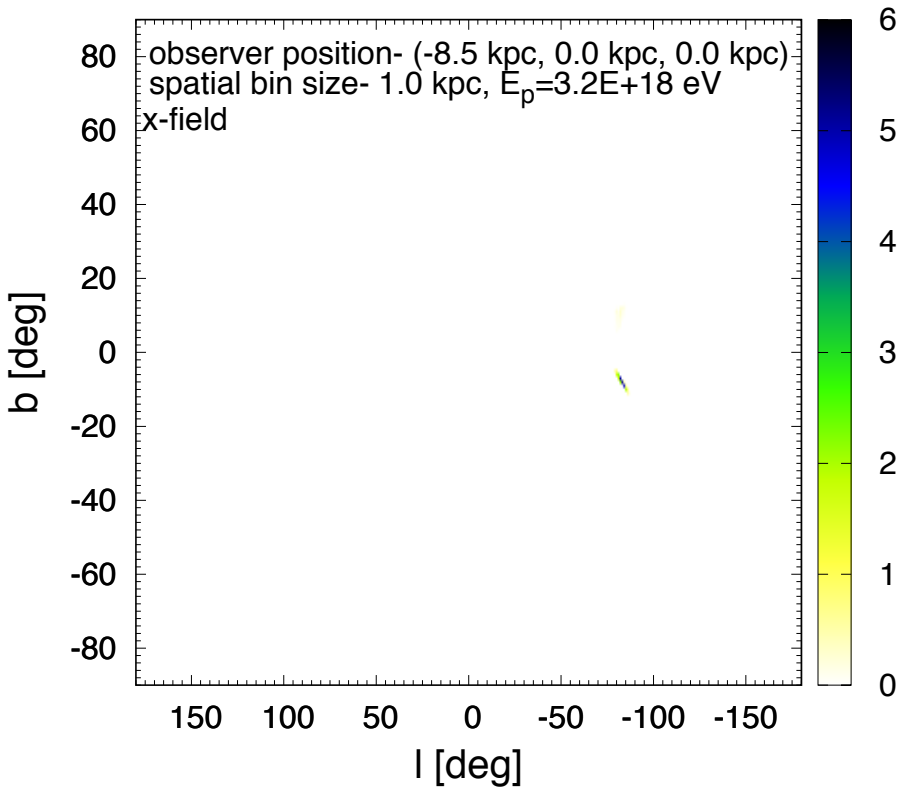




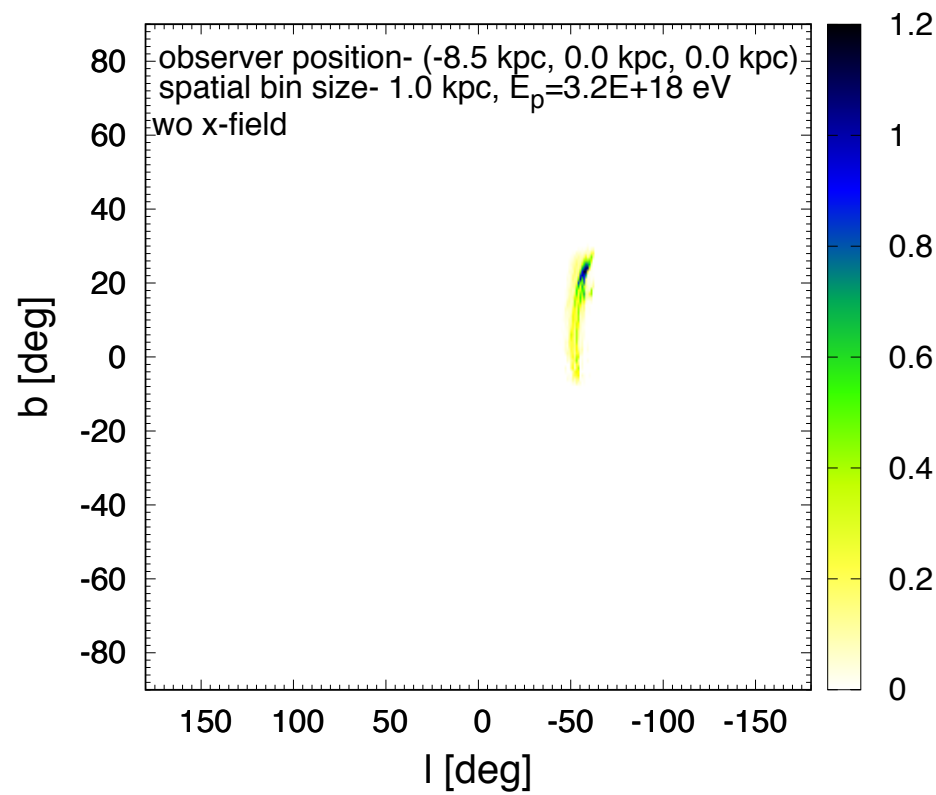
Cosmic Ray Anisotropy from Cen A?

Importance in role of X-field component of the Galactic Magnetic in shifting position of Cen A in arriving flux from beam injected

Only X-field



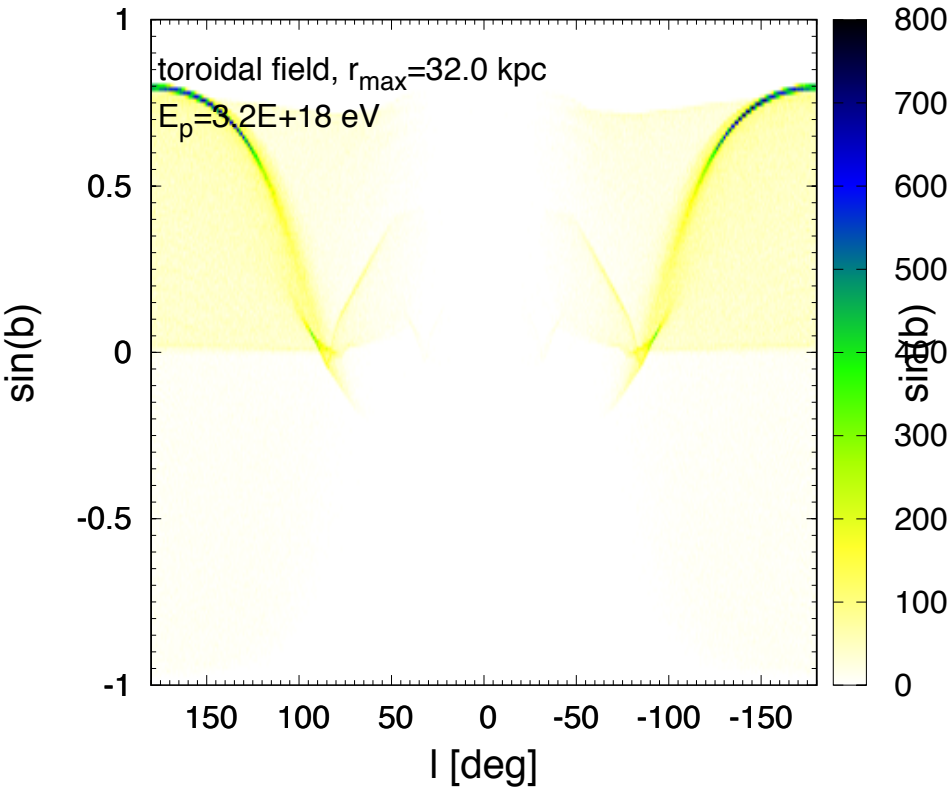
Only Toroidal + Disk Fields



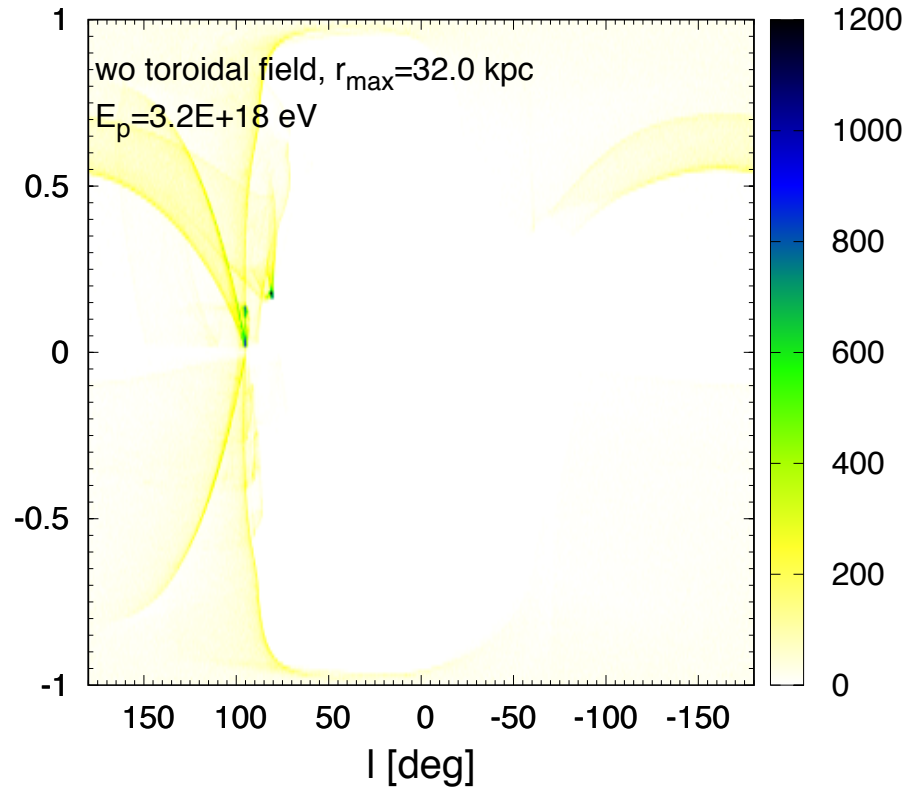
Tunnel Vision- How Isotropic Cosmic Rays at Earth Sample the Isotropic Extragalactic Sky

Importance in role of Toroidal Field in Selecting Extragalactic Regions Probed

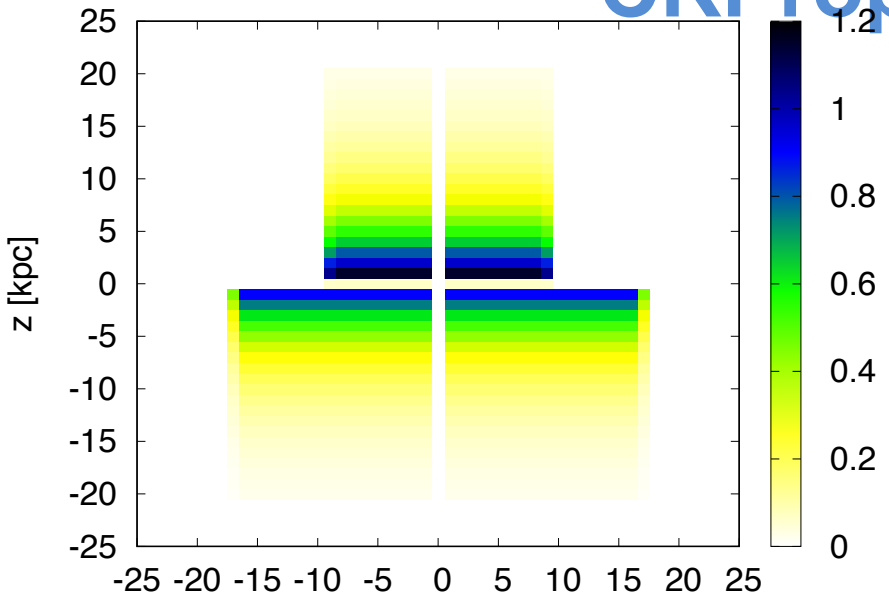
Only Toroidal Field

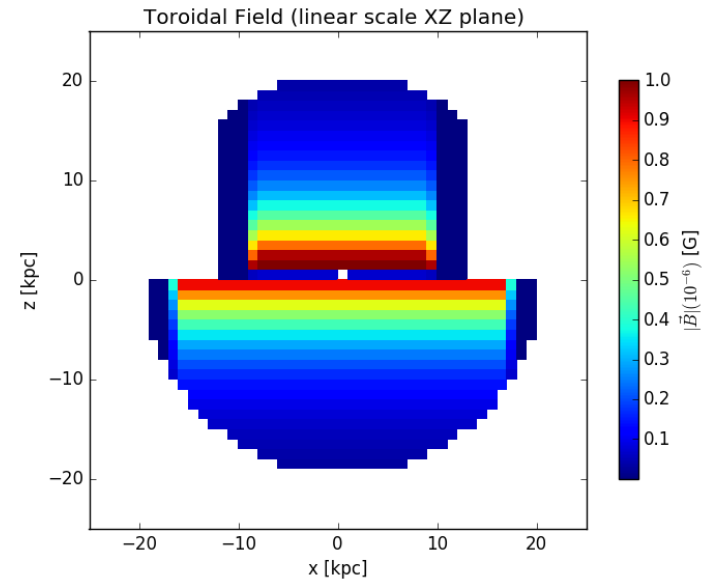


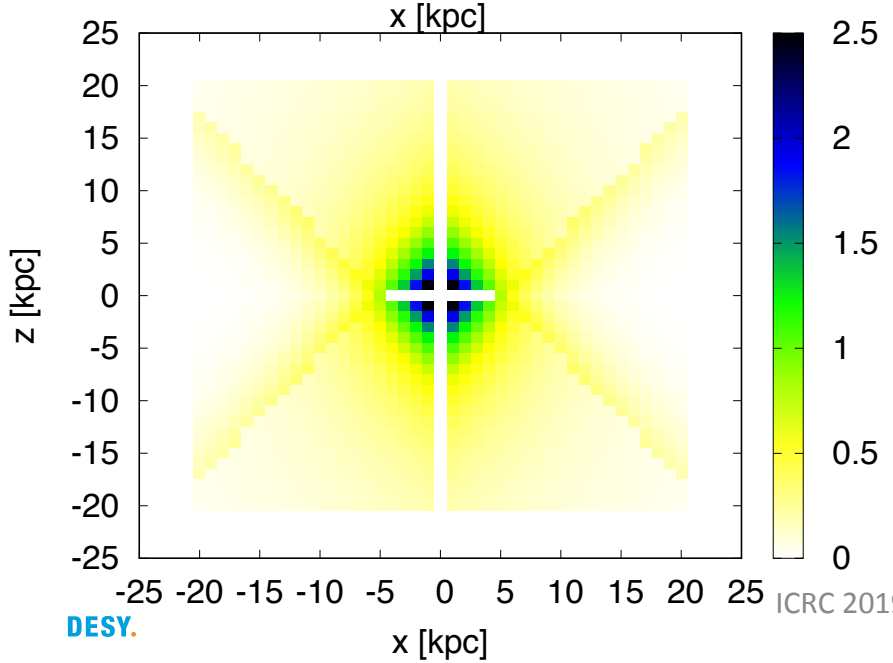
Only Disk + X-Field

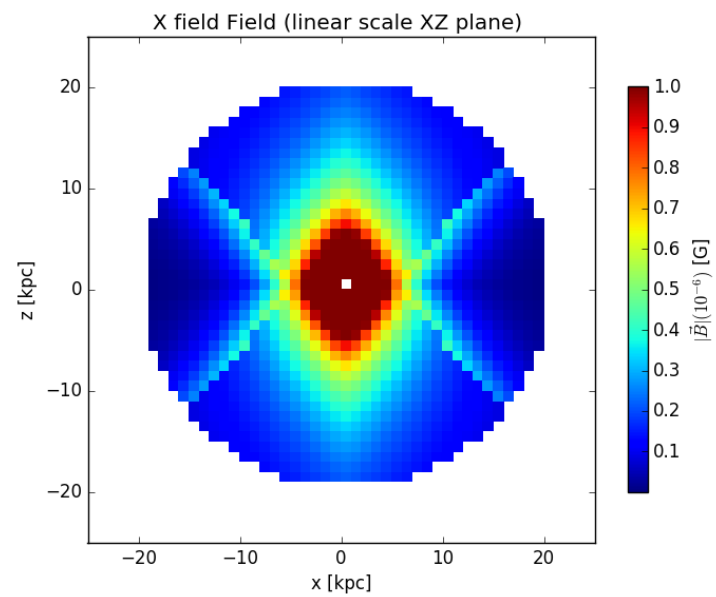


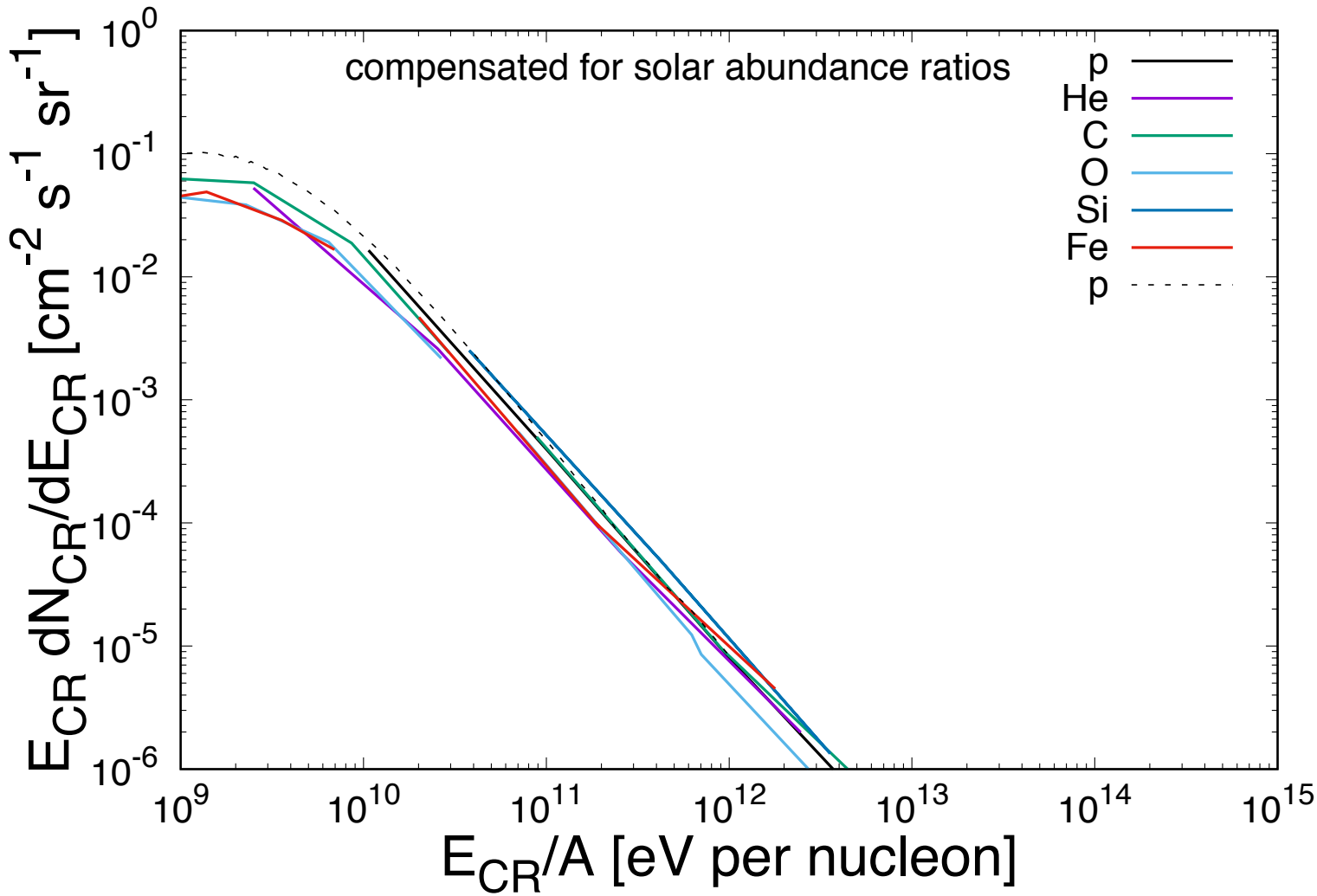
Comparison of Galactic B-field with CRPropa Authors







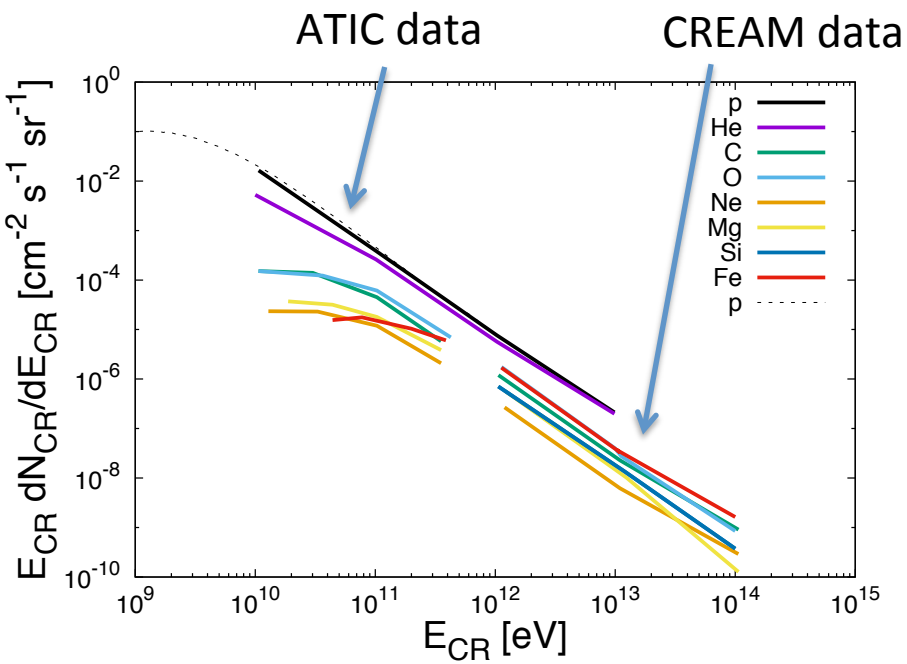


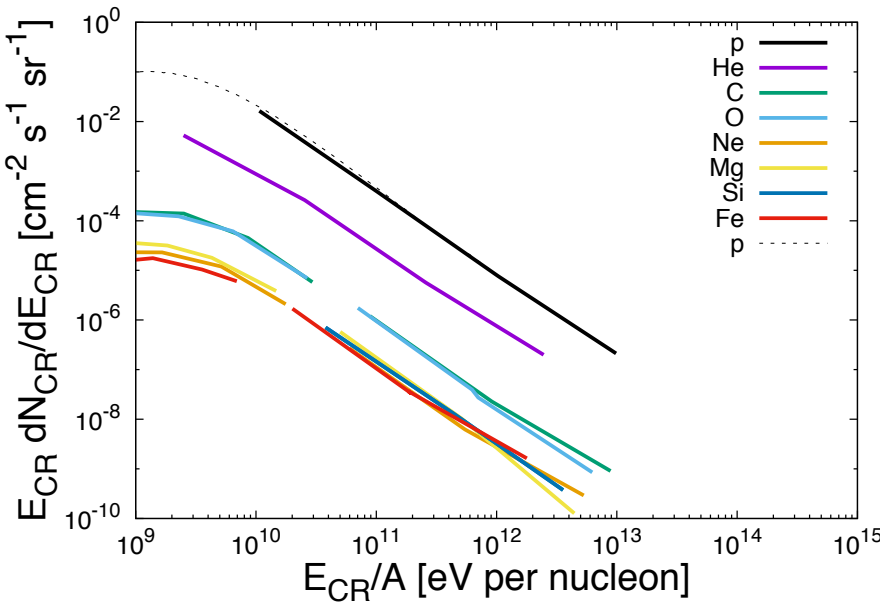

compensated for solar abundance ratios
p
He
C
O
Si
Fe
p
$E_{CR}\, dN_{CR}/dE_{CR}$ [$cm^{-2}\, s^{-1}\, sr^{-1}$]
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{9}
10^{10}
10^{11}
10^{12}
10^{13}
10^{14}
10^{15}
E_{CR}/A [eV per nucleon]

Low Energy CR Composition Investigation

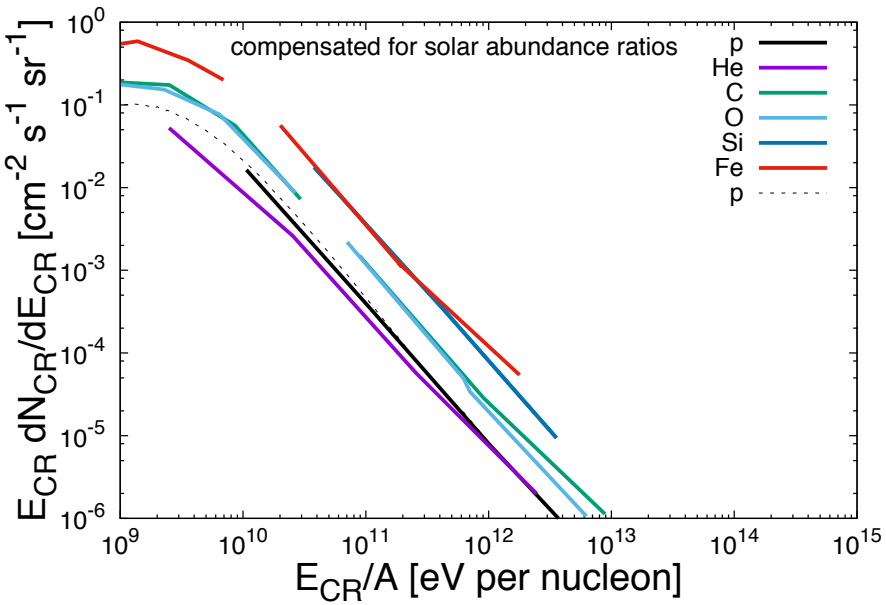
composition ratios of CR at 10~GeV per nucleon

	proton	He	C	O	Si	Fe
x_i	1.0	0.04	0.001	0.001	0.0002	0.0002





Low Energy CR Composition Investigation



solar system abundance ratios

	proton	He	C	O	Si	Fe
x_i	1.0	0.1	0.0004	0.0008	0.00003	0.00003

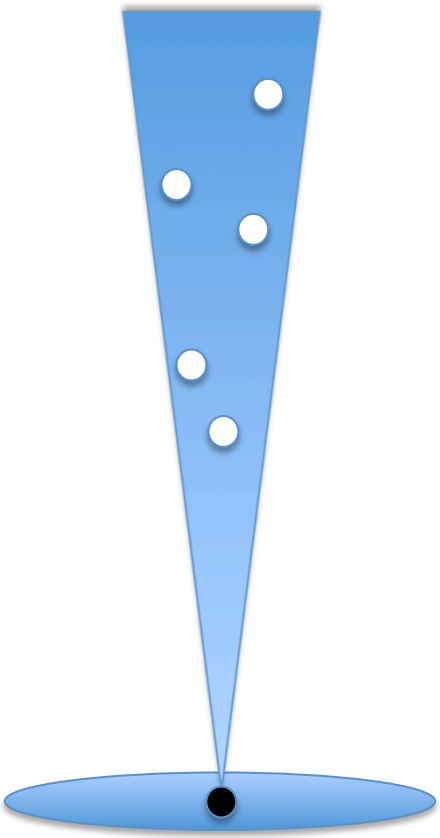
$$\mathbf{E_A \frac{dN_A}{dE_A}\left(\frac{E_A}{A}\right) = f_A E_p \frac{dN_p}{dE_p}(E_p)}$$

$$\mathbf{f_A = \frac{Z^2}{A} f_{SA}}$$

Cosmic Ray Spectrum from Cen A?

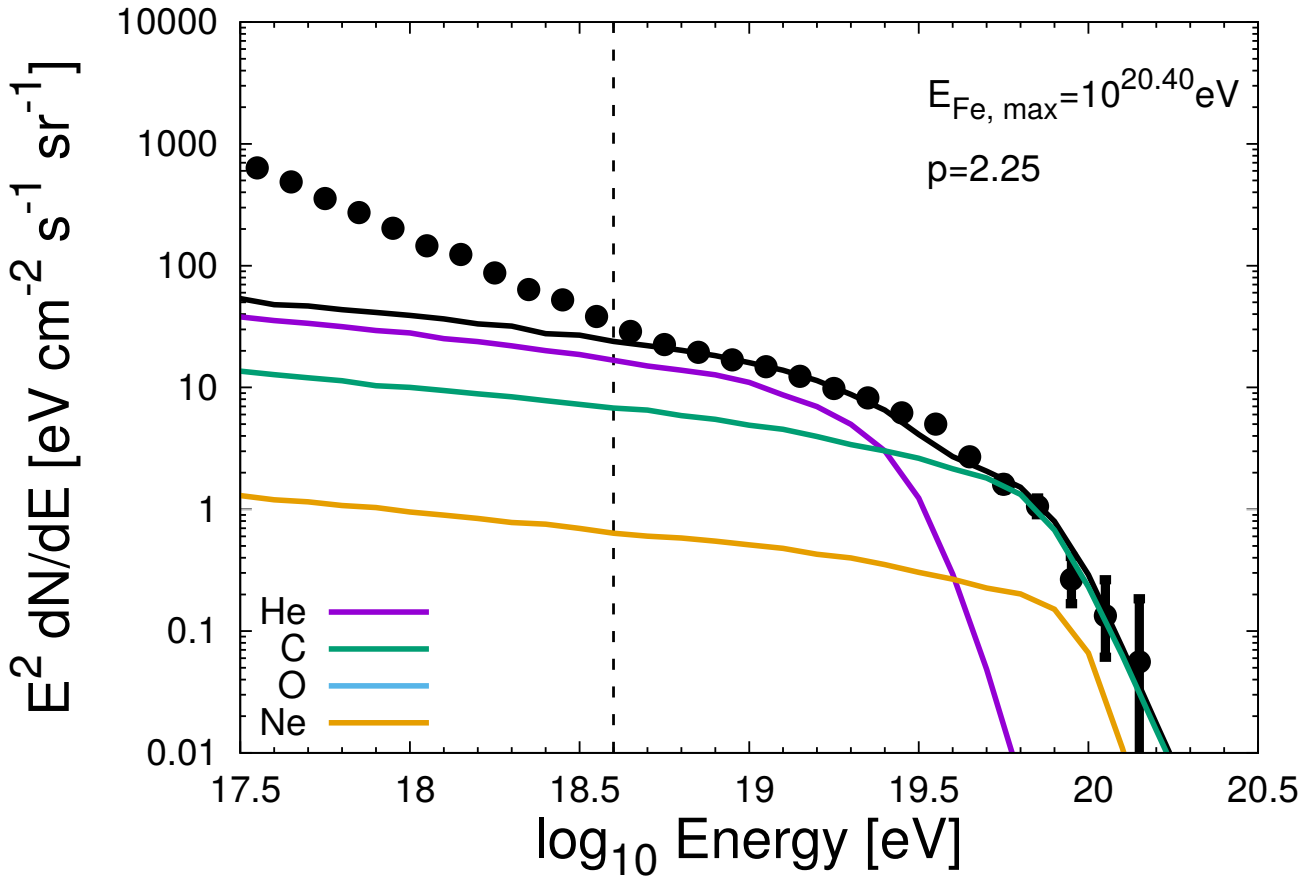
Abundance by Mass Abundance by Number

isotope	mass entrained (single lobe) ($M_\odot$)	mass rate (twin lobes) ($M_\odot\,\mathrm{yr}^{-1}$)	number rate (twin lobes) (s^{-1})
^{1}H	7.4×10^{4}	2.6×10^{-4}	1.0×10^{46}
^{3}He	3.1×10^{1}	1.1×10^{-7}	1.4×10^{42}
^{4}He	2.7×10^{4}	9.6×10^{-5}	9.1×10^{44}
^{12}C	9.5×10^{1}	3.4×10^{-7}	1.1×10^{42}
^{14}N	7.2×10^{1}	2.6×10^{-7}	7.0×10^{41}
^{16}O	3.3×10^{2}	1.2×10^{-6}	2.8×10^{42}
^{20}Ne	5.5×10^{1}	2.0×10^{-7}	3.7×10^{41}
^{22}Ne	5.0×10^{0}	1.8×10^{-8}	3.1×10^{40}
^{24}Mg	1.8×10^{1}	6.4×10^{-8}	1.0×10^{41}
^{26}Mg	2.7×10^{0}	9.6×10^{-9}	1.4×10^{40}
^{28}Si	2.3×10^{1}	8.2×10^{-8}	1.1×10^{41}
^{32}S	1.6×10^{1}	5.7×10^{-8}	6.8×10^{40}
^{56}Fe	4.1×10^{1}	1.5×10^{-7}	9.9×10^{40}



astro-ph: 1706.08229

Cosmic Ray Spectrum from Local Sources Like Cen A



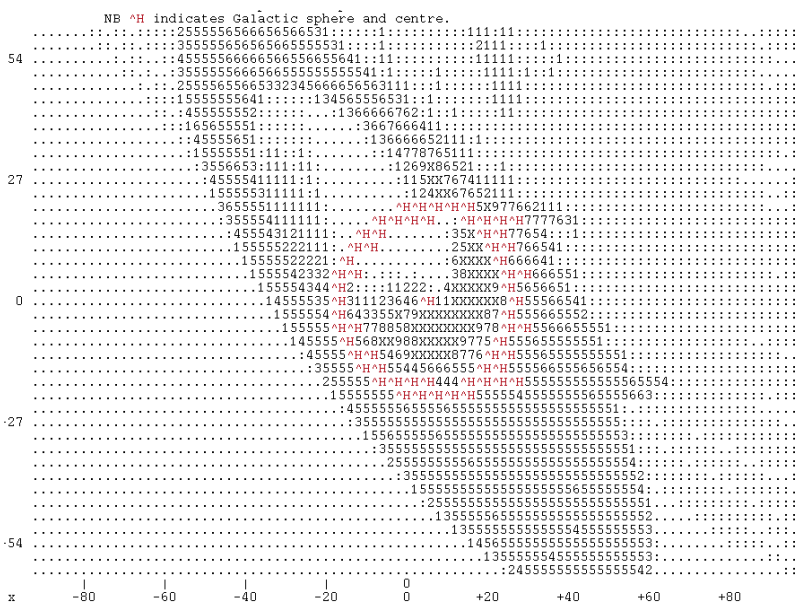
Note- no hardening of the spectrum at low energies has here been taken into account

Galactic Magnetic Field "Shadowing"

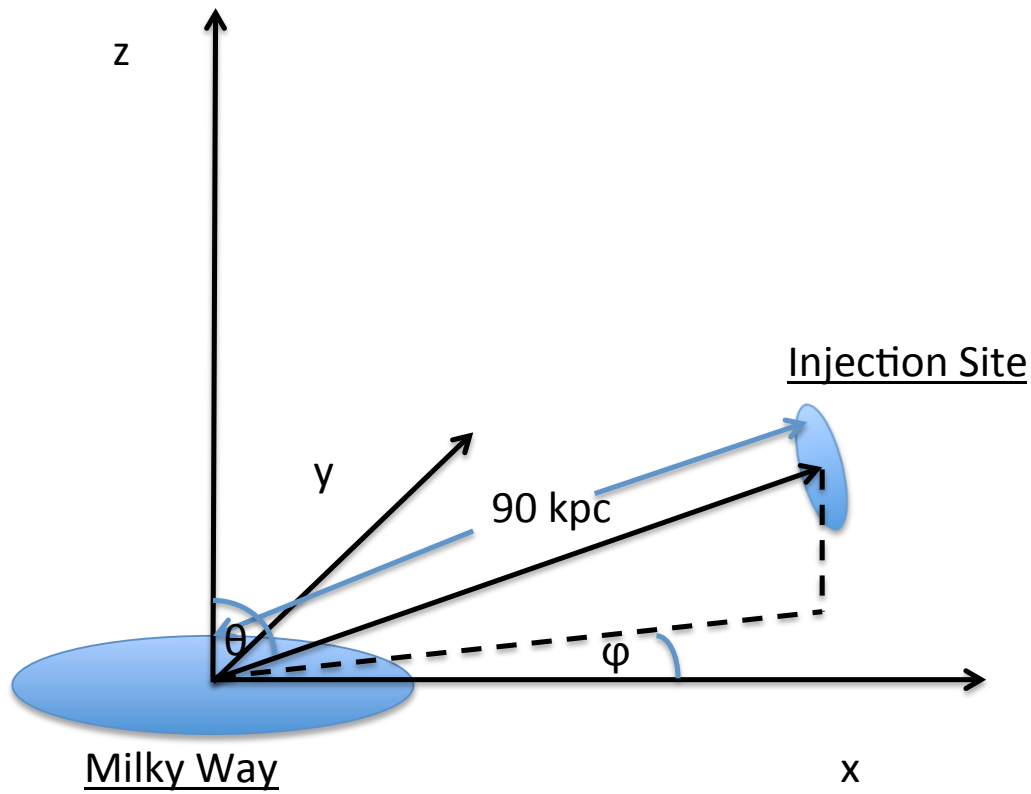
$$\mathbf{U_B^{disk} = 8 \times 10^{53}\ erg}$$

$$\mathbf{U_B^{toroid} = 4 \times 10^{54}\ erg}$$

$$\mathbf{U_B^{X-field} = 3 \times 10^{54}\ erg}$$



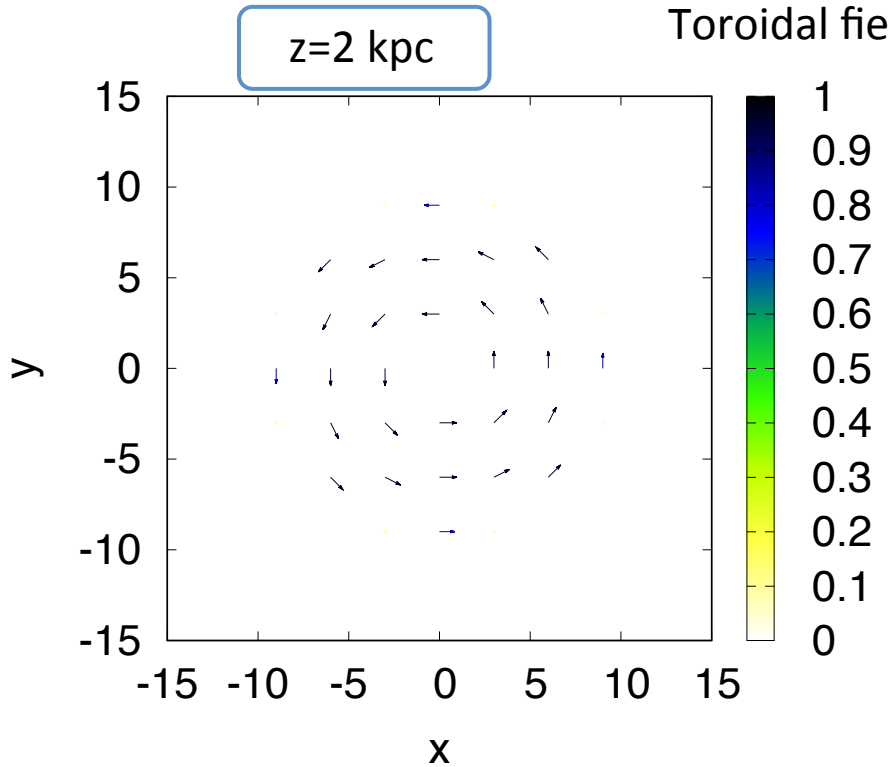
System Setup

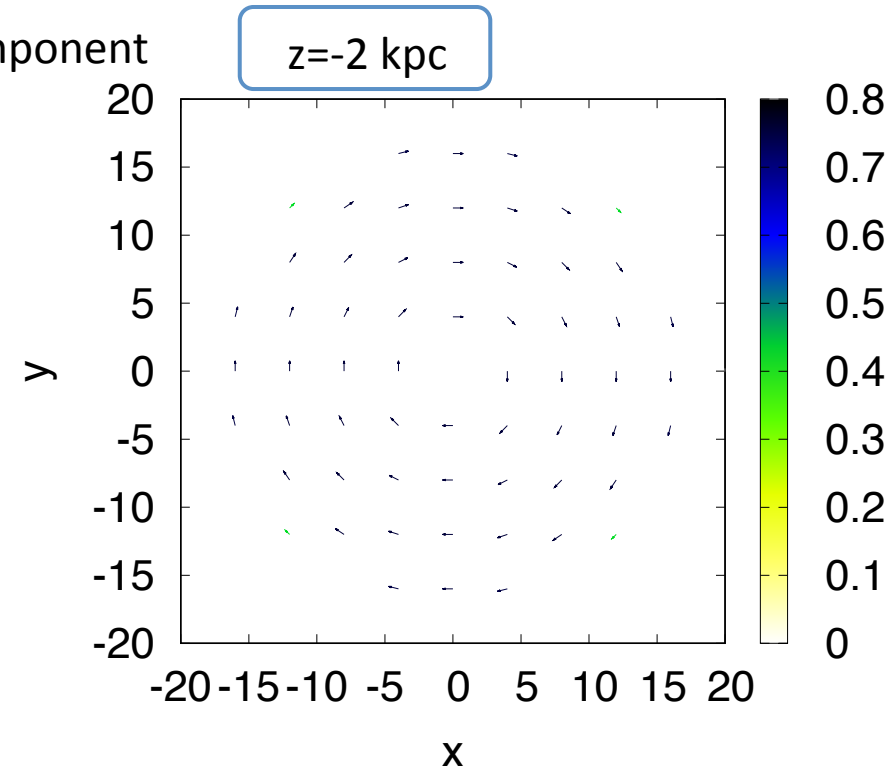


Michael & I had intended to produce a short paper on this "shadowing" effect

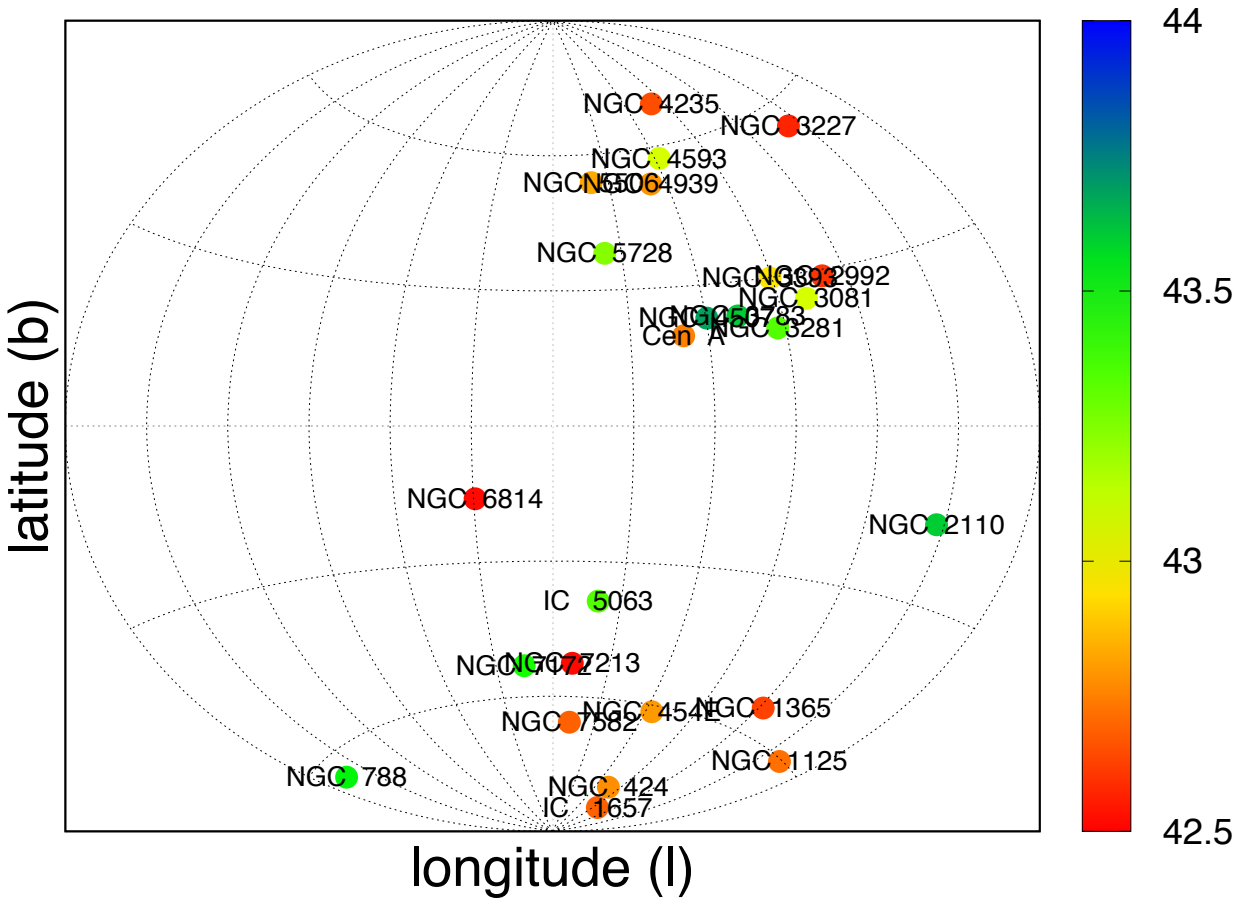
DESY.

Galactic B-field Interaction with Cen A CR Flux





Non-Thermally Luminous Objects



(Swift 58 month
Hard X-Ray catalogue)