UHECRs &Galactic halo bubbles

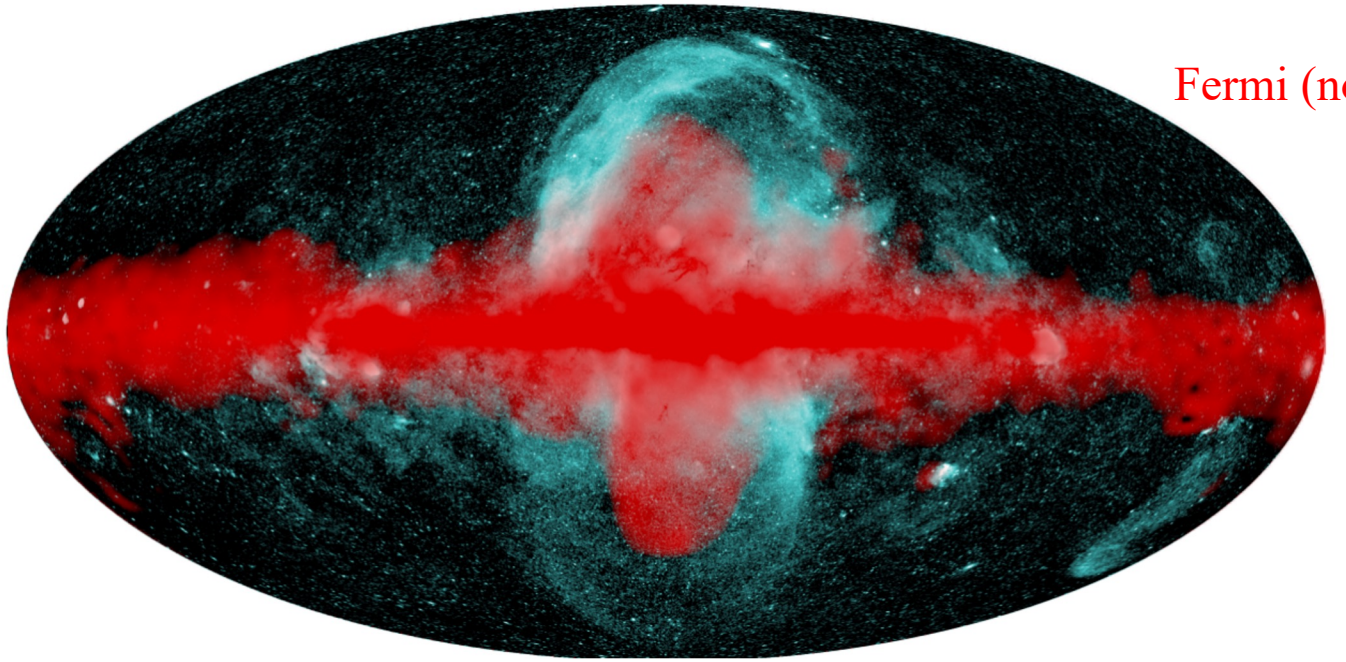
Vasundhara Shaw, Andrew Taylor, Arjen Van Vliet

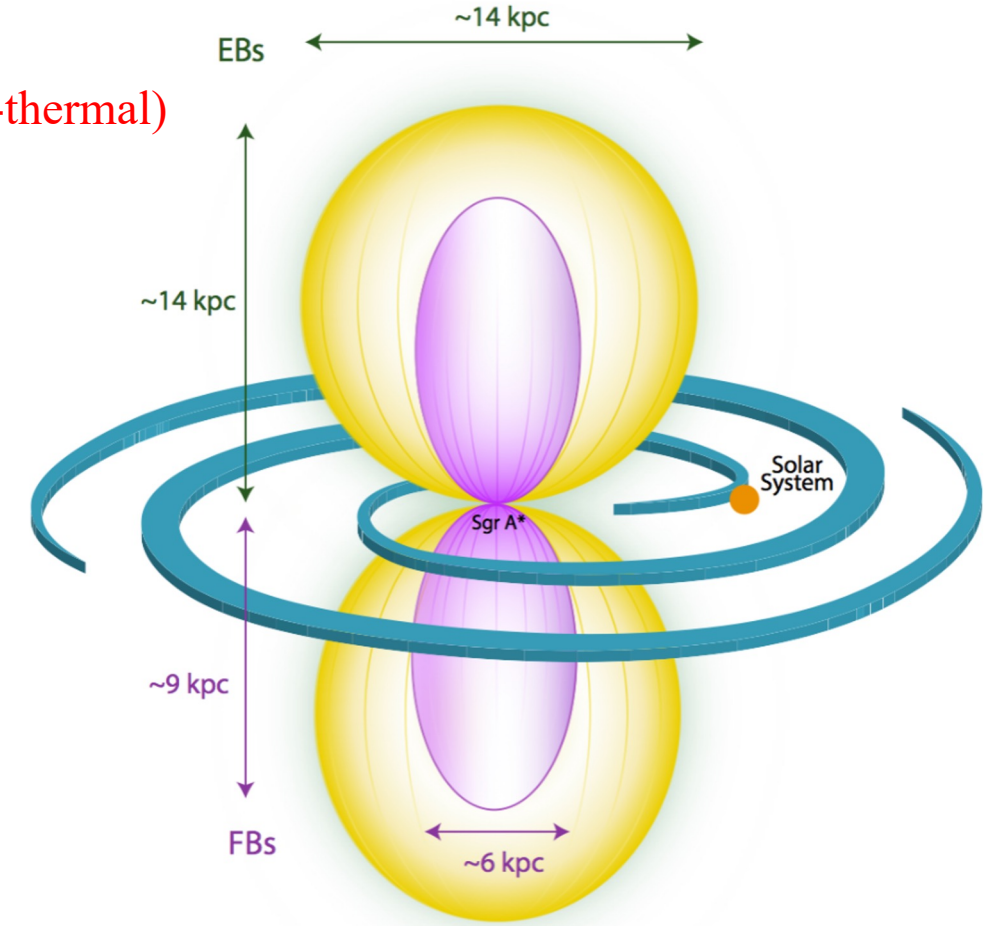
1) https://www.cosmos.esa.int/web/planck/picture-gallery
2) Predehl, P., Sunyaev, R.A., Becker, W. et al. Detection of large-scale X-ray bubbles in the Milky Way halo. Nature 588, 227–231 (2020).

Galactic Halo Bubbles

eRosita (thermal)

Fermi (non-thermal)





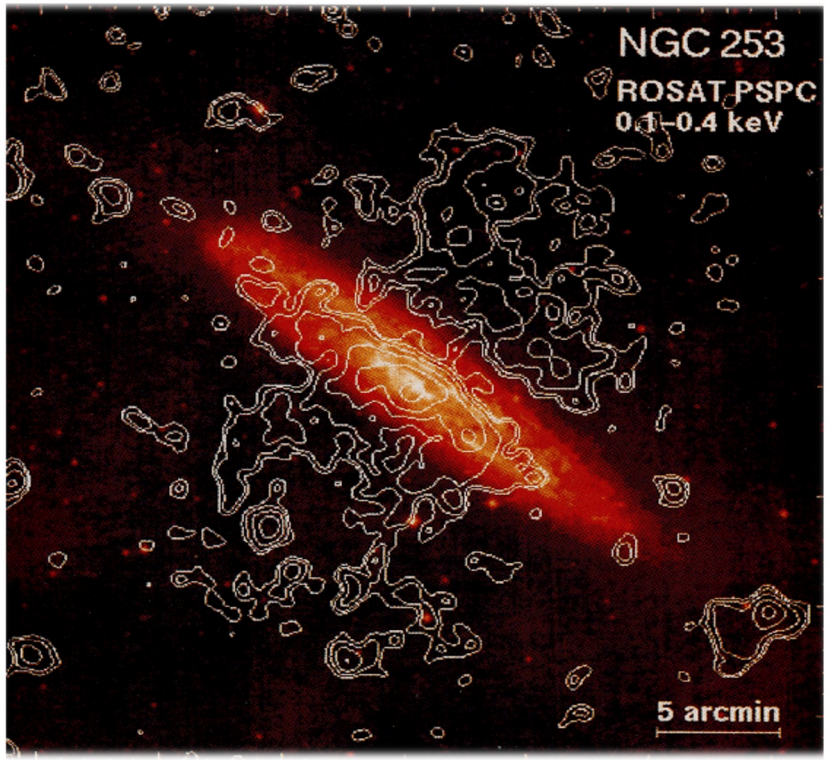
10^{56} erg in X-rays

Total energy 10^{54-55} erg in disc

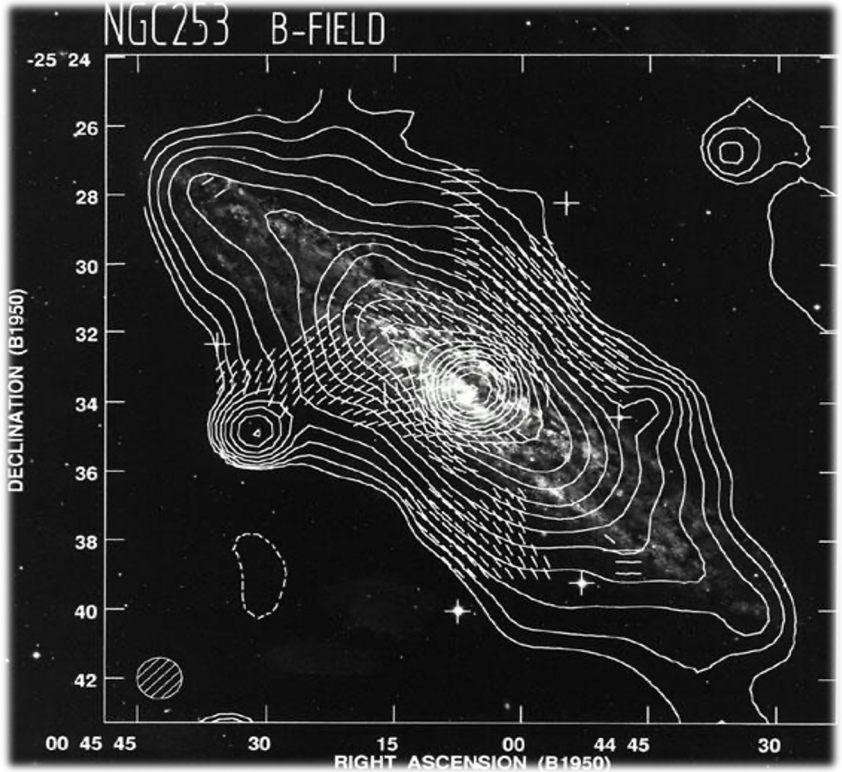
Predehl, P., Sunyaev, R.A., Becker, W. et al. Detection of large-scale X-ray bubbles in the Milky Way halo. Nature 588, 227–231 (2020). https://doi.org/10.1038/s41586-020-2979-0

Large scale structures = large scale fields

(Pietsch et.al 1996)

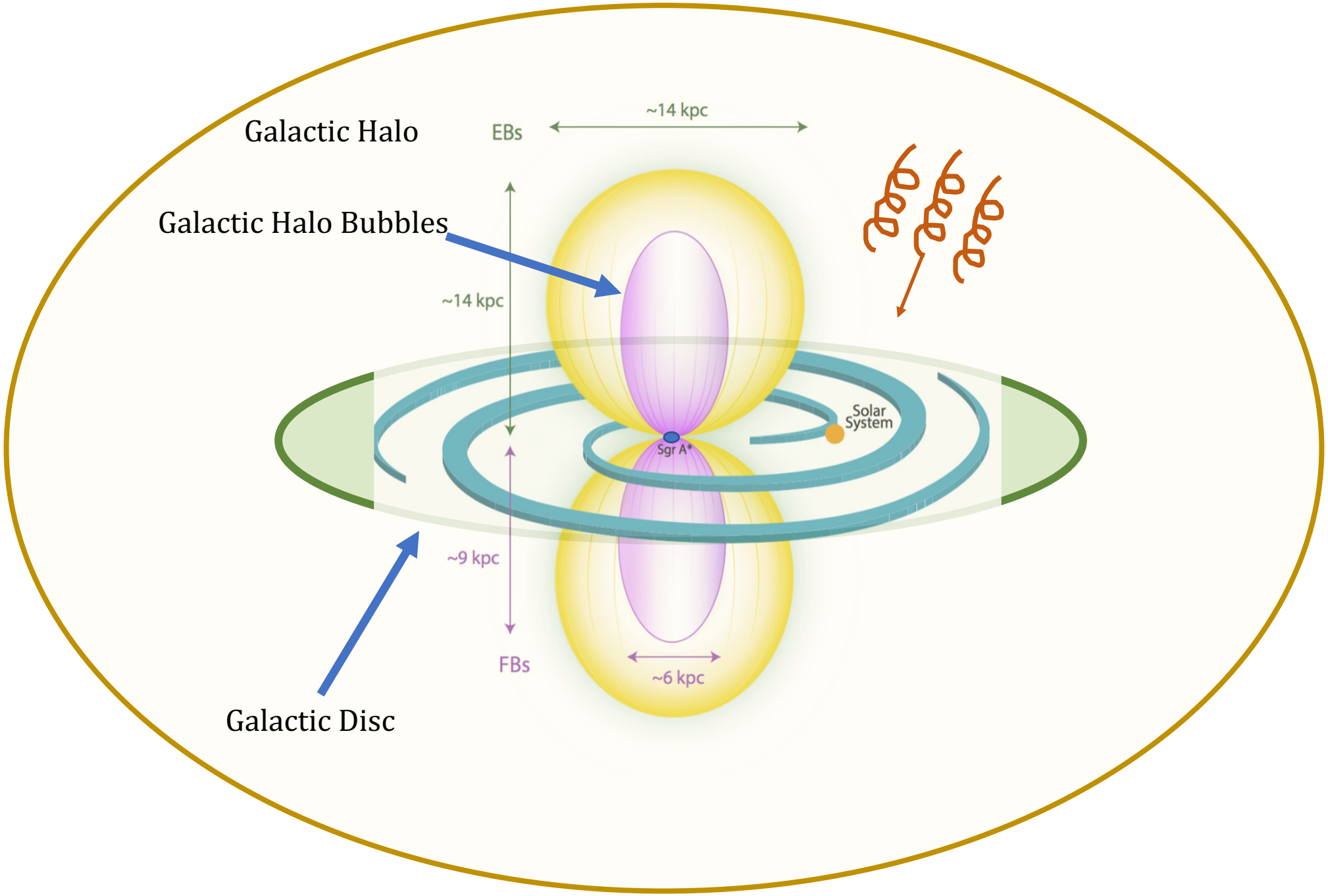


(Beck et.al 1994)

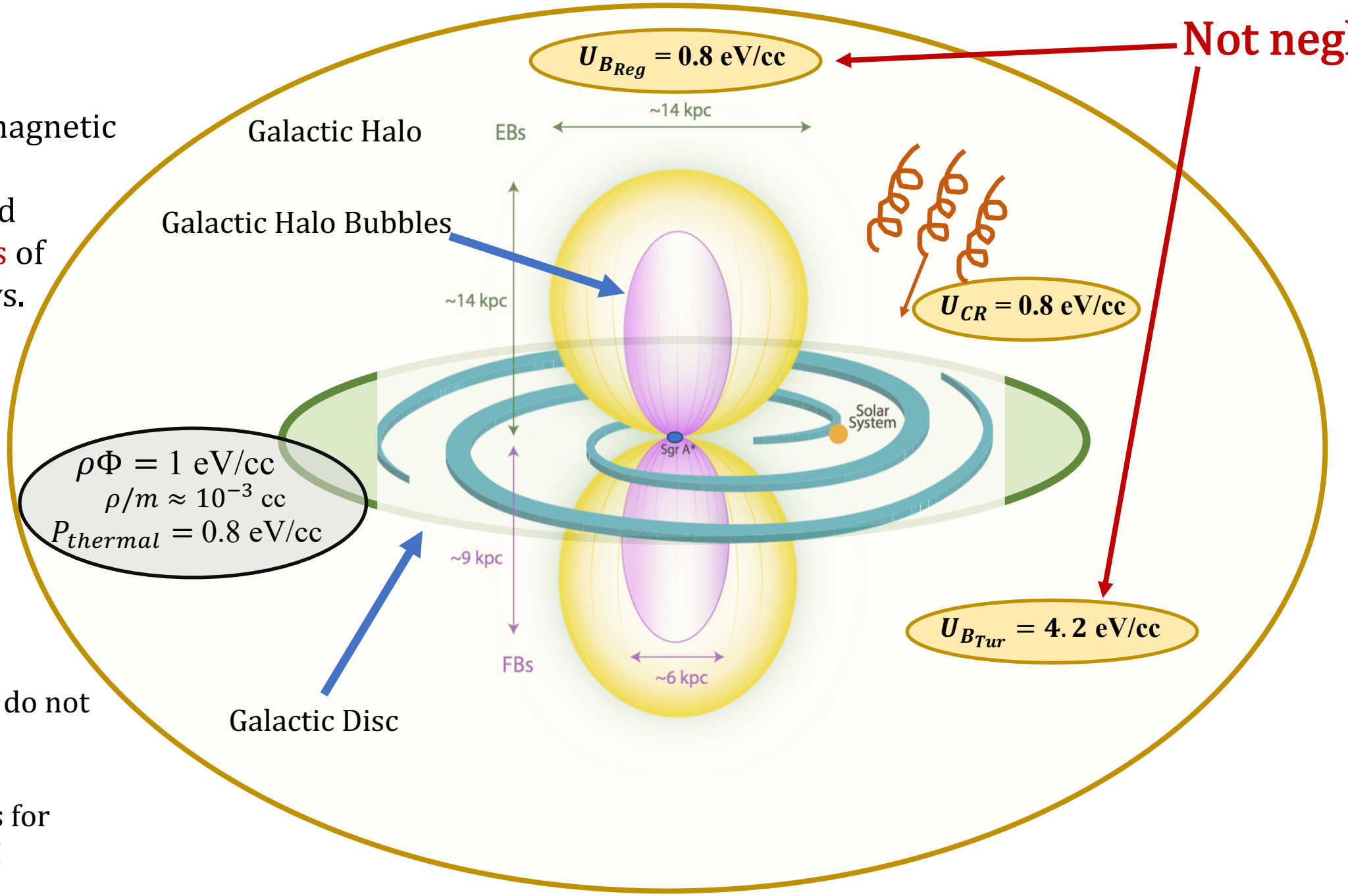


Total radio intensity (*contours*) and magnetic field orientation of NGC 253.

Milky way is not a starburst galaxy yet it has outflow!


Galactic Halo
EBs
~14 kpc
Galactic Halo Bubbles
~14 kpc
Solar System
Sgr A*
~9 kpc
FBs
~6 kpc
Galactic Disc

We need magnetic fields to understand deflections of cosmic rays.

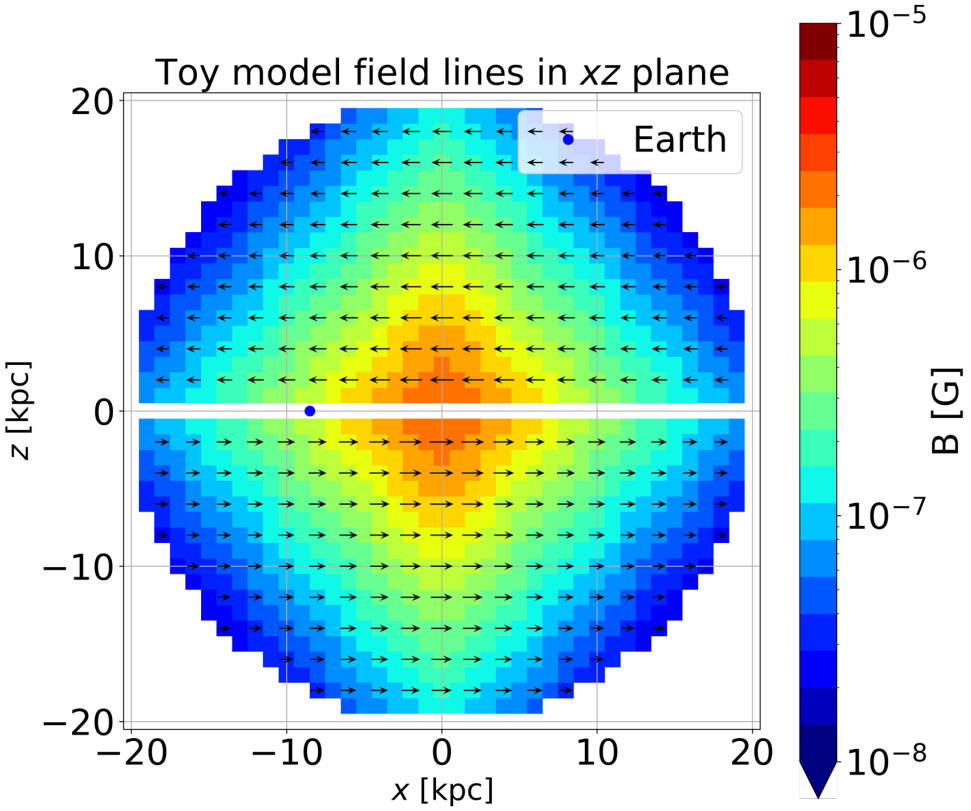


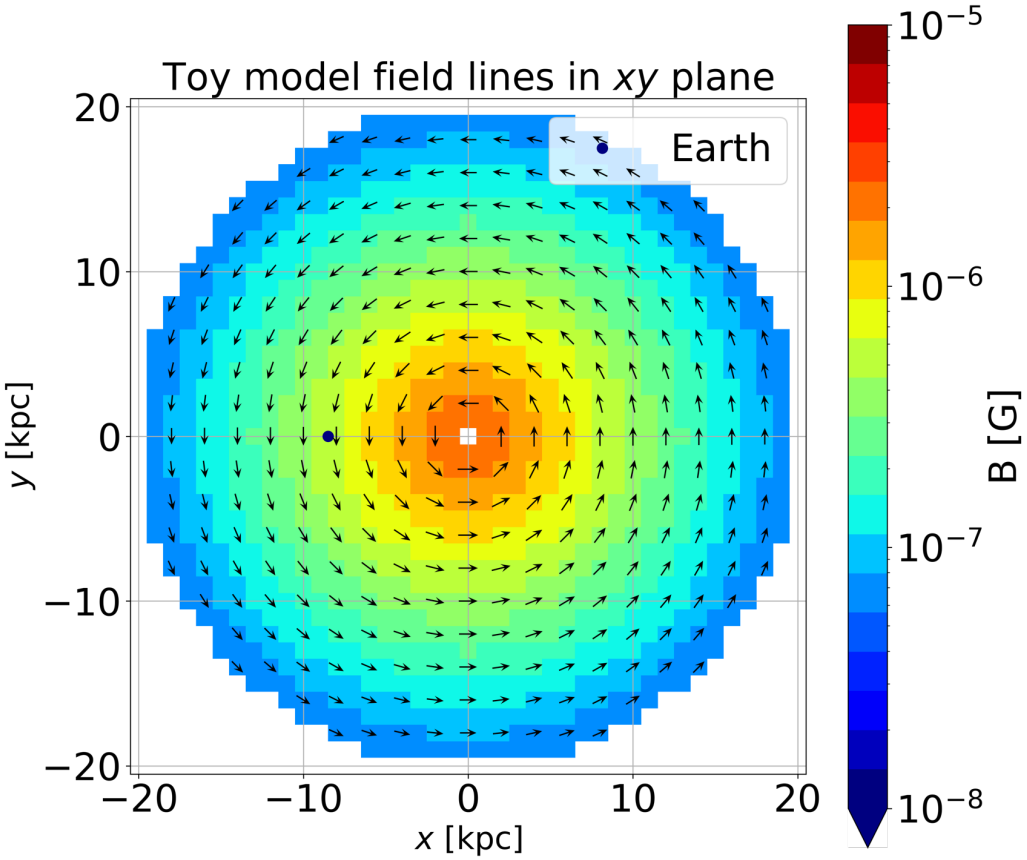
Note: We do not have any accurate estimates for the Halo !

Probing magnetic fields with synchrotron radiation

Toy Model – Structured fields

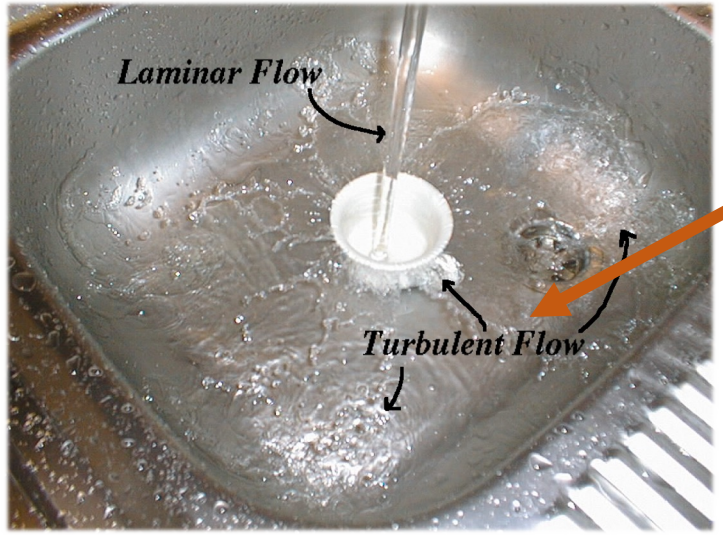
$$B_{\rm tor} = B_{\rm str} {\rm e}^{(-|z|/Z_{\rm mag})} {\rm e}^{(-z_{\rm min}/|z|)} {\rm e}^{(-|r|/R_{\rm mag})}$$





R_{mag} & Z_{mag} = 5 kpc and 6 kpc B_{str} = 3.96 μG

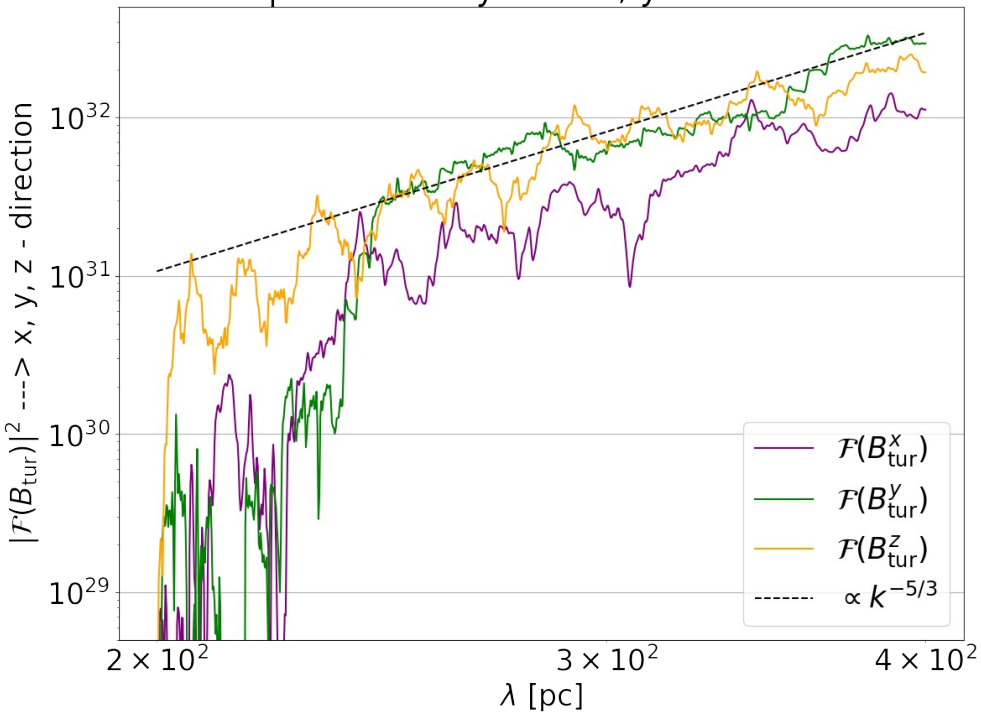
Toy Model –Turbulent fields

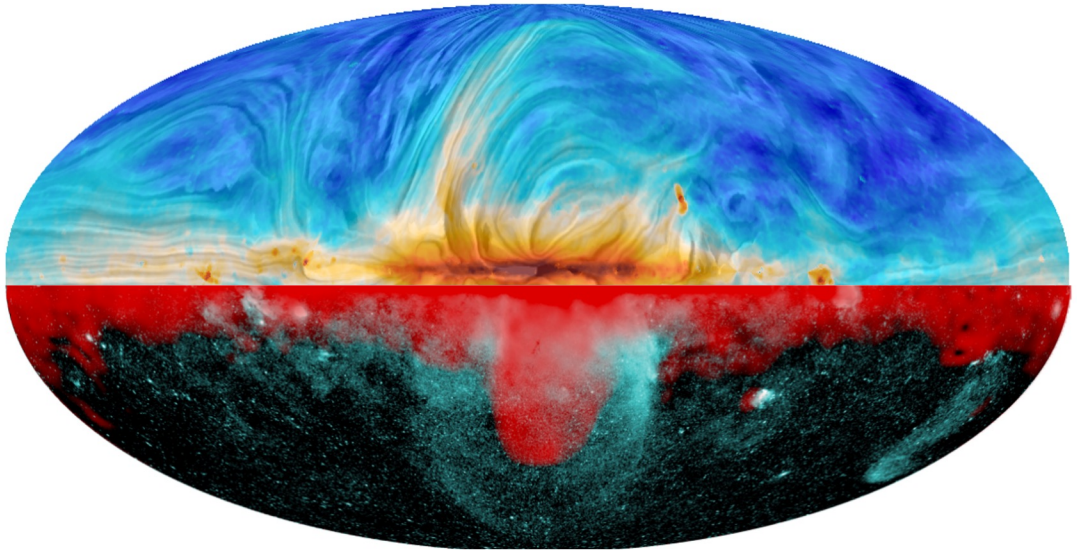


Outflow induces turbulent fields

$\frac{5}{3}$ Kolmogorov spectrum for turbulent fields

Power spectral analysis in x, y and z directions





Almost same power in each mode

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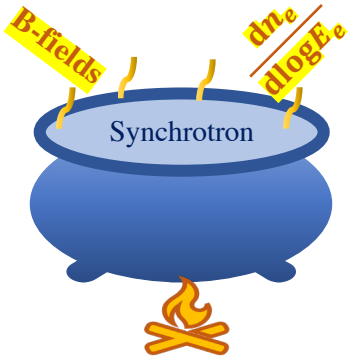
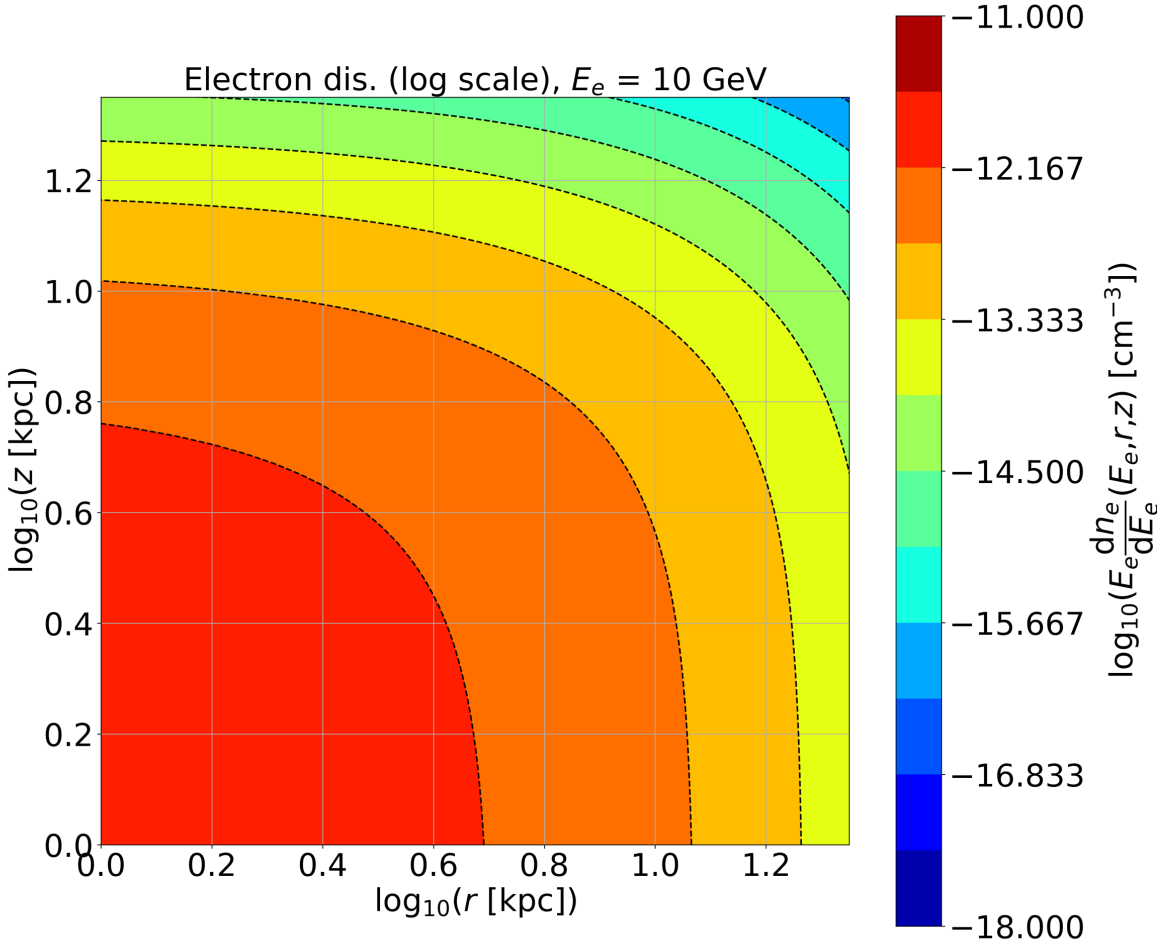
2) Predehl, P., Sunyaev, R.A., Becker, W. et al. Detection of large-scale X-ray bubbles in the Milky Way halo. Nature 588, 227–231 (2020).

Toy Model – non-thermal electron distribution at 10 GeV

$$\frac{\mathrm{d}n_e}{\mathrm{dlog}E_e} = C_{\mathrm{norm}} \left(\frac{E_e}{E_{10\mathrm{GeV}}}\right)^{-p+1} e^{-r/R_{\mathrm{el}}} \,\mathrm{sech}^2\left(\frac{z}{Z_{\mathrm{el}}}\right)$$

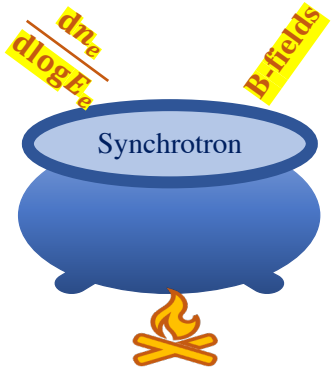
Together magnetic fields and non-thermal electrons give Synchrotron!

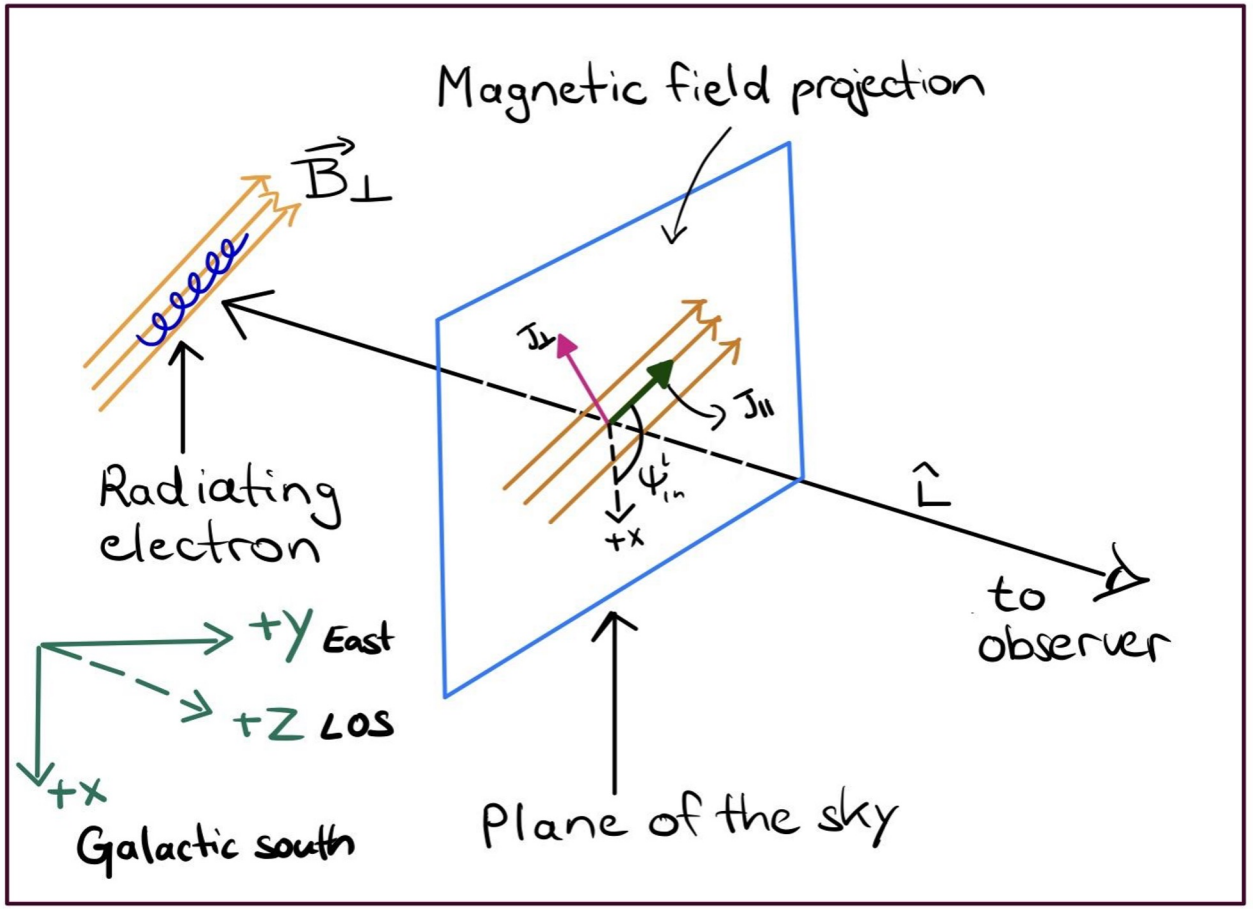




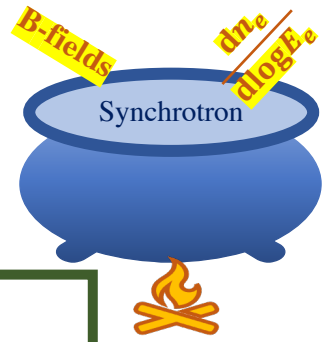
R_{el} & Z_{el} = 5 kpc and 6 kpc

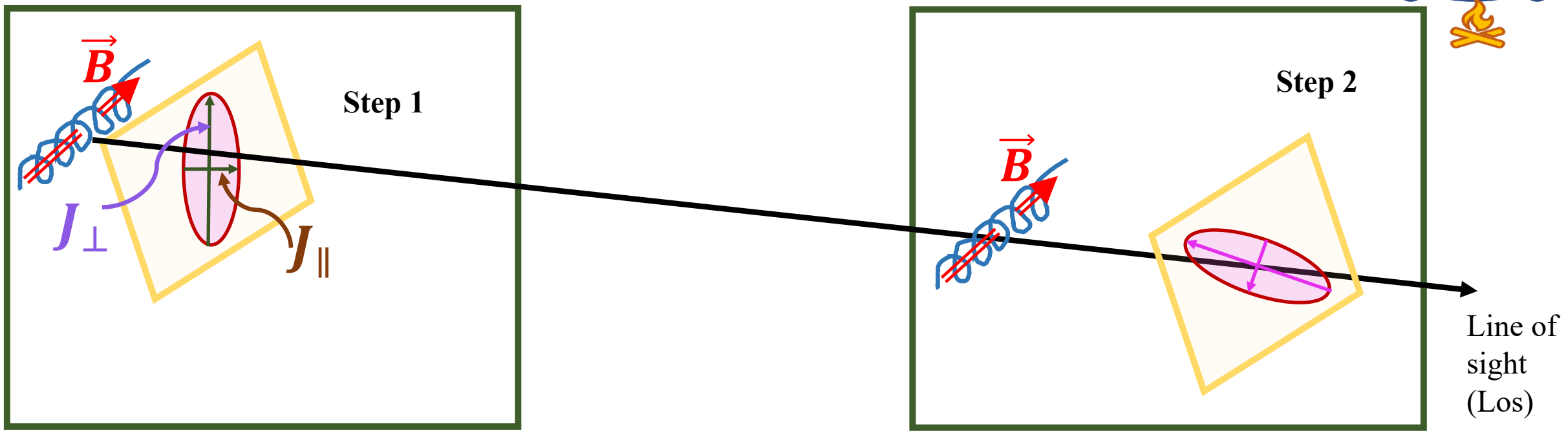
Synchrotron radiation – standard picture



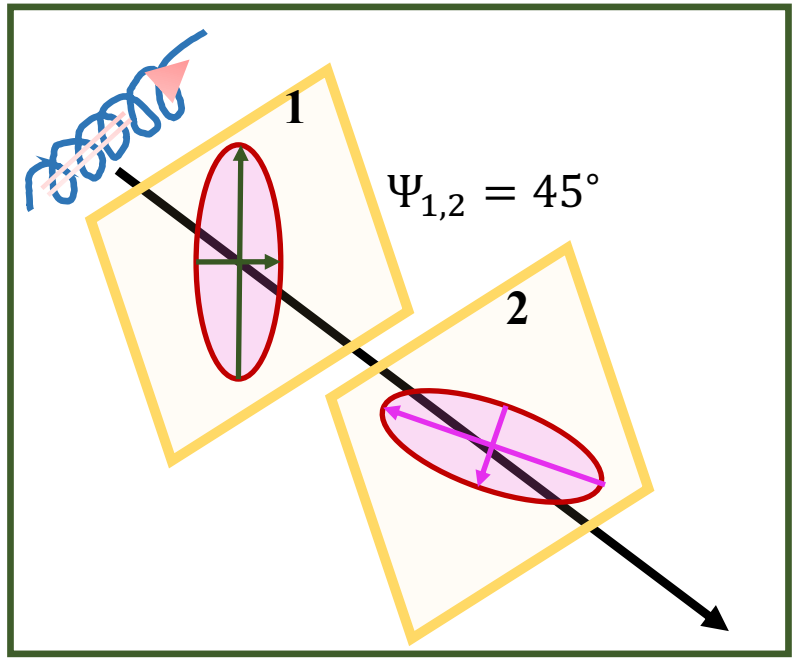


Synchrotron radiation – emission elipses



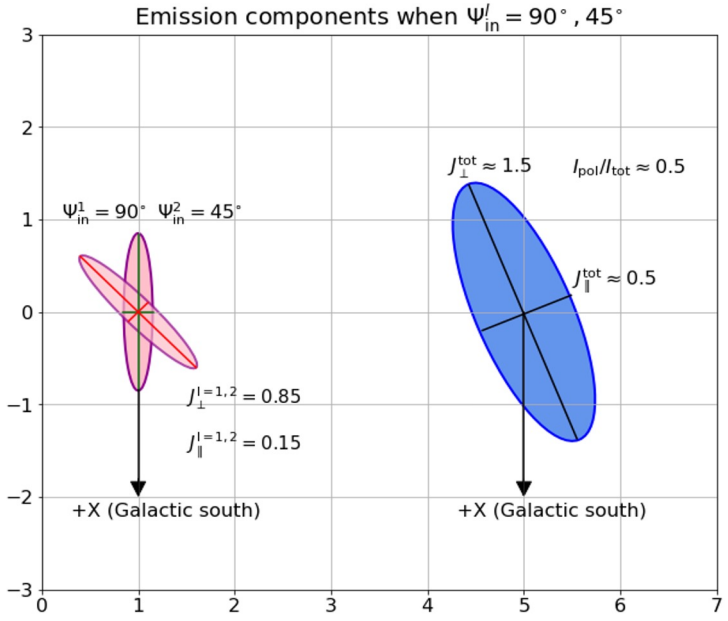


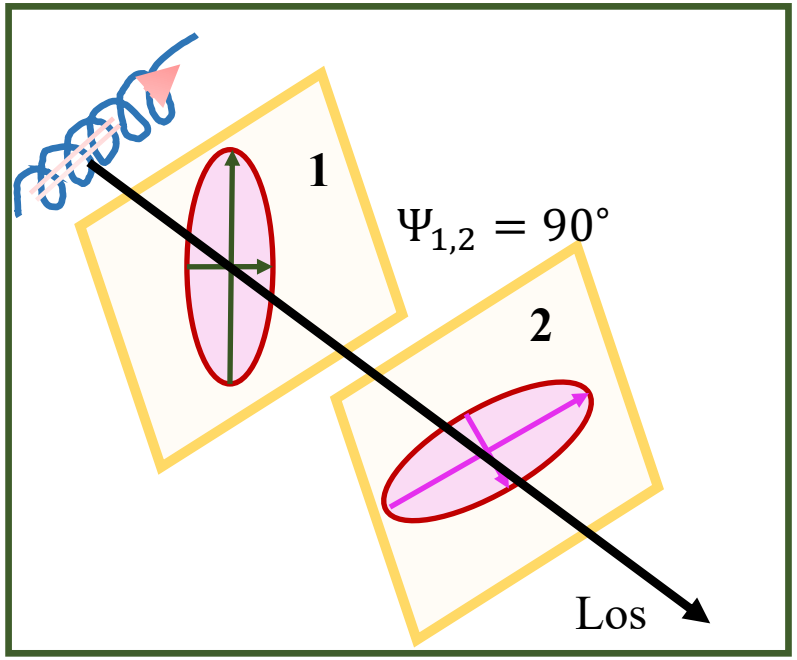
Synchrotron radiation



Polarised synchrotron

Probes magnetic field strength and geometry

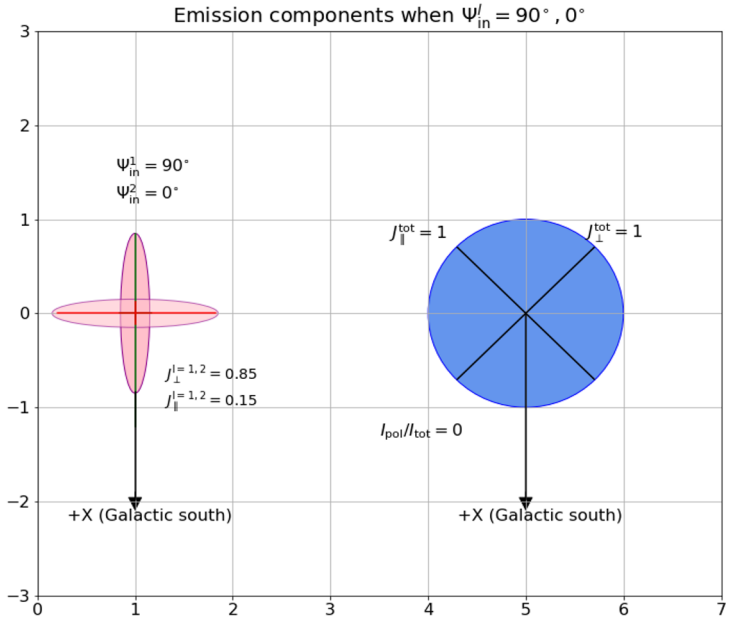




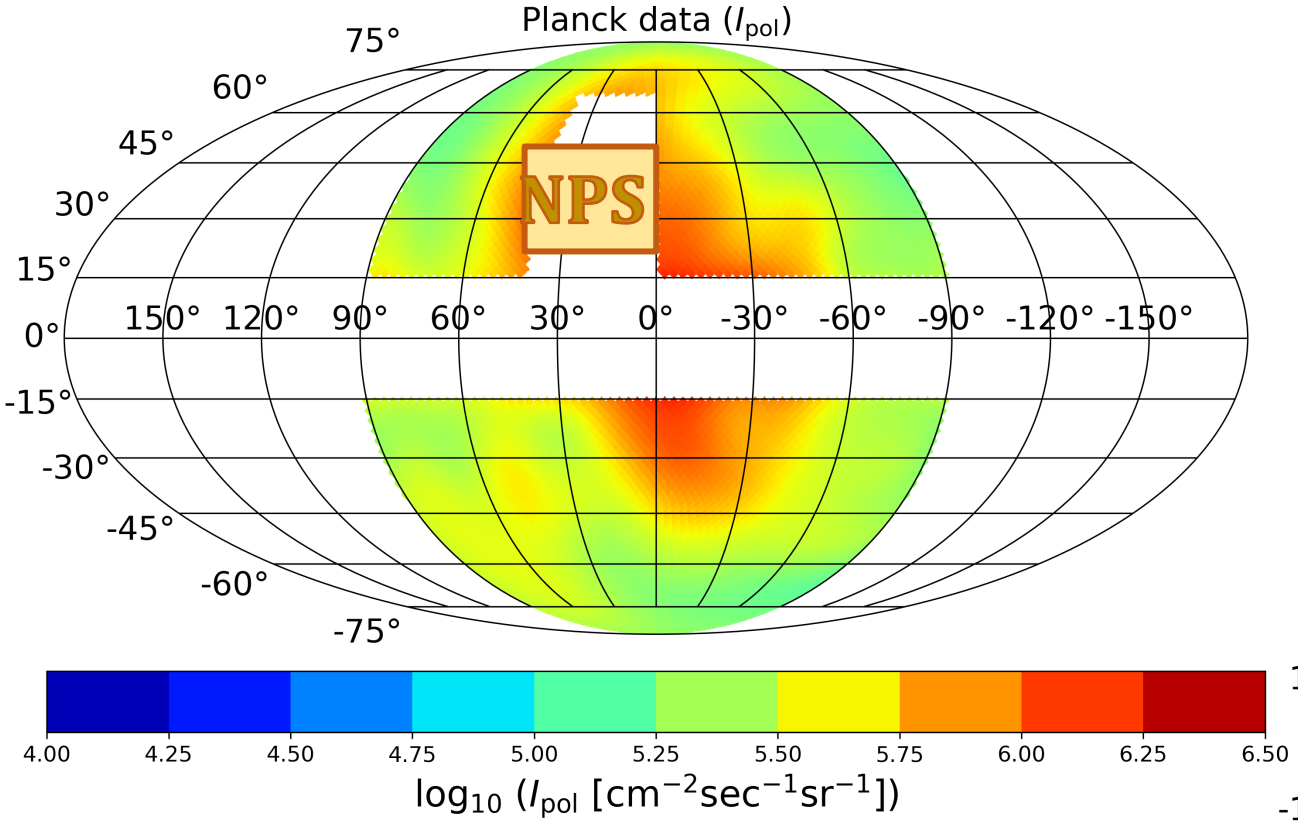
Unpolarised synchrotron

Probes magnetic field strength only

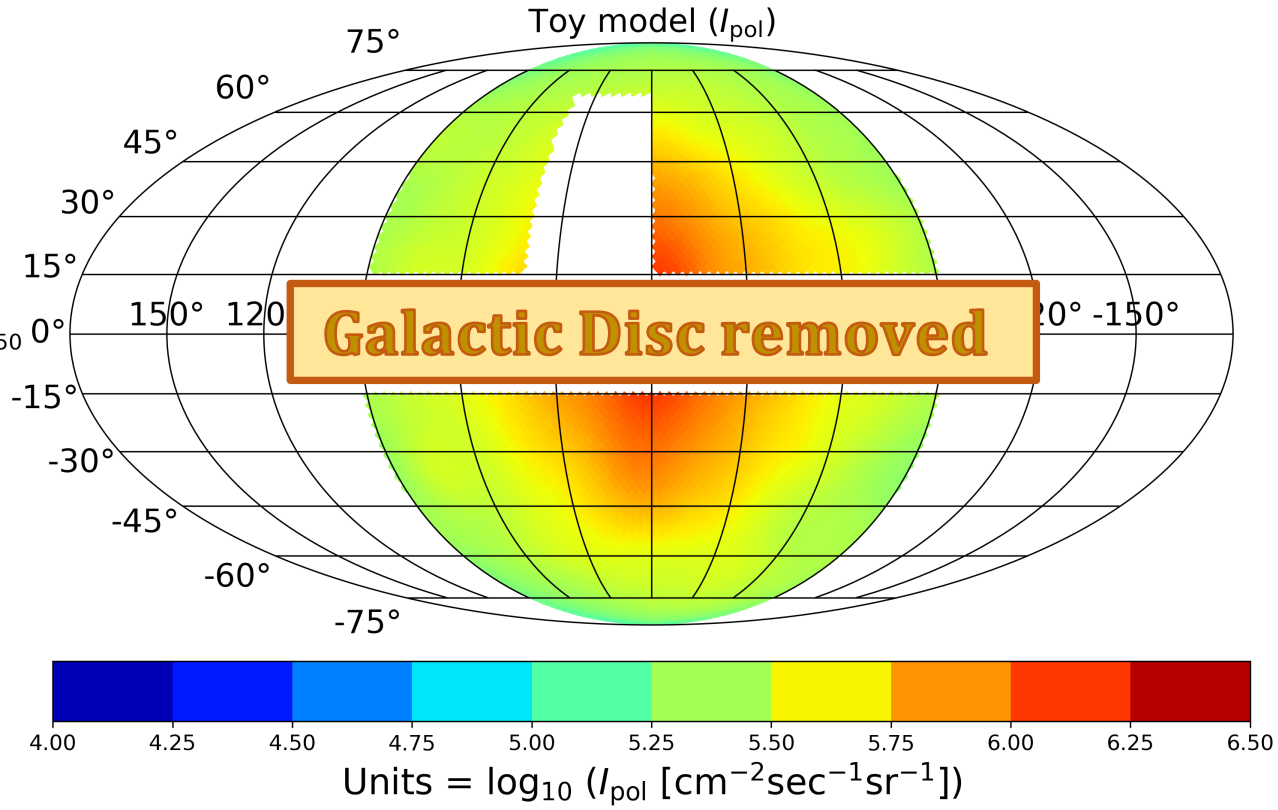
Maximum emission is observed when the electron pitch angles are perpendicular to magnetic fields.



Results – Best fit case



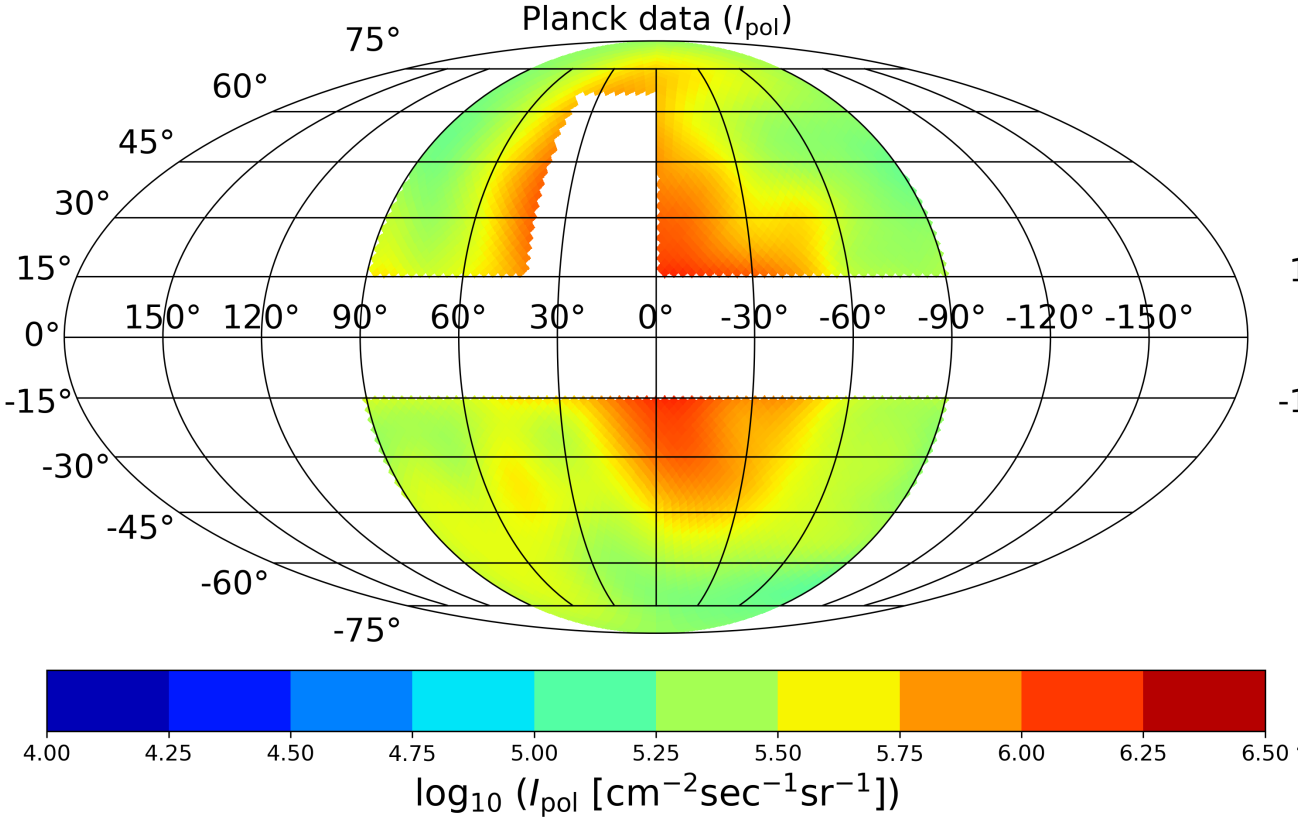
15° Gaussian smoothening

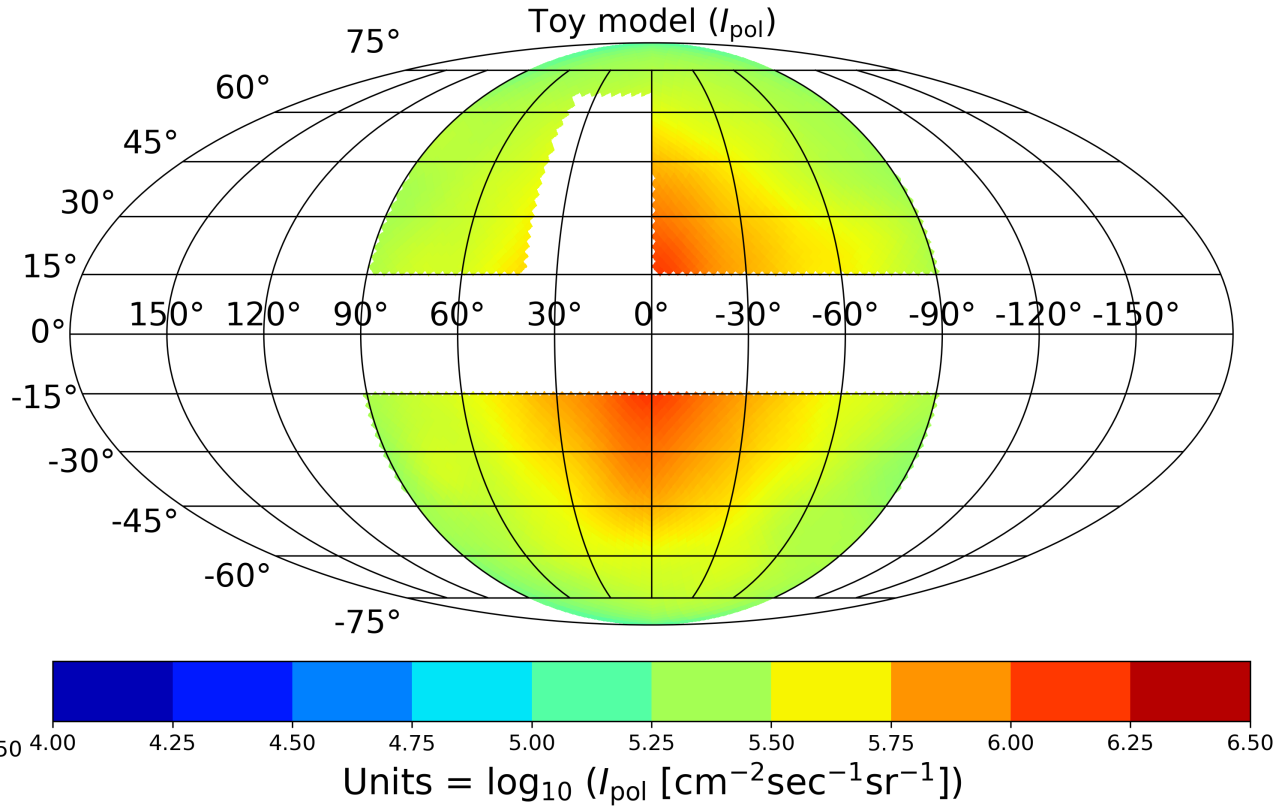


Constraints

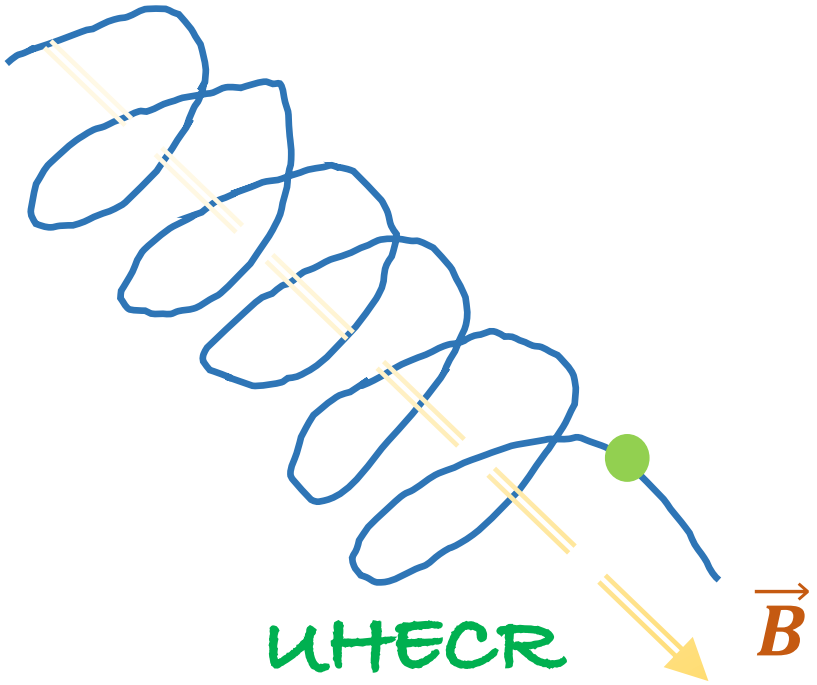
Shaw et al 2022

Best-fit value with 1σ constraint		
Parameter	Best-fit value	Description
$B_{\rm str}$	$3.96^{+6.63}_{-1.96}$ μG	Structured field strength
$B_{\rm tur}$	$6.72^{+9.97}_{-3.56}$ μG	Turbulent field strength
$R_{\rm Mag} = R_{\rm el}$	5^{+1}_{-0} kpc	Radial cut off
$Z_{\rm Mag} = Z_{\rm el}$	6^{+1}_{-0} kpc	Azimuthal cut off
$\log_{10}$ ($C_{\rm norm}$[cm^{-3}])	$-11.72^{+0.62}_{-0.93}$	Electron density at 10 GeV

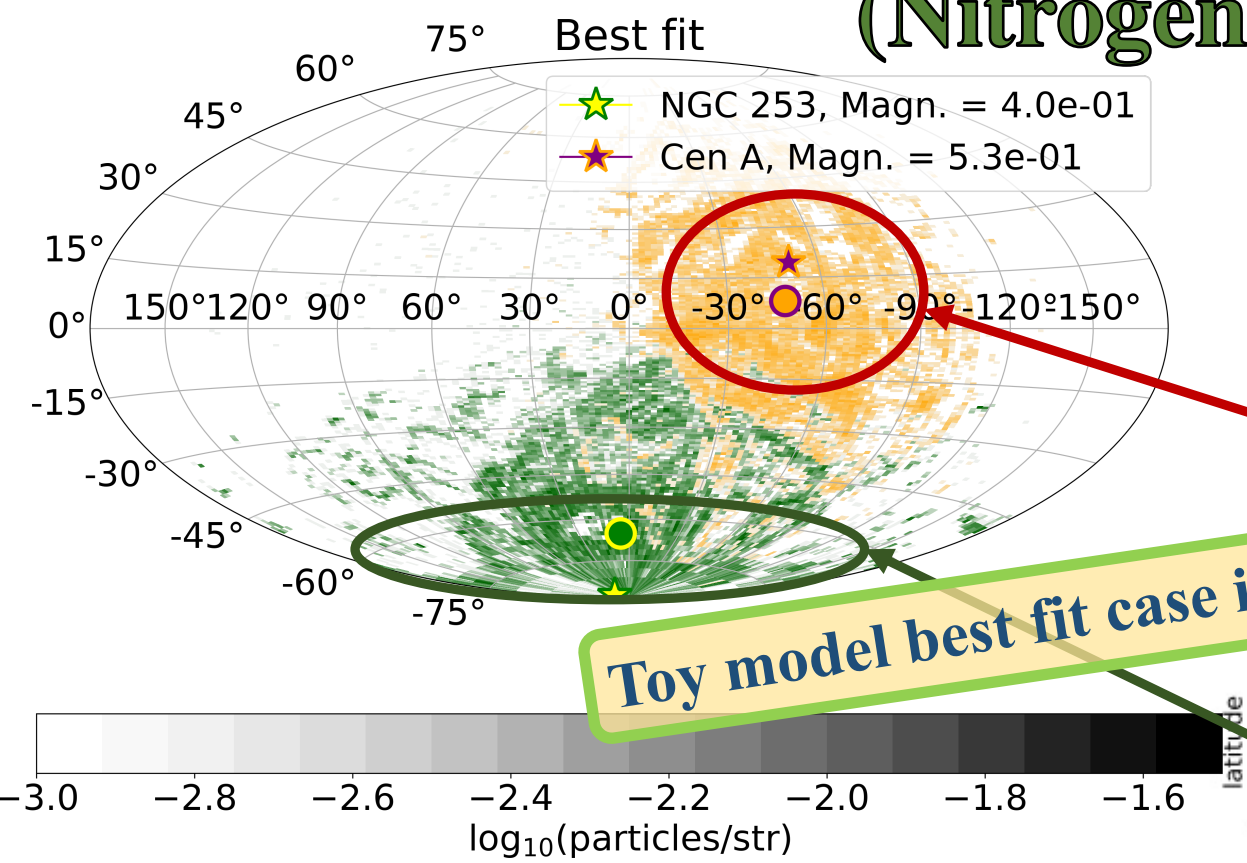


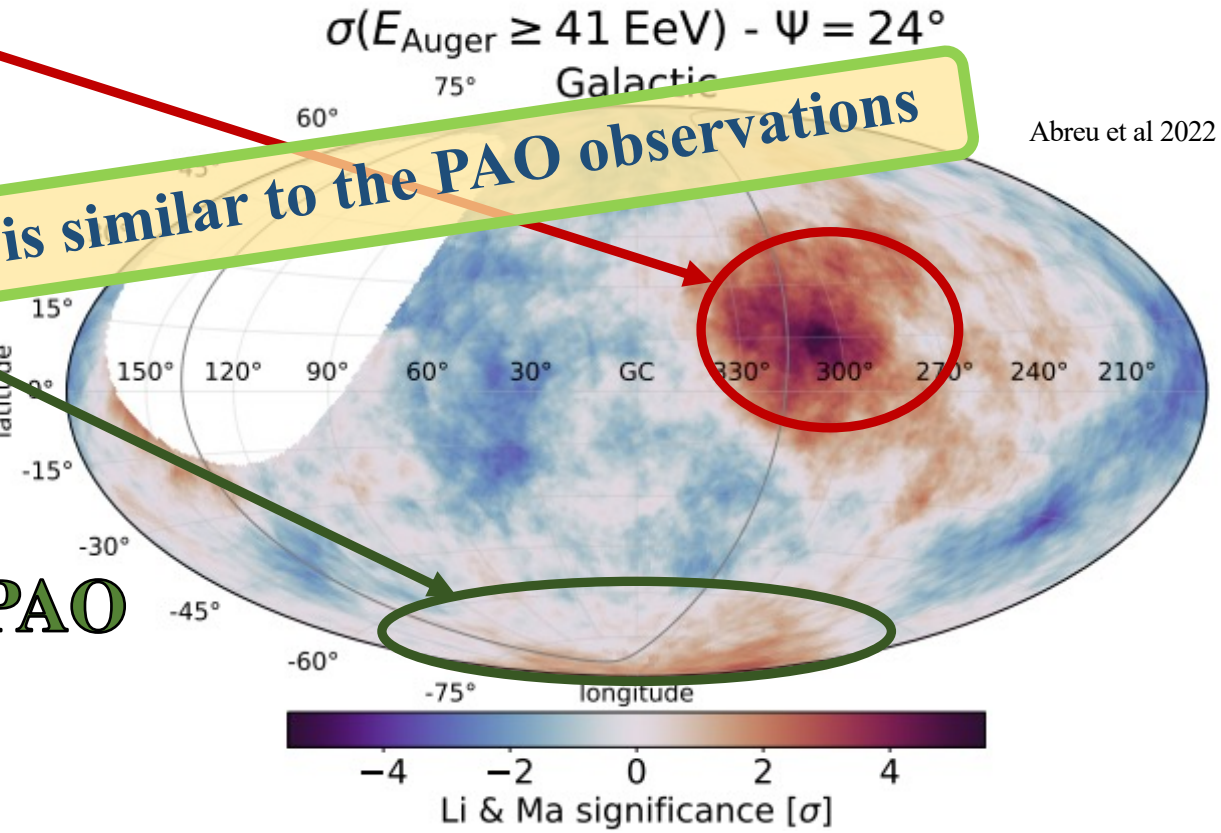


Backtracking of UHECRs through toy model using CRPropa3



Arrival directions of UHECRs – Toy Model vs Auger (Nitrogen at 40 EeV)





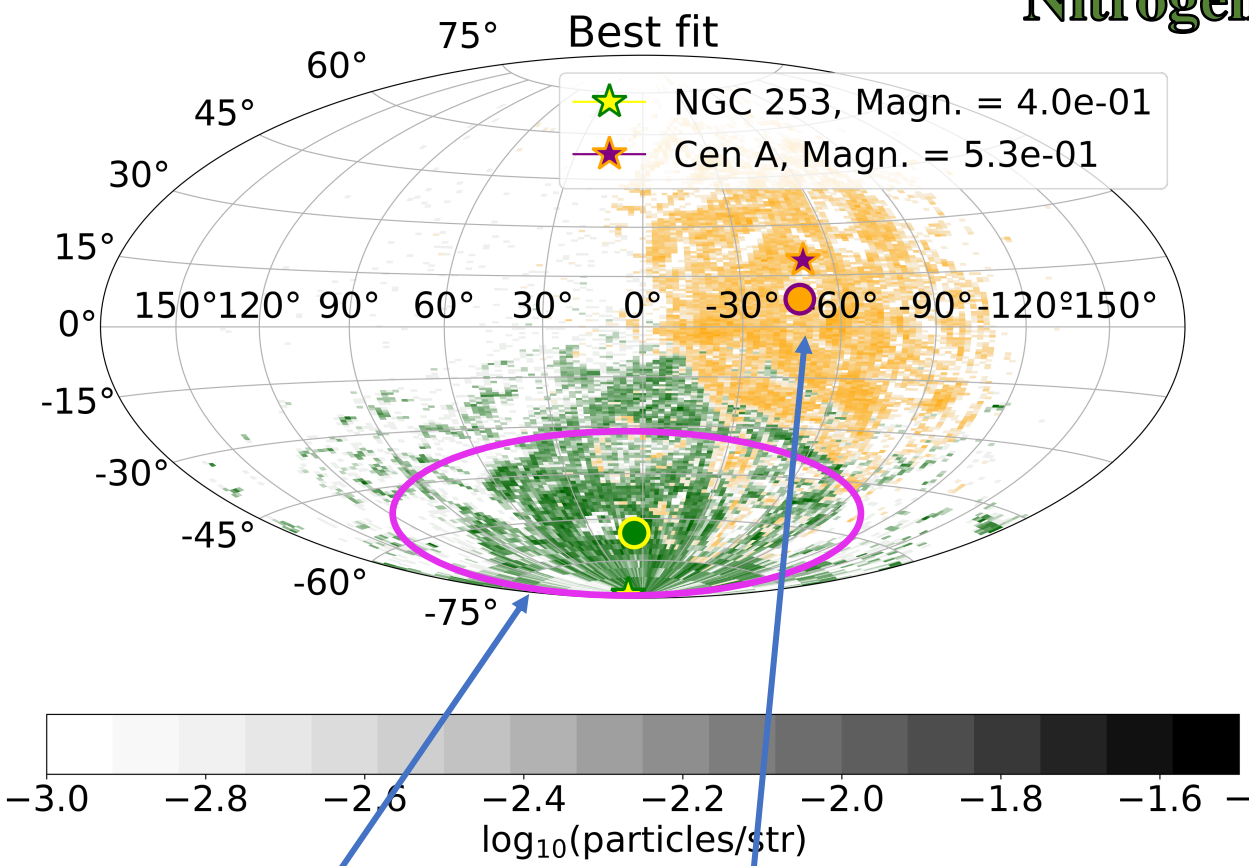
Abreu et al 2022

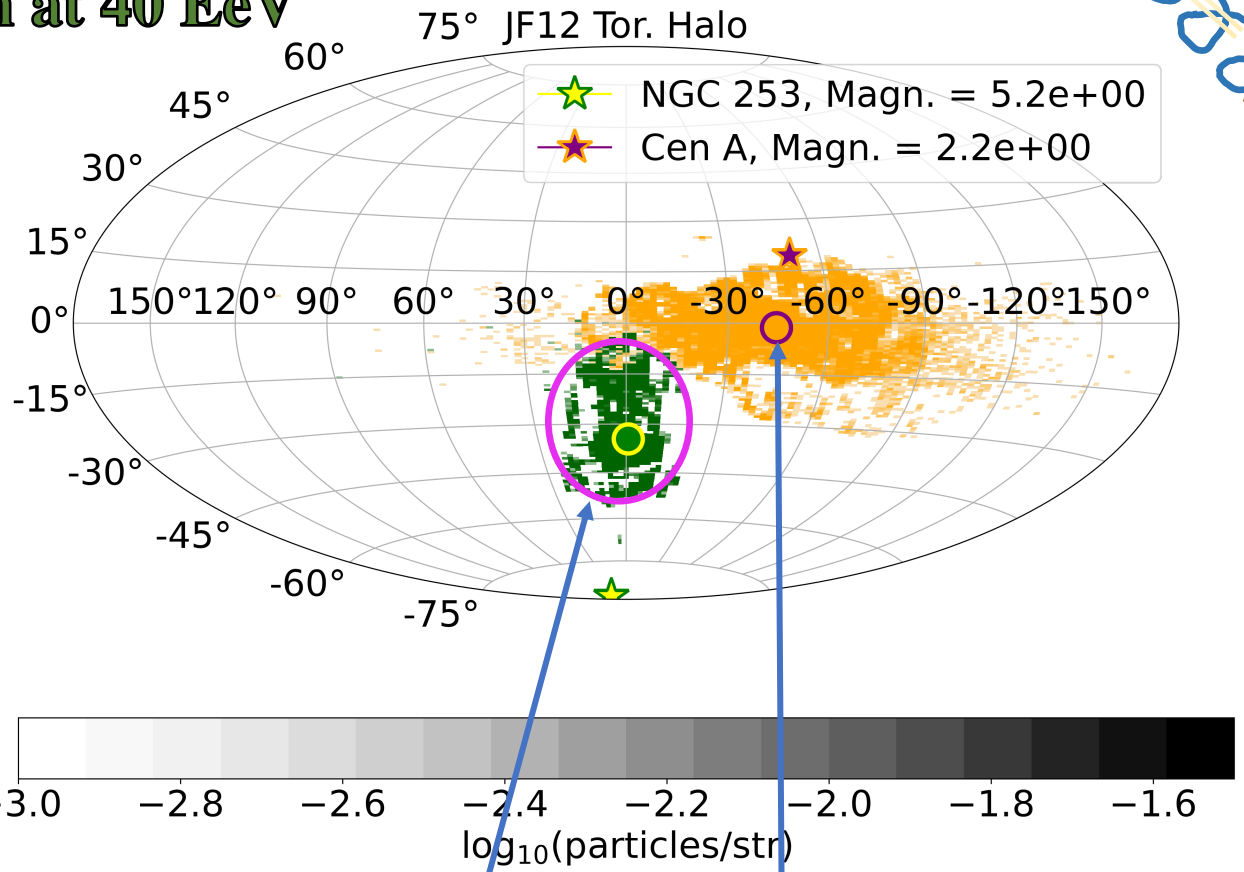
Toy model best fit case is similar to the PAO observations

Choice of rigidity & species based on PAO

Aab et al 2014 & 2018

Toy Model vs JF12 Torroidal Halo
Nitrogen at 40 EeV





$\sigma_{\text{NGC 253}} = 32^\circ, \sigma_{\text{Cen A}} = 33^\circ$

$\sigma_{\text{NGC 253}} = 9^\circ, \sigma_{\text{Cen A}} = 22^\circ$