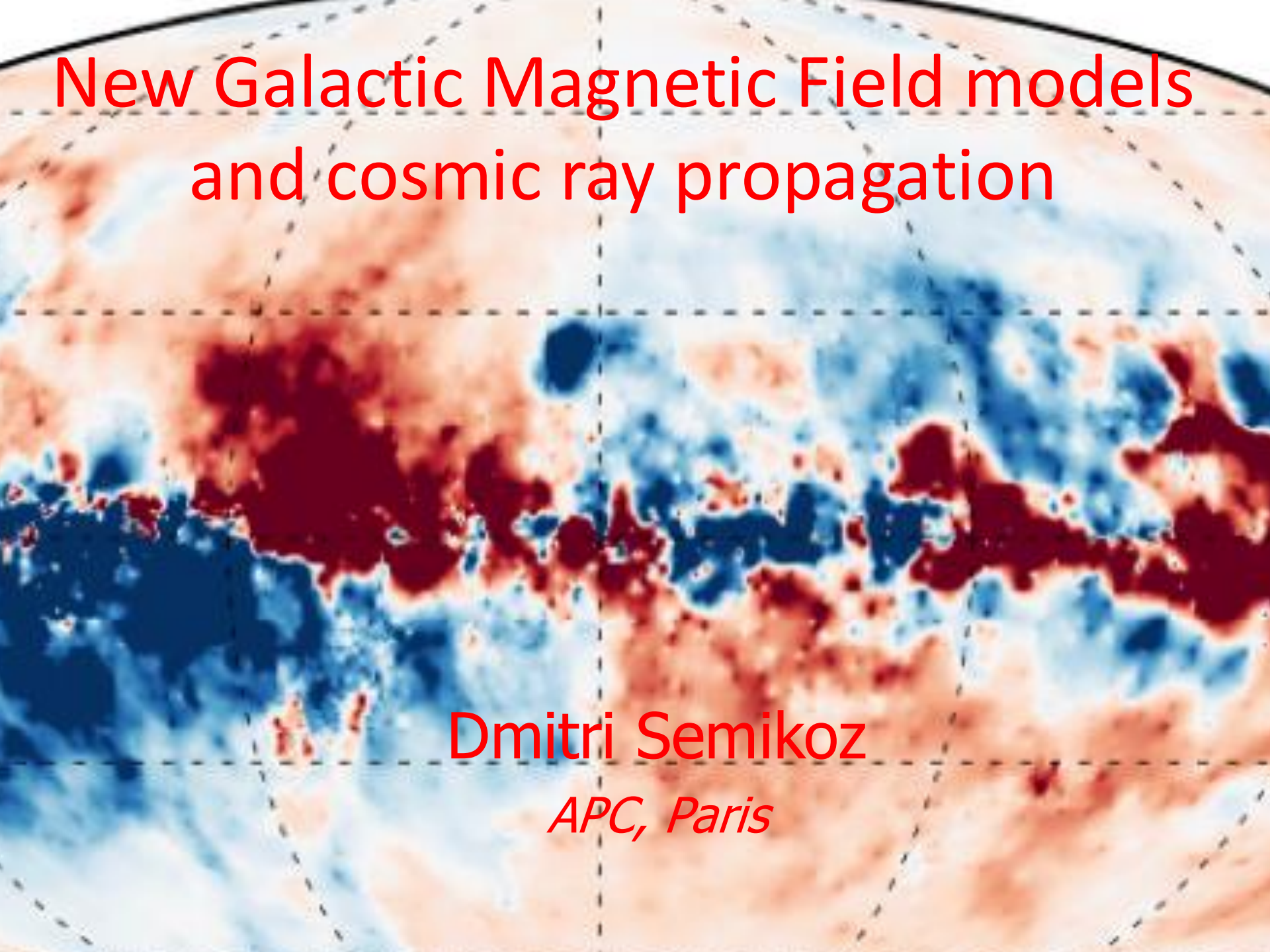
New Galactic Magnetic Field models and cosmic ray propagation



Dmitri Semikoz

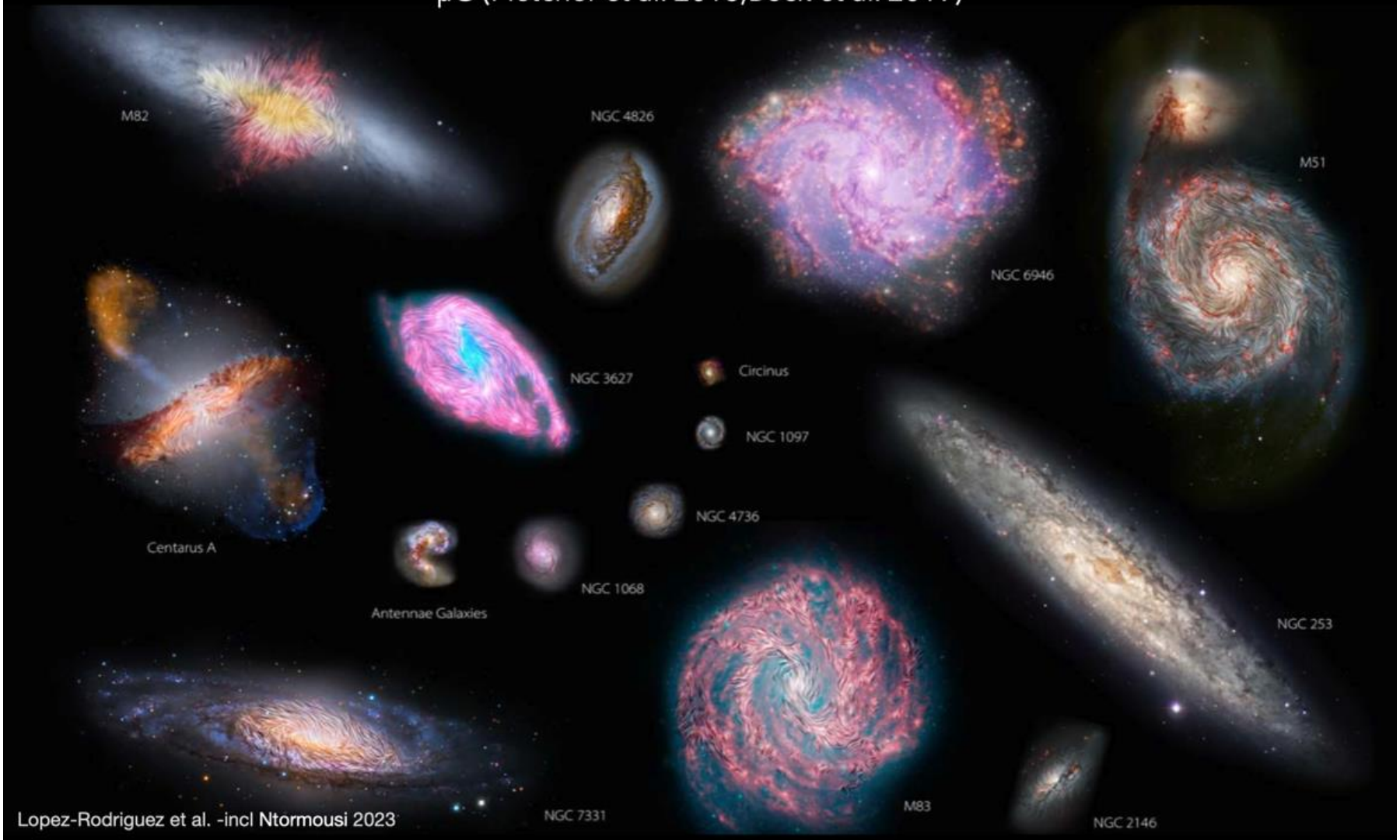
APC, Paris

Plan:

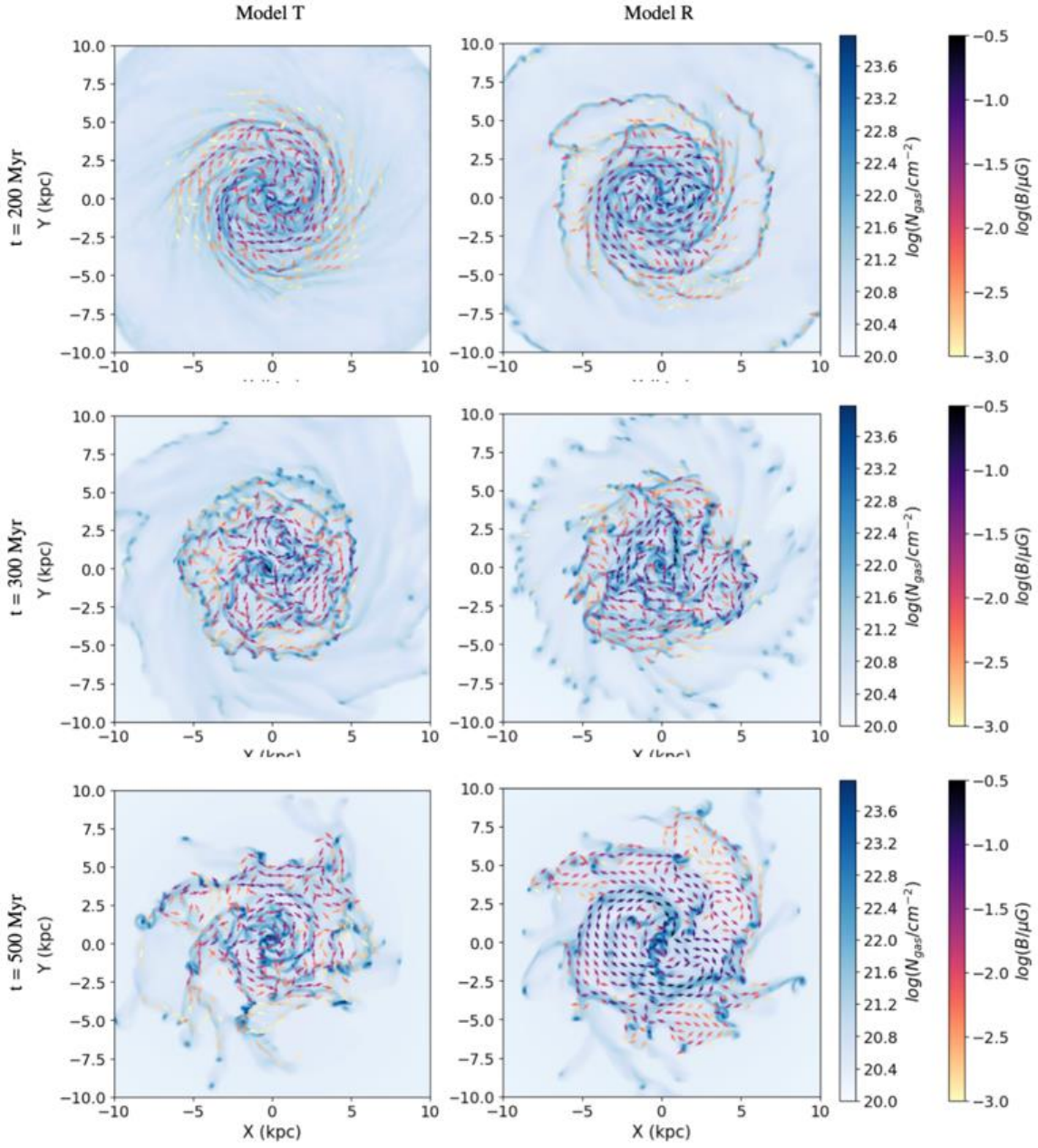
- *Introduction: Galactic Magnetic Field*
- *New models*
- *UHECR propagation*
- *LHAASO sources and GMF*
- *Conclusions*

Galactic magnetic field

Present-day spirals host large-scale coherent magnetic fields with a typical strength of a few μG (Fletcher et al. 2016,Beck et al. 2019)



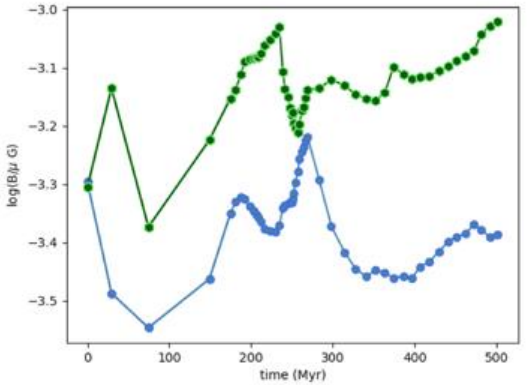
The first estimates for redshifts z>1 yield fields of the order of μG already at these epochs! (Bernet et al. 2008, Mao et al. 2017,Geach et al. 2023,Chen et al.2024)

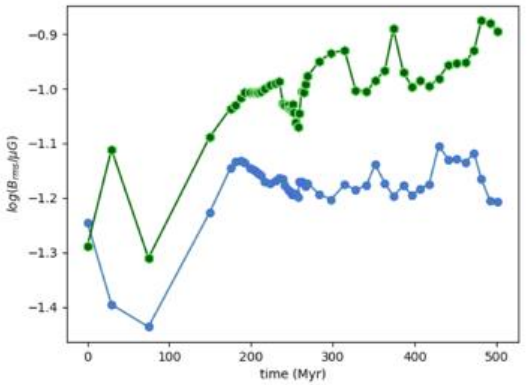


Subtle differences in the model evolution:

Model R is slightly larger in the radial direction

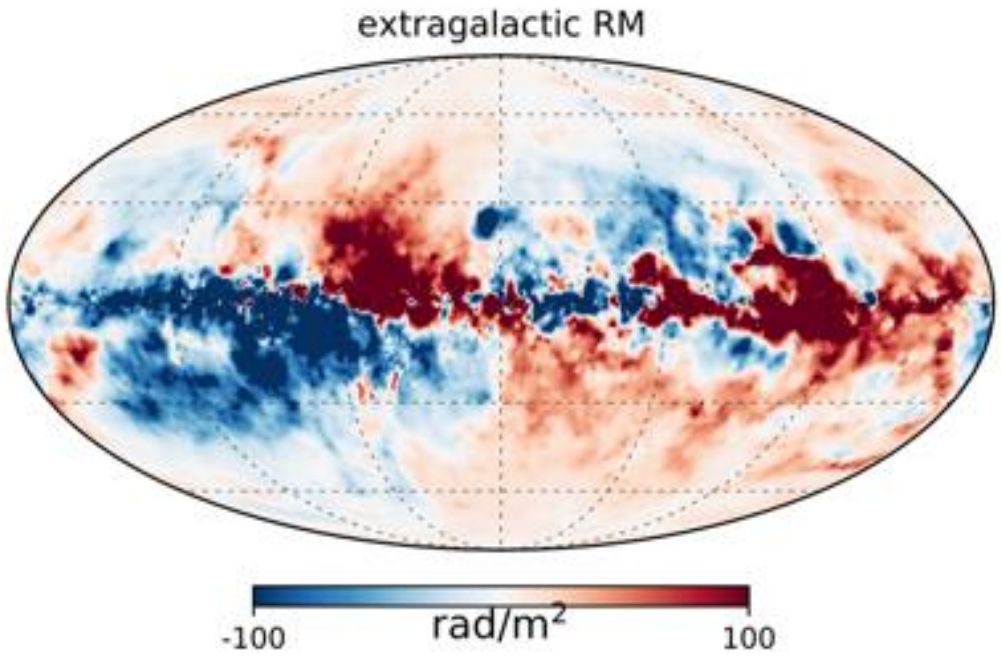
Model R's magnetic field is stronger over a wider radial range





A. Konstantinou, E. Ntormousi, K. Tassis & A. Pallottini A&A 2024

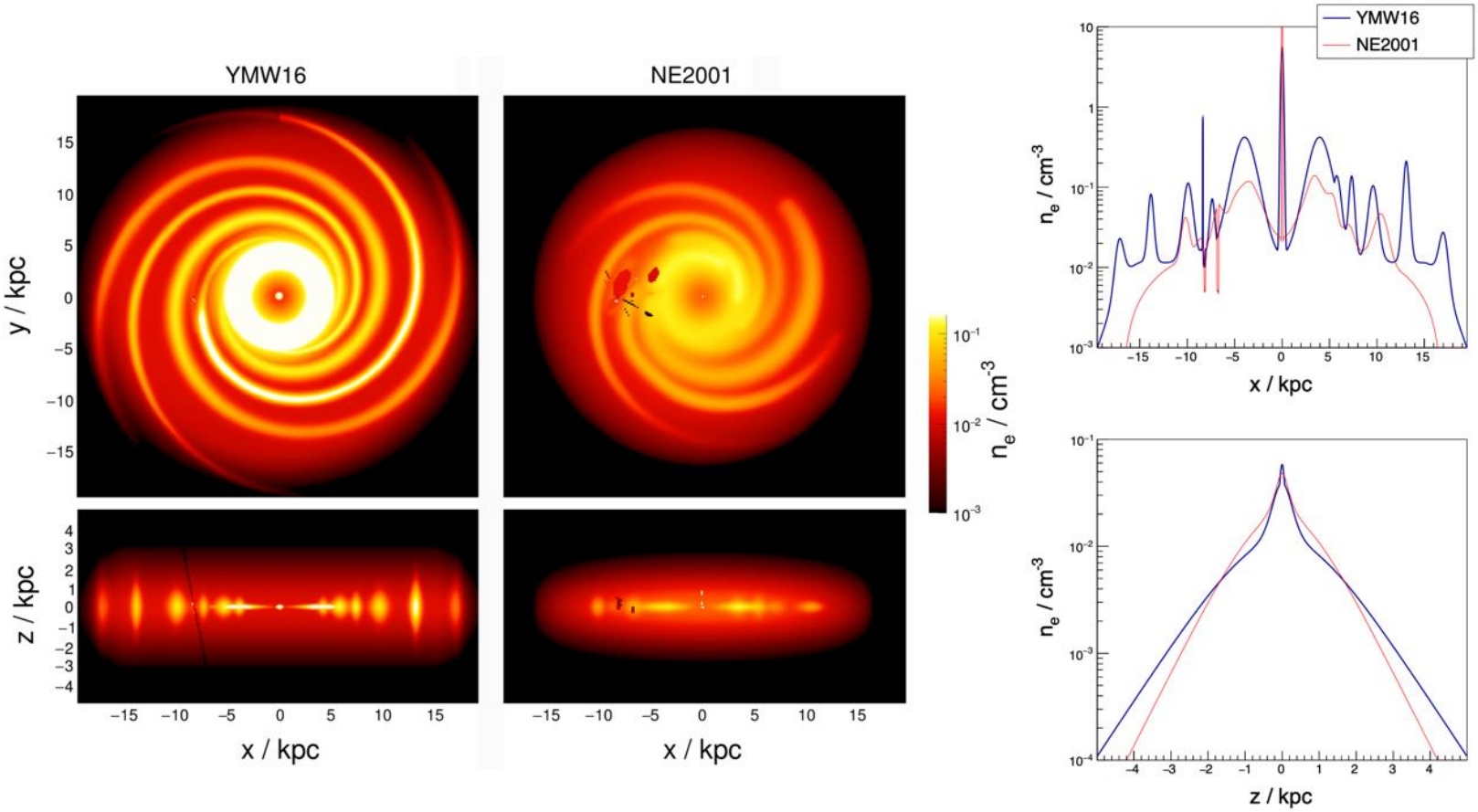
ROTATION MEASURE



60000 extragalactic objects

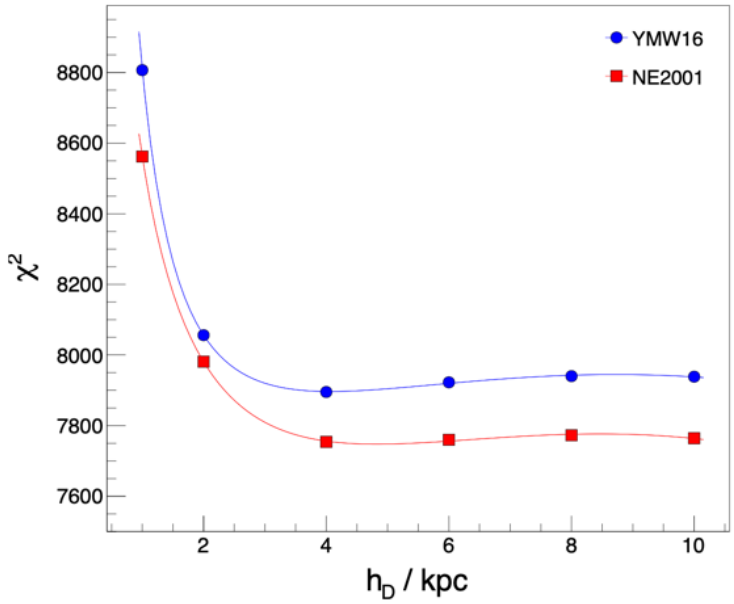
$$\mathrm{RM} \approx 0.812 \int_0^l \left[\frac{n_e(s)}{\mathrm{cm}^{-3}}\right]\left[\frac{B_\parallel(s)}{10^{-6}\,\mathrm{G}}\right]\left[\frac{\mathrm{d}s}{\mathrm{pc}}\right] \ \mathrm{rad/m^2}.$$

Thermal electrons model

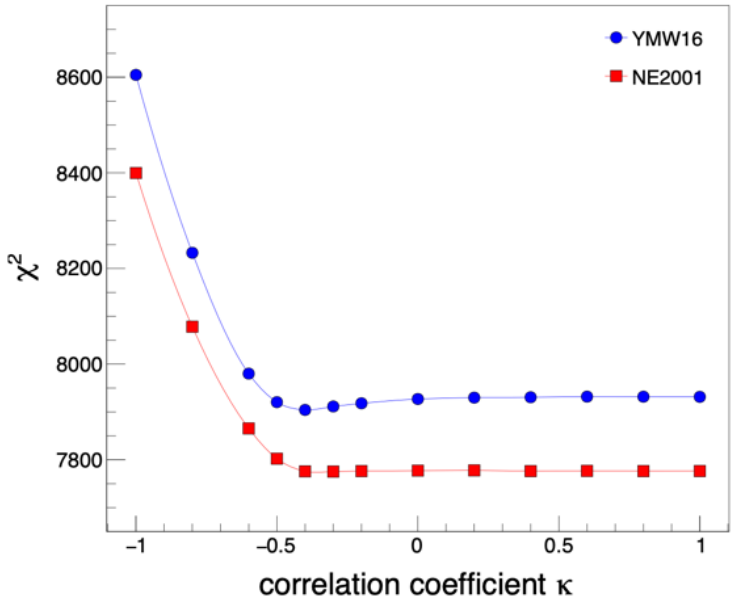


From M.Under and G.Farrar 2311.12120

Thermal electrons model



a: Half-height h_D of the cosmic-ray diffusion volume.



b: Correlation coefficient κ between the magnetic field and thermal electron density.

From M.Under and G.Farrar 2311.12120

Anti-symmetric RM sky: halo B fields = A0 dynamo

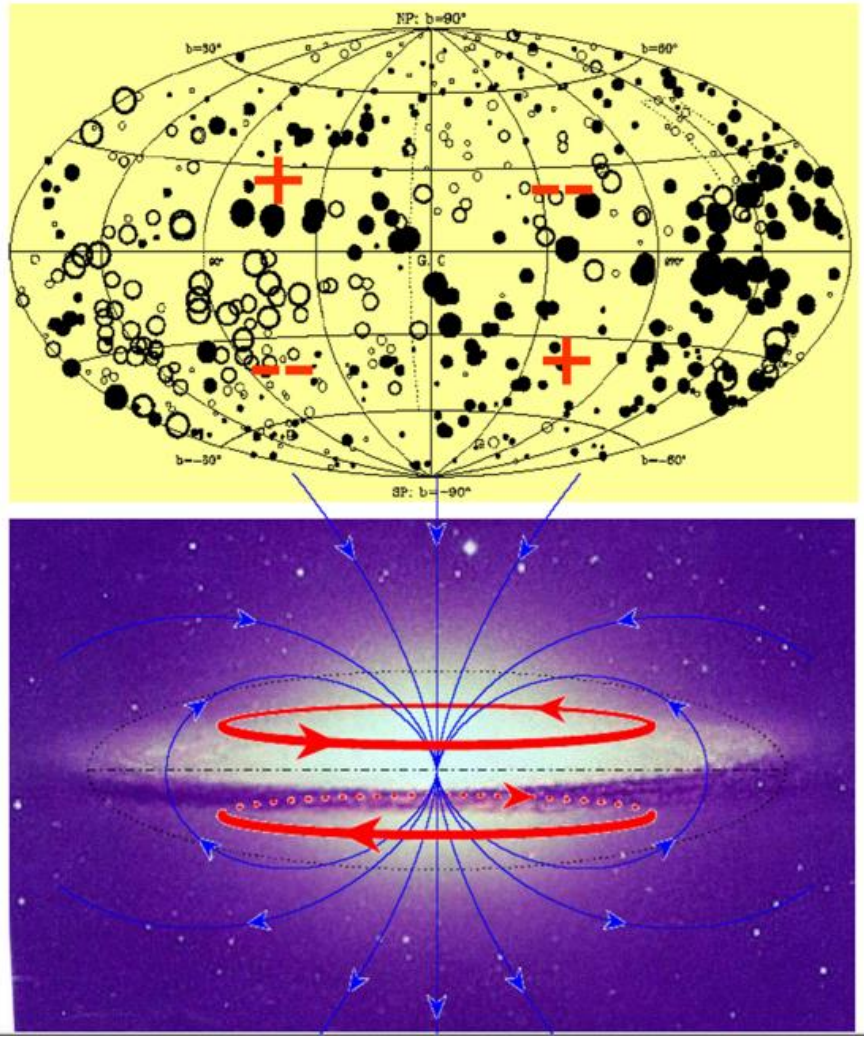
(Han et al. 1997, A&A322, 98)

Evidence for global scale B

- High anti-symmetry to the Galactic coordinates
- Only in inner Galaxy
- nearby pulsars show it at higher latitudes

Implications

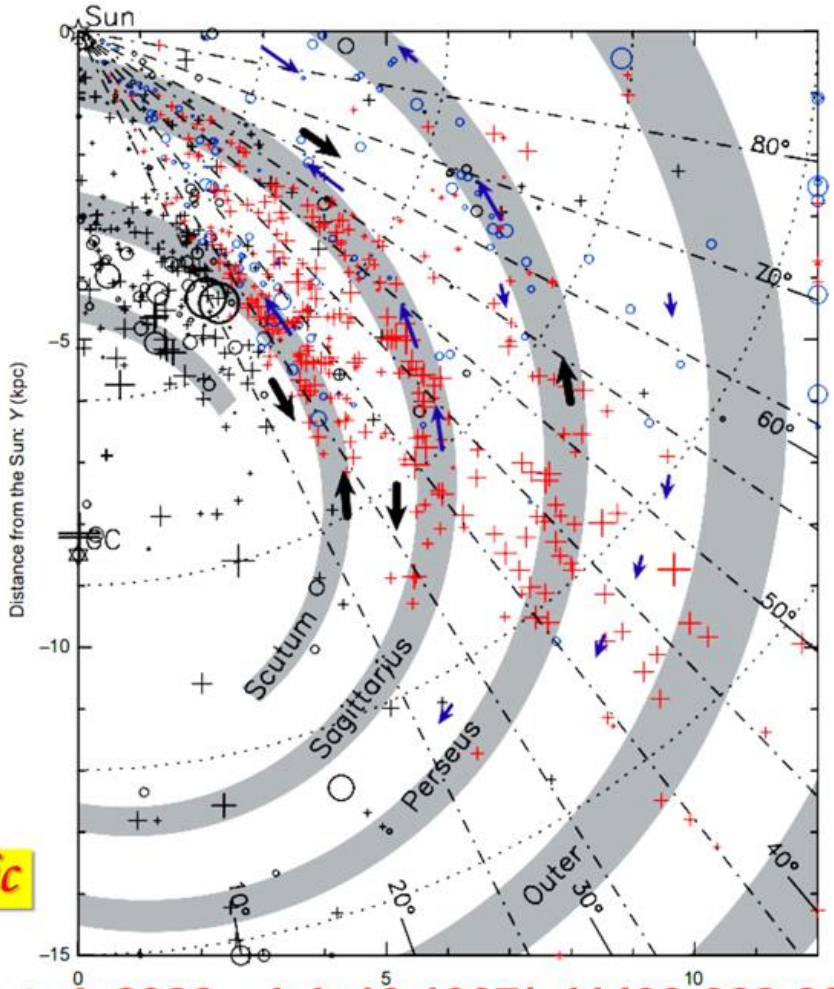
- Consistent with B-field configuration of A0 dynamo
- **The first dynamo mode identified on galactic scales**



Magnetic fields in the first quadrant of the Galactic disk

- In FAST pulsar database (Wang et al. 2022) we determined RMs for 311 pulsars for the first time
- Large number of RMs in (26°<l<90°) increased by a factor of two compared to the previous work.
- Explore the fields in farther arms up to 15 kpc

Without FAST, it is very difficult to explore magnetic fields in such wide areas

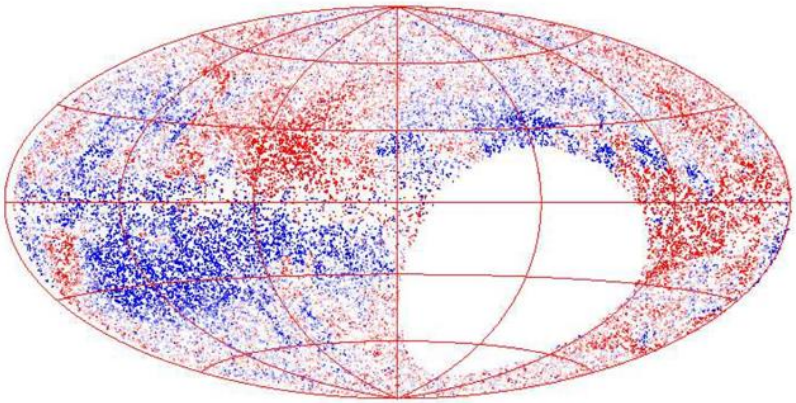


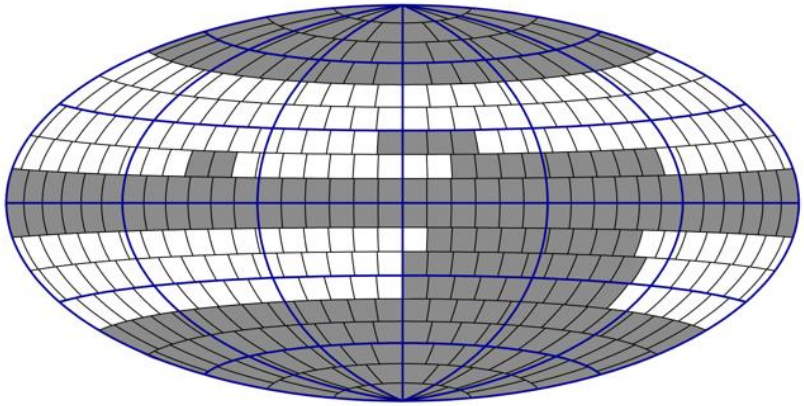
(Xu et al. 2022, doi: 10.1007/s11433-022-2033-2)

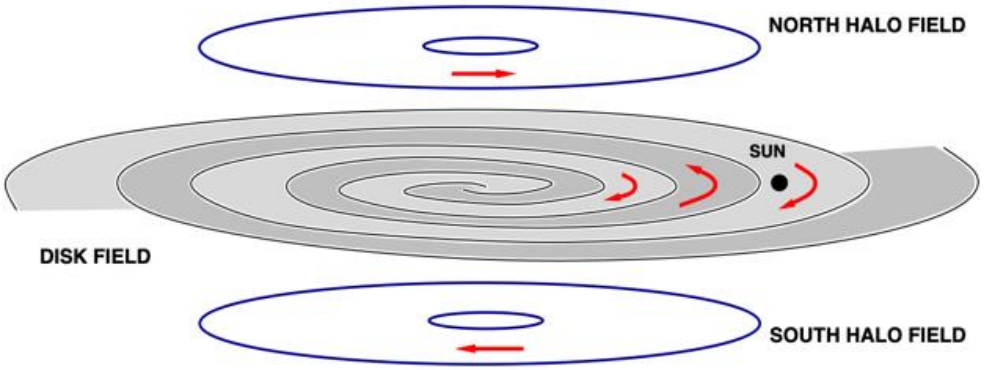
From JL Han's talk Dec 2024

Pshirkov,Tinyakov, Kronberg and Newton-McGee

model 2011







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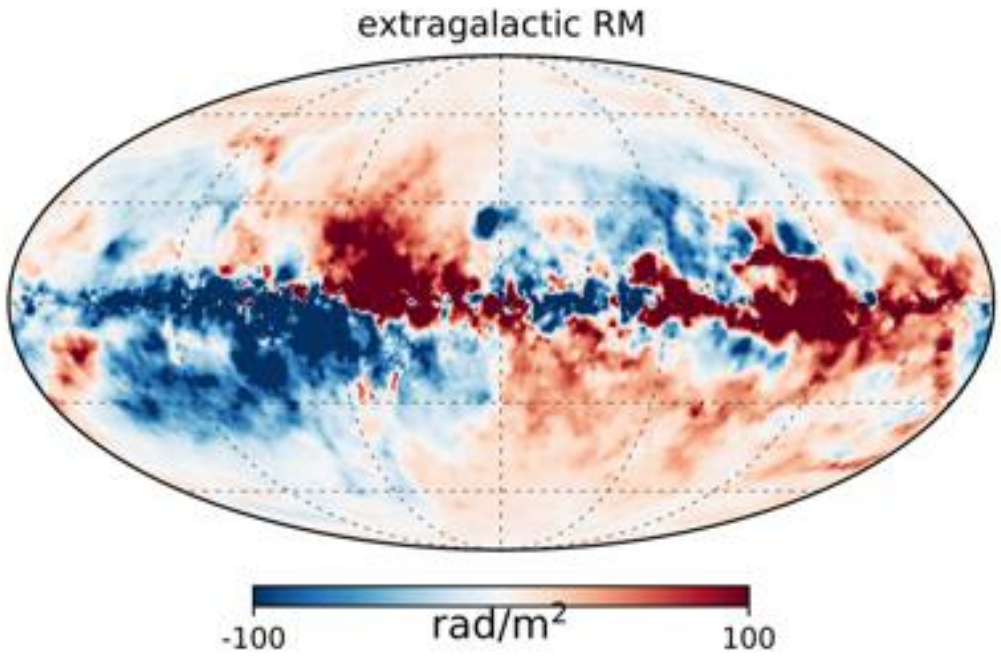
ROTATION MEASURE



60000 extragalactic objects

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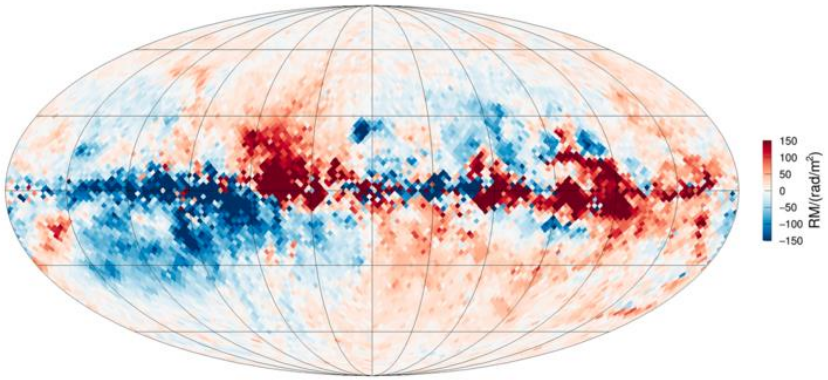
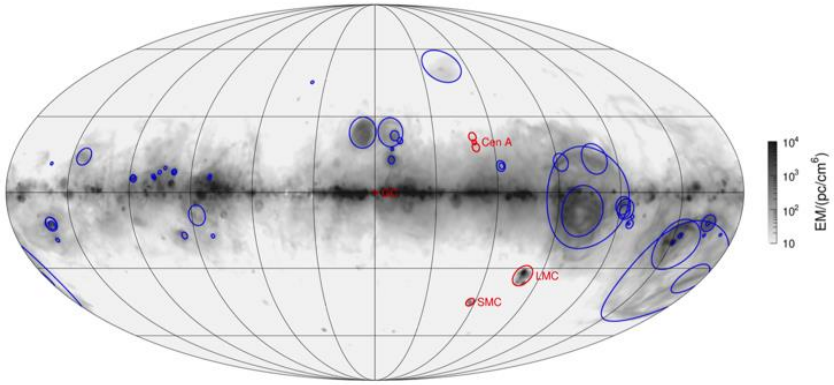
Remove foreground regions

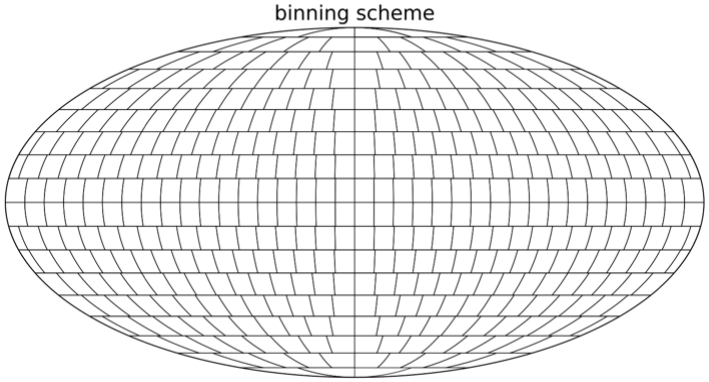


a: Sky map of extragalactic rotation measures (44857 RMs averaged over $N_{\rm side} = 32$ HEALPIX pixels). The color scale is saturated at $|{\rm RM}| \geq 150\,{\rm rad/m^2}$)

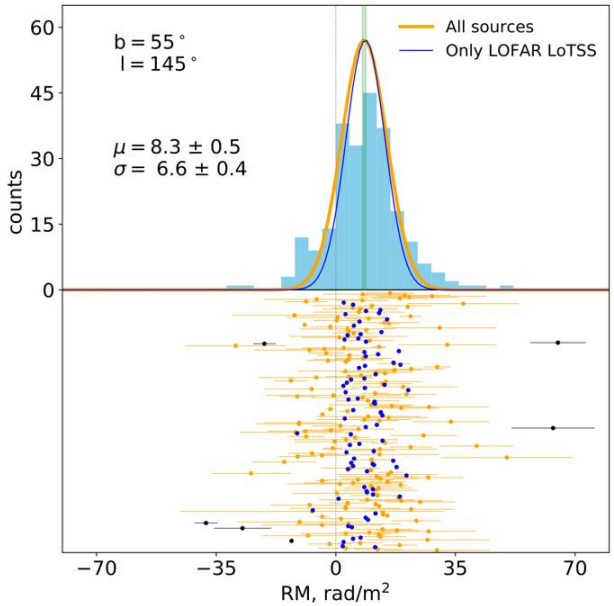


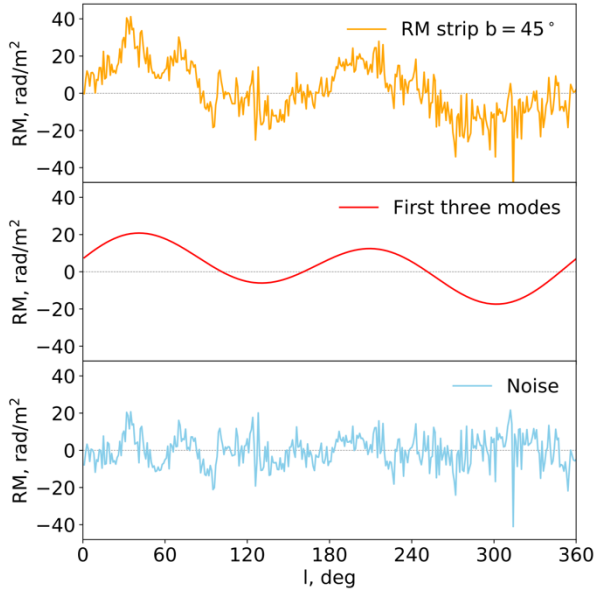
M.Under and G.Farrar 2311.12120

Model RM



	χ^2	χ^2/ndf	ndf	χ^2_{var}	χ^2_{var}/ndf
RM	544	**1.92**	283	145	0.51
Q	385	**1.11**	348	238	0.68
U	482	**1.38**	348	251	0.72
total	1411	**1.36**	1037	634	0.61

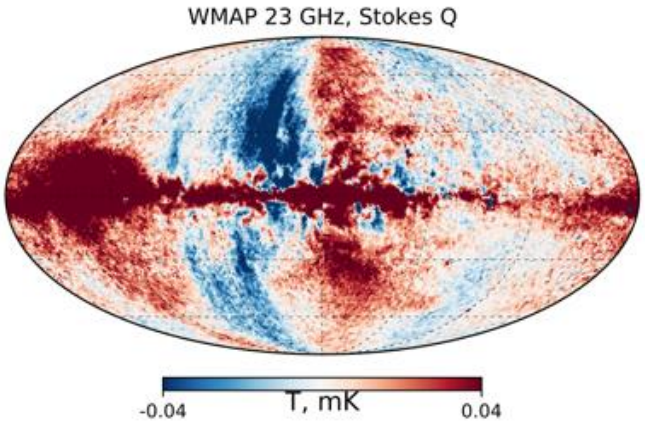


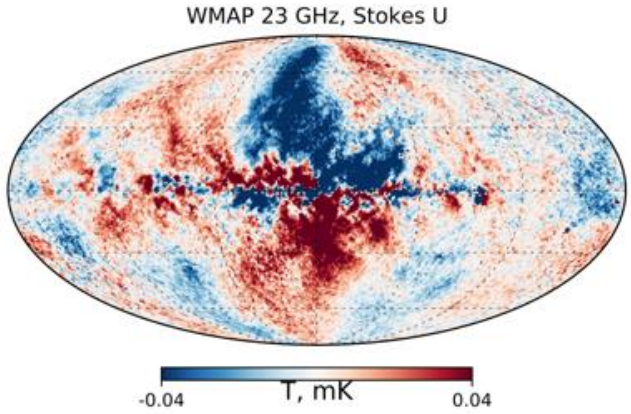


Synchrotron radiation

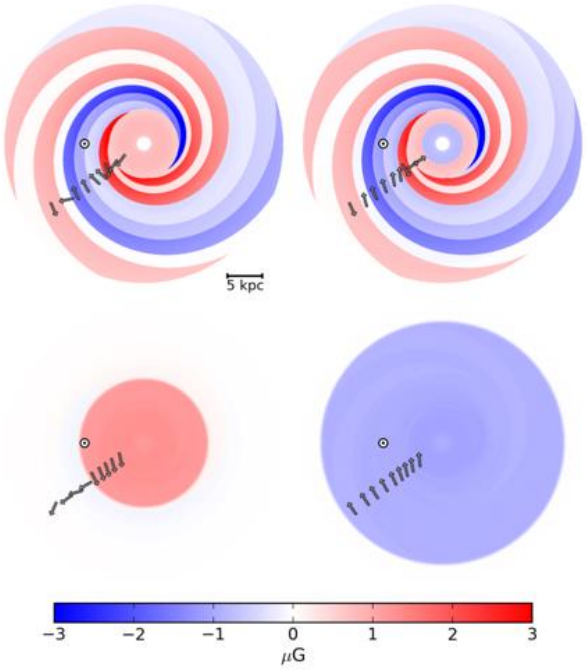
$$n_{\rm cre}(E) = n_0 E^{-p}$$

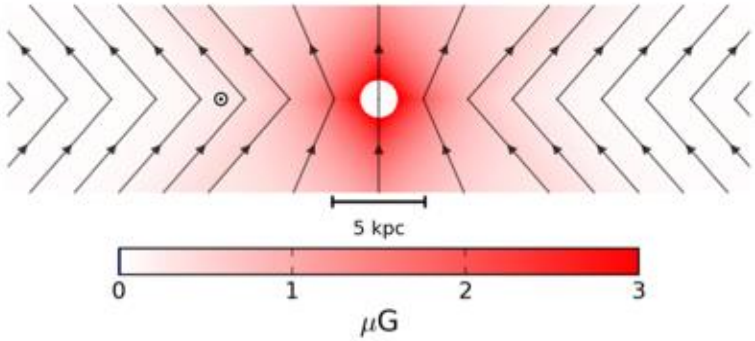
$$j_\nu \propto n_0 \nu^{\frac{-(p-1)}{2}} B_\perp^{\frac{p+1}{2}} \overset{p=3}{=} n_0 \nu^{-1} B_\perp^2$$





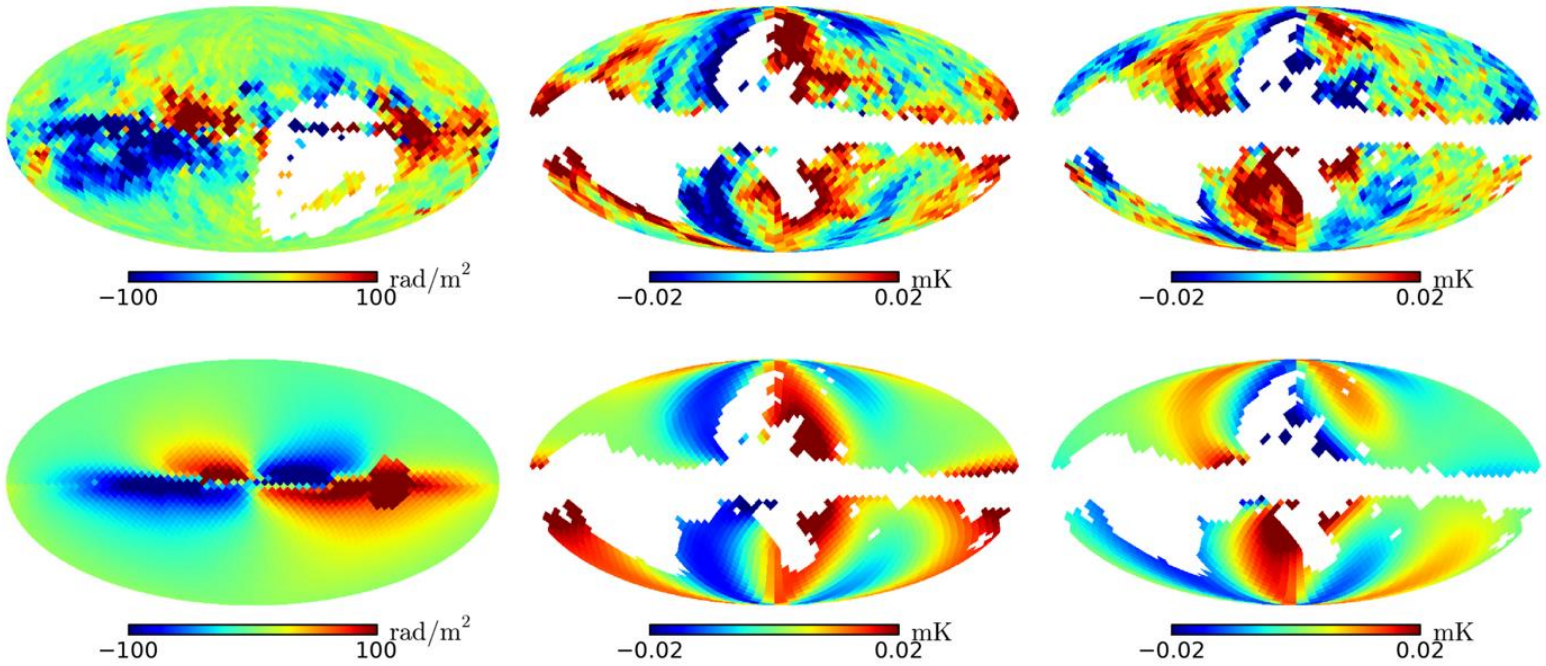
Jansson-Farrar 2012 model



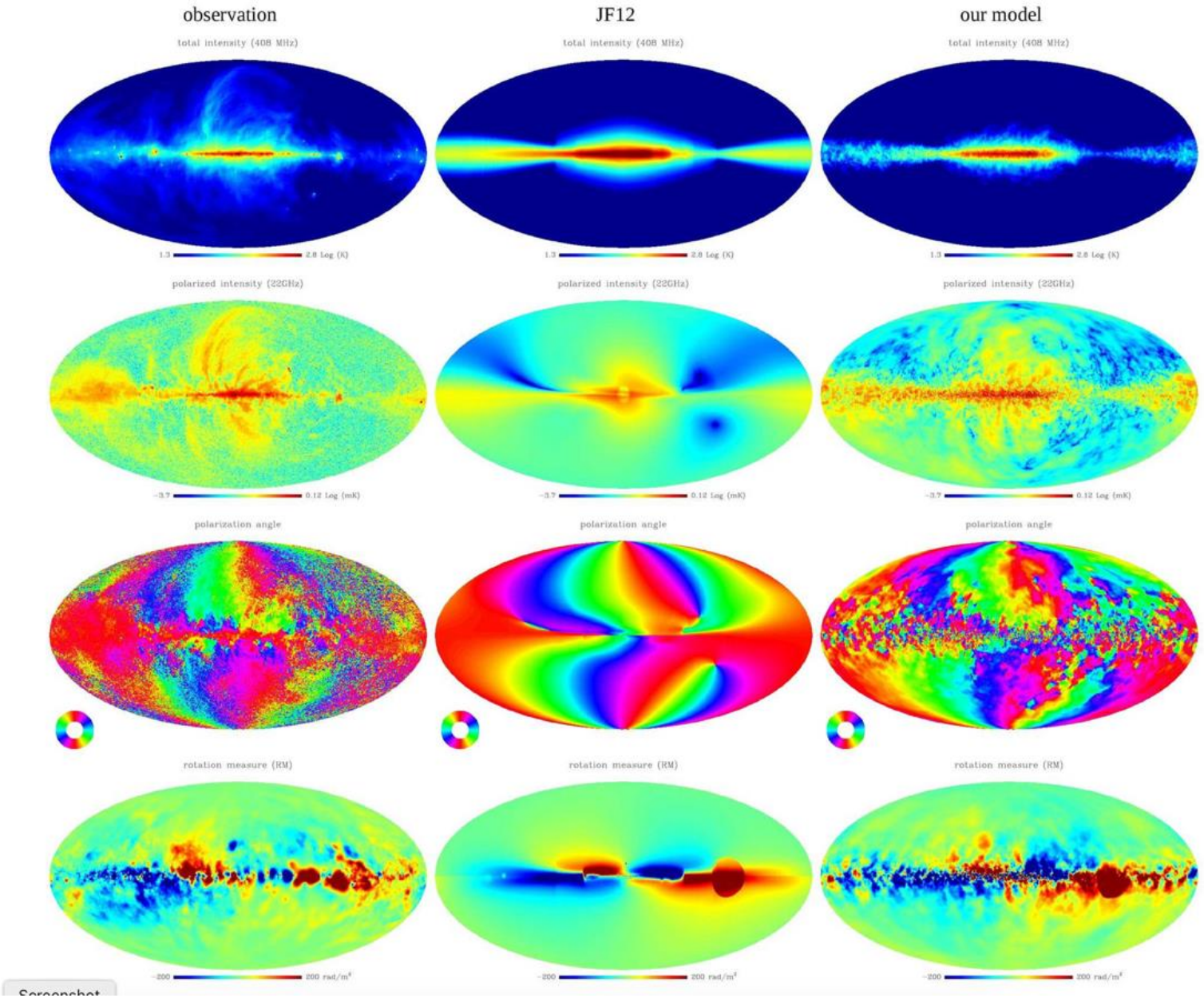


Jansson and Farrar, 1204.3662

Jansson-Farrar 2012 model

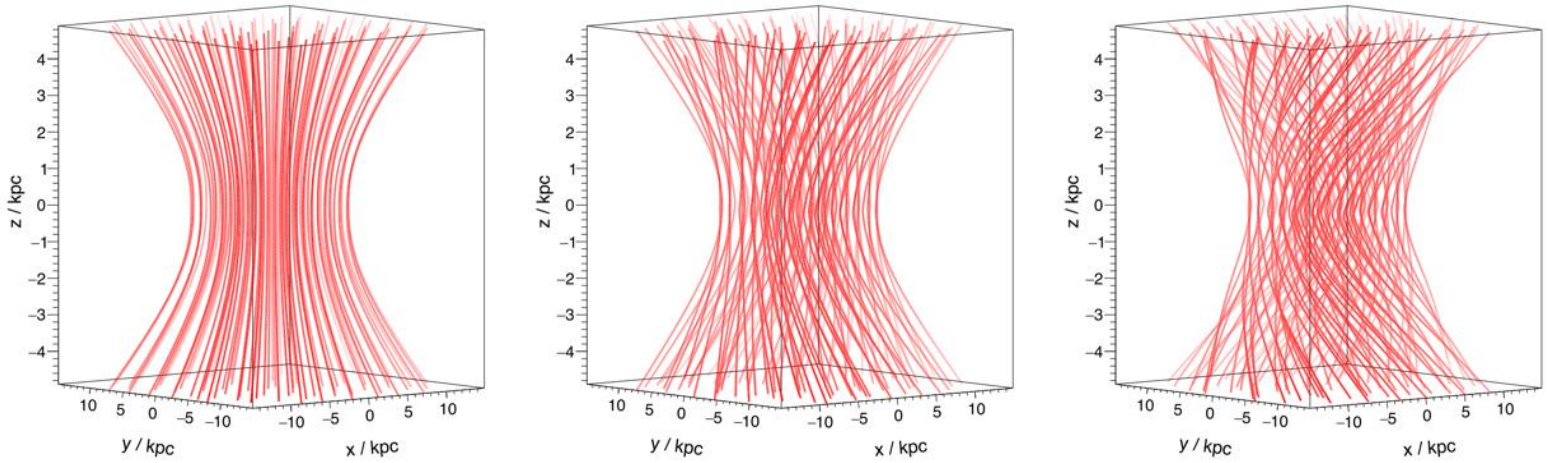


But striated field needed to fit model



Beck et al, 1409.5120

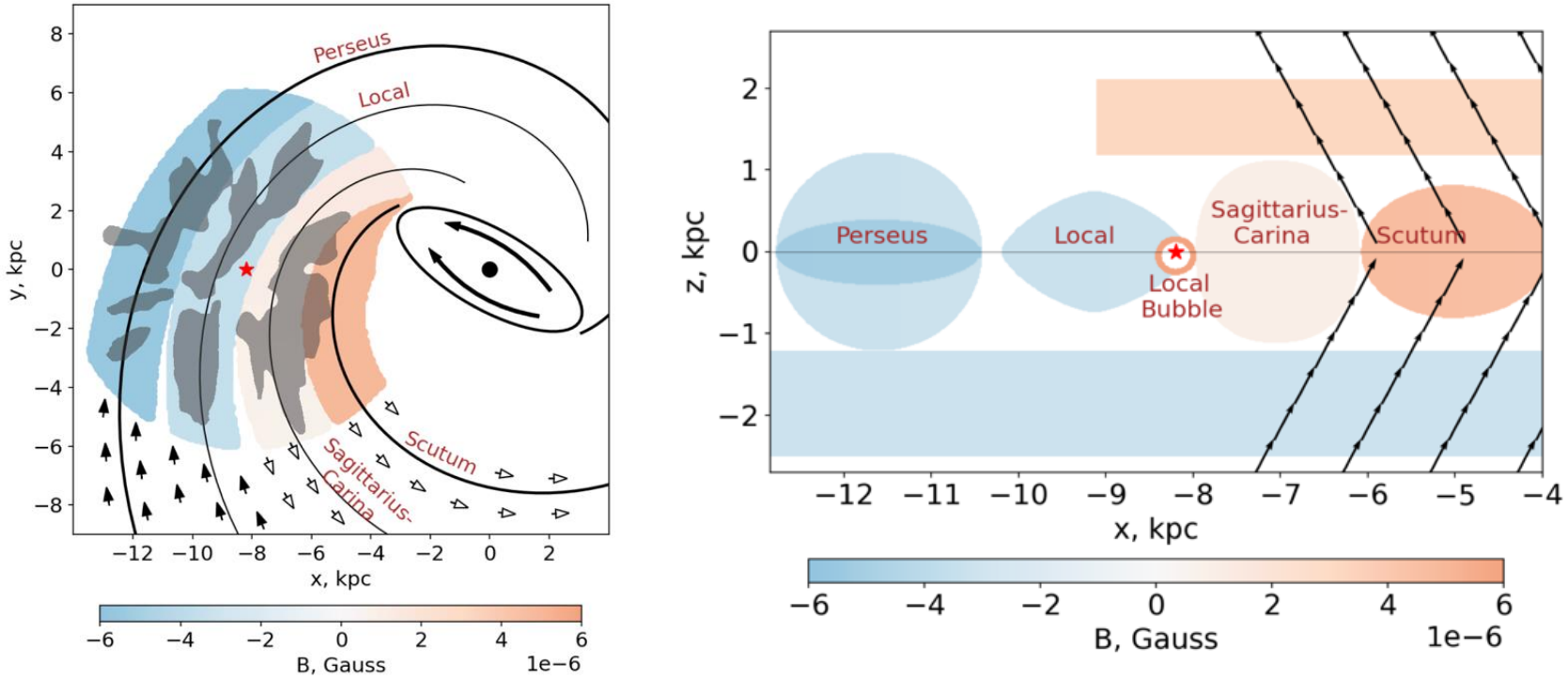
Dynamical halo model



a: $t = 0$ Myr b: $t = 25$ Myr c: $t = 50$ Myr

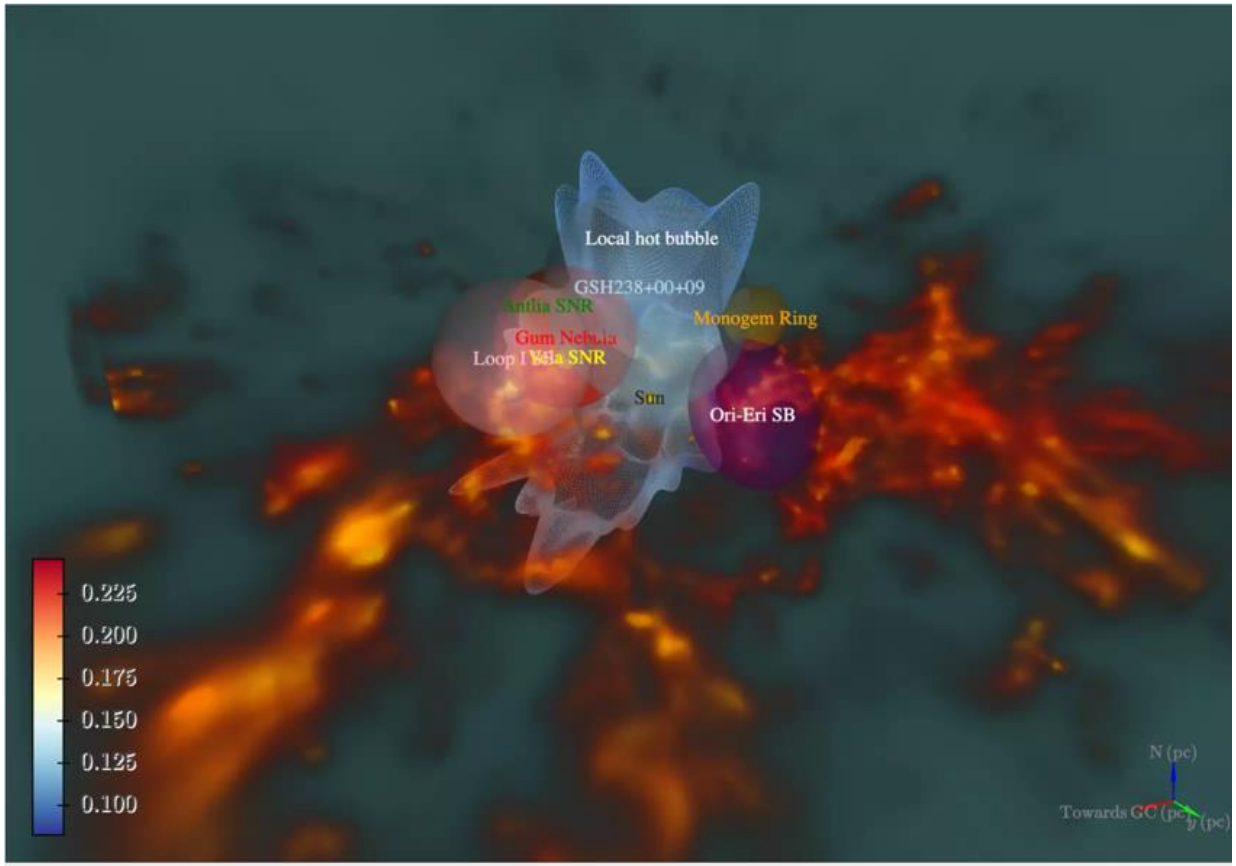
M.Under and G.Farrar 2311.12120

New model 2024



A.Korochkin, D.S. and P.Tinyakov, 2407.02148

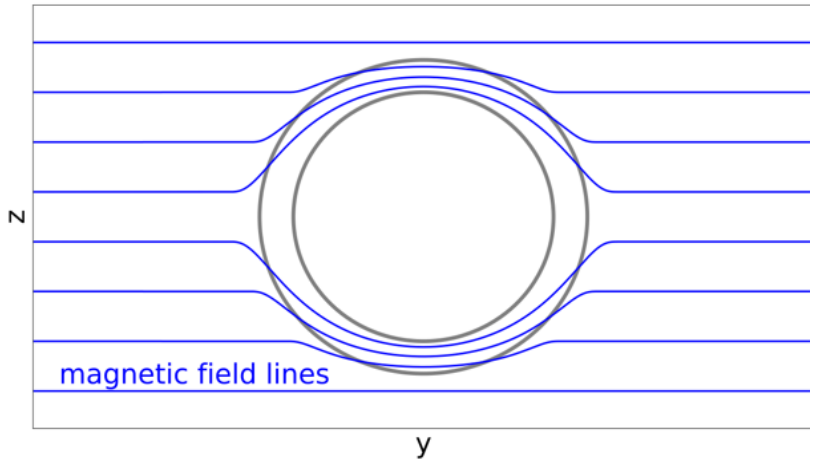
Local Bubble

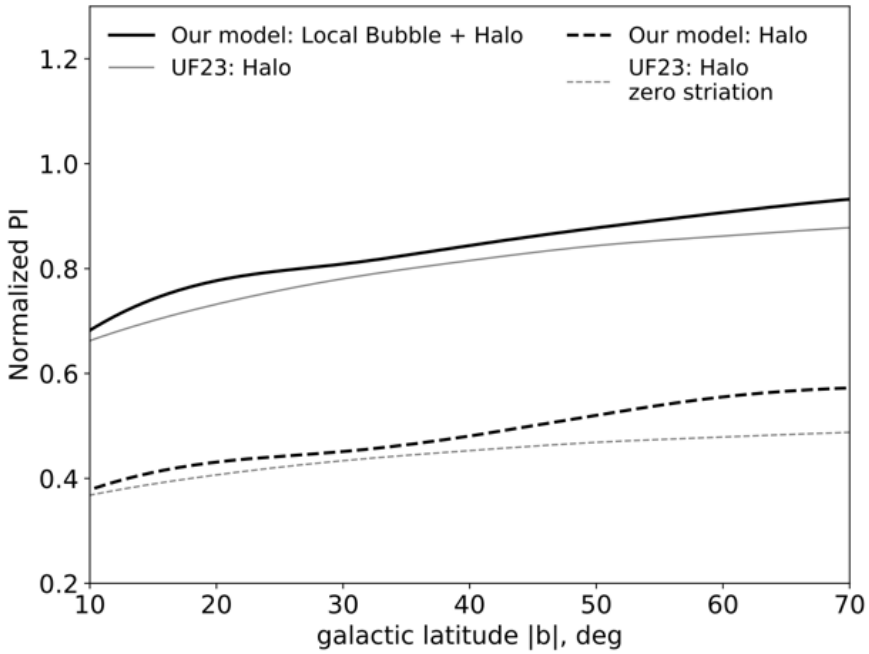


3D model of the solar neighbourhood. The colour bar represents the temperature of the LHB as coloured on the LHB surface. The direction of the Galactic Centre (GC) and Galactic North (N) is shown in the bottom right. The link to the interactive version can be found at the bottom of the page.

[less]

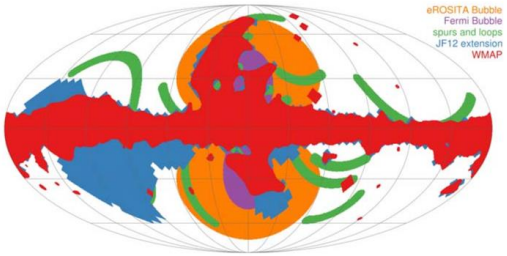
Local Bubble solved discrepansy between RM and synchrotron



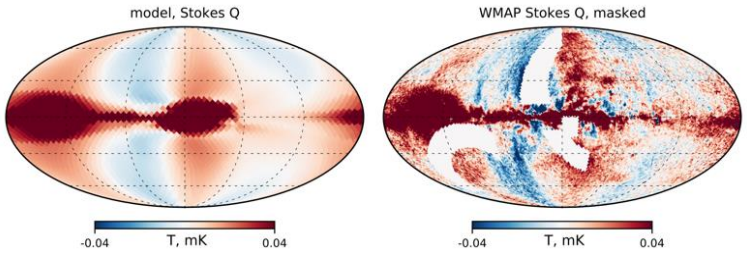


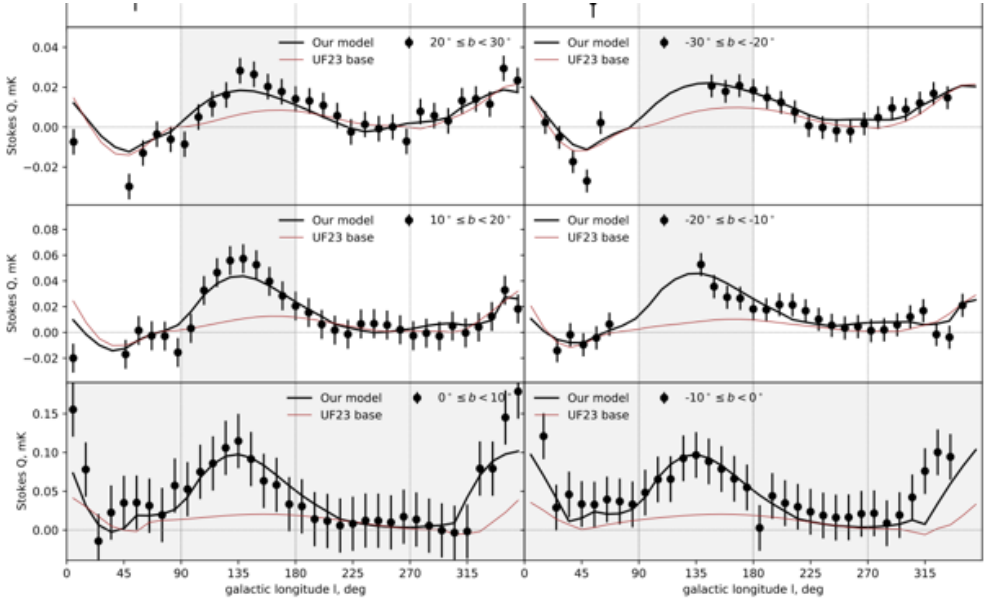
A.Korochkin, D.S. and P.Tinyakov, 2407.02148

FAN REGION



UF 2023



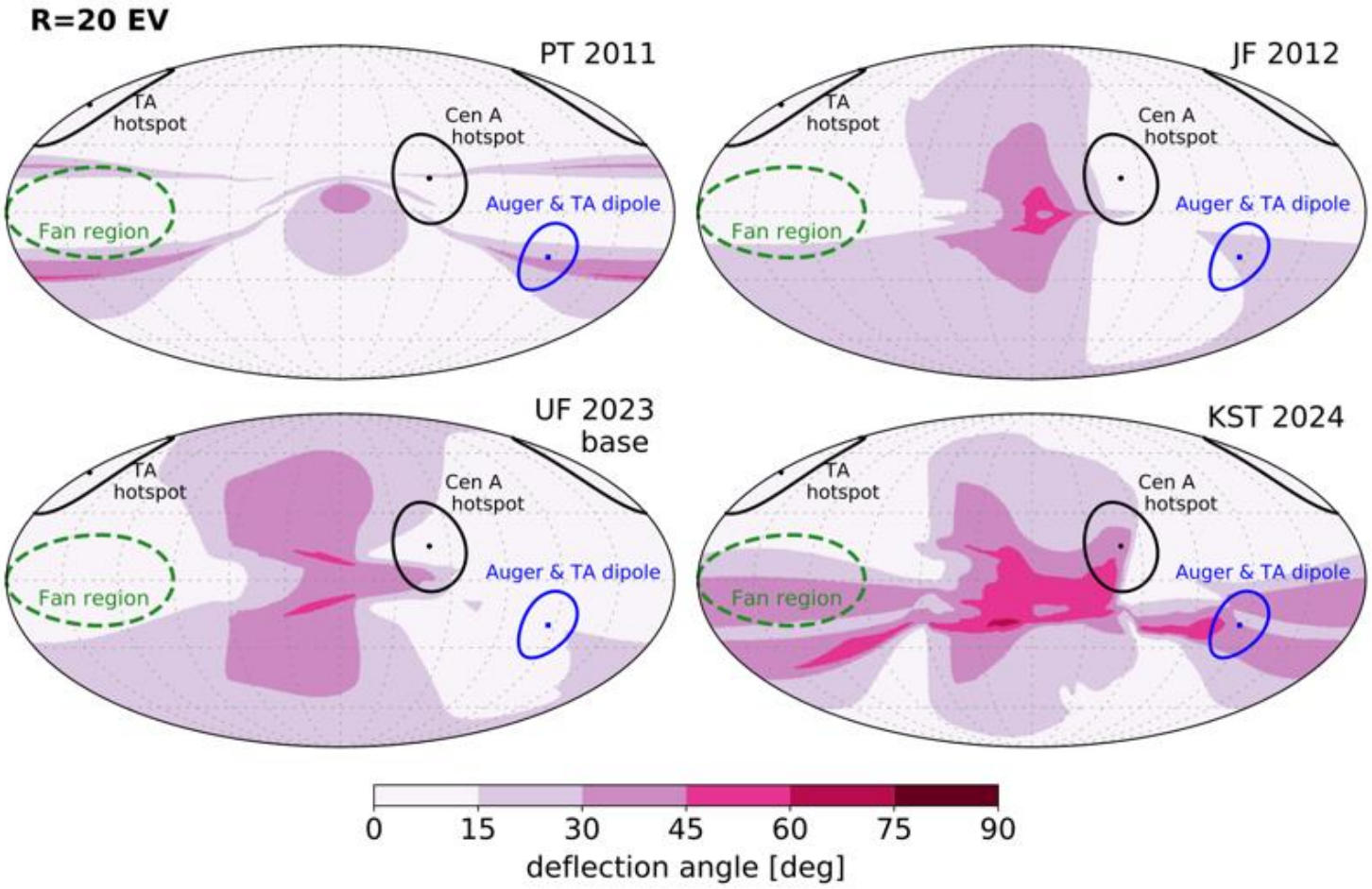


For the first time self-consistent in this region: electrons are in same GMF model of arms with DRAGON code

A.Korochkin, D.S. and P.Tinyakov, 2407.02148

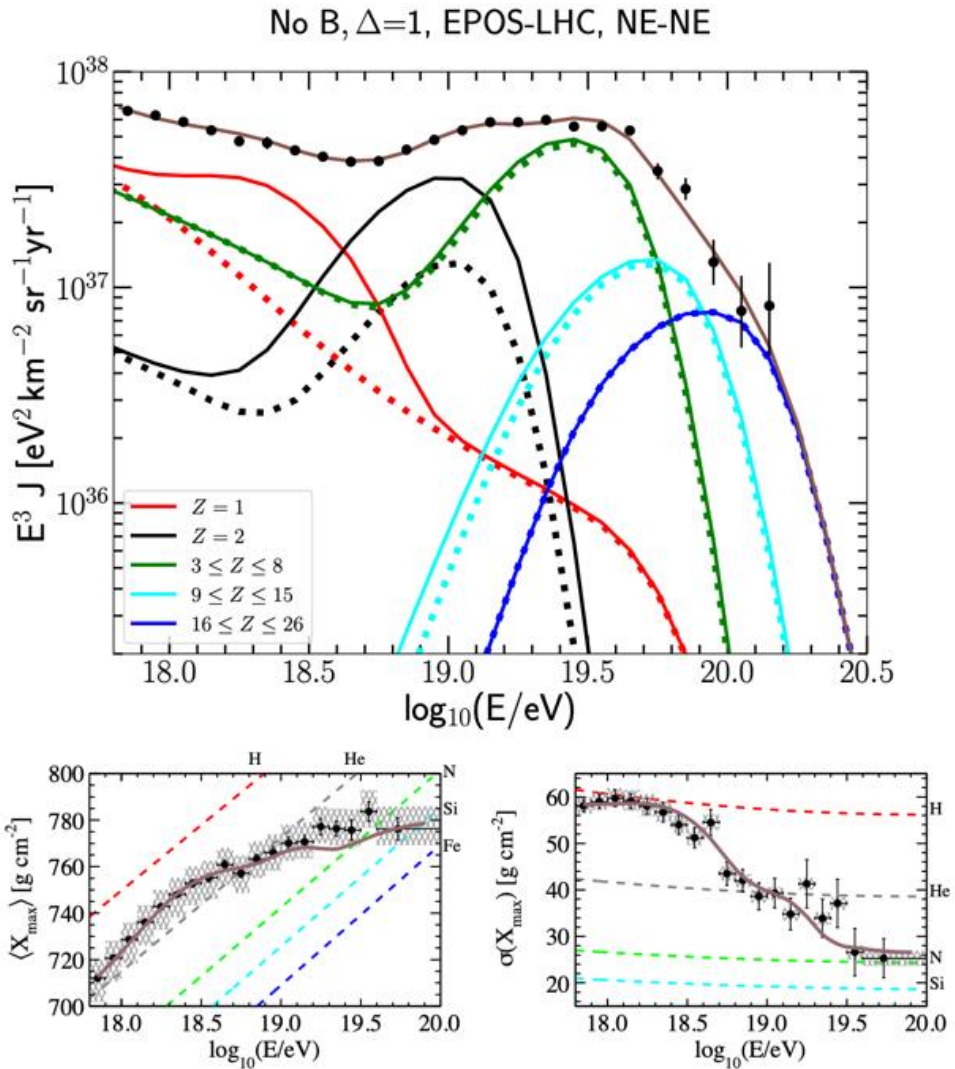
UHECR propagation

UHECR R=20 EV



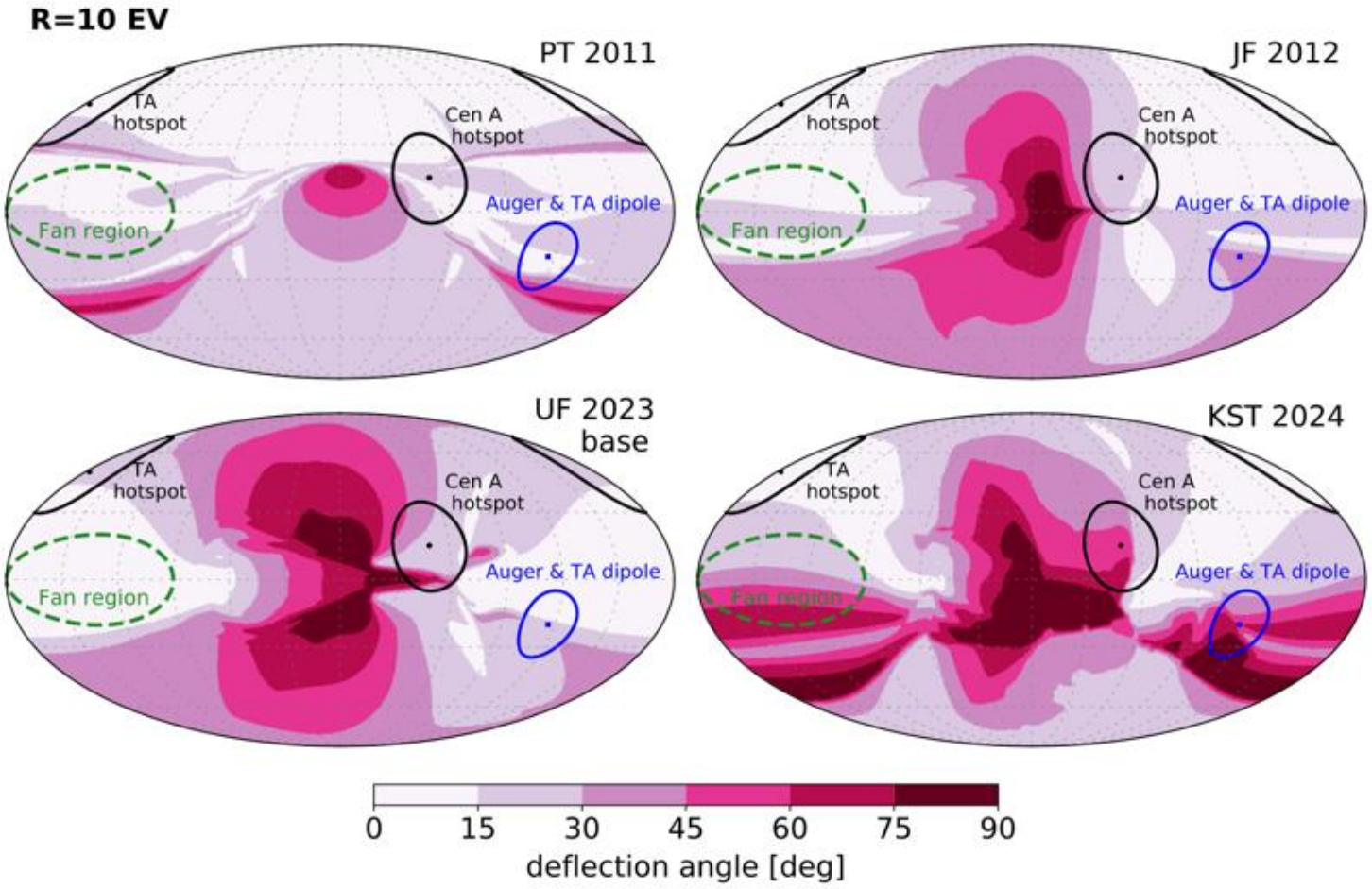
A. Korochkin, D.S. and P.Tinyakov 2501.16158

Auger spectrum and composition



Pierre Auger Collaboration, 2404.03533

UHECR R=10 EV



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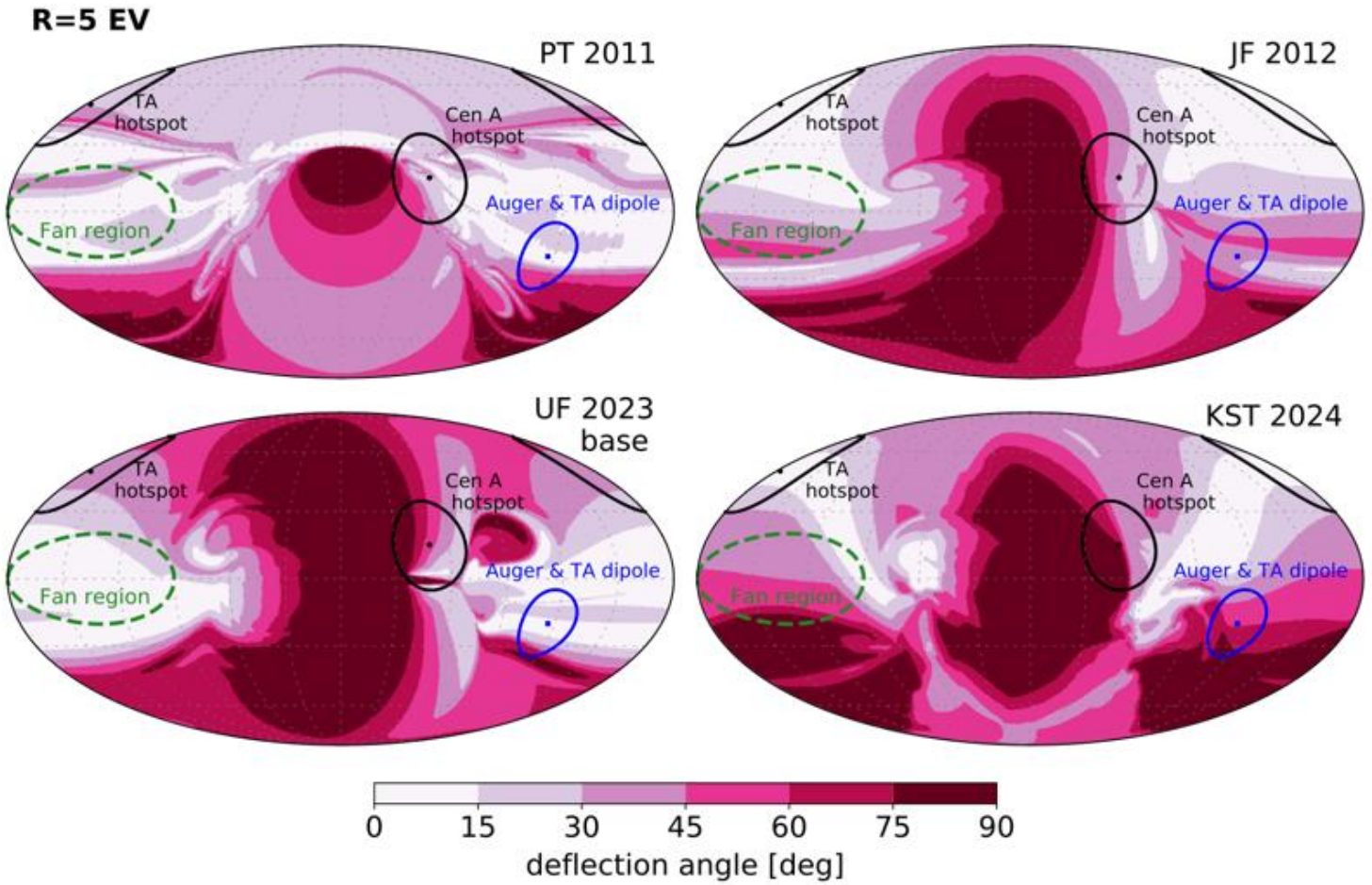
UHECR R=5 EV



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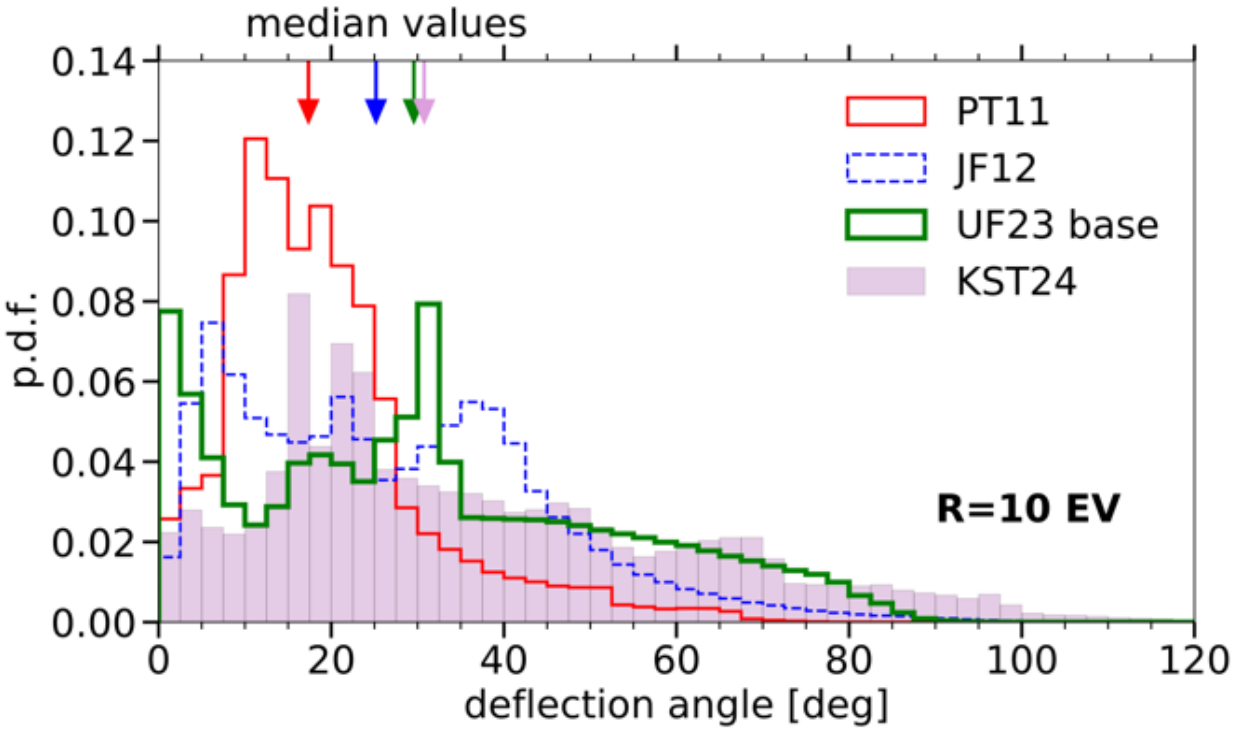
UHECR deflections R=10 EV



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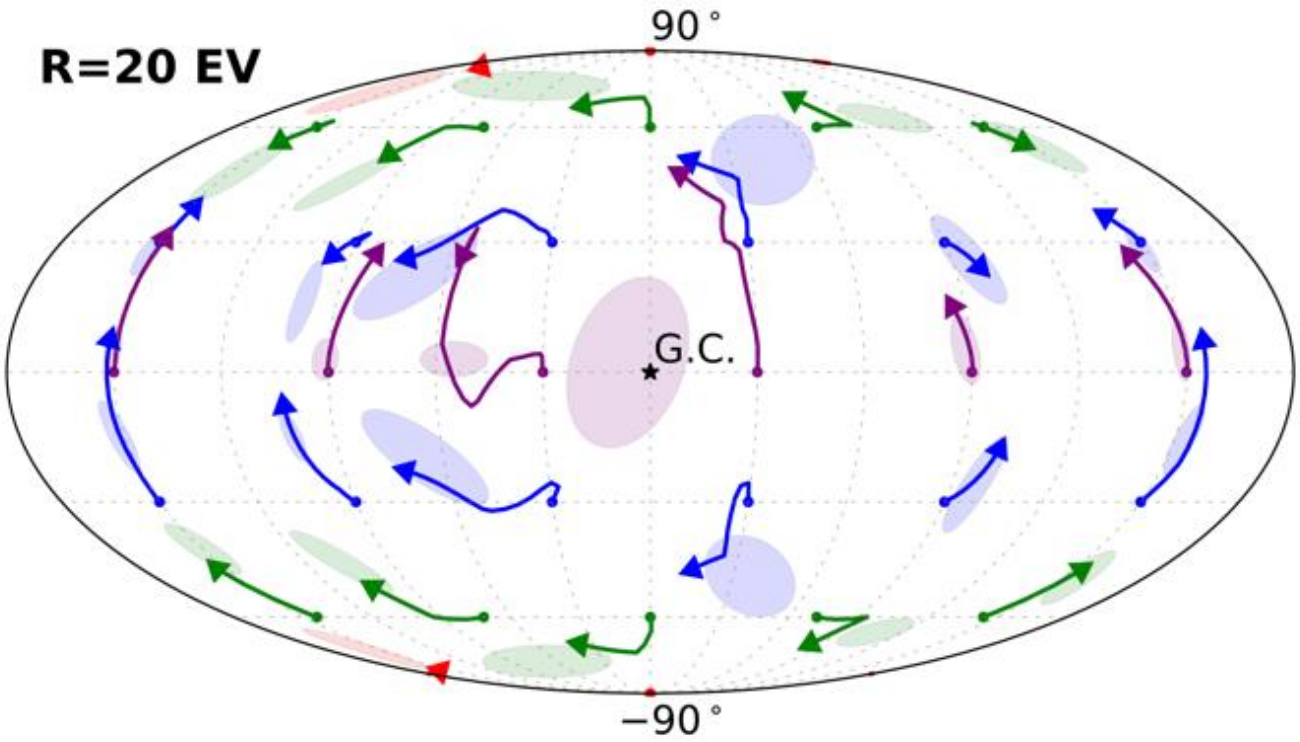
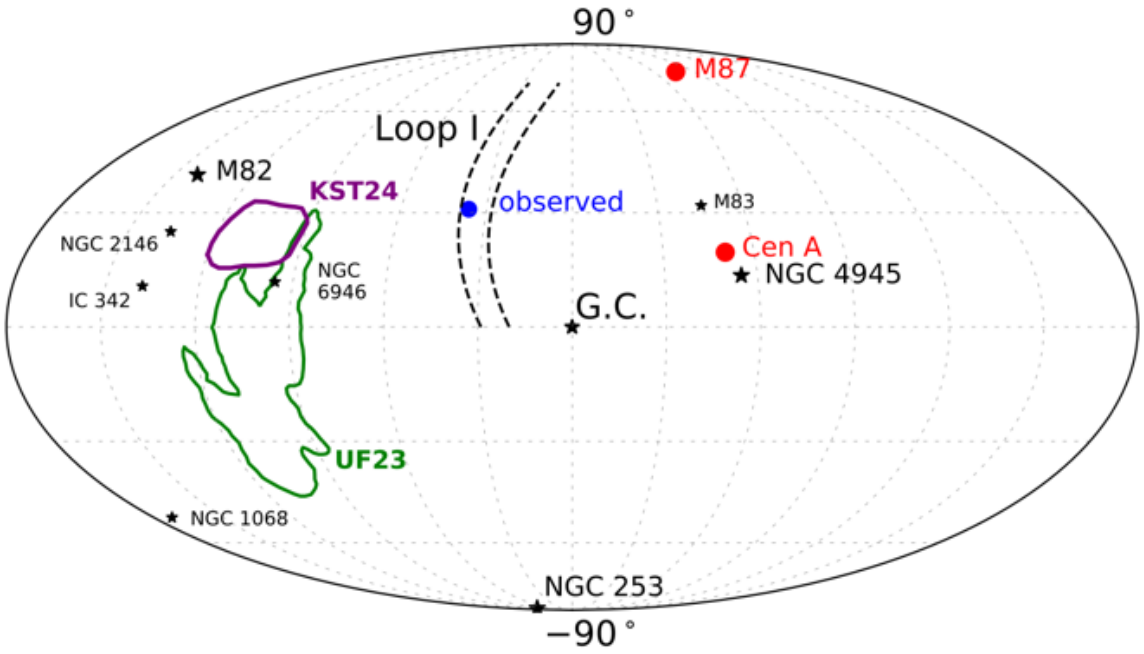
GMF UHECR deflection model-variartition



A. Korochkin, D.S. and P.Tinyakov 2501.16158

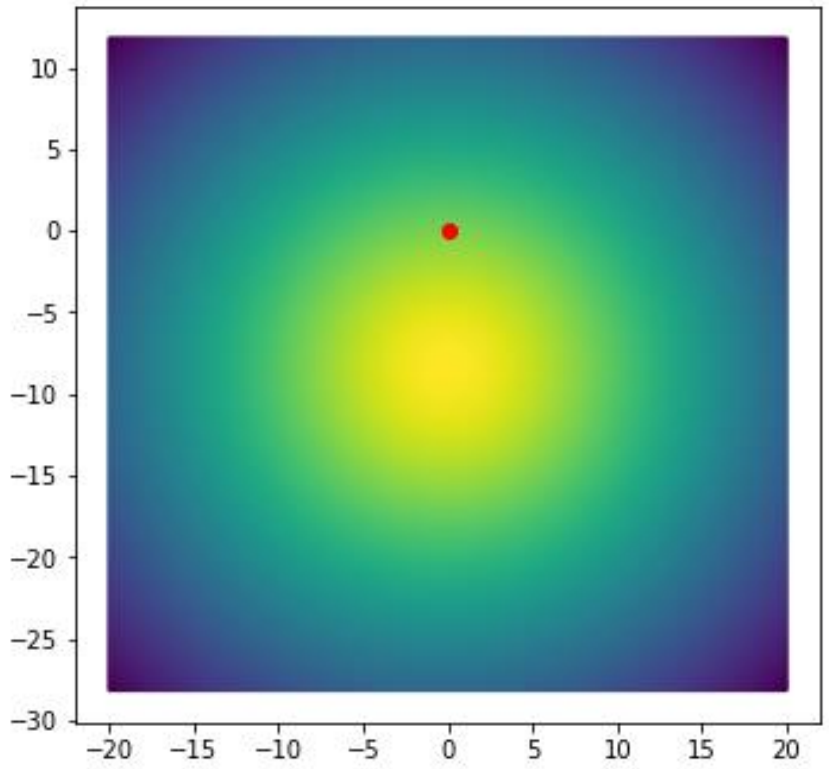
Amaterasu particle E=220 EeV for Fe or R=8 EV

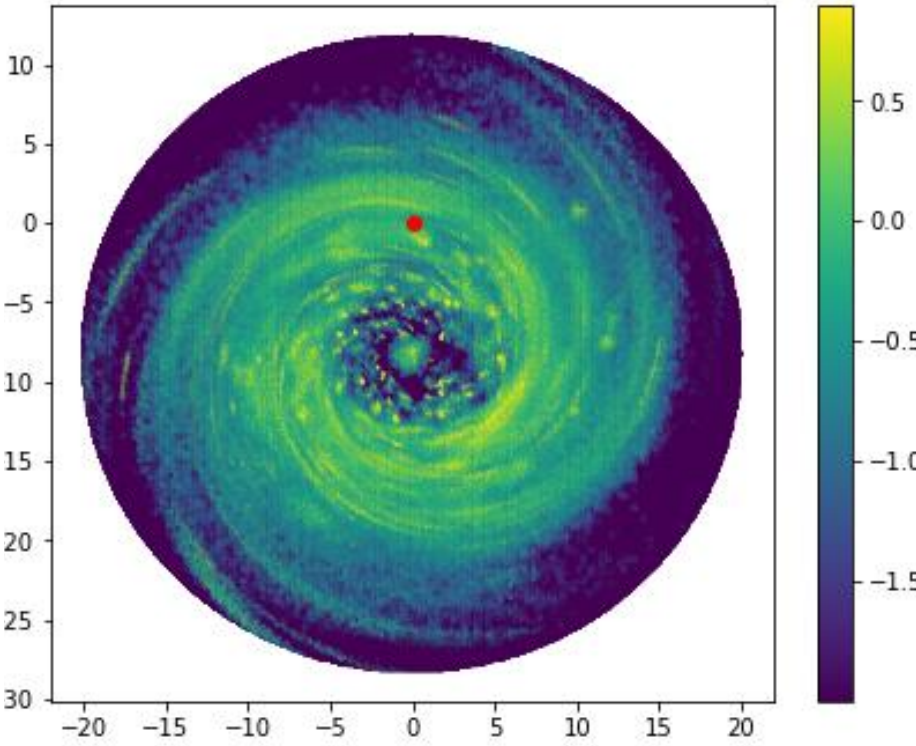


A. Korochkin, D.S. and P.Tinyakov 2501.16158

LHAASO sources and GMF

1 PeV CR density in the Gal. plane

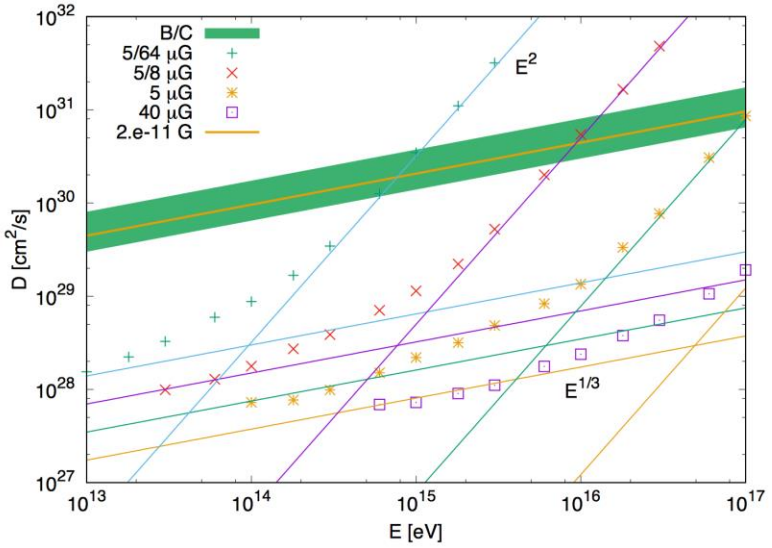


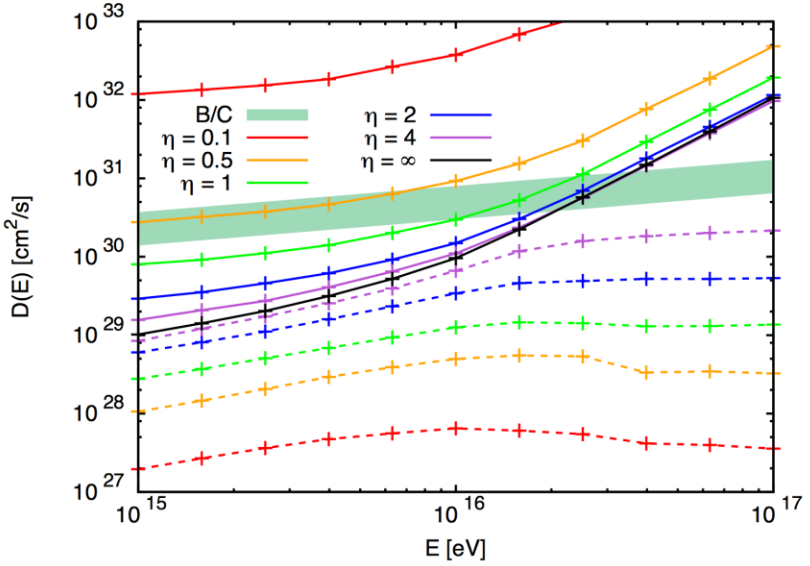


P. Lipari & S.Vernetto
1804.10114

G.Giacinti & D.S., 2305.10251

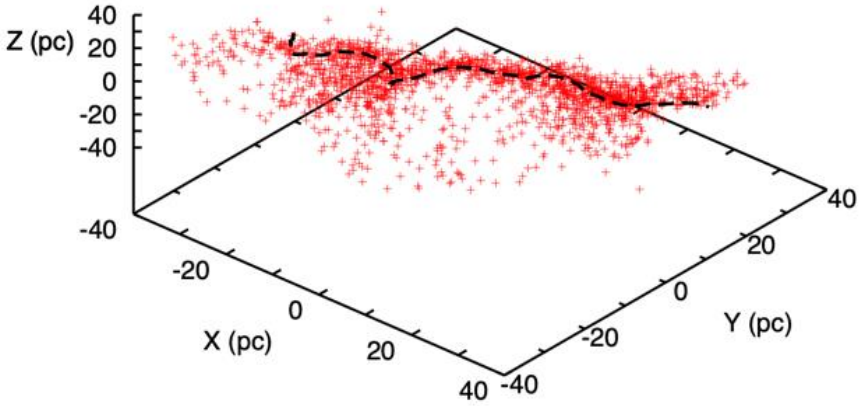
Regular and turbulent diffusion



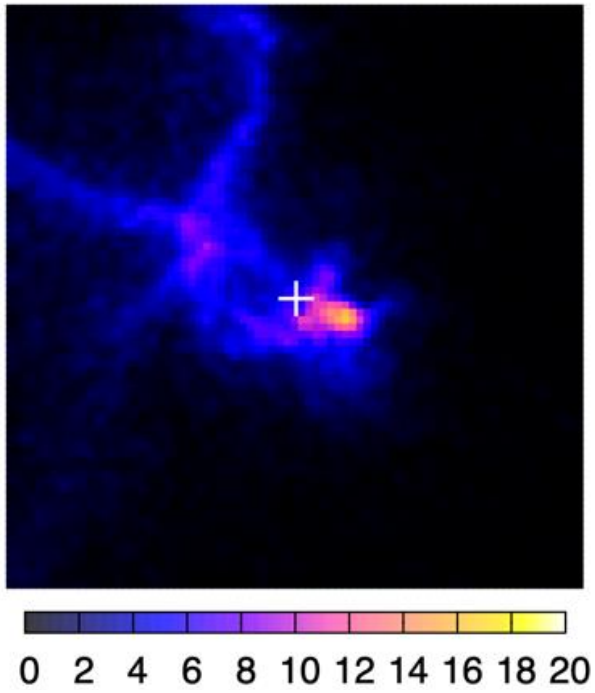


Giacinti et al, 1710.08205

Anisotropic sources from anisotropic propagation in GMF



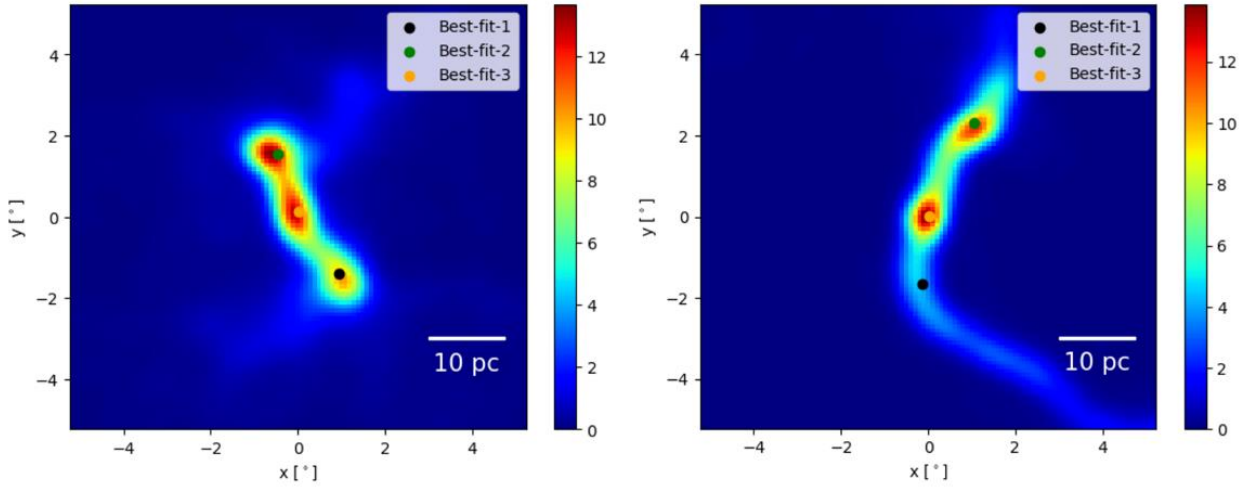
PeV cosmic rays



Gamma-rays from PeV CR

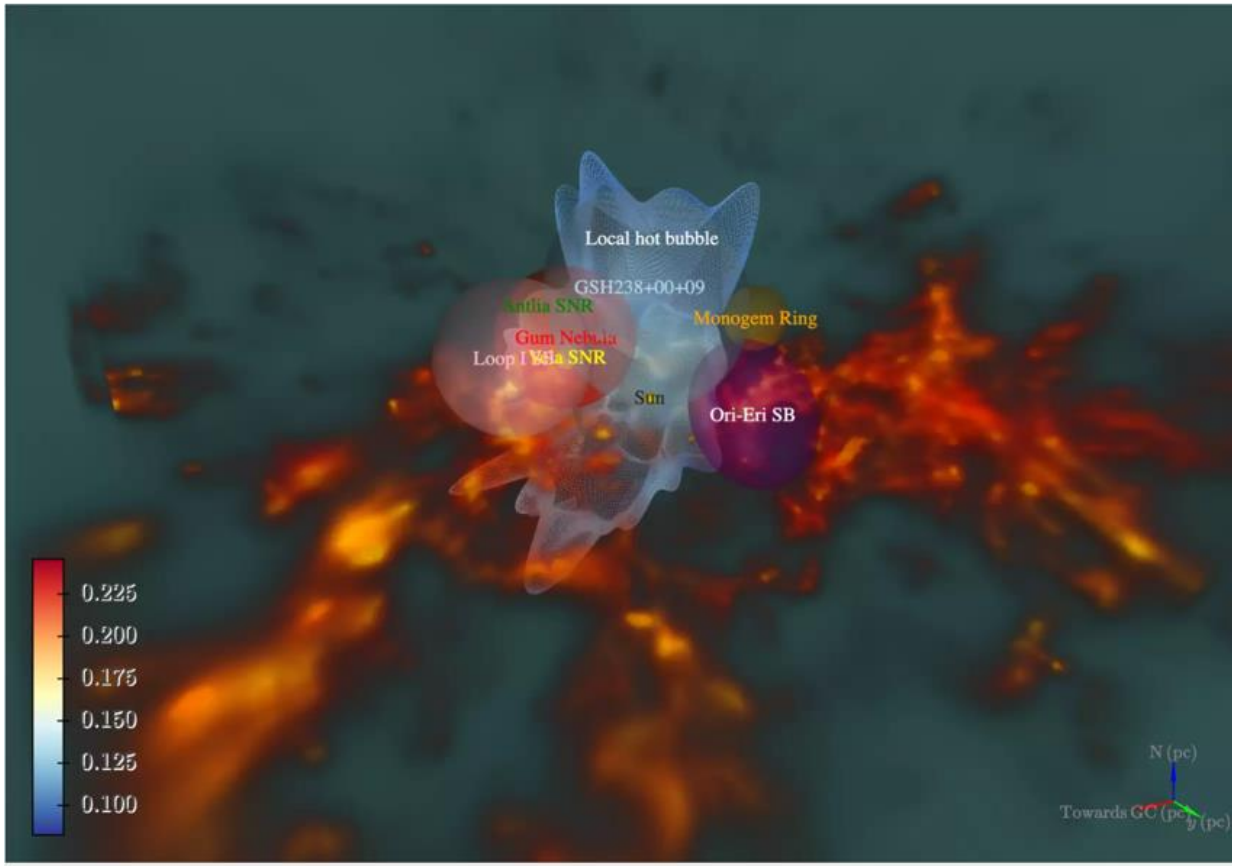
G.Giacinti, M.Kachelriss and D.S. 1306.3209

Anisotropic CR propagation: mirage sources



Yiwei Bao, Gwenael Giacinti, Ruo-Yu Liu, Hai-Ming Zhang, and Yang Chen
2407.02478 and 2407.02829

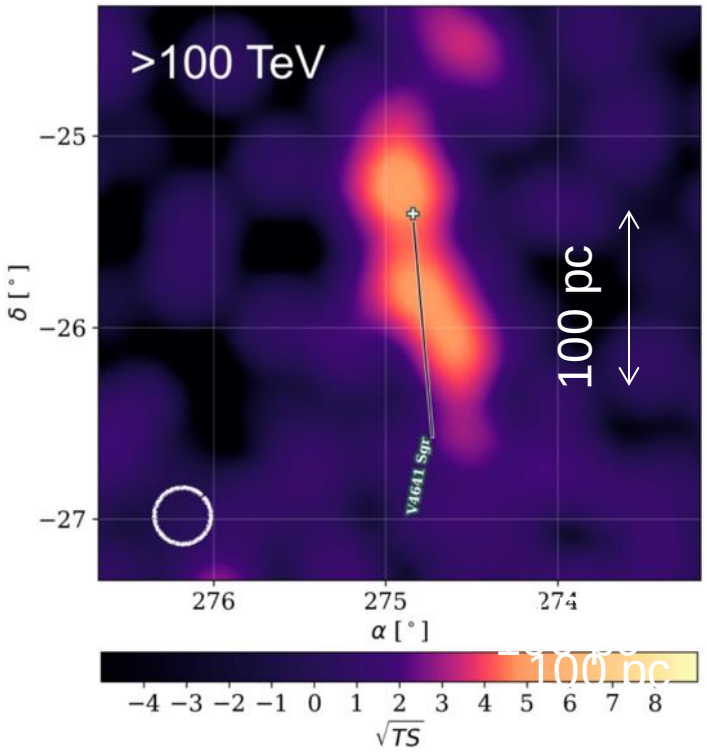
Difficult to observe in disk

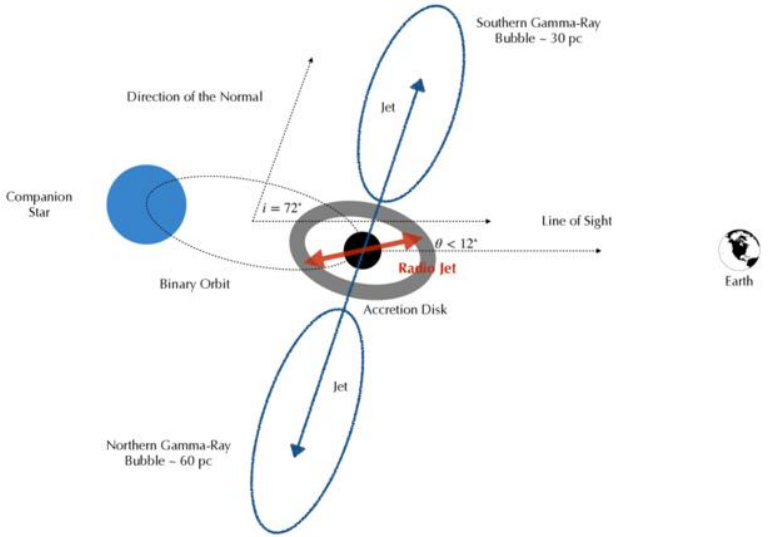


3D model of the solar neighbourhood. The colour bar represents the temperature of the LHB as coloured on the LHB surface. The direction of the Galactic Centre (GC) and Galactic North (N) is shown in the bottom right. The link to the interactive version can be found at the bottom of the page.

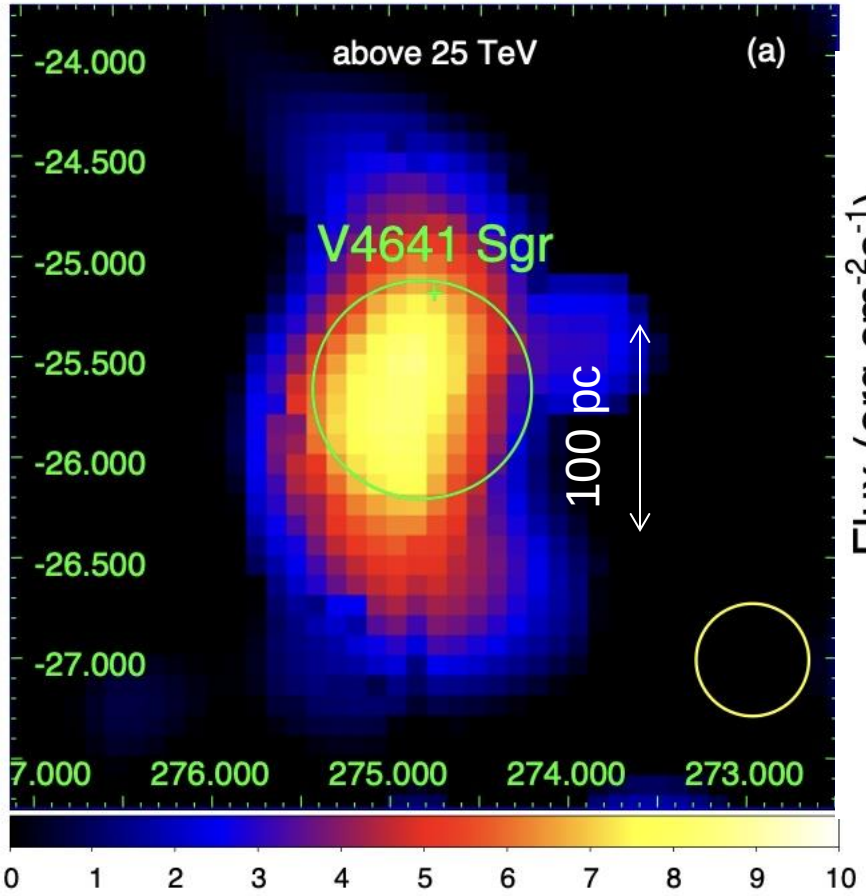
[less]

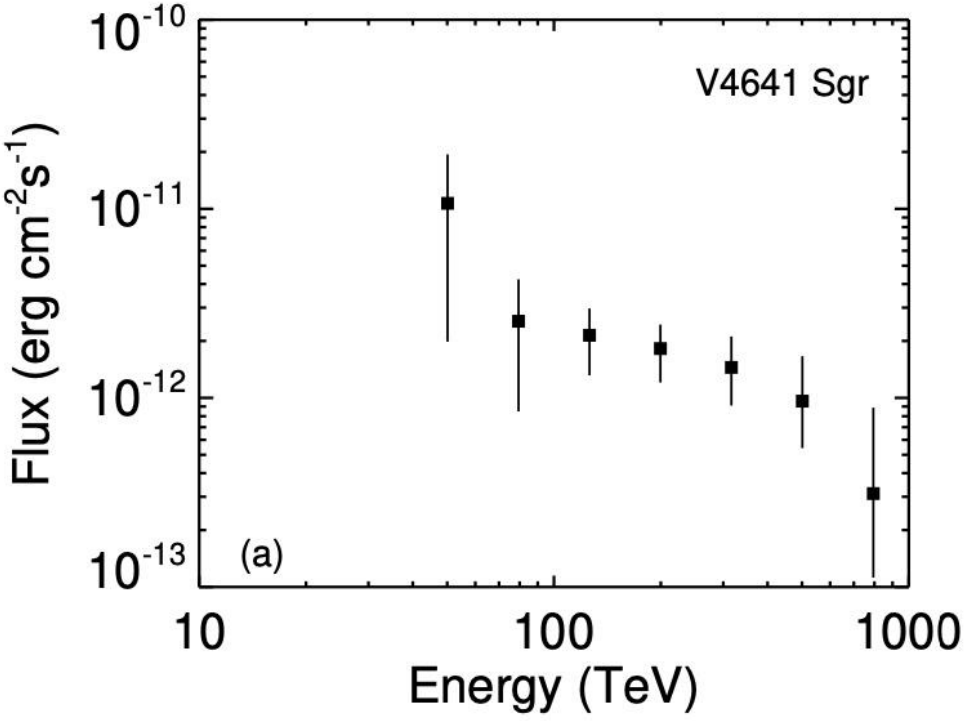
V4641 Sgr HAWC



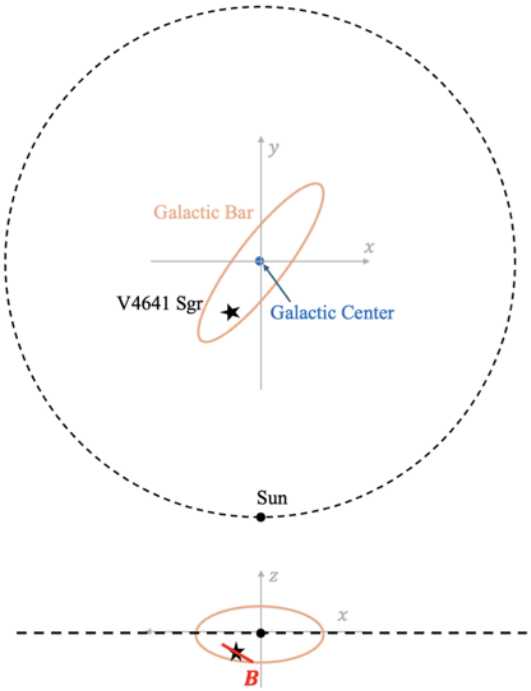


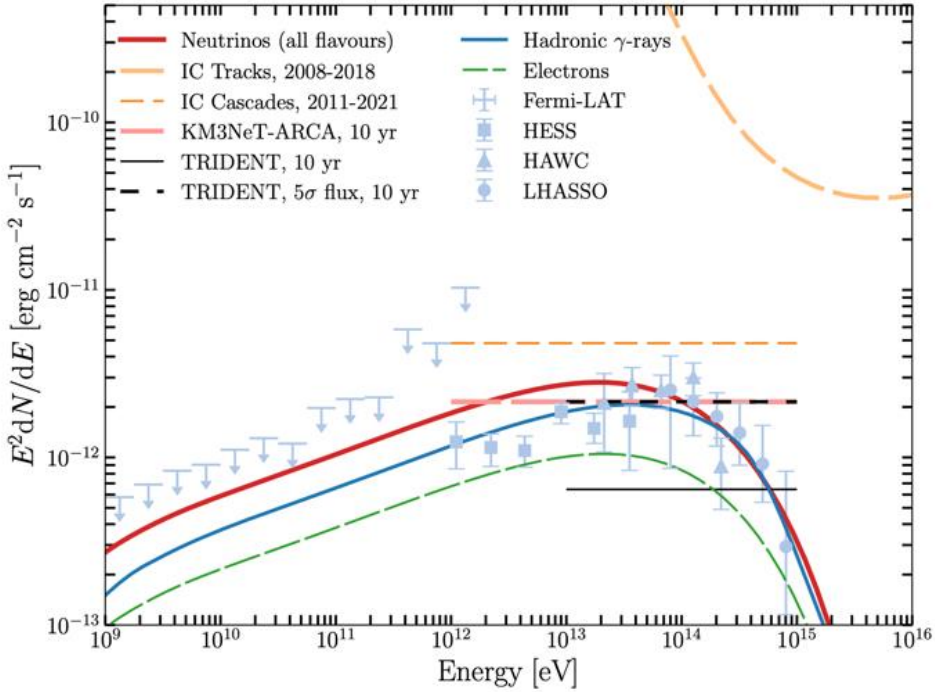
V4641 Sgr LHAASO



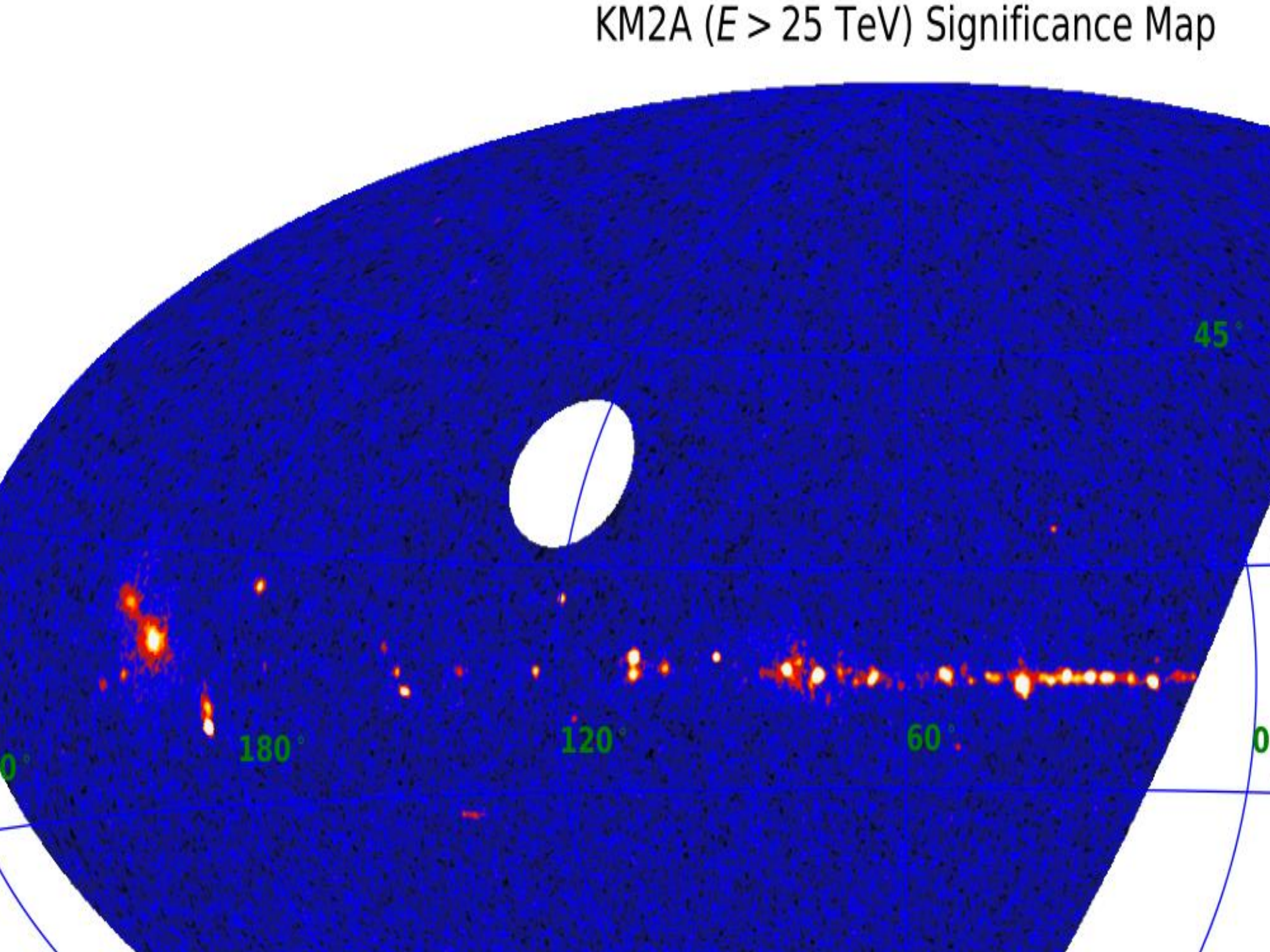


V4641 Sgr model

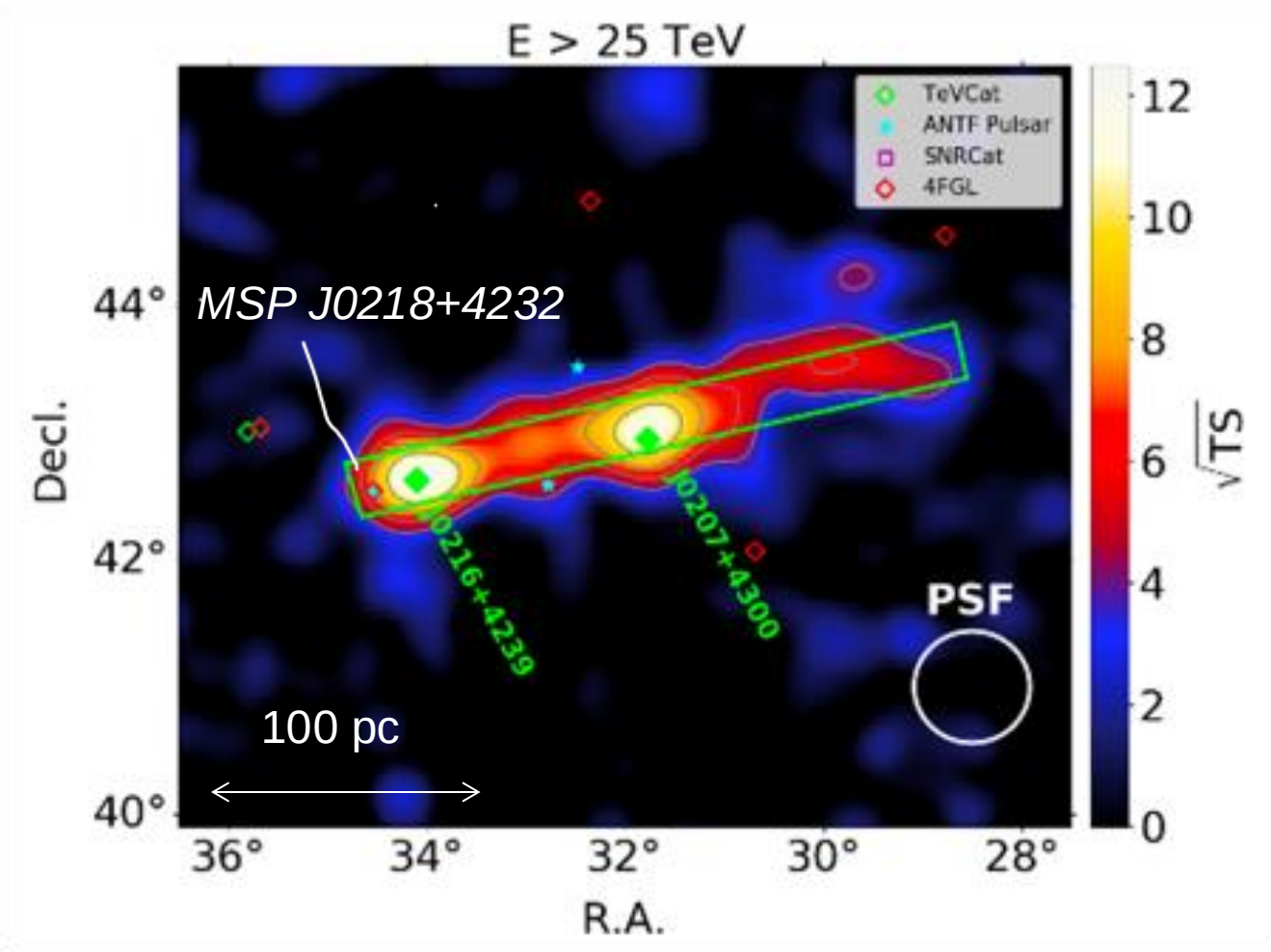




Andrii Neronov, Foteini Oikonomou and D.S.,
arXiv: 2410.17608


KM2A ($E > 25$ TeV) Significance Map
45°
180°
120°
60°
0°
0

MSP J0218+4232



Zhe Lee's talk tomorrow for details

Summary

- *Large scale structure of GMF constraint by rotation measures and synchrotron data, but uncertain due to systematics in electron models*
- *GMF model is updated, but need more work on electron models and field in the disk*
- *UHECR deflections are strongly GMF-dependent*
- *LHAASO sources will give us independent information of GMF*