“X-riStMAs” under PNRR from MUIR funded by NextGenerationEU
(**X-r**ay **i**n **St**udying the **M**ultiphase **As**trophysics)

Non-thermal radiation due to cosmic ray transport in **the magnetic halo of the Milky Way**

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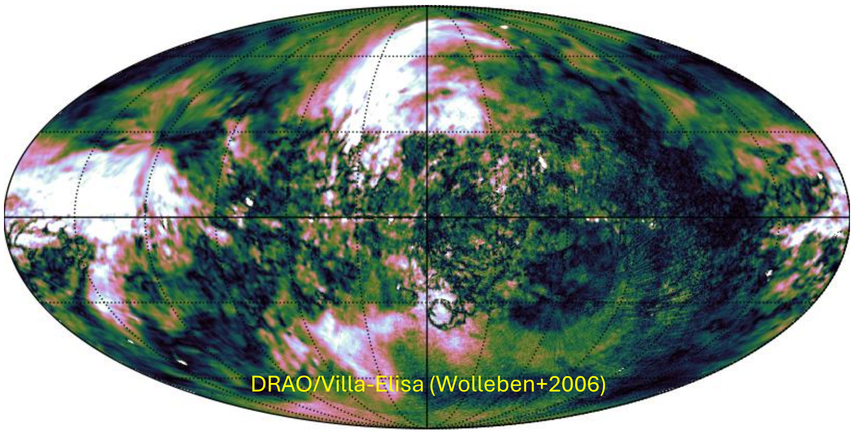
Based on **Zhang et al 2024,** ArXiv: 2408.06312

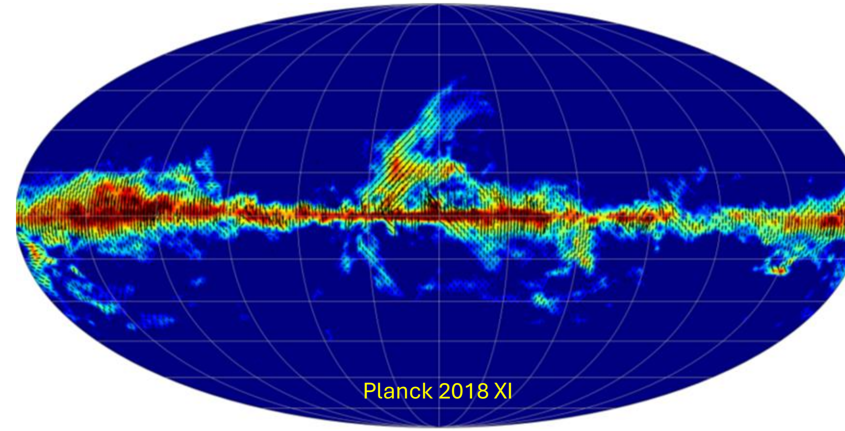
γ 2024
8th Heidelberg International Symposium on
High Energy Gamma Ray Astronomy
Milano, 2-6 September 2024

1. Large scale structures

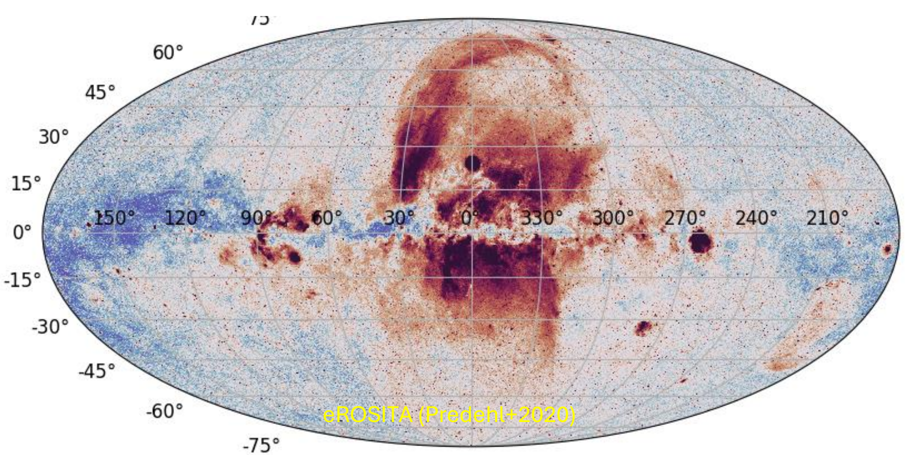
Radio sky (1.4GHz)



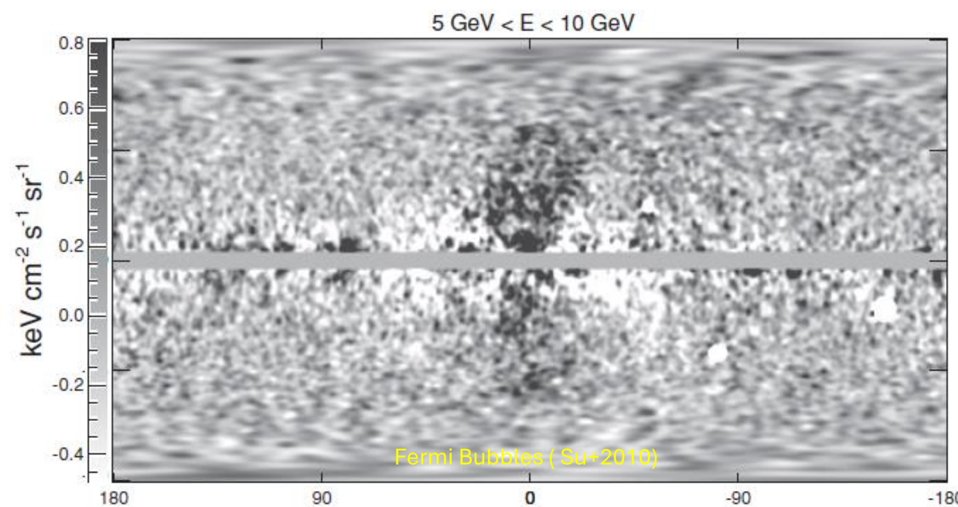
Dust sky (353 GHz)



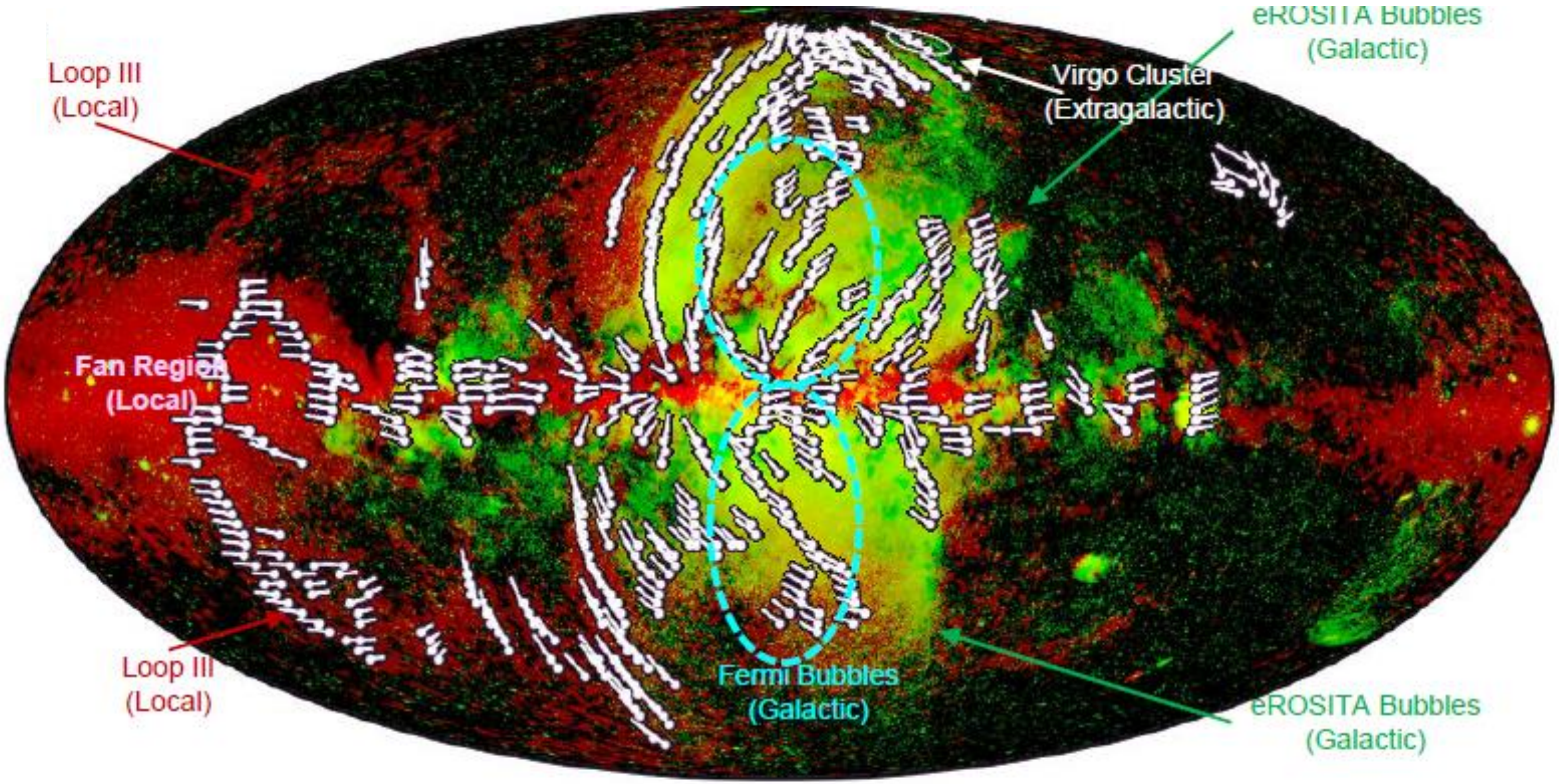
X-ray sky (eROSITA Bubbles, 0.6-1.0 keV)



gamma-ray sky (Fermi Bubbles)



2. The Magnetic ridges vs the eROSITA Bubbles



Zhang et al 2024 ArXiv: **2408.06312**

White bars: magnetic field (23 GHz)
Green: 0.6-1.0 keV X-ray

Within Local Spiral Arm, or beyond the Galactic Disc?

3. Question: Local or Galactic?

A gigantic structure observed in the sky could be either within the Local Bubble in a few tens of pcs, or Galactic structure (several kpcs).

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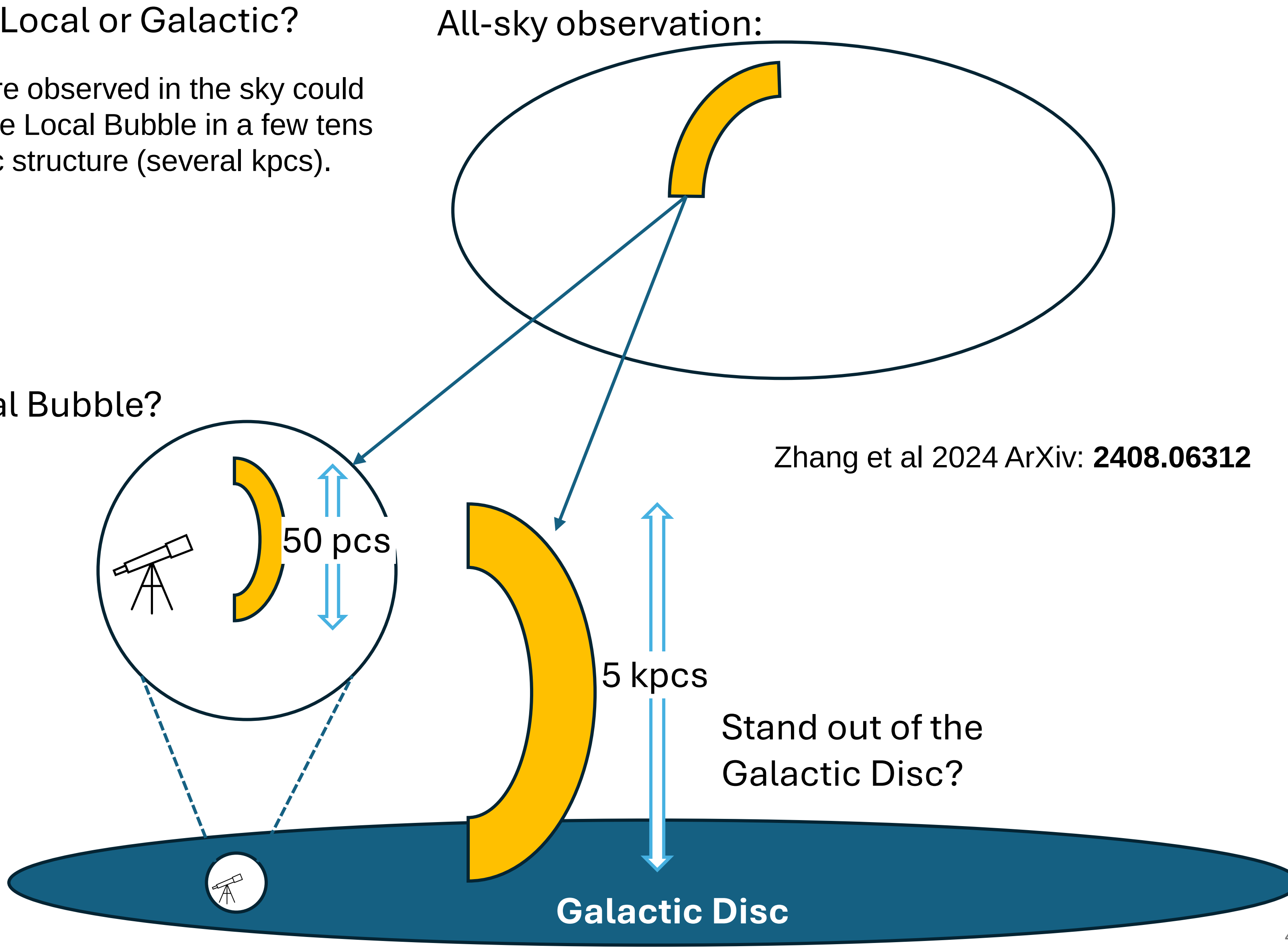
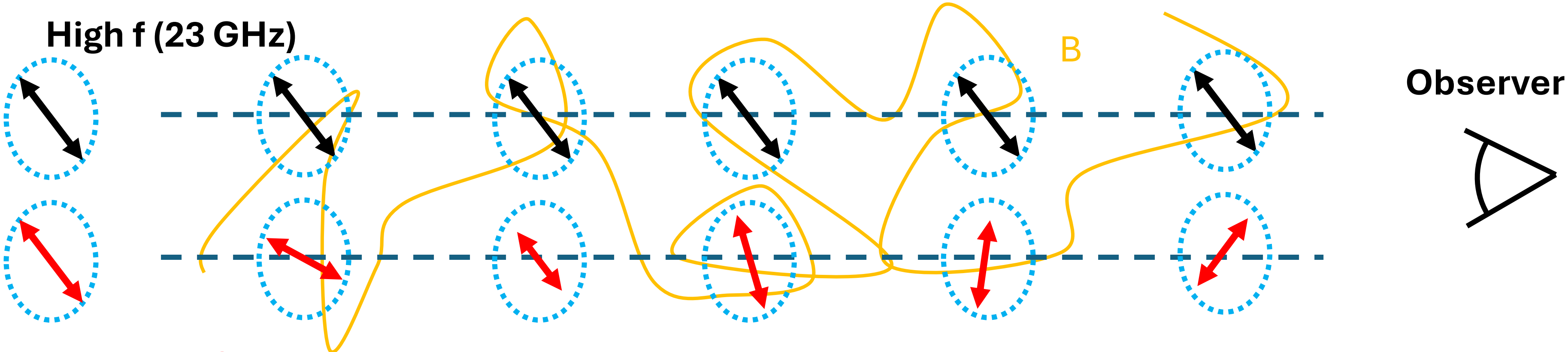


3. Question: Local or Galactic?

Faraday Rotation Depolarization

Polarized signal from synchrotron will be Faraday rotated, Signals depolarized in turbulent foreground.

High f (23 GHz)



Low f (1.4 GHz)

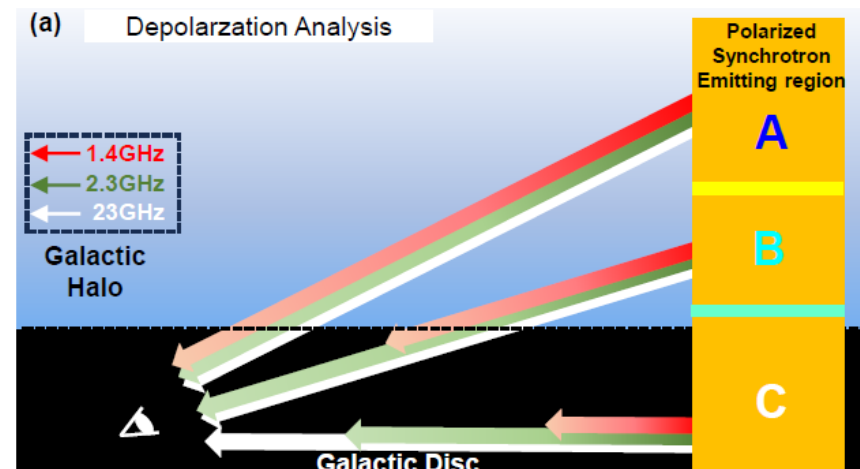
Rotation measure: $\sigma_{RM} = 0.81\,\sigma_{B\|}\, n_e\, d\, N_{\|}^{1/2}$

Dispersion angle: $\Delta\Phi = \sigma_{RM}\lambda^2$

The Galactic Disc will **imprint on the synchrotron structure!**

Lower frequency signal
(longer wavelengths)

More disc imprint



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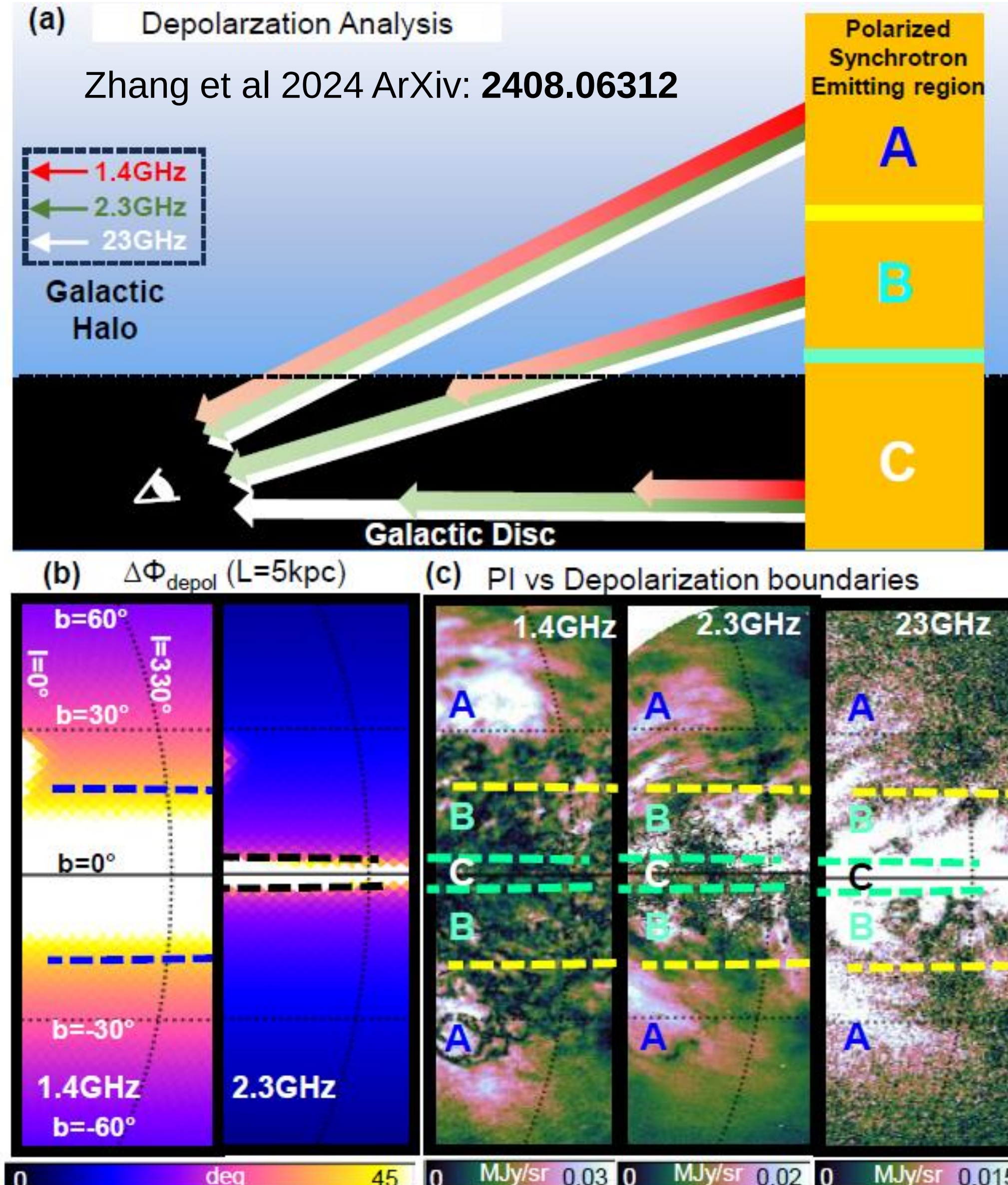
3. Question: Local or Galactic?

Distance measurements with Faraday Rotation Depolarization

Lower frequency signal

More disc imprint

Depolarization screen at 5kpc anti-correlated with the observed polarized synchrotron emission.



3. Question: Local or Galactic?

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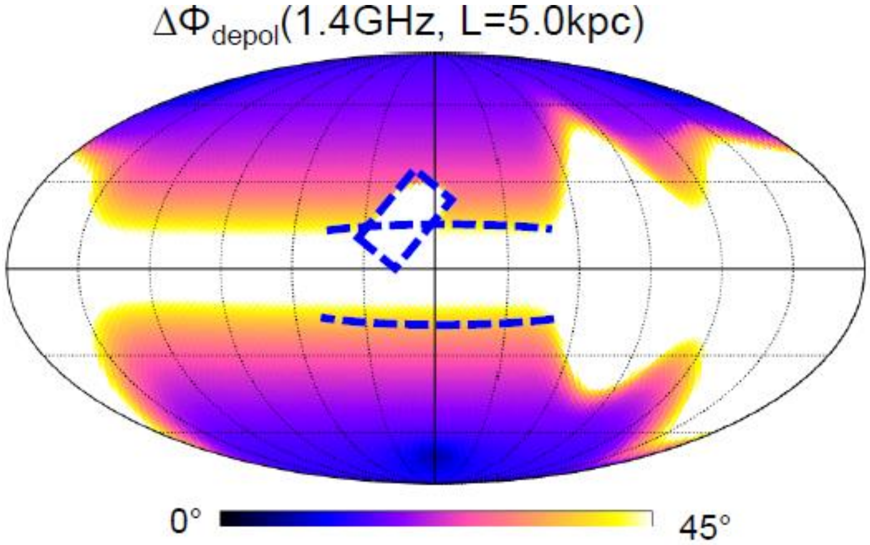
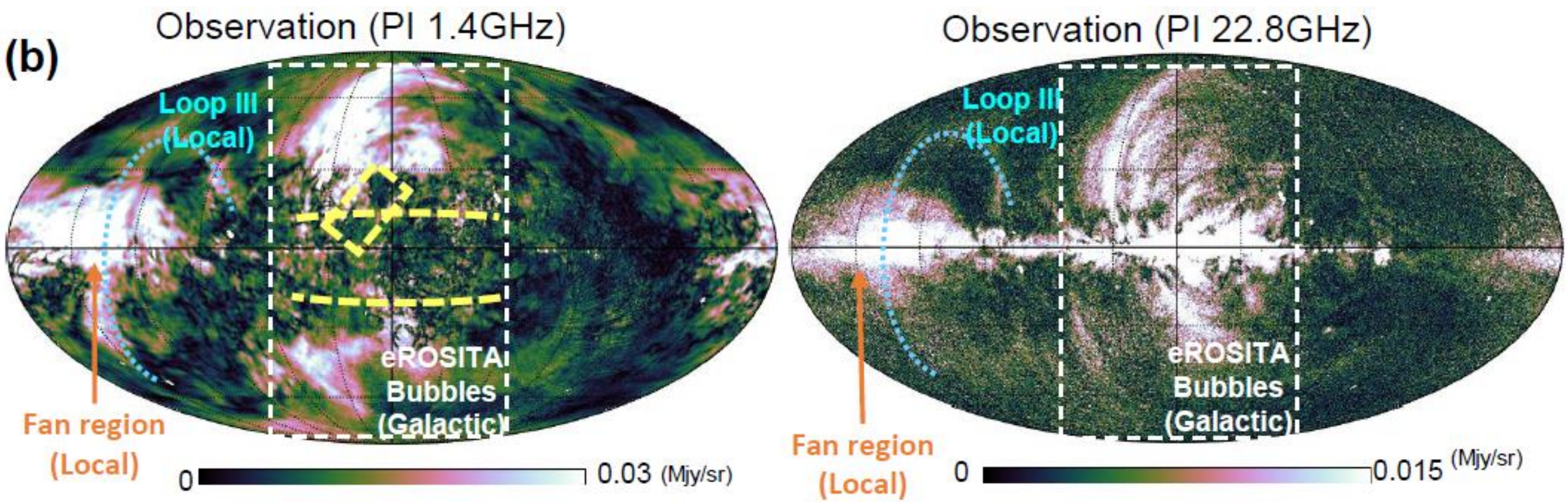


Faraday Rotation depolarization screen

Local: in front of the screen

Galactic: behind the screen



3. Question: Local or Galactic?

Answer: Galactic X-ray halo

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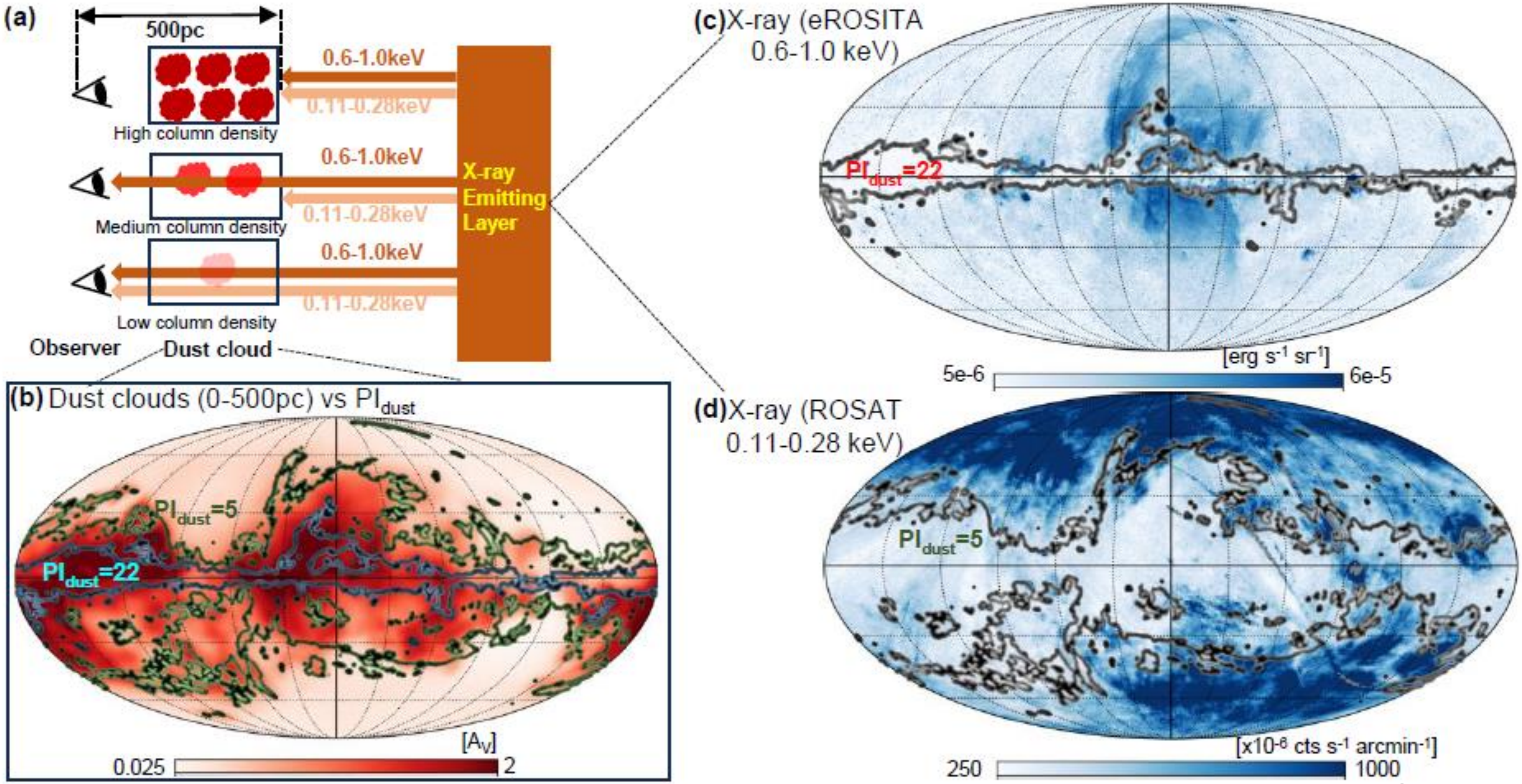
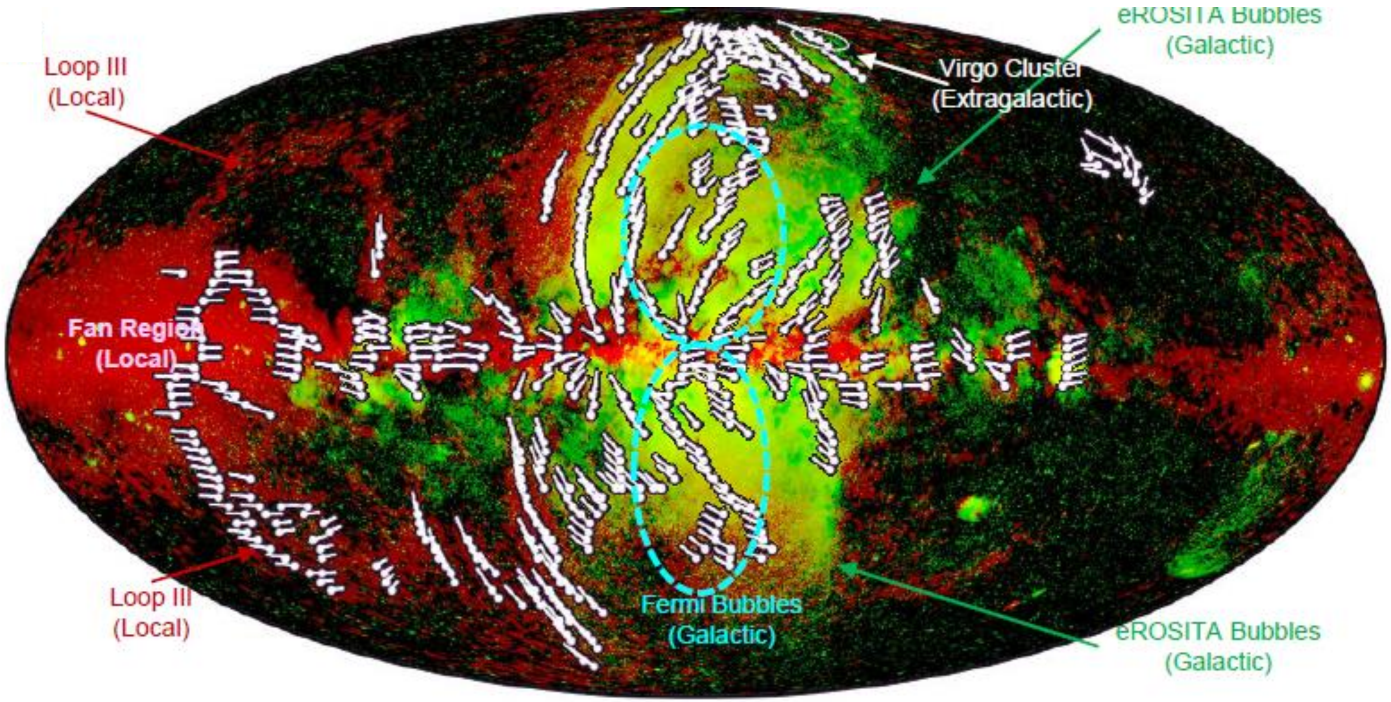


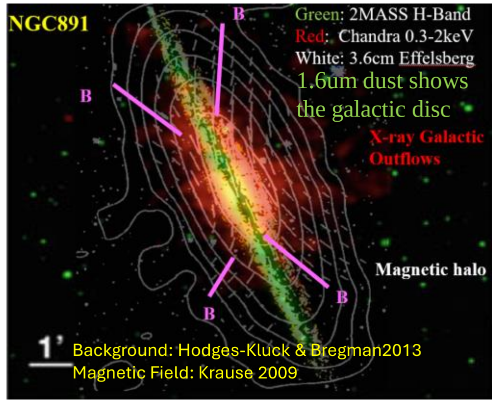
The eROSITA Bubbles - out of the Galactic plane!

4. Magnetic and X-ray emitting halo

The Milky Way



Zhang et al 2024 ArXiv: **2408.06312**



Beyond the Galactic Disc, Coherent ridges in the central +60°>l>-60°.

4. Gamma-ray counterpart of the magnetic halo

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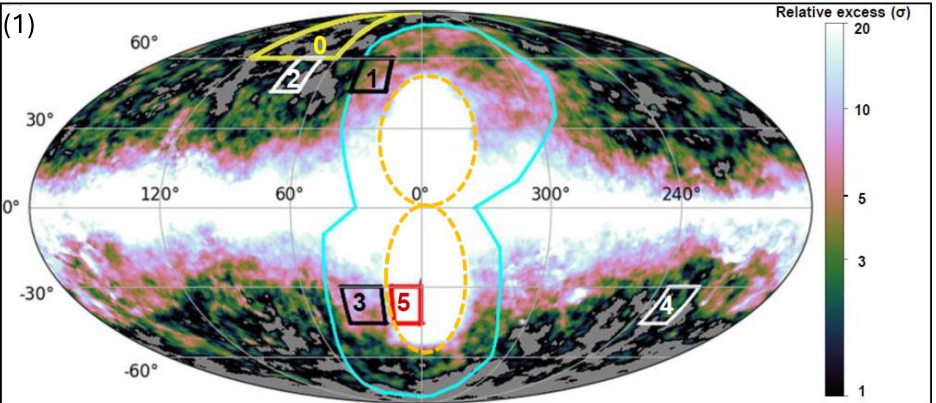
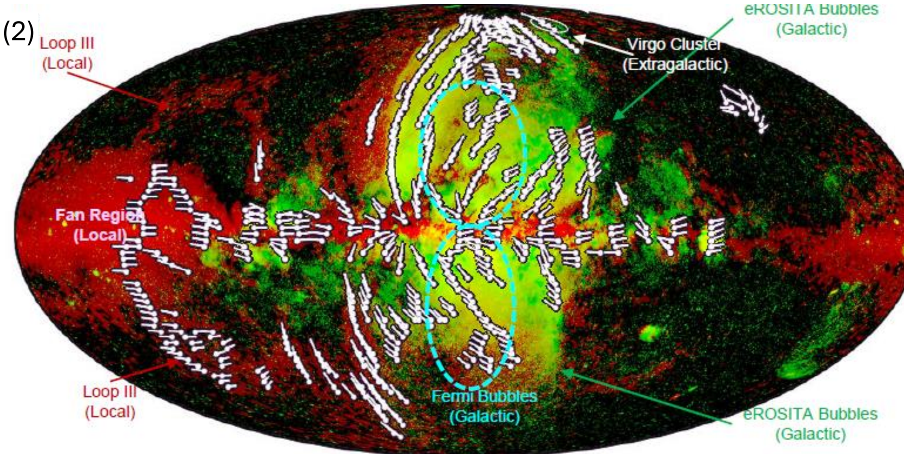
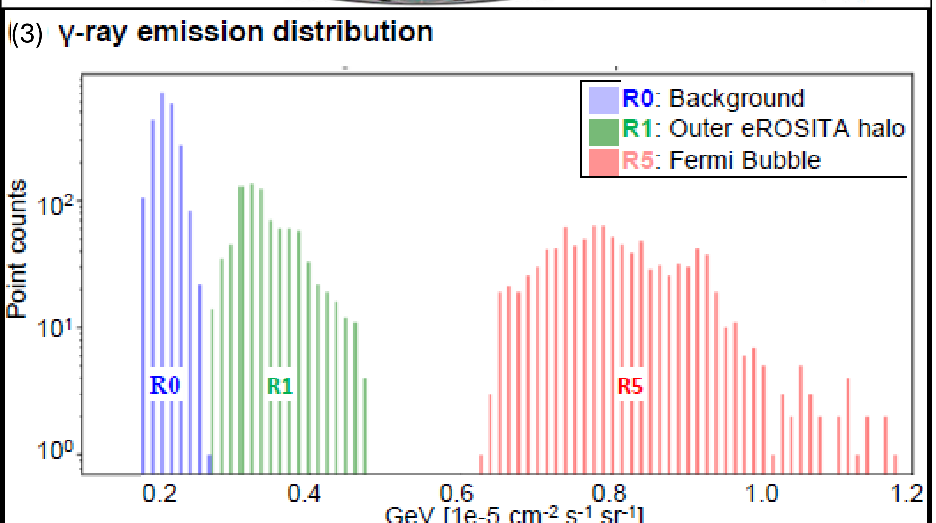
(1)



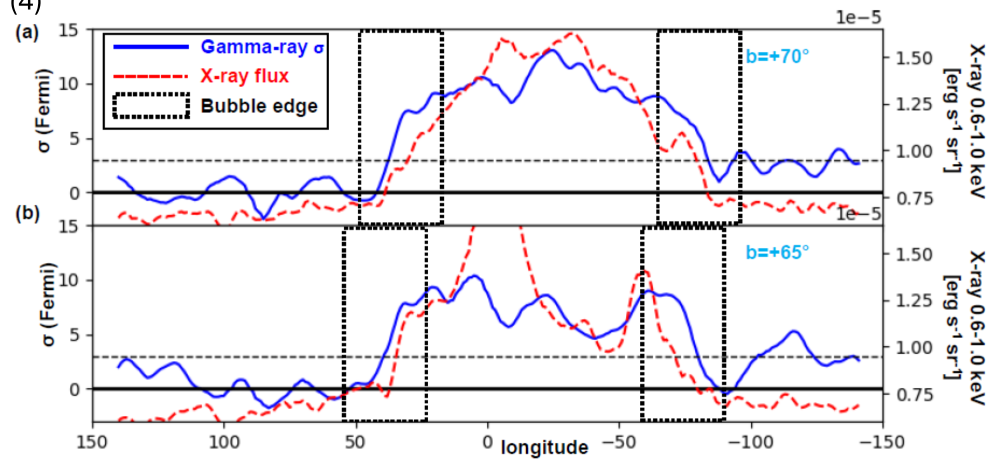
(2)



(3) γ-ray emission distribution

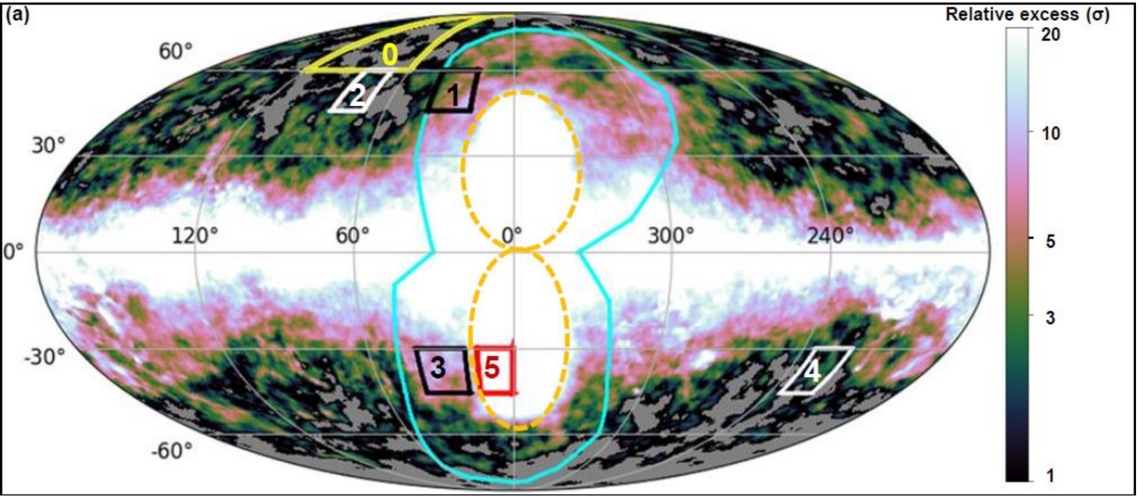


(4)



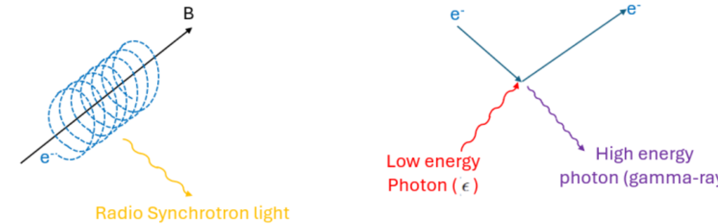
A gamma-diffuse halo (see 1), with magnetic ridges enhanced at the edges (see 2), independent of the background or Fermi Bubbles (see 3), and similar morphology to the eROSITA Bubbles (see 4)

5. Magnetic field strength measurements



Magnetic field strength diagnostic from multi-messenger approach

- Synchrotron:
  Relativistic electrons radiate when gyrating around the magnetic field
- Inverse Compton (IC):
  Relativistic electrons scatters low energy photons to gamma-ray



$E_{syn} = 10^{-4}(E_e/40\mathrm{GeV})^2(B/1\mu\mathrm{G})\,\mathrm{eV}$.

$E_{IC} \approx 3(E_e/40\,\mathrm{GeV})^2(\epsilon/0.4\mathrm{eV})\,\mathrm{GeV}$

ISRF+CMB

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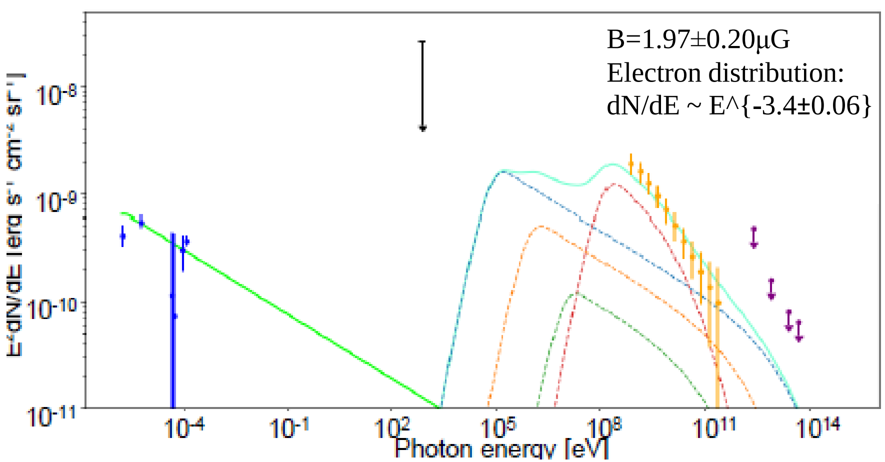
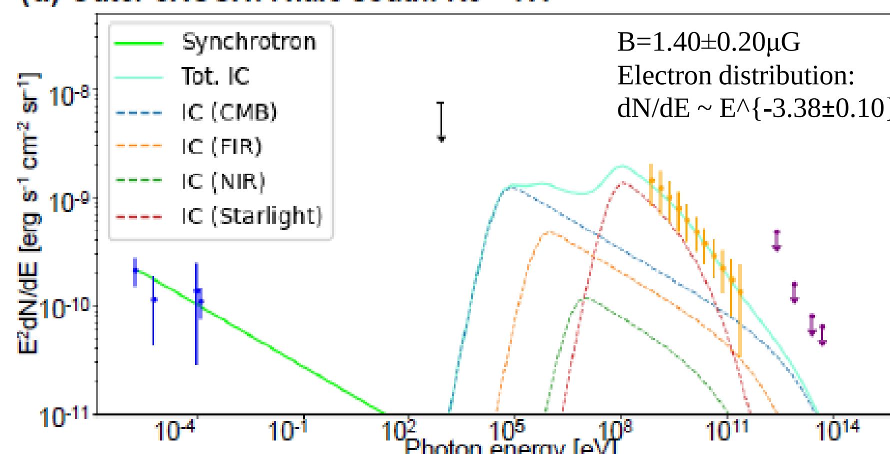
(c) Outer eROSITA halo north: R1 – R2

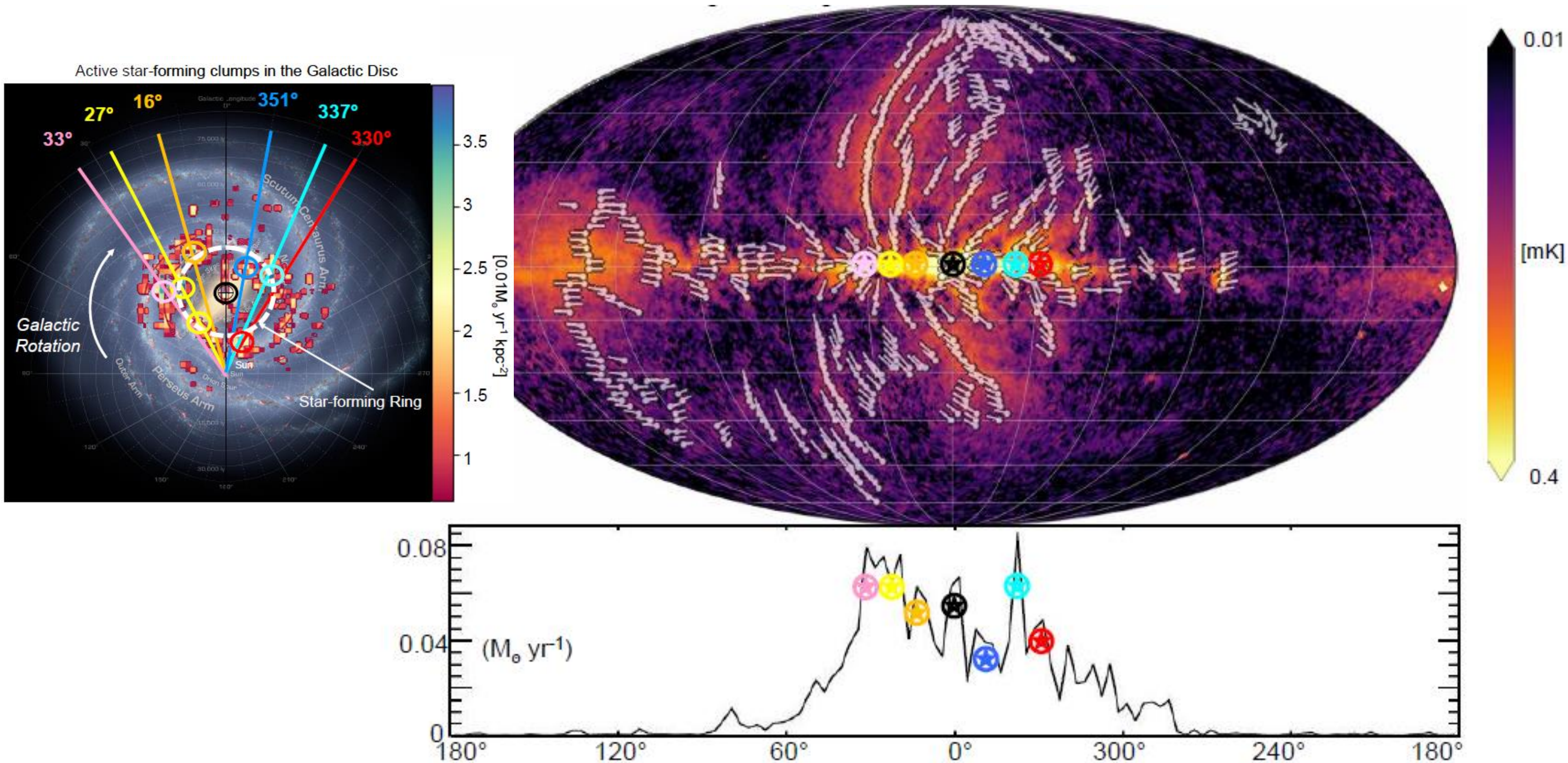


(d) Outer eROSITA halo south: R3 – R4



North-South non-thermal symmetry: **similar magnetic field, similar electron index, plasma-beta around 10**!

6. Magnetic Ridges in the halo vs Star Formation in the disc



Footpoints of the Magnetic ridges for Fermi Bubbles and eROSITA Bubbles are different:

Fermi Bubbles to the GC;

eROSITA Bubbles to a few kpcs from the GC!

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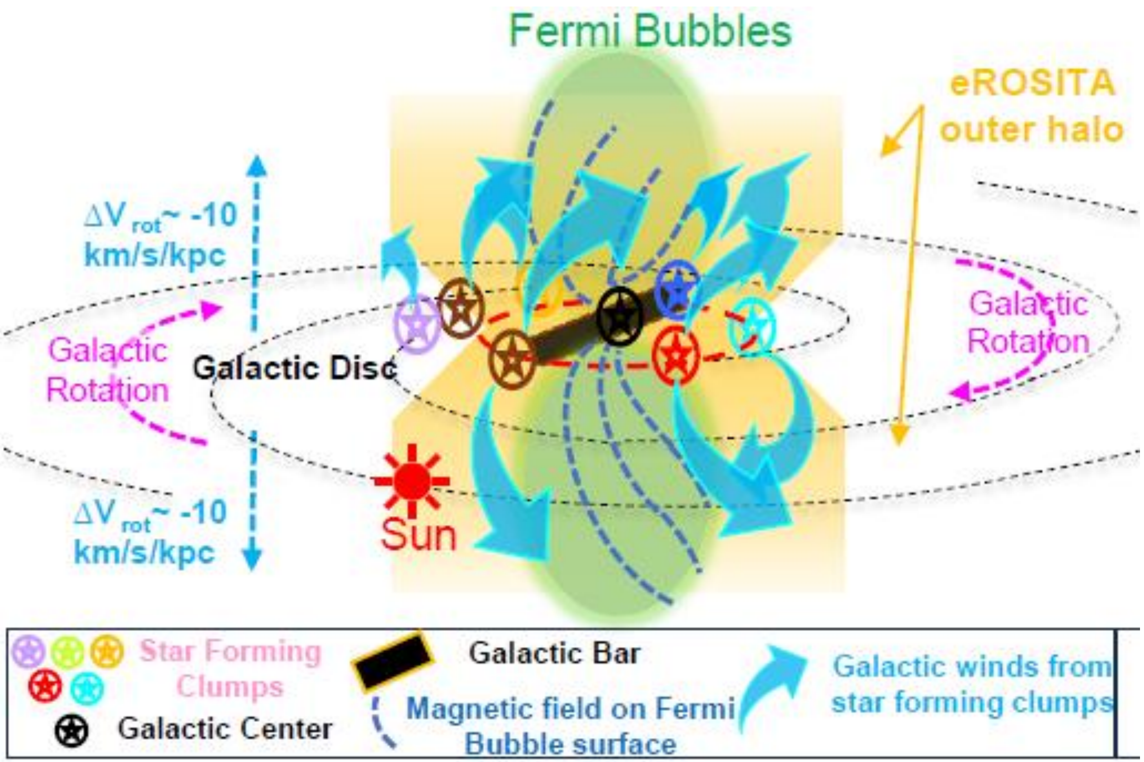
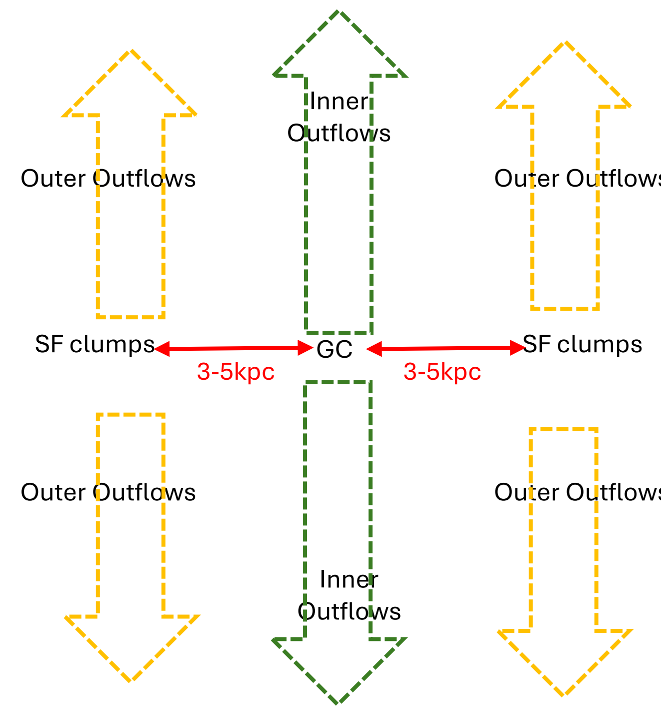
7. Magnetic halo and Galactic Outflows





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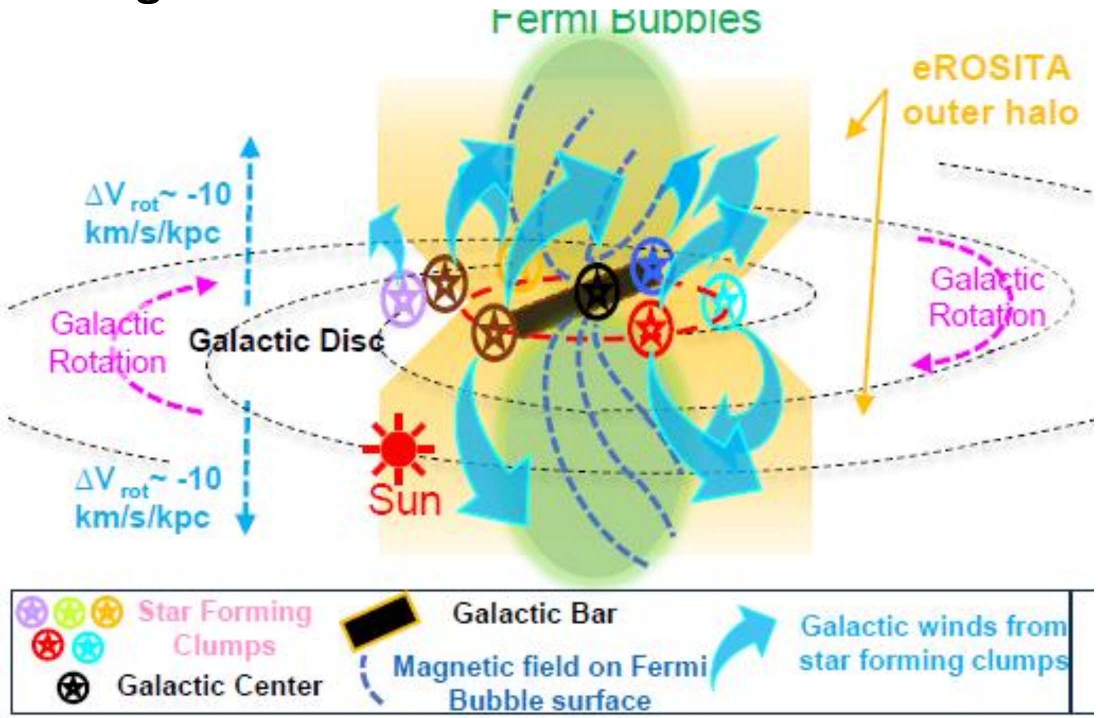

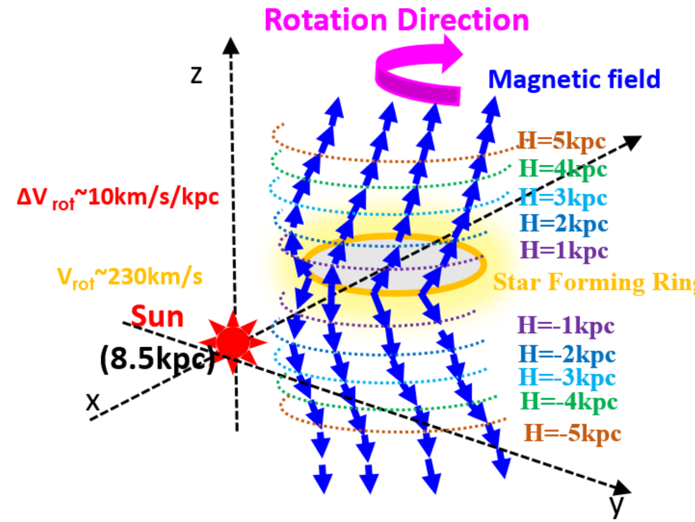

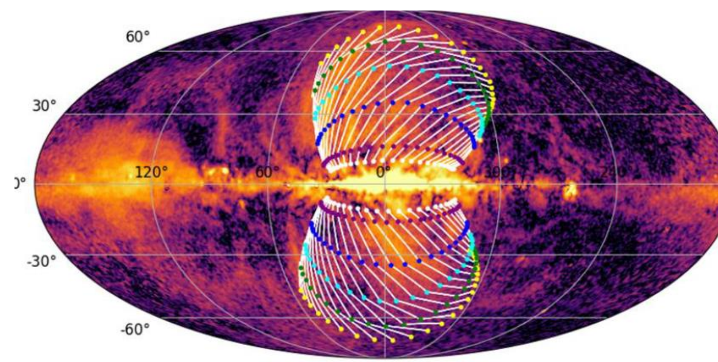

Magnetic field lines in the halo trace the Galactic outflows!

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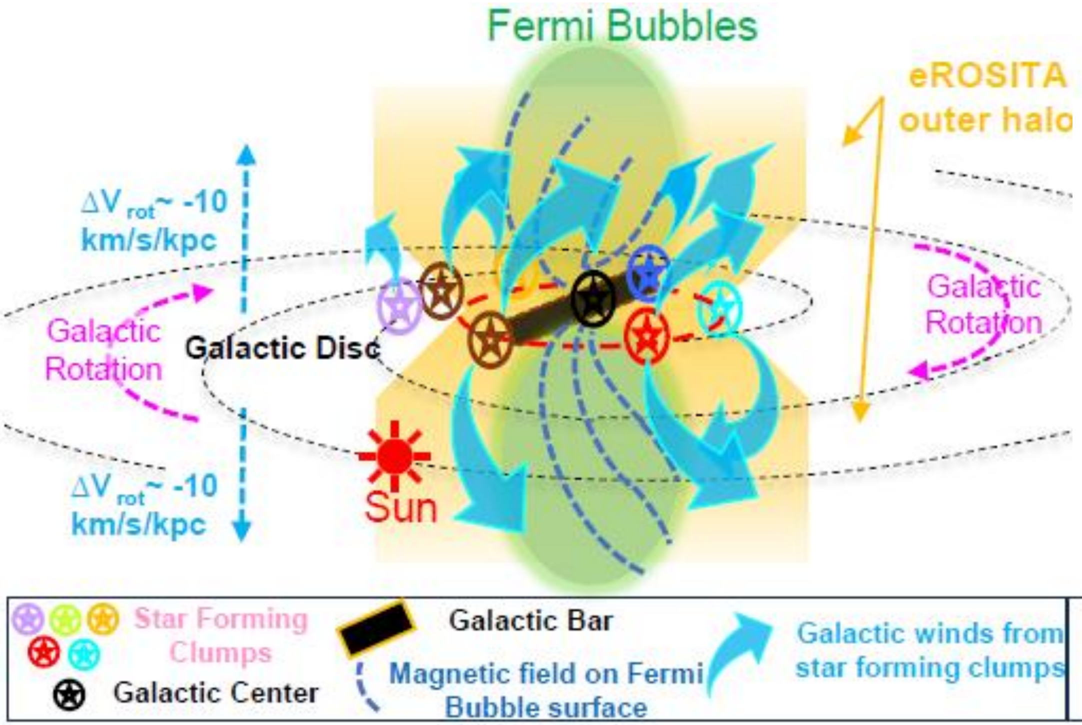
7. Magnetic halo and Galactic Outflows



Assumptions						
H_{sys} [kpc]	4		7		10	
t_{dyn} [yrs]	10^8	10^9	10^8	10^9	10^8	10^9
Results						
E_{therm} [$\times 10^{55}$ erg]	5.9		10		14	
E_B [$\times 10^{55}$ erg]	1.5		3.3		5.3	
E_{tot} [$\times 10^{55}$ erg]	8.6		15		21	
$\dot{E}_{inj}$ [$\times 10^{40}$ erg/s]	2.7	1.4	4.7	2.5	6.6	3.5
χ_{inj} [%]	8.5	4.5	14.6	7.7	20.5	10.8
$\dot{M}_{inj}$ [$M_\odot$/yr]	0.54	0.28	0.92	0.49	1.3	0.68

The SNR rate in the 3-5 kpc star-forming ring is around 1 per century: $\dot{E}_{SFR} \simeq 3.2 \times 10^{41}$ erg/s.

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1. The outer outflows can be powered by the 3-5 kpc star-forming ring by a few to 20% of their mechanical energy from SNe;
2. The mass injection rate required around 0.3 ~ 1.3 Solar mass / year.

Summary

1. The Milky Way has inner outflows from GC (Fermi Bubbles) and outer outflows from the star forming clumps (eROSITA Bubbles, footpoints span several kpc)
2. The magnetic field is coherent and highly anisotropic in the Galactic halo, tracing the Galactic outflows

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