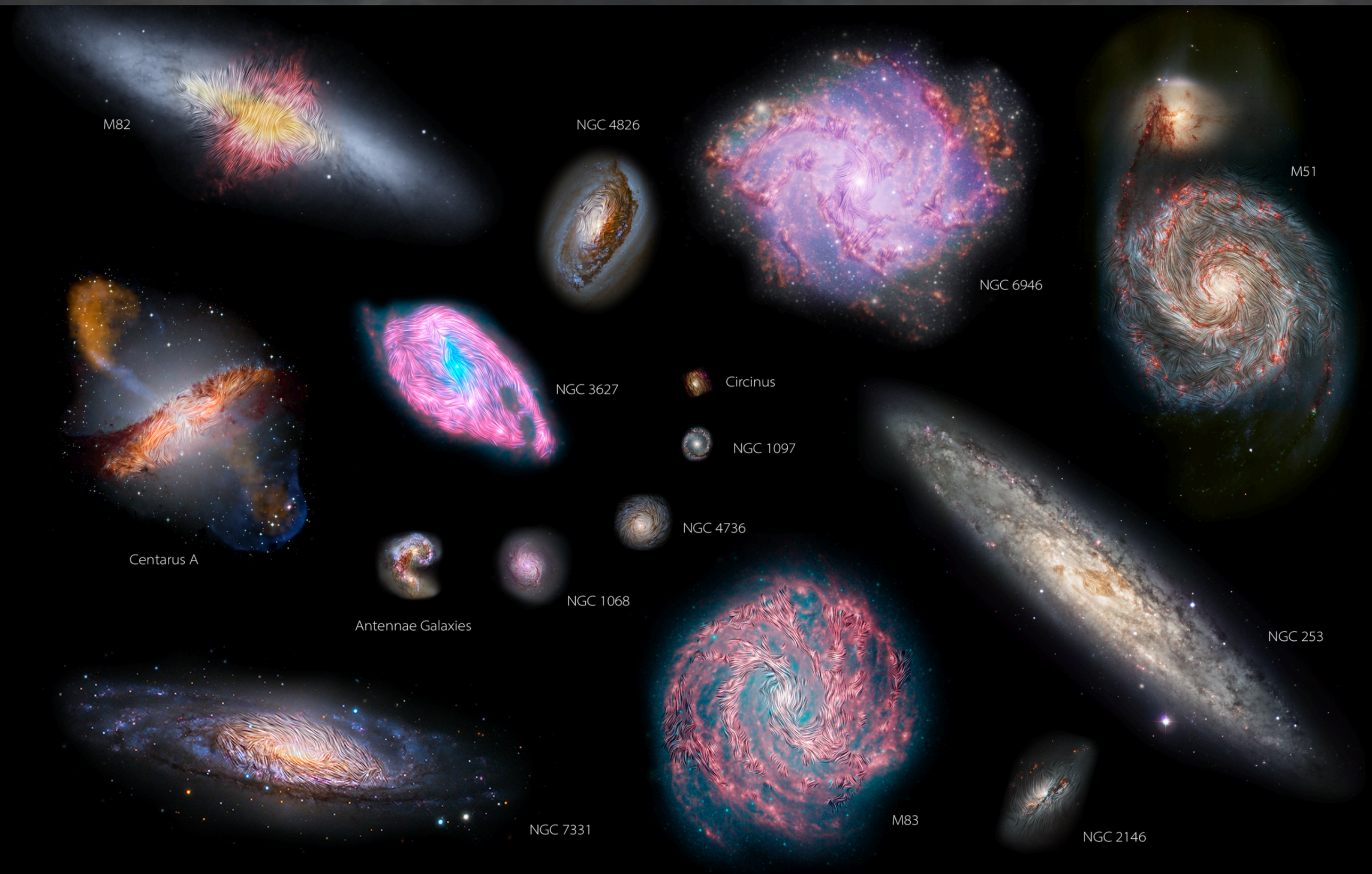
Magnetic Fields in the *turbulent, multi-phase* interstellar medium

Susan E. Clark | Stanford University, KIPAC

With many collaborators, including the
Stanford Cosmic Magnetism & Interstellar Physics Group:

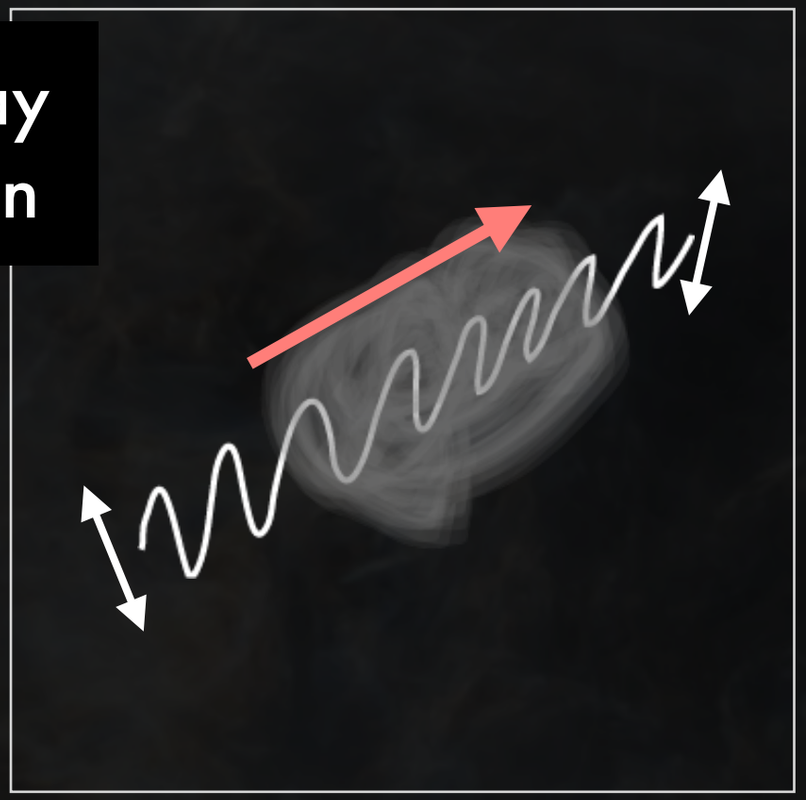
Iryna Butsky, Sanskriti Das, Ben Dodge, Philipp Frank, Dylan Jow, Jaeyeon Kim, Kaitlyn Karpovich, Minjie Lei, Sergio Martin Alvarez, Eric Moseley, Marta Nowotka, ++

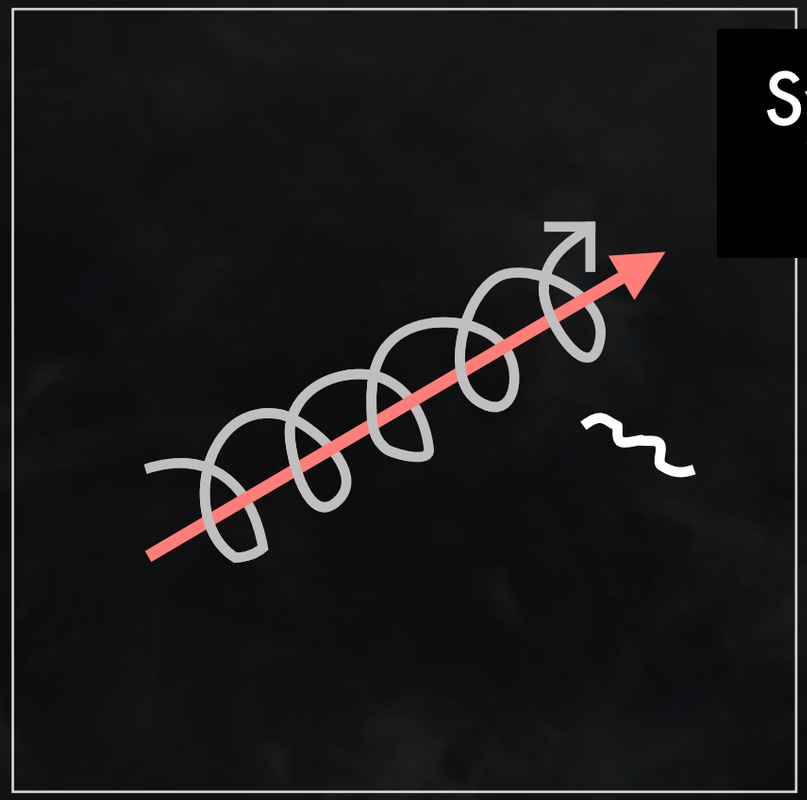
NSF NASA ALFRED P. SLOAN FOUNDATION



Borlaff, Lopez-Rodriguez, Beck, Clark+ 2023

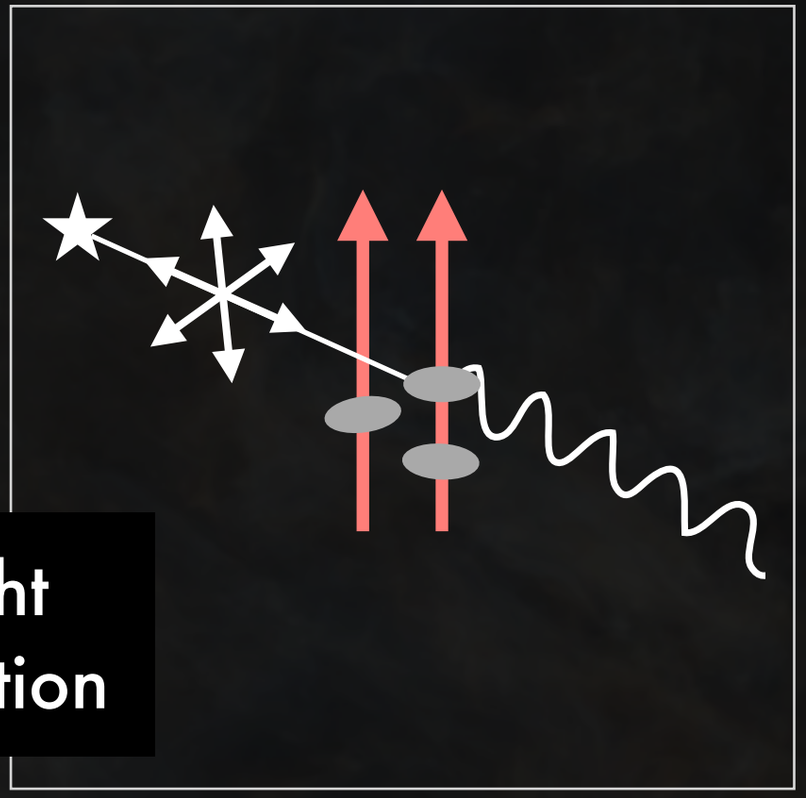
Faraday rotation

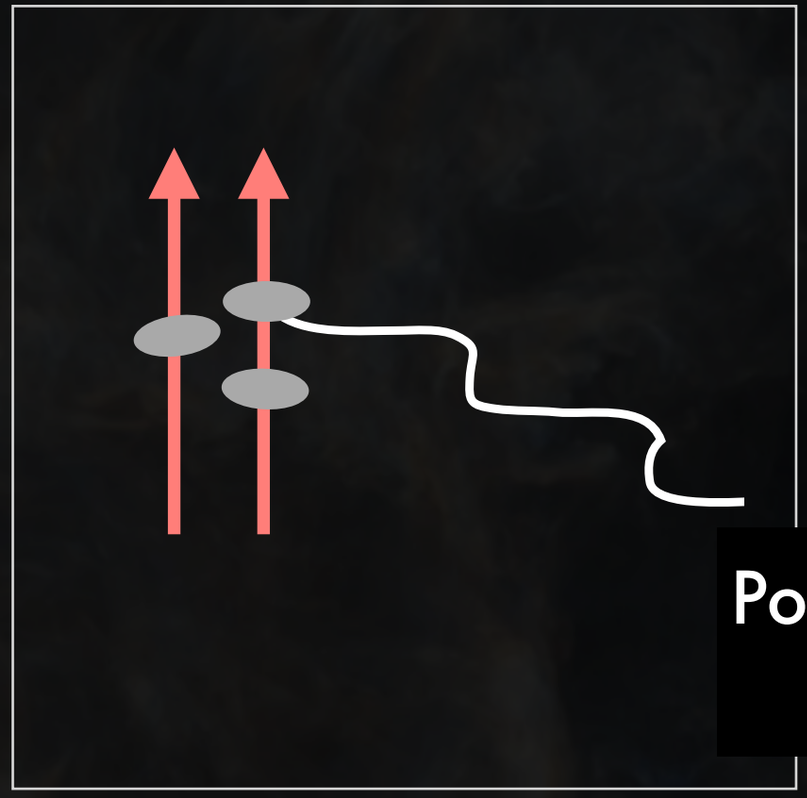




Synchrotron radiation

Starlight polarization

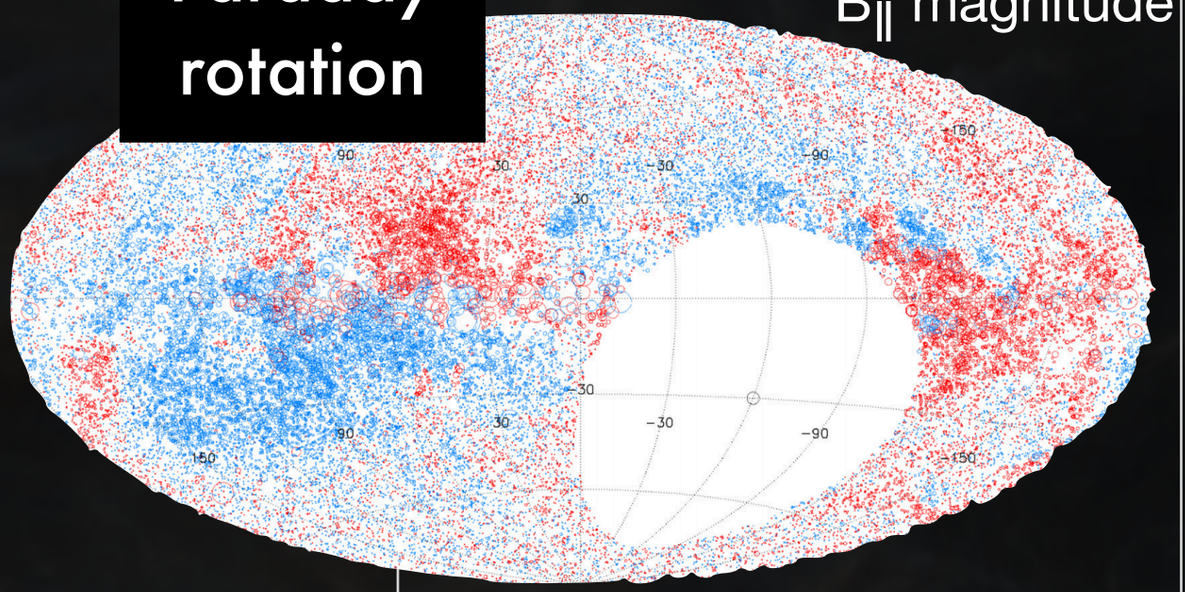




Polarized dust emission

Faraday rotation

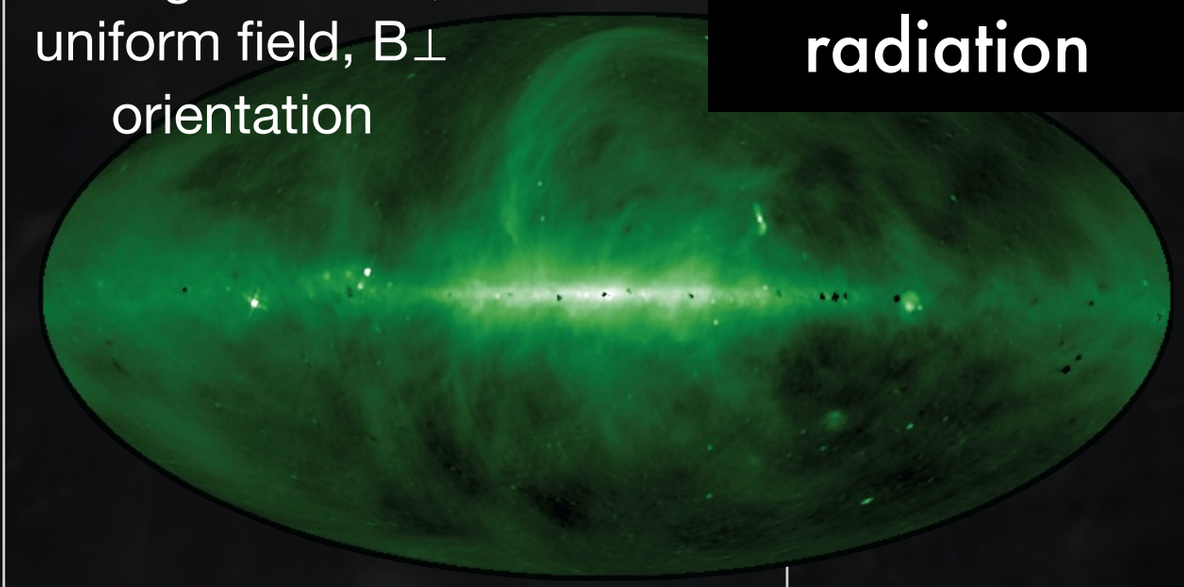
Ionized gas, $B_{\parallel}$ magnitude



Taylor+ 2009

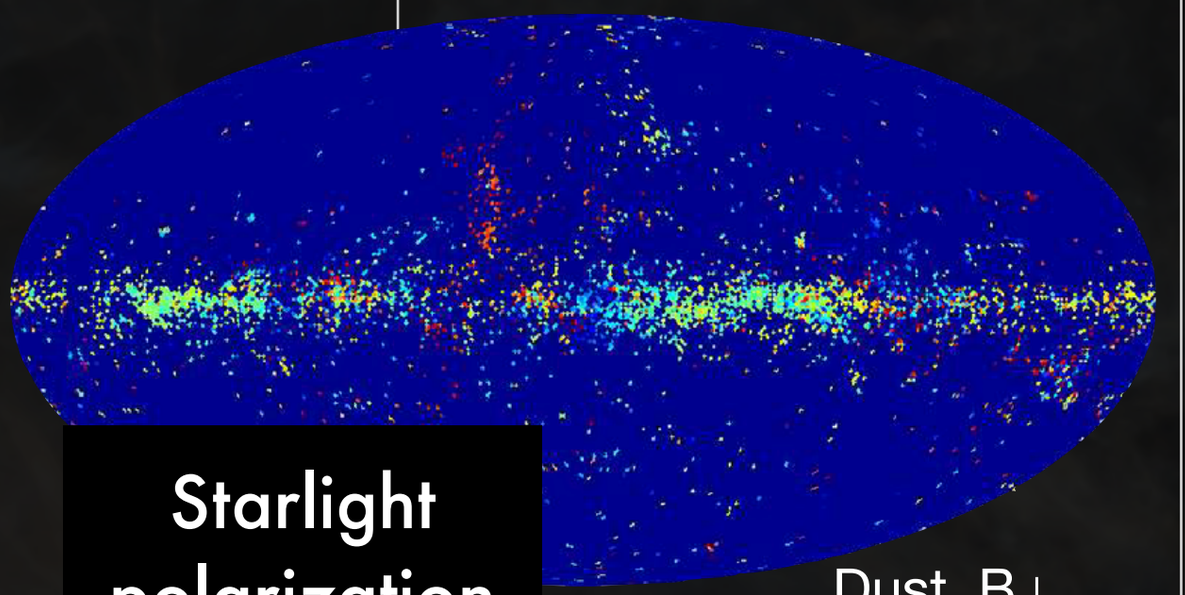
Synchrotron radiation

Cosmic rays, strength of total, uniform field, $B_{\perp}$ orientation



Planck

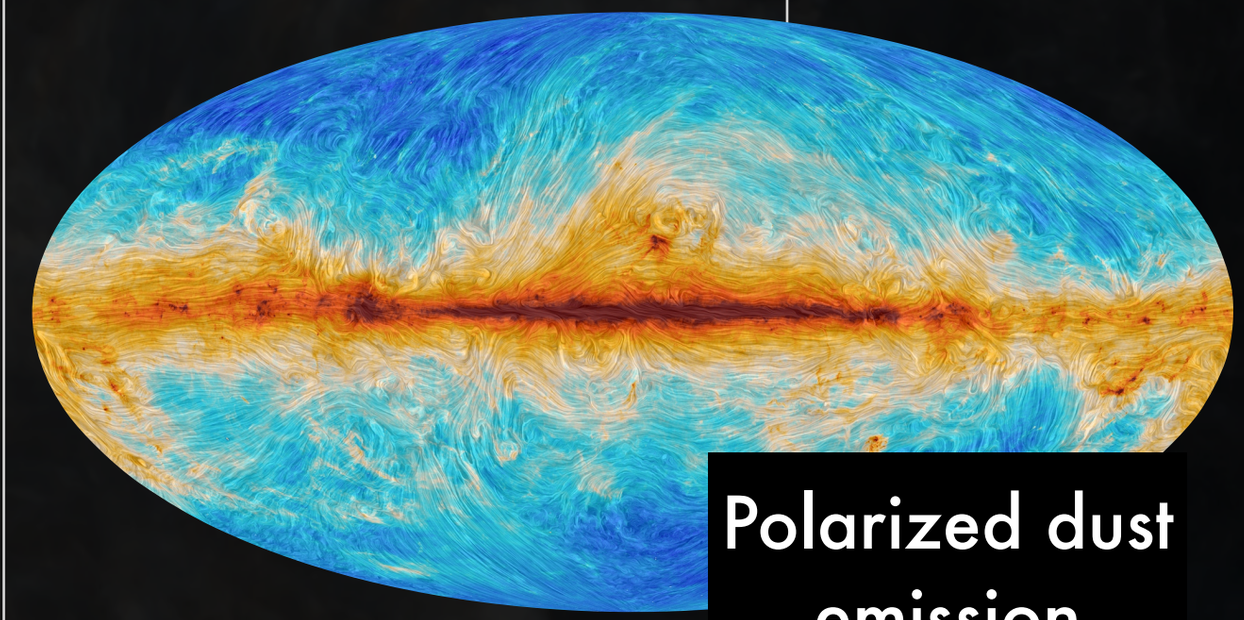
Starlight polarization



Heiles 2000

Dust, $B_{\perp}$ orientation to star

Polarized dust emission

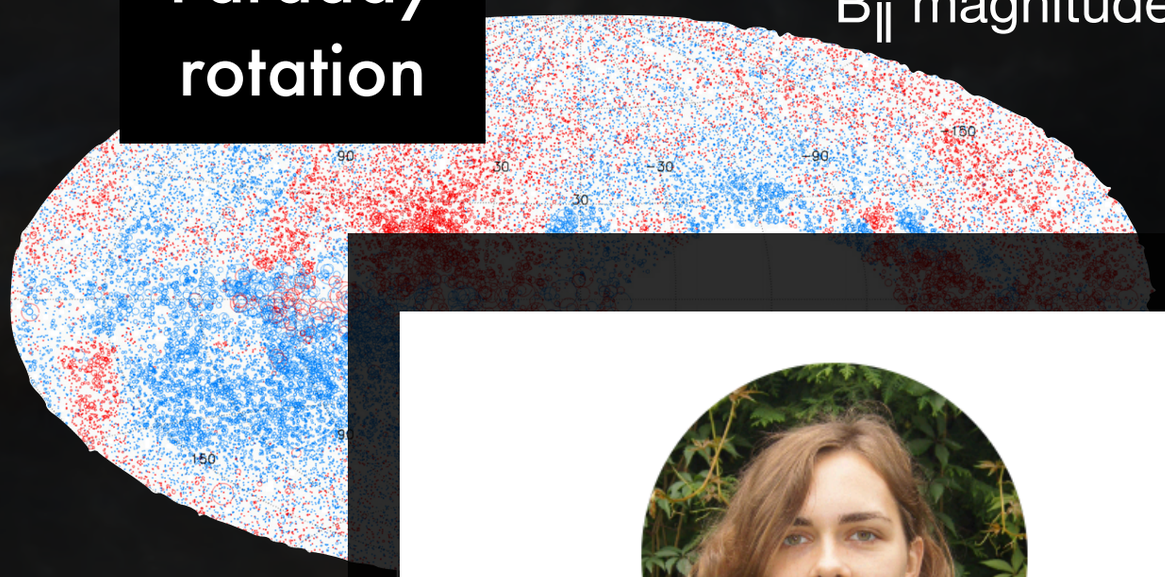


Planck

Dust, $B_{\perp}$ orientation

Faraday rotation

Ionized gas, $B_{\parallel}$ magnitude



Cosmic rays, strength of total, uniform field, $B_{\perp}$ orientation

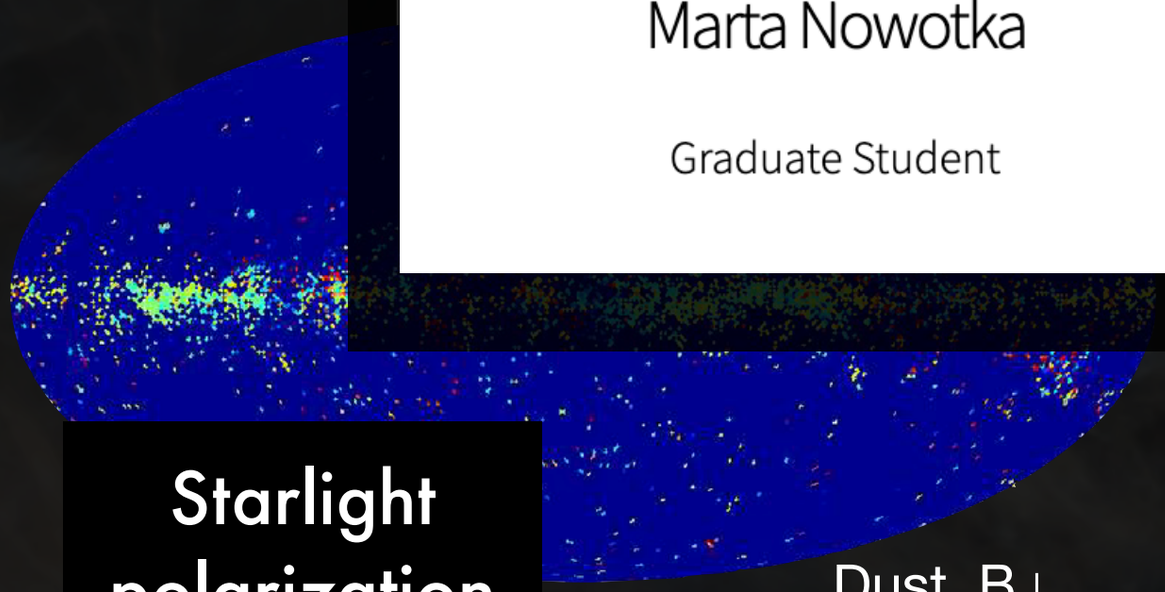
Synchrotron radiation



Marta Nowotka

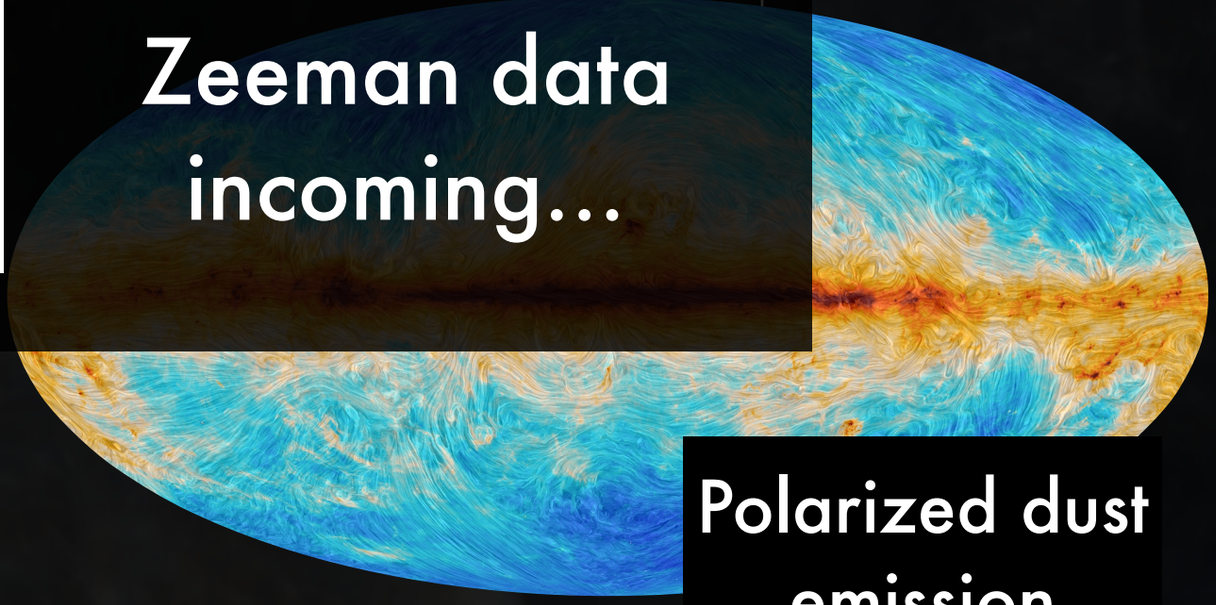
Graduate Student

+ Zeeman splitting! FAST HI absorption + GBT emission Zeeman data incoming…



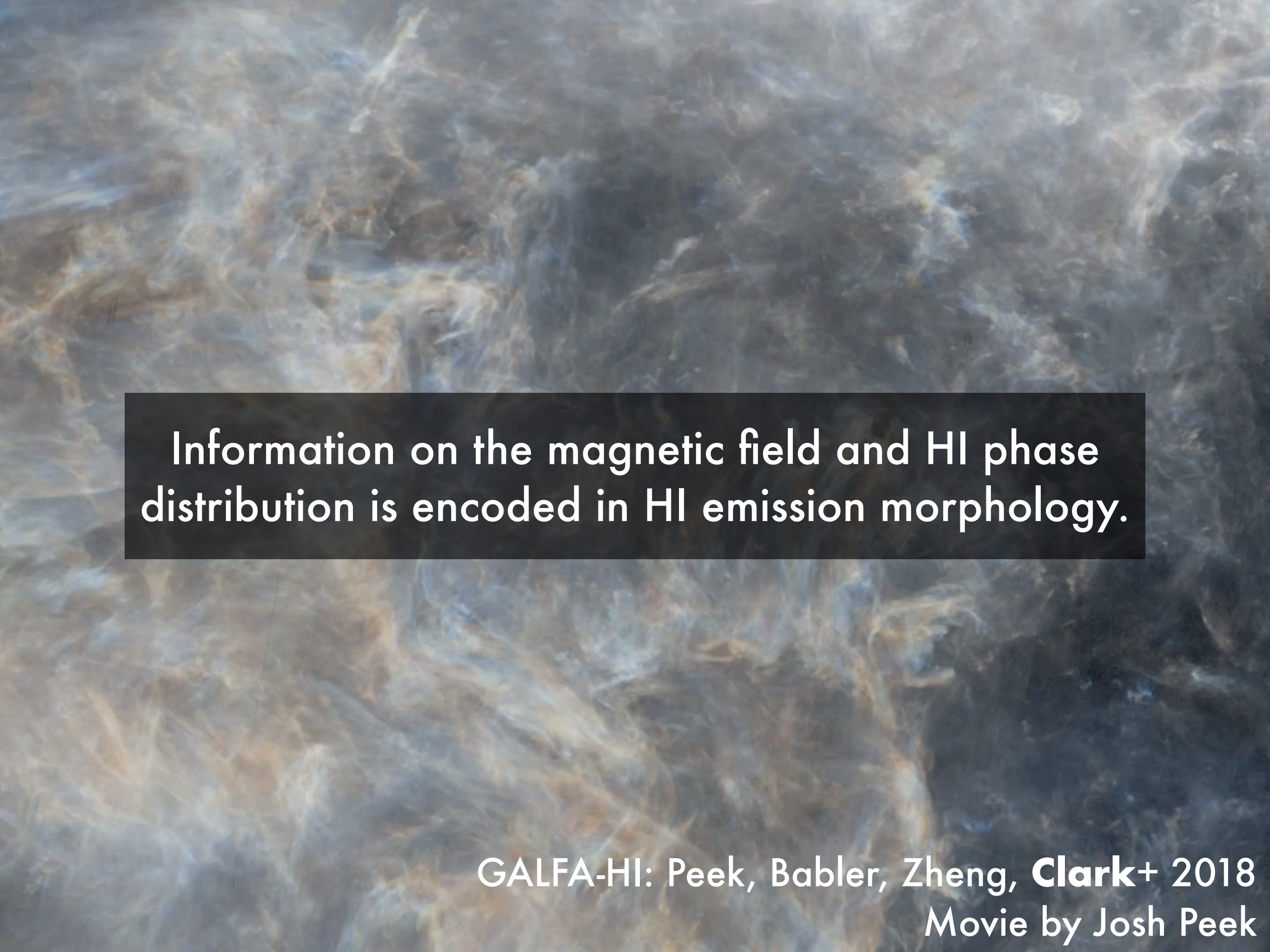
Starlight polarization

Dust, $B_{\perp}$ orientation to star



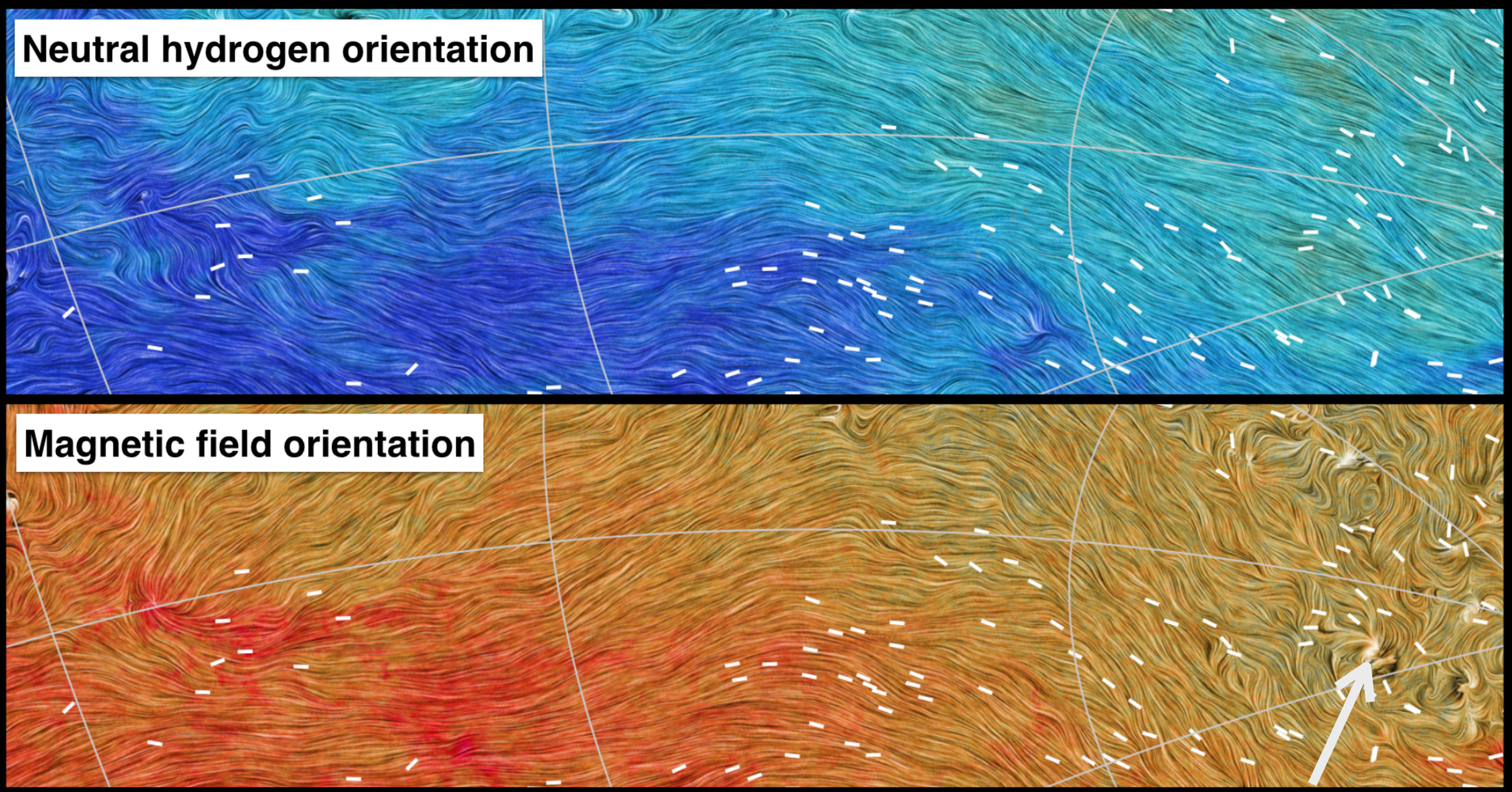
Dust, $B_{\perp}$ orientation

Polarized dust emission


Information on the magnetic field and HI phase distribution is encoded in HI emission morphology.
GALFA-HI: Peek, Babler, Zheng, **Clark**+ 2018
Movie by Josh Peek

The orientation of linear HI structures traces the plane-of-sky magnetic field.

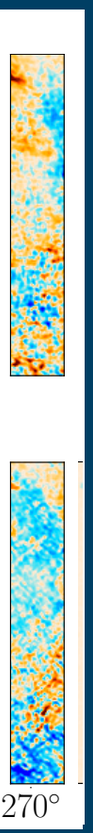
Clark+ 2015, PRL



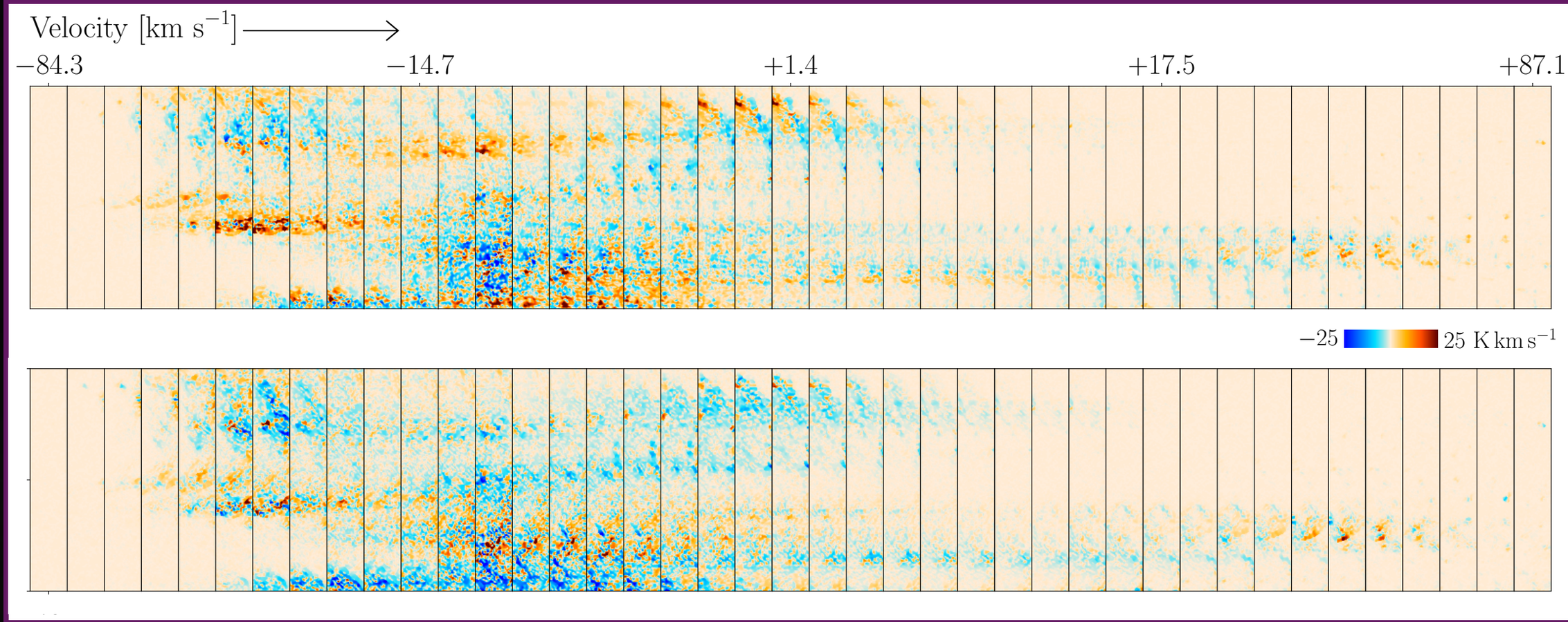
Starlight polarization: Heiles 2000

The magnetic ISM in 3D: Stokes Q and U maps as a function of velocity.

Planck **view (2D)**



Clark & Hensley **view (3D)**

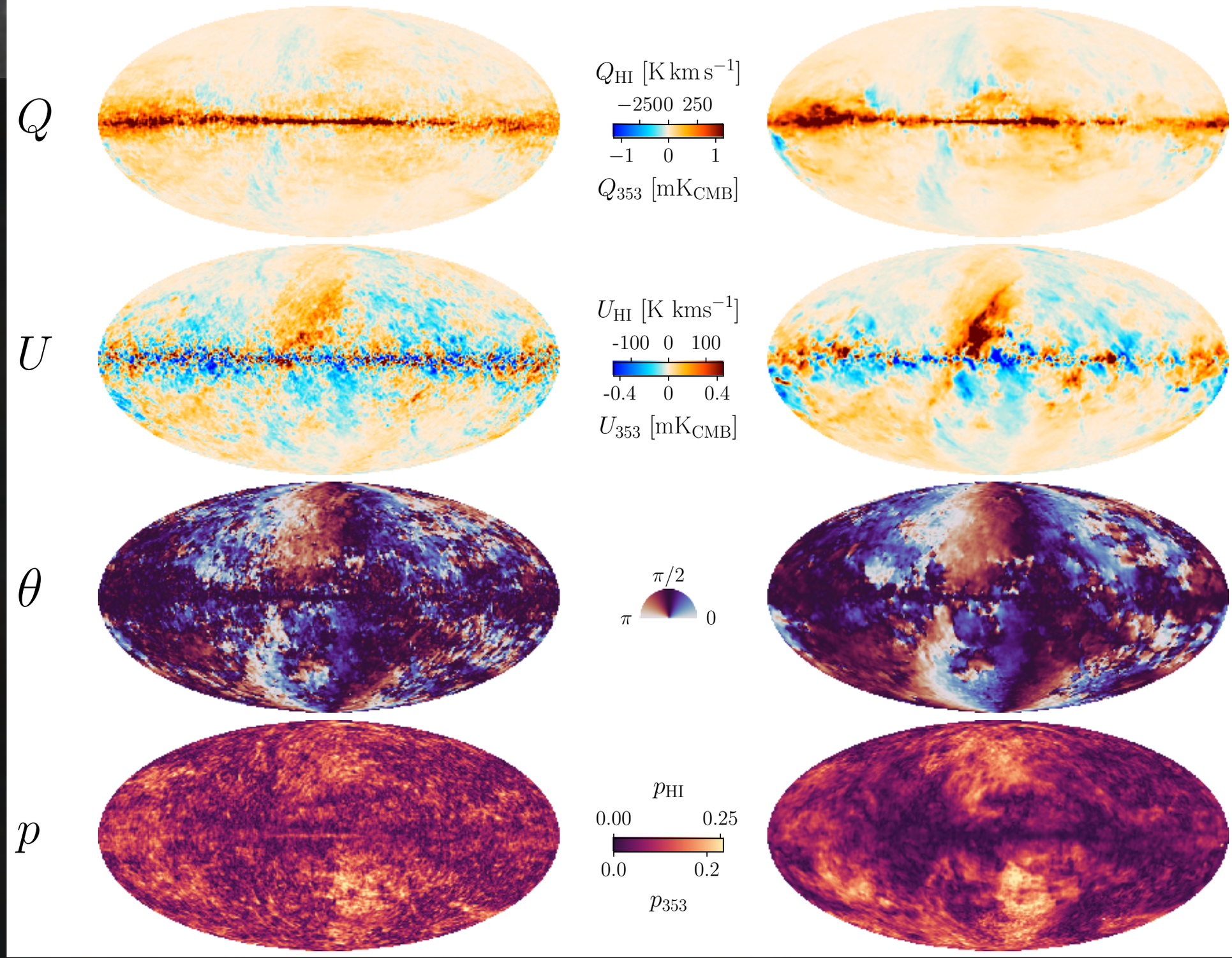


Clark & Hensley 2019

HI only maps

Planck 353 GHz

We reproduce polarized dust measurements with remarkable fidelity.



Clark & Hensley 2019

What is the strength and structure of the magnetic field in the nearby ISM?

How is the magnetic field structured across phases in the ISM?

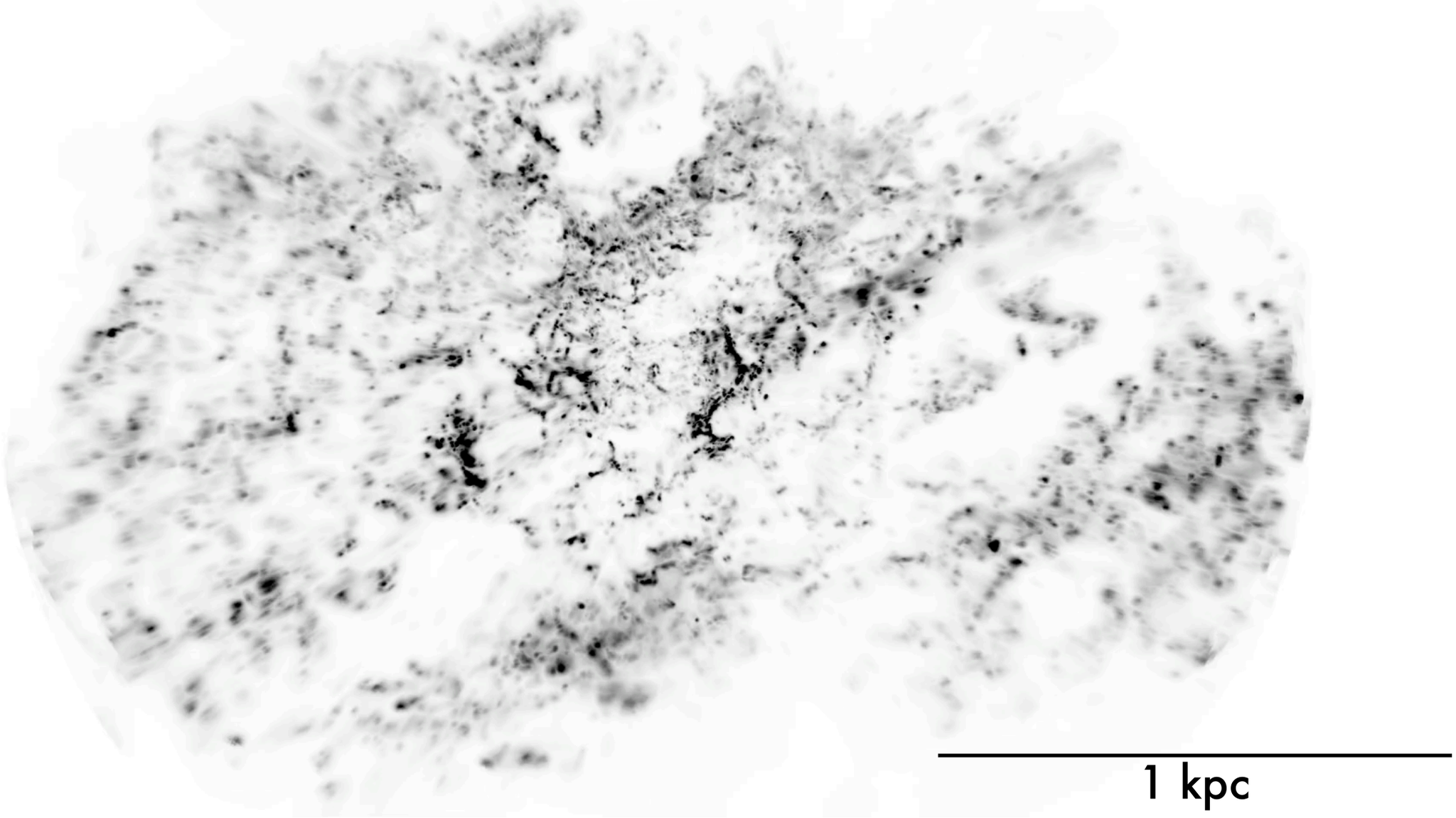
What is the strength and structure of the magnetic field in the nearby ISM?

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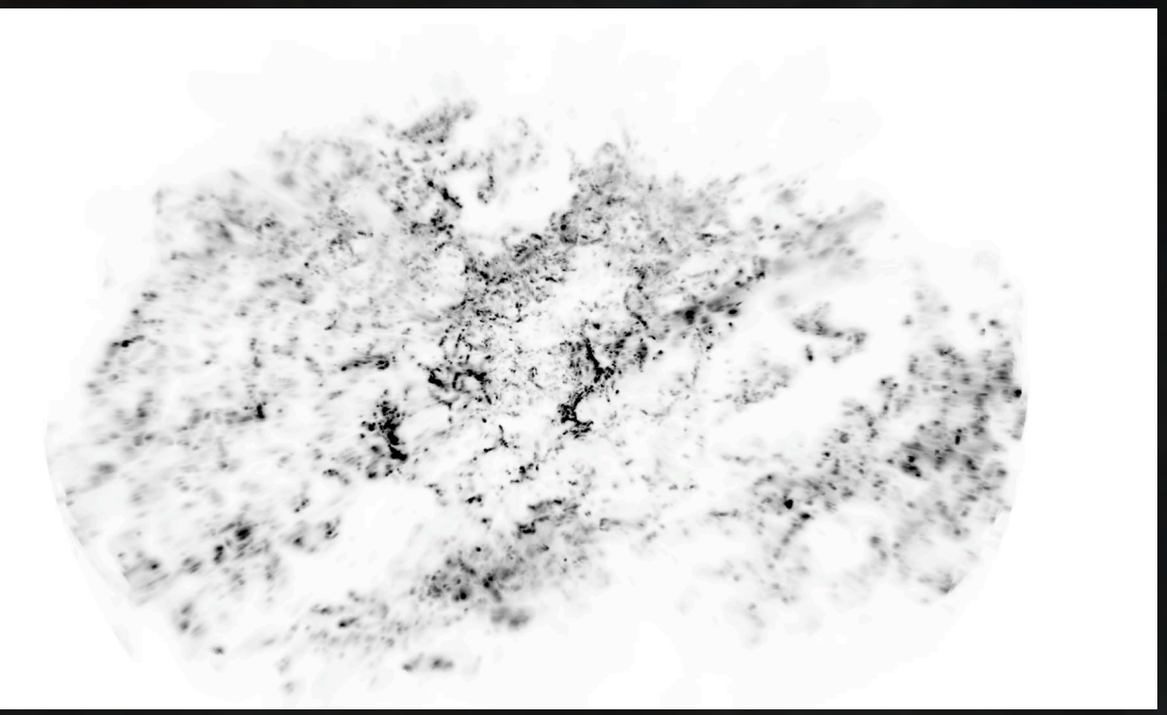
Recent progress: new data, clever new techniques

We continue to improve our view of the nearby ISM in 3D.

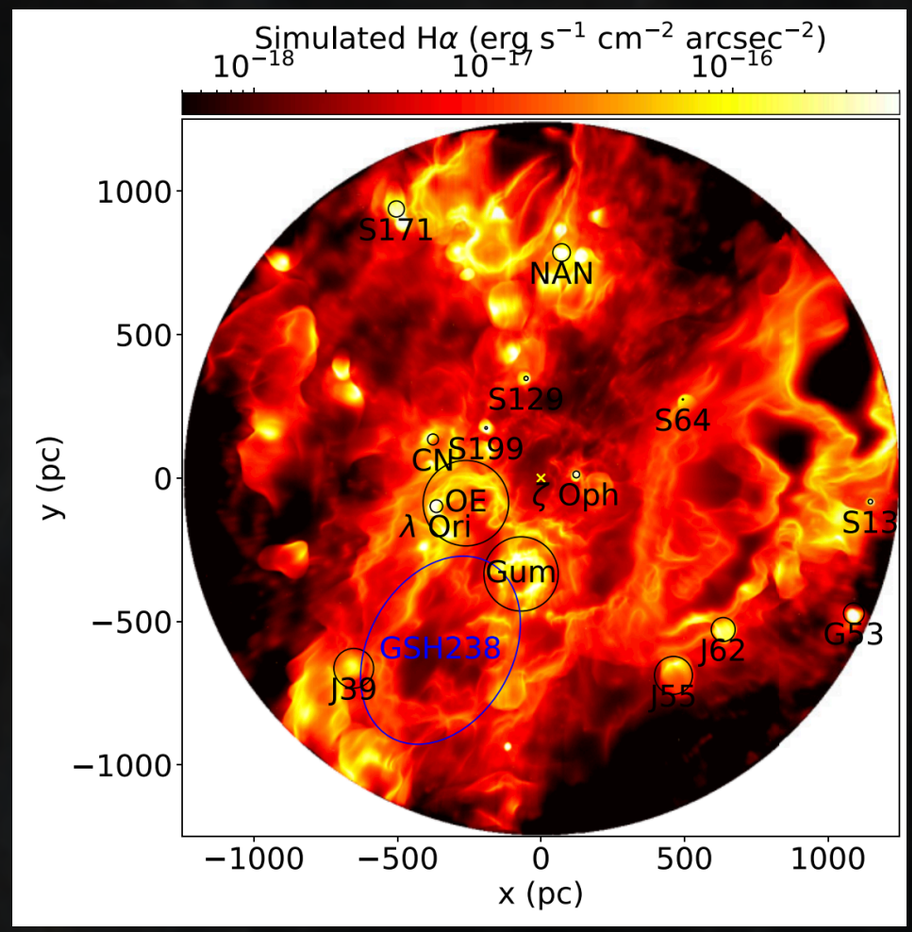
Edenhofer, Zucker, Frank, Saydjari+ 2024



We continue to improve our view of the nearby ISM in 3D, enabling new investigations.



Known positions of O stars



McCallum, Wood, Benjamin+ 2025

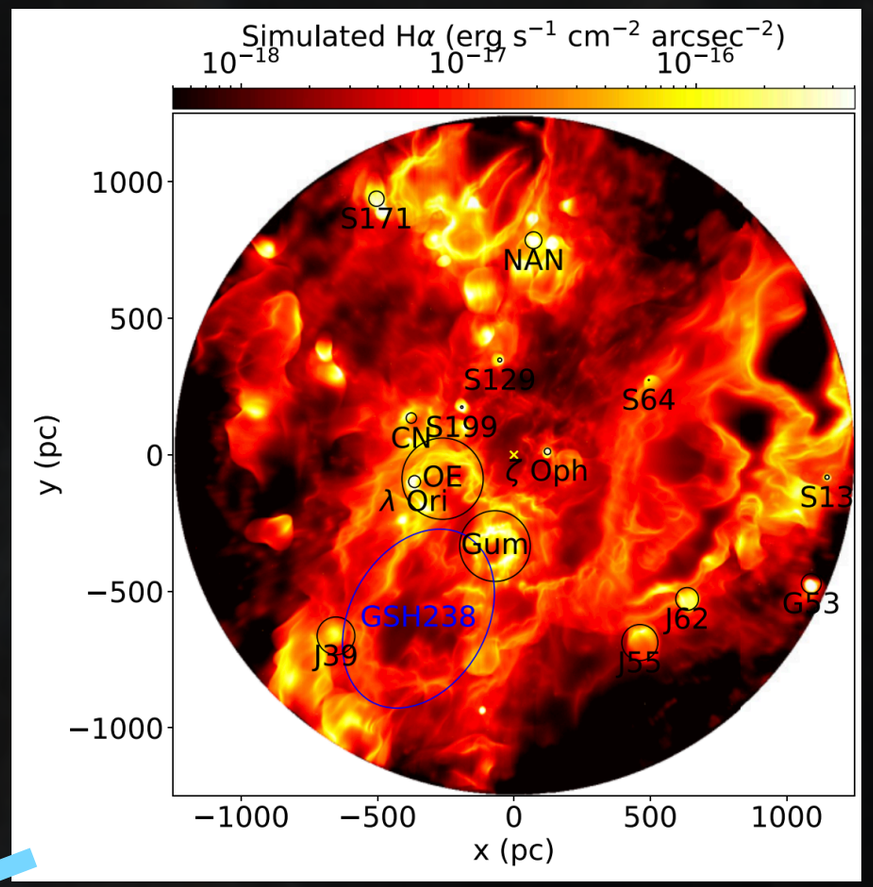
See also: Bish+ 2026

We continue to improve our view of the nearby ISM in 3D, enabling new investigations.

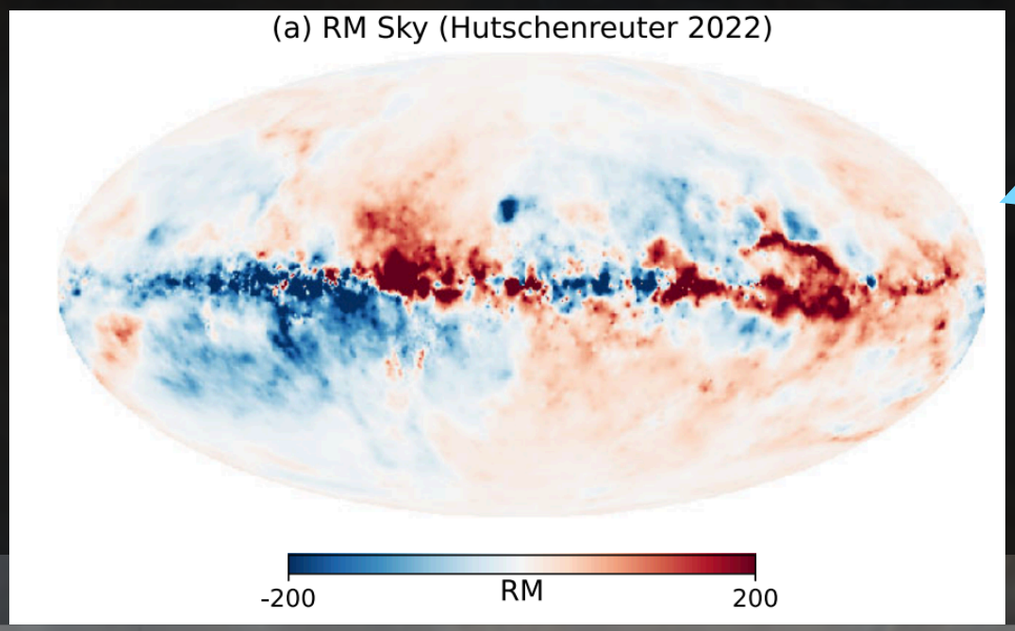


Edenhofer, Zucker, Frank+ 2026

Known positions of O stars



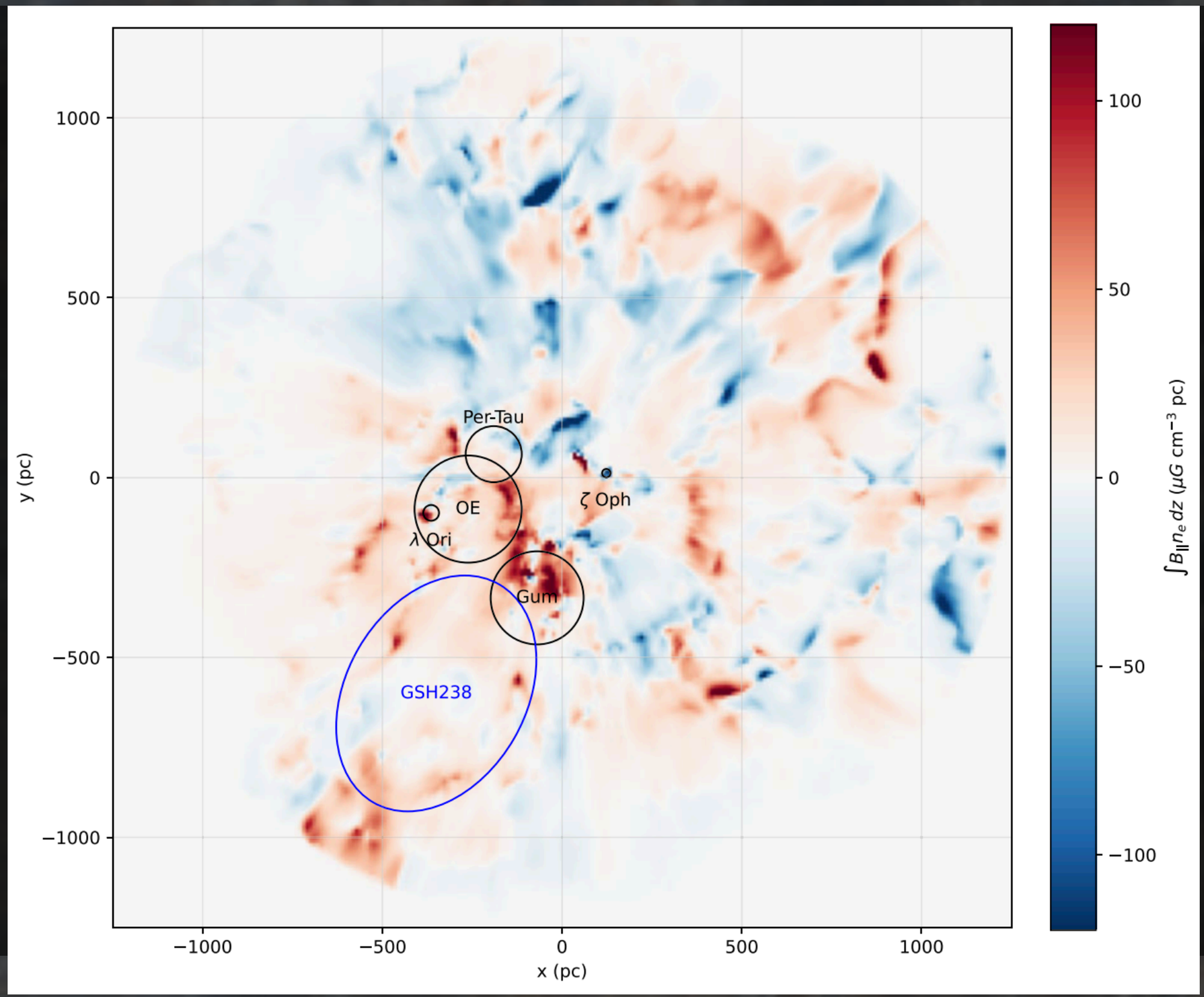
McCallum, Wood, Benjamin+ 2025



Forward model the RM sky

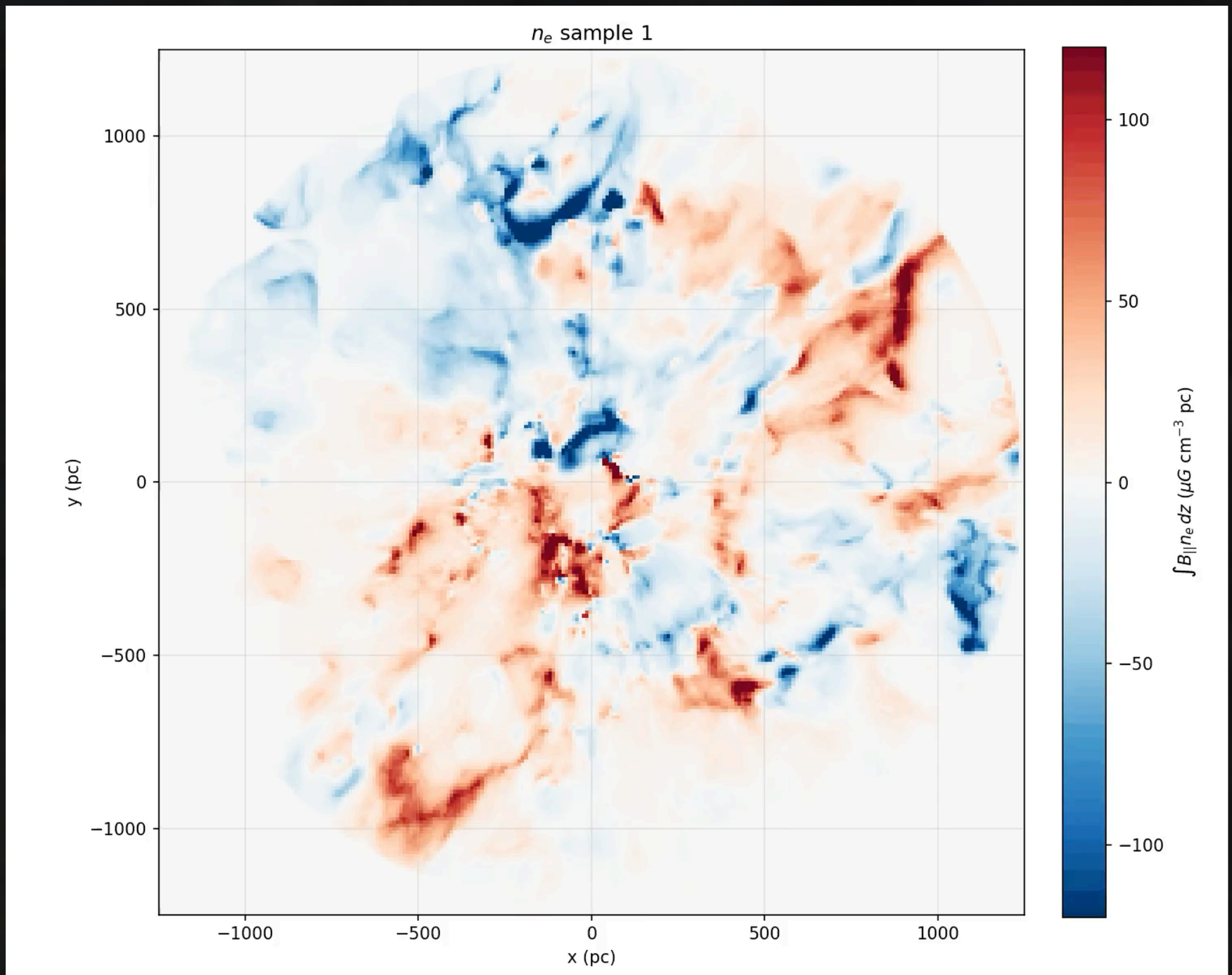
$$RM \propto \int n_e B_{||} \cdot dl \quad \text{1 kpc}$$

A first attempt at a 3D map of the radial component of the magnetic field



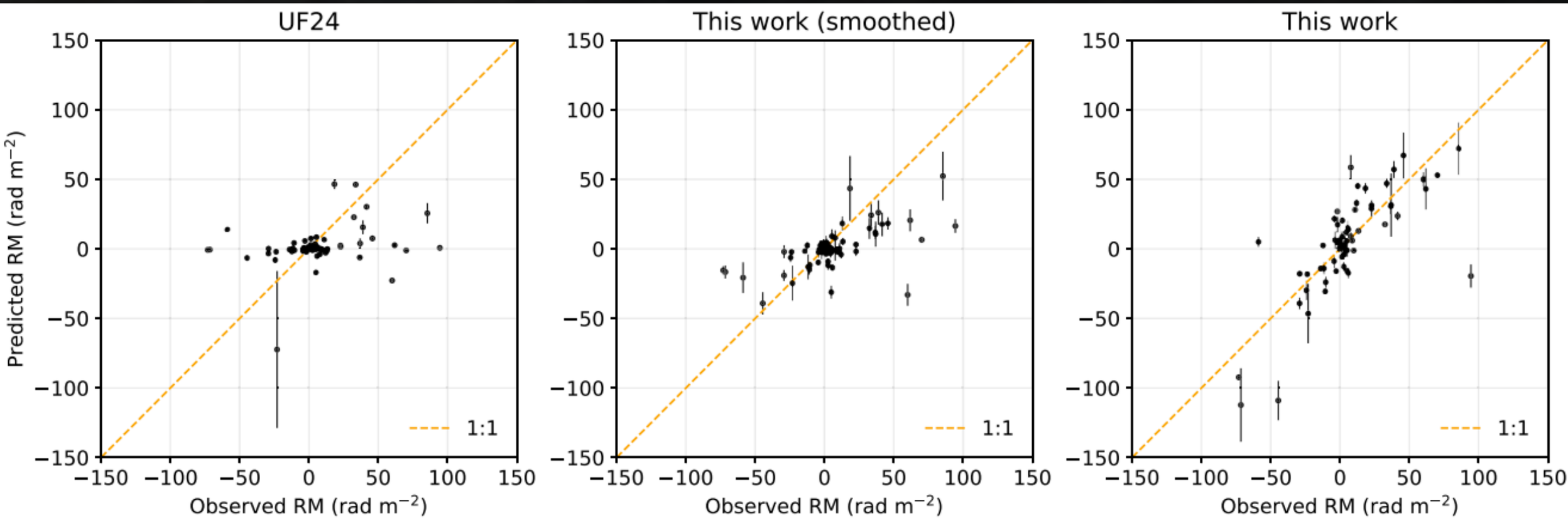
McCallum, Frank+ 2026

A 3D map of the radial component of the magnetic field: posterior samples



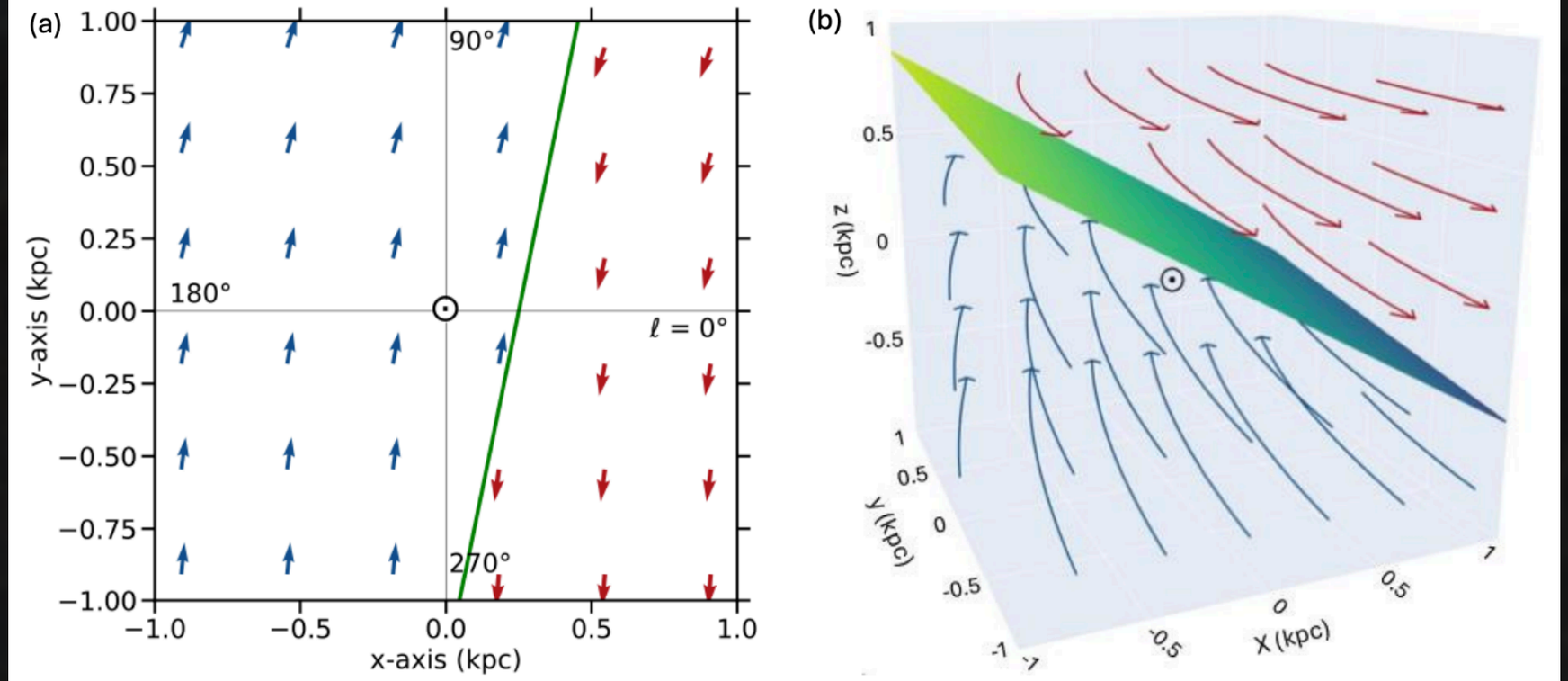
McCallum, Frank+ 2026

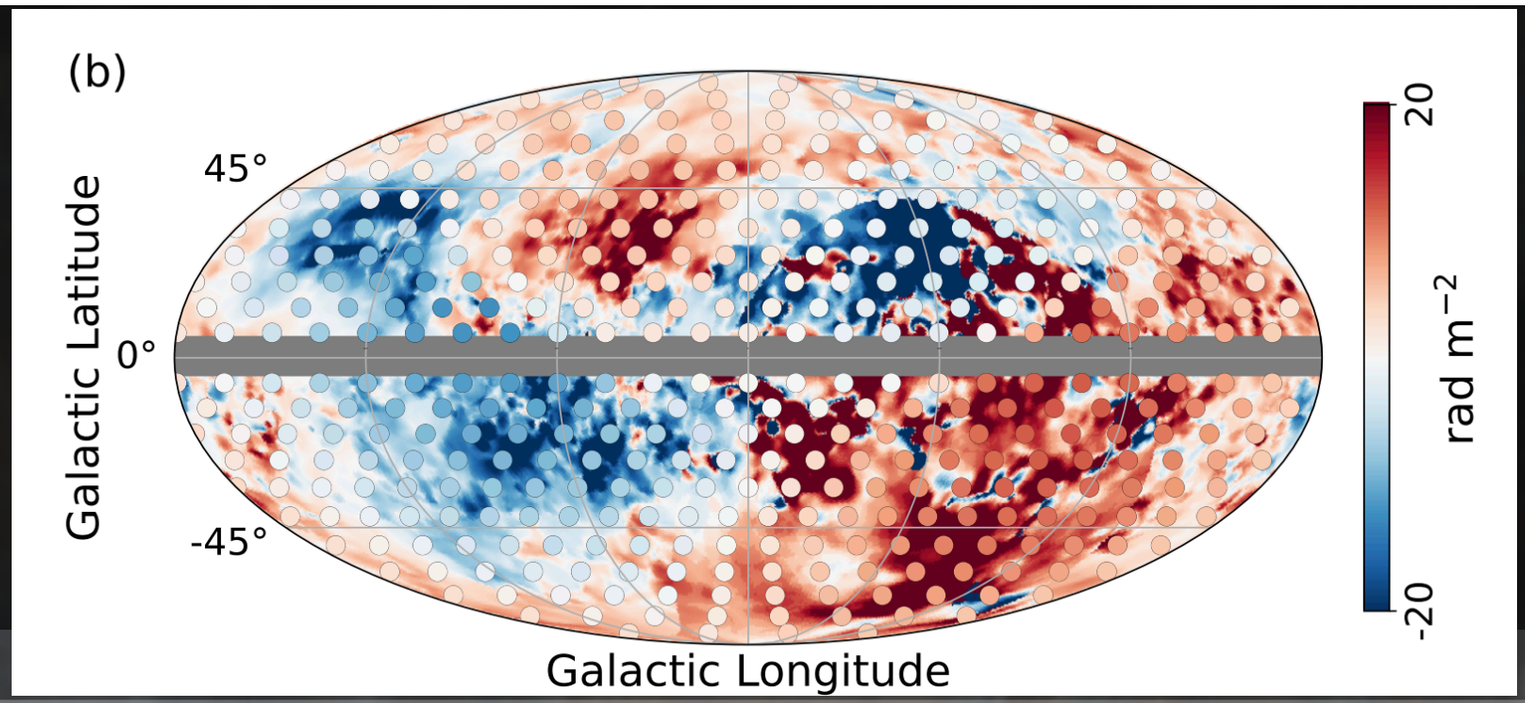
The small-scale map structure is necessary for consistency with pulsar RM data.



McCallum, Frank+ 2026

See also: A 3D model for a nearby magnetic field reversal

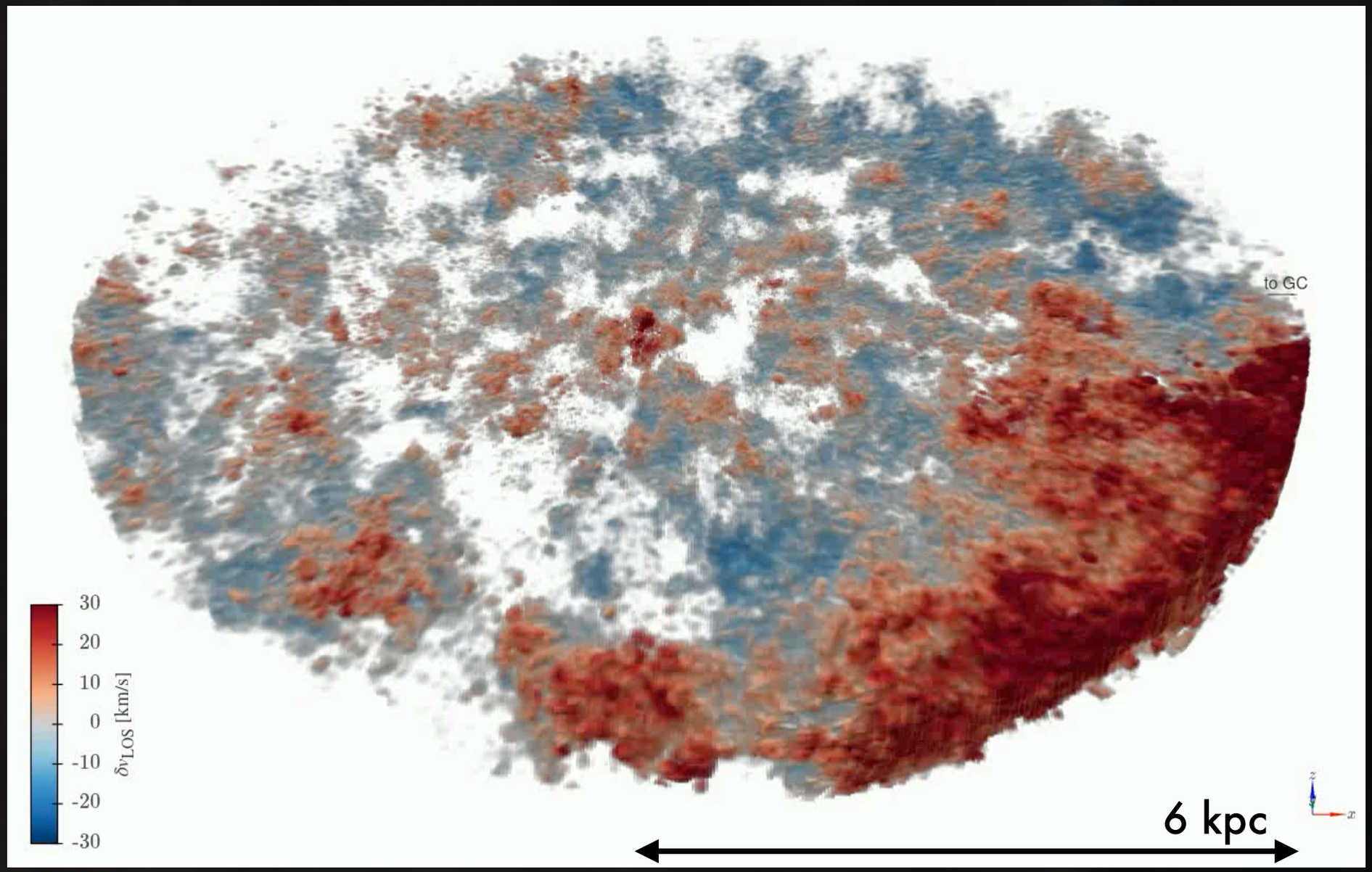




Background:
DRAGONS+STAPS
Faraday depth moment 1
Dots: reversal model

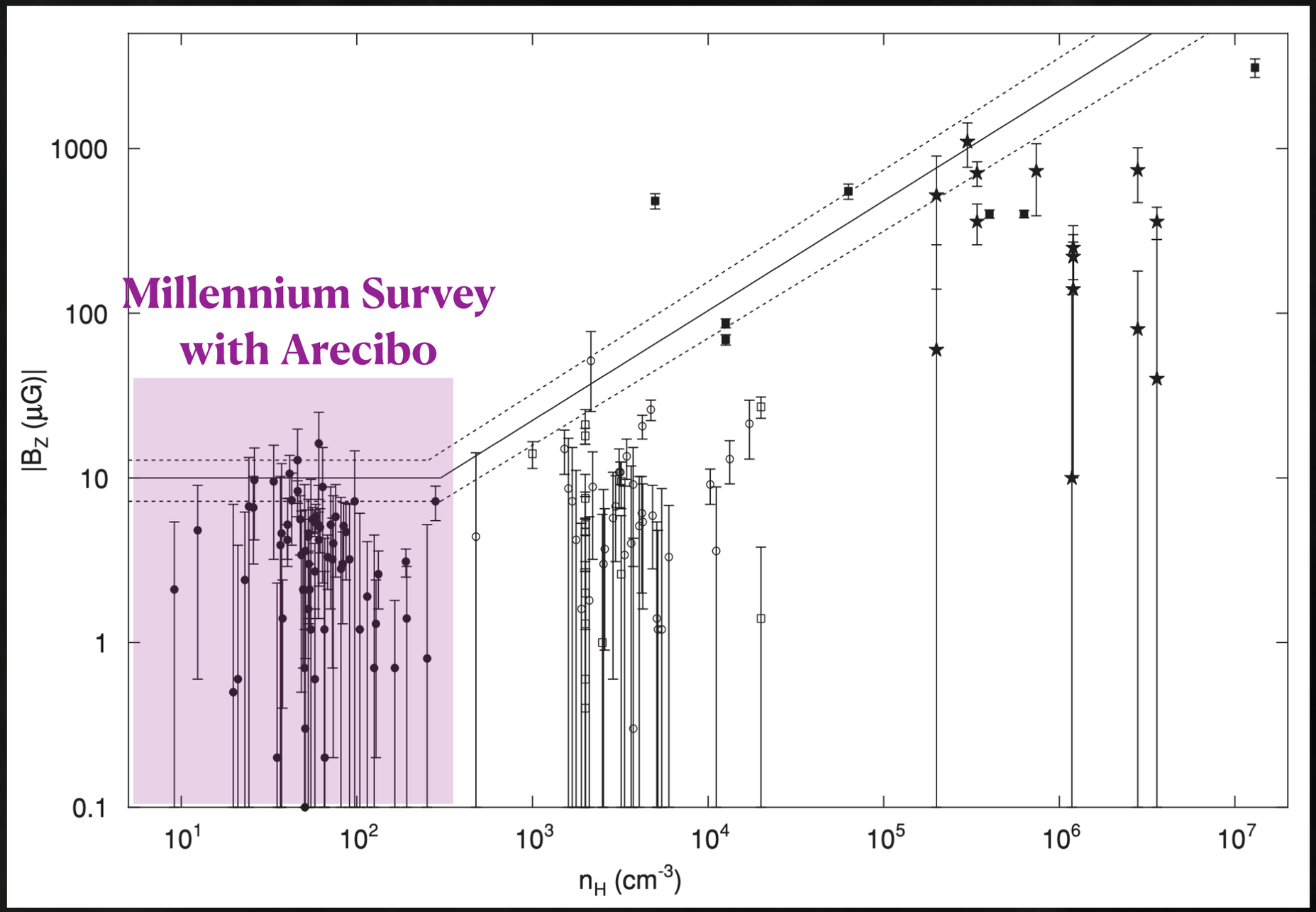
Booth, Ordog+ 2026

See also: A forthcoming 3D inference of the differential velocity field from DIB absorption data



Frank, Saydjari+ in prep

Zeeman splitting: The only direct ISM magnetic field strength measurements (for the ISM beyond Voyager)

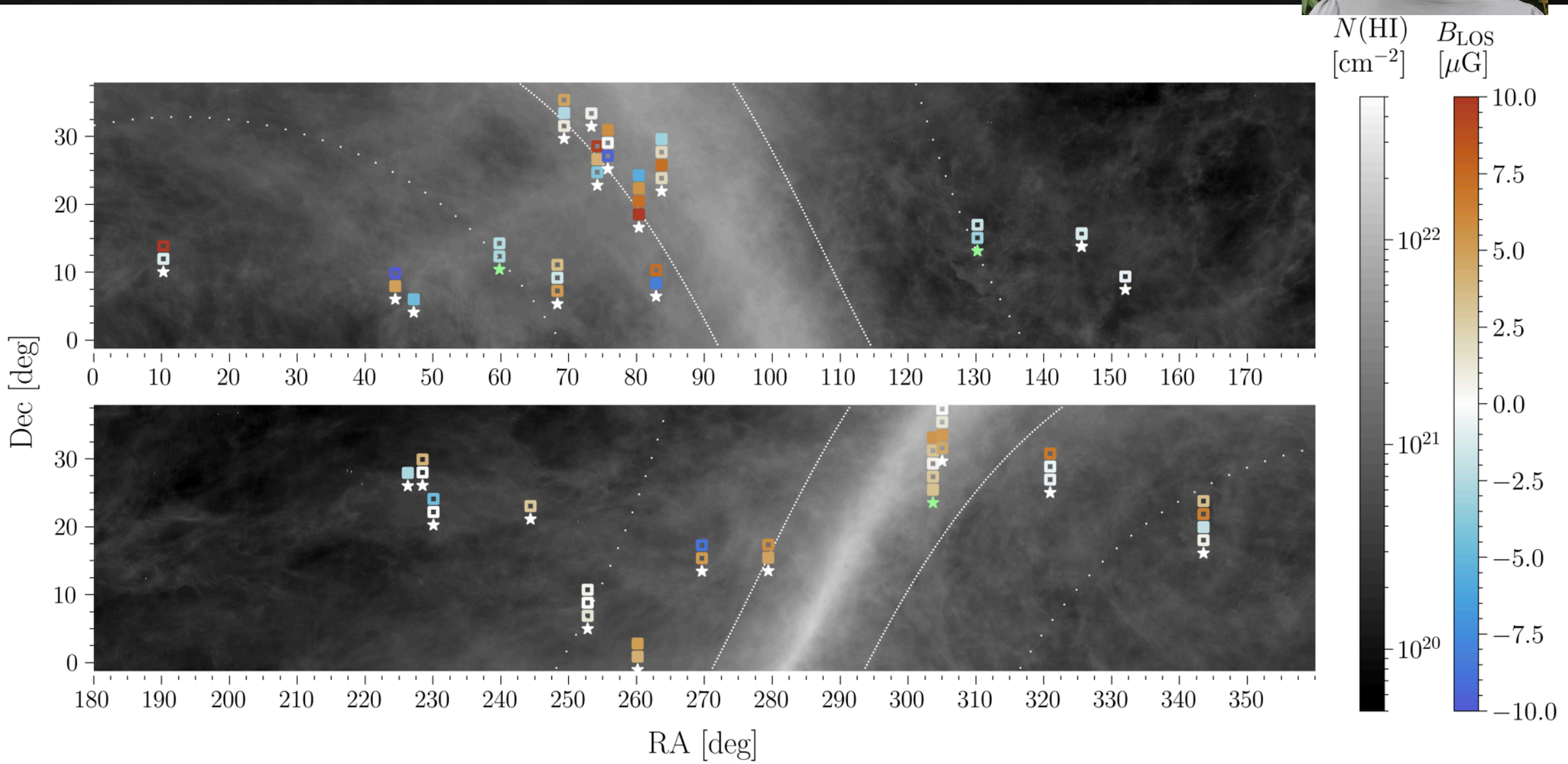


Crutcher+ 2010

Zeeman splitting gives a local measurement of B_{LOS}.

Marta Nowotka



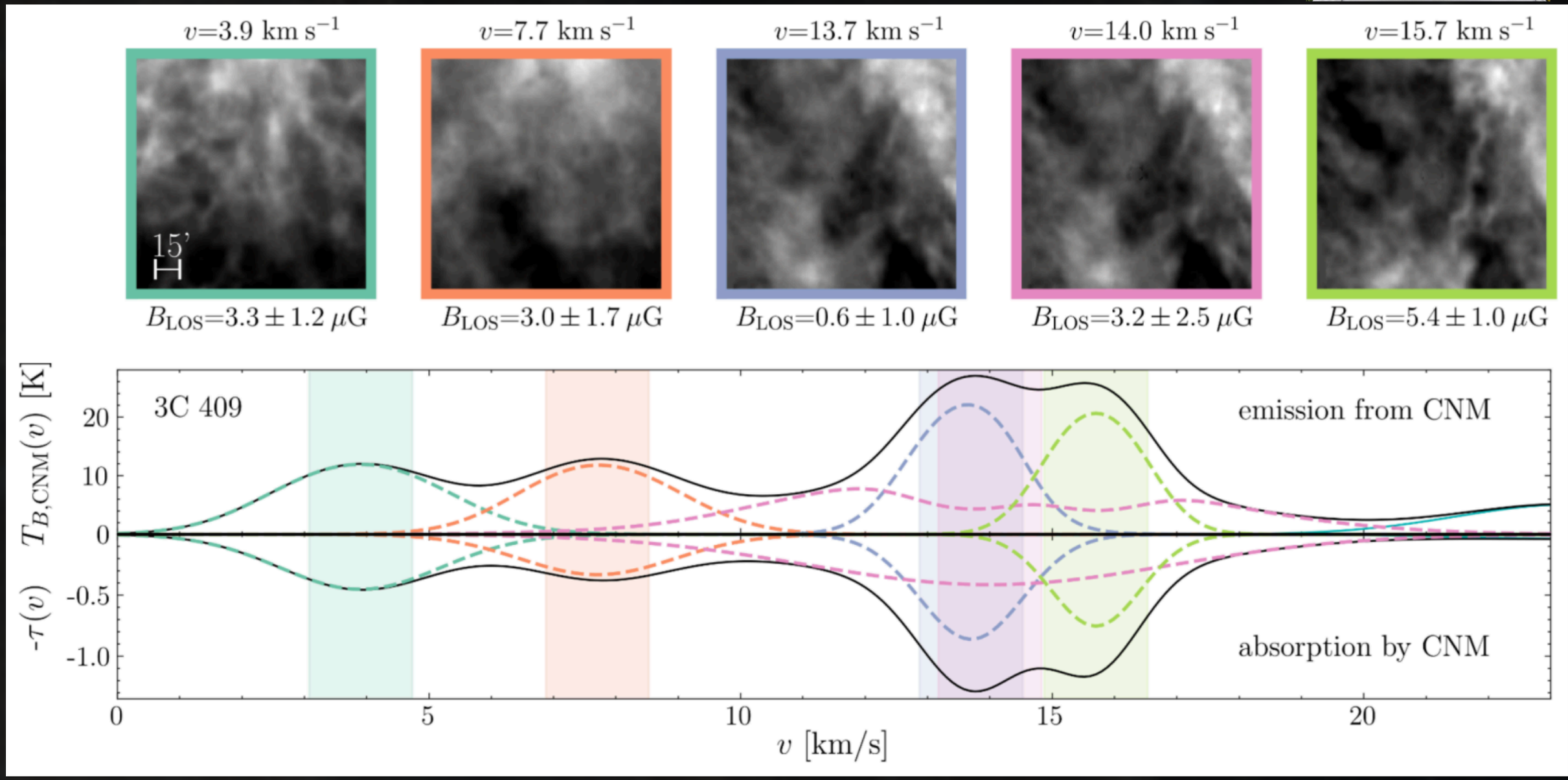


Nowotka, Clark+ 2025

Zeeman measurements of B_{LOS} correlate with the dispersion of local HI emission filaments.

Marta Nowotka

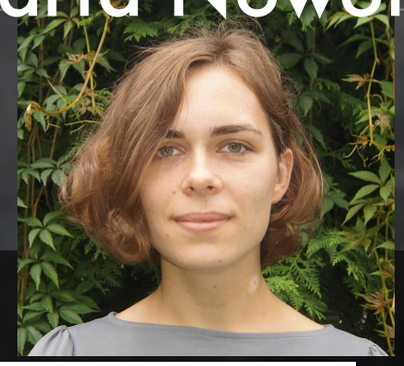


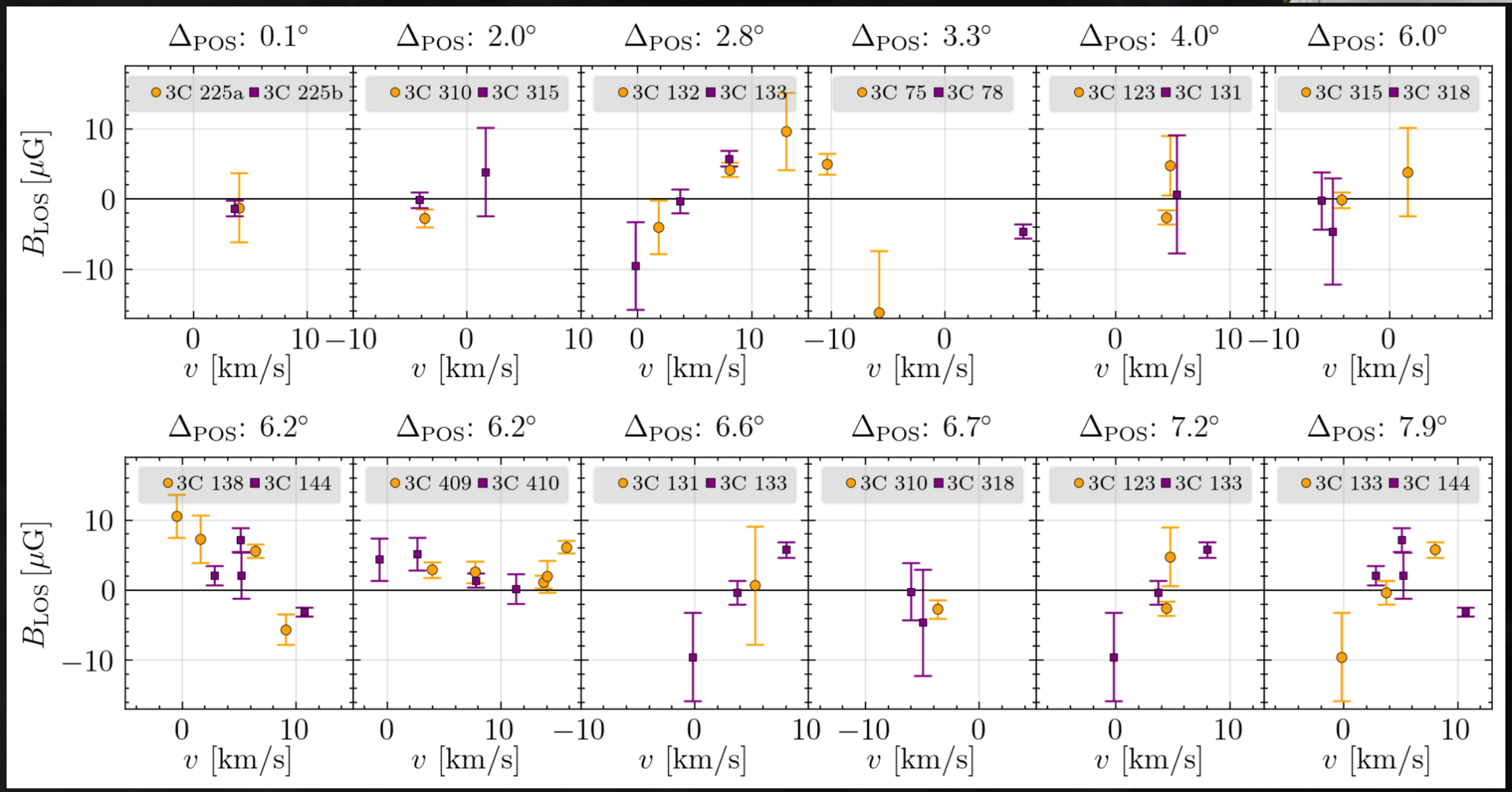


Nowotka, Clark+ 2025

We constrain the coherence of the magnetic field in the cold gas.

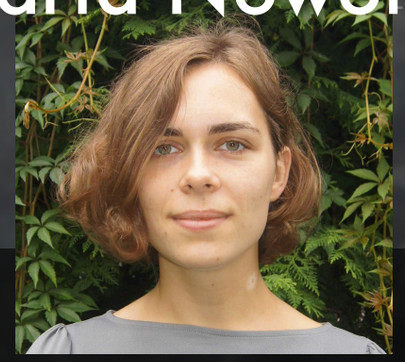
Marta Nowotka



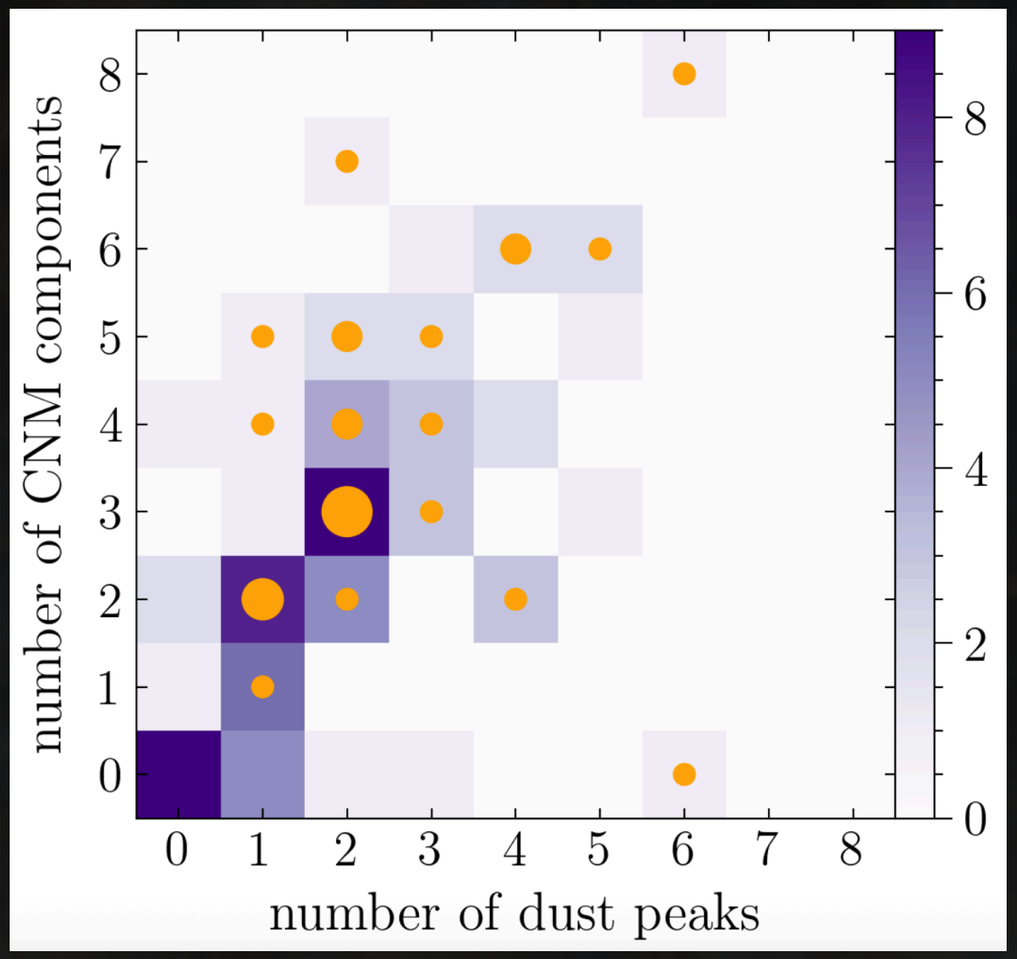


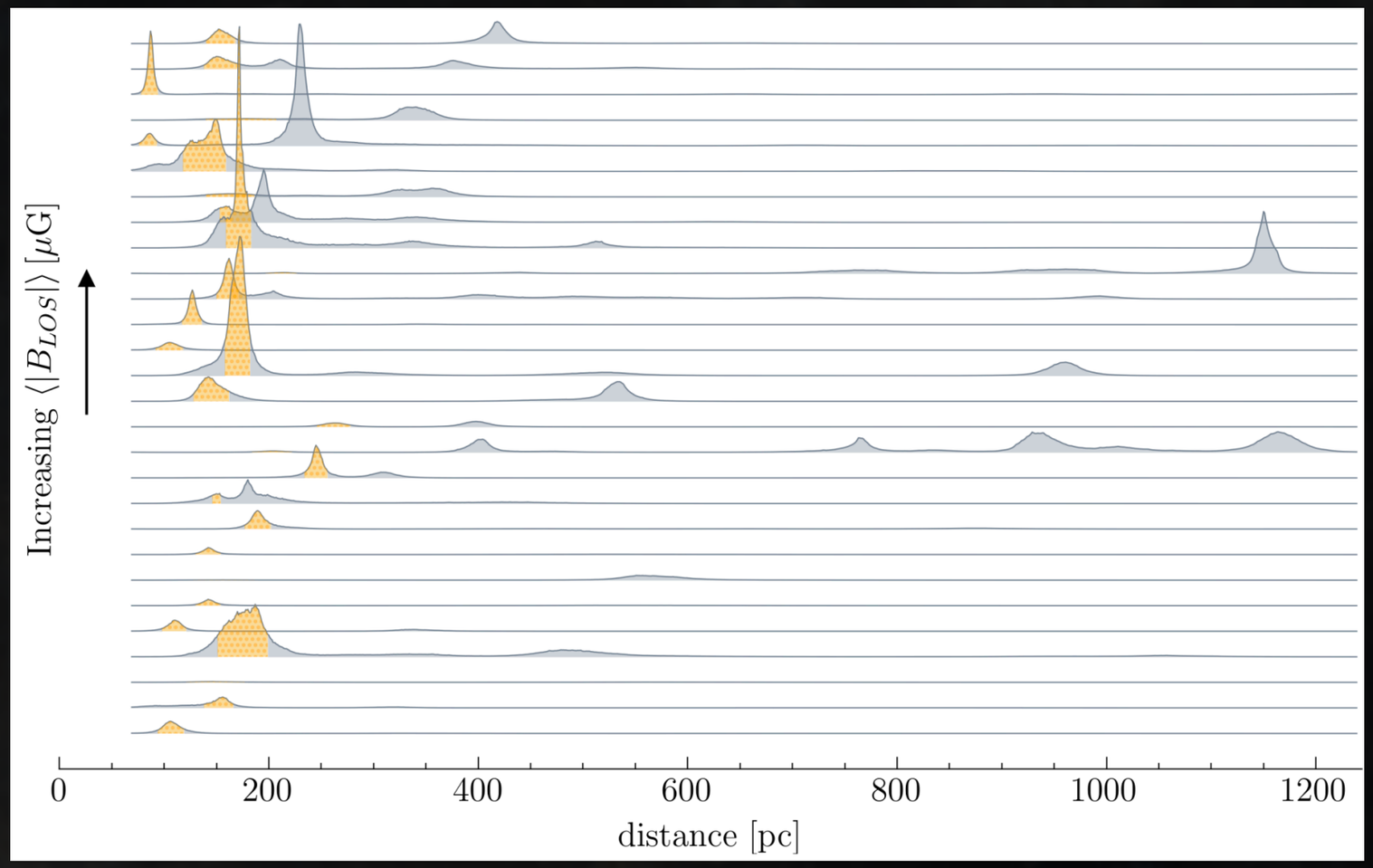
Nowotka, Clark+ 2025

Marta Nowotka



We constrain the *spatial* coherence of the magnetic field in the cold gas.



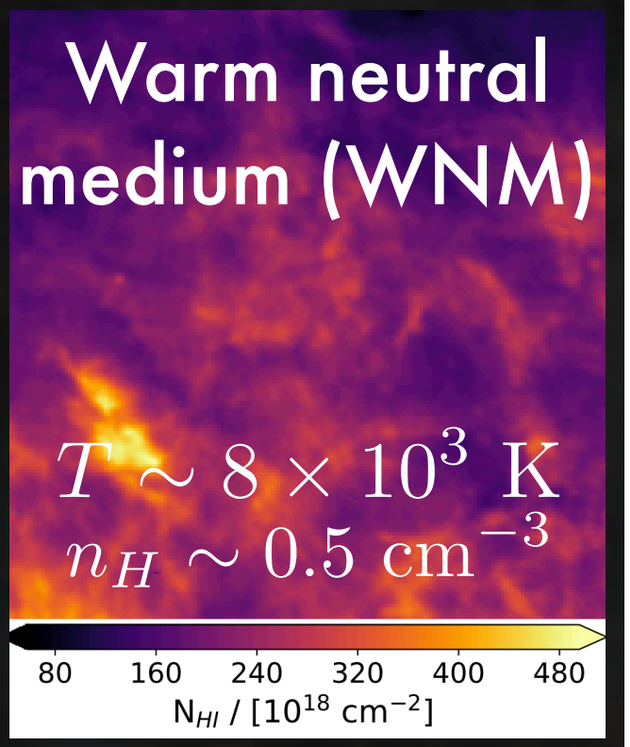


Coherent magnetic fields on scales of $\gtrsim 7$ pc

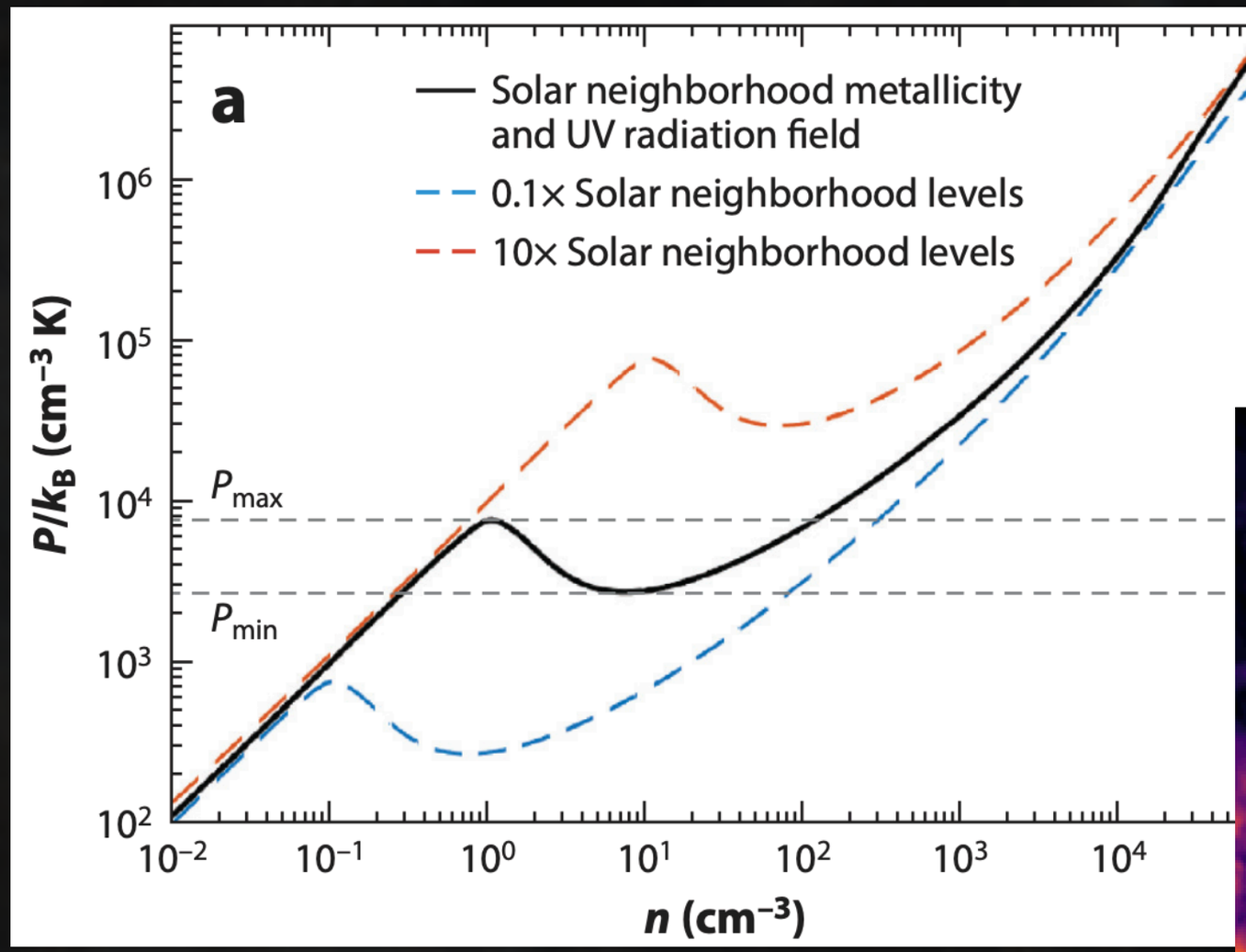
Nowotka, Clark, Burkhart, Fissel, Ching, Robishaw, Heiles 2025
arXiv:2508.20065

The neutral ISM is multi-phase.

Warm neutral medium (WNM)



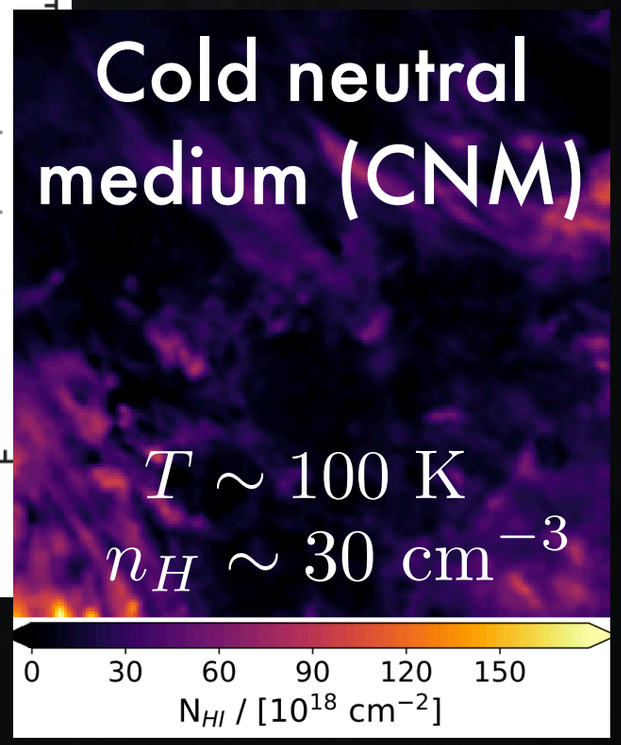
Marchal+ 2019



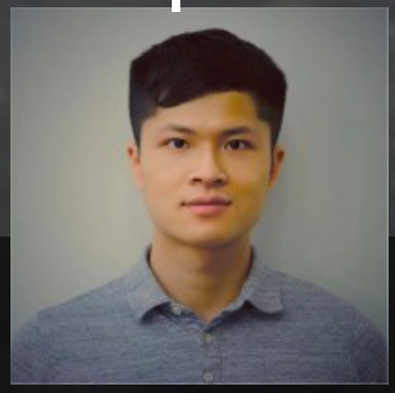
McClure-Griffiths+ 2023

See also Field+ 1969, Wolfire+ 2003

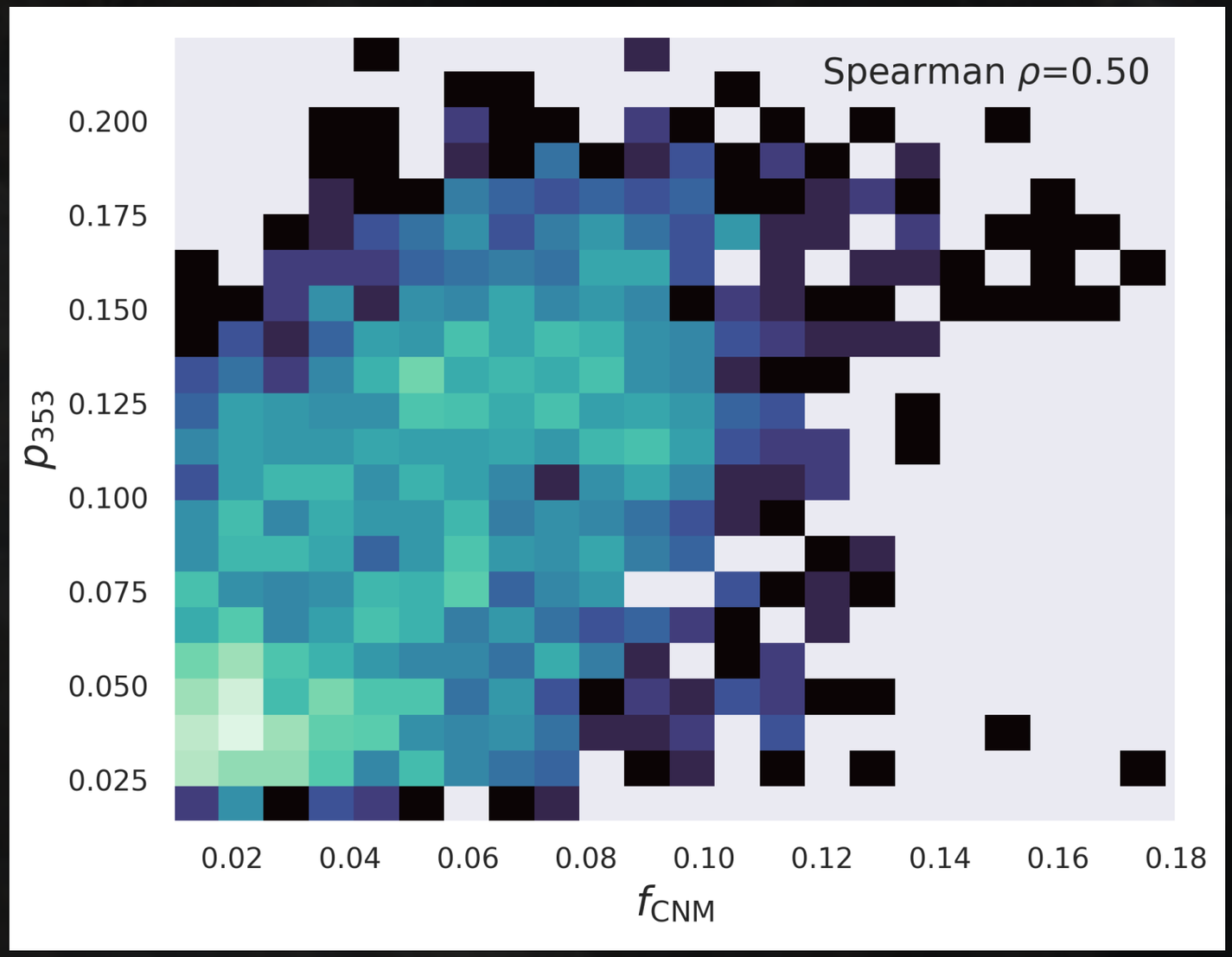
Cold neutral medium (CNM)



Minjie Lei



The dust polarization fraction is correlated with the CNM mass fraction in the diffuse ISM.

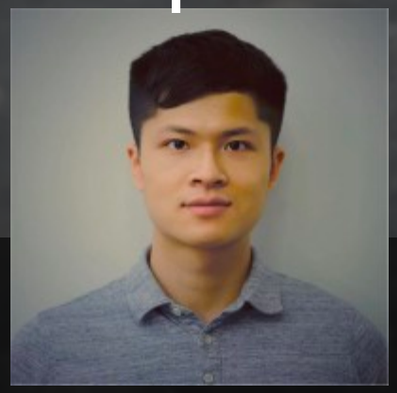


p_{353} from Planck

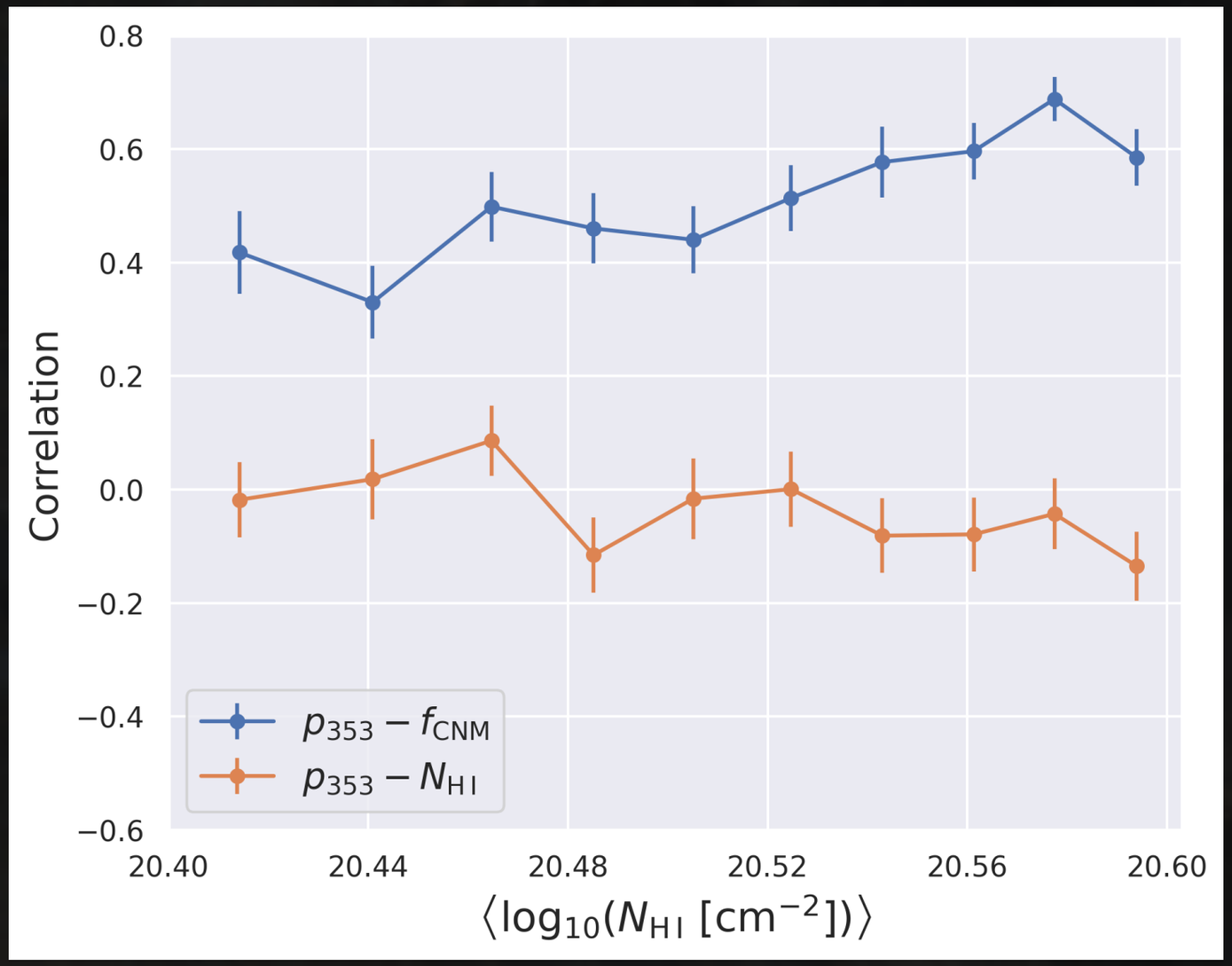
f_{CNM} from Murray+ 2020

Lei & Clark 2024

Minjie Lei



The dust polarization fraction is correlated with the CNM mass fraction in the diffuse ISM.



The dust polarization fraction is correlated with the CNM mass fraction in the diffuse ISM…

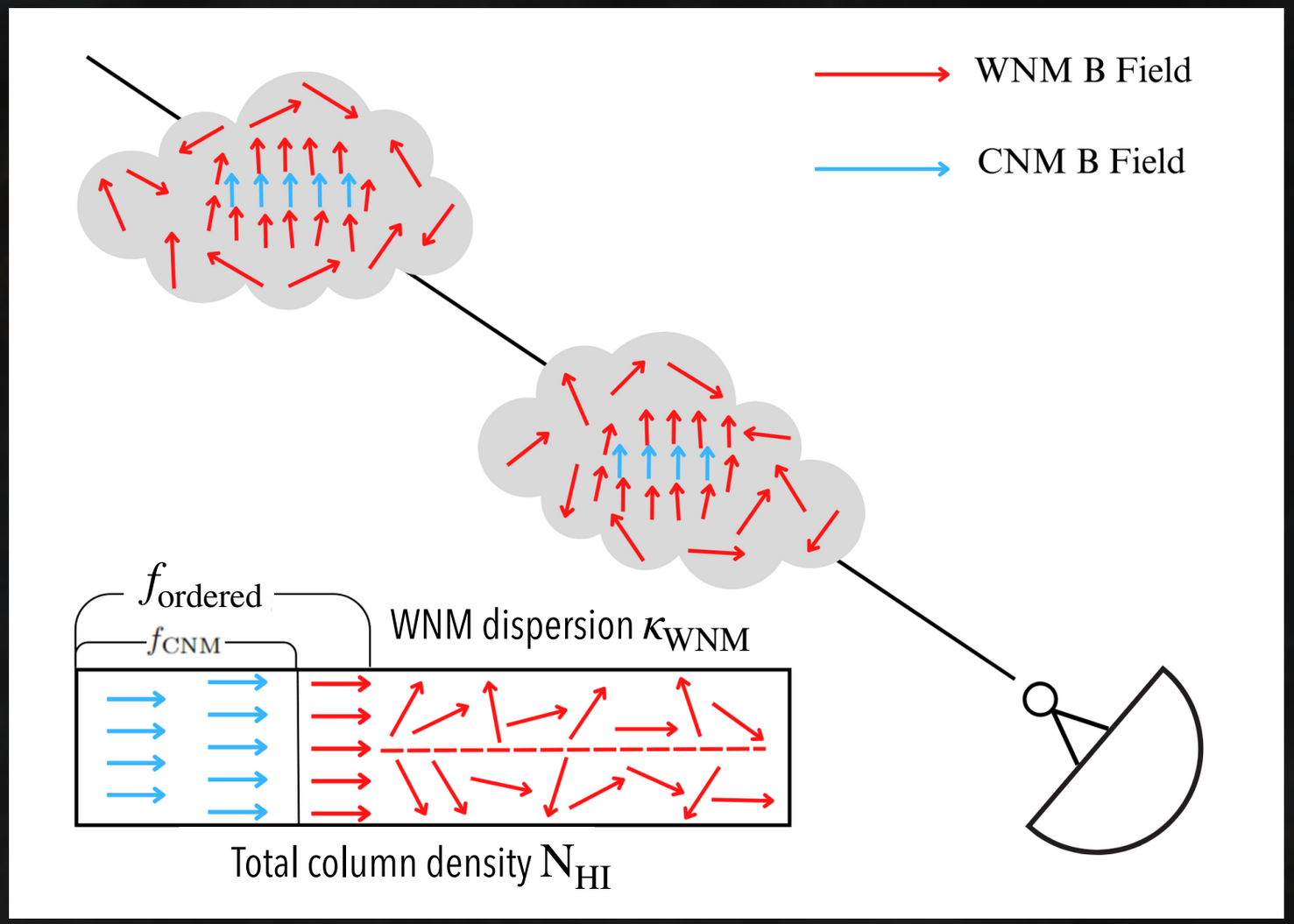
…where it is uncorrelated with the total HI column.

p_{353} from Planck

f_{CNM} from Murray+ 2020

Lei & Clark 2024

We constrain the relative degree of magnetic disorder between CNM and WNM columns.

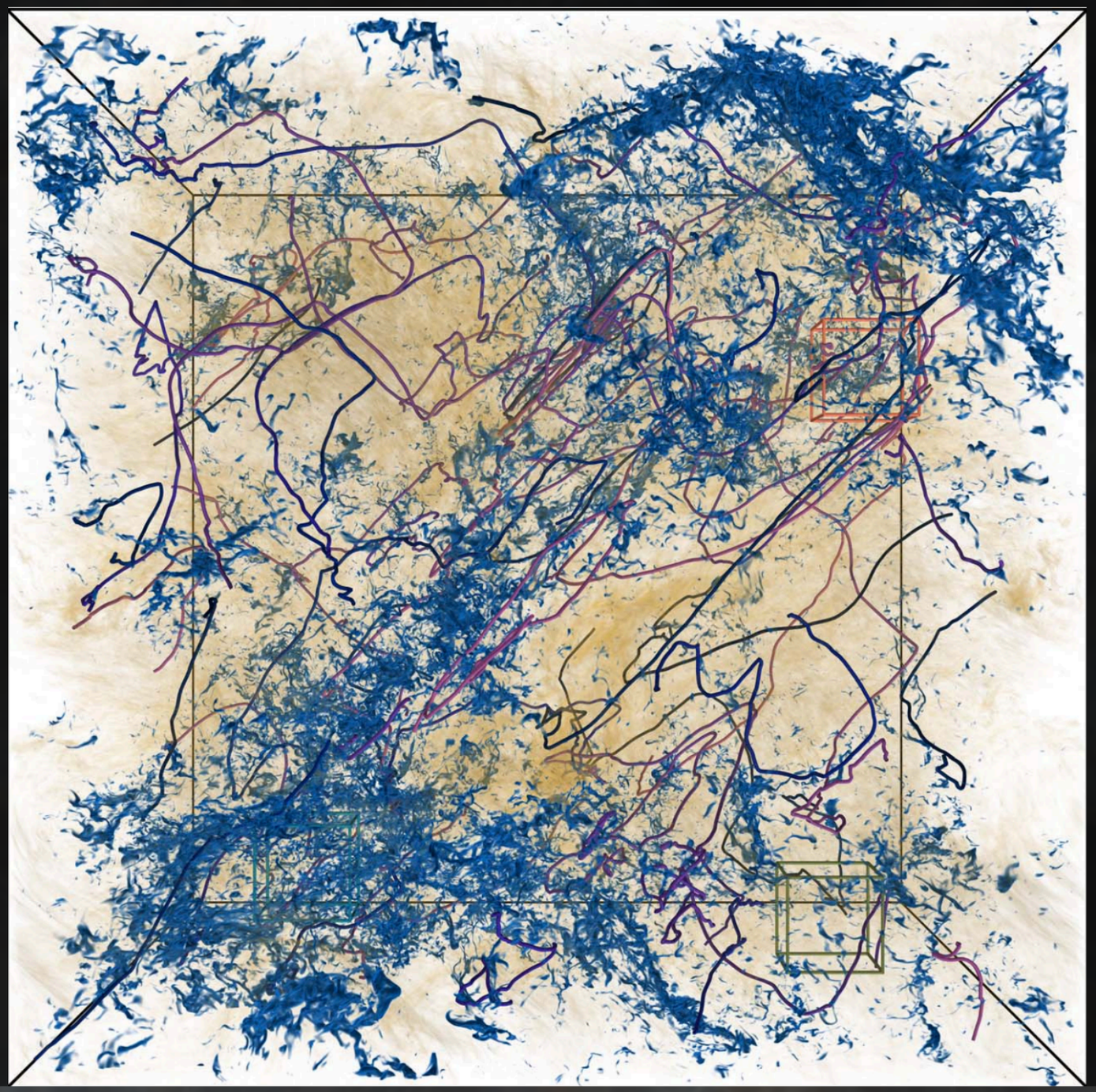


The data suggest a more magnetically ordered CNM forming out of a disordered WNM.

Lei & Clark 2024

We find $p_{\rm WNM} \sim 0.2\ p_{\rm CNM}$ and a relatively ordered magnetic field in an additional $18\,\%$ of the HI mass

The data suggest a more magnetically ordered CNM forming out of a disordered WNM.



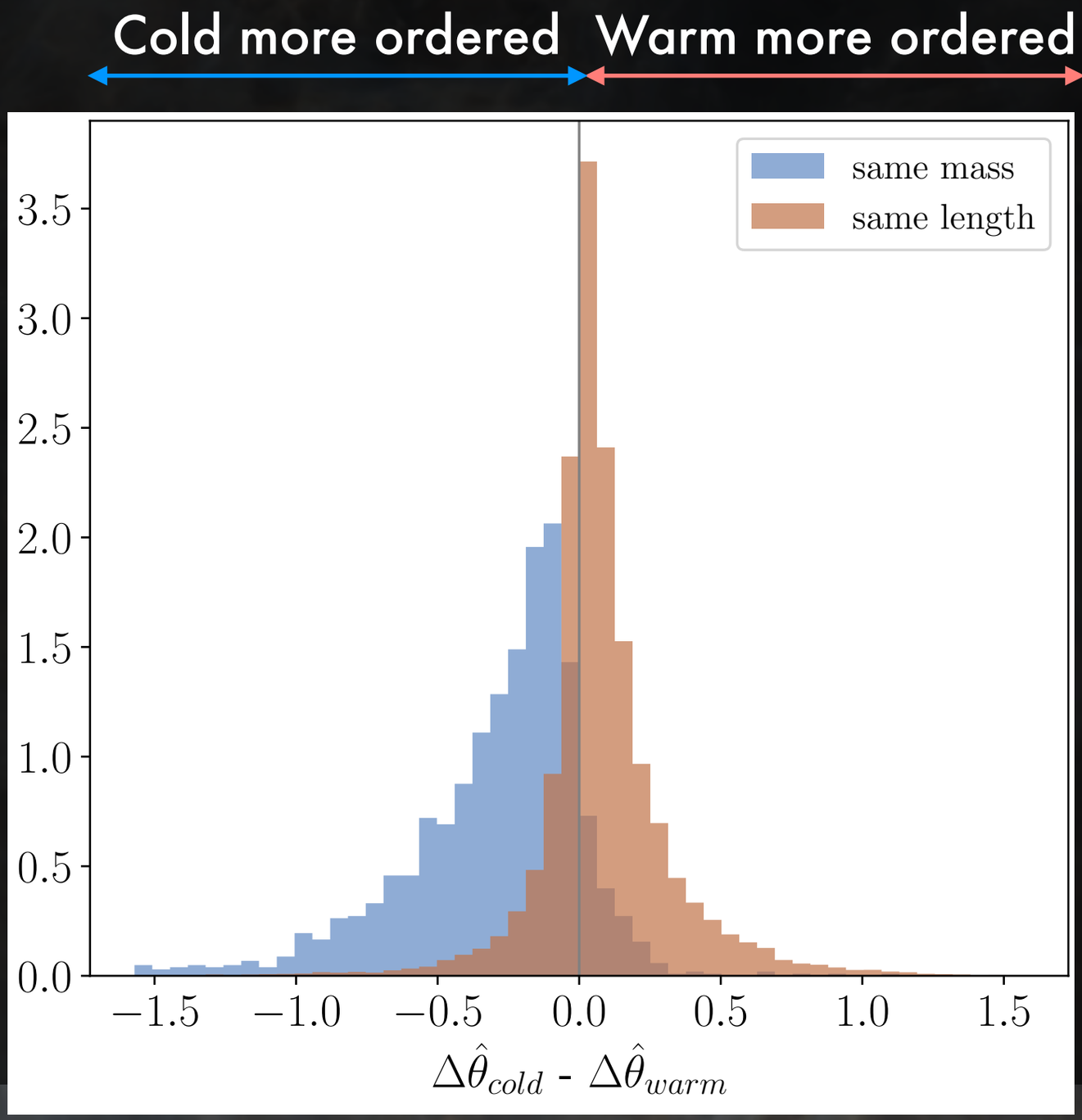
Do we find the same in high-resolution, multi-phase numerical simulations?

Fielding+ 2023

At equal mass, a cold cloud tends to be more magnetically ordered than a warm one.



Iryna Butsky



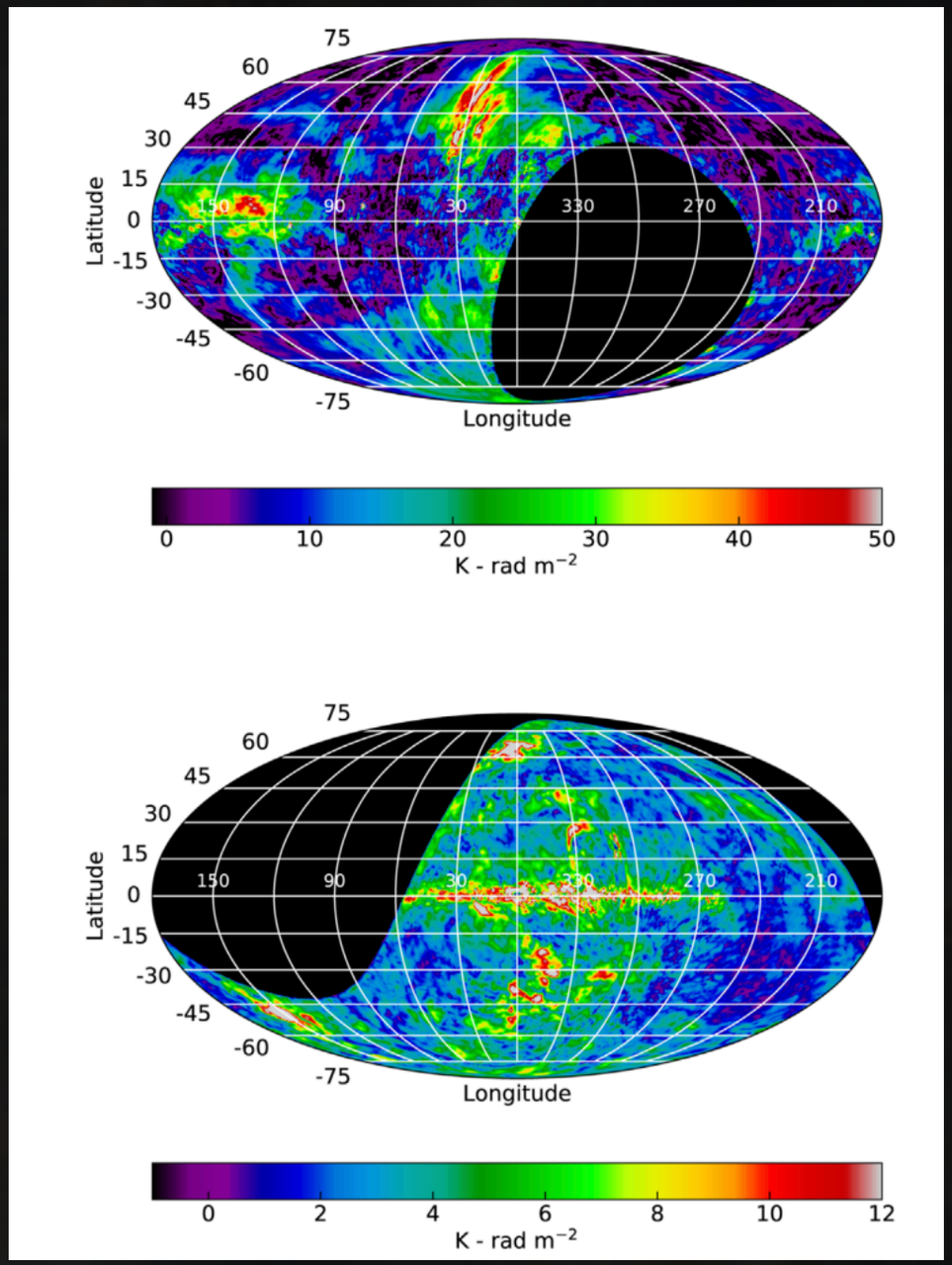
Histogram of magnetic disorder for cold - warm cloud pairs

Butsky, Redshaw, Lei, Clark, Fielding 2026

The Global Magneto-Ionic Medium Survey (GMIMS) surveys polarized synchrotron emission.

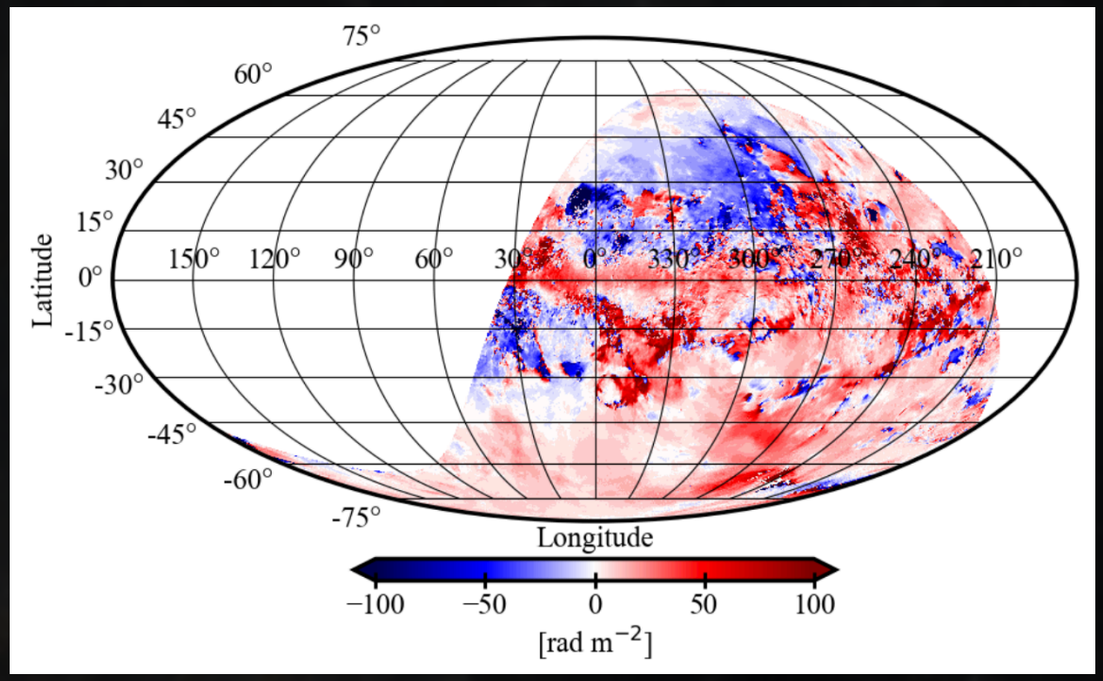
DRAO
1270 - 1750 MHz

Parkes
300 - 480 MHz



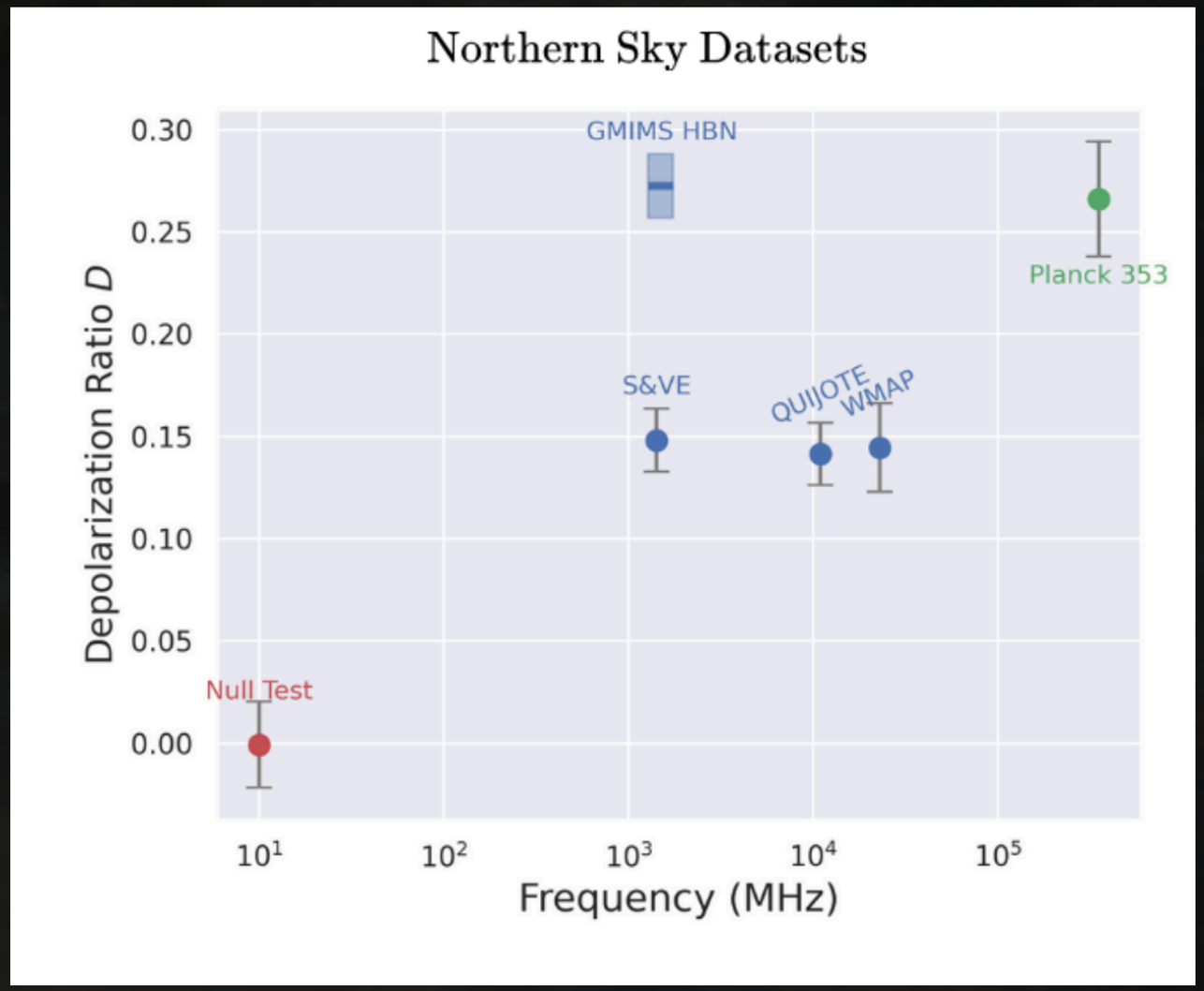
Dickey, Landecker+ 2019

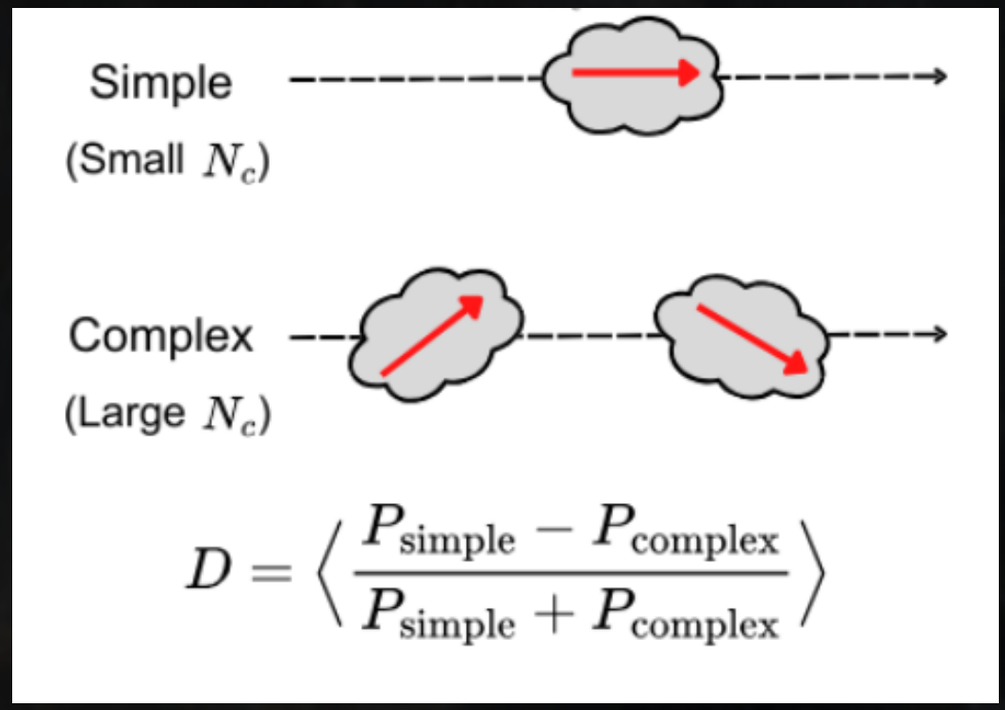
Parkes
1328–1768 MHz



Raycheva, Haverkorn+ 2025

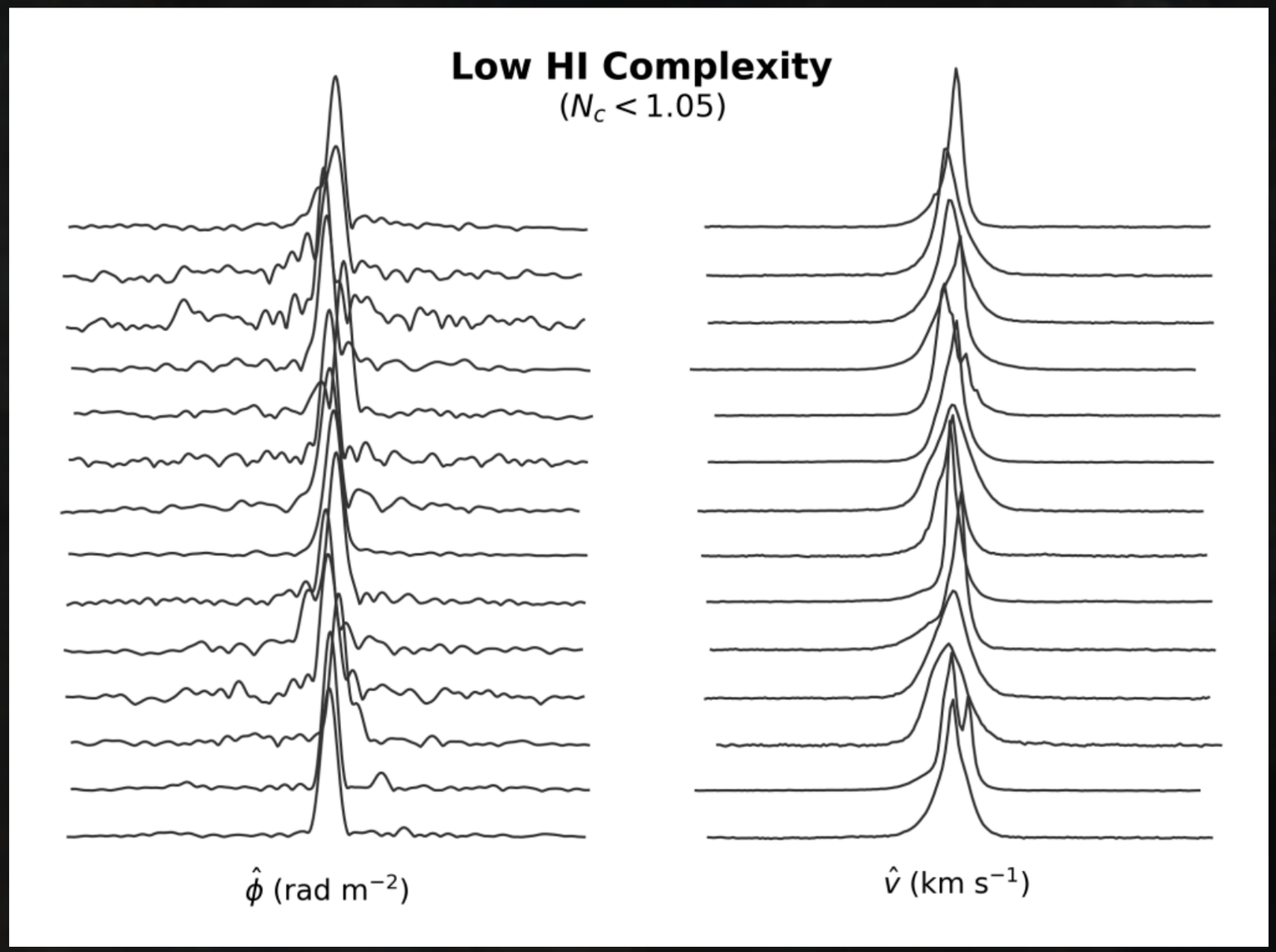
We measure an imprint of the neutral medium on Faraday-rotated diffuse synchrotron emission.





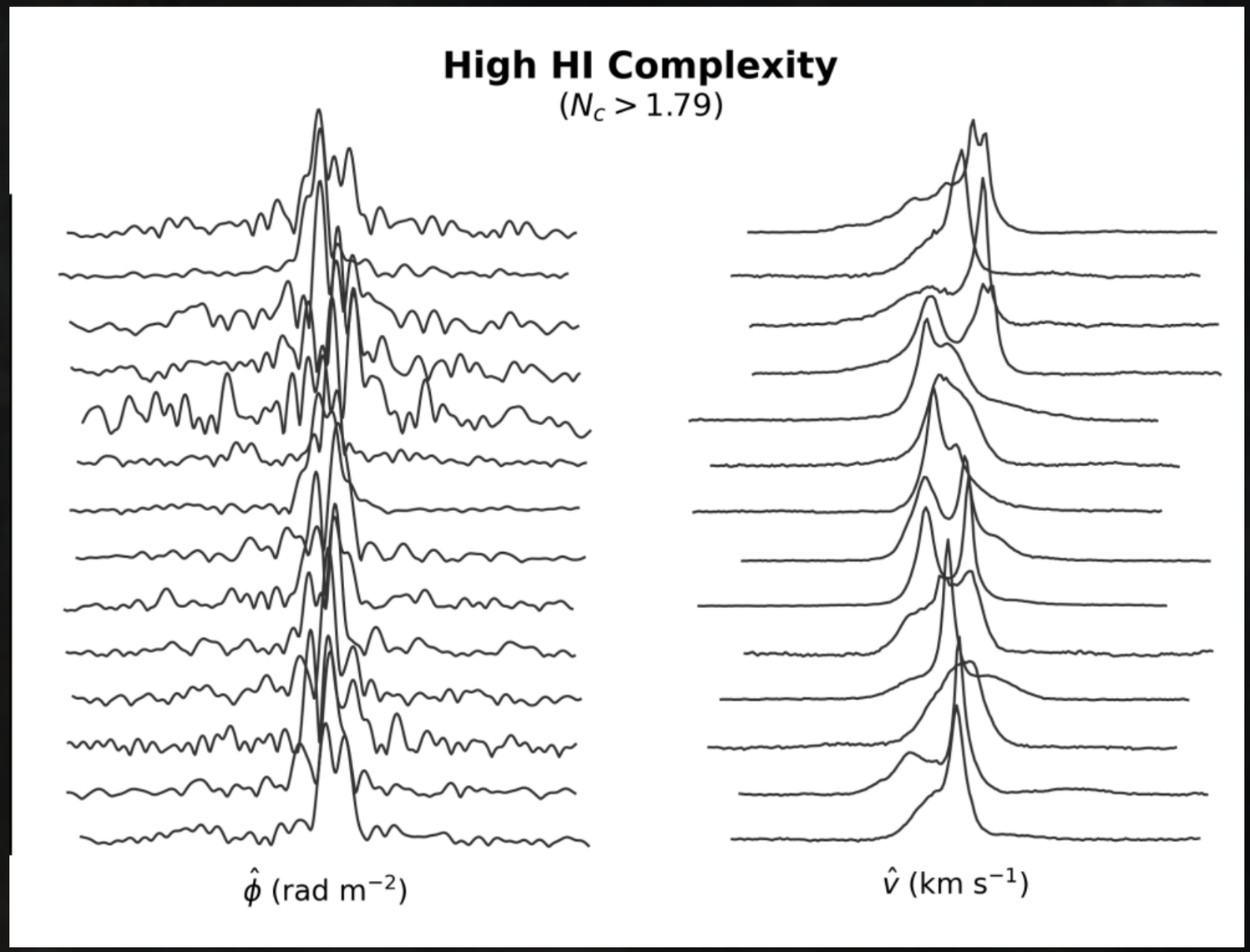
Lei, Clark+ 2026
arXiv:2606.11359

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We have new JWST observations of the cold ISM on very small scales!



Peek et al in prep incl S.E. Clark, Marta Nowotka, Andrew Saydjari, Armin Rest, Claire Murray, Catherine Zucker, Chris Clark, Christina Lindberg, Danny Milisavljevic, Dennis Hartmann, Drummond Fielding, E F Schlafly, Elizabeth Tarantino, Erik Tollerud, Jacob Jencson, Karl Gordon, Marc-Antoine Miville-Deschênes, Rodrigo Angulo, Sebastian Gomez

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Marta Nowotka

Comparing these data to tiny-scale atomic structure:
Nowotka et al.
in prep

August 19, 2024

Observations of the interstellar medium
contain a wealth of morphological information.
Multi-tracer analyses are particularly powerful.

We are in a new era of probing the physics
of the nearby interstellar medium in 3D.

We report a new constraint on the coherence of magnetic fields in the cold ISM (Nowotka+ 2025) and the relative magnetic field disorder between neutral ISM phases (Lei & Clark 2024).

Creative techniques unlock the rich physics
encoded in our data.

clarkgroup.stanford.edu