

# The Diffuse & Translucent interstellar medium

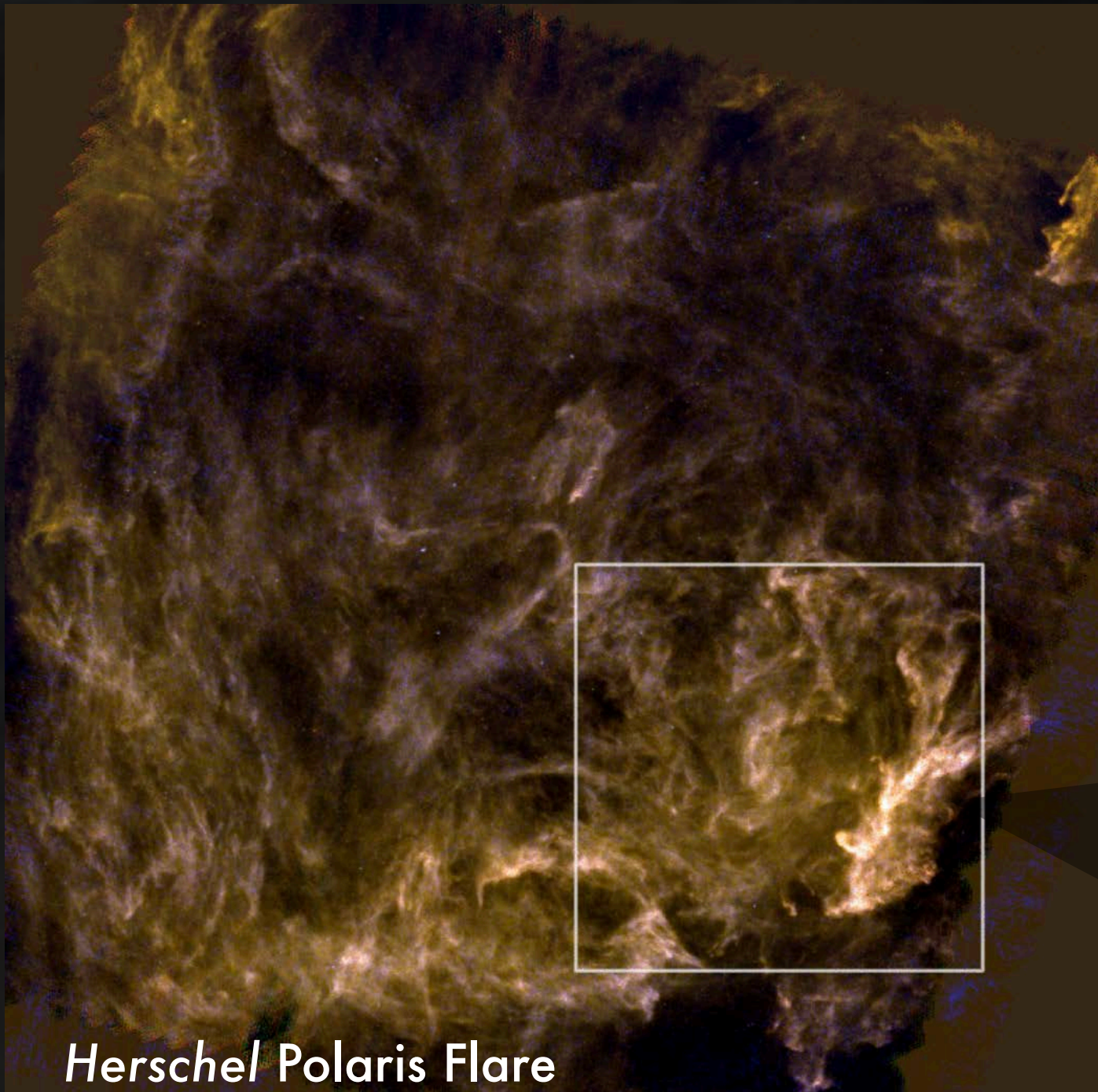
Susan E. Clark | Stanford University,  
KIPAC

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

Ari Cukierman, Laywood Fayne, Francesca Fernandes, Eliza Gallagher,  
George Halal, Minjie Lei, Marta Nowotka, Iñigo Valenzuela Lombera,  
Enrique Lopez Rodriguez, Will Surgent, Kendall Zylstra



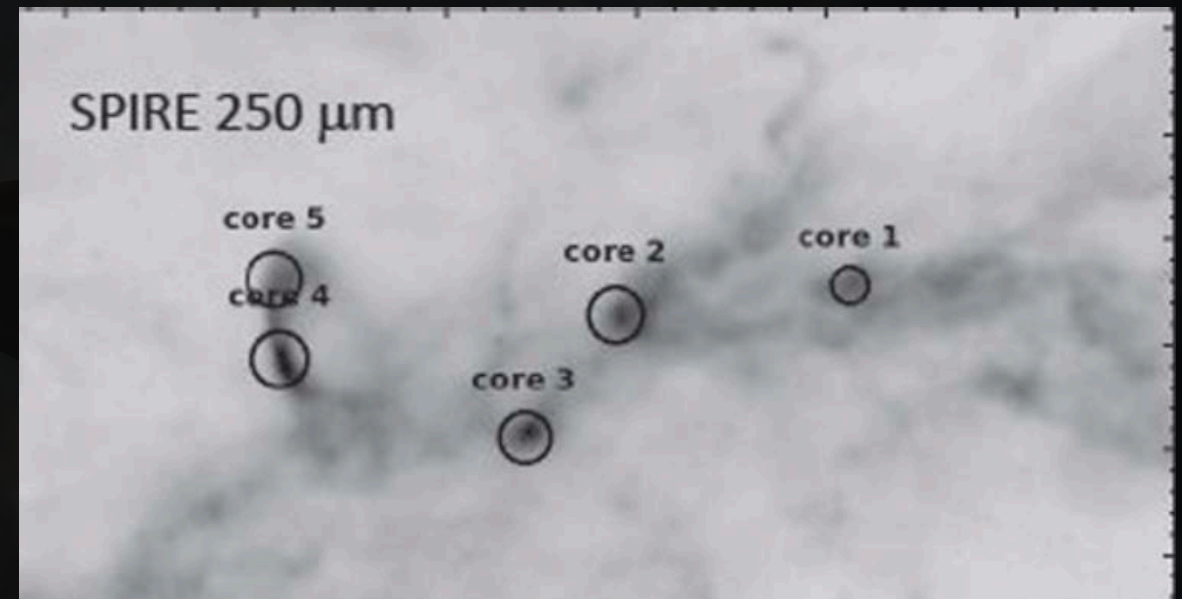
The diffuse and translucent ISM is sculpted by rich multi-scale physics.



Herschel Polaris Flare  
Men'shchikov+ 2018



GALFA-HI diffuse HI  
Clark 2018a





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# The diffuse and translucent ISM: a few questions

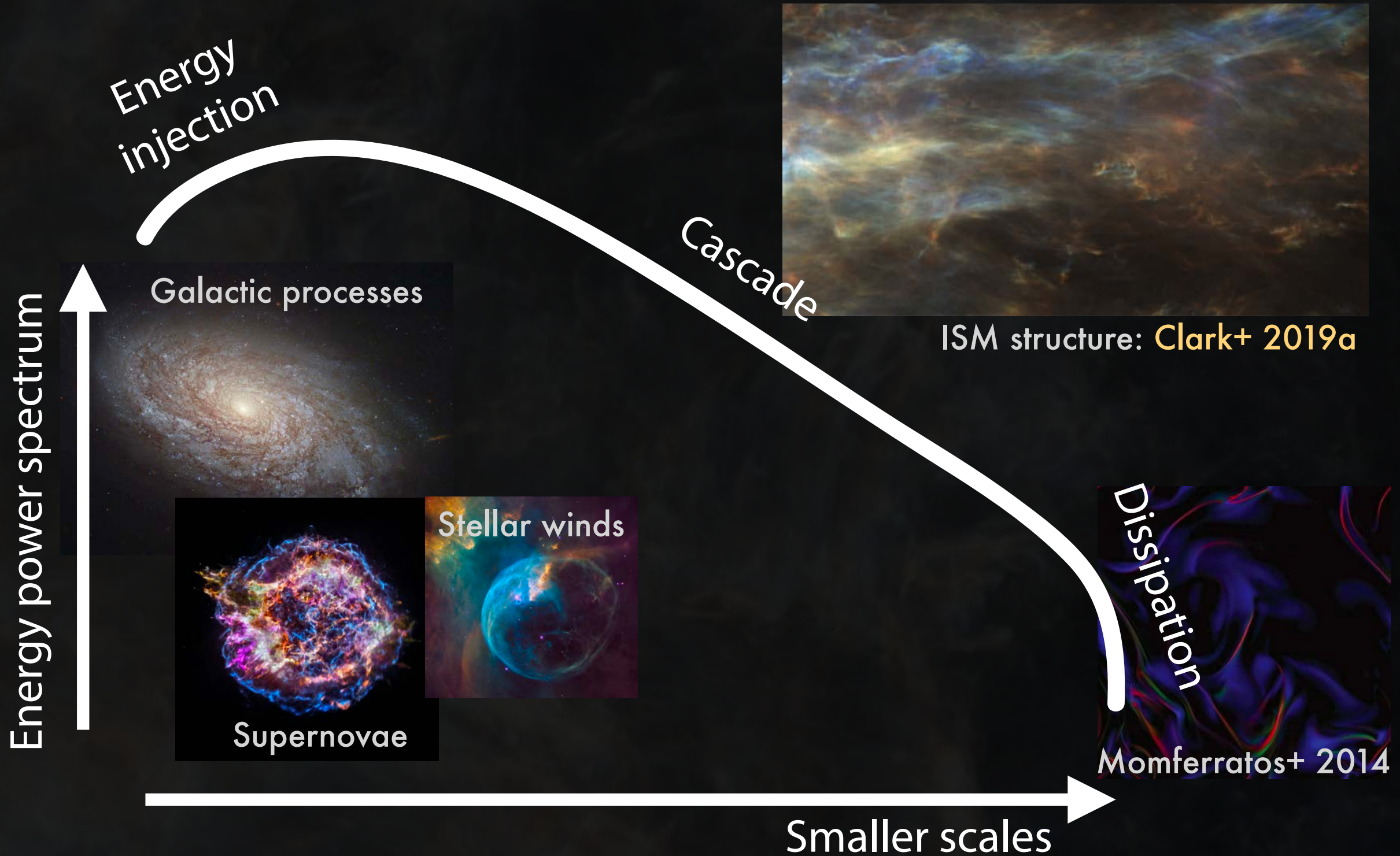
What is the nature of **MHD turbulence** in the ISM?  
What dominates turbulent dissipation?

How do **magnetic fields** affect structure formation in the diffuse medium?

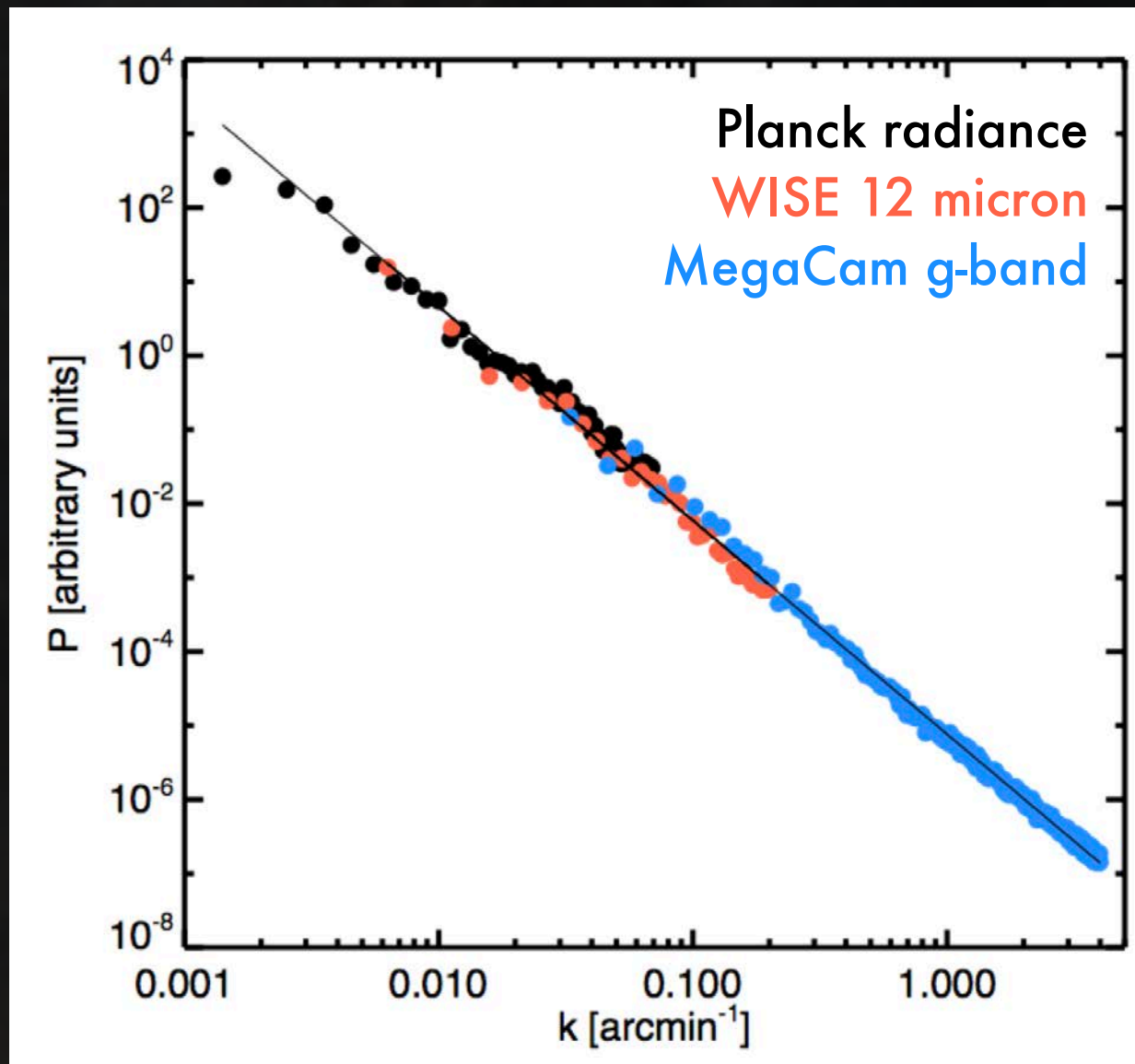
What role do the above play in **phase transitions**?



# What is the nature of magnetohydrodynamic turbulence in the ISM?



# What dominates turbulent dissipation in the ISM?

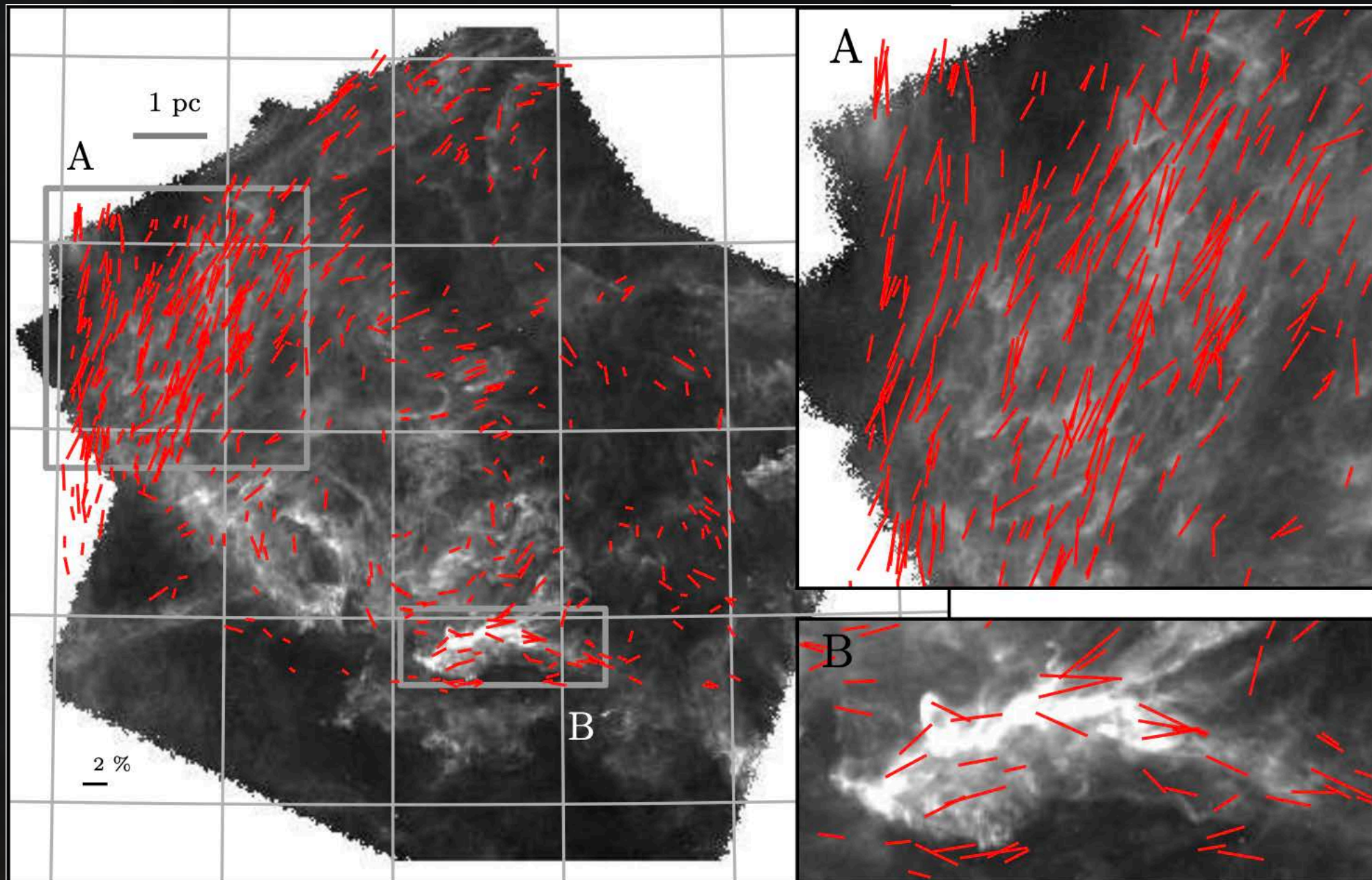


Miville-Deschenes+ 2016

No sign of dissipation  
at  $\sim 0.01$  pc in CNM



# How do magnetic fields affect structure formation in the diffuse and translucent medium?



*Herschel* Polaris Flare  
Panopoulou+ 2018



# Morphology

encodes complex physical information

## Cloud Identification Chart

### Clouds of Great Vertical Extent



Cumulonimbus calvus



Cumulonimbus capillatus



Cumulonimbus capillatus

### Cloud Names

Clouds are classified by family based on their altitude: high, middle, low, or vertical. The families include 10 principal cloud types called **genera** which are named after their altitude and form. Each genus is subdivided into **species** describing the size, shape, and form of cloud elements within a layer.

Genus	Species
High Family	castellanus
	fibratus
	floccus
	spissatus
uncinus	
Middle Family	castellanus
	floccus
	lenticularis
	stratiformis
Low Family	fibratus
	nebulosus
Middle Family	castellanus
	floccus
	lenticularis
Middle Family	stratiformis
	stratiformis
	stratiformis
Low Family	fractus
	humilis
	mediocris
Low Family	congestus
	capillatus
	capillatus
Low Family	fractus
	nebulosus
	nebulosus
Low Family	castellanus
	lenticularis
	stratiformis

Not shown here is the subdivision of species called **varieties**. The variety describes layer thickness, the arrangement of cloud elements, or the presence of multiple layers.

**Example Names**  
 Genus only: Altocumulus  
 Genus + species: Altocumulus castellanus  
 Genus + species + variety: See website

### High Family














### Middle Family















### Low Family














### Accessory Clouds



Arcus (Shelf Cloud)



Mamma



Pileus (Cap Cloud)

### Identifying Clouds

**By Form**

**Cirriform:** Thin, wispy, with white delicate filaments, patches or narrow bands.

**Cumuliform:** Puffy, rounded, tufted clouds with distinct vertical cells or elements.

**Stratiform:** Layered, sheet-like clouds with a smooth appearance.

**By Altitude**

**High Family**  
 Above 16,500 feet (5,000 m)

Temperatures: Below freezing  
 Content: Ice crystals and some supercooled water  
 Cloud forms: Cirriform, stratiform, cumuliform  
 Principal types: Cirrus, cirrocumulus, cirrostratus

**Middle Family**  
 6,500 to 20,000 feet (2,000 - 6,000 meters)

Temperatures: Above and below freezing  
 Content: Supercooled water, water, and ice crystals  
 Cloud forms: Cumuliform, stratiform  
 Principal types: Altocumulus, altostratus, nimbostratus

**Low Family**  
 Below 6,500 feet (2,000 meters)

Temperatures: Above and below freezing  
 Content: Water, supercooled water, and ice crystals  
 Cloud forms: Stratiform, cumuliform  
 Principal types: Stratus, cumulus, stratocumulus, cumulonimbus

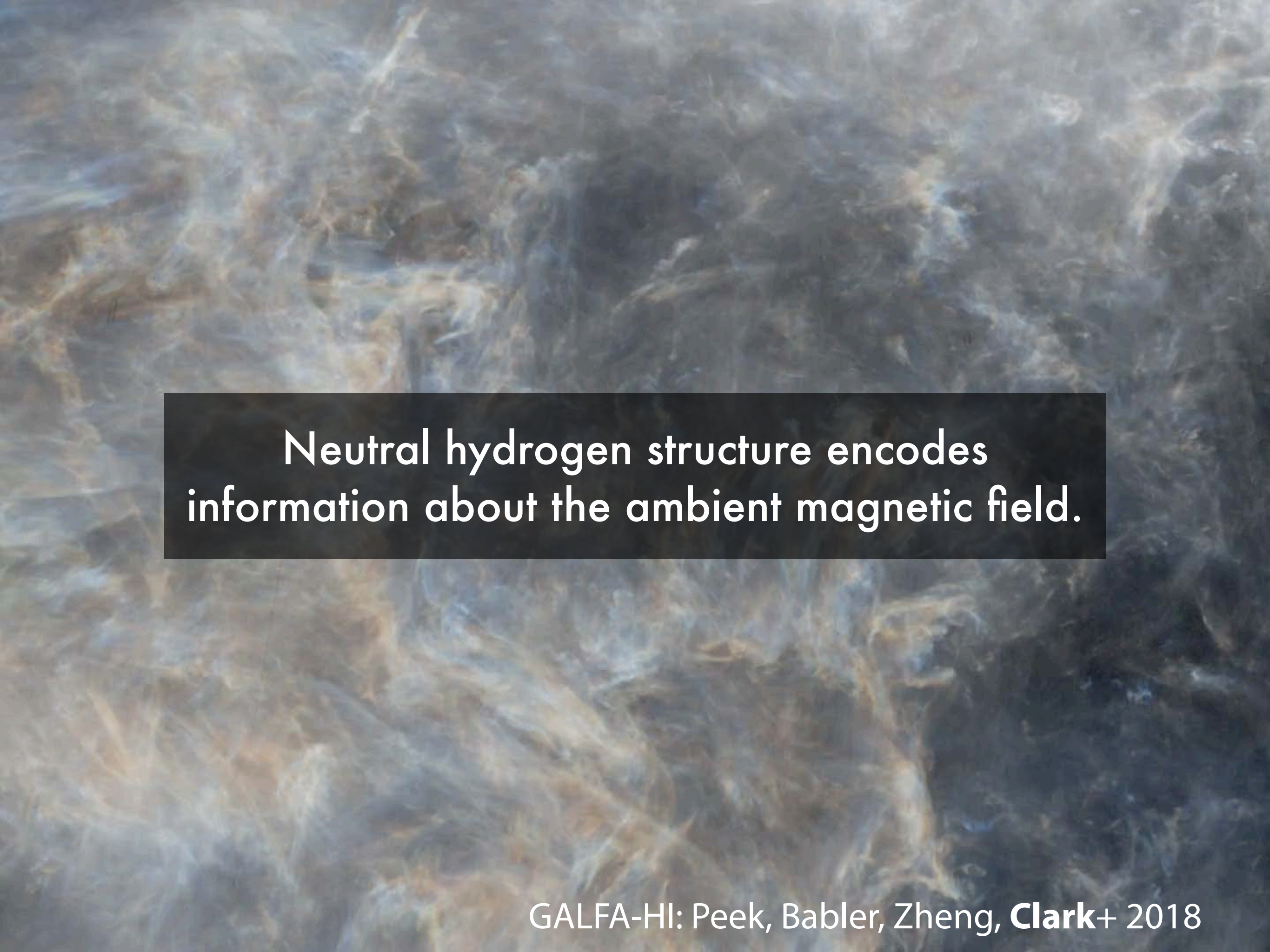
These altitudes are typical of the middle latitudes. Clouds may be lower in polar regions and reach higher altitudes in the tropics.

**Accessory Clouds**  
 A cloud that depends on a parent cloud for its existence. It may be an appendage but it is often found adjacent to the parent cloud.

**Clouds of Great Vertical Extent**  
 These clouds extend through multiple layers. When their base forms in the low level they are classified as a low cloud.

Learn more at [www.weatherbriefing.com](http://www.weatherbriefing.com)

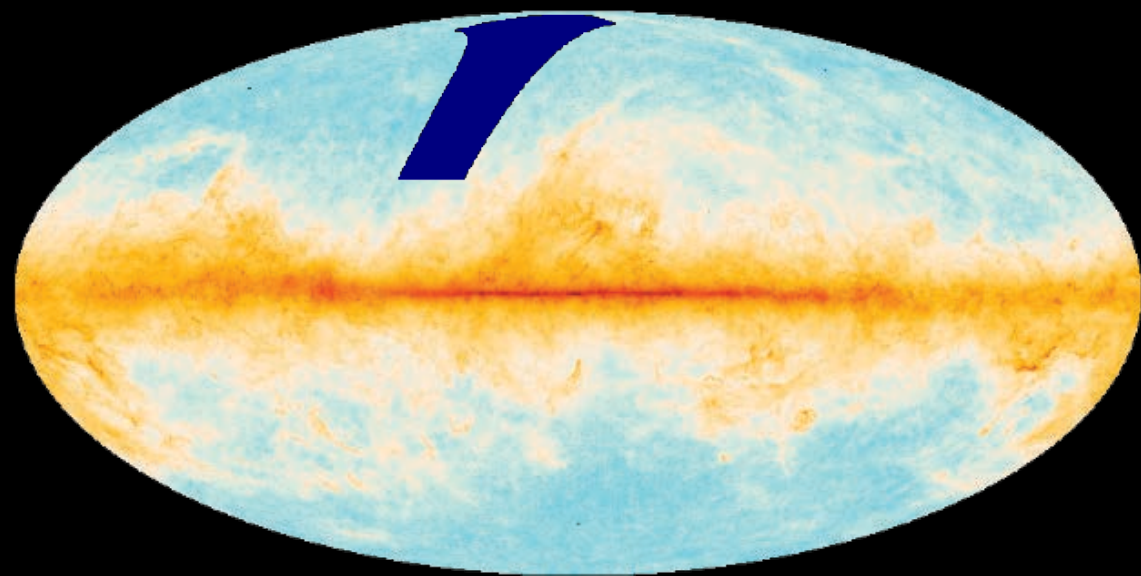
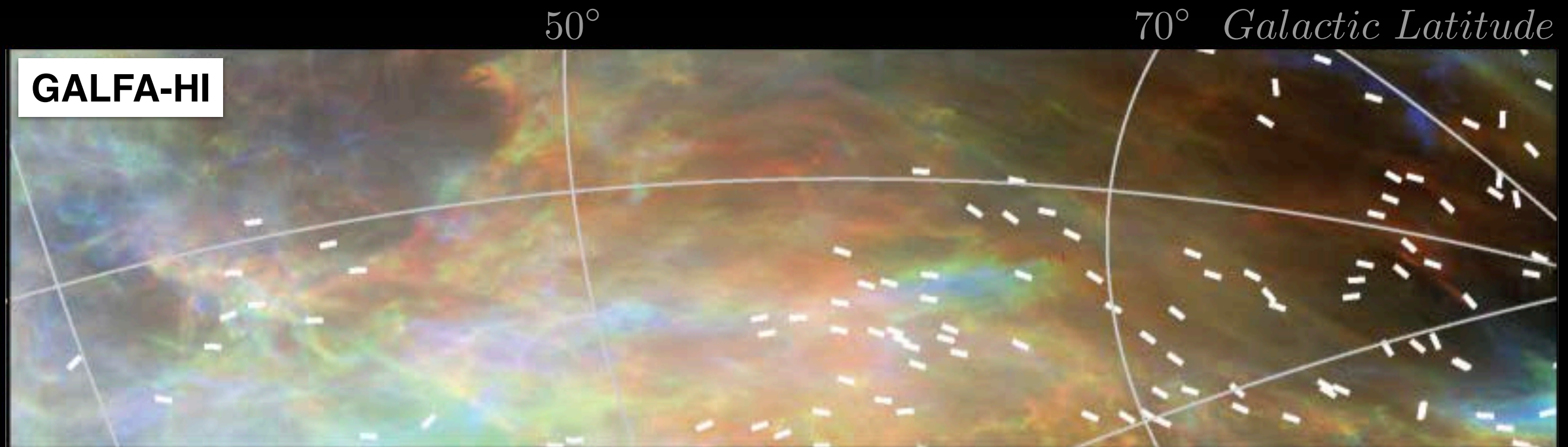




Neutral hydrogen structure encodes  
information about the ambient magnetic field.



# Characterize the orientation of high-latitude GALFA-HI structures.

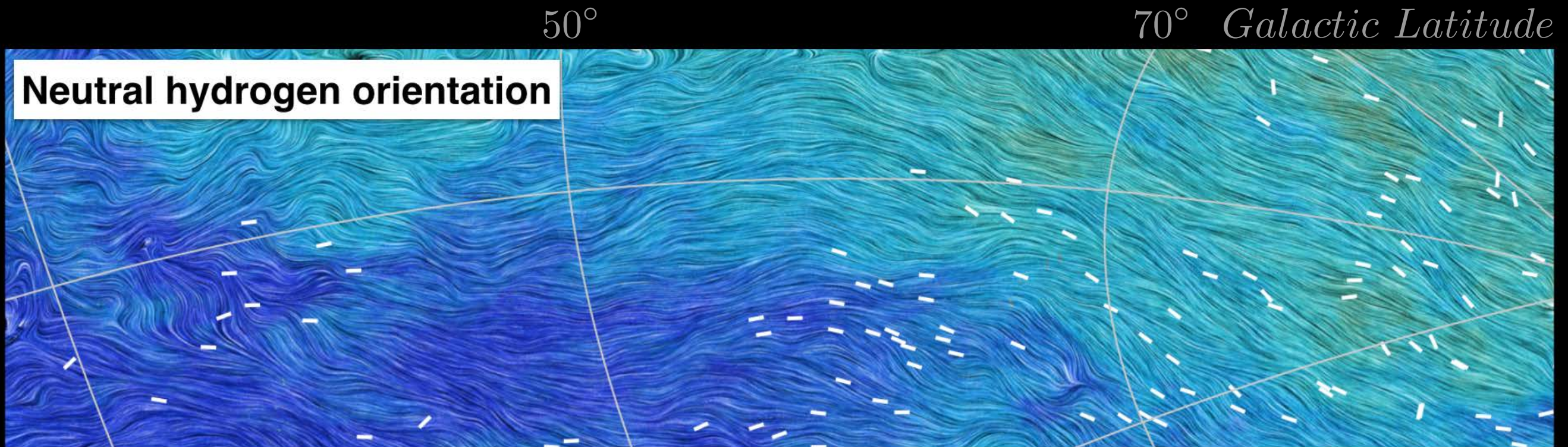


-3 km/s  
0 km/s  
+3 km/s

Clark+ 2015, PRL



# Characterize the orientation of high-latitude GALFA-HI structures.



 [github.com/seclark/RHT](https://github.com/seclark/RHT)

Clark+ 2015, PRL

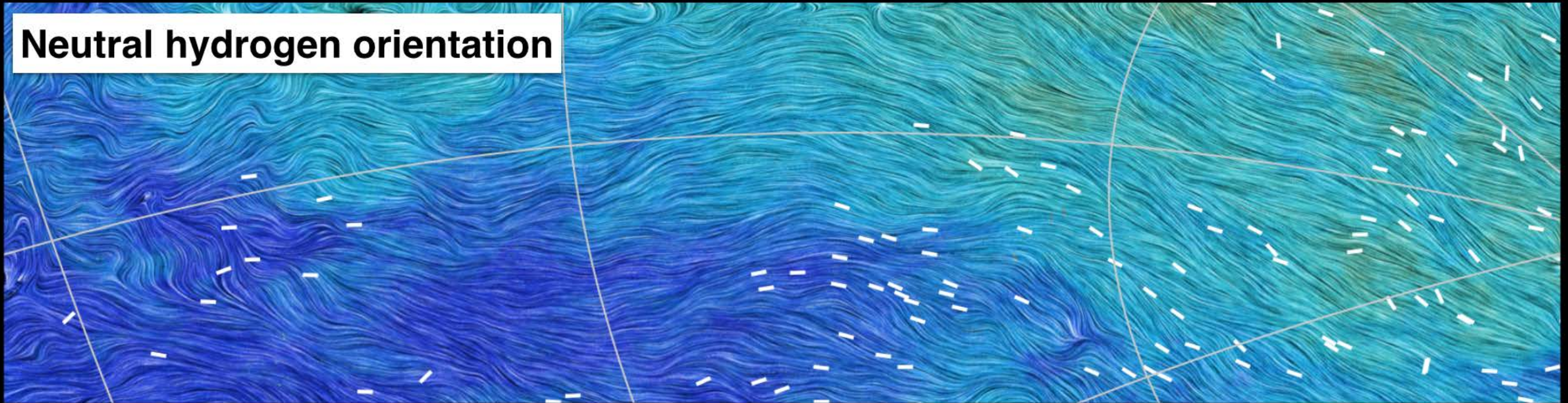


# High-latitude GALFA-HI structures are aligned with the *Planck* magnetic field orientation.

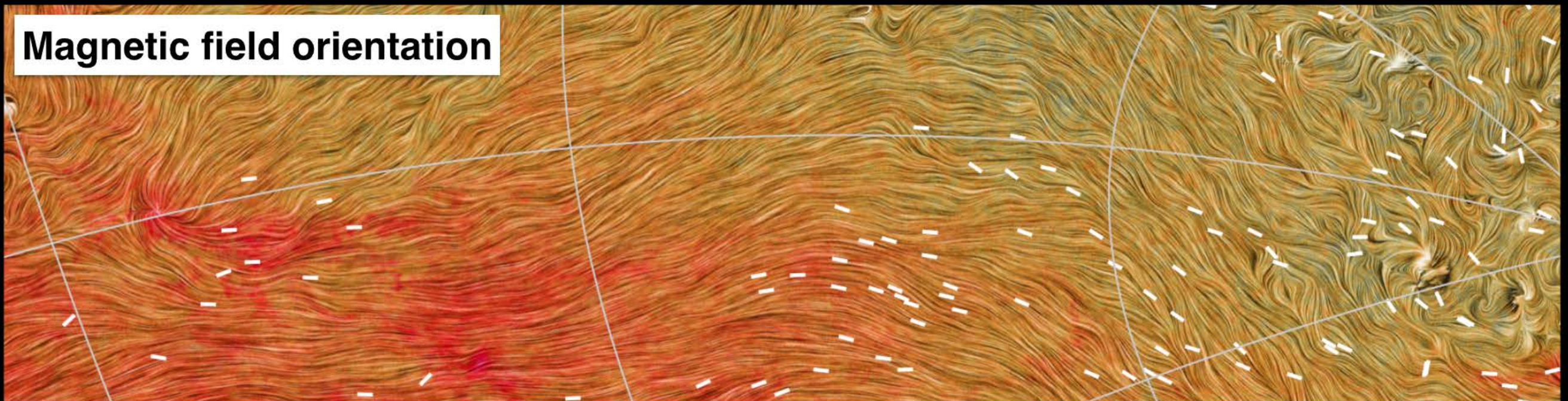
50°

70° *Galactic Latitude*

**Neutral hydrogen orientation**



**Magnetic field orientation**



Starlight polarization: Heiles 2000

Clark+ 2015, PRL

S.E. Clark, Stanford

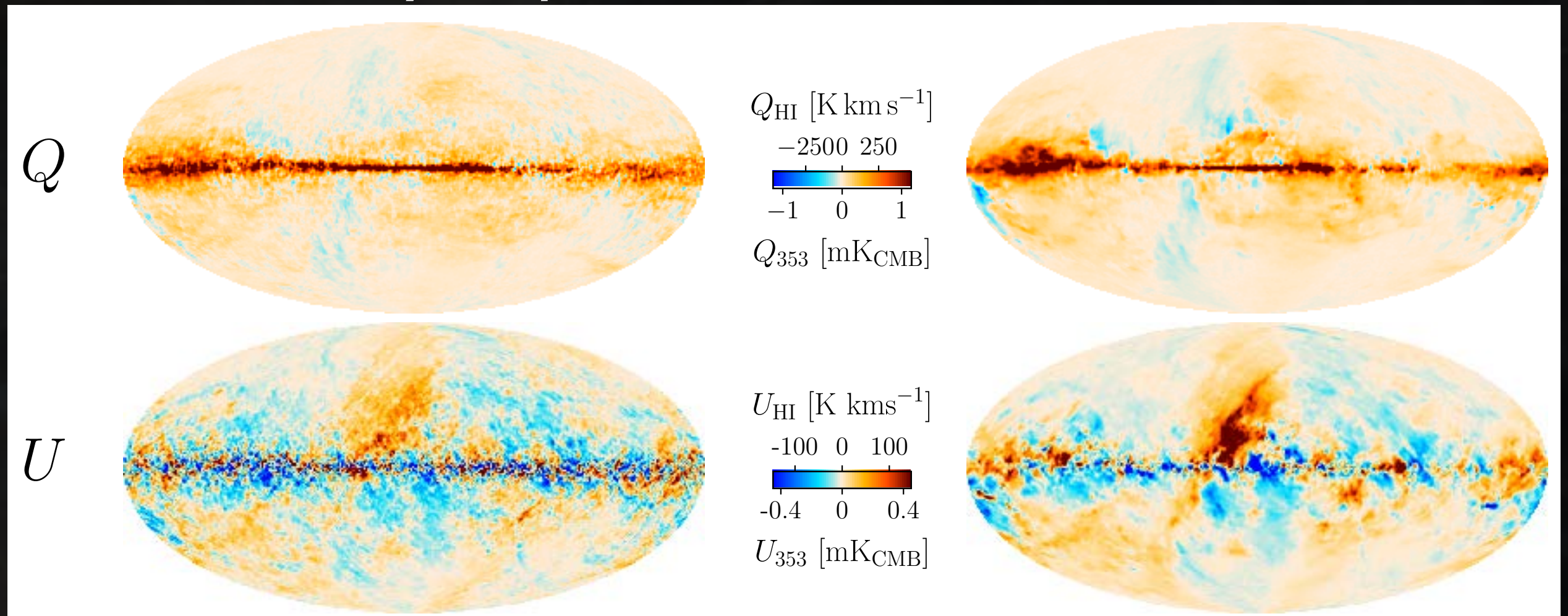
Our Galactic Ecosystem



# We can model the polarized dust sky from HI morphology alone.

HI only maps

Planck 353 GHz



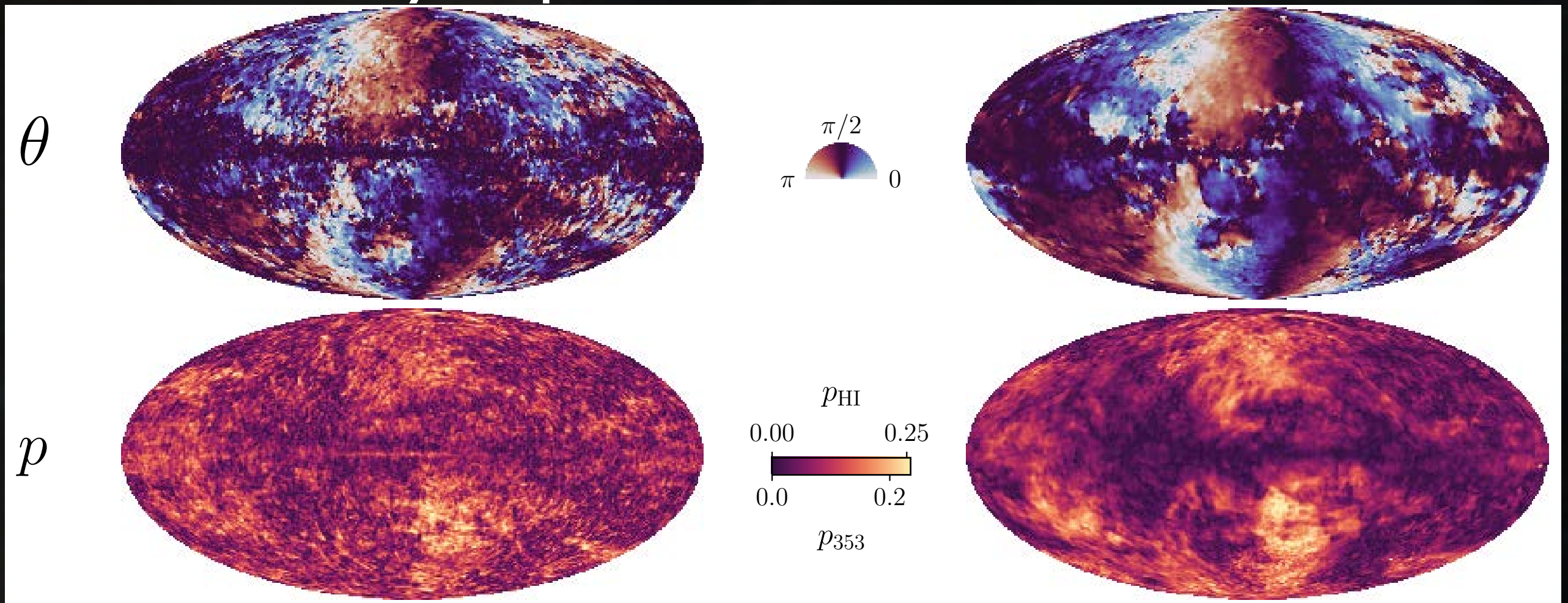
Clark & Hensley 2019



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HI only maps

Planck 353 GHz



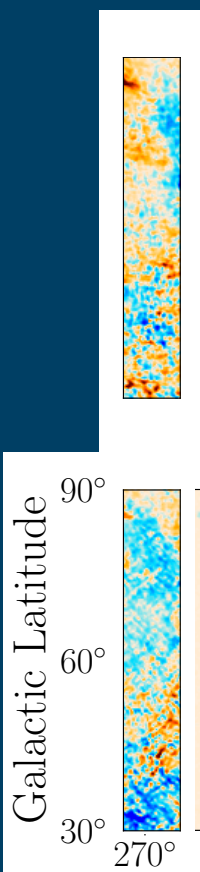
Clark & Hensley 2019

See also Clark 2018, ApJL

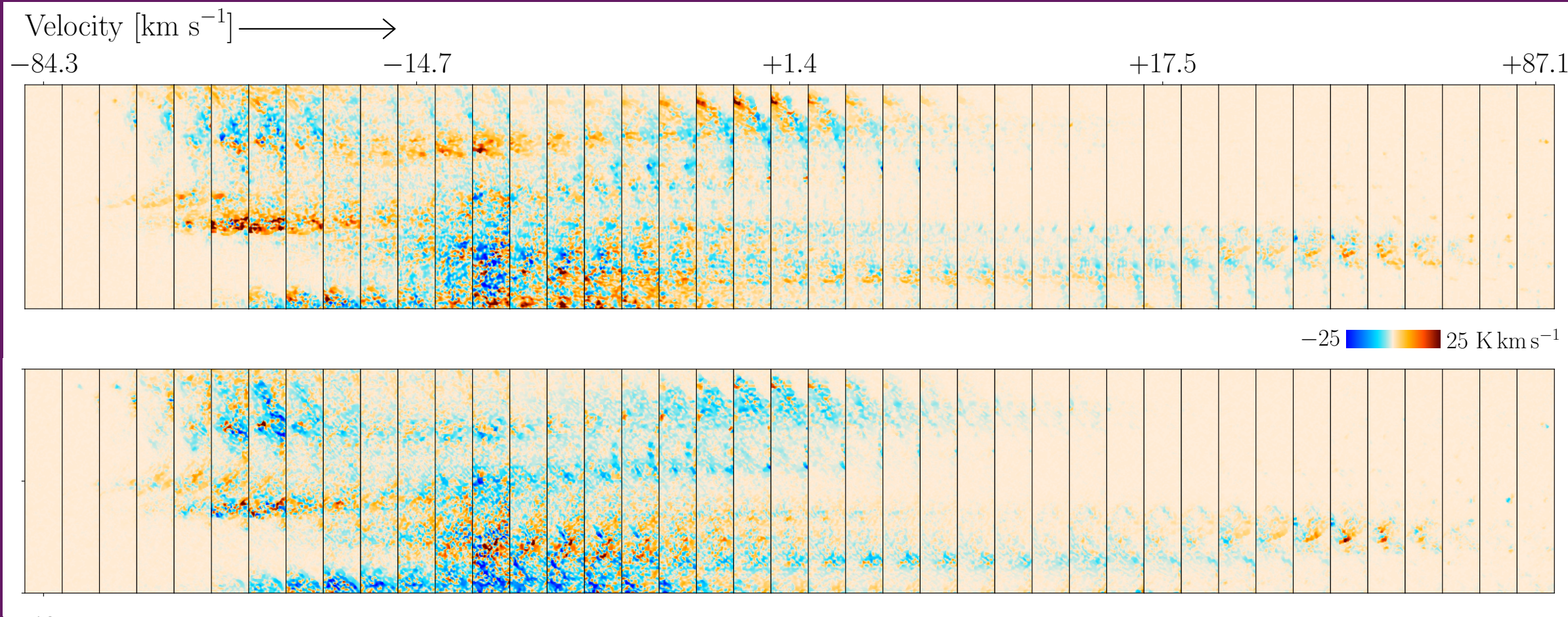


# We can model the polarized dust sky **in 3D** from *HI morphology alone*.

**Planck  
view  
(2D)**

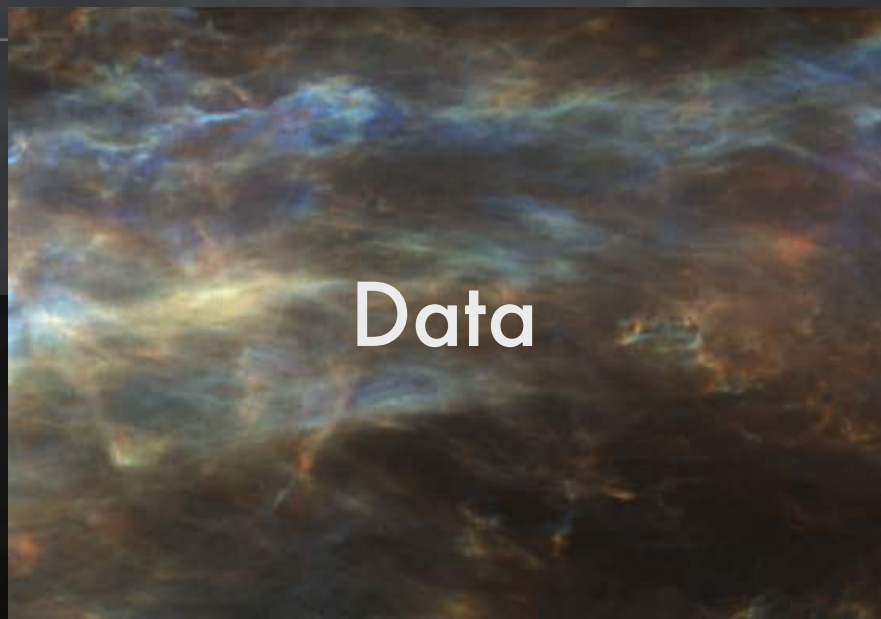


**Clark & Hensley view (3D)**



**Clark & Hensley 2019**



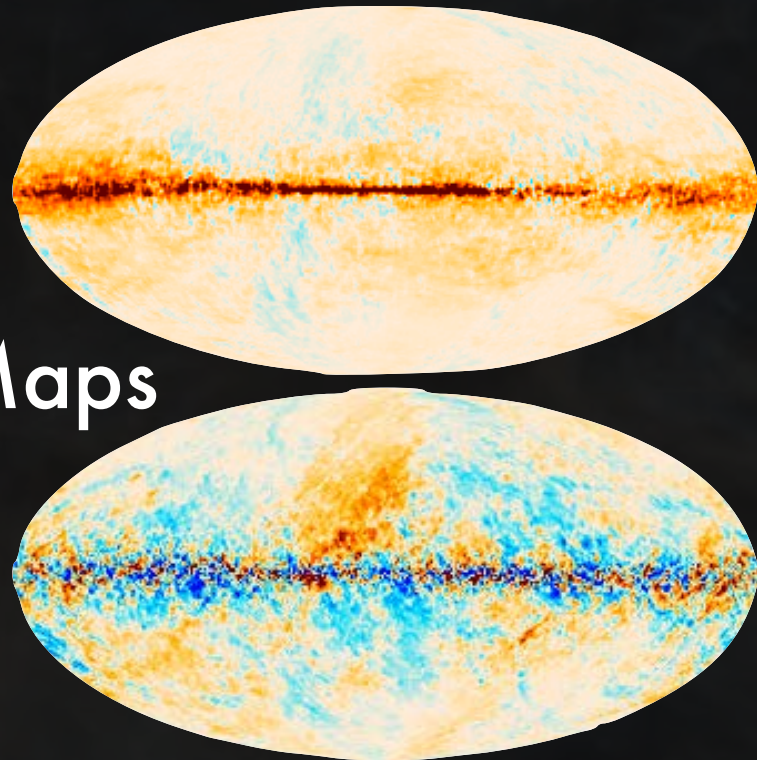


Model



George Halal, Physics graduate student

Maps



- How can we build a better HI-based **model** of the dust polarization?
- What does this teach us about turbulent structure formation in the ISM?





*Morphology* encodes rich physical information.  
What new statistical tools can we devise?



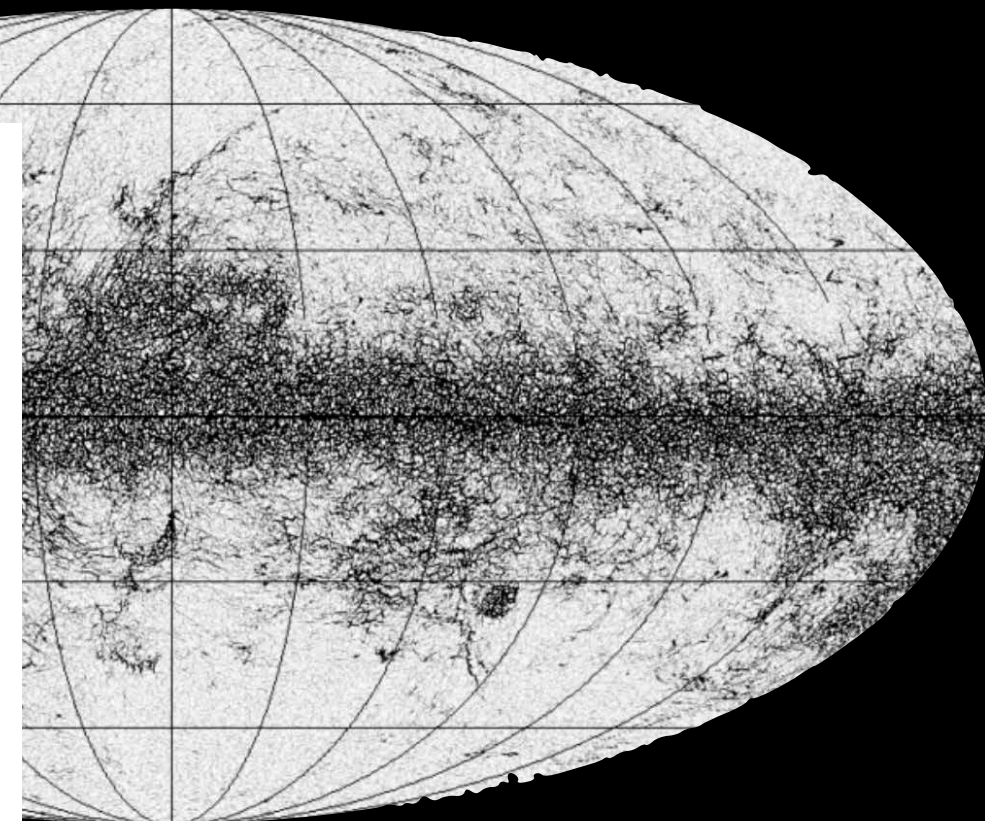
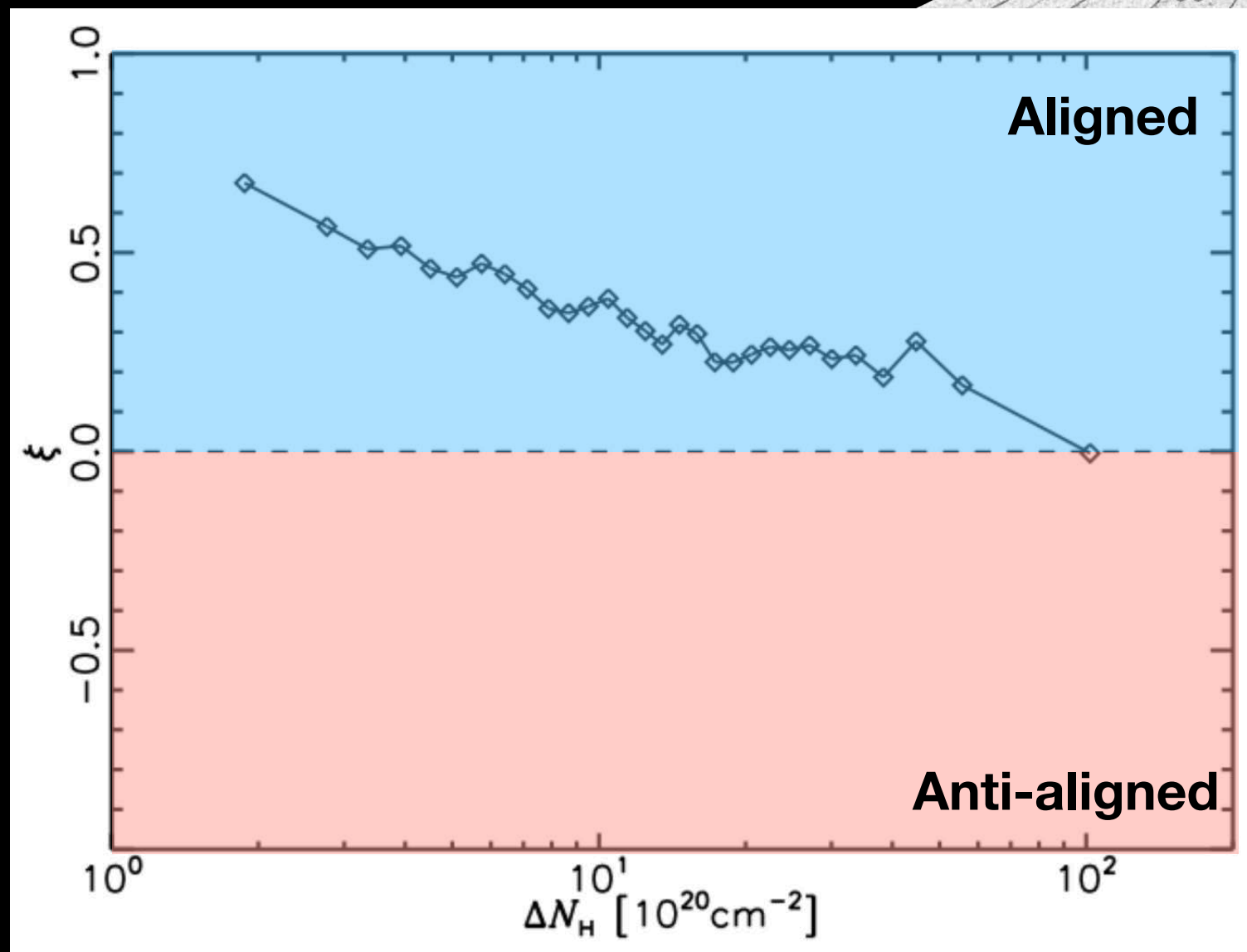
Clark+ 2014, 2015



Diffuse ISM: structures || B-field  
Molecular clouds: change  
in relative orientation



*Planck* enabled statistical studies of the magnetic field and ISM filaments.

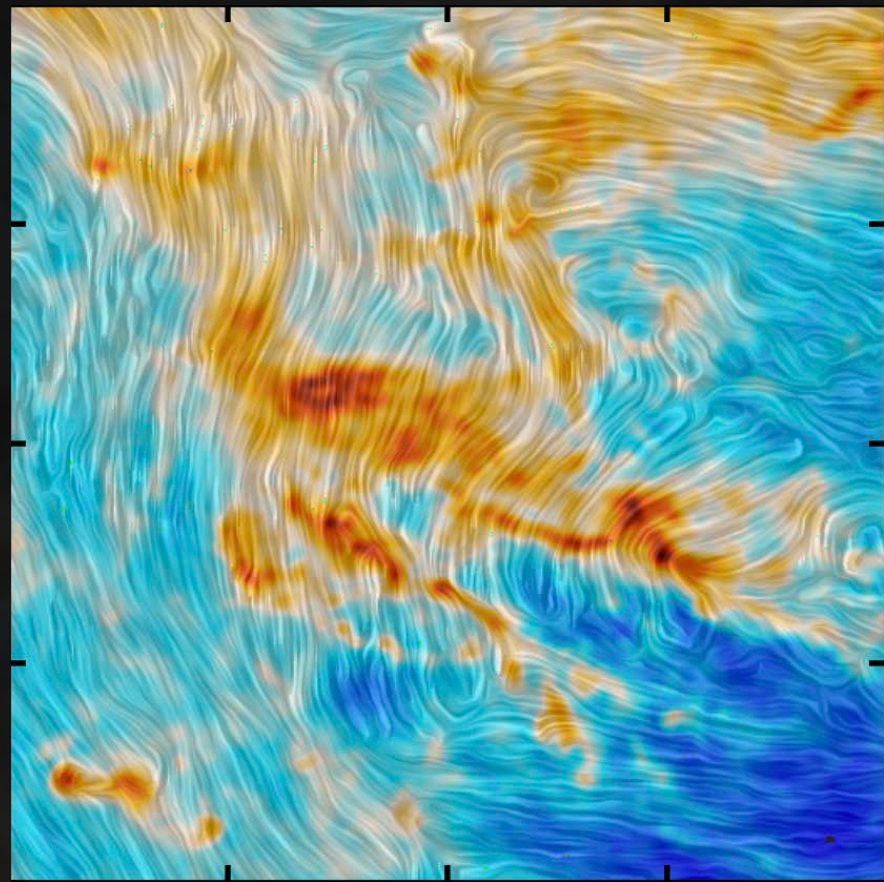


Planck Int. XXXII

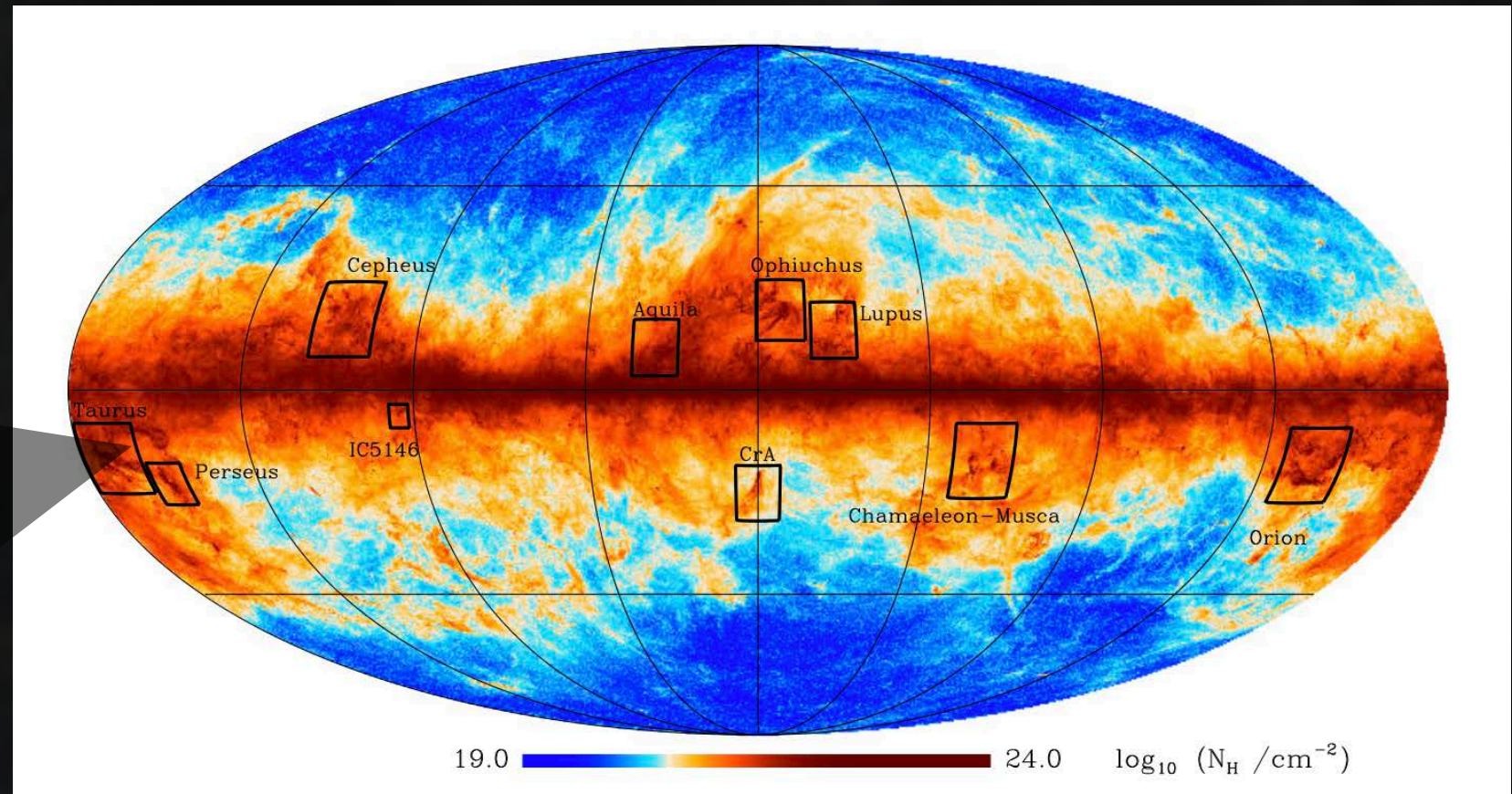
See also Alina+ 2019



*Planck* studied this correlation in nearby Gould Belt molecular clouds.

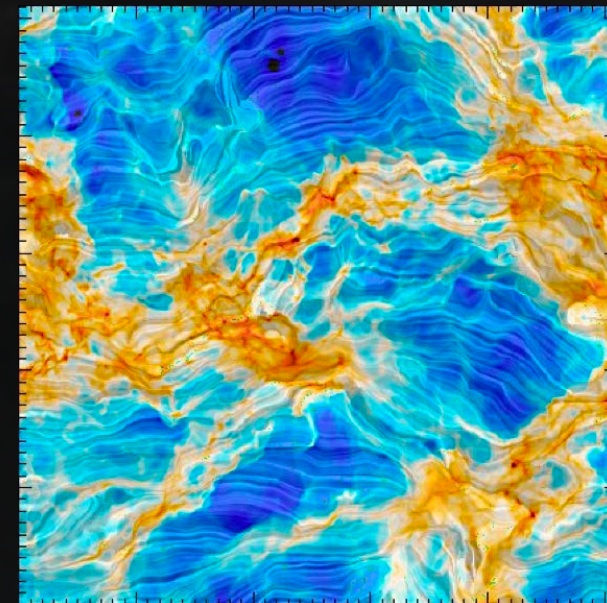
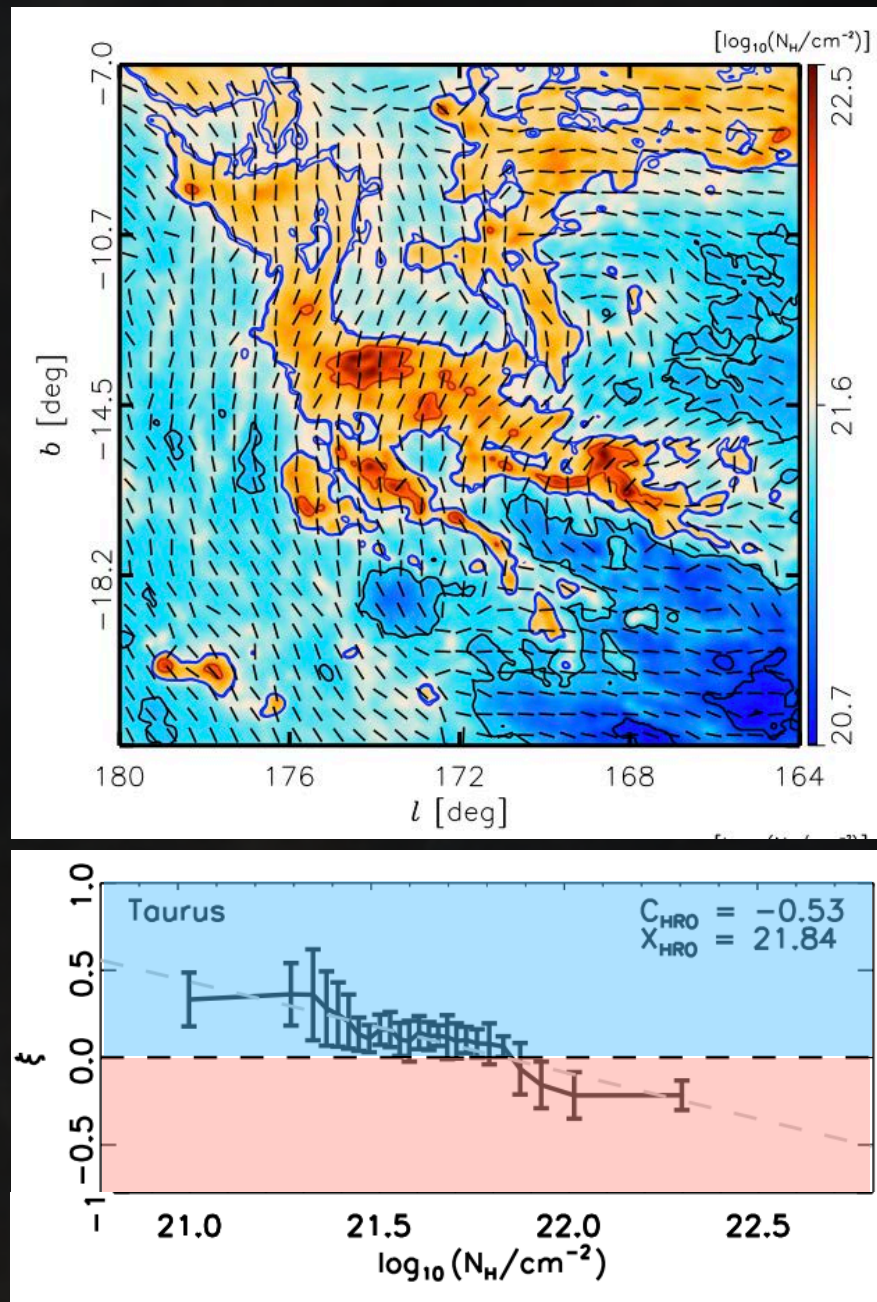


Planck Int. XXXV



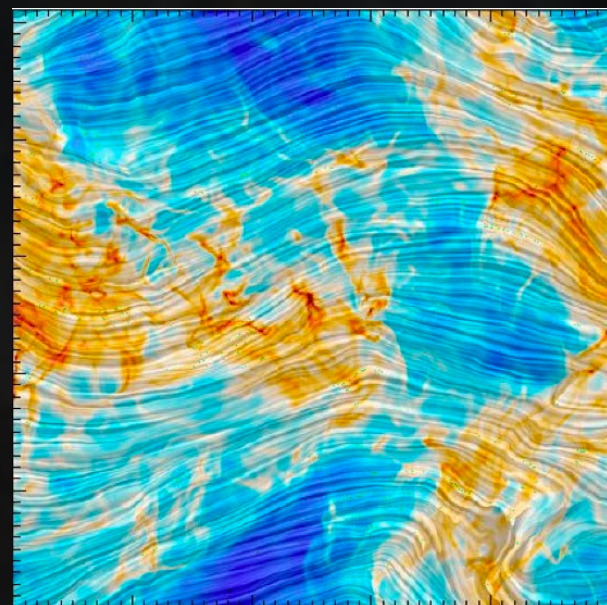


# Denser cloud structures are perpendicular to the magnetic field orientation.



$$\beta = 100$$

Soler+ 2013



$$\beta = 0.1$$

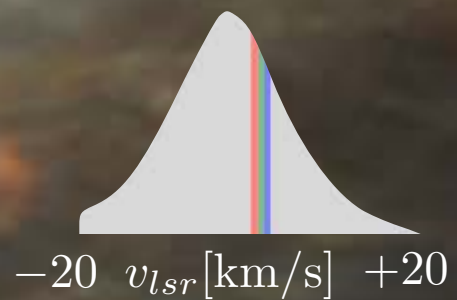
See also Mocz & Burkhardt 2018,  
Seifried+ 2020

See also Jow+ 2018, Fissel+ 2019



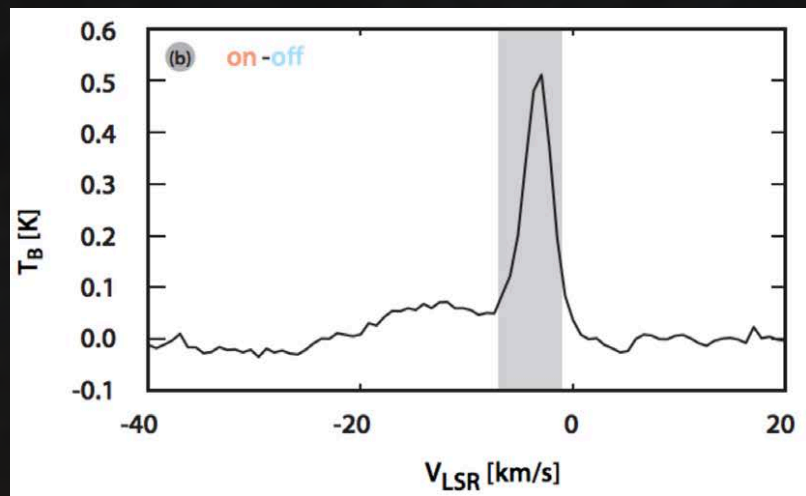
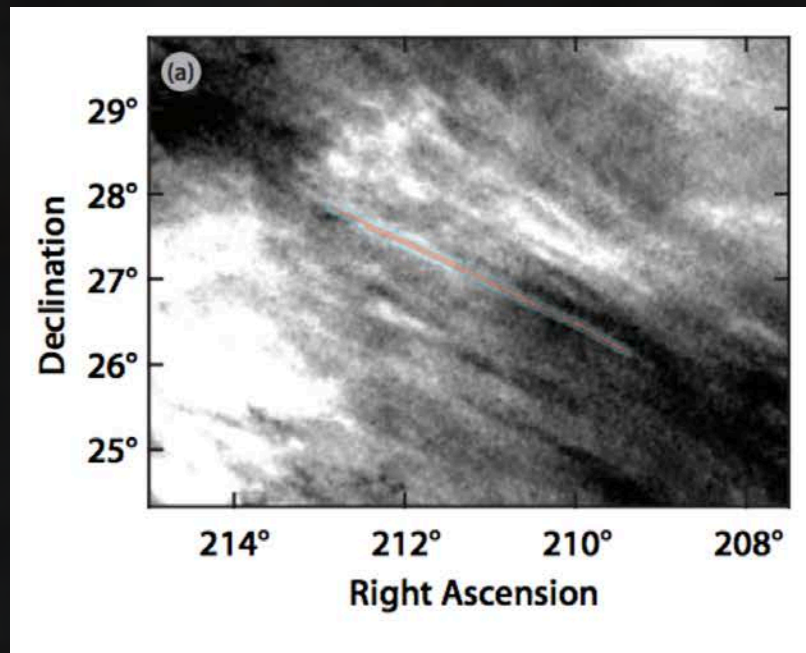


What is driving the measured magnetic alignment of diffuse HI structures?



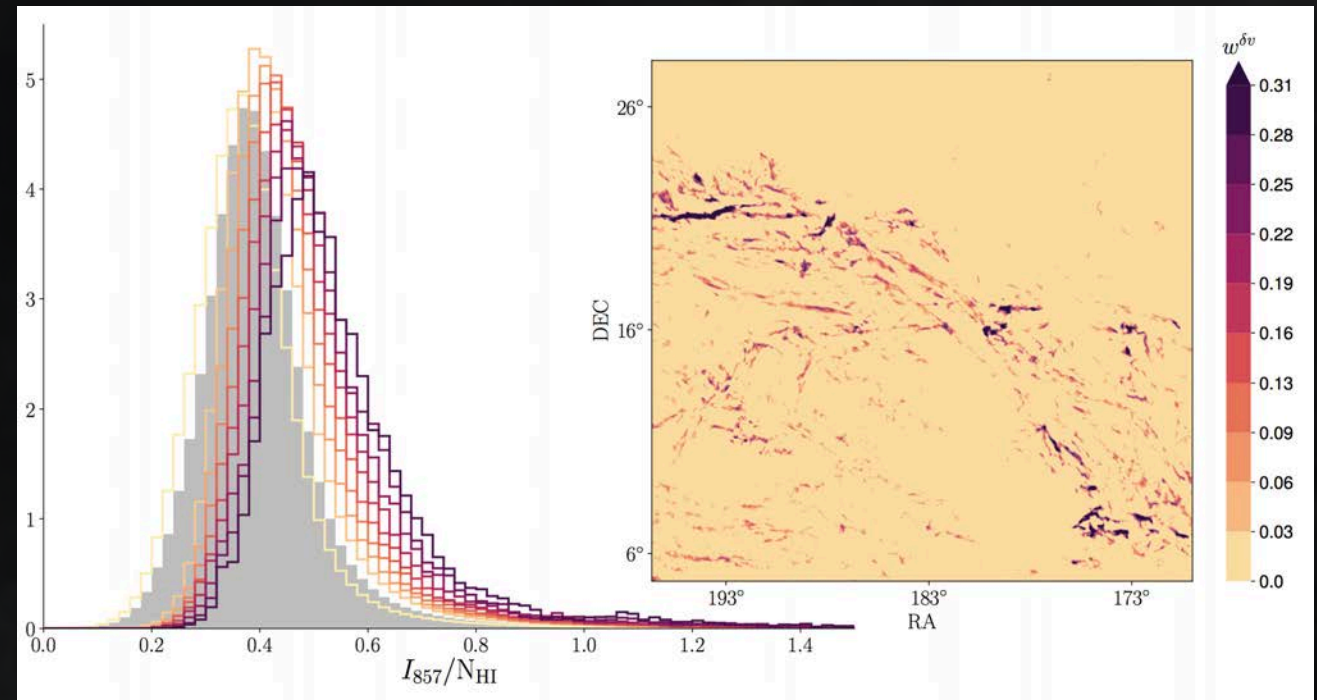


Linewidth measurements, FIR/ $N_{\text{HI}}$  correlations, and Na I D absorption are all consistent with cold density structures.

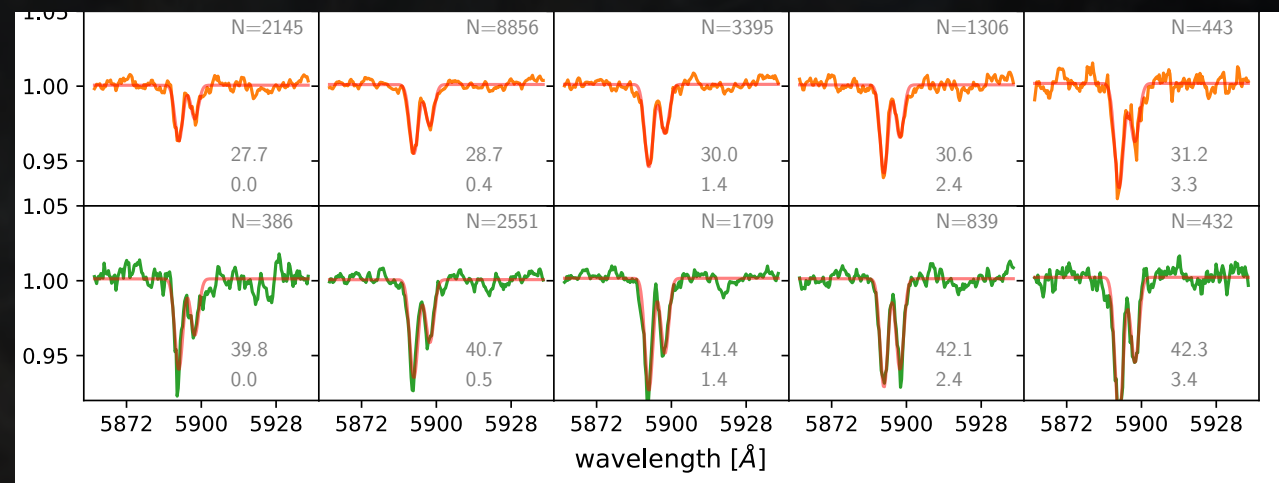


Clark+ 2014

See also: Kalberla+ 2016  
Murray+ 2020



Clark+ 2019

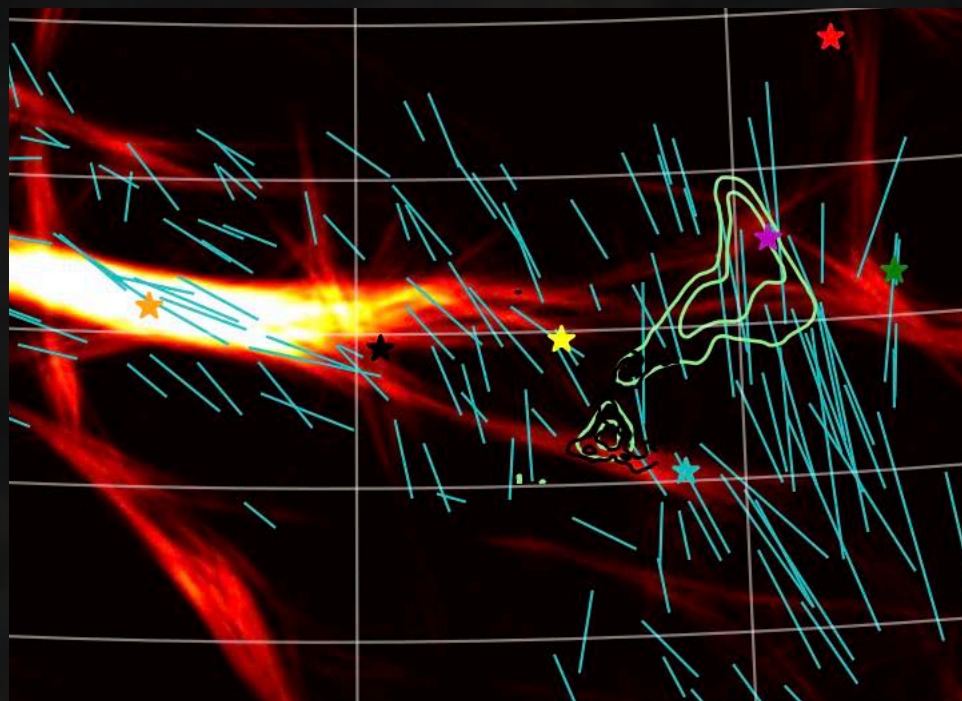


Peek & Clark 2019



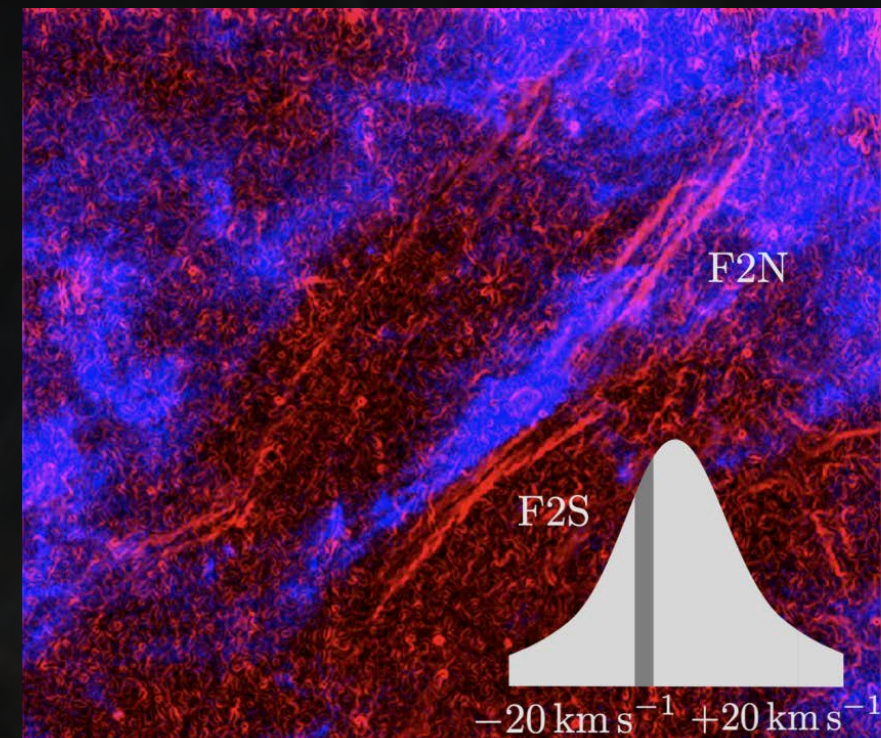
# Promising directions for the multi-phase, magnetic, diffuse ISM: **multi-tracer data**

Structure-magnetic field correlations in transition regions



Skalidis+ 2021

Multi-tracer analyses that probe magnetic fields in different phases



Campbell+ 2021

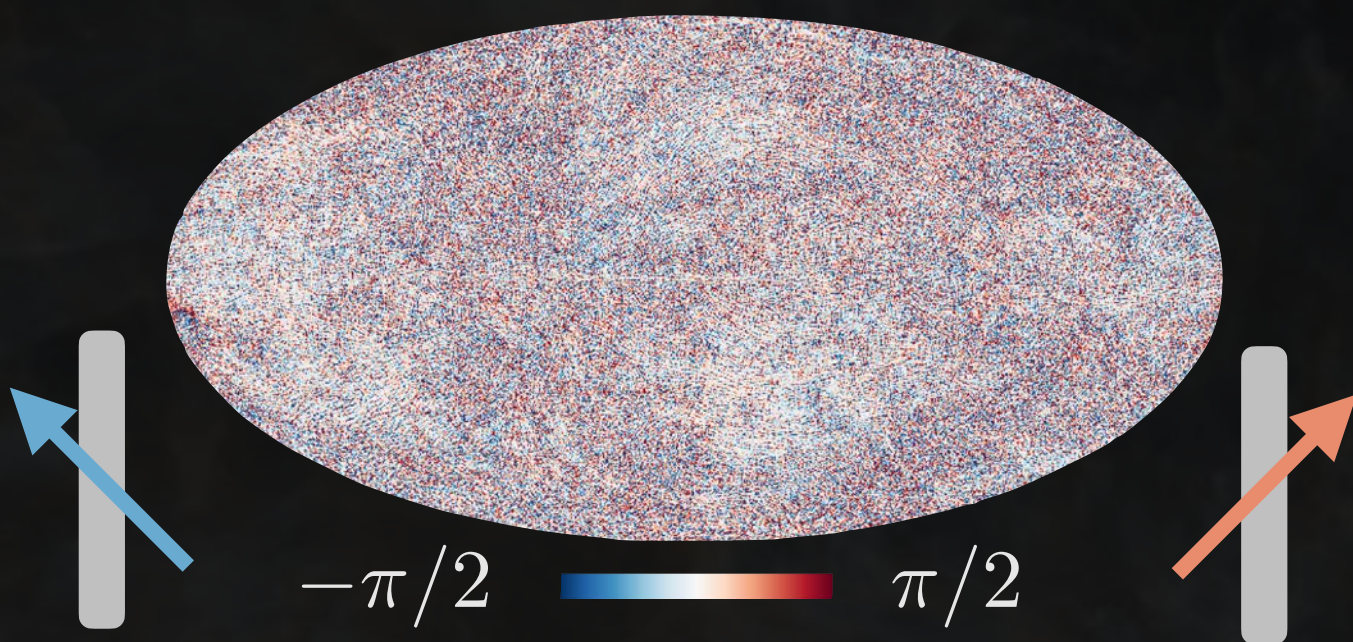
**+ the talks in this session!**



# Promising directions for the multi-phase, magnetic, diffuse ISM: **new statistics**

Parity-odd quantities trace magnetic misalignment

$$\Delta\theta(HI, 353)$$



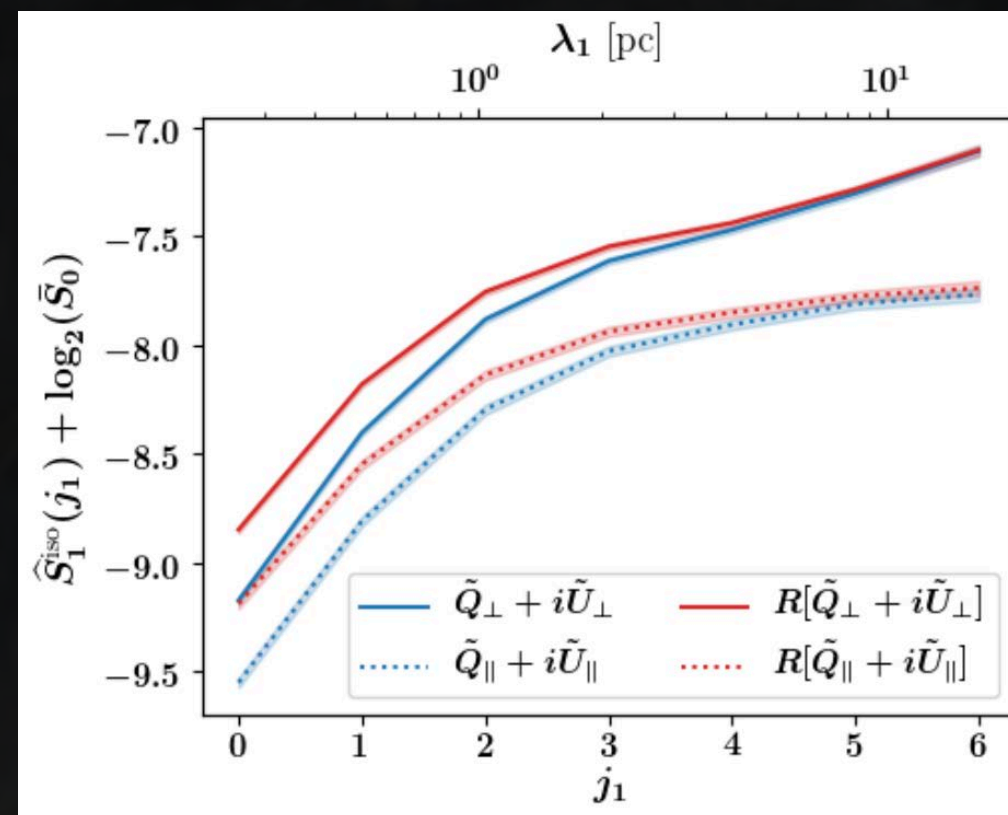
Clark+ 2021

Cukierman+ in prep



S.E. Clark, Stanford

Non-Gaussian statistics



Regaldo-Saint Blancard+ 2020

Ongoing work by  
Minjie Lei



Our Galactic Ecosystem

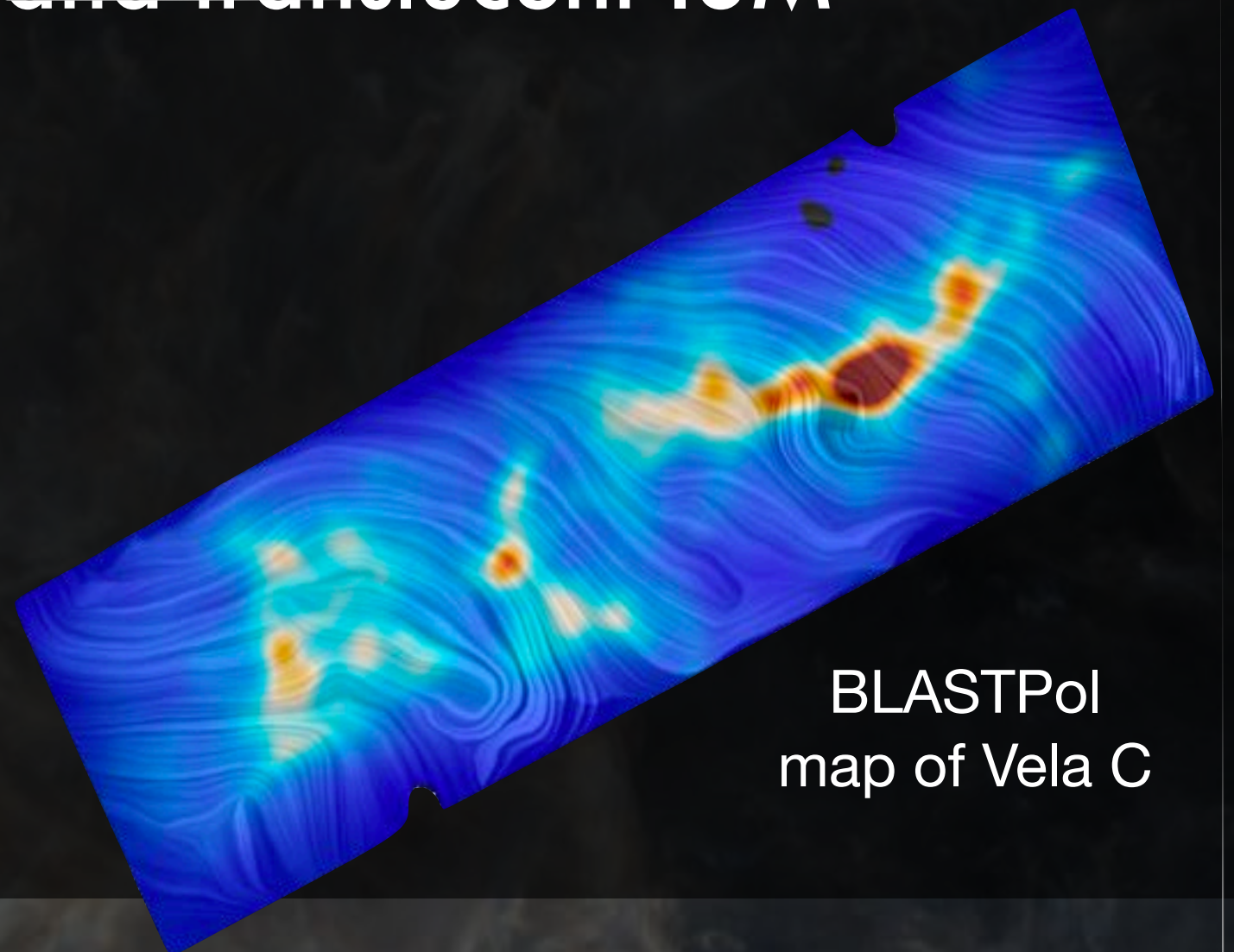


# The Balloon-Borne Large Aperture Submillimeter Telescope (BLAST) Observatory

Spatially resolved FIR polarimetry over 100 sq. deg. regions of diffuse and translucent ISM

Plus nearby molecular clouds, Galactic plane, LMC/SMC, and shared risk obs!

Lowe+, SPIE  
arXiv:2012.01376





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# The diffuse and translucent ISM: a few questions

What is the nature of **MHD turbulence** in the ISM?  
What dominates turbulent dissipation?

How do **magnetic fields** affect structure formation in the diffuse medium?

What role do the above play in **phase transitions**?



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The diffuse and translucent ISM: a few <sup>more</sup> questions

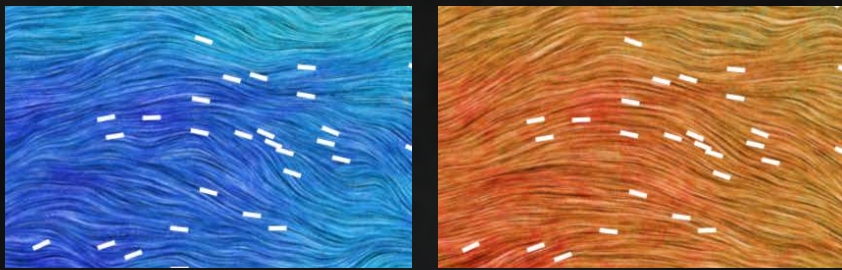
ISM morphology carries rich information. How do we optimally extract the physics?

These are high dynamic range problems spanning physical states. How do we combine tracers?

What other opportunities can we identify?



# The diffuse and translucent ISM: some recent progress



Clark+ 2015

The diffuse ISM is structured by the ambient magnetic field.

Magnetic alignment in the HI is driven by anisotropic, cold density structures.



Clark+ 2019

Rich opportunities to combine tracers and quantitative morphological analyses

Stay tuned: [clarkgroup.stanford.edu](http://clarkgroup.stanford.edu)