Modeling Polarized Dust Emission from the 3D ISM with Neutral Hydrogen Data

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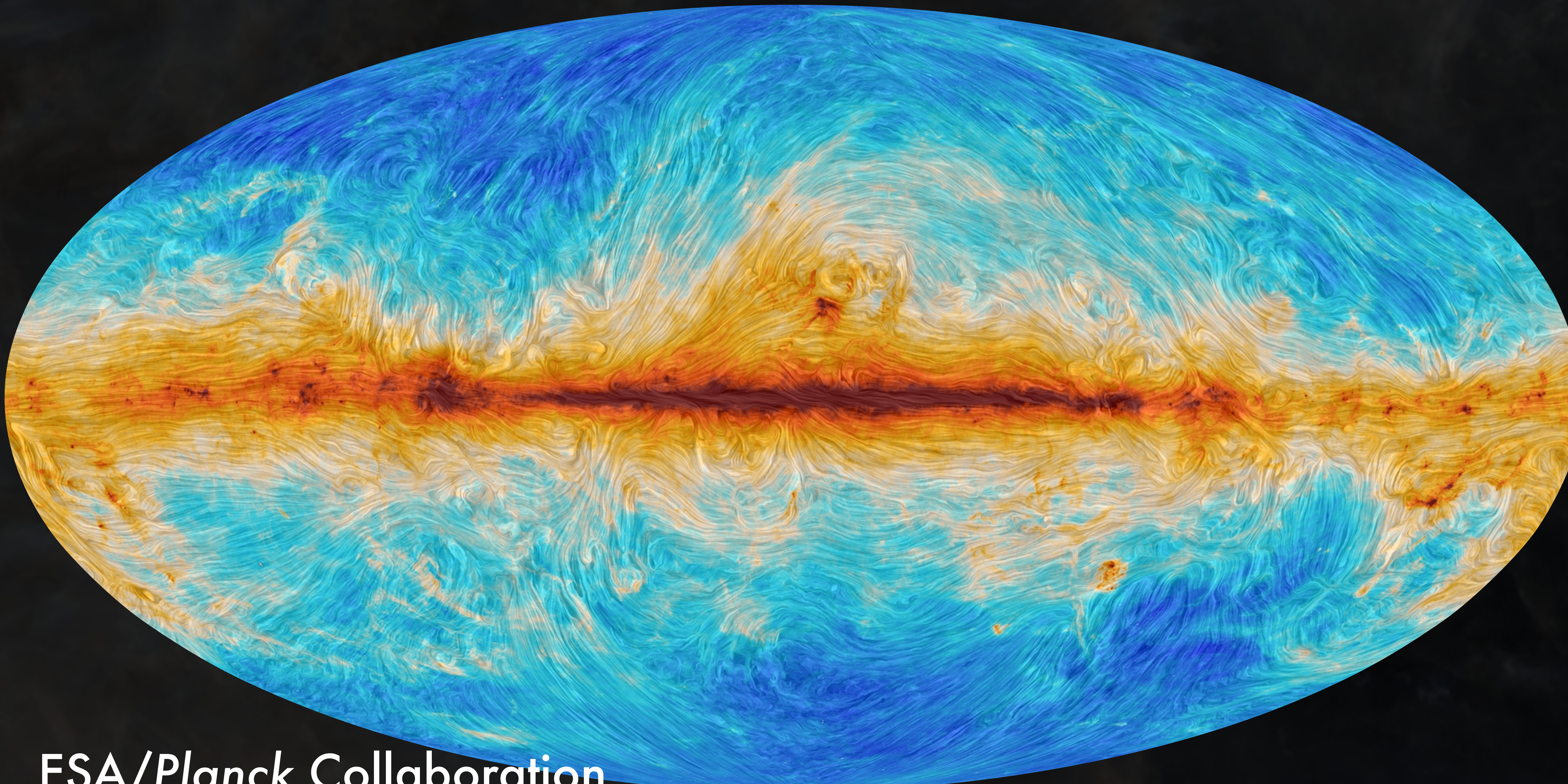
Institute for Advanced Study

With Brandon Hensley (Princeton)

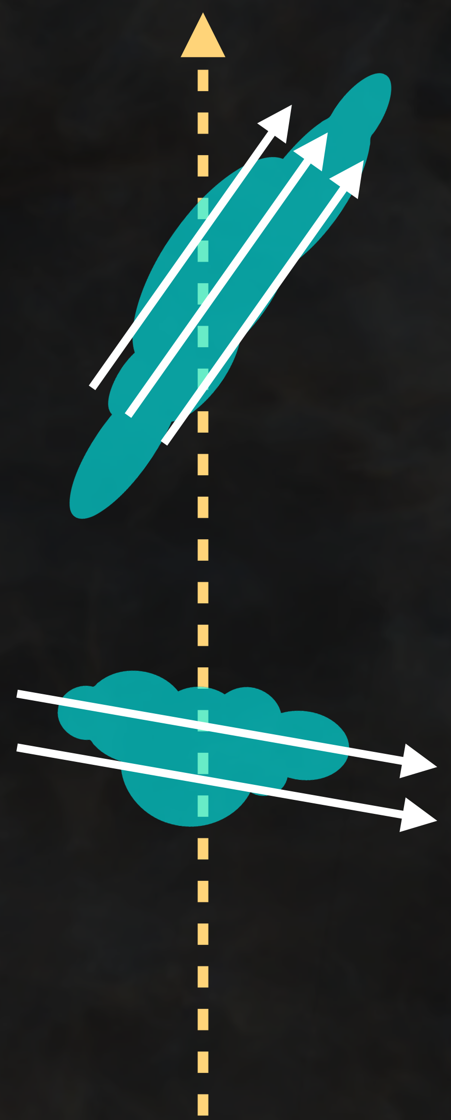
Clark & Hensley 2019
ApJ 887, 2

Planck mapped the full sky in 353 GHz polarized dust emission.



ESA/*Planck* Collaboration
Planck Int. XIX

Dust polarization encodes the sum over dusty regions along the line of sight.

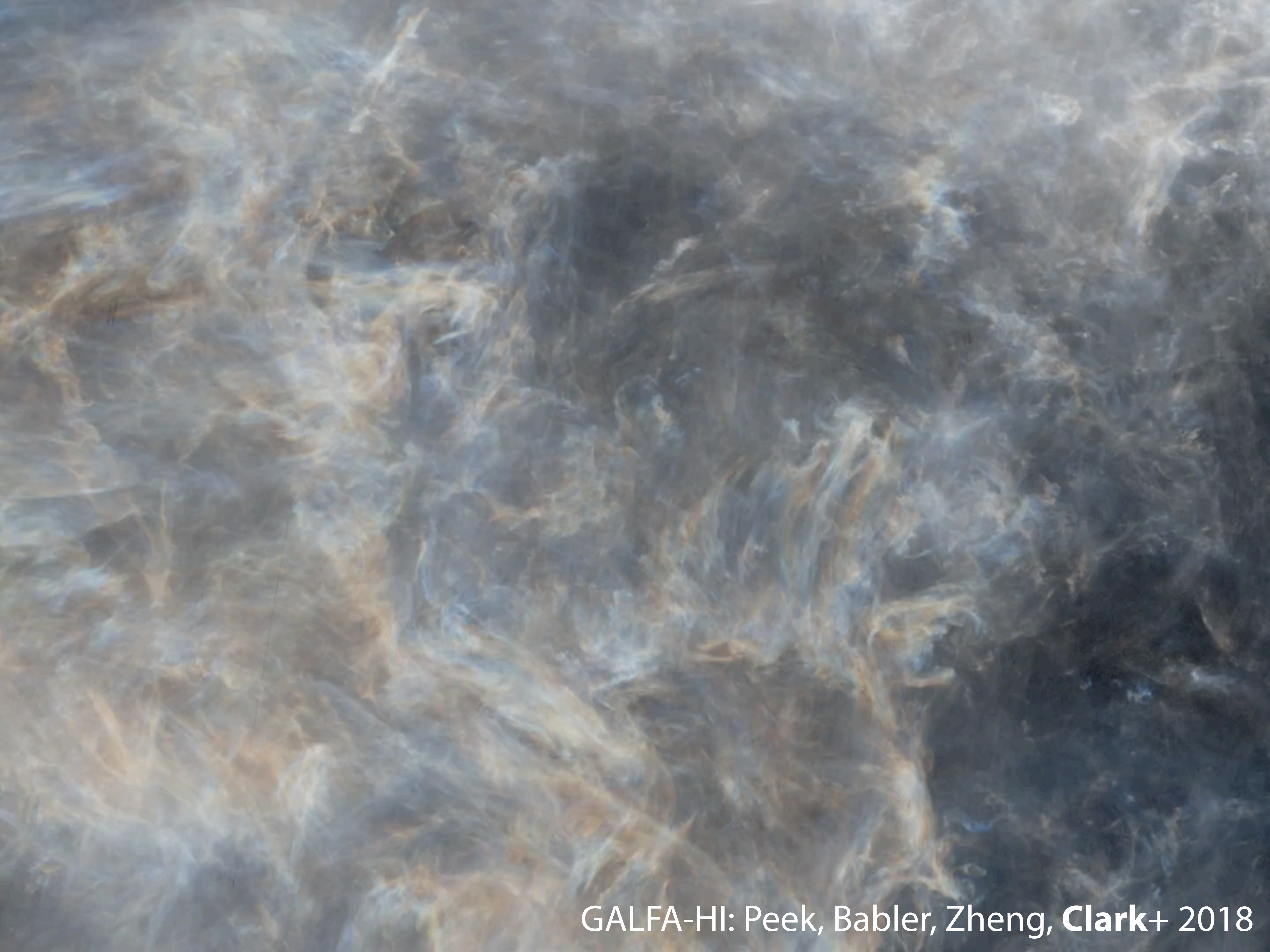


$$I_\nu = \sum_i B_\nu(T_d)\left[\kappa_\nu - \mathcal{R}\kappa_\nu^{pol}\left(\cos^2\gamma - \frac{2}{3}\right)\right]$$

$$Q_\nu = \sum_i B_\nu(T_d)\mathcal{R}\kappa_\nu^{pol}\cos(2\theta)\cos^2\gamma$$

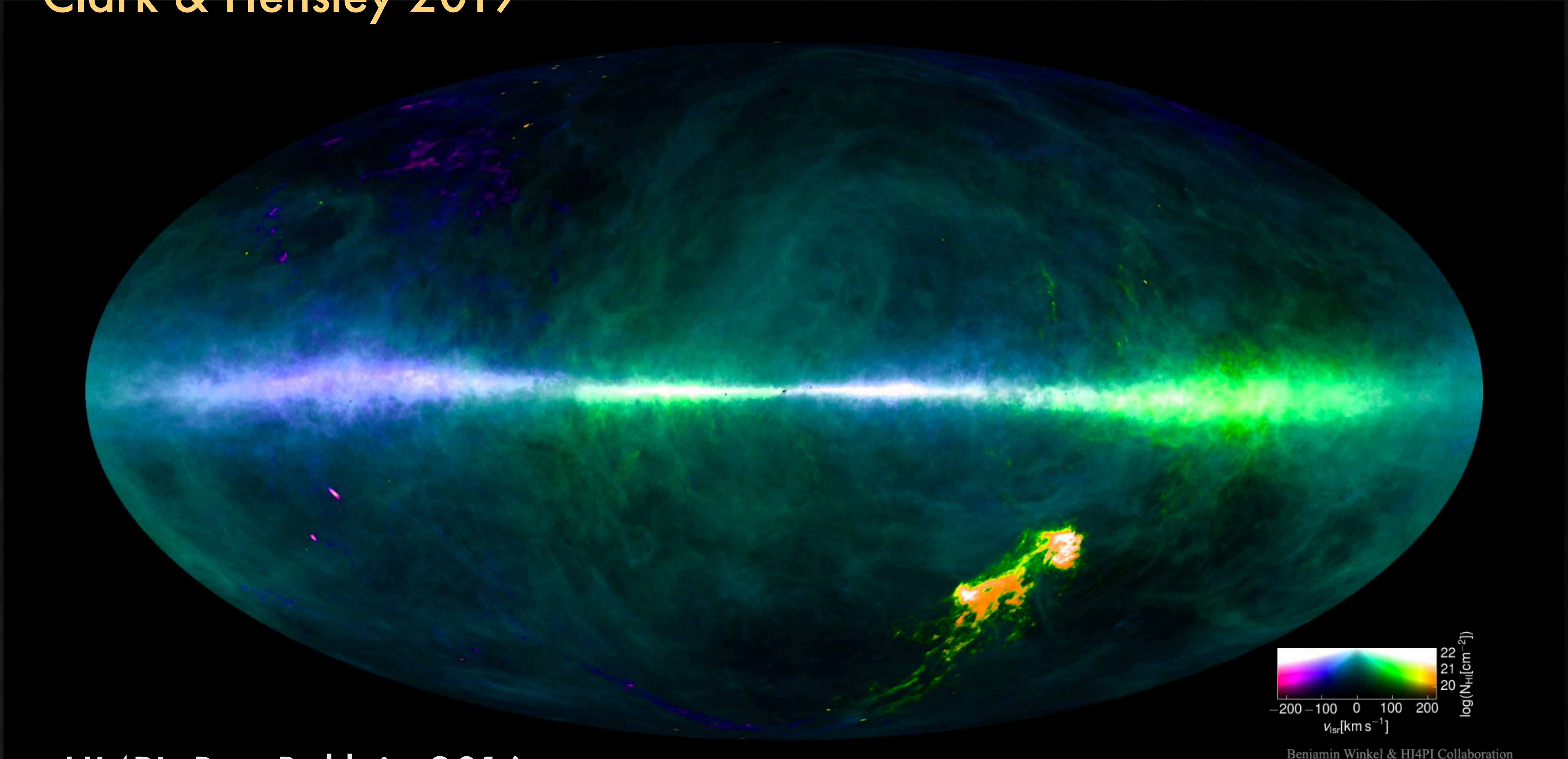
$$U_\nu = \sum_i B_\nu(T_d)\mathcal{R}\kappa_\nu^{pol}\sin(2\theta)\cos^2\gamma$$

Line-of-sight information is not directly accessible from the dust emission.


GALFA-HI: Peek, Babler, Zheng, **Clark**+ 2018

The goal is a three-dimensional map of the magnetic properties of the neutral ISM.

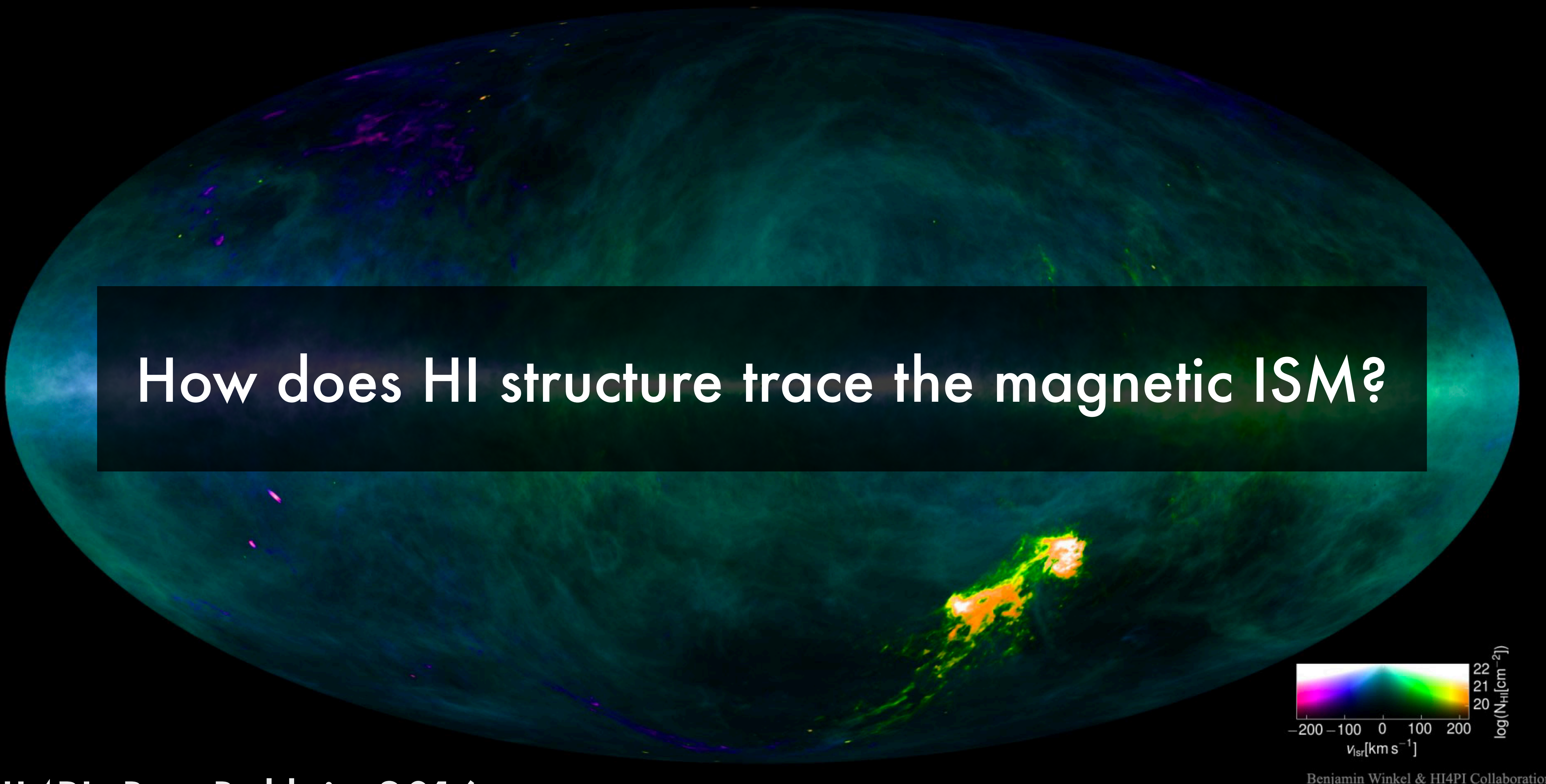
Clark & Hensley 2019



HI4PI: Ben Bekhti+ 2016

The goal is a three-dimensional map of the magnetic properties of the neutral ISM.

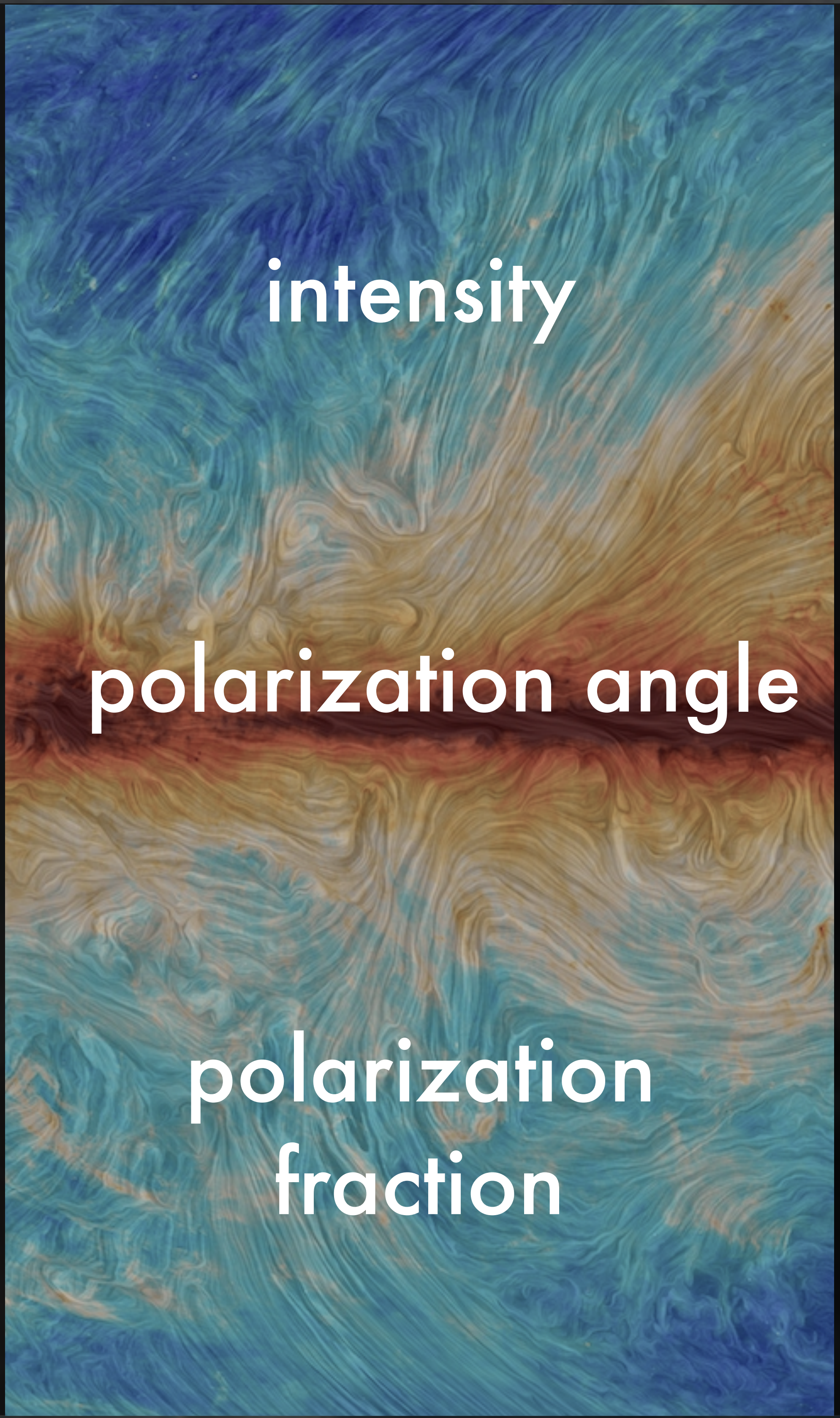
Clark & Hensley 2019

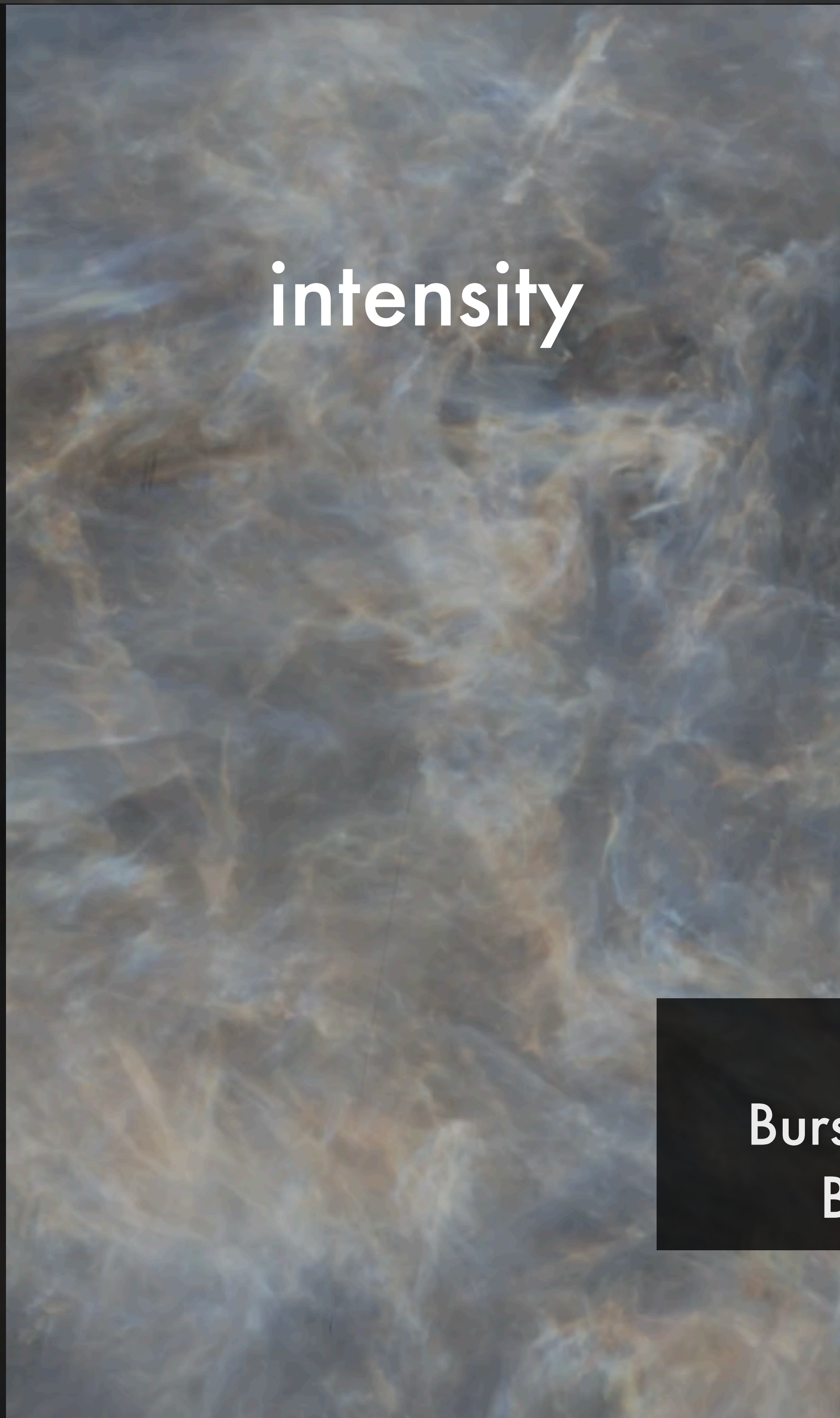


How does HI structure trace the magnetic ISM?

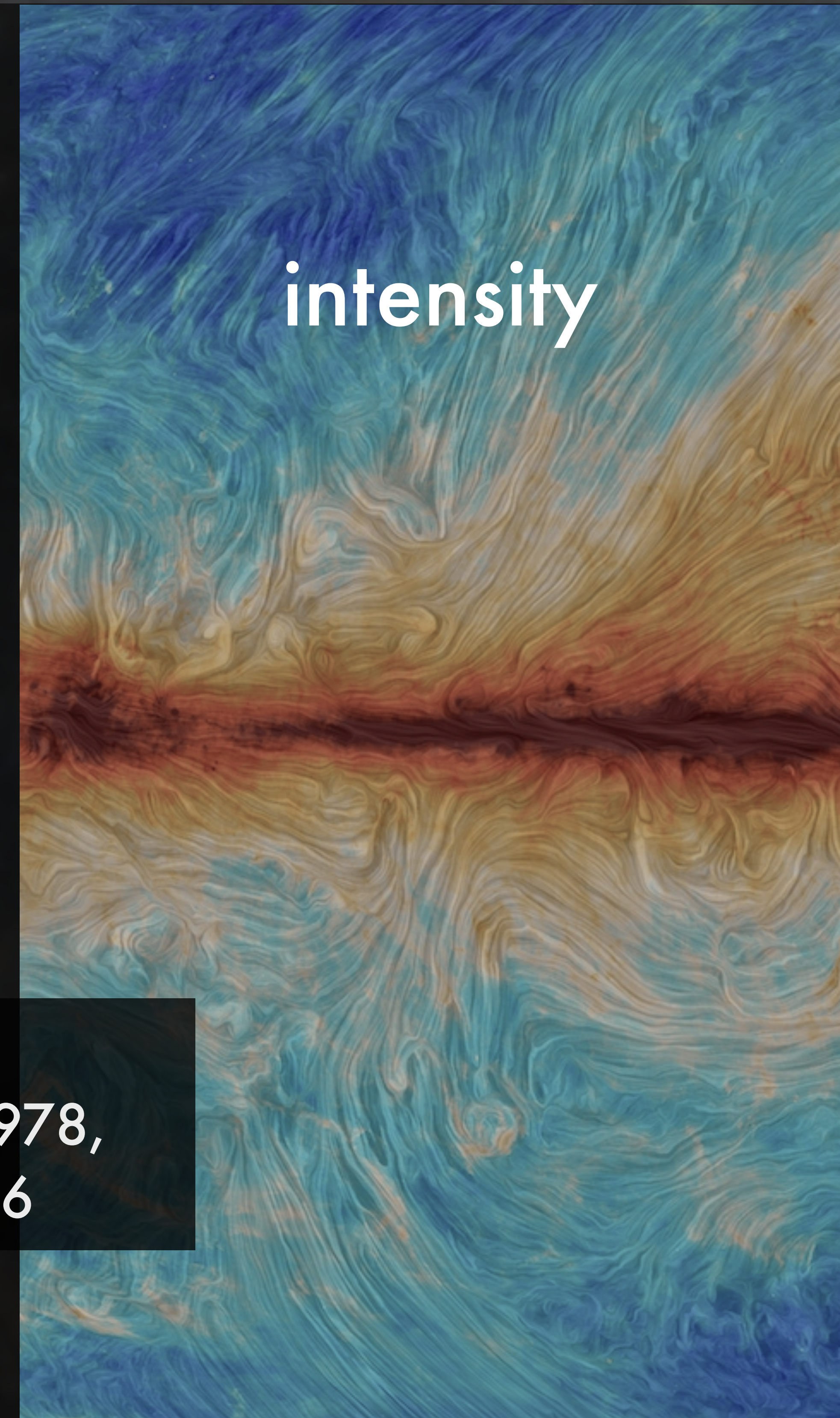
HI4PI: Ben Bekhti+ 2016

is correlated with





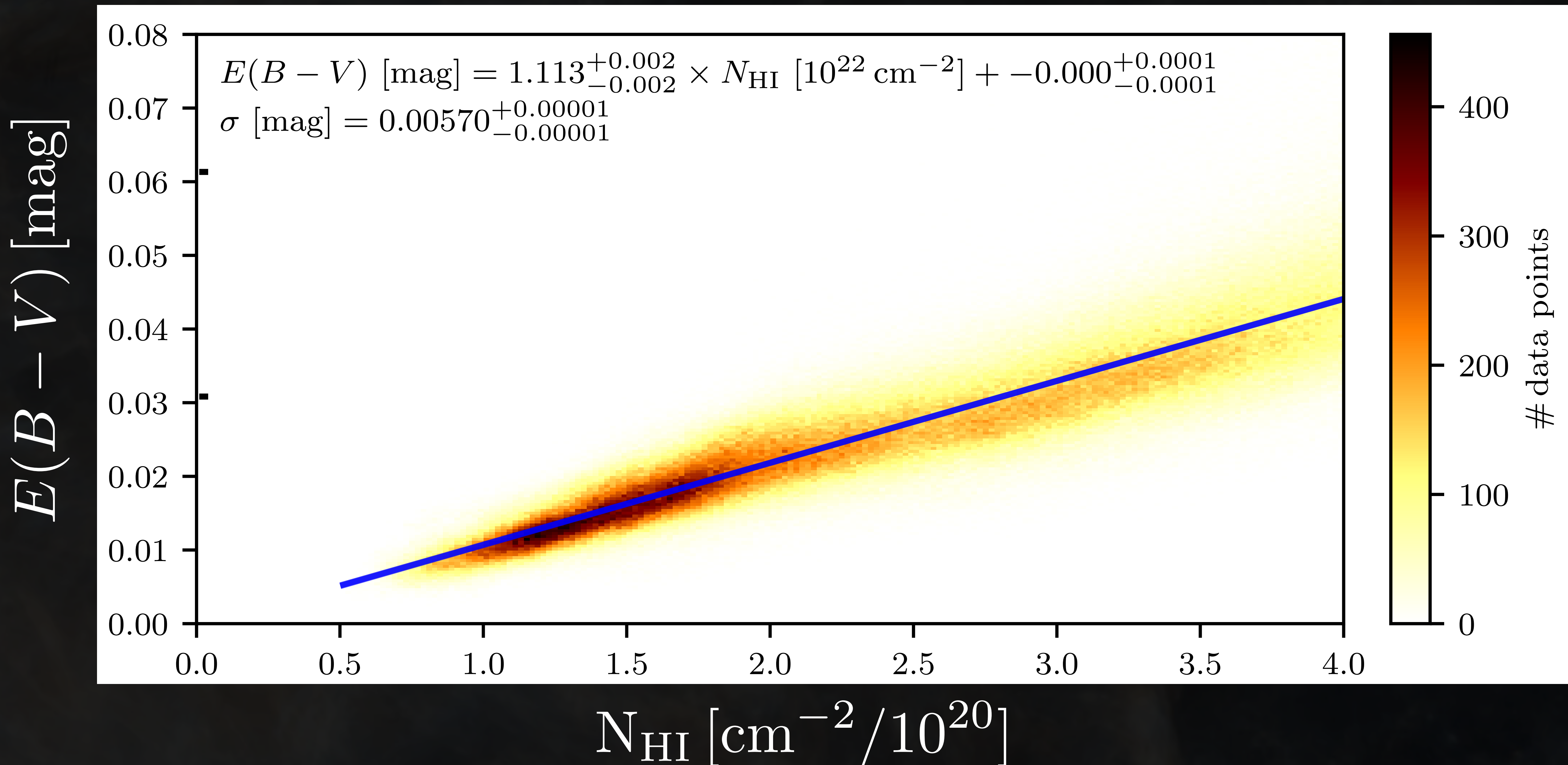
is
correlated
with



e.g.
Burstein & Heiles 1978,
Boulanger+ 1996

1. HI column traces dust column.

Lenz, Hensley, Doré 2017



orientation

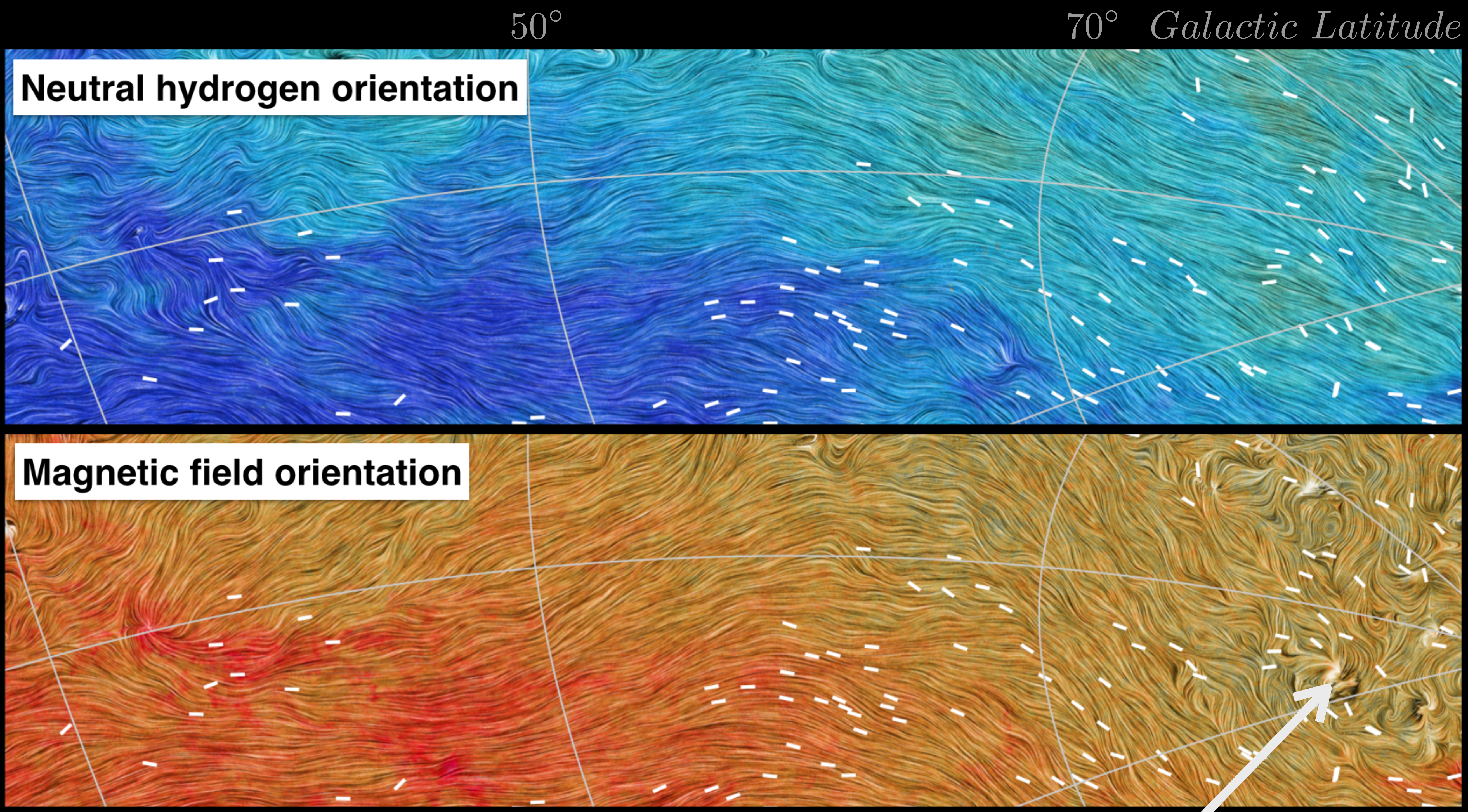
is correlated with

polarization angle

Clark, Peek, Putman 2014
Clark+2015

2. Orientation of HI in narrow spectral channels traces POS magnetic field

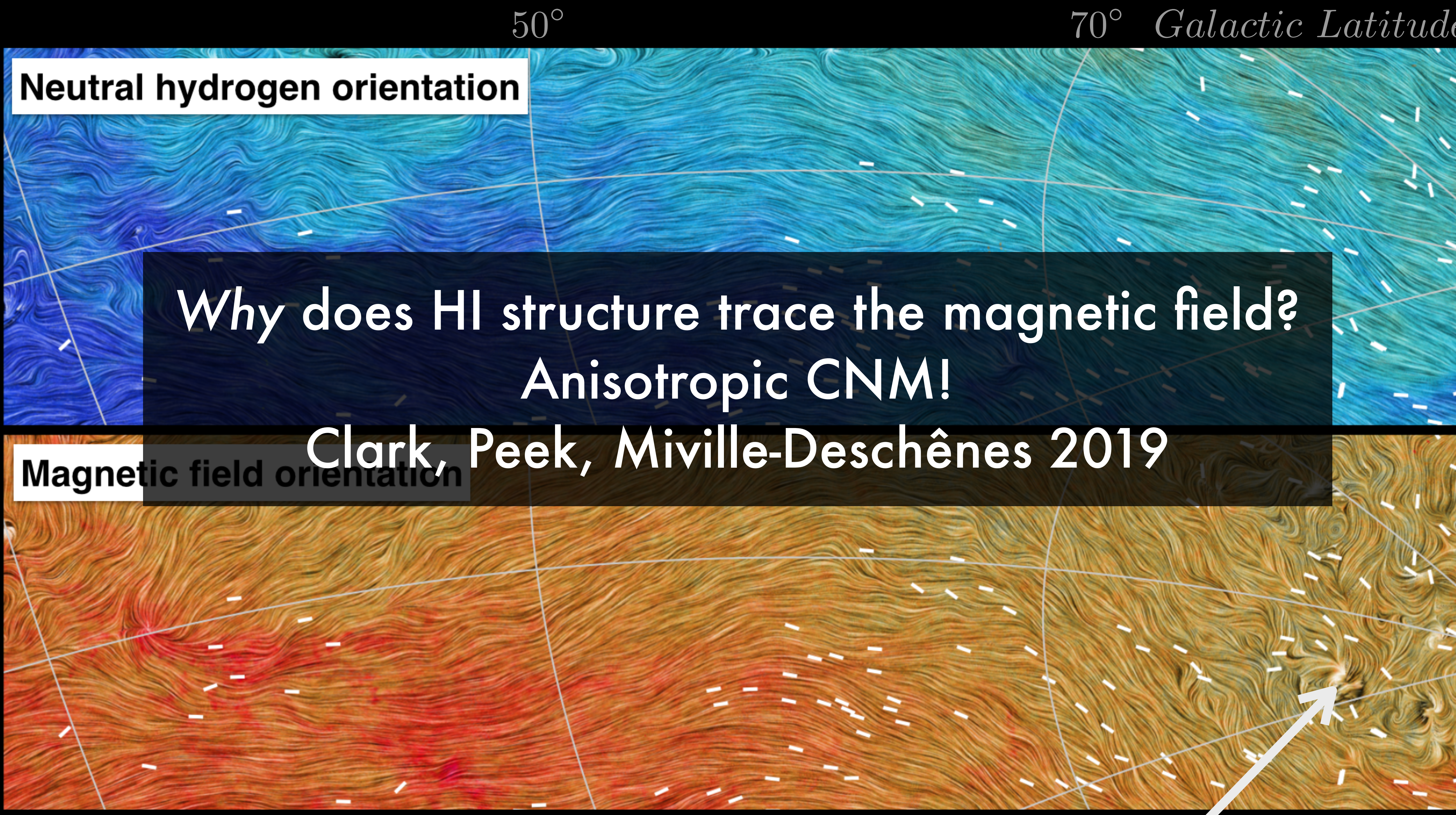
Clark, Hill+ 2015, PRL



Starlight polarization: Heiles 2000

2. Orientation of HI in narrow spectral channels traces POS magnetic field

Clark+ 2015, PRL



Why does HI structure trace the magnetic field?

Anisotropic CNM!

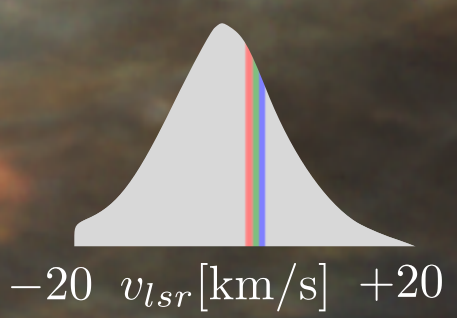
Clark, Peek, Miville-Deschênes 2019

Starlight polarization: Heiles 2000

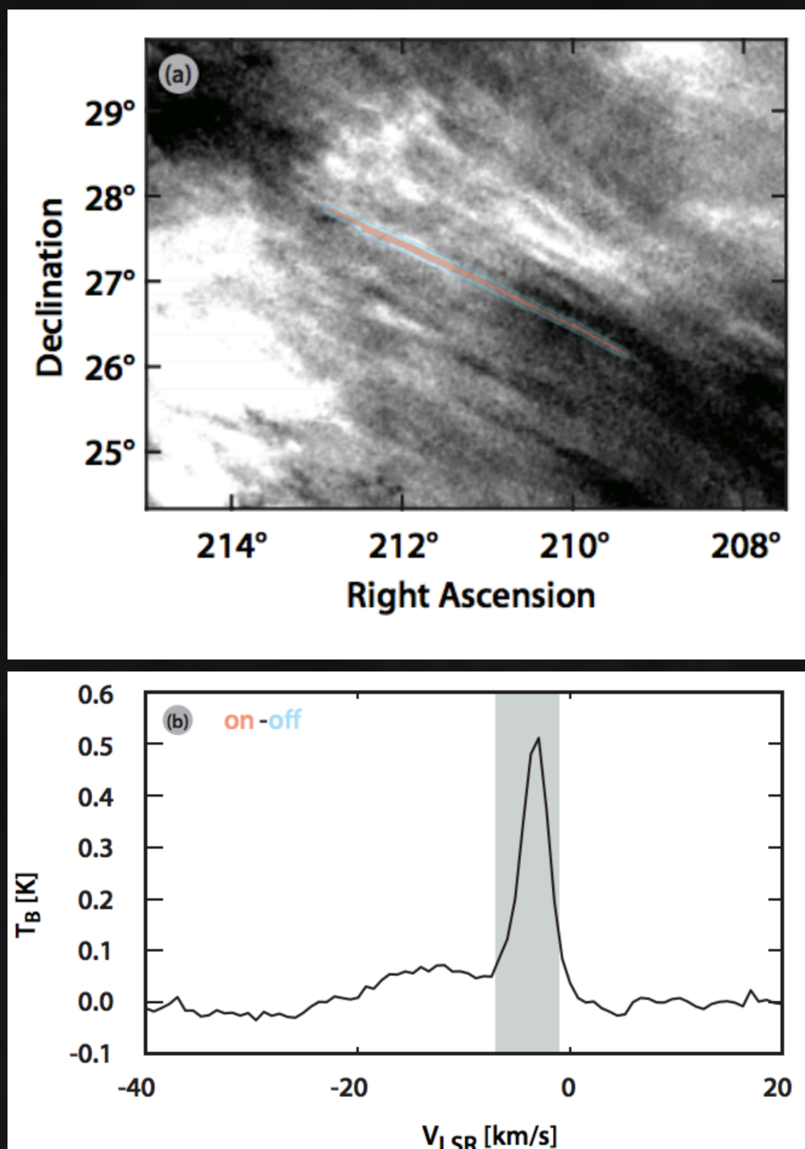
Are the magnetically aligned structures an effect of the turbulent velocity field?

No. Small-scale channel map structures are strongly correlated with the FIR.

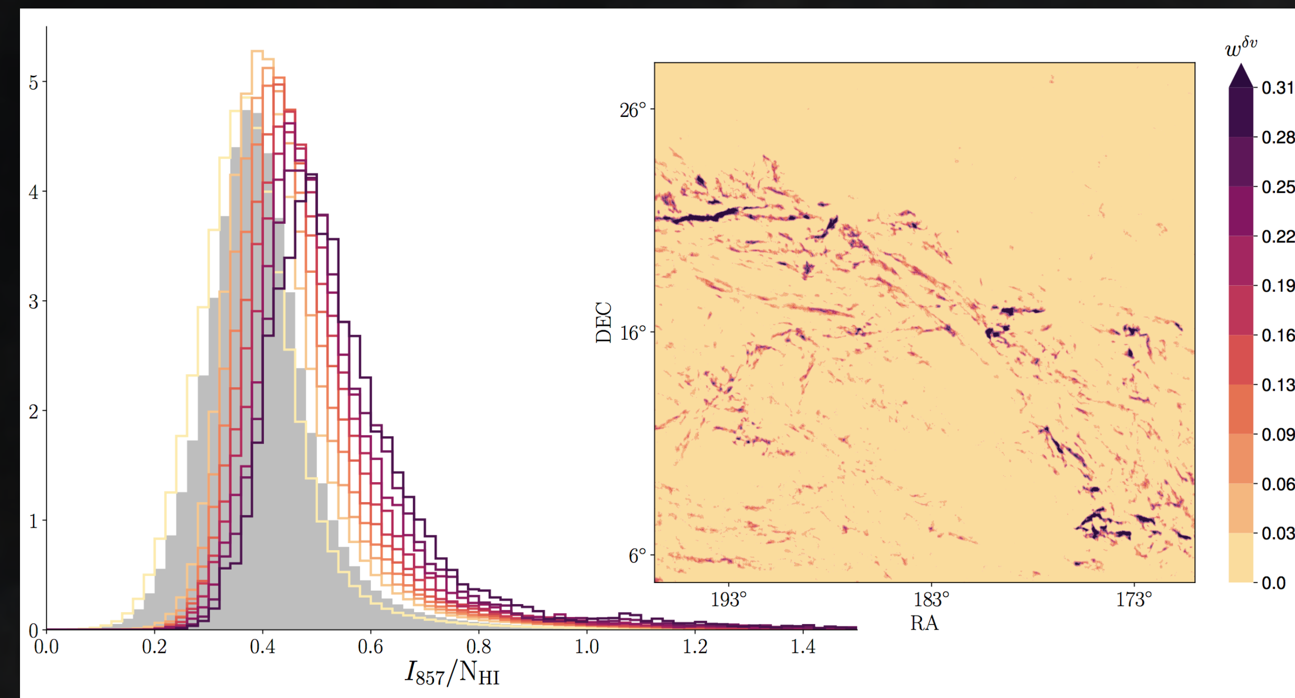
Clark, Peek, Miville-Deschênes 2019



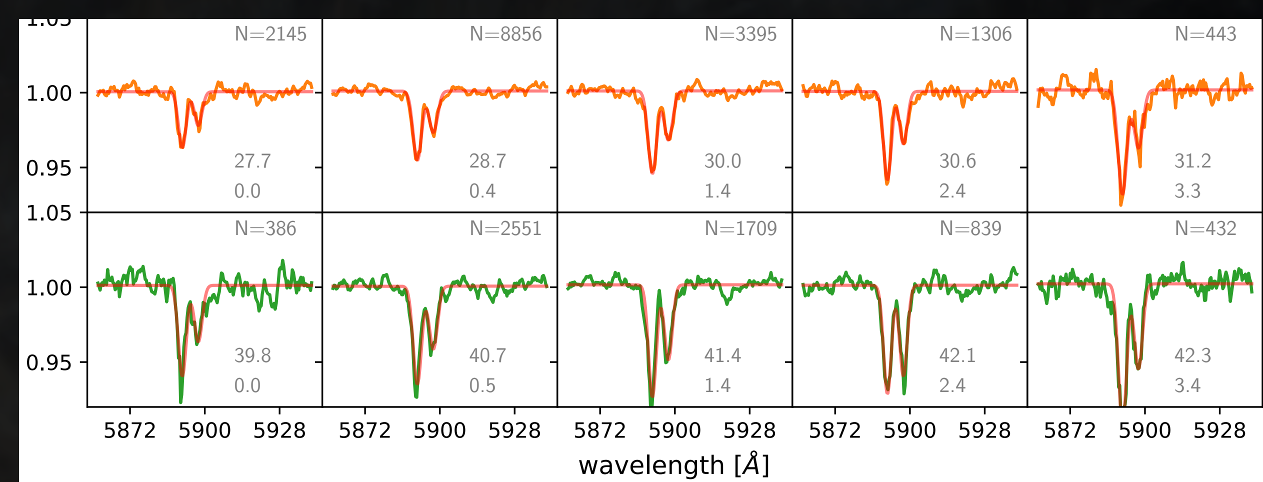
Linewidth measurements, FIR/NHI correlations, and Na I D absorption are all consistent with cold density structures.



Clark+ 2014
See also: Kalberla+ 2016



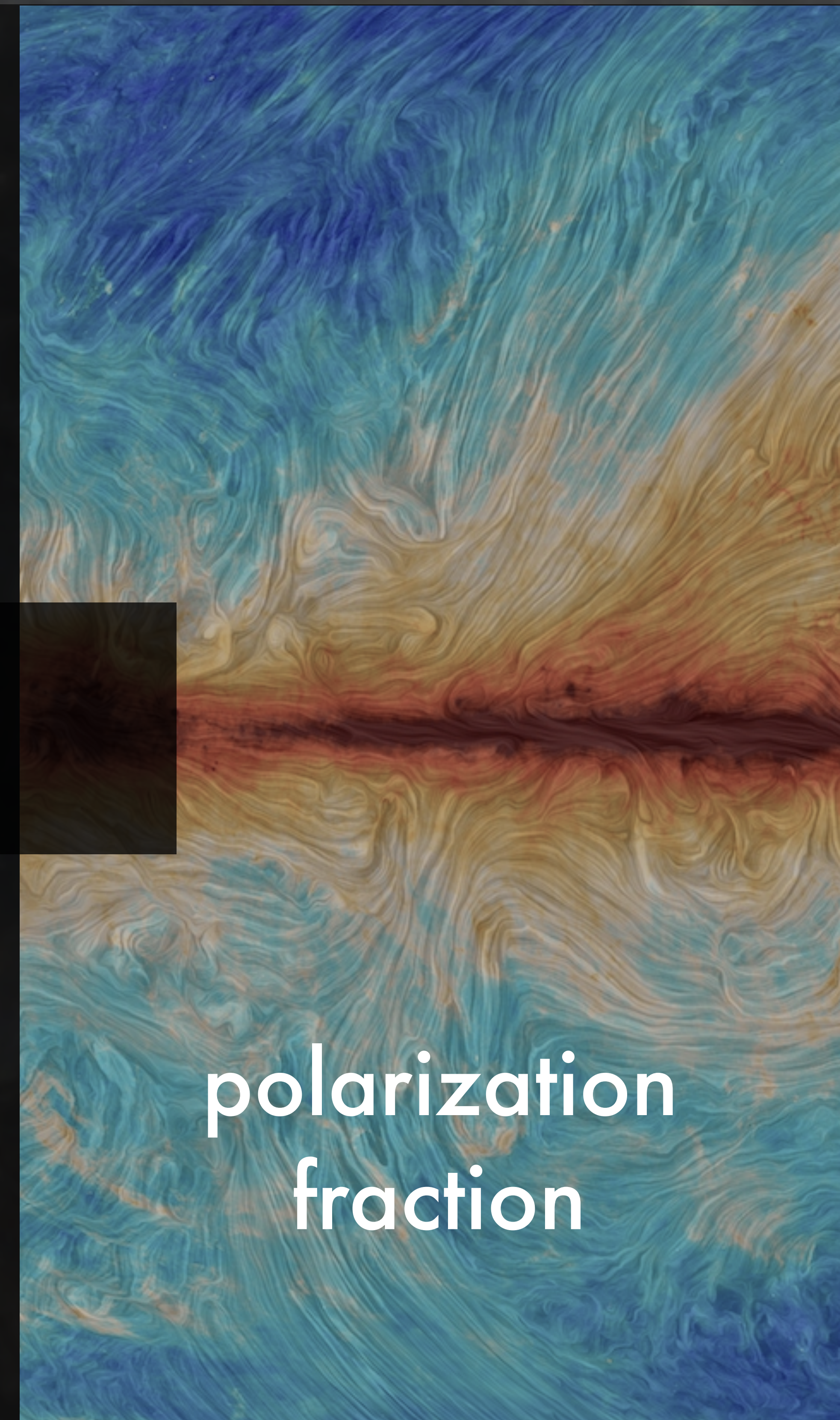
Clark+ 2019



Peek & Clark 2019

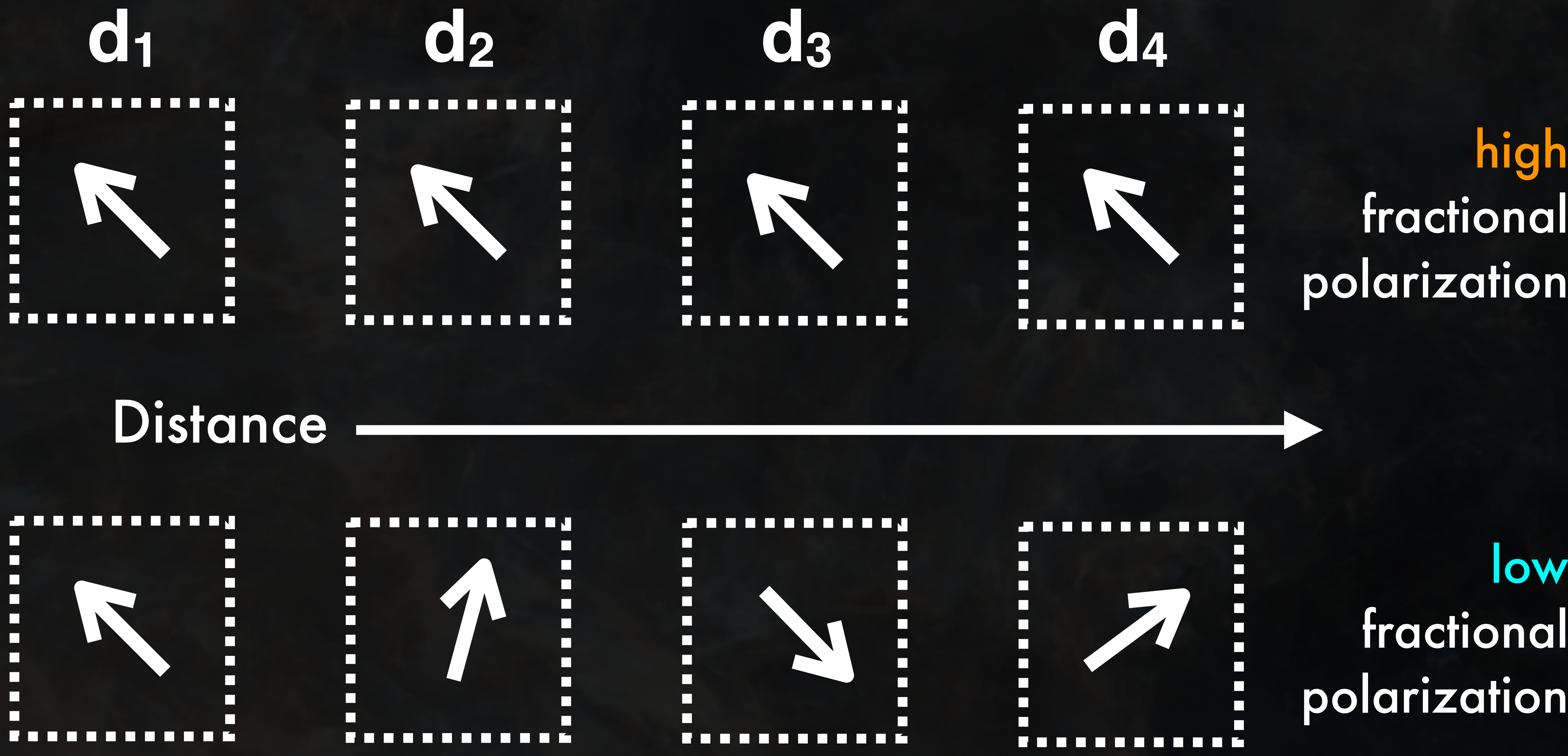
Clark 2018

is
correlated
with



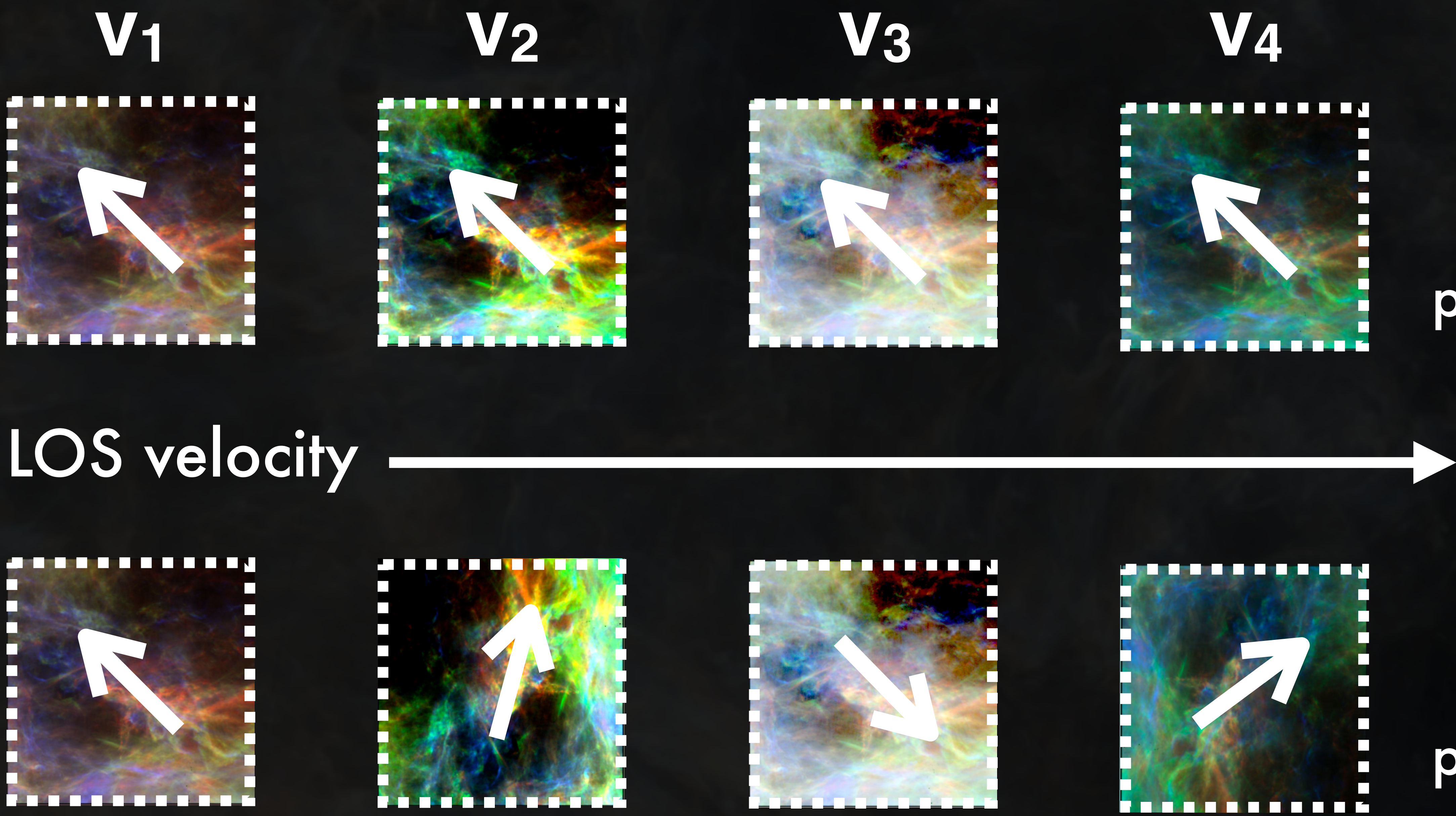
LOS magnetic field tangling

Clark 2018



A new probe of line-of-sight magnetic field tangling

Clark 2018



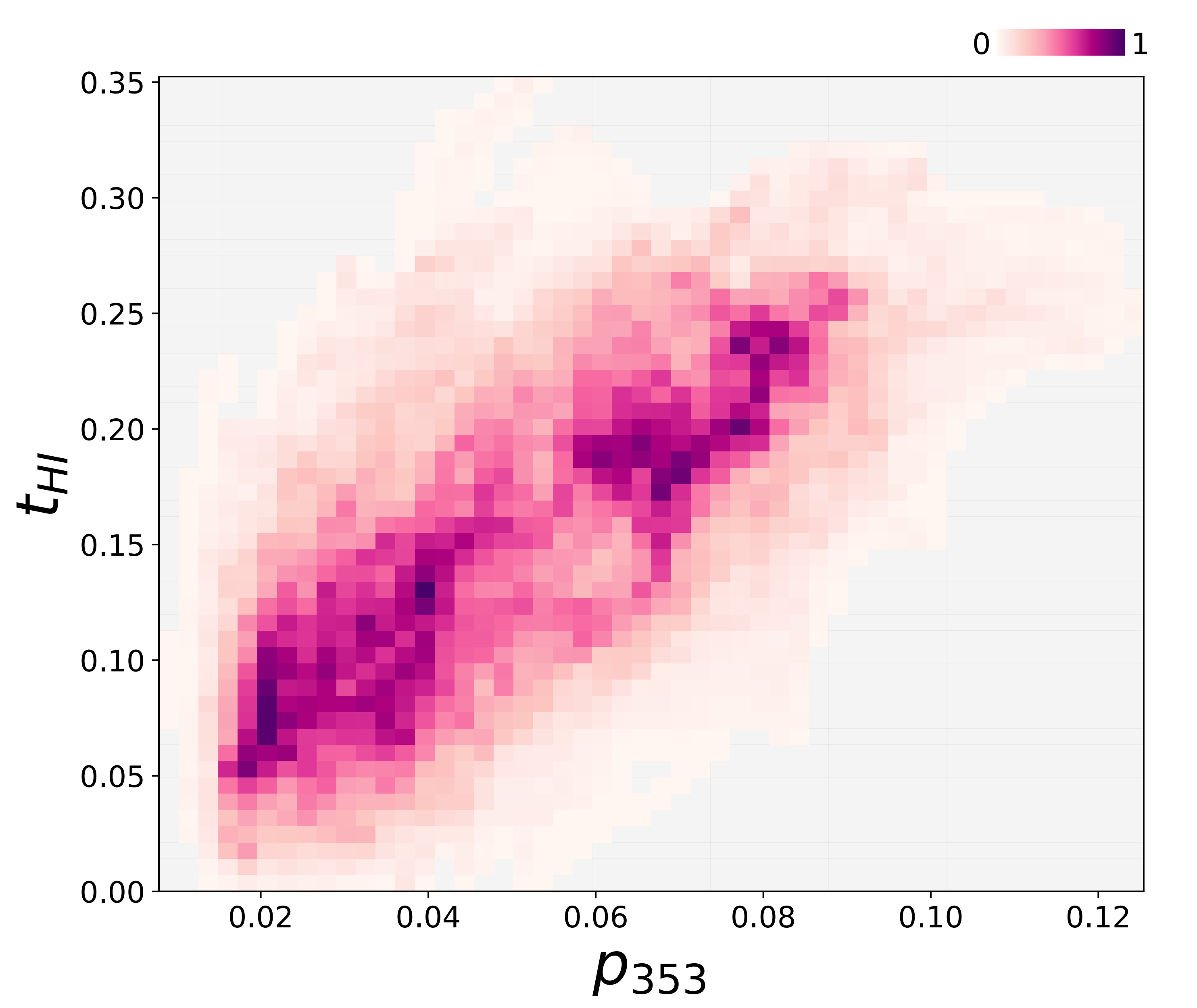
high fractional polarization

low fractional polarization

(P.S. to SED modelers: a data-driven way to model frequency decorrelation!)

3. Velocity coherence of HI orientation traces dust polarization fraction.

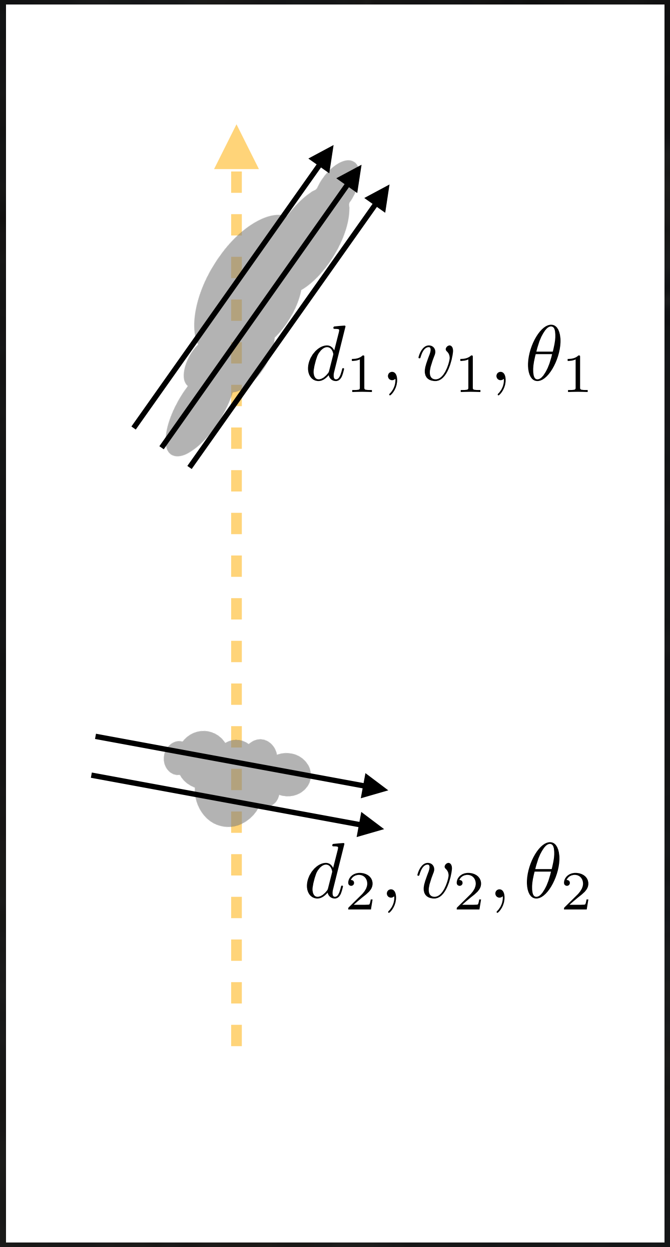
HI coherence



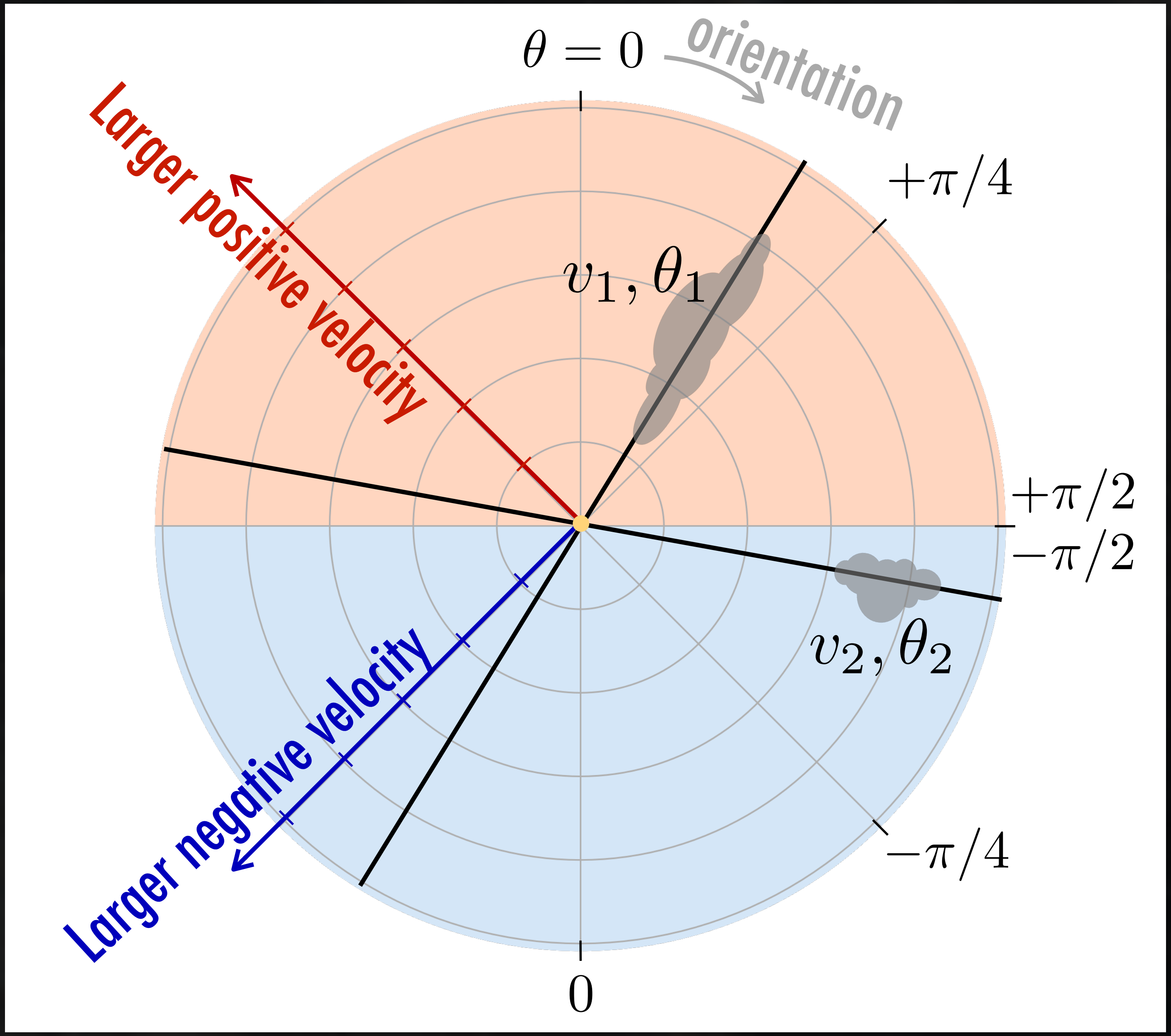
Polarization fraction

Clark 2018

Model: "magnetically coherent" clouds.



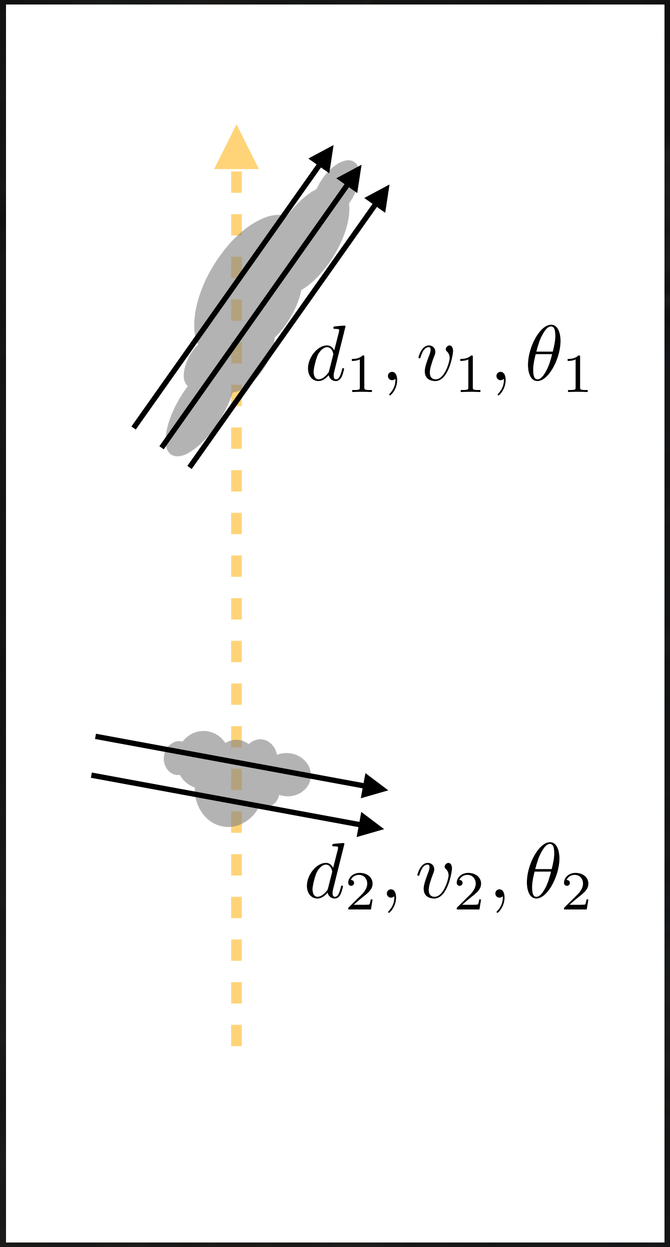
Real Space



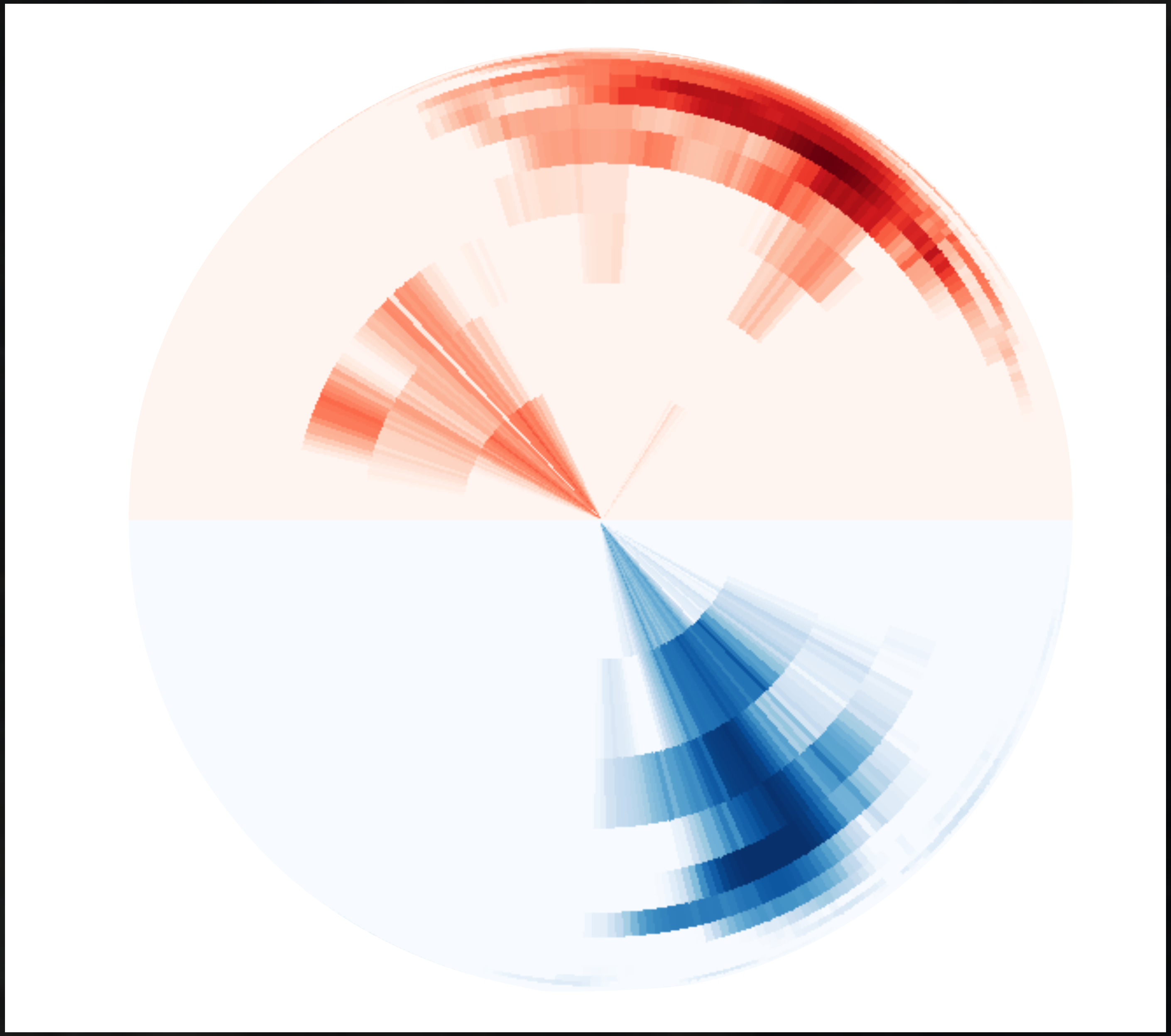
Velocity-Orientation Space

Clark & Hensley 2019

Model: “magnetically coherent” ~~clouds.~~ dusty structures



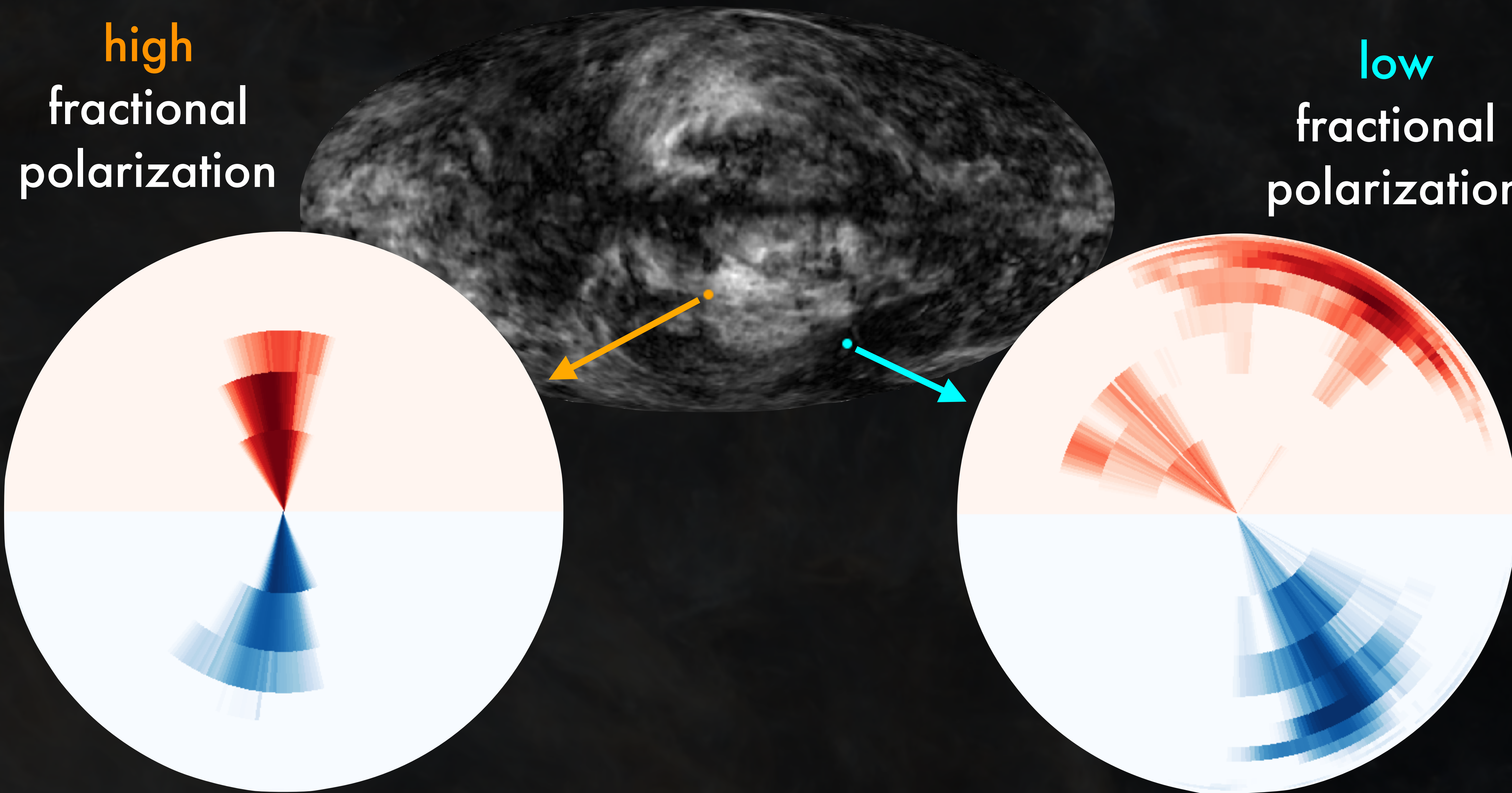
Real Space



Velocity-Orientation Space

Clark & Hensley 2019

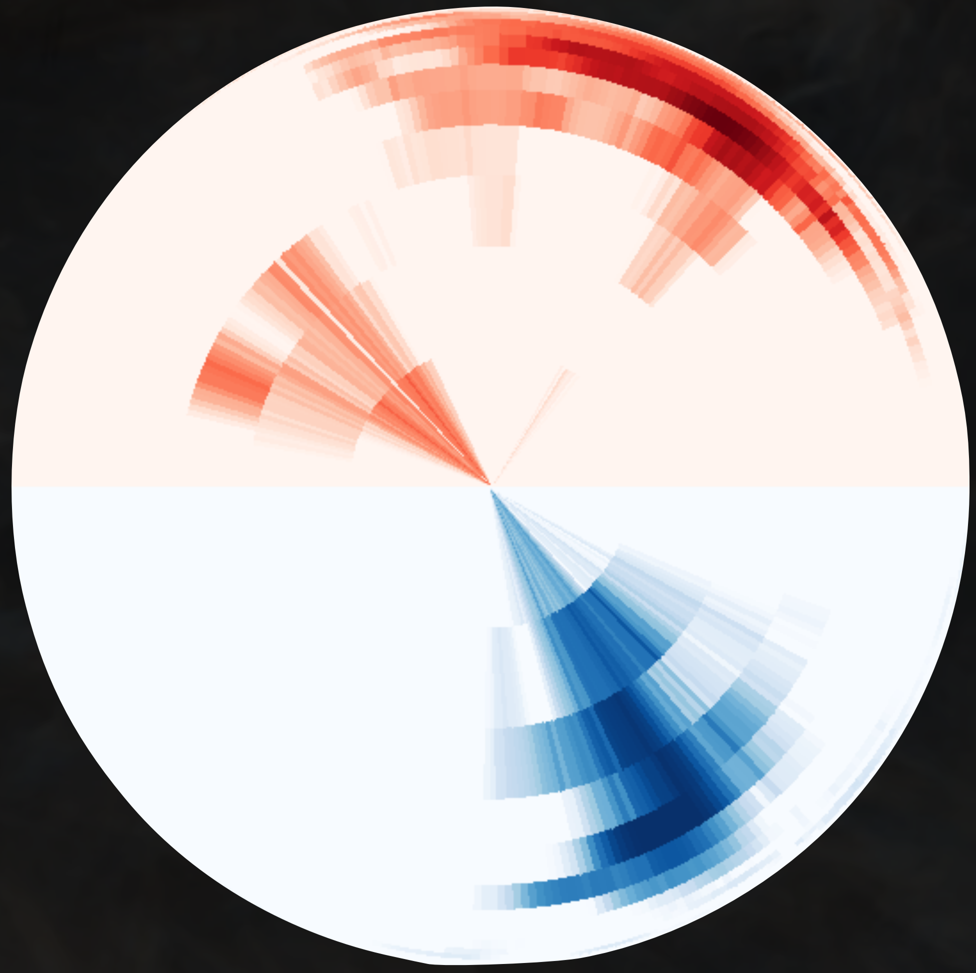
Model: “magnetically coherent” ~~clouds.~~ dusty structures



Clark & Hensley 2019

We compute Stokes Q and U maps as a function of velocity.

$R(v,\theta)$

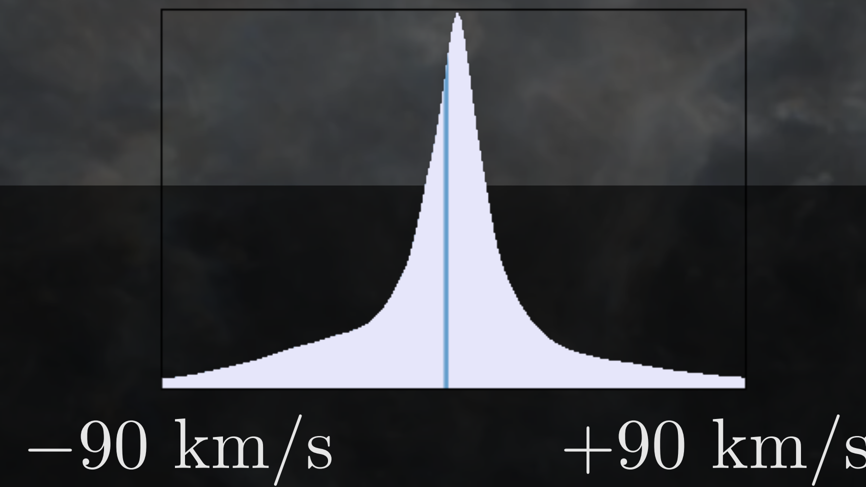


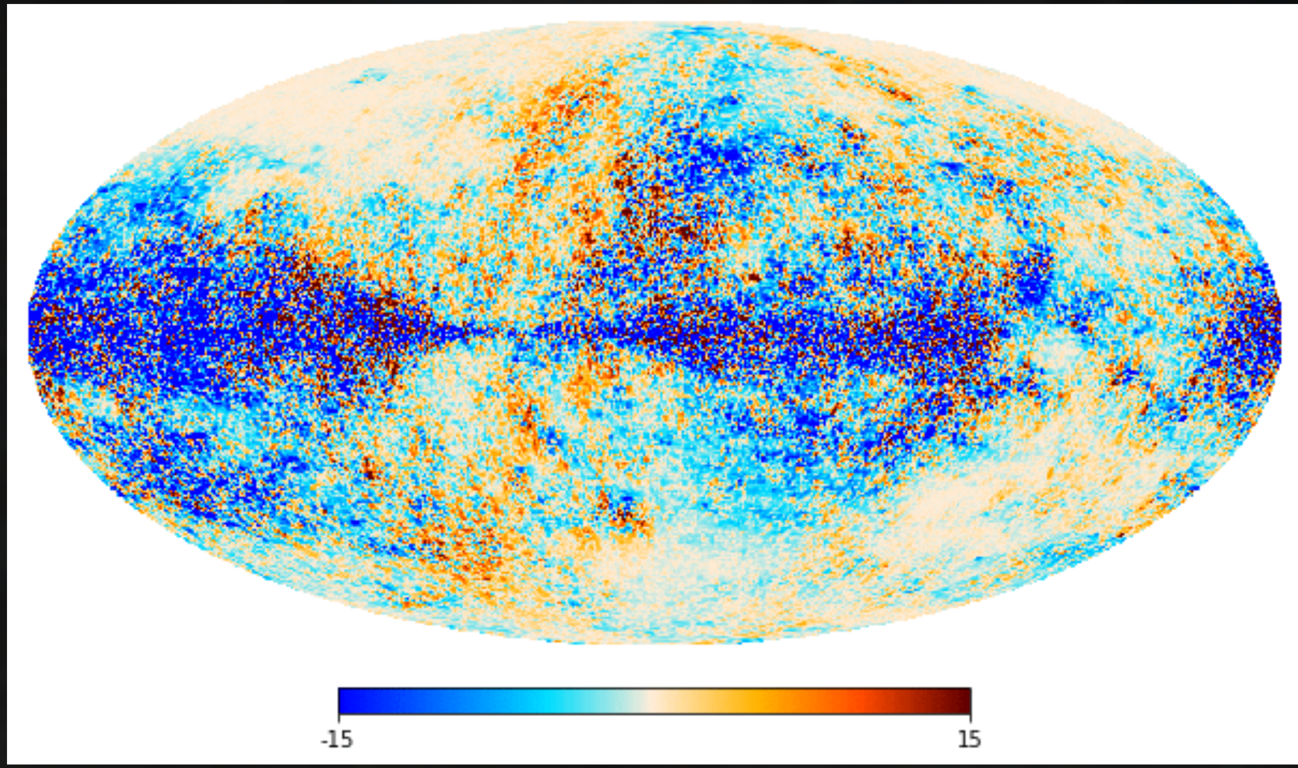
$$Q_{\mathrm{HI}}(v) = I(v) \sum_{\theta} R(v,\theta) \cos(2\theta)$$

$$U_{\mathrm{HI}}(v) = I(v) \sum_{\theta} R(v,\theta) \sin(2\theta)$$

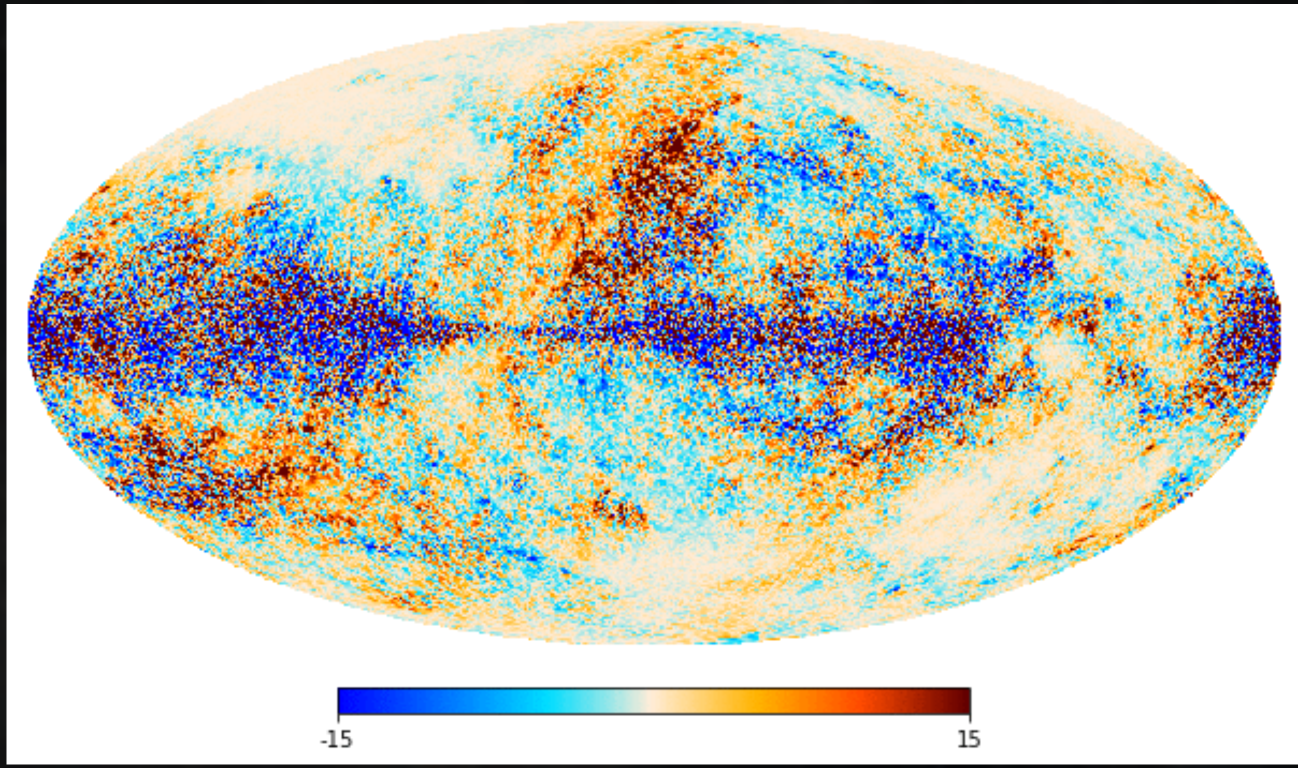
Clark & Hensley 2019

We compute Stokes Q and U maps as a function of velocity.





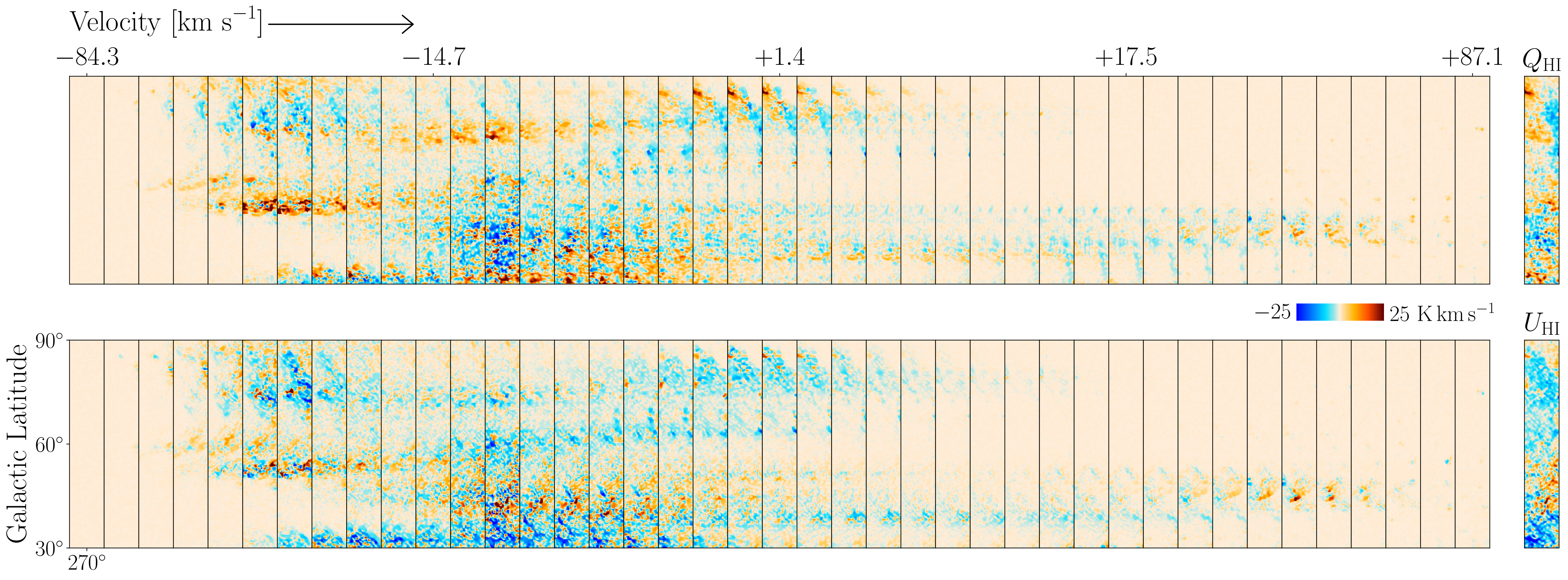
$Q_{\rm HI}(v)$



$U_{\rm HI}(v)$

Clark & Hensley 2019

We compute Stokes Q and U maps as a function of velocity.

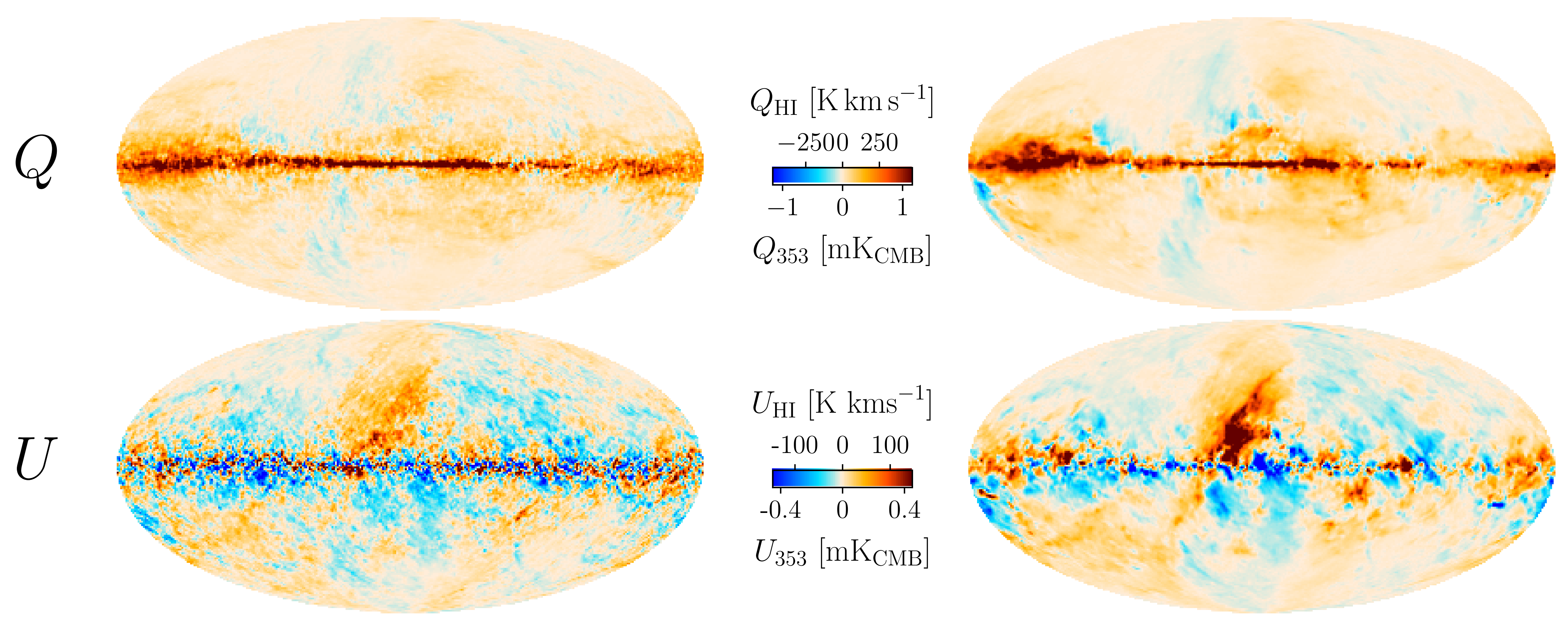


Clark & Hensley 2019

We integrate our maps over the velocity dimension to compare them to *Planck* observations.

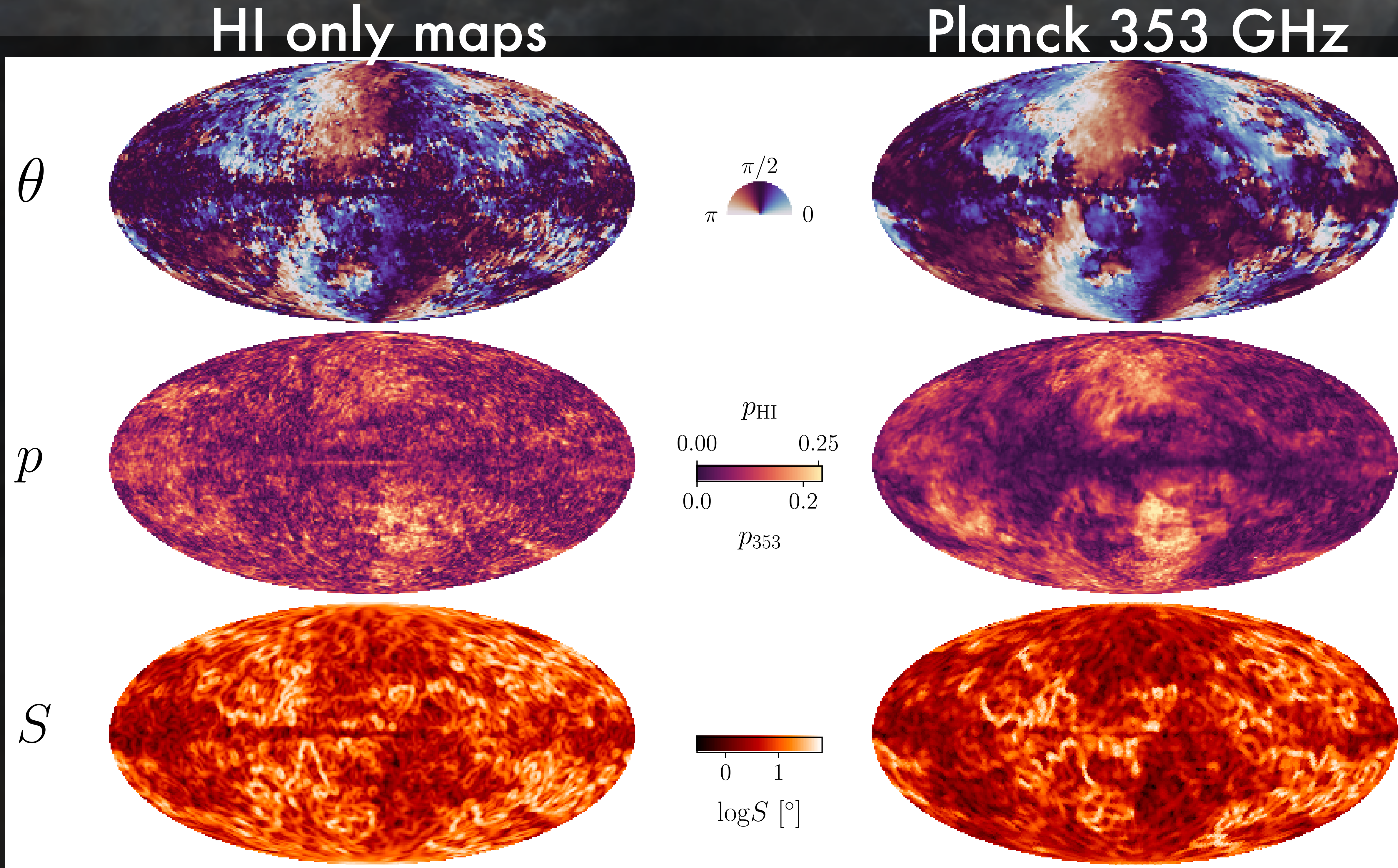
HI only maps

Planck 353 GHz



Clark & Hensley 2019

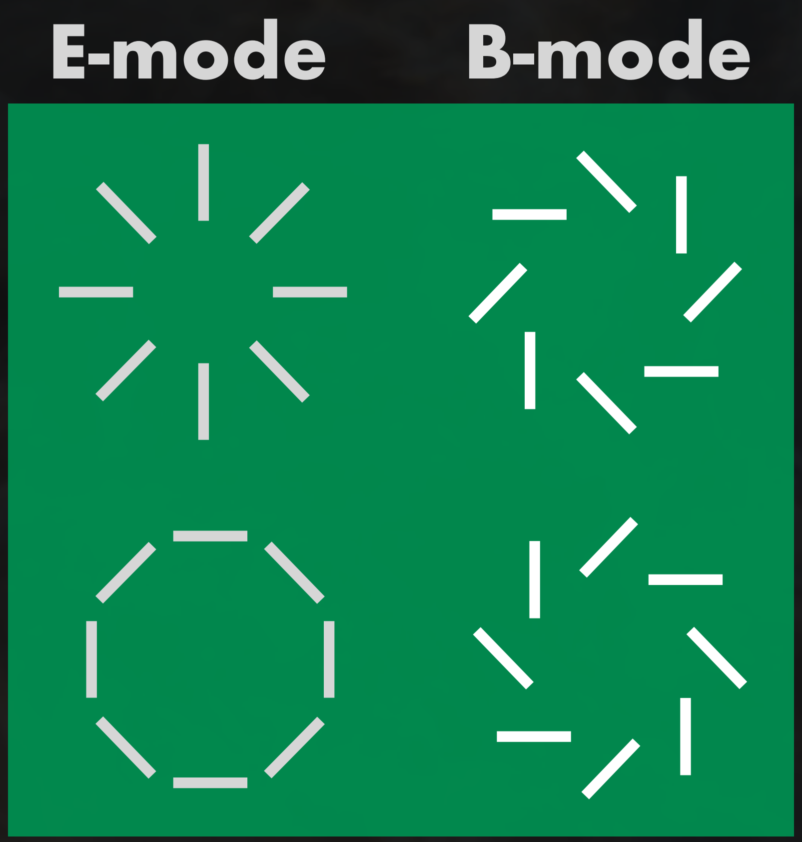
Compare derived quantities like the polarization angle, polarization fraction, and polarization angle dispersion function.

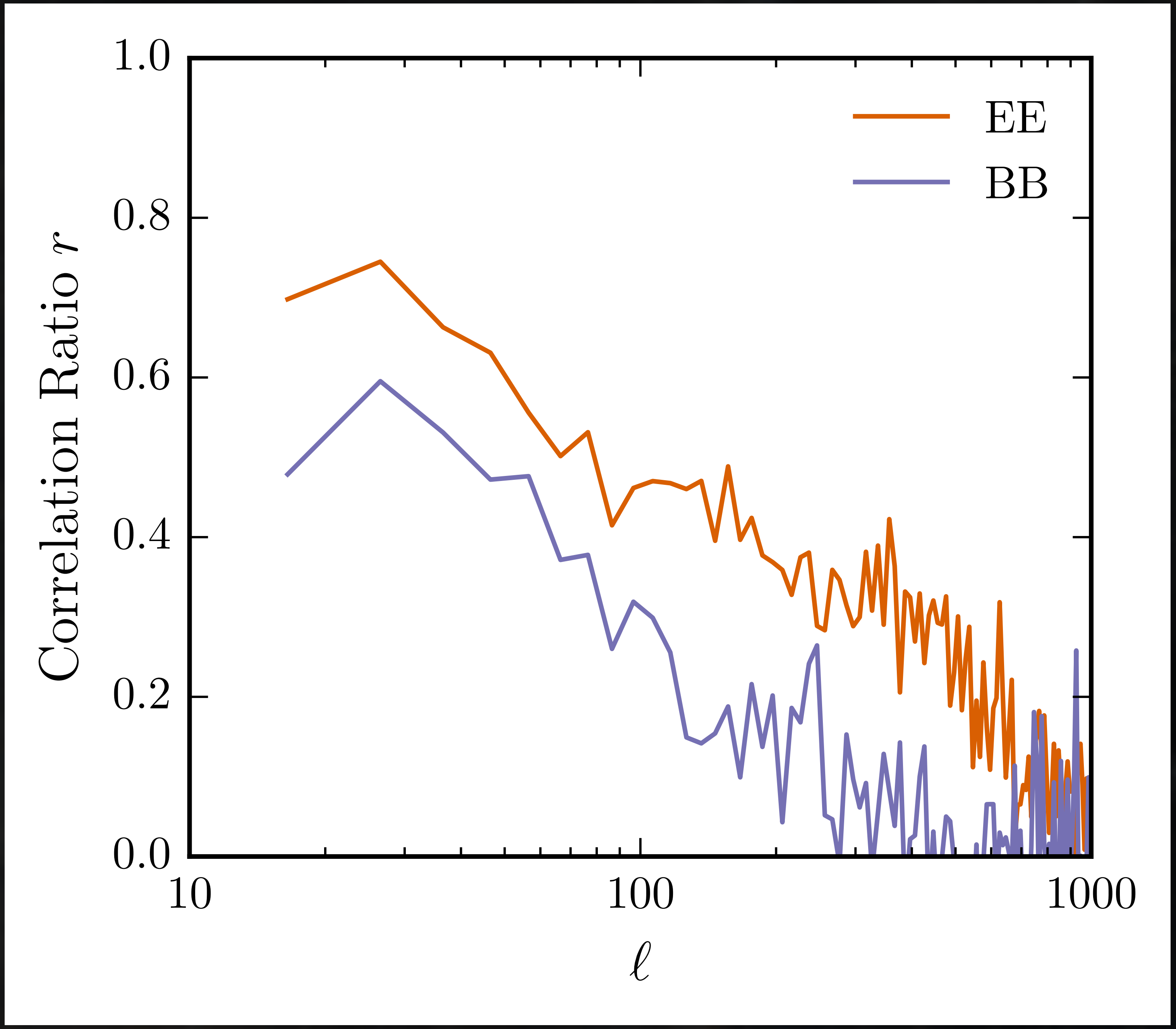


Clark & Hensley 2019

These maps are very well correlated with *Planck*, especially on large angular scales.

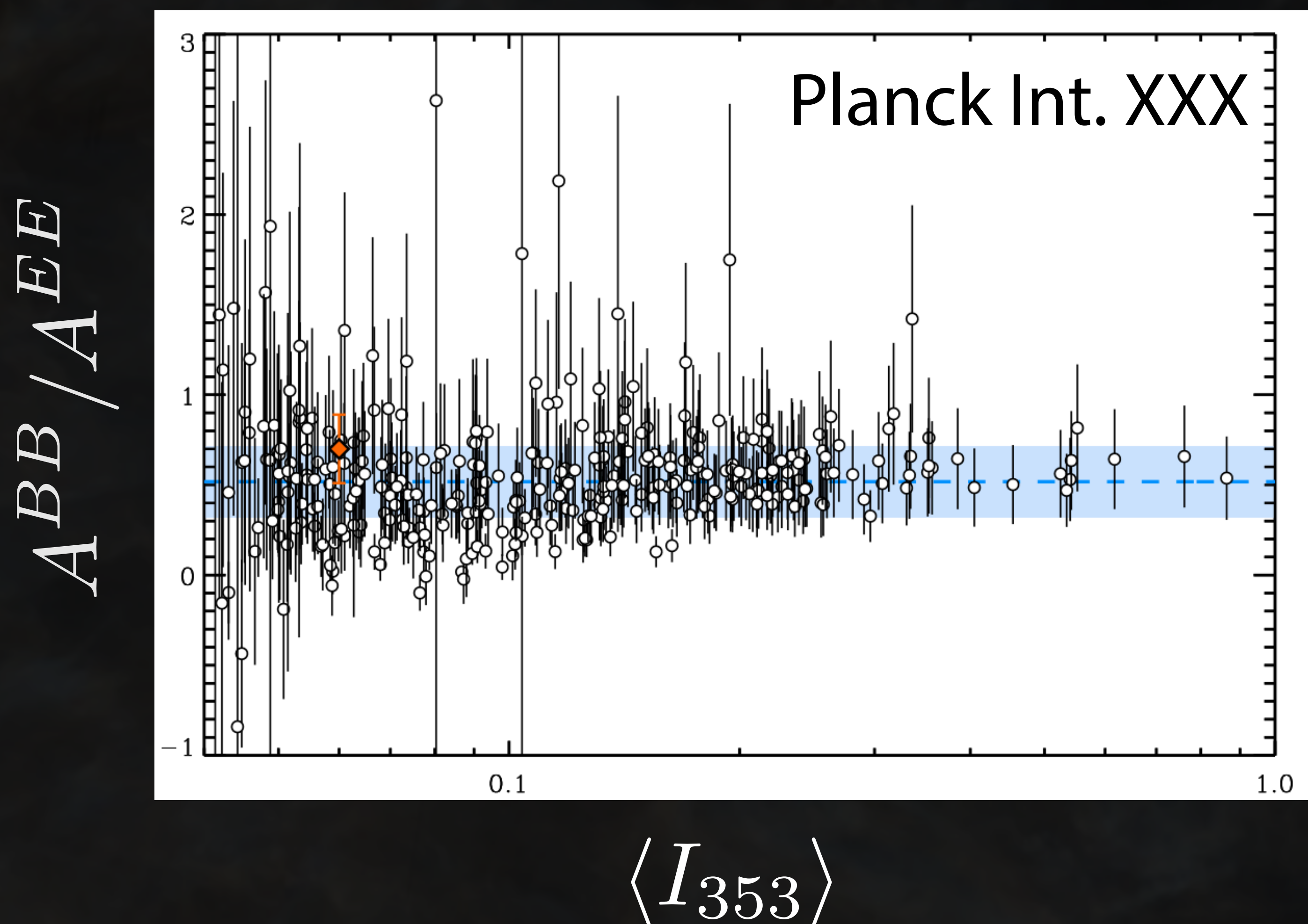
$$r^{XX}_{\mathrm{HI}\times 353} \equiv \frac{D_\ell^{X_{\mathrm{HI}} X_{353}}}{\sqrt{D_\ell^{X_{\mathrm{HI}} X_{\mathrm{HI}}} D_\ell^{X_{353} X_{353}}}}$$

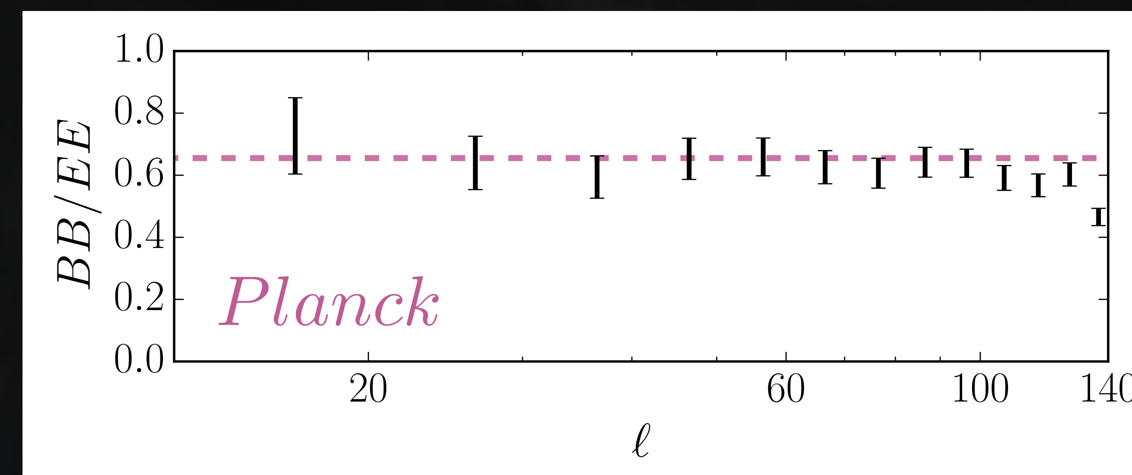




Clark & Hensley 2019

Planck measured a non-unity amplitude ratio in the dust E- and B-modes.



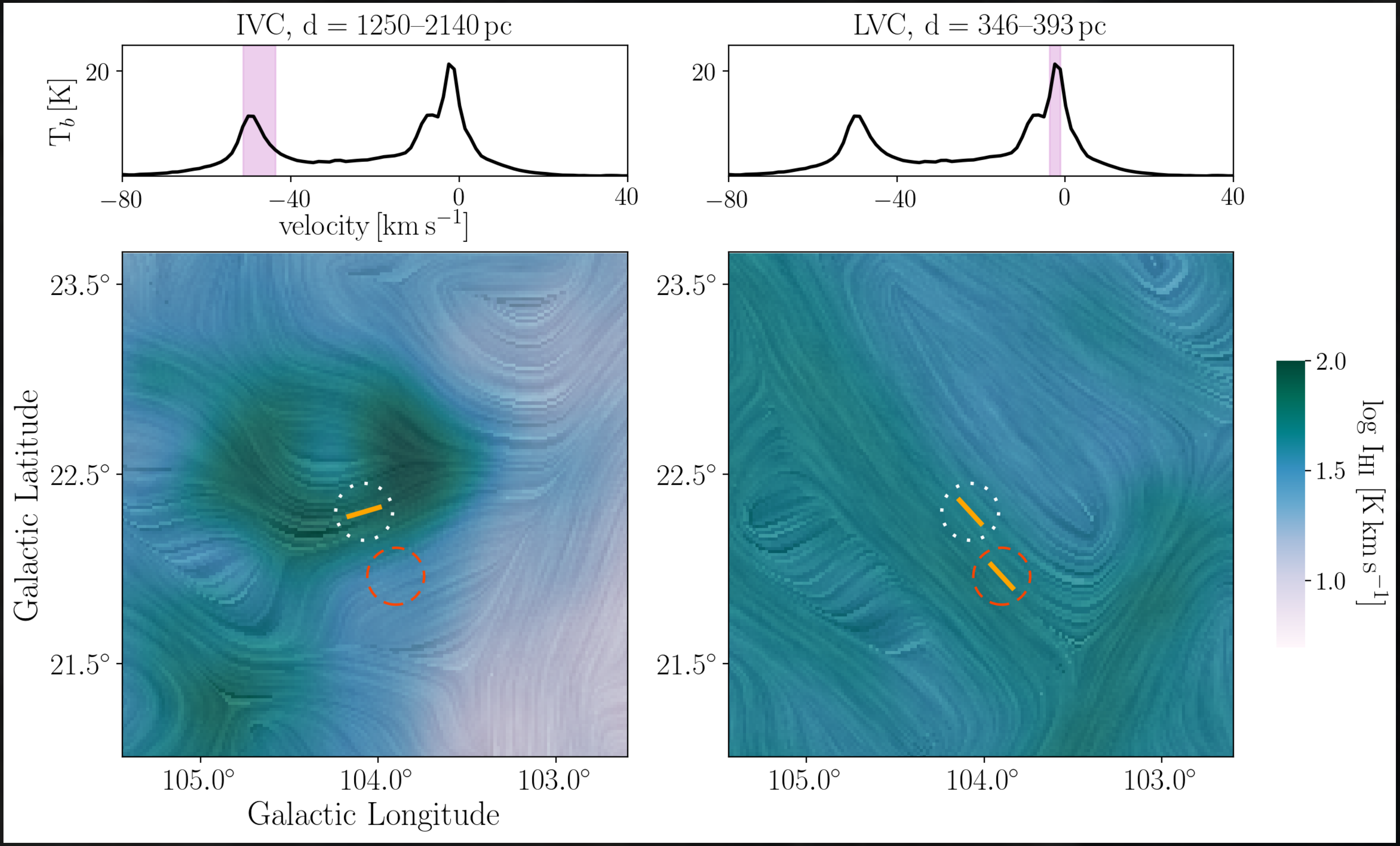


Clark & Hensley 2019

See also
Planck Int. XXXVIII,
Clark+ 2015

We reproduce this in the HI-based maps.

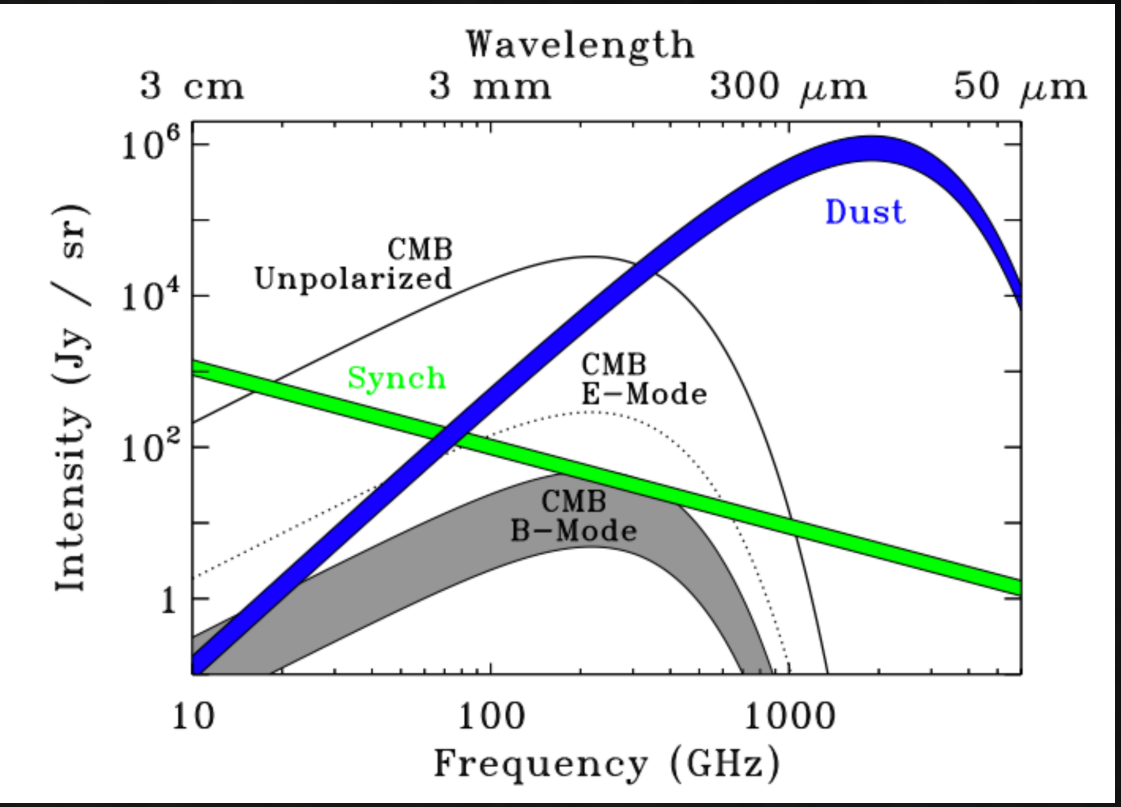
Our maps provide a local estimate of the magnetic field orientation as a function of velocity.



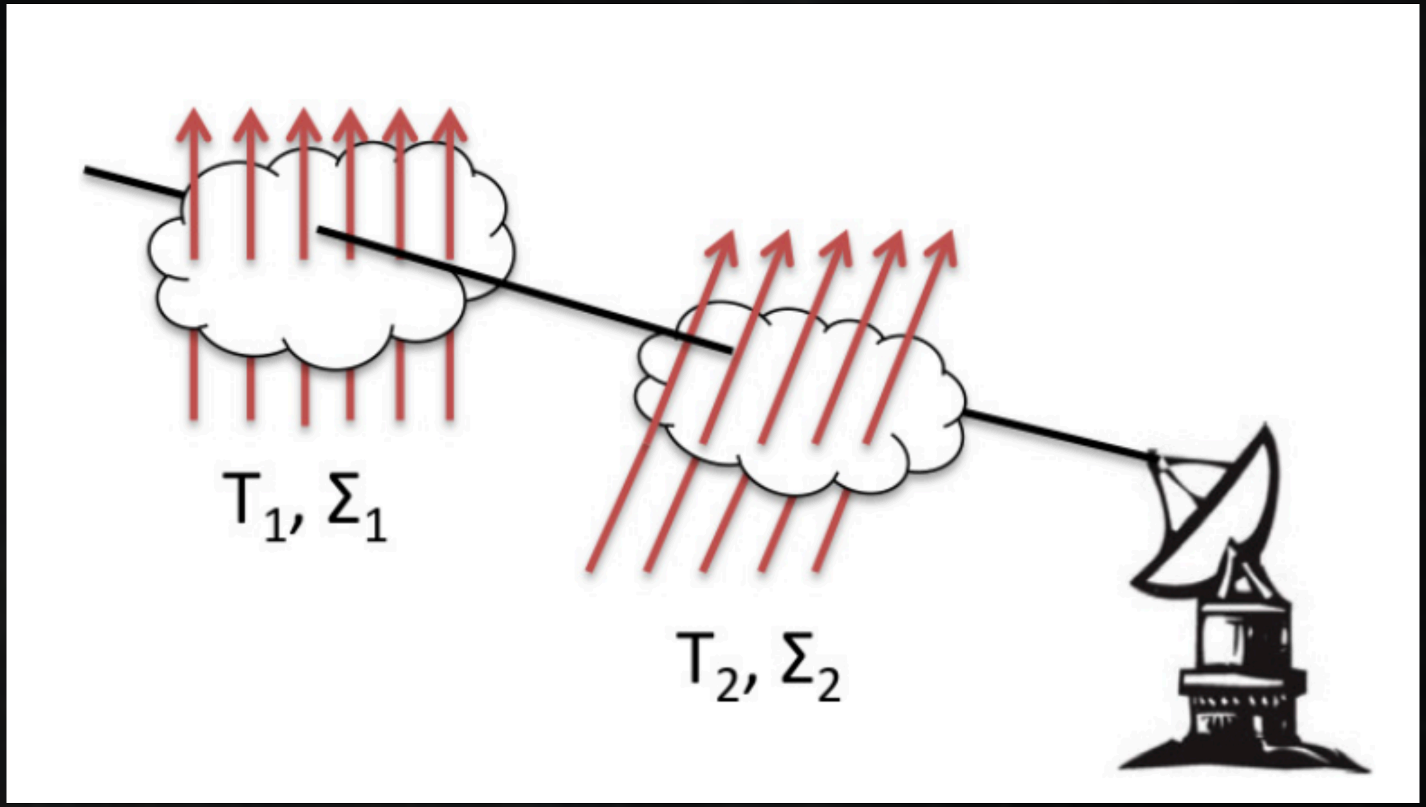
Orientations: Panopoulou+ 2019

Background: Clark & Hensley

The three-dimensional structure of dust and magnetic fields complicates foreground subtraction.



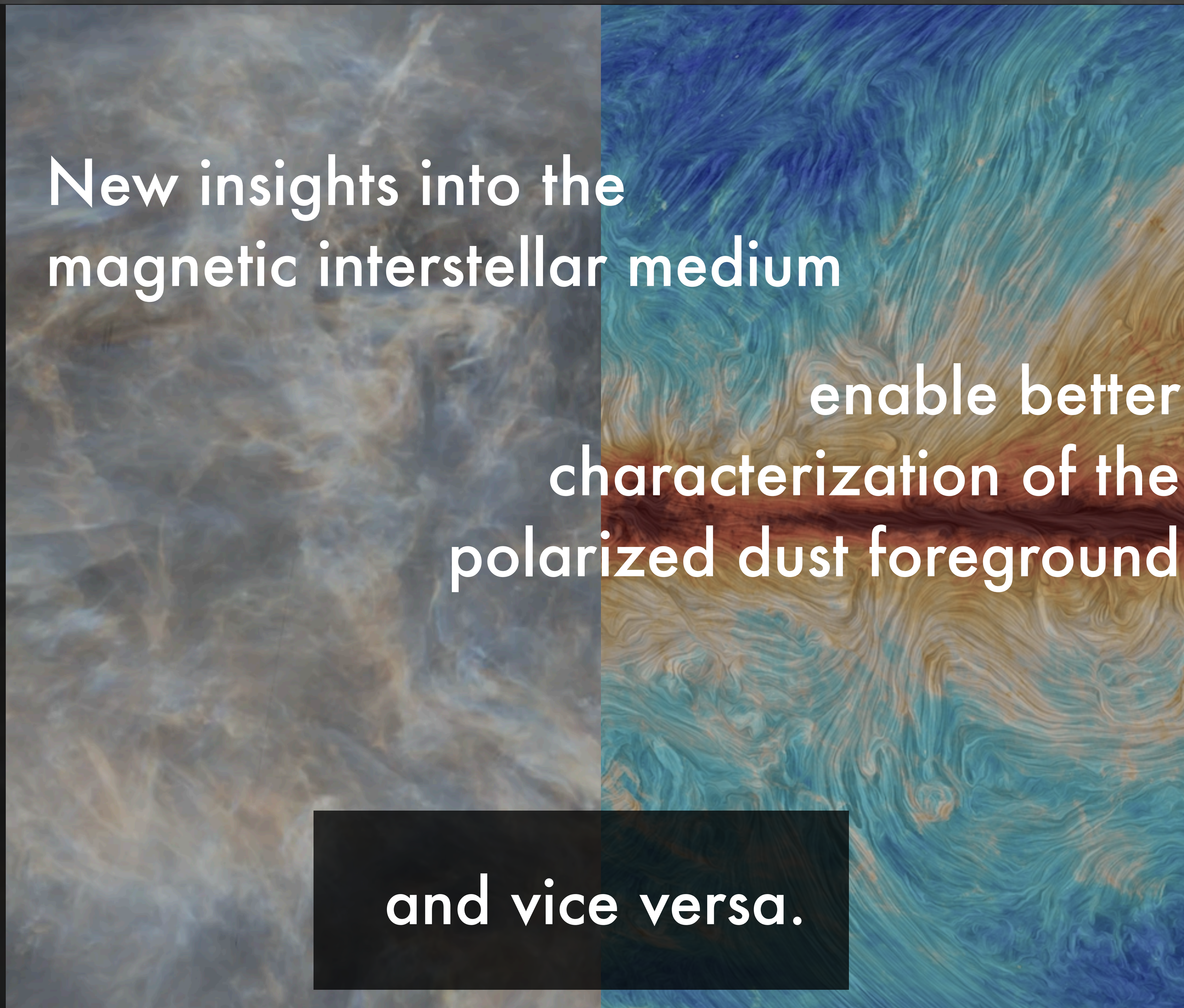
Kogut & Fixsen 2016



Tassis & Pavlidou 2015

What's next? Data-driven predictions of frequency decorrelation.

Brandon Hensley's talk

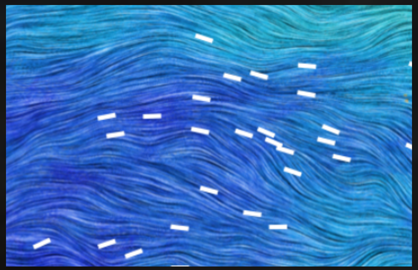


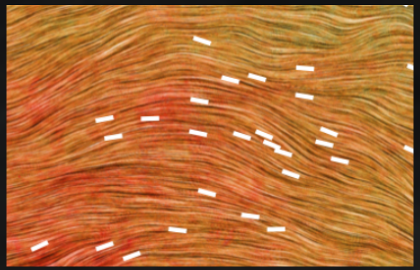
New insights into the
magnetic interstellar medium

enable better
characterization of the
polarized dust foreground

and vice versa.

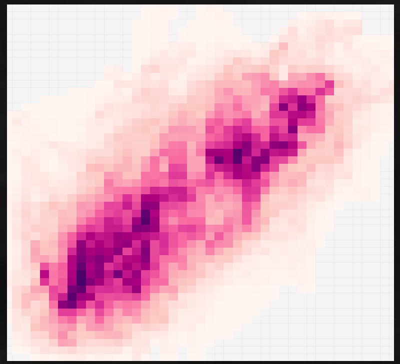
Neutral hydrogen in the diffuse ISM is well aligned with the ambient magnetic field.





Clark+ 2014
Clark+ 2015

The magnetic alignment is driven by anisotropic cold neutral medium structure.
Clark+ 2019



The velocity structure of HI morphology probes line-of-sight magnetic field tangling. Clark 2018

We map magnetic coherence in three dimensions using only HI data.

Clark & Hensley 2019, ApJ 887, 2
arXiv:1909.11673