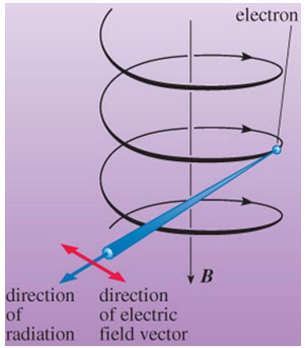
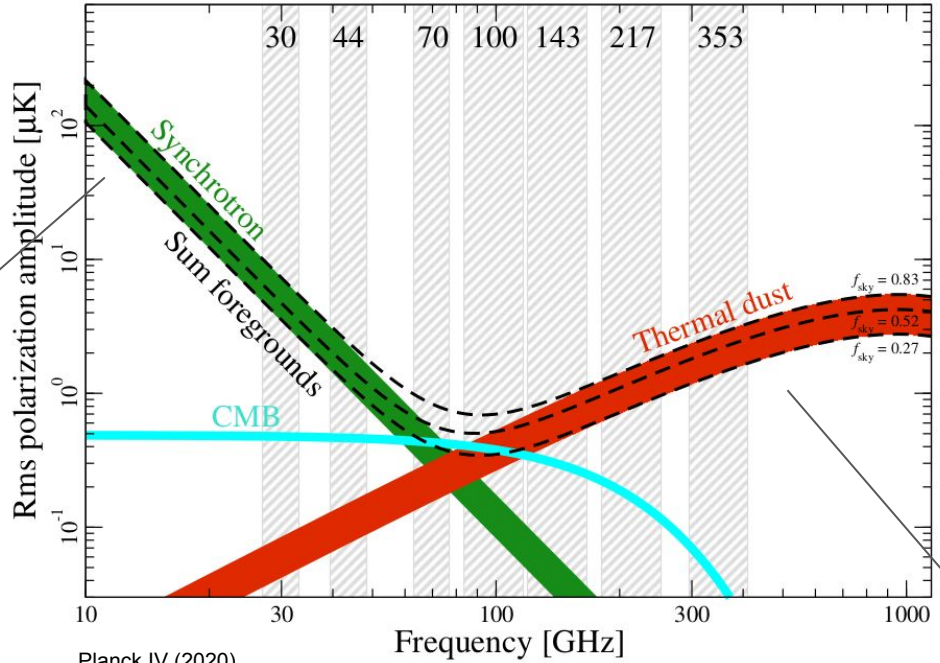
The Galactic ISM in 3D: Plenary summary

Gina Panopoulou & Brandon Hensley

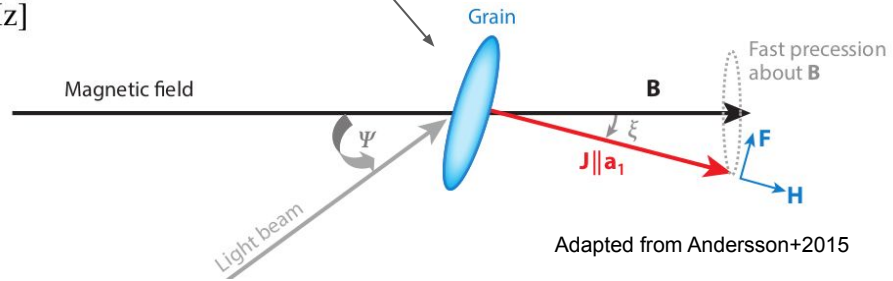
CMB S4 Summer Meeting 2021

Imprint of Galactic magnetic field at CMB frequencies



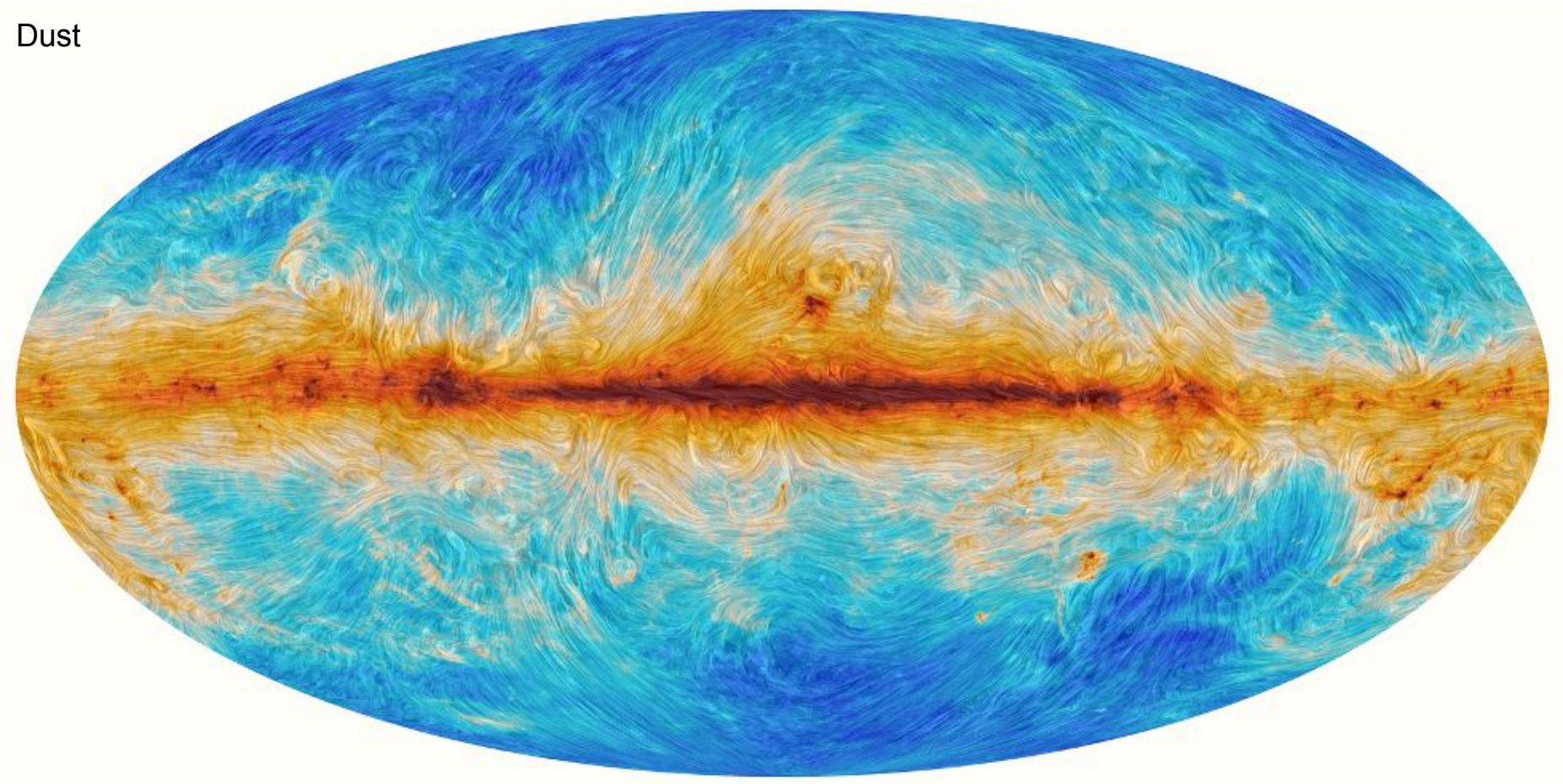


Planck IV (2020)



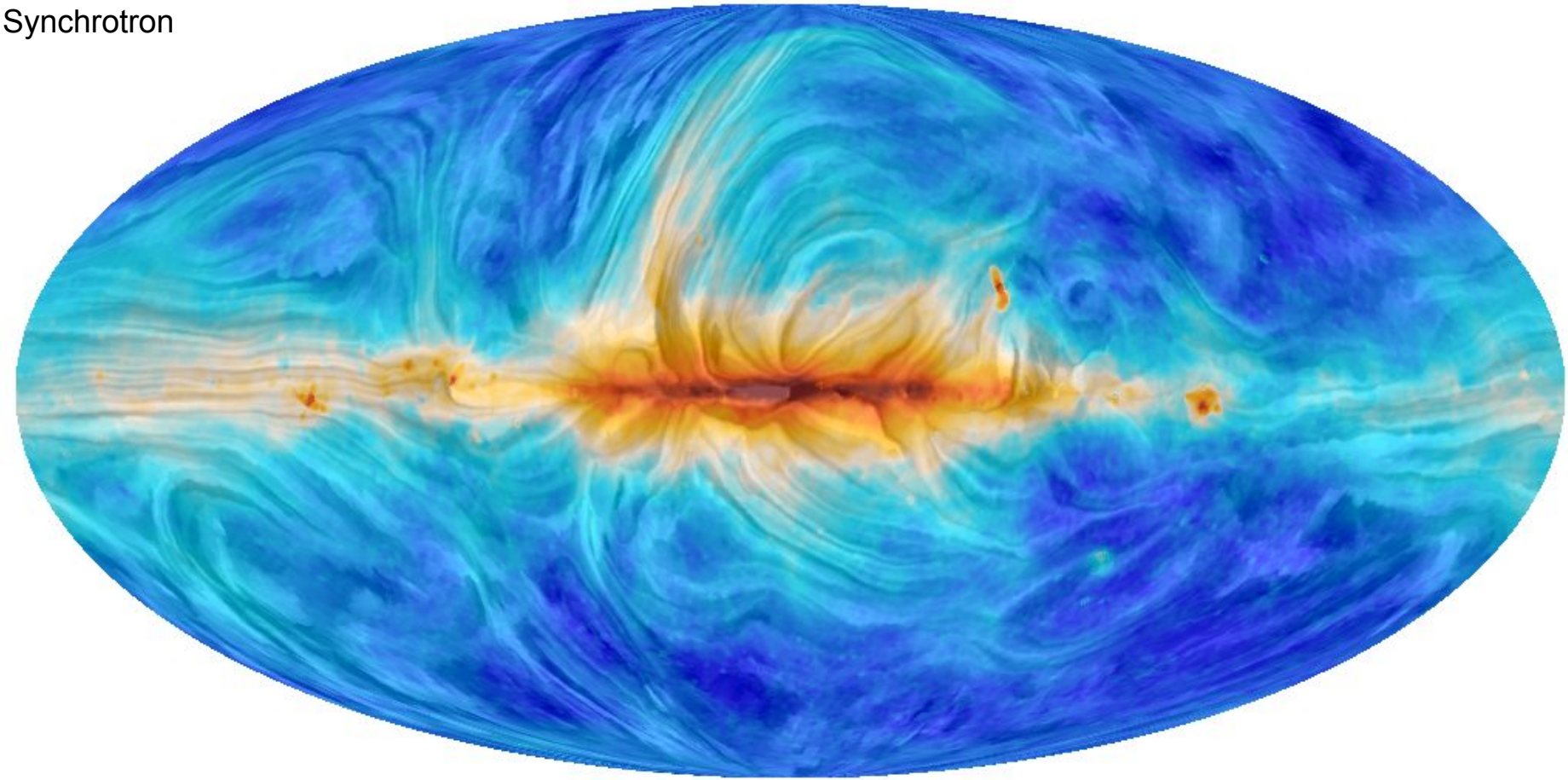
Adapted from Andersson+2015

Dust



ESA/Planck

Synchrotron



ESA/Planck

A new era for ISM studies: Open questions post-Planck

> 1 kpc

Structure of the Galactic Magnetic Field

- (How) can we create an accurate 3D model?
- What is the effect of local (~kpc radius from Sun) ISM structure on polarization maps?

~ μm

Microphysics of dust grains

- What is the composition of dust grains?
- How are dust properties affected by galactic environment?

Initial conditions of star formation

~100s pc

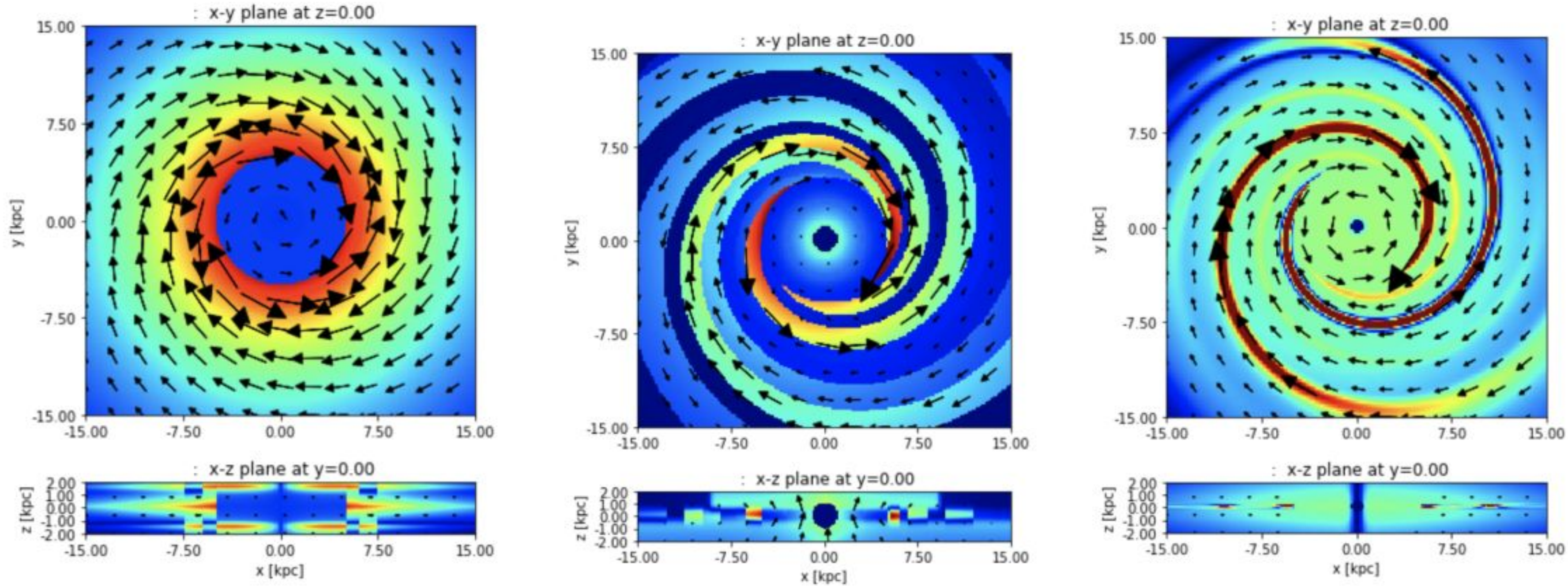
- How do star-forming clouds form from the diffuse, strongly magnetized ISM?
- How is the evolution of cloud structure affected by the magnetic field?

MHD turbulence in multiphase ISM

- What leads to structural correlation between cold neutral and ionized phases?
- How does turbulence influence the propagation of cosmic rays?

0.01 - 100 pc

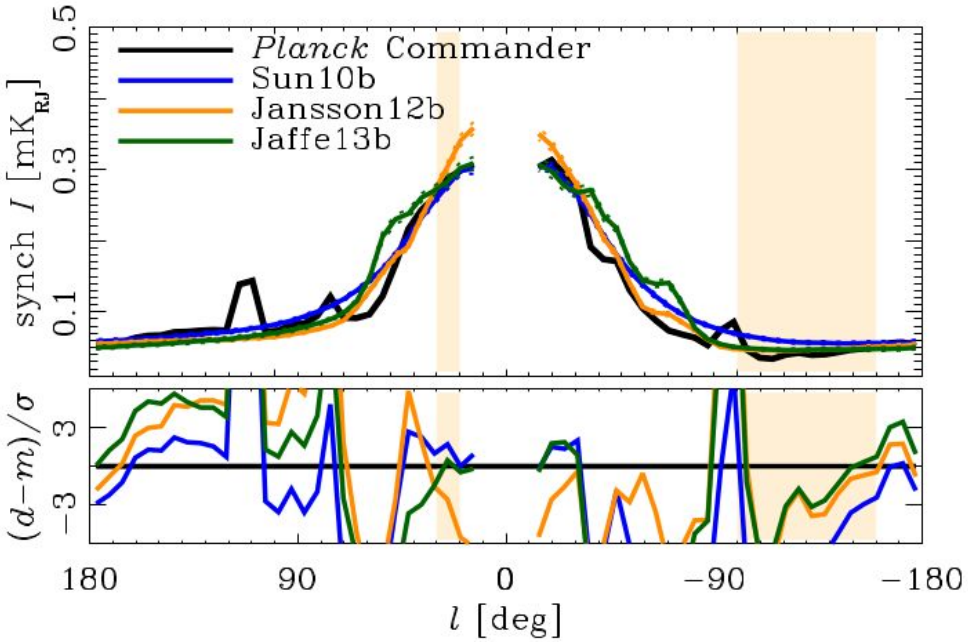
Current models of Galactic Magnetic Field



Jaffe (2019)

Which one (if any) is correct?

Current observations (Planck) cannot discriminate between models



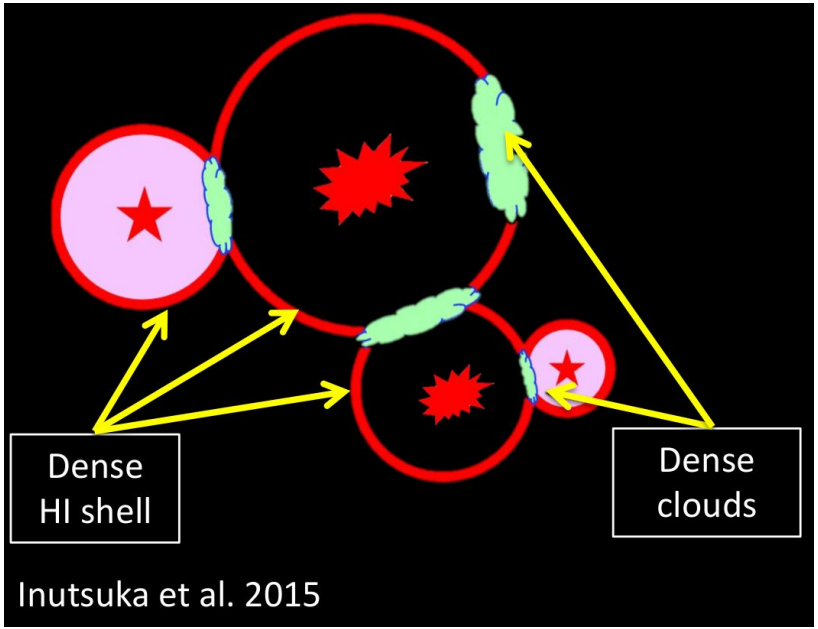
(Planck Collaboration XLII 2016)

Situation worse with dust emission: no model reproduces observed properties

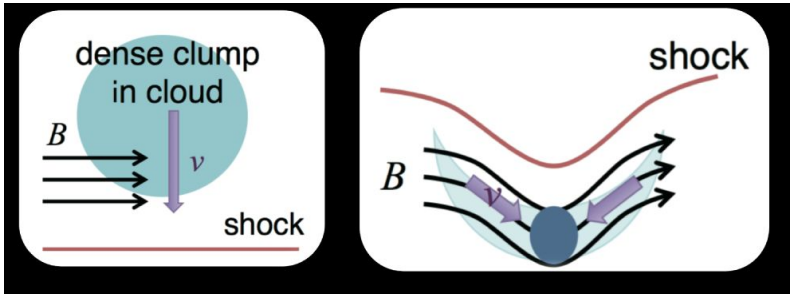
Accurate models of 3D Galactic Magnetic Field are missing, but essential...

Large-scale B field structure needed to test models for **molecular cloud formation**

M. Tahani's talk



Clouds proposed to form from consecutive compressions driven by SN shocks



Inoue (2018)

3D B field would show bow shock geometry related to initial velocity and Galactic magnetic field

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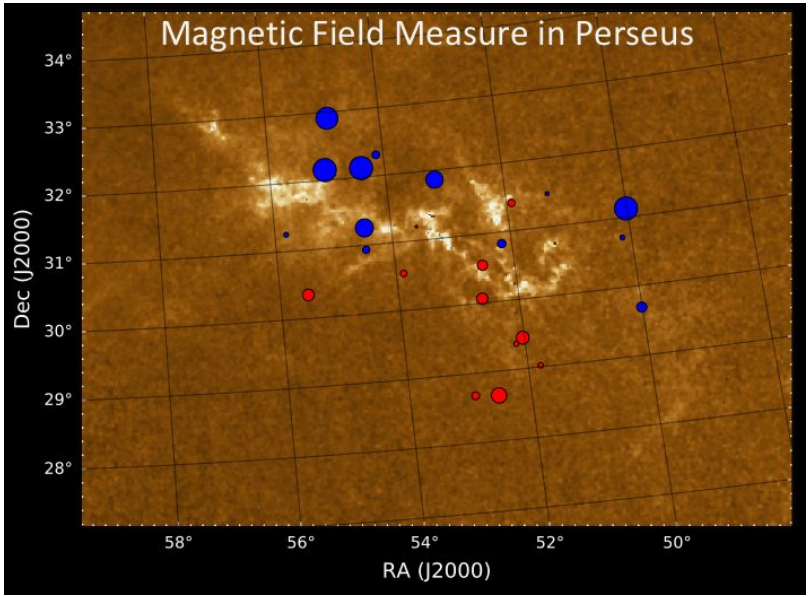
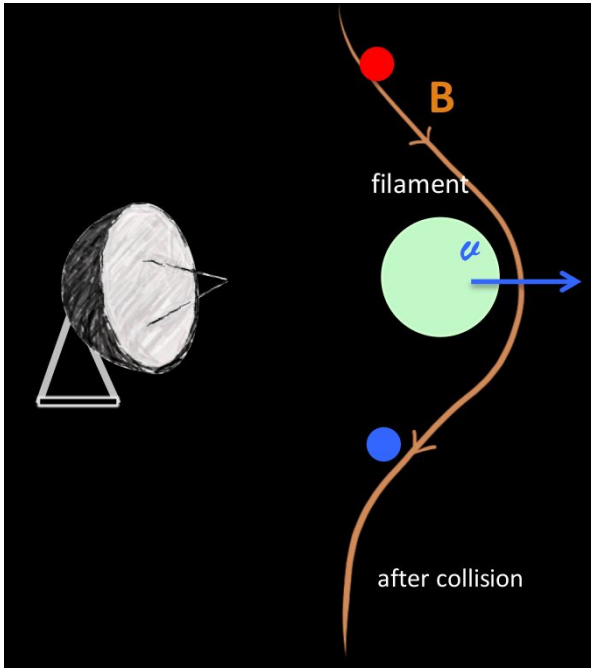


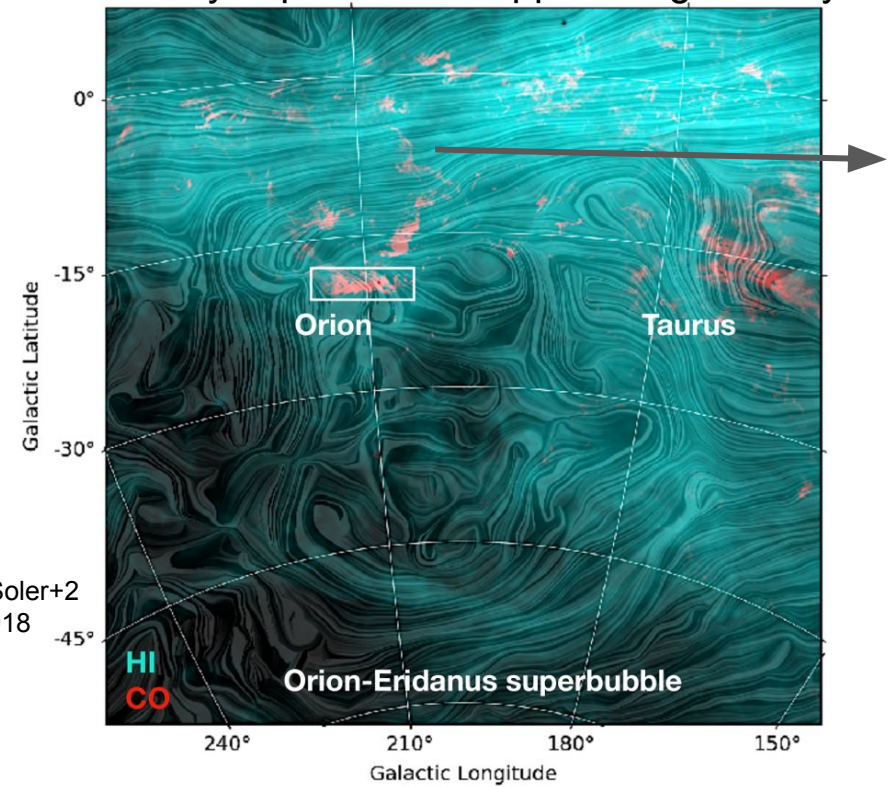
Hint of bow shock geometry from Rotation measures towards Perseus cloud



Need initial configuration of B field to distinguish from alternative formation scenarios

Galactic B field models missed memo about structures within our neighborhood

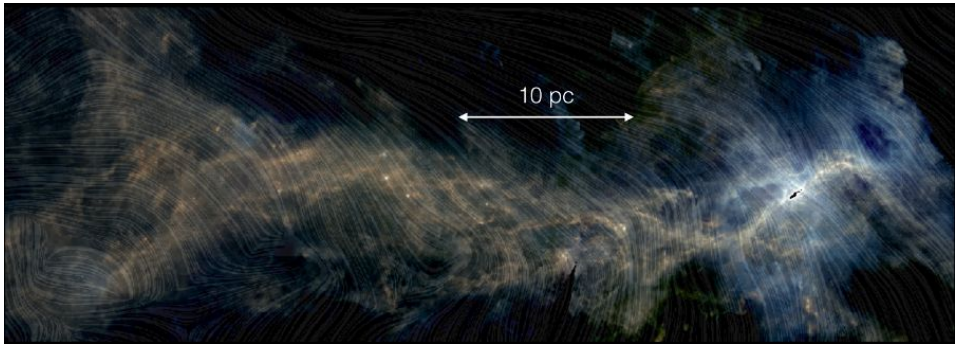
SN + stellar winds shape Galactic B field =>
nearby superbubbles appear large on sky



Soler+2018

J. Soler's talk

Soler+2019



Planck dust emission B field (5') + Herschel 20" dust map

Evolution of cloud structure depends on B field
- so does star formation

Access to high resolution critical

A new era for ISM studies: Open questions post-Planck

Structure of the Galactic Magnetic Field

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MHD turbulence in multiphase ISM

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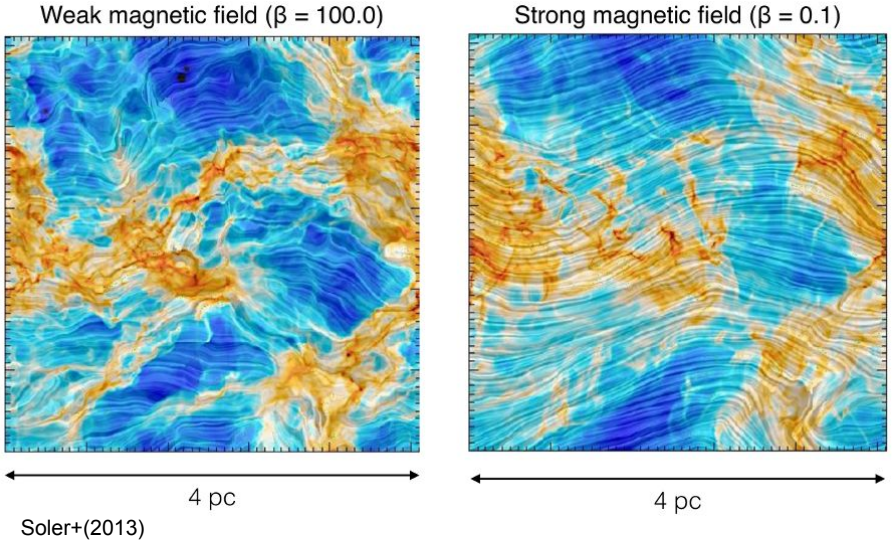
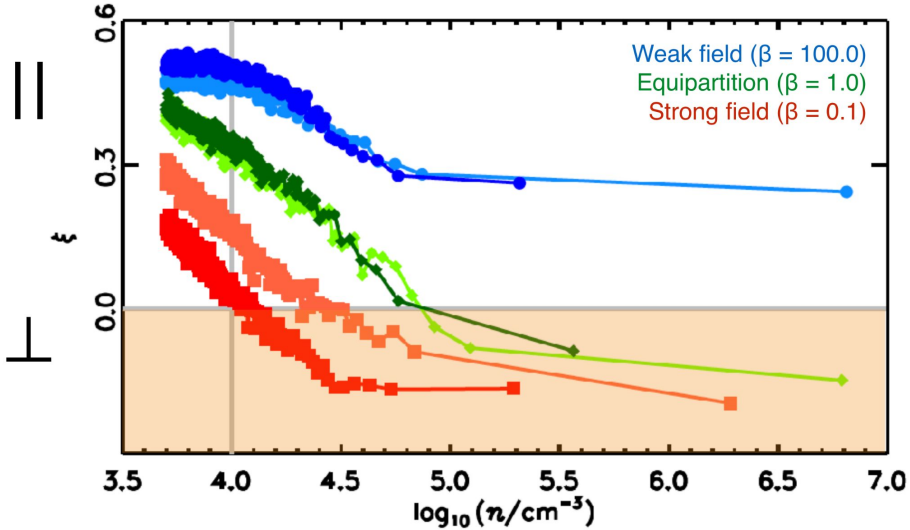
New insights on MHD turbulence motivated by Planck



Soler+(2013)

Level of magnetization determines the relative orientation between filaments and the magnetic field

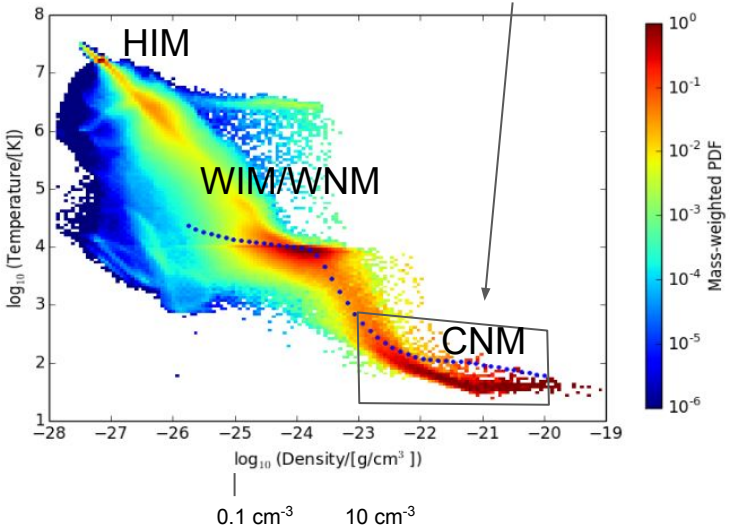


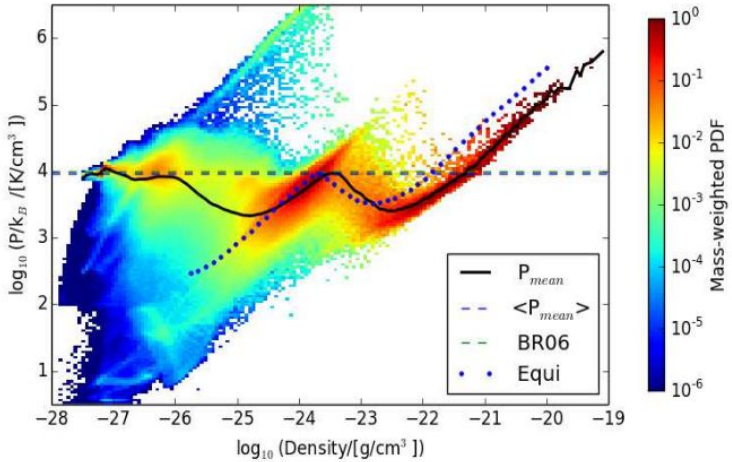
Soler+(2013)

Filaments parallel or perpendicular to B field are attractor solutions of MHD equations (Soler+Hennebelle 2017)

But Planck only sees *part* of the turbulent cascade

Traced by Planck
polarized dust emission



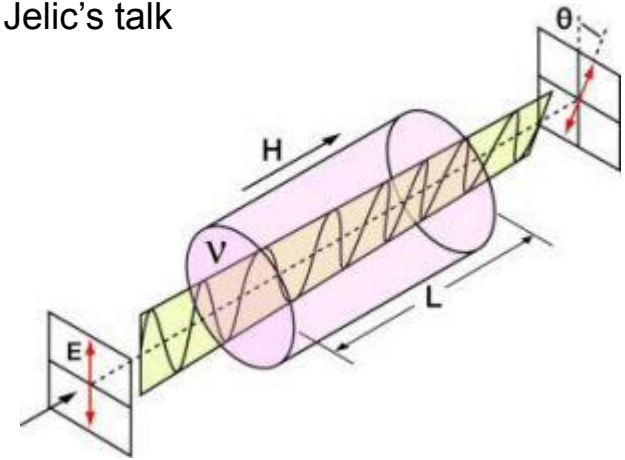


Simulations by
Walch+(2015)

To probe the magnetized ionized medium we need a different tracer...

Faraday rotation probes ionized medium.. in 3D!

V. Jelic's talk



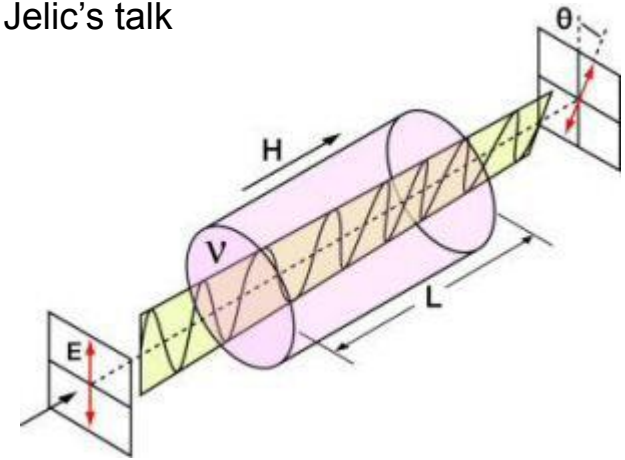
$$\theta = \theta_0 + \lambda^2 \left(\text{const.} \int_0^d n_e \mathbf{B} \cdot \mathrm{d}\mathbf{l} \right)$$

FARADAY DEPTH

Measurable at low frequencies (< 5 GHz) for general ISM

Faraday rotation probes ionized medium.. in 3D!

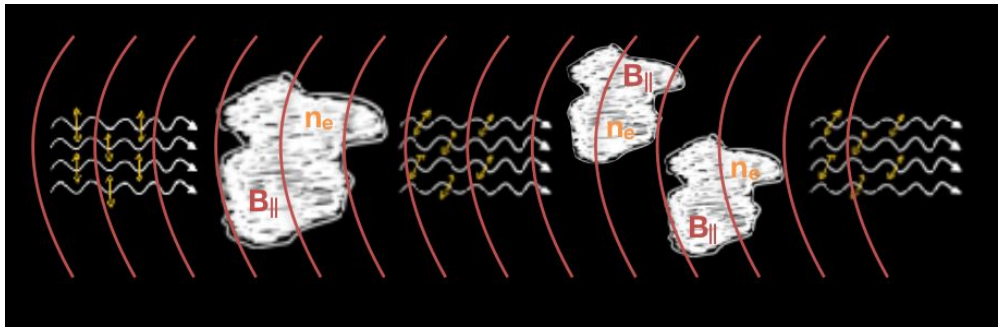
V. Jelic's talk



$$\theta = \theta_0 + \lambda^2 \left(\text{const.} \int_0^d n_e \mathbf{B} \cdot \mathrm{d}\mathbf{l} \right)$$

FARADAY DEPTH

Faraday tomography/RM synthesis

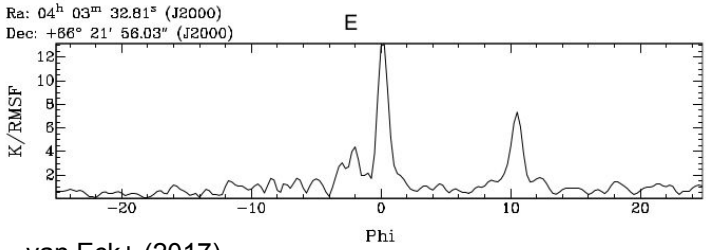


$$\mathbf{P}(\lambda^2) = \mathbf{Q}(\lambda^2) + i\mathbf{U}(\lambda^2)$$

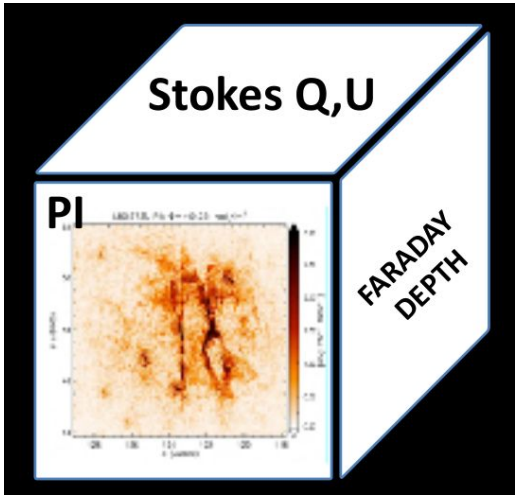
$$F(\Phi) = \int_{-\infty}^{+\infty} W(\lambda^2) P(\lambda^2) e^{-i2\Phi\lambda^2} d\lambda^2$$

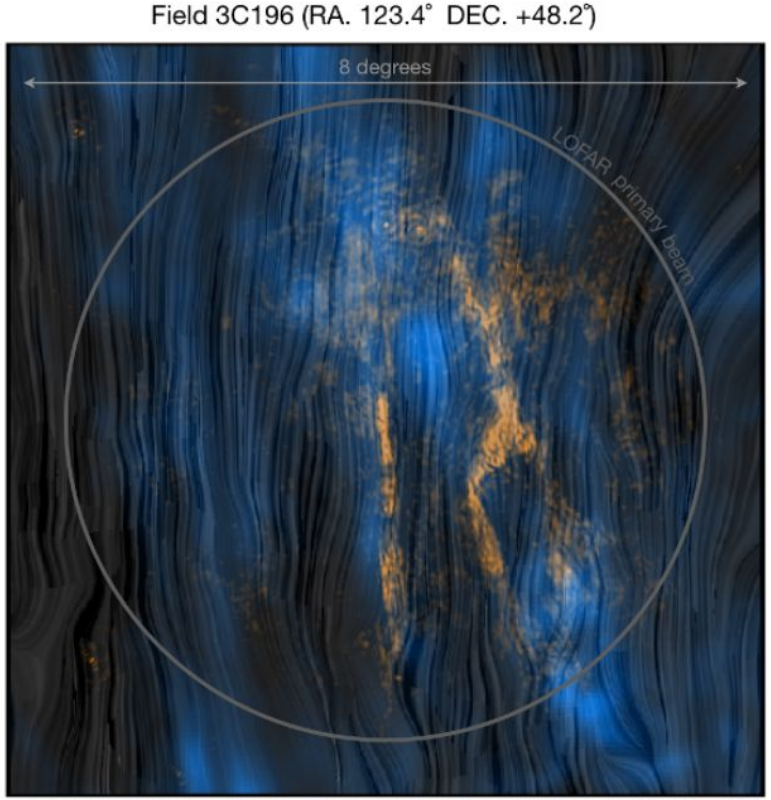
Faraday rotation probes ionized medium.. in 3D!

Along each LOS: spectrum of Faraday rotating components



van Eck+ (2017)





Jelic+(2020)

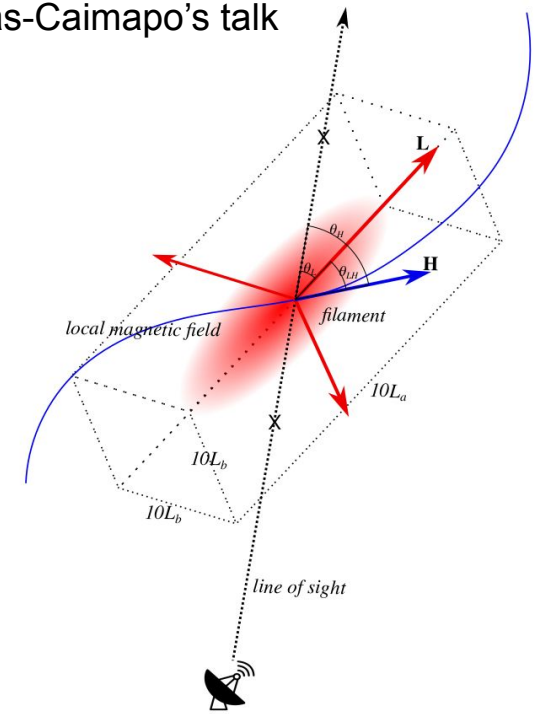
Faraday tomography finds surprising correlation between ISM phase structure & B field

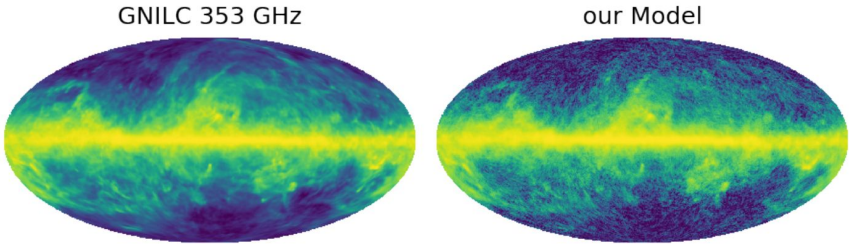
Alignment between:
Neutral medium HI filaments
Magnetic field
Faraday depth structures (Pol. intensity enhancements + decrements)

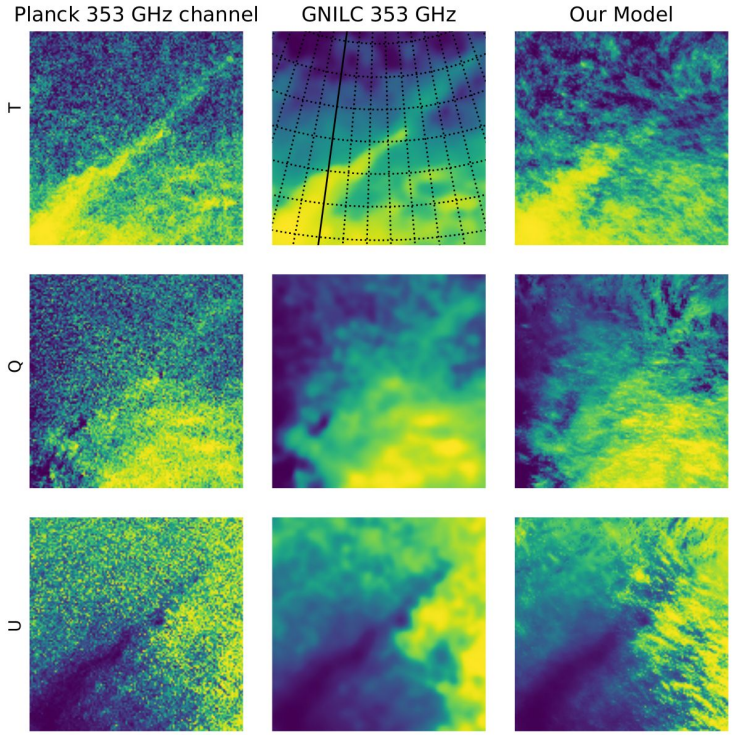
Origin of correlations still unknown, but
we can still make empirical models for modeling foregrounds...

All-sky dust emission modeling based on filaments

C. Hervias-Caimapo's talk

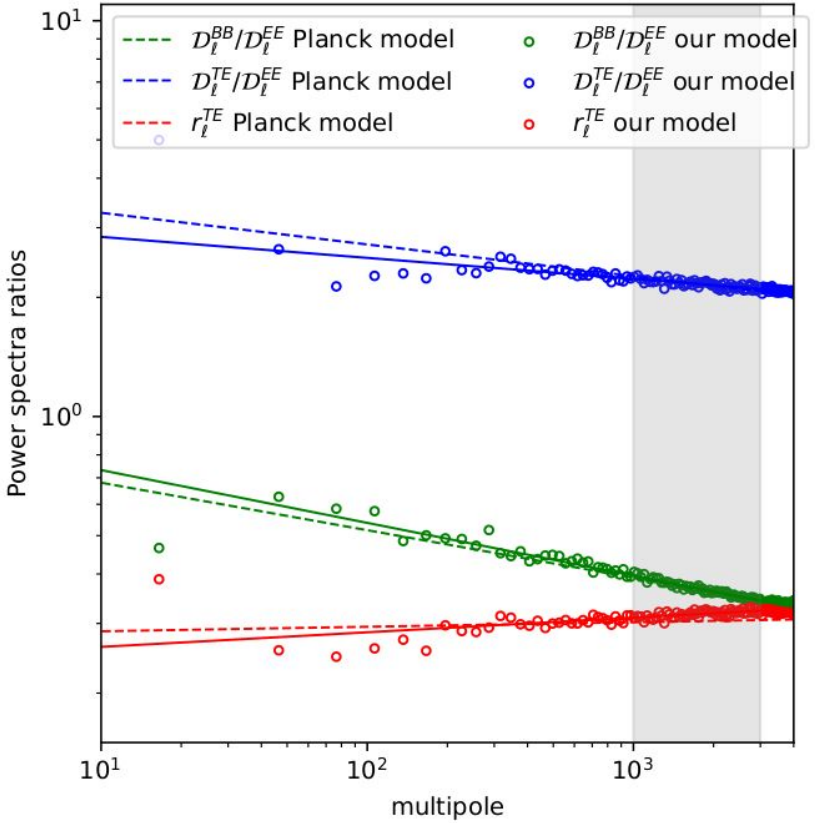




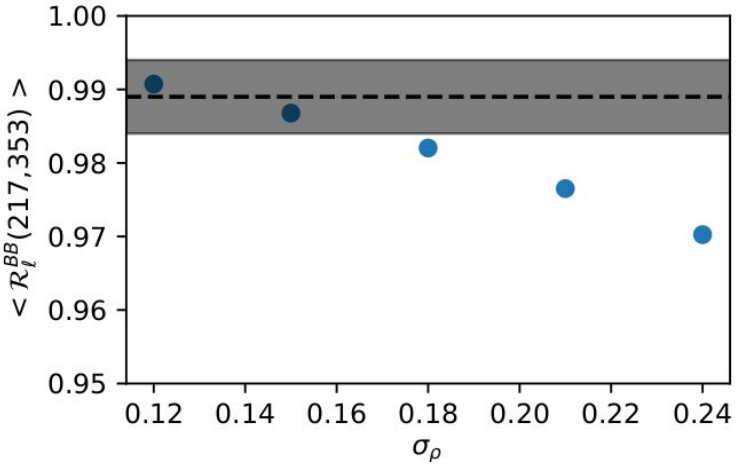


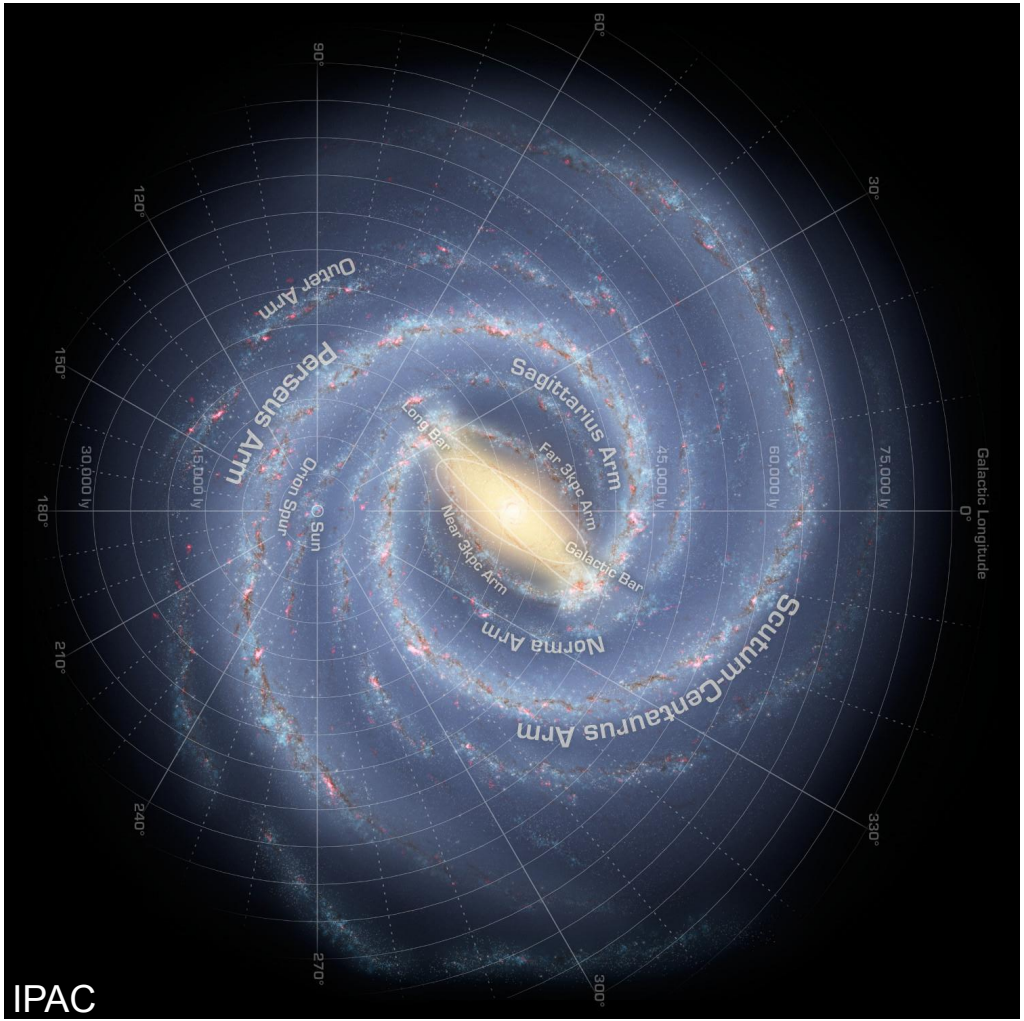
Model reproduces Planck power spectra up to much higher multipoles

C. Hervias-Caimapo's talk

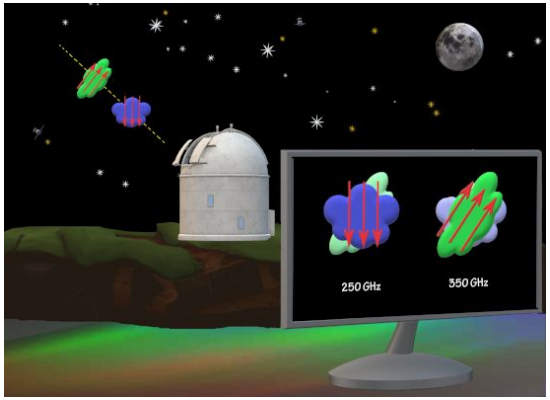


Can be used to see effect of decorrelation





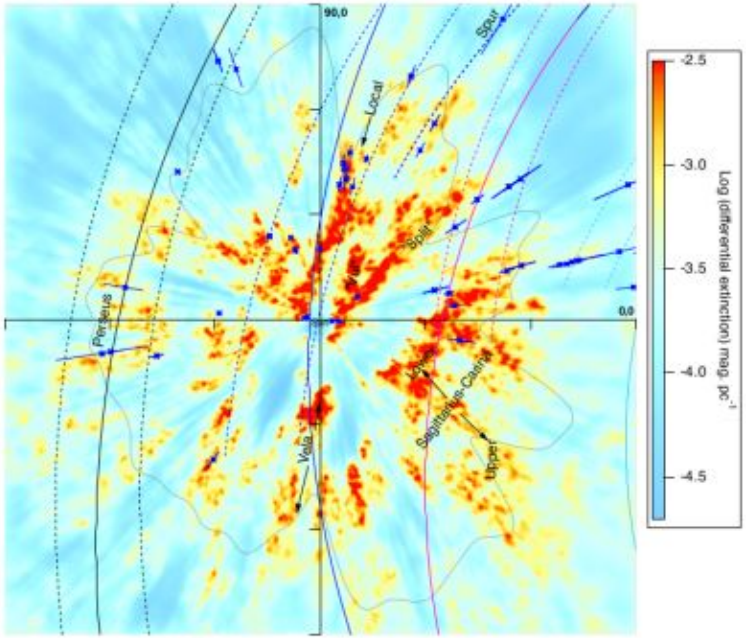
ISM properties (including dust) change along the LOS



Pelgrims+2021

We now have maps of local ISM to exploit!

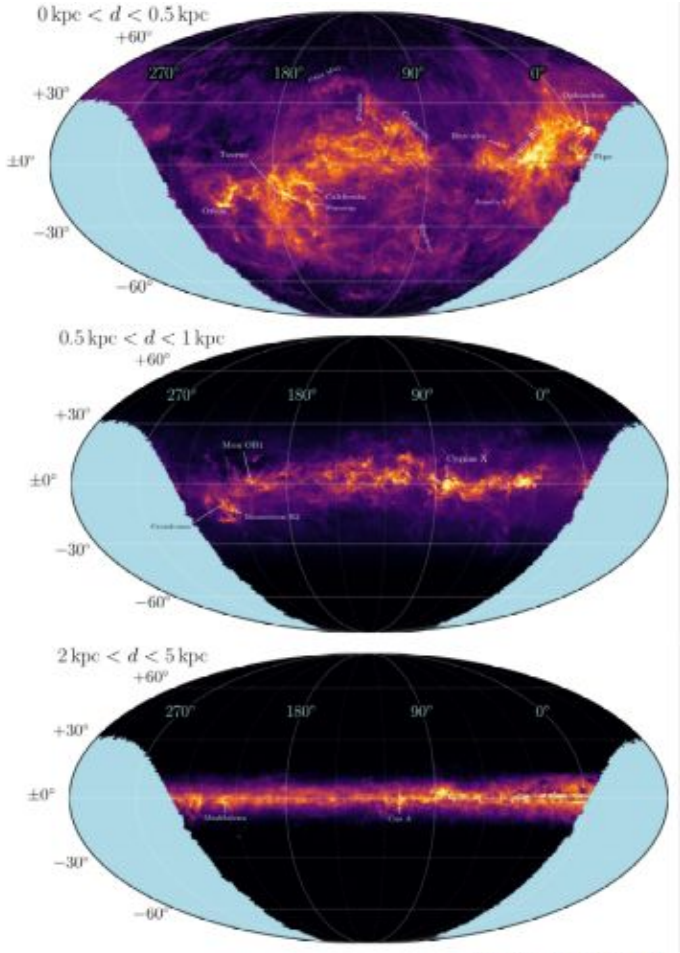
ISM structure revealed by 3D dust extinction maps



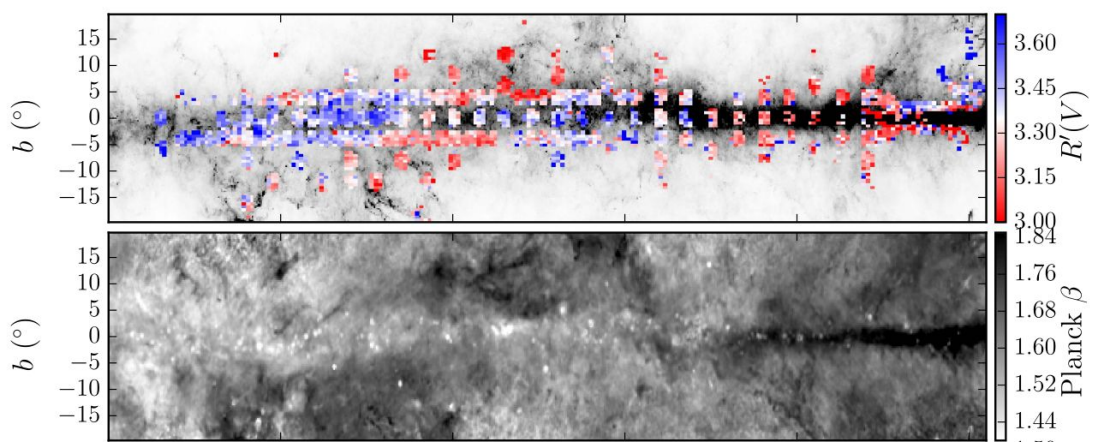
Lallement+ 2019

6 kpc

Increasing distance from Sun



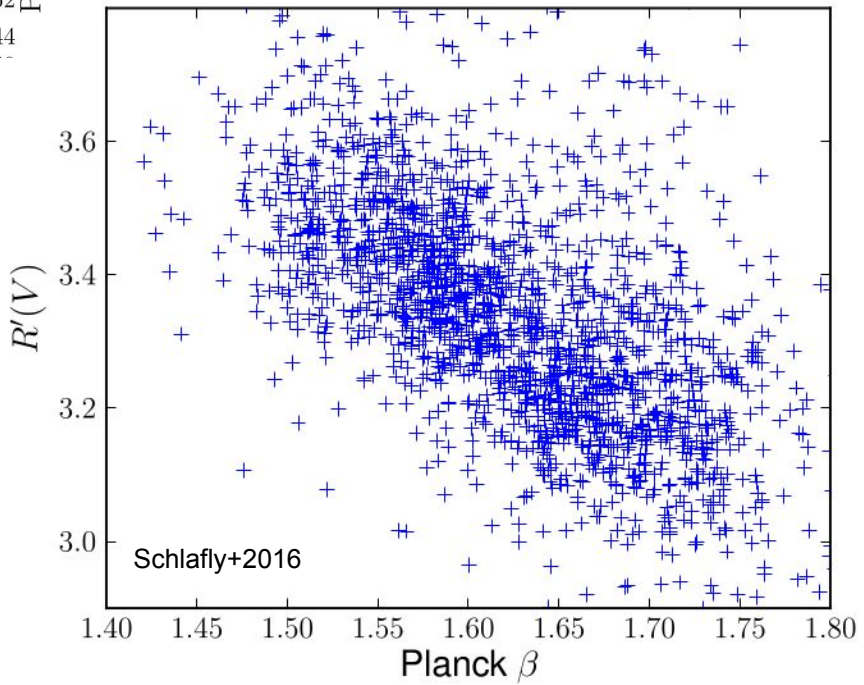
Green et al. (2019)



Schlafly+2017

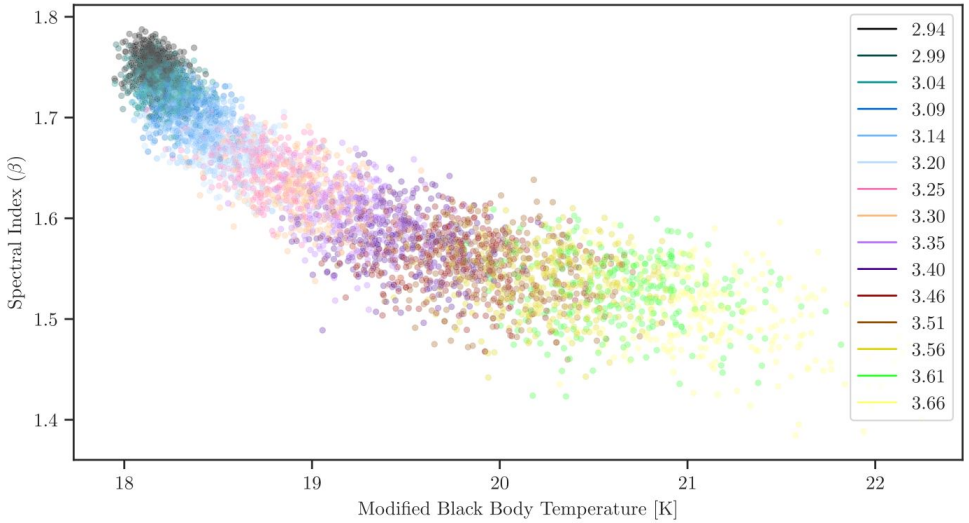
Dust properties are measured to vary on large (kpc) scales..

Variations in extinction law tied to changes in emission



Ioana Zelko's talk

Dust grain composition changes along with grain size distribution one way to explain observed variations



Zelko+2020

Ioana Zelko's talk

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The path forward

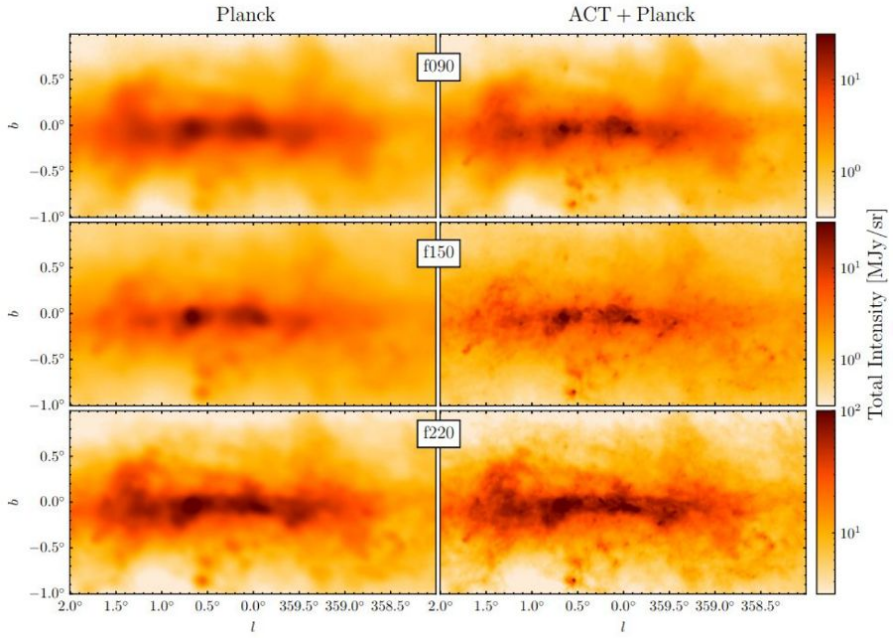
Y. Guan's talk

Combination of synchrotron & dust emission

Developing tools & diagnostics for existing data

Testing dust models in 3D

…



Guan+2021

Maps available on LAMBDA