High-precision magnetometry in the interstellar medium

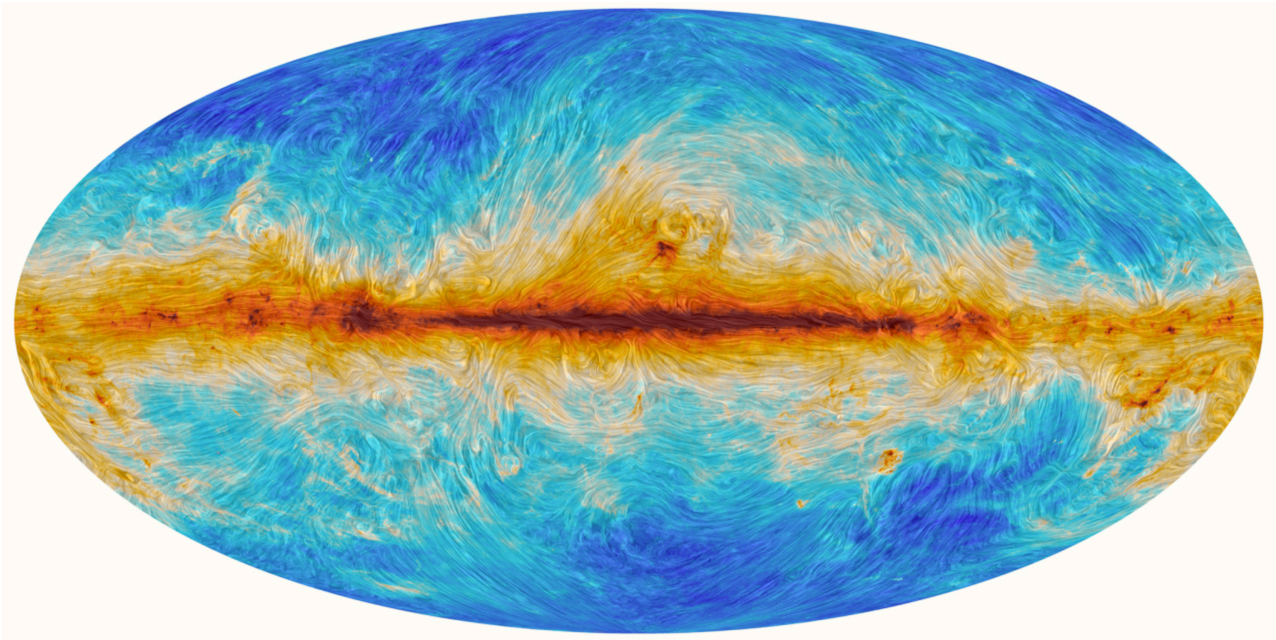
Raphael Skalidis

Hubble Fellow

Collaborators: Tassis, Beattie, Pavlidou, Sternberg, PASIPHAE collaboration

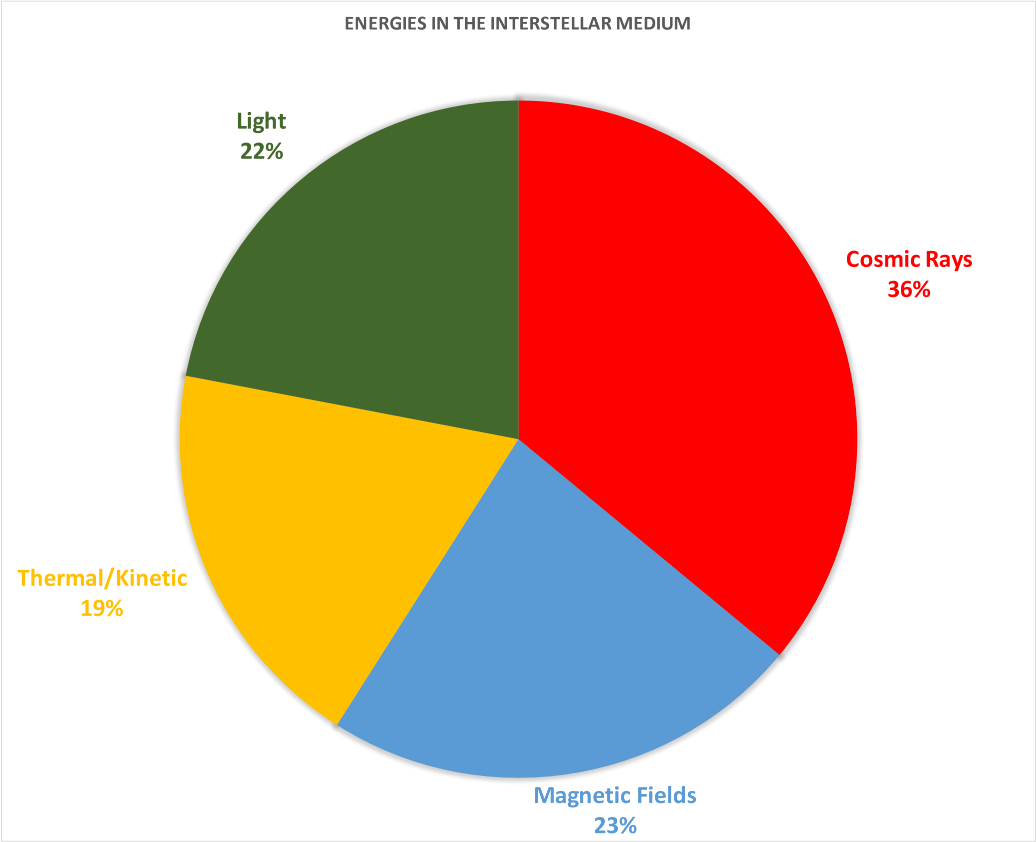
NASA Hubble Fellowship Program

Why Galactic magnetism?



Credit: ESA/Planck, Miville-Deschenes

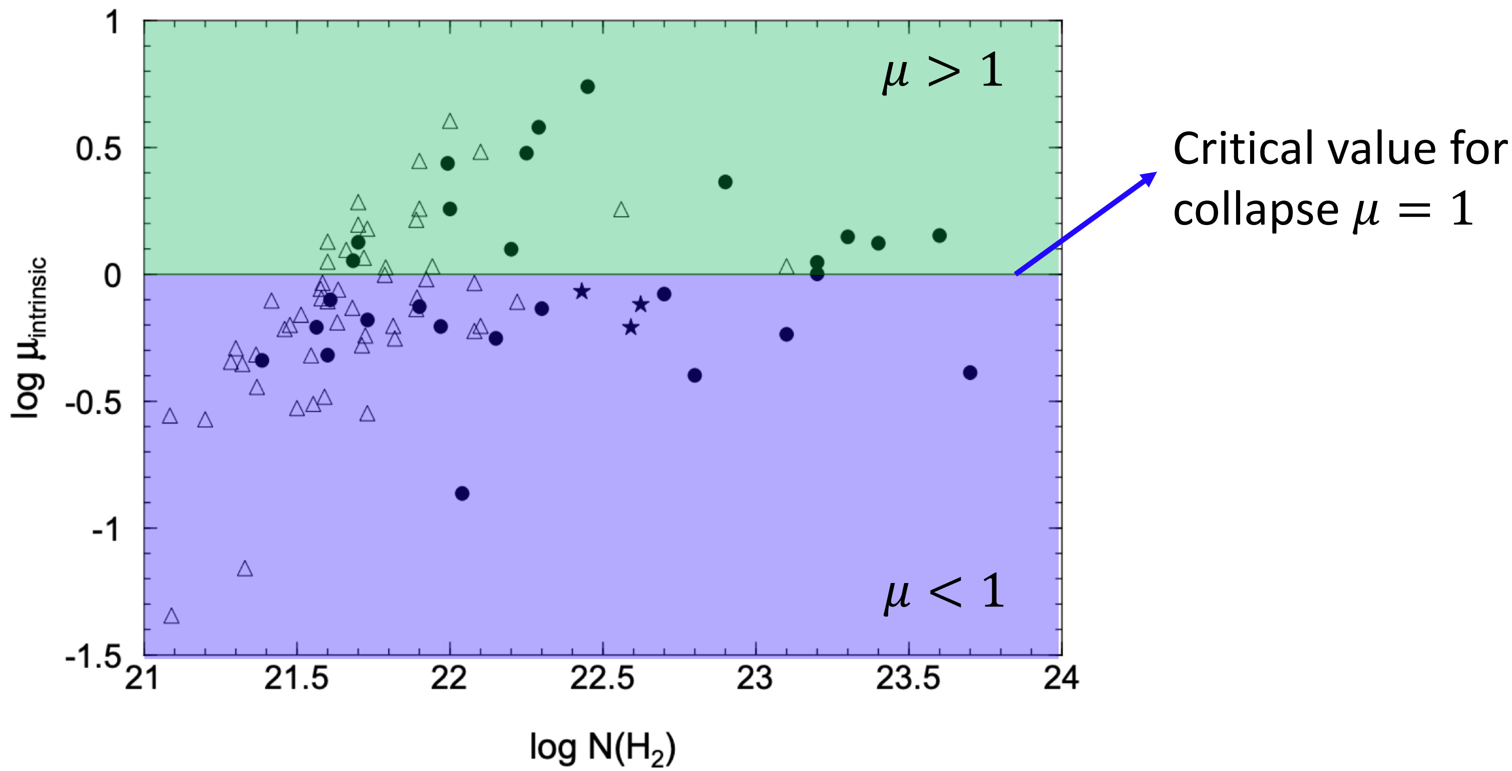
Why higher precision?



Draine's book

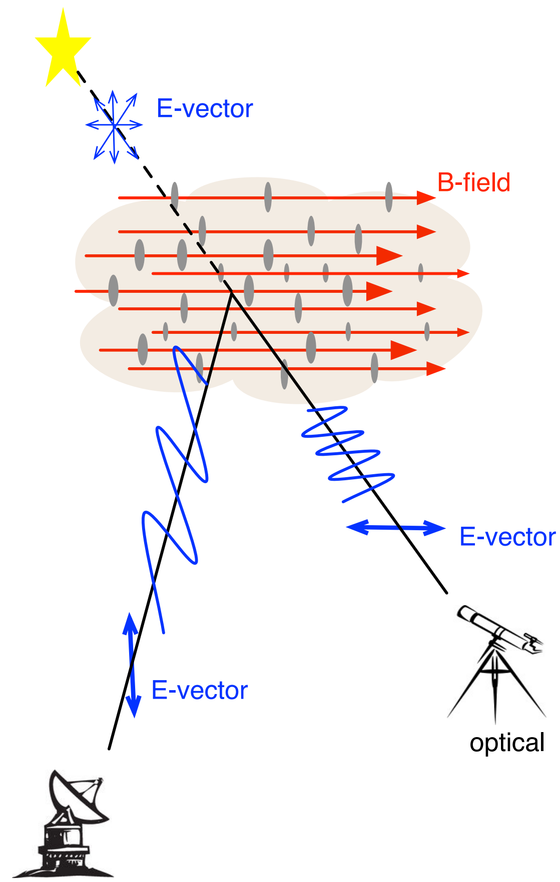
Why higher precision?

$$\mu = \frac{M_G}{\Phi_B}$$



Heiles & Crutcher 2005

Magnetic fields and dust polarization

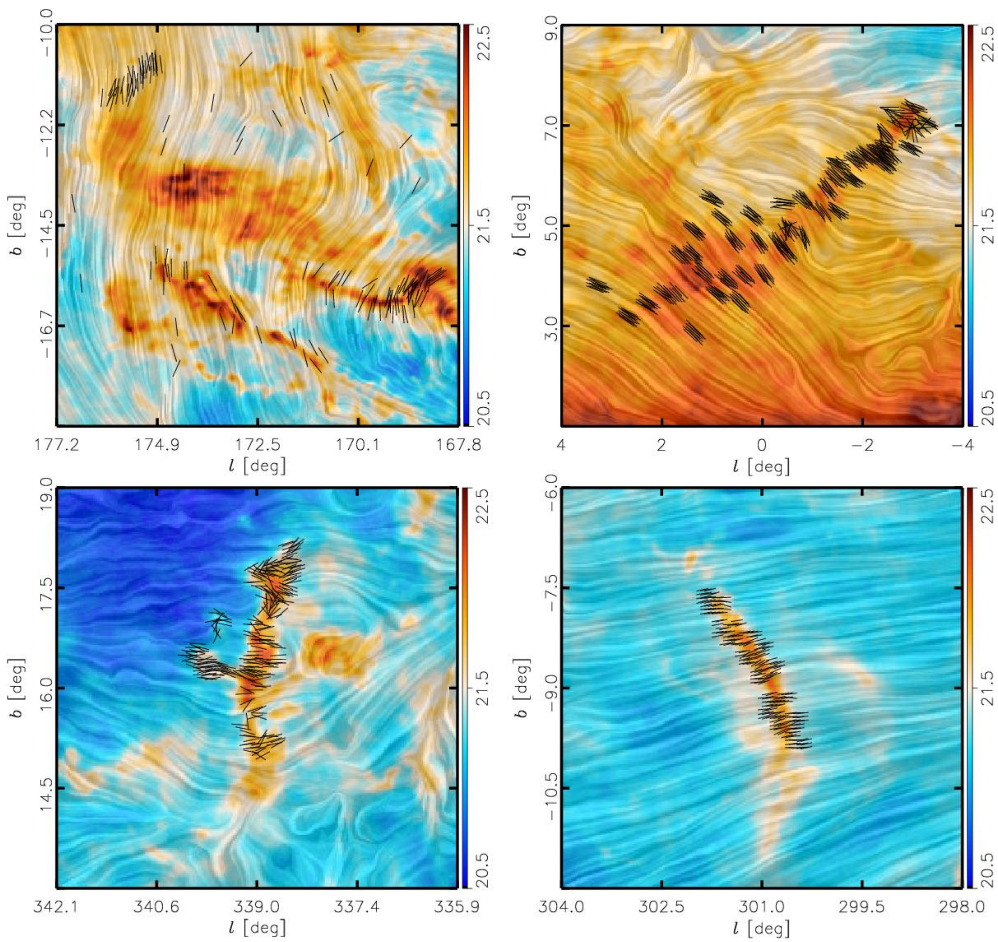


Tassis et al. 2018

Magnetic fields in molecular clouds

Taurus

Pipe

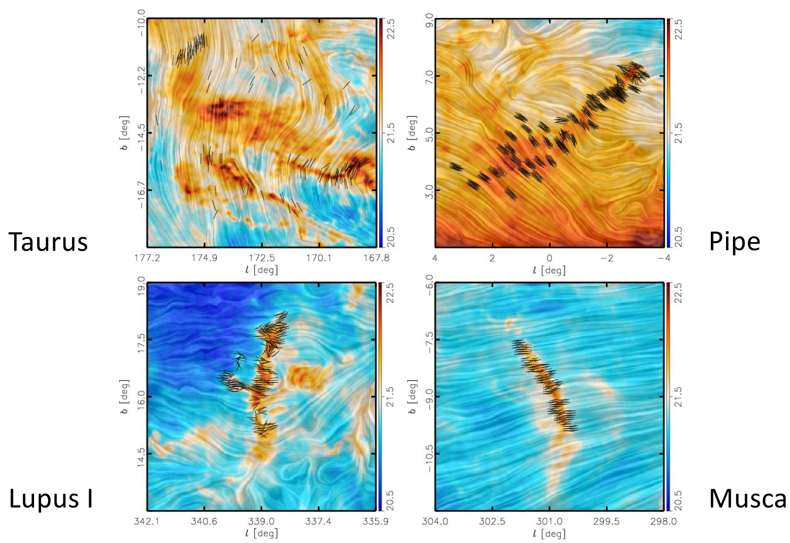


Lupus I

Musca

Soler et al. 2016

Magnetic fields in molecular clouds

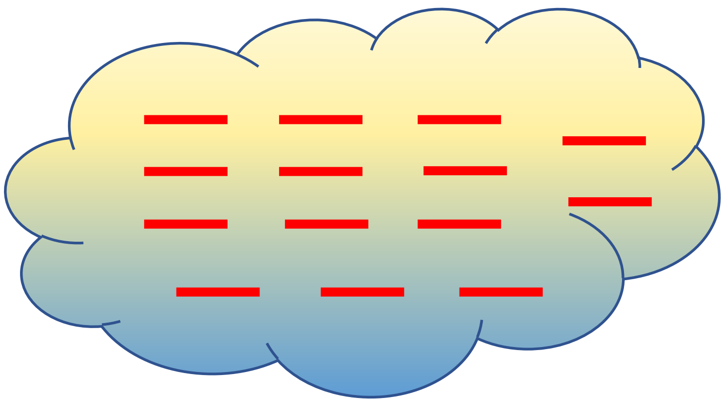


Dust polarization traces the magnetic field orientation, **but directly not its strength.**

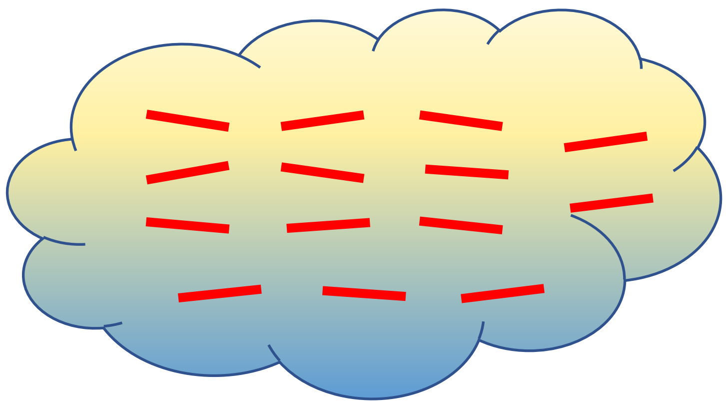
Soler et al. 2016

DCF method - physical picture

Without Alfvén waves
$(\boldsymbol{B}_{\text{tot}} = \boldsymbol{B}_0)$



With Alfvén waves
$(\boldsymbol{B}_{\text{tot}} = \boldsymbol{B}_0 + \boldsymbol{\delta B})$



Davis 1951, Chandrasekhar & Fermi (1953)

Scalings

Incompressible
(DCF)

$$B_0 = \sqrt{4\pi\rho}\frac{\langle u^2 \rangle^{1/2}}{\delta\theta}$$

Modifications:
Heitsch+01, Falceta-Goncalves+2008, Hildebrand+09, Houde+09, Cho+16, Liu+21, Chen+22

Compressible
(Skalidis & Tassis 2021)

$$B_0 = \sqrt{4\pi\rho}\frac{\langle u^2 \rangle^{1/2}}{\sqrt{2\delta\theta}}$$

Scalings

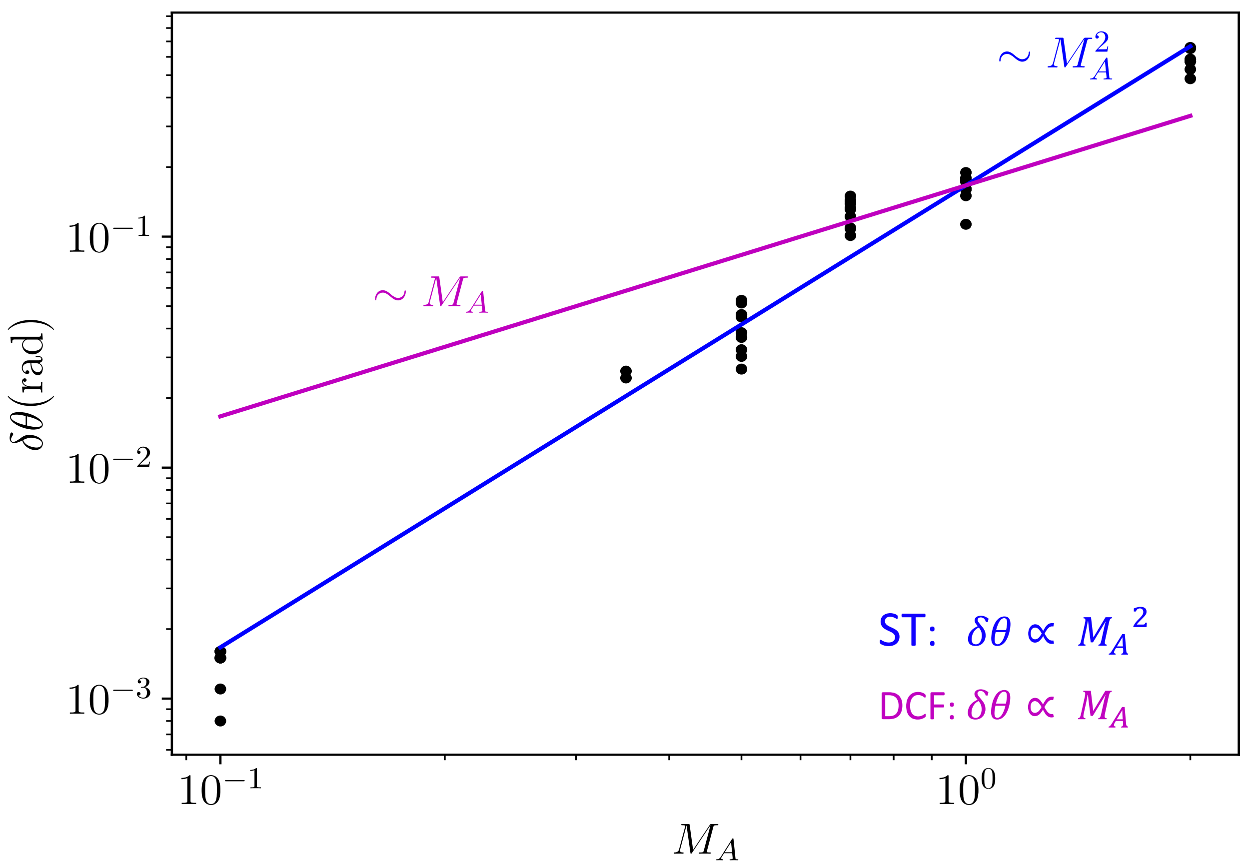
Incompressible
(DCF)

$$\mathscr{M}_A \propto \delta\theta$$

Compressible
(Skalidis & Tassis 2021)

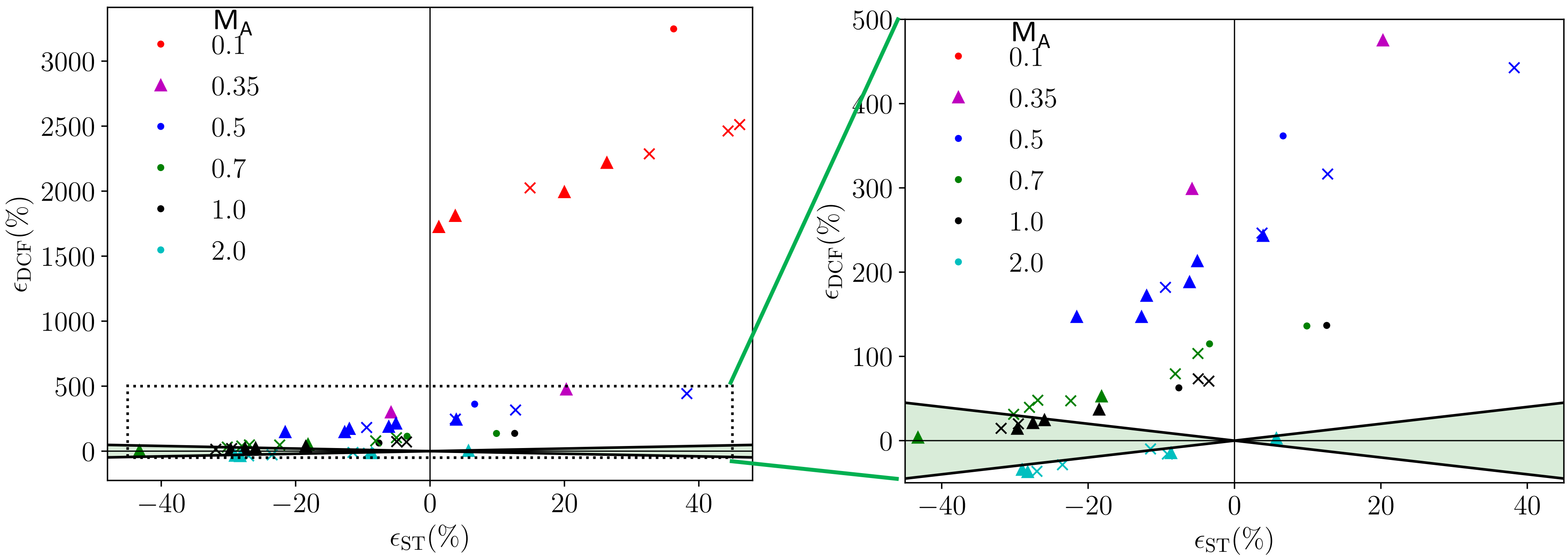
$$\mathscr{M}_A \propto \sqrt{\delta\theta}$$

Testing the scalings



Skalidis et al. 2021

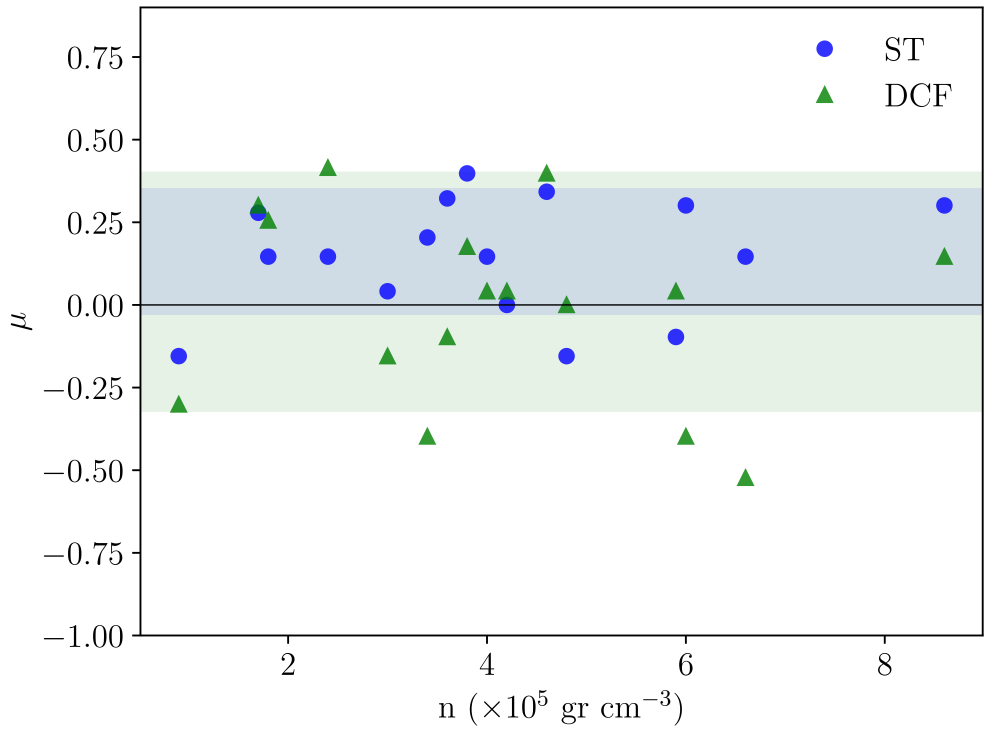
Comparison of the two methods



Skalidis et al. 2021

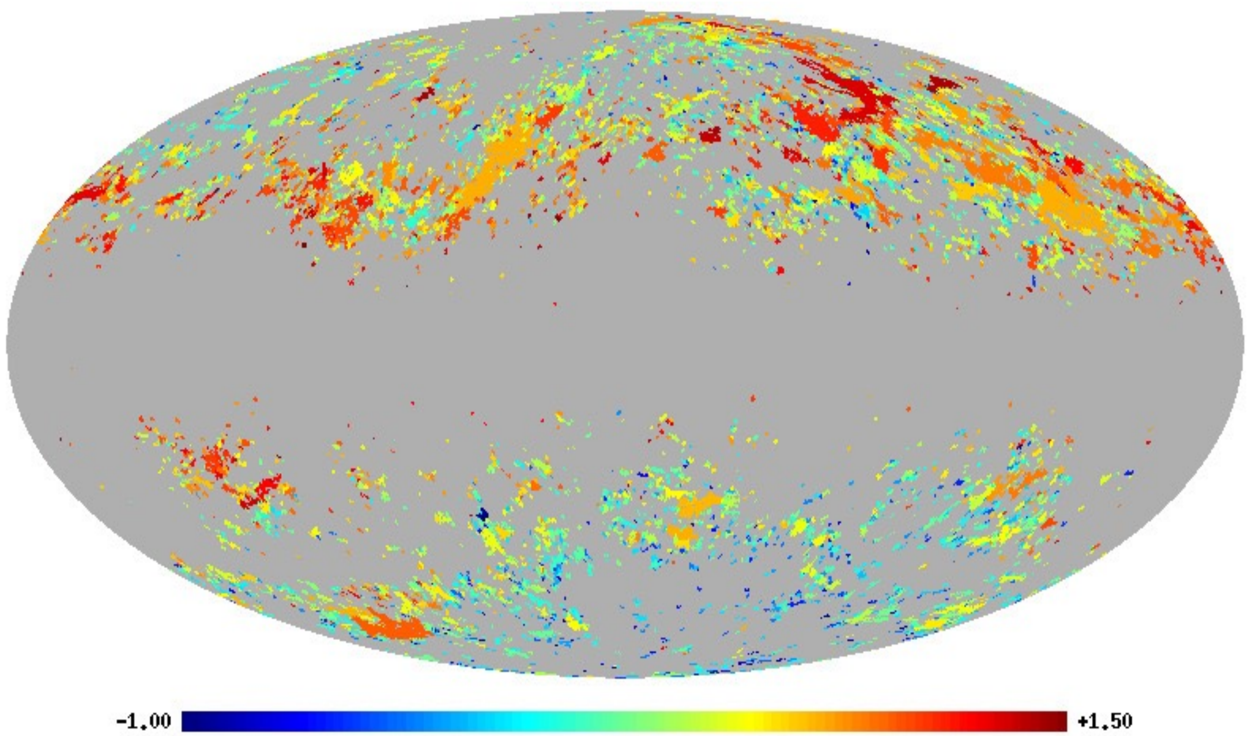
Observational tests

$$\mu = \frac{M_G}{\Phi_B}$$



Data from Palau et al. 2021

2D: Large-scale Galactic magnetic field strength map



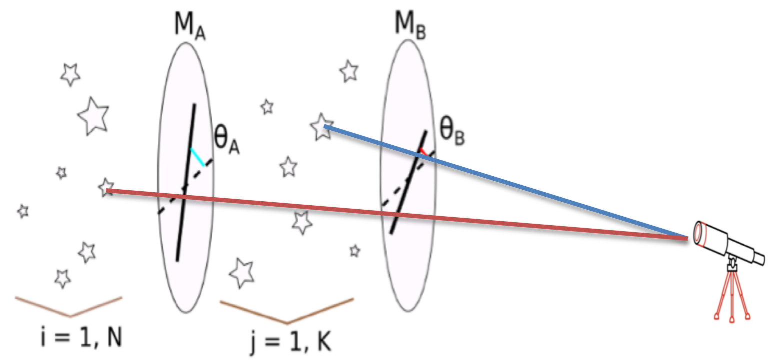
Logarithm (|B|)

Diffuse ISM
<B> = 4.4 μG

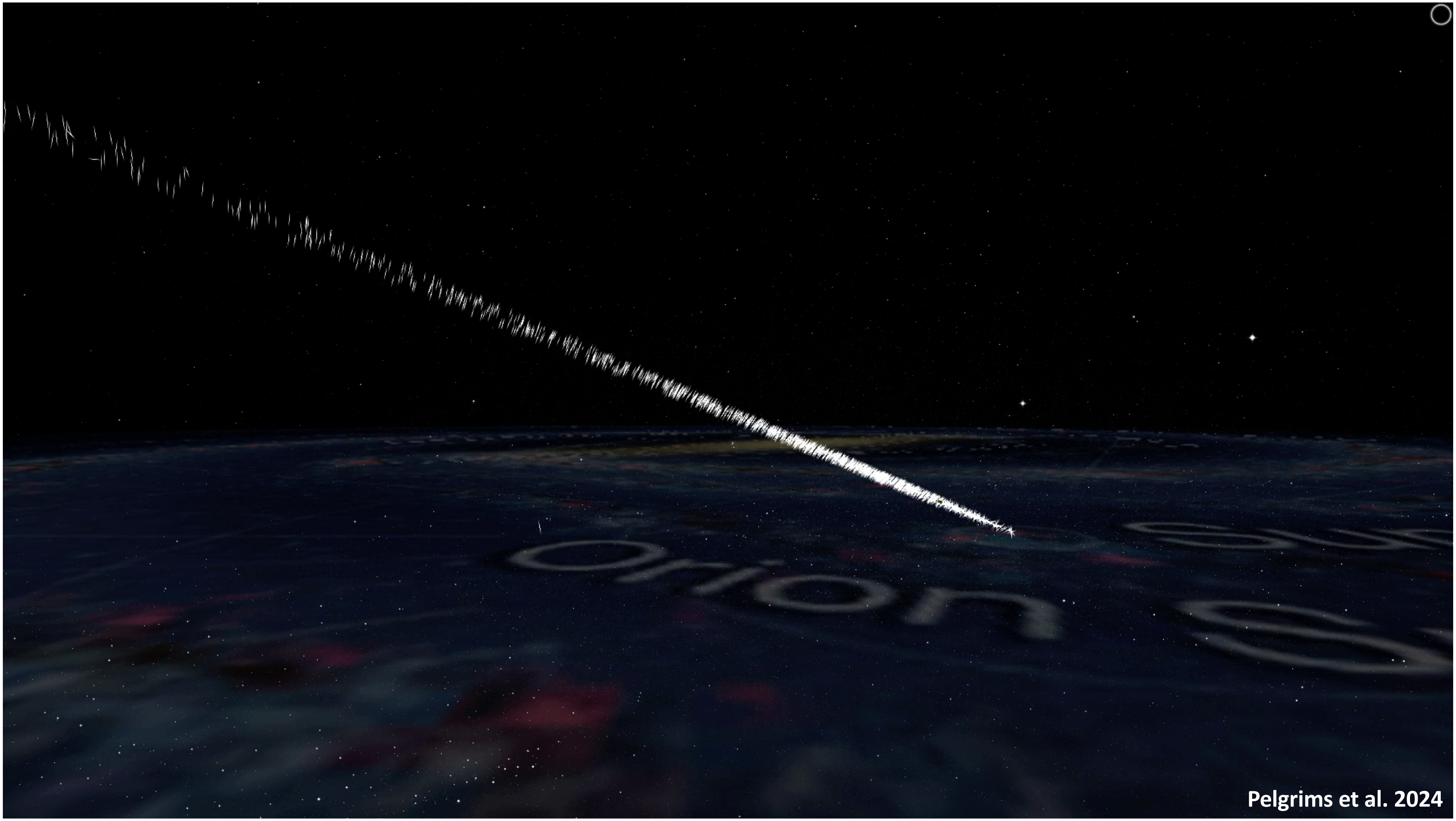
Kalberla et al. 2023

Future Prospects - PASIPHAE

- Use stars of **known distances** as lamp posts
- Measure **stellar polarization**
  - get B direction in different clouds
  - measure and model out 3D effects



Possible for the first time



Orion
Pelgrims et al. 2024

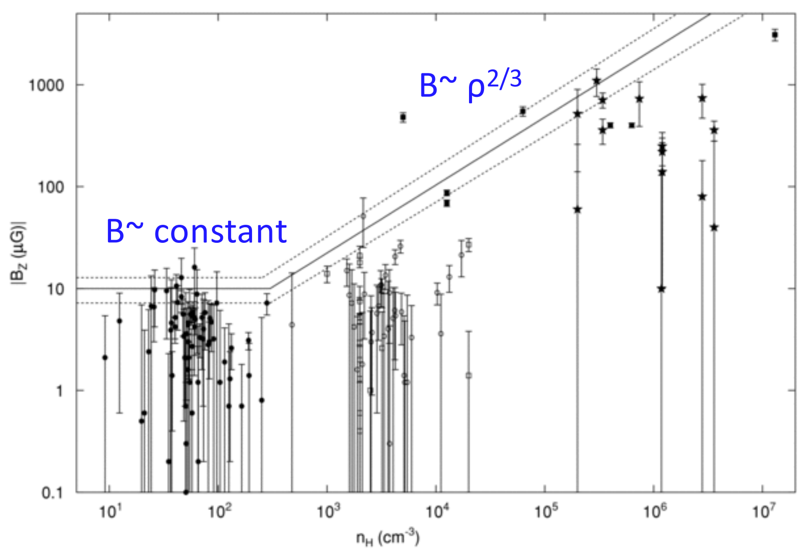
Thank you for your attention

Take home message

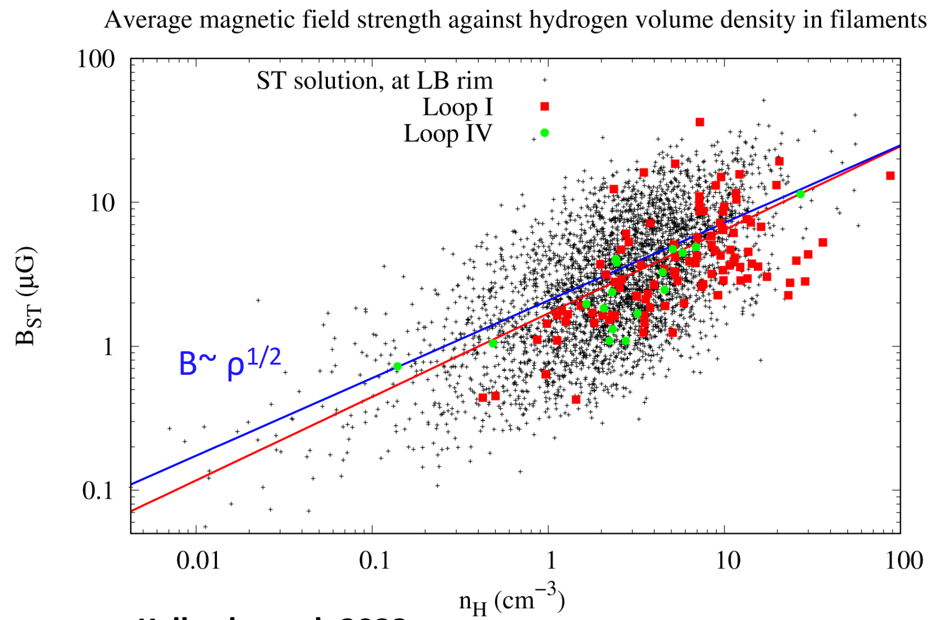
$$B_0 \approx \sqrt{4\pi\rho}\,\frac{\delta u}{\sqrt{2\delta\theta}}$$

Skalidis & Tassis 2021, Skalidis et al. 2021, 2023

B-field estimates: Zeeman versus Dust polarization

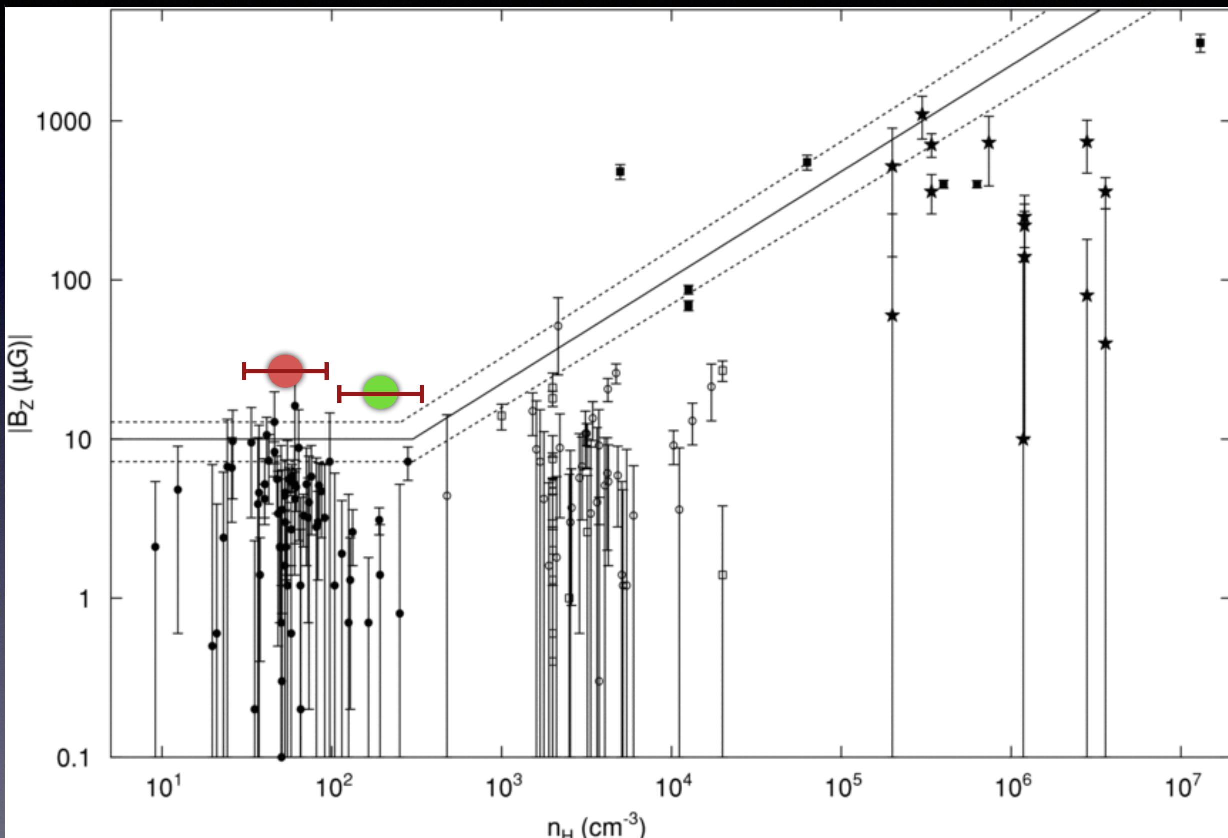


Crutcher et al. 2010



Kalberla et al. 2023

Ursa Major cirrus



Crutcher et al. 2010

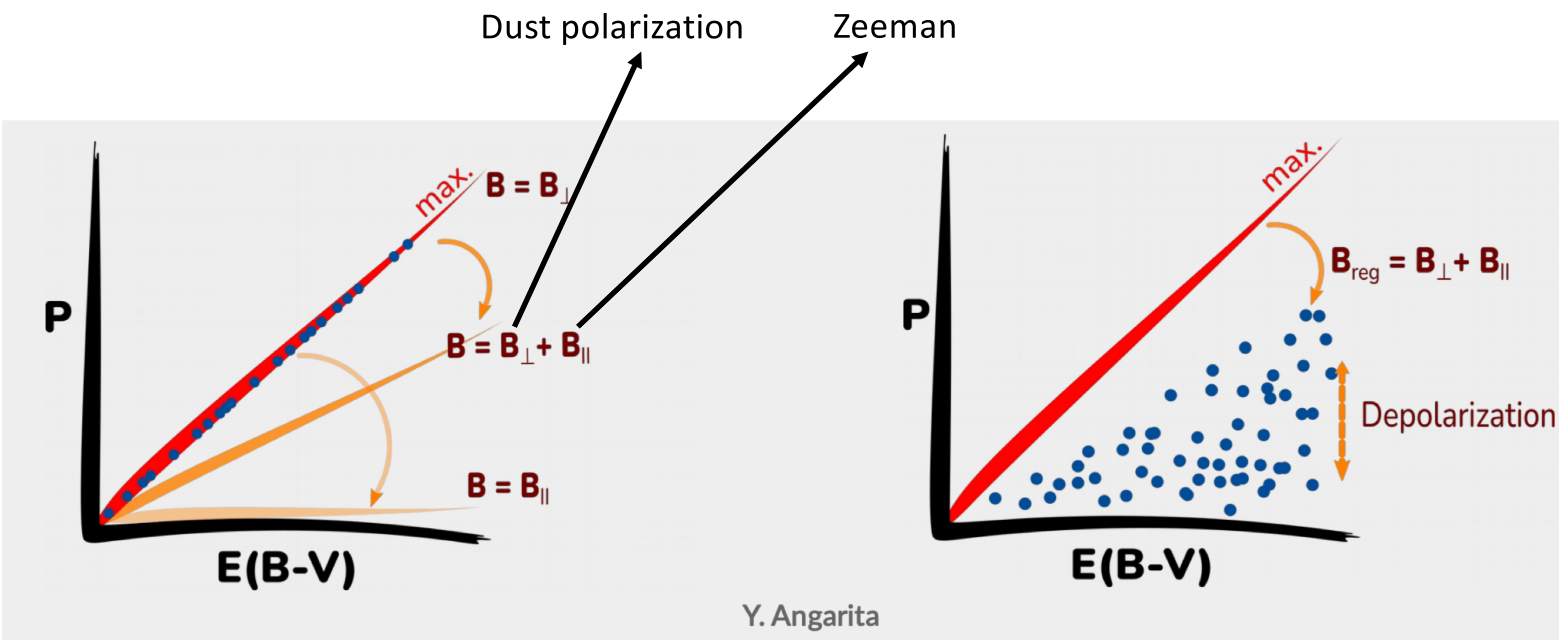
Skalidis & Tassis 2021

$$B_{POS} = \sqrt{2\pi\rho}\frac{\sigma_{v,turb}}{\sqrt{\delta\theta}}$$

Skalidis et al. 2022

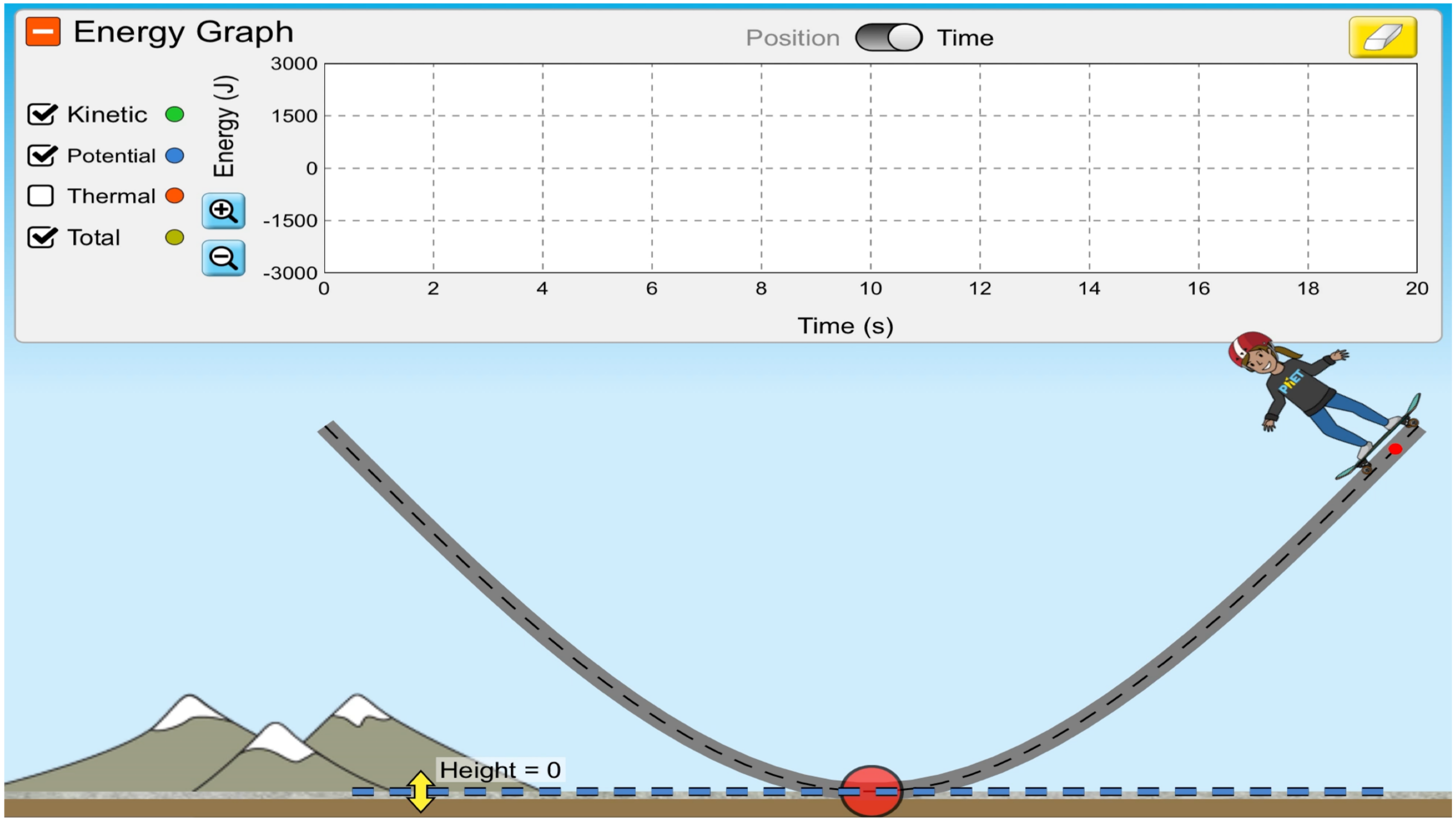
$$B_{POS} = 20 - 30\ \mu G$$

Dust polarization versus reddening



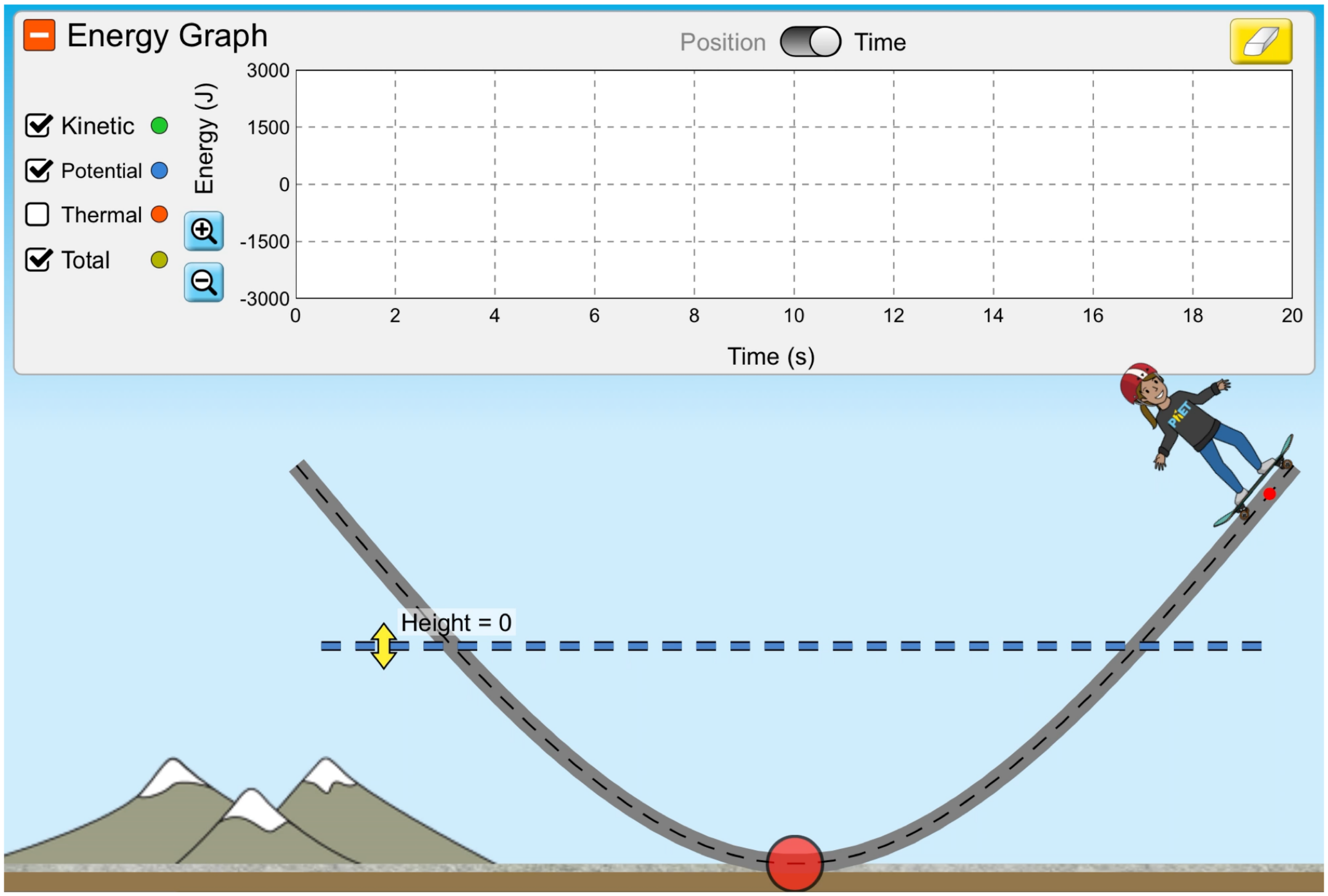
Angarita's Talk

Gravity – compressible MHD turbulence



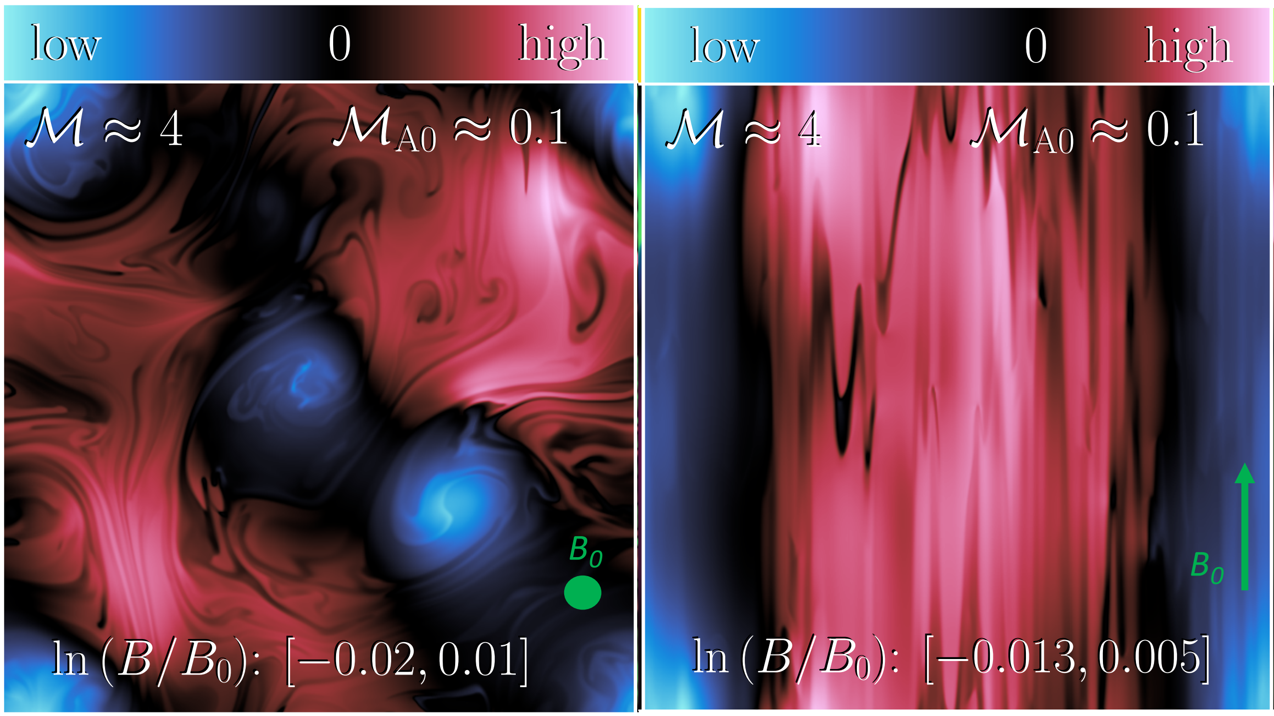
PhET simulations

Gravity – compressible MHD turbulence



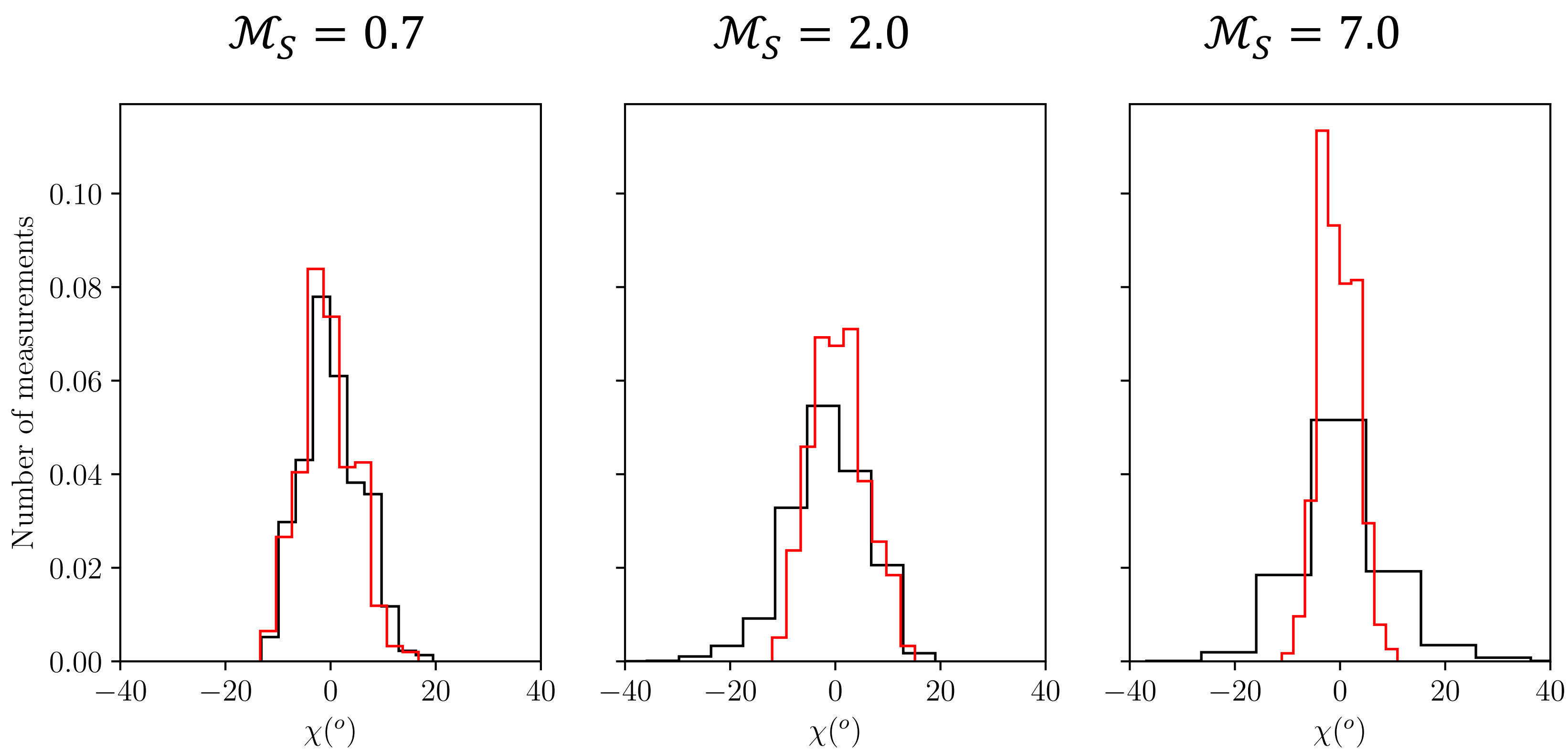
PhET simulations

Coherent structures



Beattie+2022

Non-homogeneity effect



- Density = in-homogeneous
- Density = homogeneous

Skalidis & Tassis 2021