Maps of Magnetic Field Strength in the OMC-1 Region

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Talk Content

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    2. Angle dispersion analysis.
2. Maps of POS Magnetic Field Strength.
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    2. Zeeman calibration.
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    2. Maps of B in the Gould Belt Molecular Clouds
    3. Disambiguation of B_{POS} direction

DCF Method

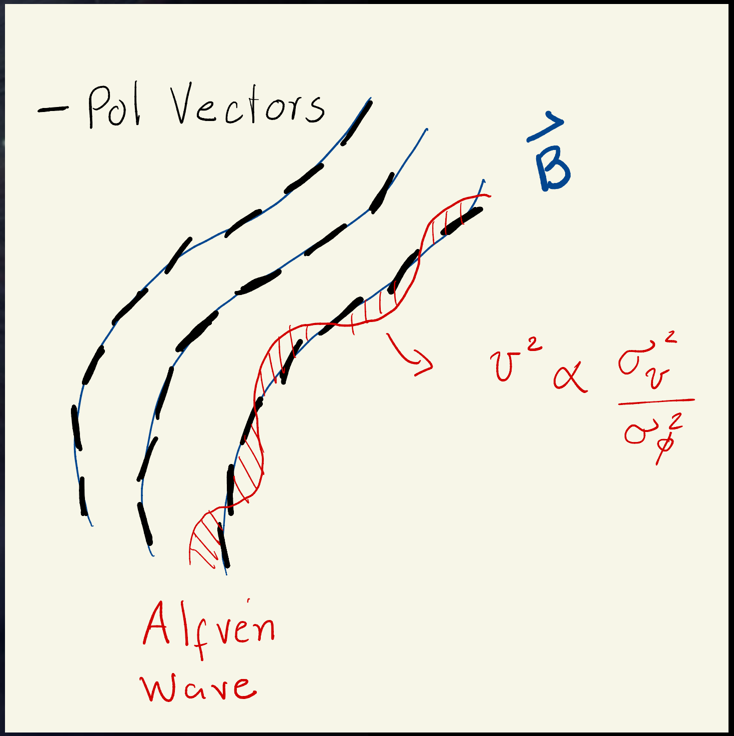
Polarization dispersion and POS magnetic field:
The Davis-Chandrasekhar-Fermi (DCF) method.

Mass Density ($\boldsymbol{\rho}$)

Velocity Dispersion ($\boldsymbol{\sigma}_{\mathrm{v}}$)

Angle Dispersion (σ_{ϕ})

$$B_{POS} = \sqrt{4\pi\rho}\,\frac{\sigma_v}{\sigma_\phi}$$



Dispersion Analysis

Polarization dispersion and POS magnetic field:

Two-component dispersion function (Houde et. al., 2013)

Angle difference

$$1 - \langle \cos[\Delta\phi(l)] \rangle = \frac{1}{1 + \mathcal{N}\left[\frac{\langle B_t^2 \rangle}{\langle B_0^2 \rangle}\right]^{-1}} \left\{ 1 - exp\left(-\frac{l^2}{2(\delta^2 + 2W^2)} \right) \right\} + a_2 l^2$$

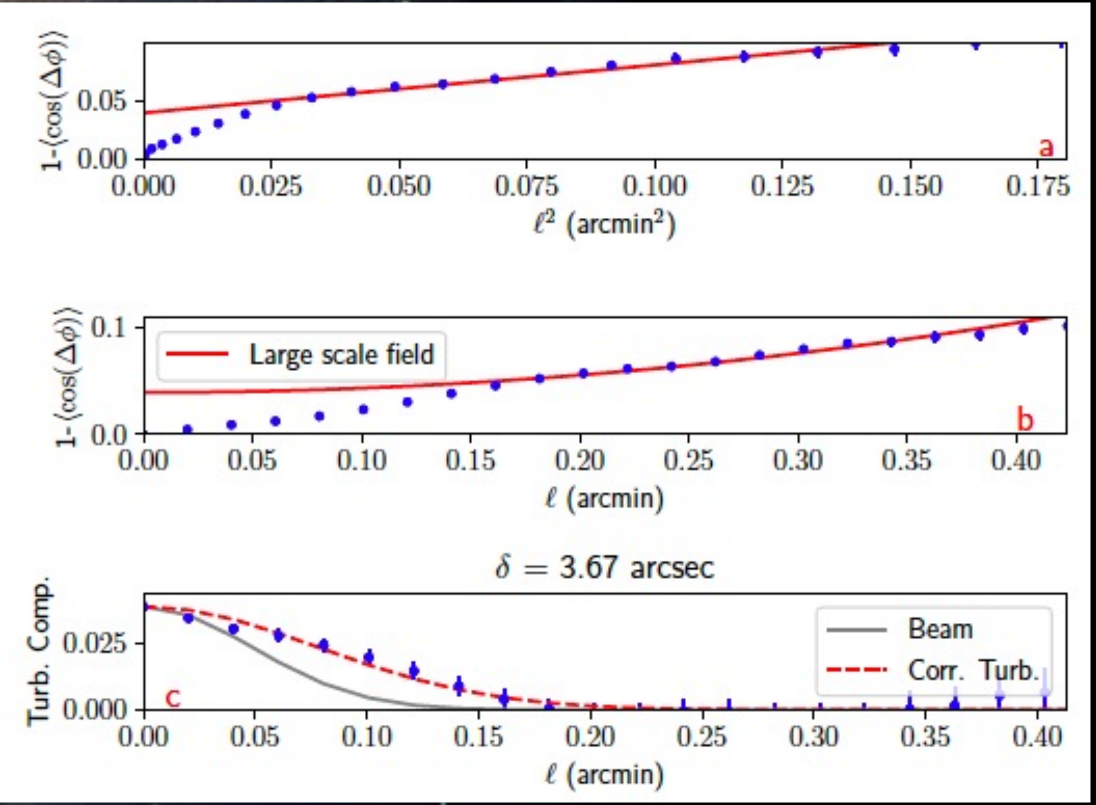
turbulent cells in LOS

Ratio of B-fields energies

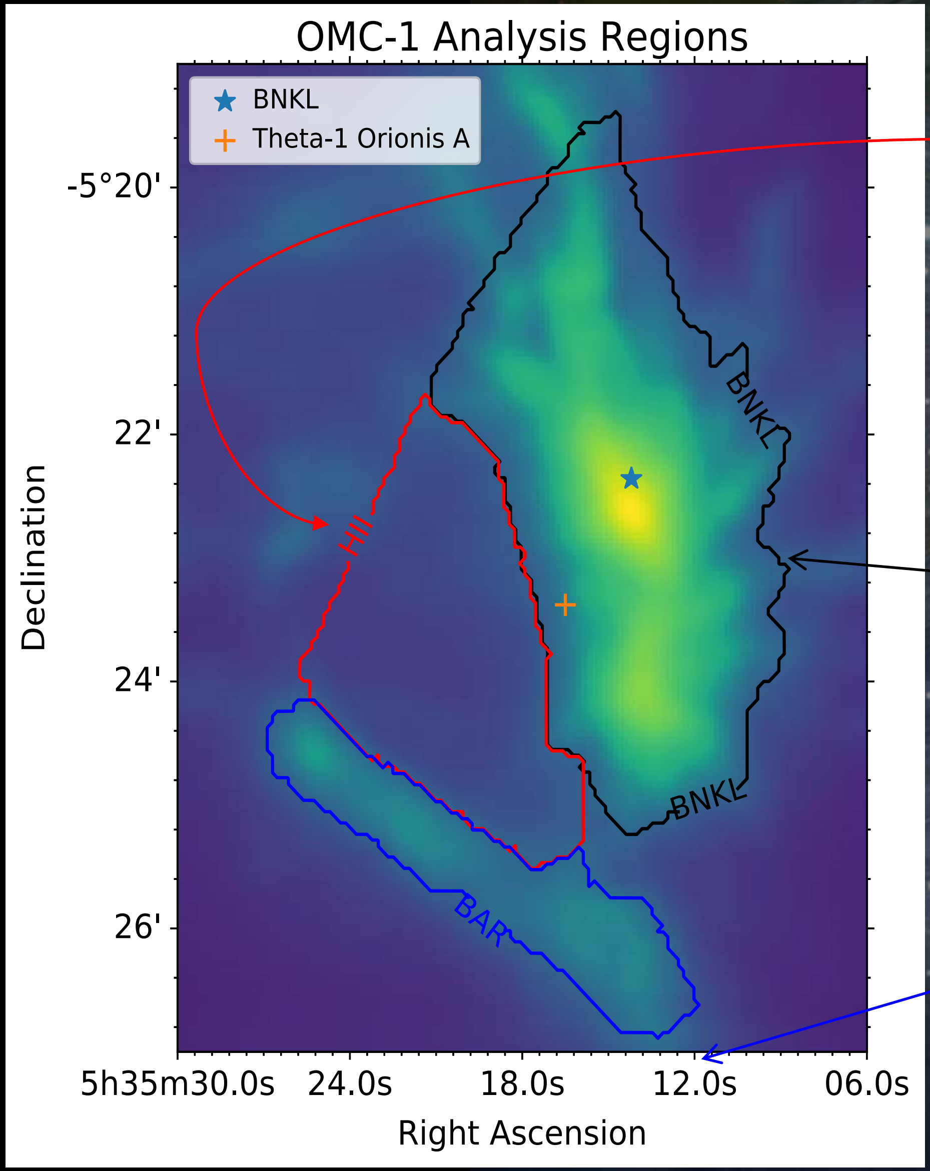
Turbulence correlation length

Obs. Beam size

$$\sigma_\phi^2 \approx \frac{\langle B_t^2 \rangle}{\langle B_0^2 \rangle}$$



POS B in OMC-1



δ: 4 – 10 arcsec
$\langle B_t^2\rangle/\langle B_0^2\rangle$:
0.23 – 0.34
N: 10 - 30
B_0: ~0.3 mG

δ: 9 – 34 arcsec
$\langle B_t^2\rangle/\langle B_0^2\rangle$:
0.37 – 0.43
N: 4 - 8
B_0: ~ 1mG

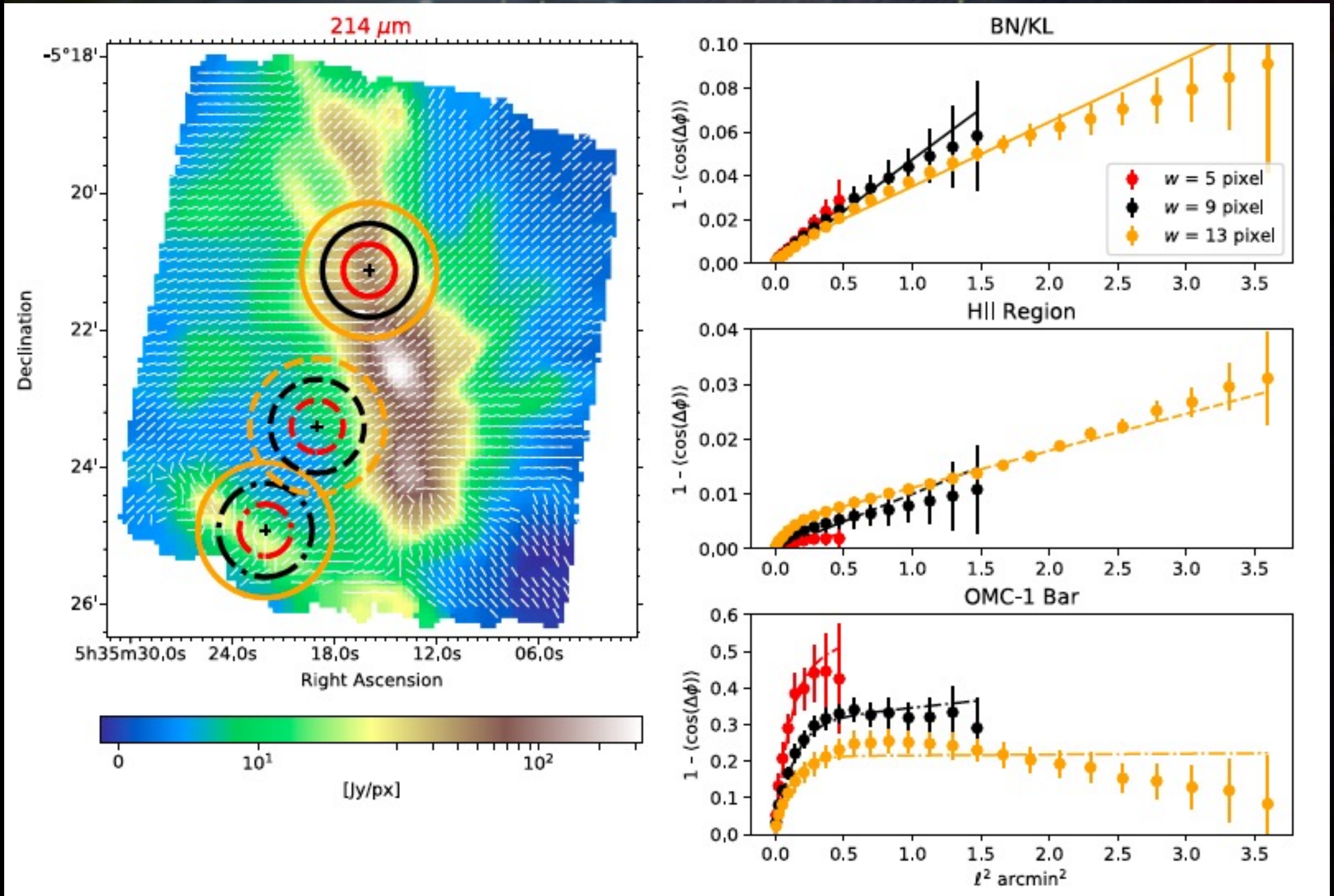
δ: 7 – 10 arcsec
$\langle B_t^2\rangle/\langle B_0^2\rangle$:
1.61 – 1.77
N: ~ 8.5
B_0: ~ 0.3 mG

Using the DCF method and dispersion function with HAWC+/SOFIA data. Of OMC-1.

Chuss et. al. , 2019

Maps of POS B strength

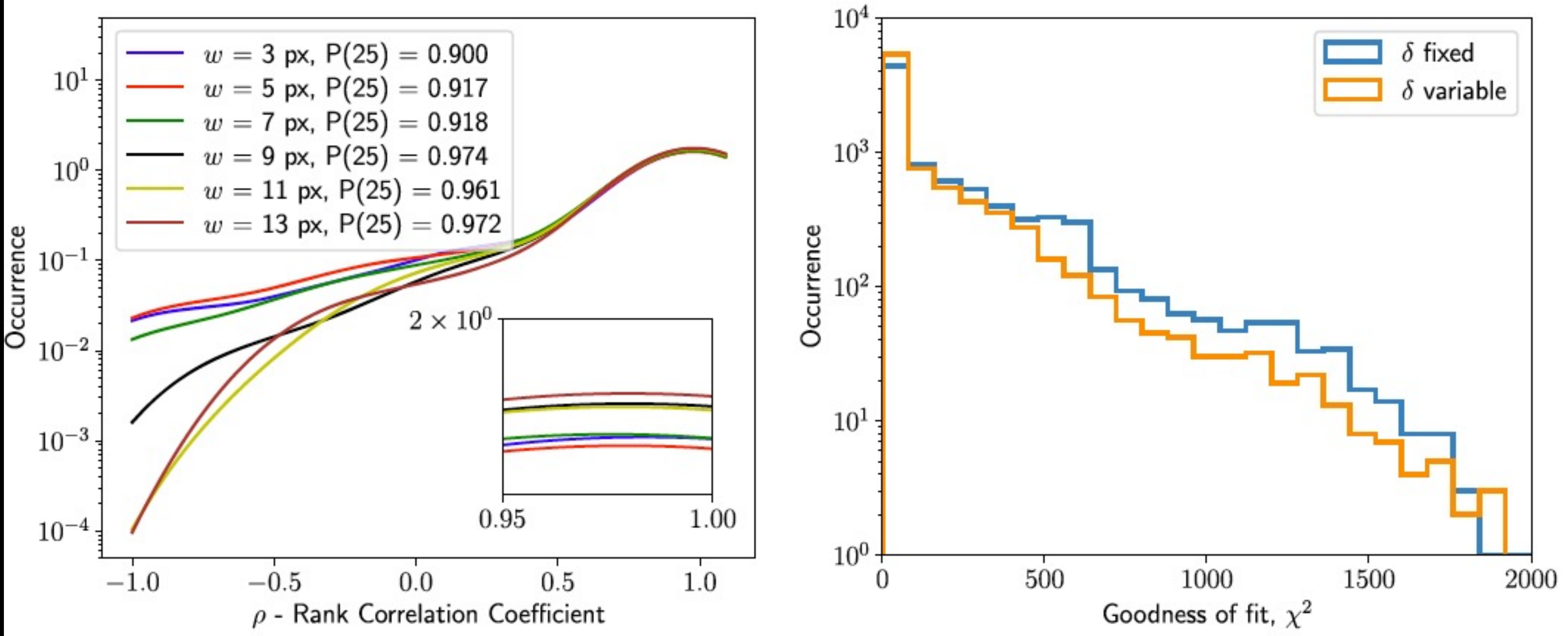
1. Applying the DCF method + dispersion analysis in a circular kernel.



Guerra et. al. , 2021

Maps of POS B strength

Choosing the optimal kernel size.

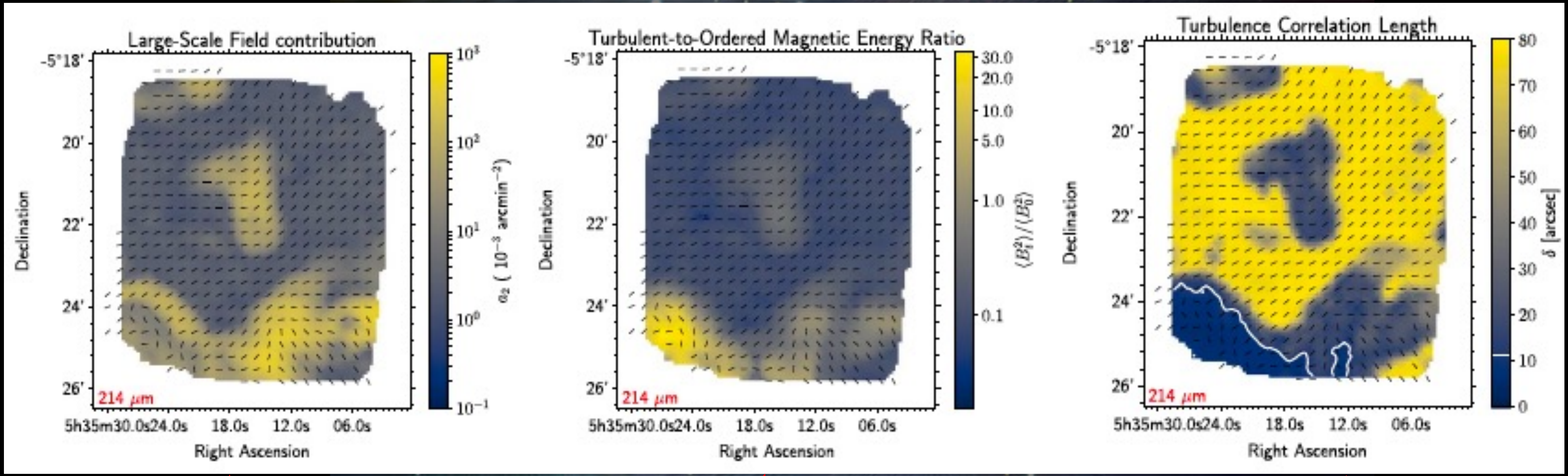


Guerra et. al. , 2021

Maps of POS B strength

MCMC solver: parameter maps.

Guerra et. al. , 2021

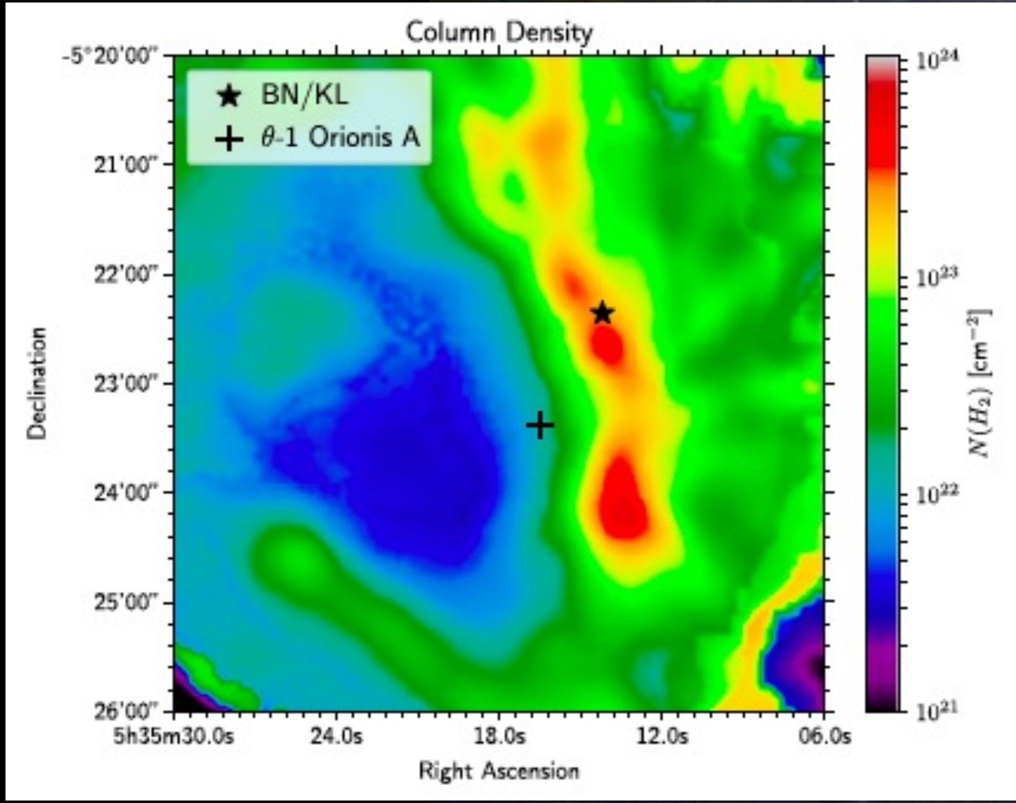


$$1 - \langle \cos[\Delta\phi(l)] \rangle = \frac{1}{1 + \mathcal{N}\left[\frac{\langle B_t^2 \rangle}{\langle B_0^2 \rangle}\right]^{-1}} \left\{ 1 - exp\left(-\frac{l^2}{2(\delta^2 + 2W^2)} \right) \right\} + a_2 l^2$$

Maps of POS **B** strength

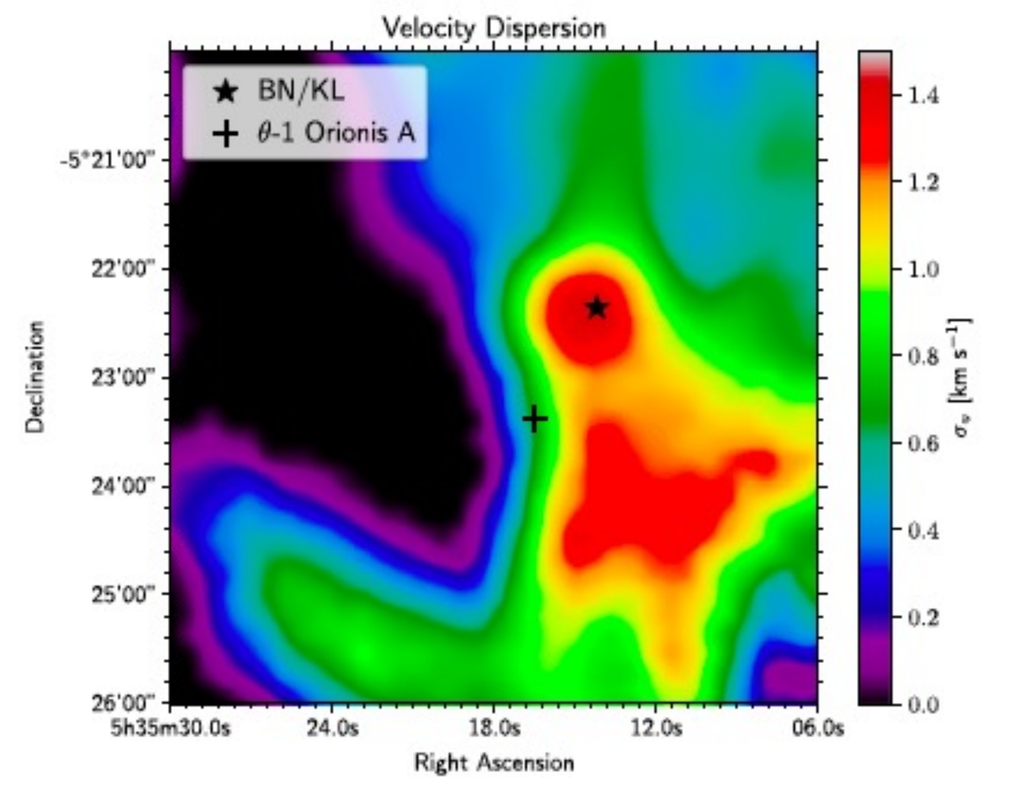
Auxiliary data: Column density and Velocity dispersion.

Spectral Density Energy (SDE) fitting



Chuss et. al. , 2019

NH_3 multi-line Gaussian fitting

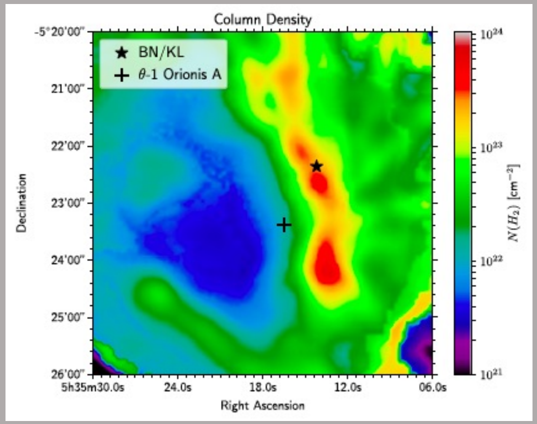


Friesen et. al. , 2017

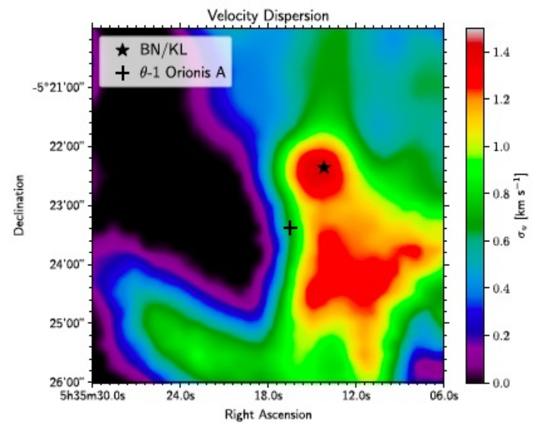
Maps of POS **B** strength

Combining maps: common resolution.

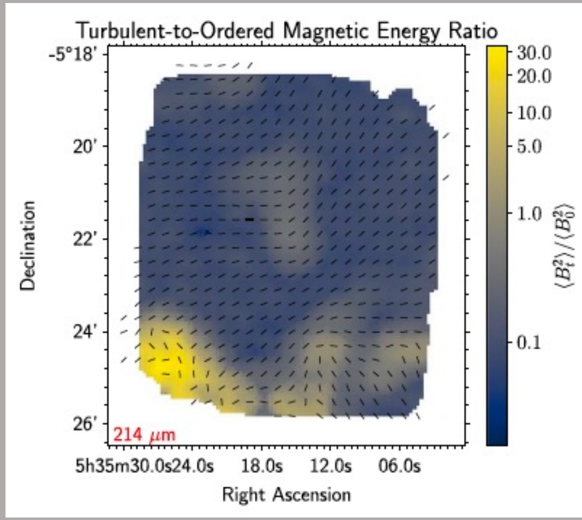
22”



32”

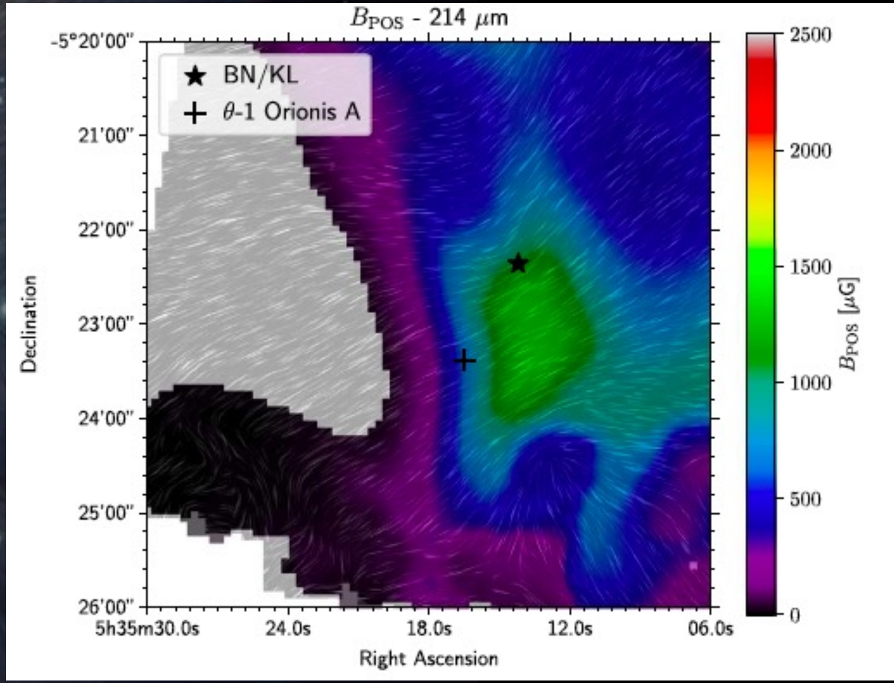


21”(A)
33”(C)
58”(D)
77”(E)



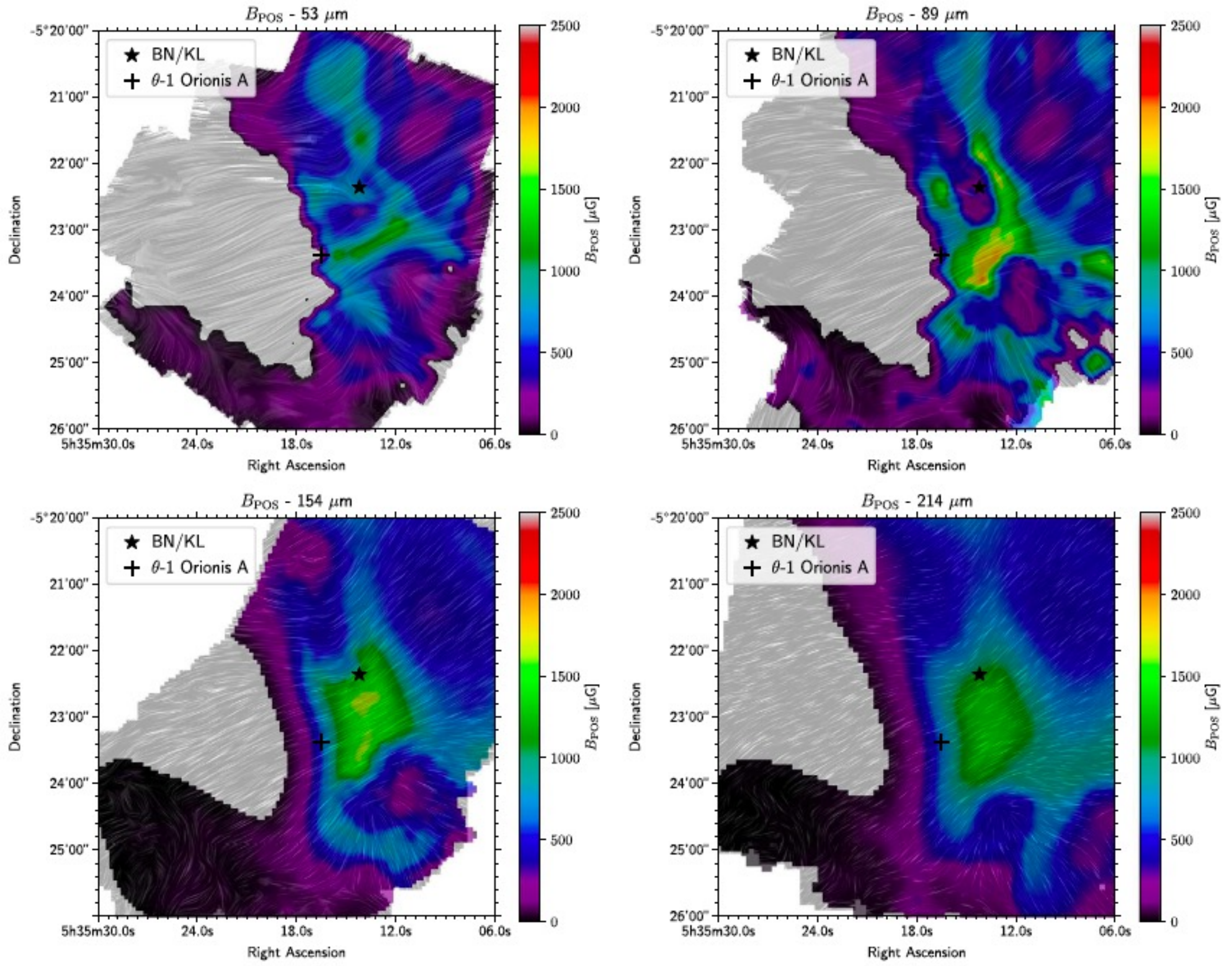
Gaussian smoothing

77”



Maps of POS **B** strength

- POS strength increases with resolution.
- BN/KL case:
  - Strong POS B.
  - “Cavity”
- Possibility: warm dust is deeper inside the cloud.



Guerra et. al. , 2021

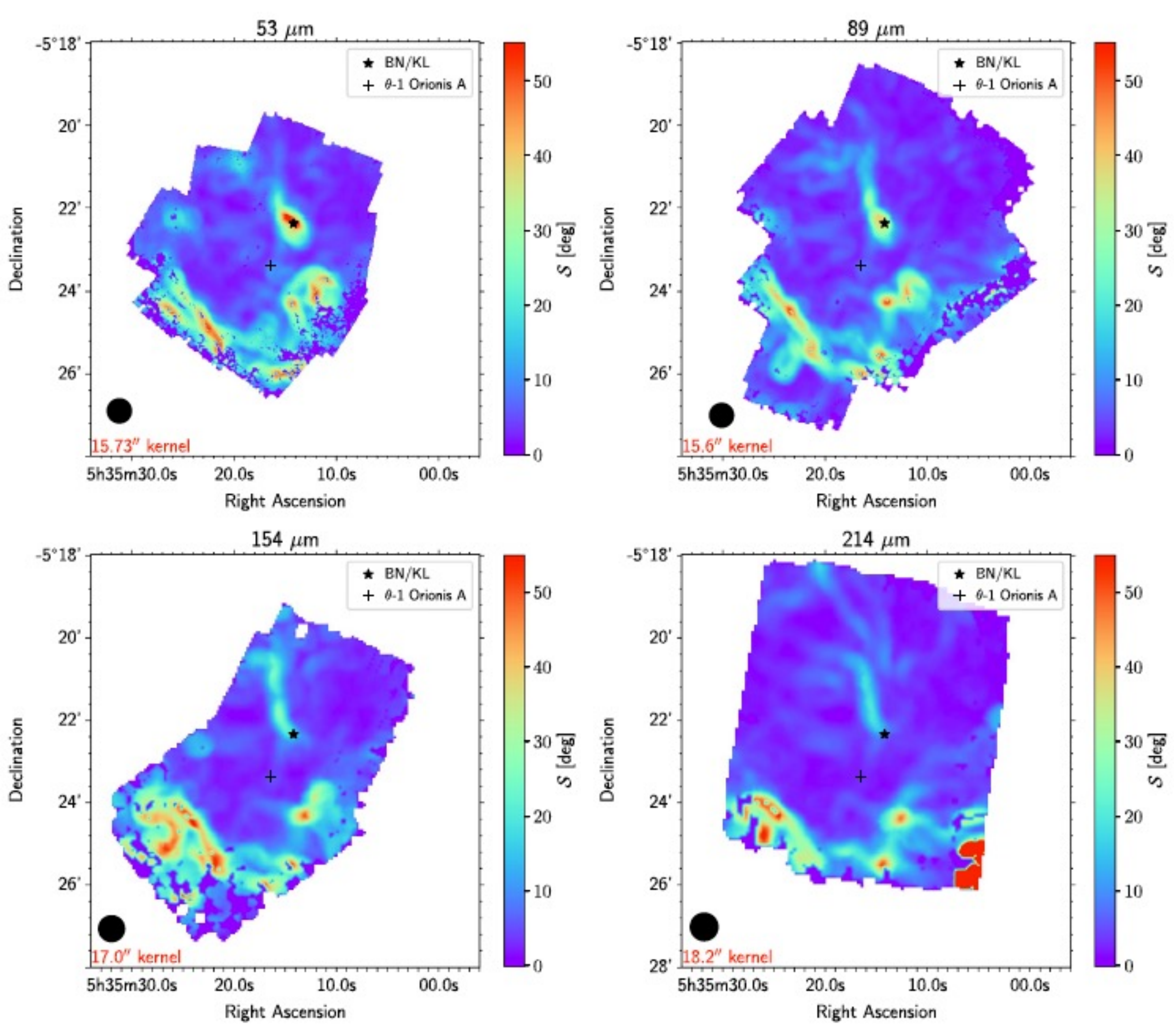
Maps of LOS **B** strength

Local dispersion $\mathcal{S}$:

$$\mathcal{S} = \sqrt{\frac{1}{N}\sum_{i=0}^{N}(\phi_i - \bar{\phi})^2}$$

which is debiased

$$\mathcal{S} = \begin{cases} \sqrt{\mathcal{S}_m^2 - \sigma_{\mathcal{S}}^2}, \mathcal{S}_m > \sigma_{\mathcal{S}} \\ 0, \quad otherwise \end{cases}$$



Guerra et. al. , 2021

Maps of LOS **B** strength

Combination of dispersion & Zeeman measurement:

Assuming the dispersion $\mathcal{S}$ is dominated by LOS angle (Hensley et. al.,2019)*

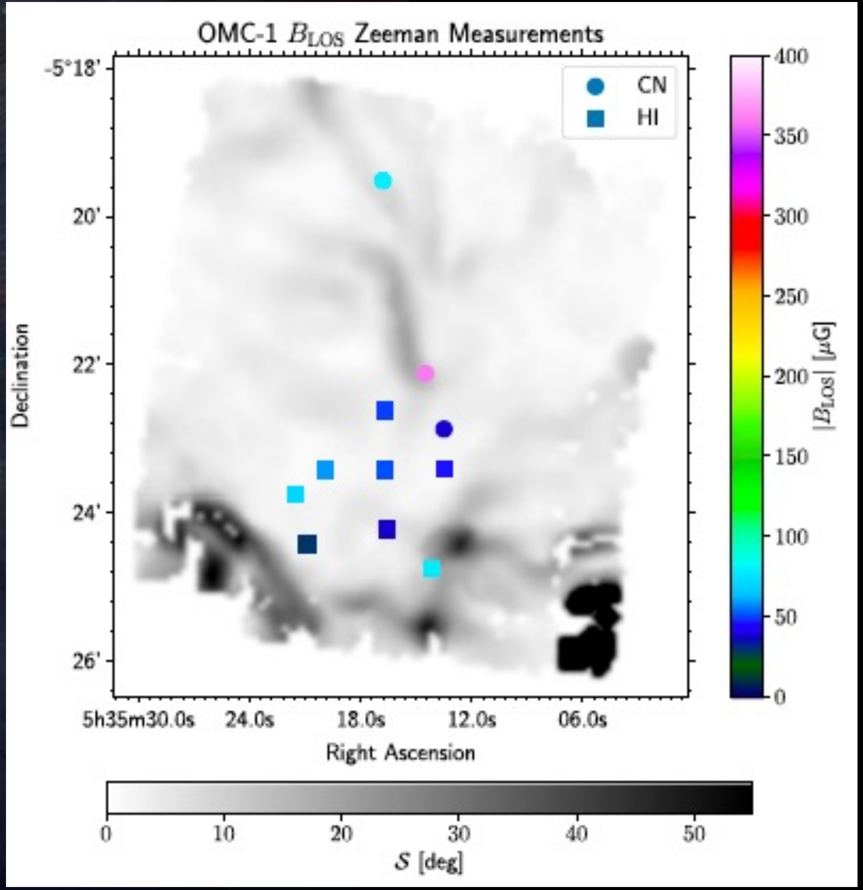
$$sin^2(\varphi) = a\mathcal{S}^n$$

along with

$$\tan(\varphi) = \frac{B_{POS}}{B_{LOS}}$$

the LOS component can be written as

$$B_{LOS} = B_{POS}\sqrt{\frac{1 - a\mathcal{S}^n}{a\mathcal{S}^n}}$$



Maps of LOS **B** strength

Determining power-law parameters

Exponent:

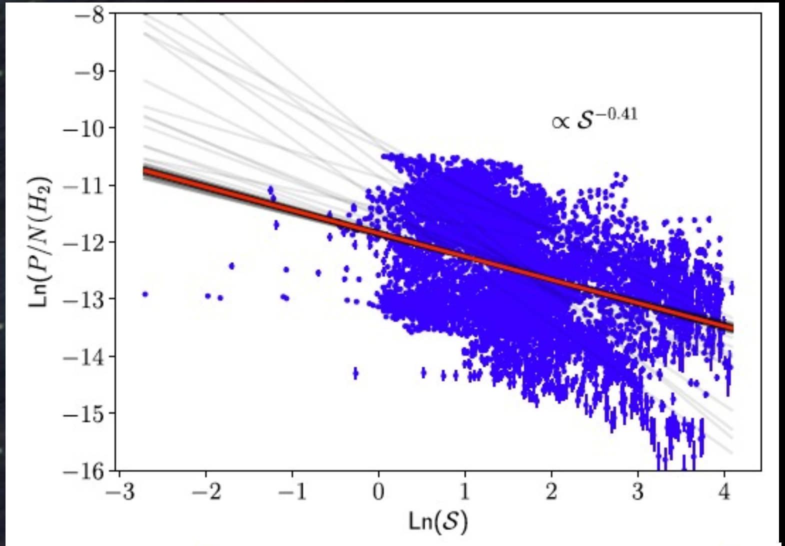
$$P/N(H_2) \propto \mathcal{S}^n$$

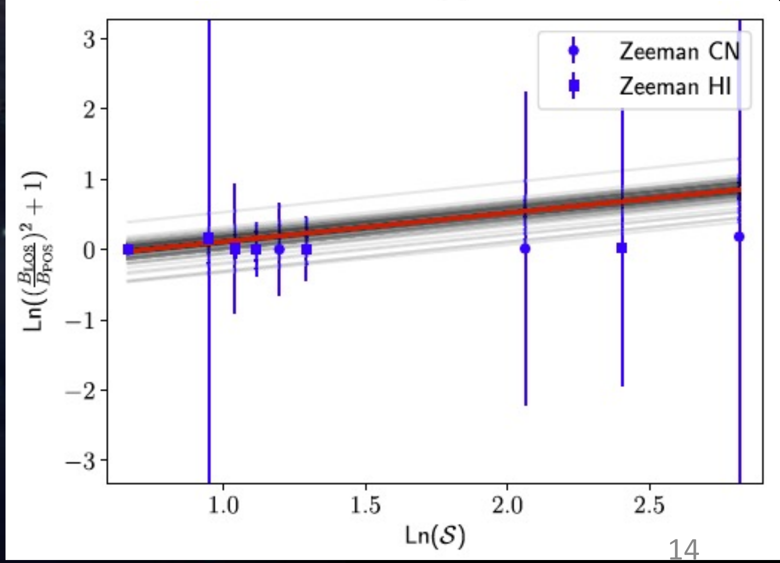
Constant:

$$\ln\left[\left(\frac{B_{LOS}}{B_{POS}}\right)^2 + 1\right] = -\ln(a) - n\ln(\mathcal{S})$$

Wavelength (μm)	n	a	$\mathcal{S}_c$ (deg)
53	$-0.68^{+0.01}_{-0.01}$	$2.77^{+0.68}_{-0.61}$	4.47
89	$-0.34^{+0.01}_{-0.05}$	$1.42^{+0.14}_{-0.12}$	2.80
154	$-0.52^{+0.01}_{-0.01}$	$1.39^{+0.39}_{-0.32}$	1.88
214	$-0.41^{+0.01}_{-0.02}$	$1.34^{+0.14}_{-0.13}$	2.04

Guerra et. al. , 2021

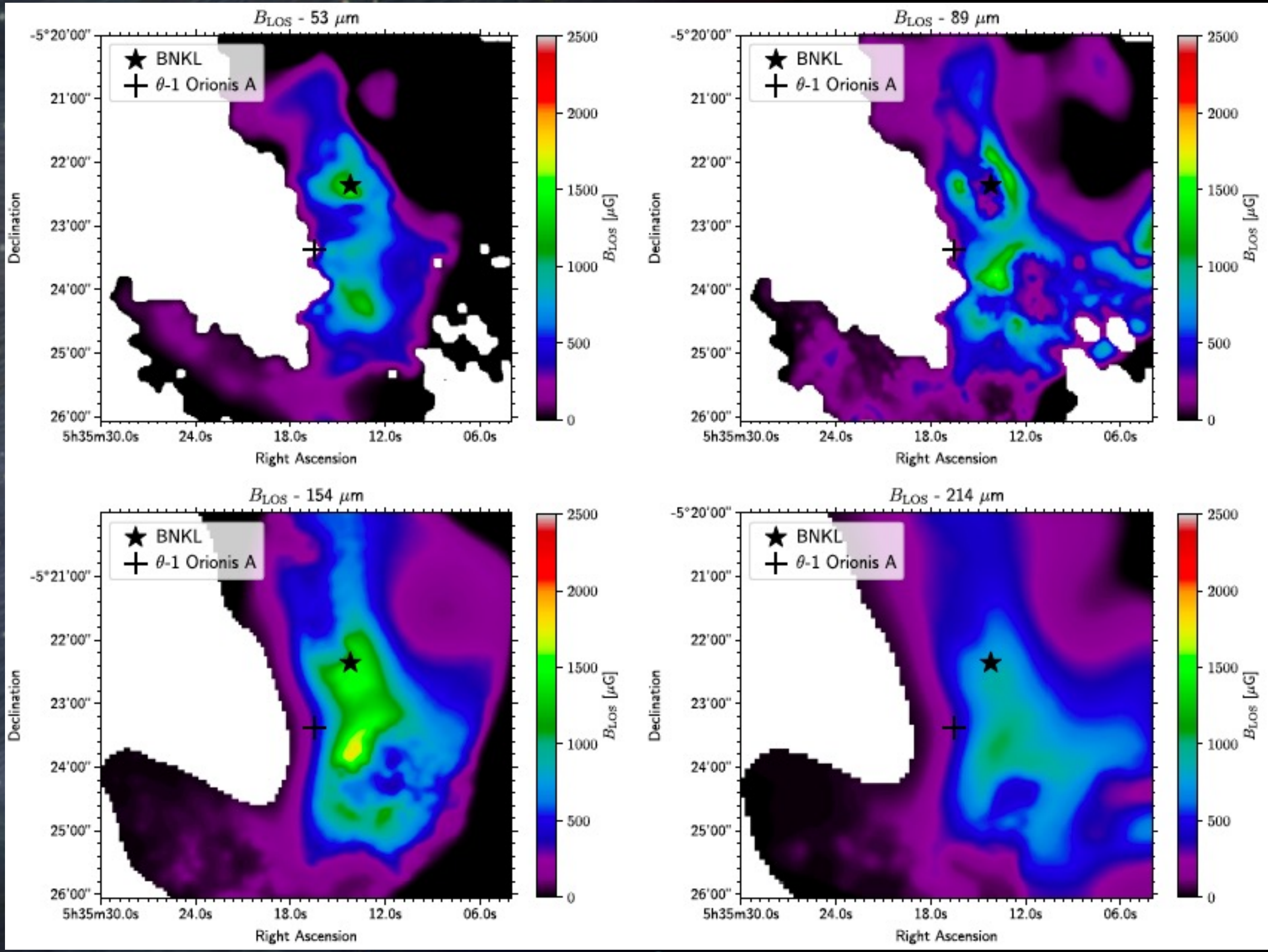




Maps of LOS **B** strength

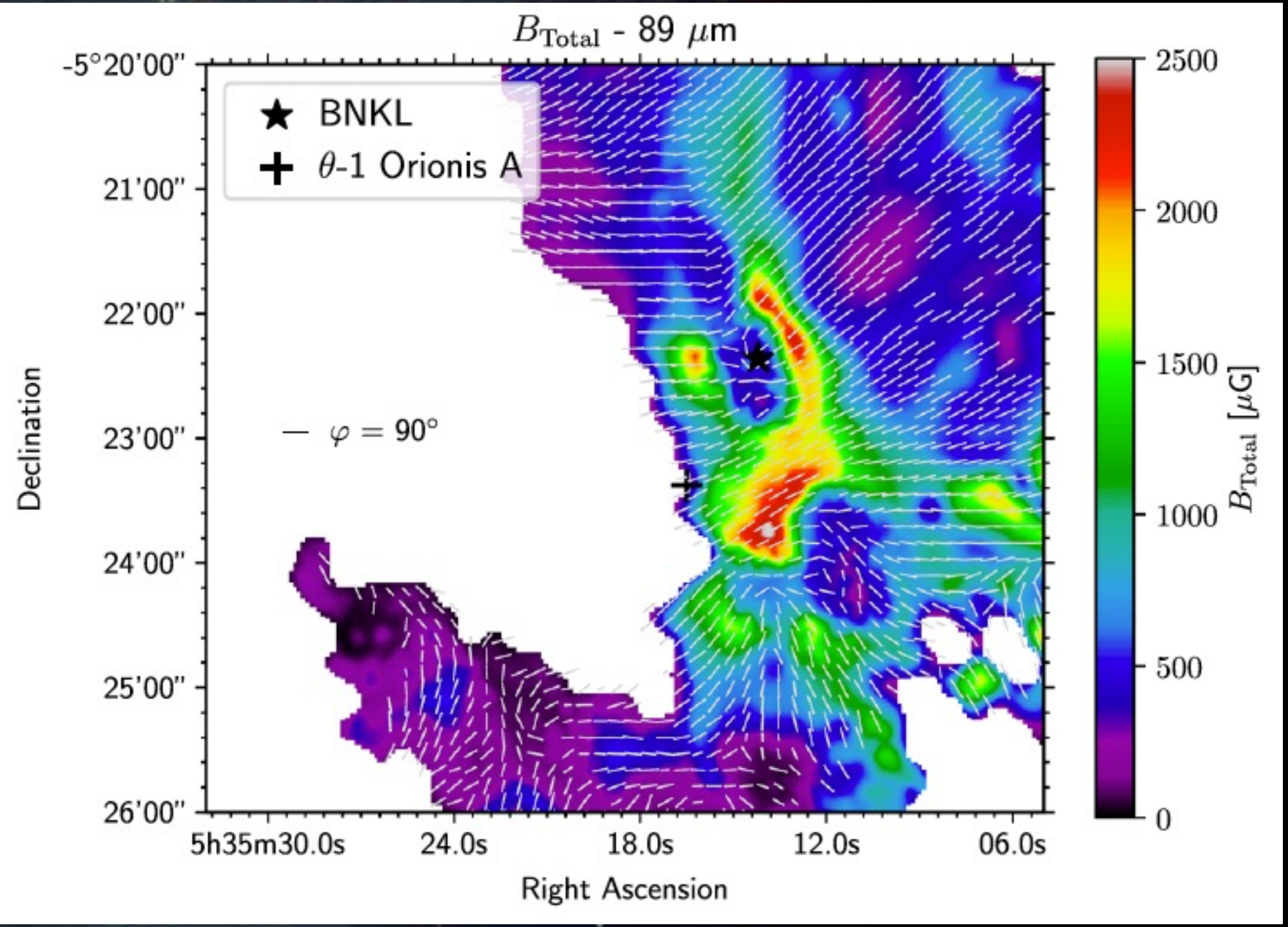
- "Very" first approximation.
- Scarcity of Zeeman measurements.
- Covariance with B_{POS} maps.

Guerra et. al. , 2021



Maps of Total **B** strength

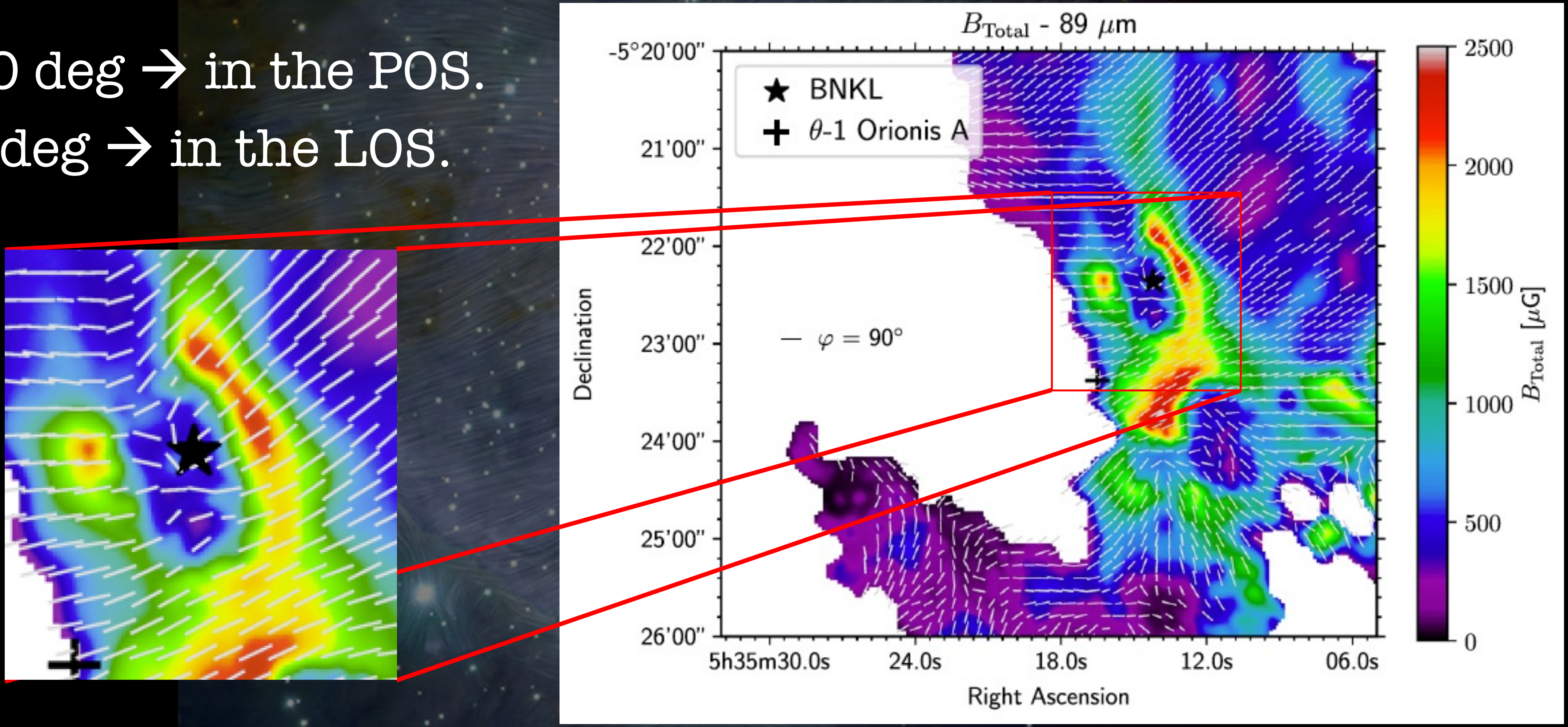
- φ = 90 deg → in the POS.
- φ = 0 deg → in the LOS.



Guerra et. al. , 2021

Maps of Total **B** strength

- φ = 90 deg → in the POS.
- φ = 0 deg → in the LOS.



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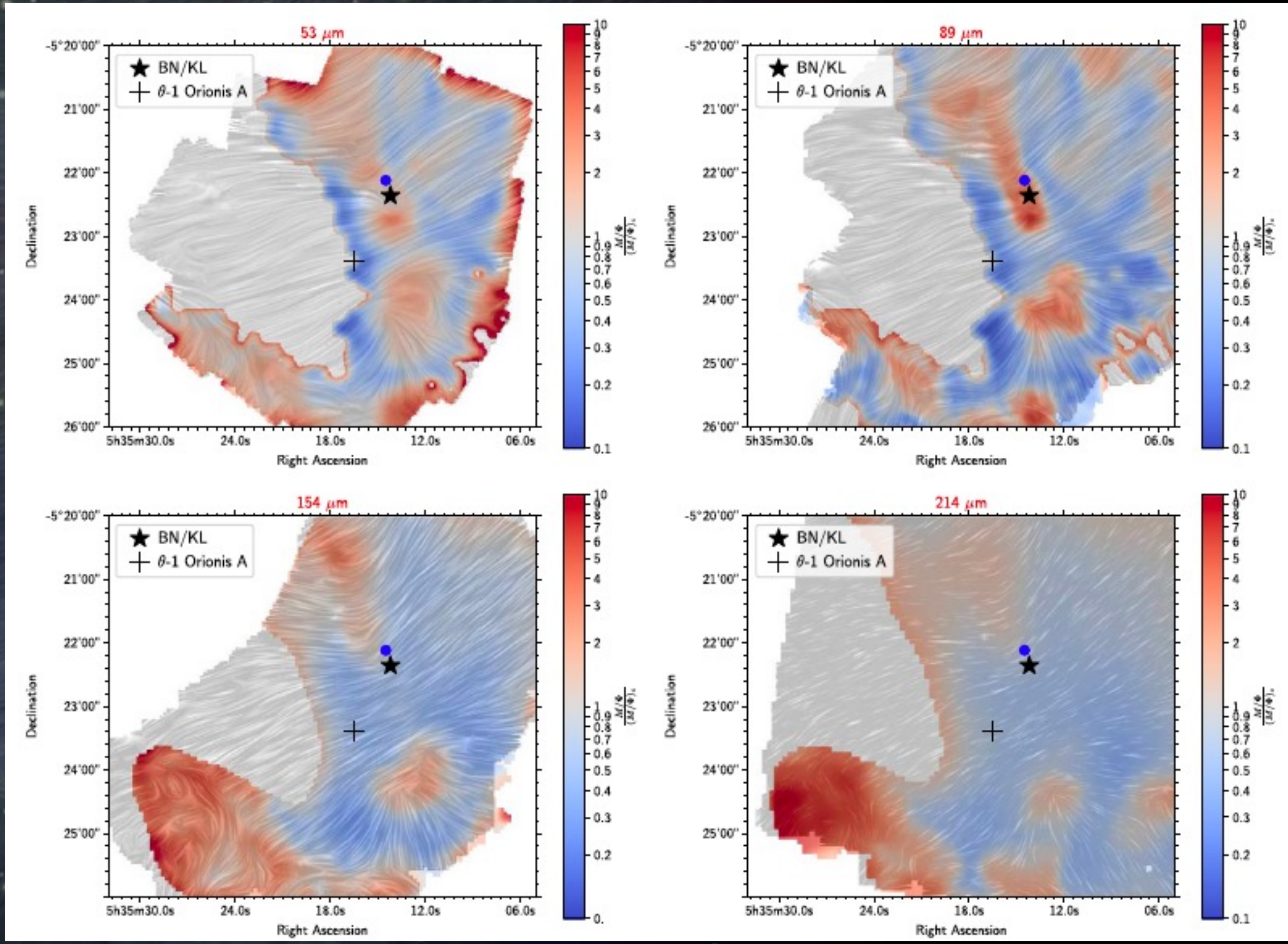
M/Φ Maps

Super-critical → gravity dominated

Sub-critical → B-field dominated



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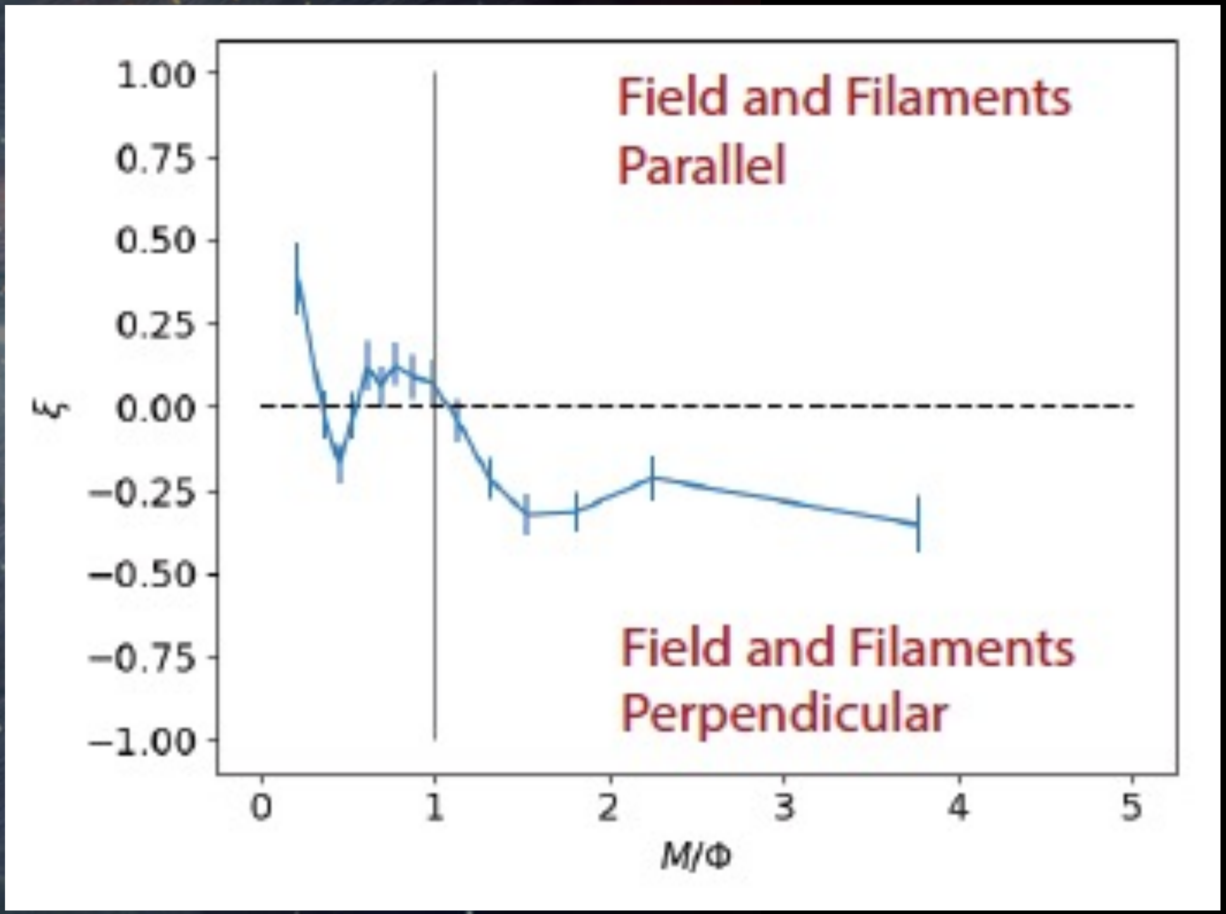
B - Filament Alignment

89 μm



Advantage of M/$\boldsymbol{\Phi}$:

- Constructing Histograms of Relative Orientation (HRO).
  - M/$\boldsymbol{\Phi}$ >1 (M.D.) → Perpendicular.
  - M/$\boldsymbol{\Phi}$ < 1 (G.D.) → No preference.

Summary

- DCF + dispersion analysis within kernel provides a way to construct maps of POS B field.
- Local dispersion might contain information regarding LOS B – needs further (observations + simulations) testing.
- Variation with wavelength can be more than a resolution issue.
- Maps of M/$\boldsymbol{\Phi}$ can complement HROs.

Future Work

1. Calibration of the DCF method

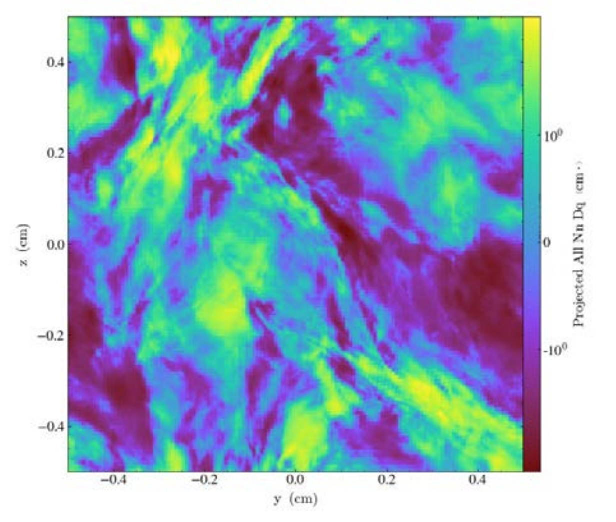
DCF known biases:

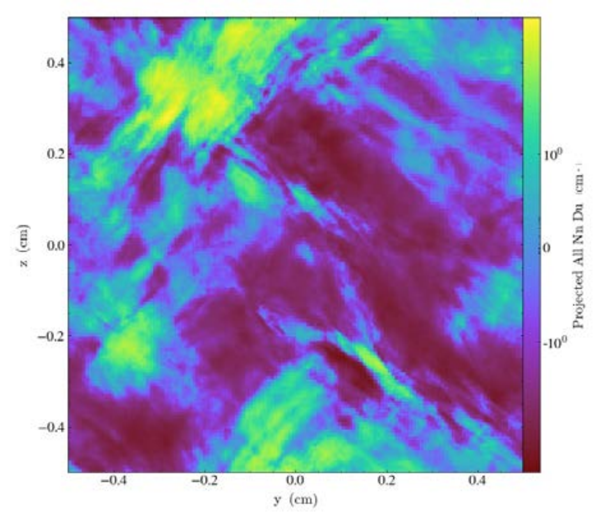
- Isotropic turbulence (assumption)
- Flows (assumption)
- Angular resolution
- Turbulence scale and type (solenoidal, compressive)
- Cloud's depth (uniform vs. non-uniform)

Numerical MHD simulations:

www.mhdturbulence.com

Synthetic q map





Synthetic u map

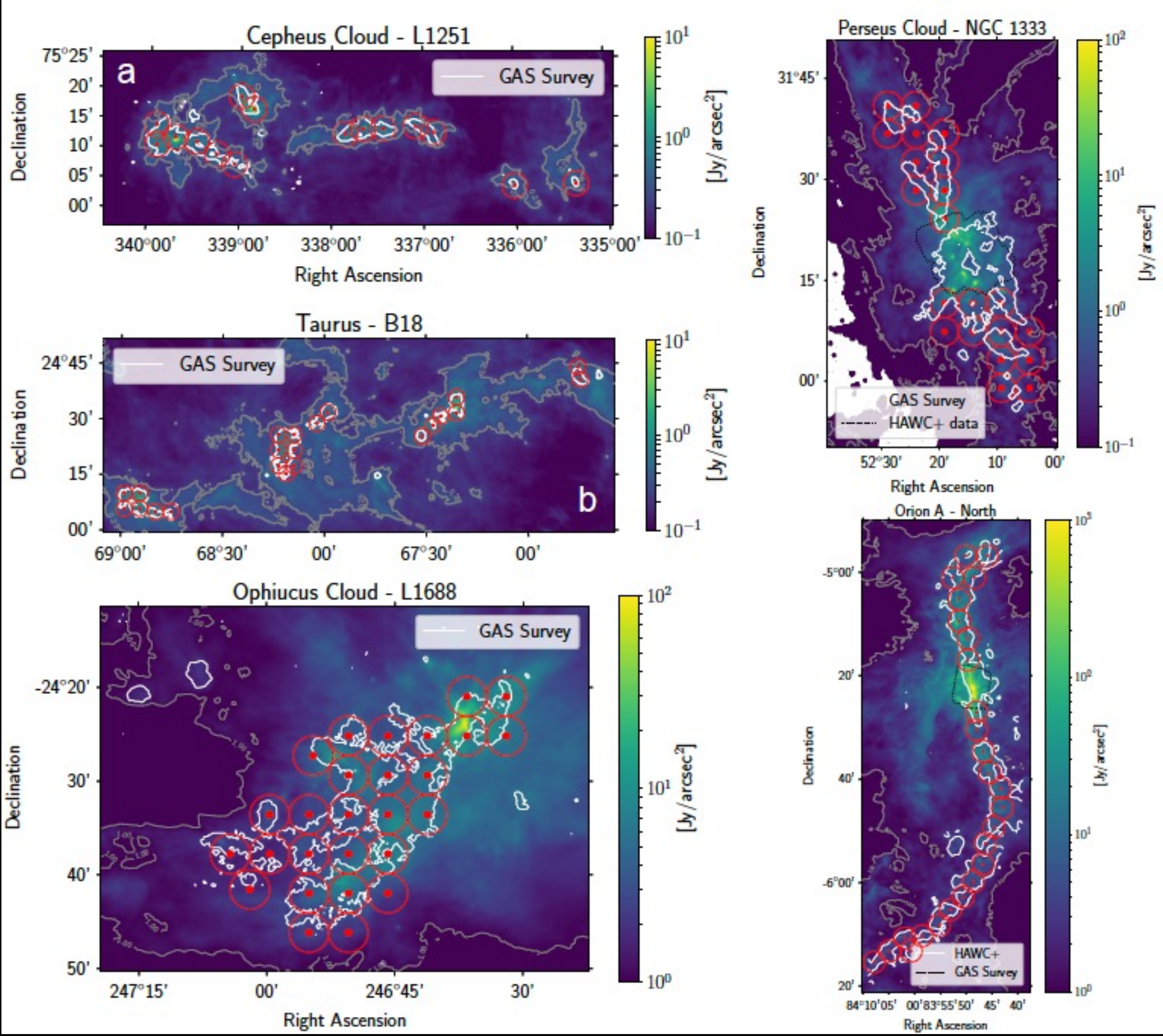
Future Work

2. Magnetic Field in the Molecular Clouds of the Gould Belt

- Archival data: HAWC+, Herschel, GAS.

Target Type	Cloud Complex	σ_v Tracer	Distance [pc]	HAWC+ Regions Observed	HAWC+ band	Spatial Scale [pc]
Primary	Orion	$NH_3(1,1)$	450	OMC-1	A, C, D, E	0.01-0.04
				OMC-2,3	D	0.03
	Ophiuchus	$NH_3(1,1)$	140	ρ-Oph	A, C, D	0.003-0.009
				L1688	C, D	0.006-0.009
	Perseus	$NH_3(1,1)$	300	NGC 1333	C	0.01
				NGC 1448 IRAS 4A	D, E	0.02-0.03
				L1448	E	0.03
	Taurus	$NH_3(1,1)$	140	L1544 Core	D	0.02
Secondary	Musca	-	160	Musca Filament	E	0.01
	Aquila Rift	-	260	Serpens S-1	D, E	0.01-0.02

- New observations: SOFIA DC9 HAWC+ 214 um Survey of GB clouds.
- Construction of M/$\boldsymbol{\Phi}$ maps and HROs.



Future Work

3. <u>Disambiguation of POS B field direction</u>

Energy minimization:

$$E = |J_{LOS}| + |\nabla \cdot B|$$

through simulated annealing:

- Randomly flip a vector → calculate E.
- Accept:
  - $E < E_0$
  - $P(E) = \exp(-(E-E_0)/T) > P_{th}$
- Reduce T.
- Repeat.

89 μm