Heritage of SOFIA – Scientific Highlights and Future Perspectives, 24 April 2024

MAGNETIC FIELDS IN THE DENSE ISM: A NEED FOR IR POLARIMETRY

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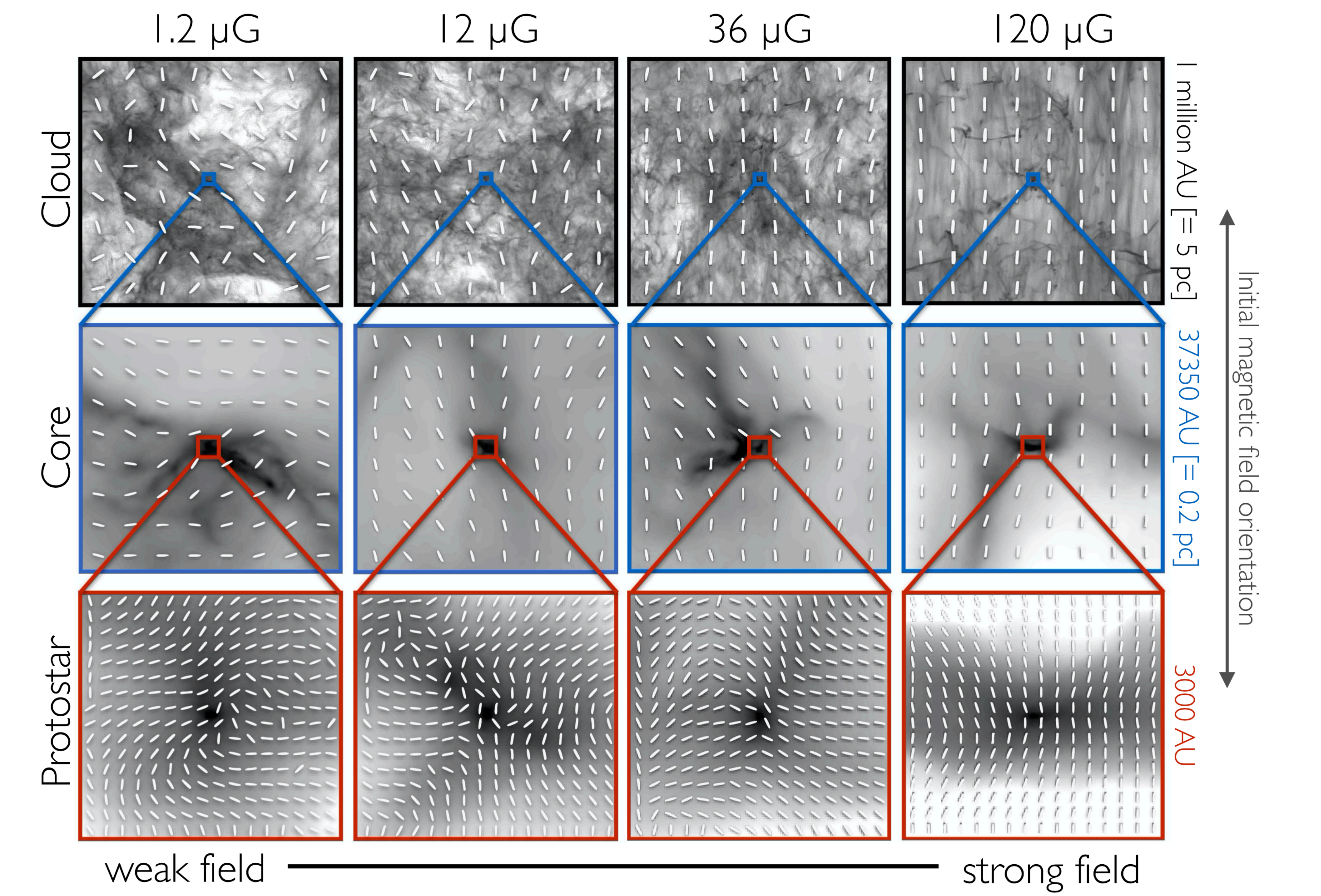
OUTLINE

- Why would B-Fields Matter for Star Formation?
- ~~How can we probe magnetic fields: Techniques Relevant for IR Polarimetry~~
- What are the observed trends in nearby clouds?
- New insights from SOFIA/HAWC+

B-FIELDS MAY SUPPRESS FRAGMENTATION

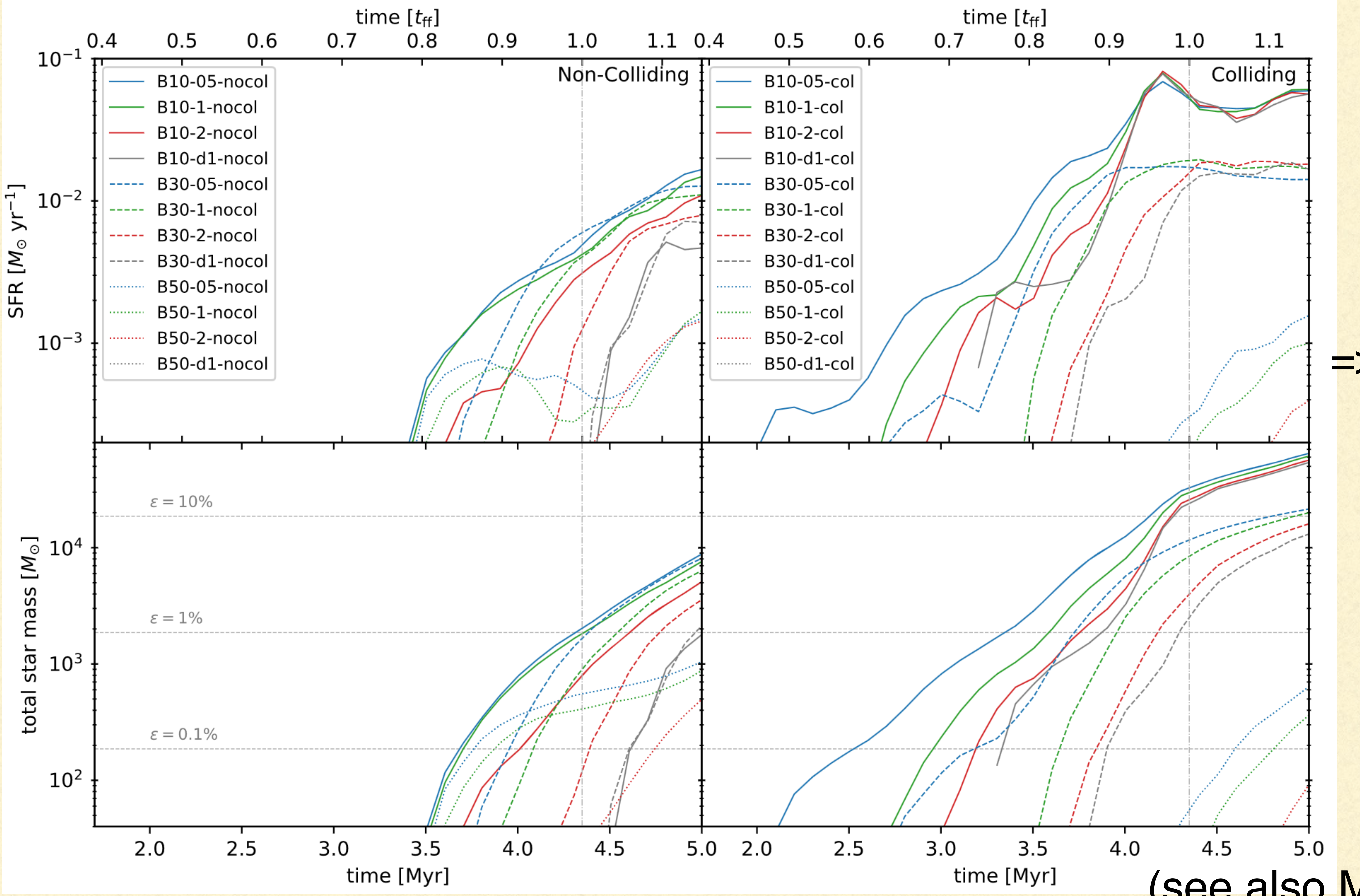


Hull et al. 2017

Relative role of magnetic fields

=> “magnetic field plays a role in dictating the formation of the source structure”

B-FIELDS MAY REDUCE SF EFFICIENCY

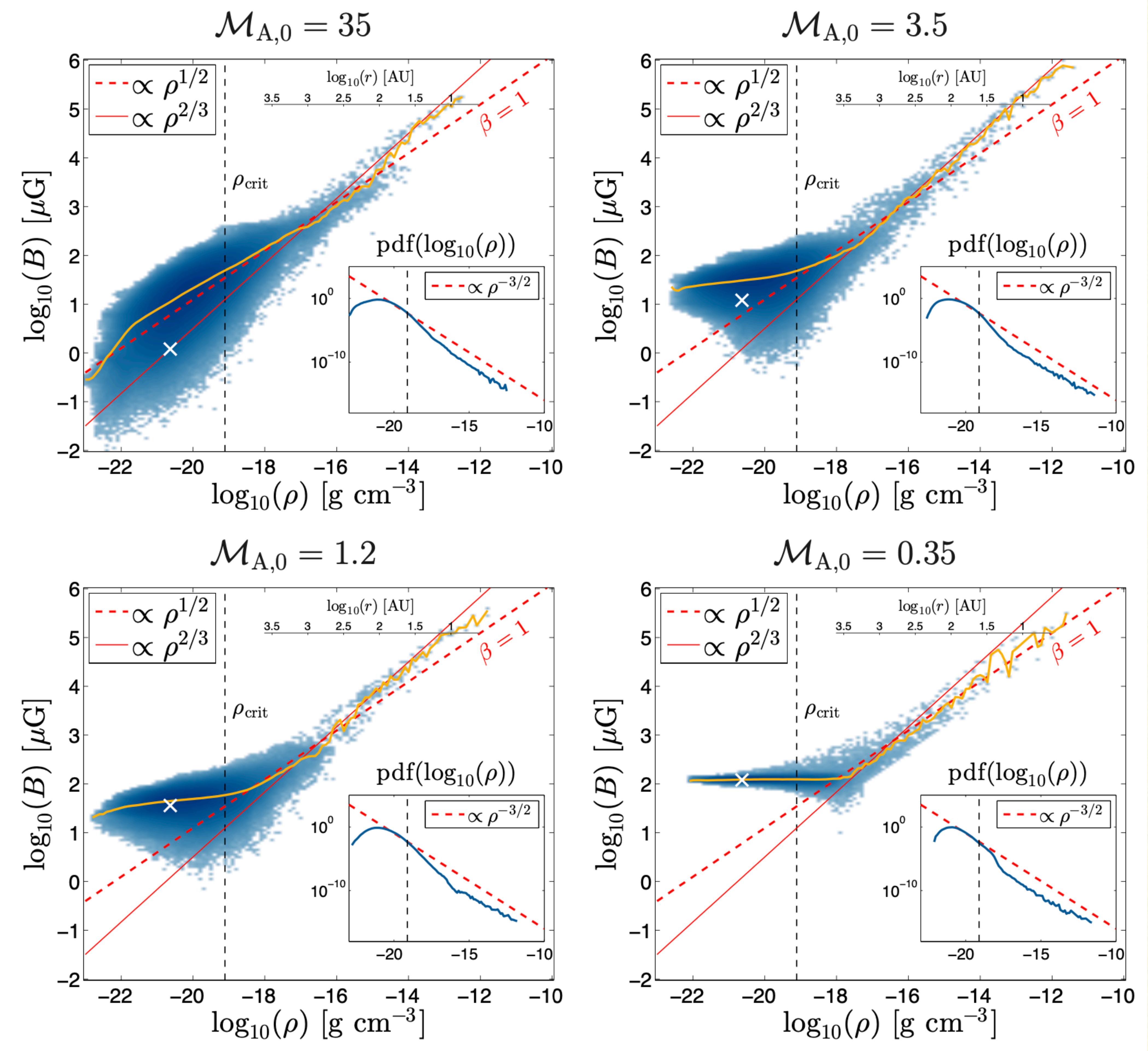


Wu et al. 2020

=> magnetic fields can reduce star-formation rate

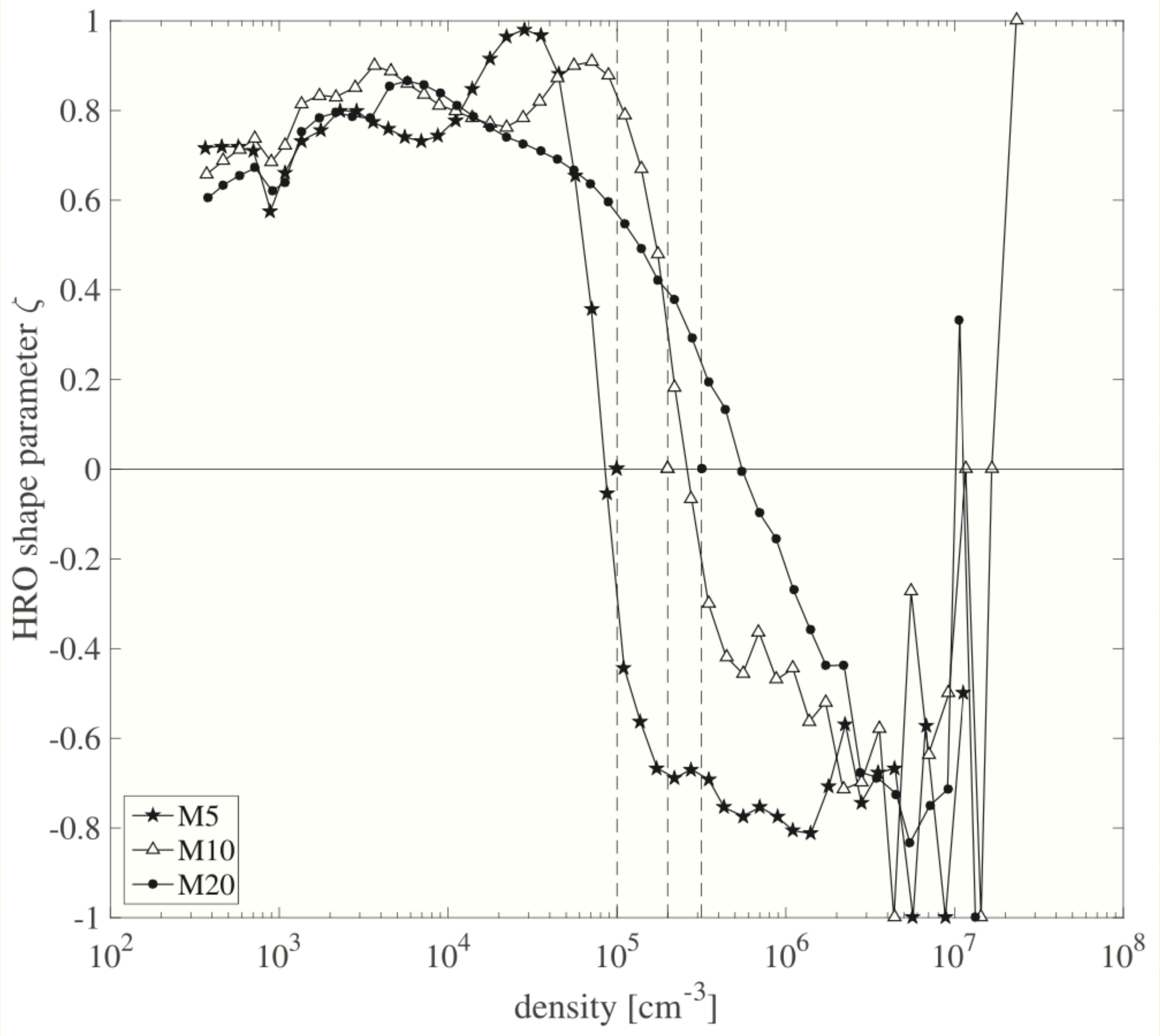
(see also Myers et al. 2014, Federath 2015, Wurster 2019)

B-FIELDS IMPACT DENSITY RELATIONS



Mocz et al. 2020

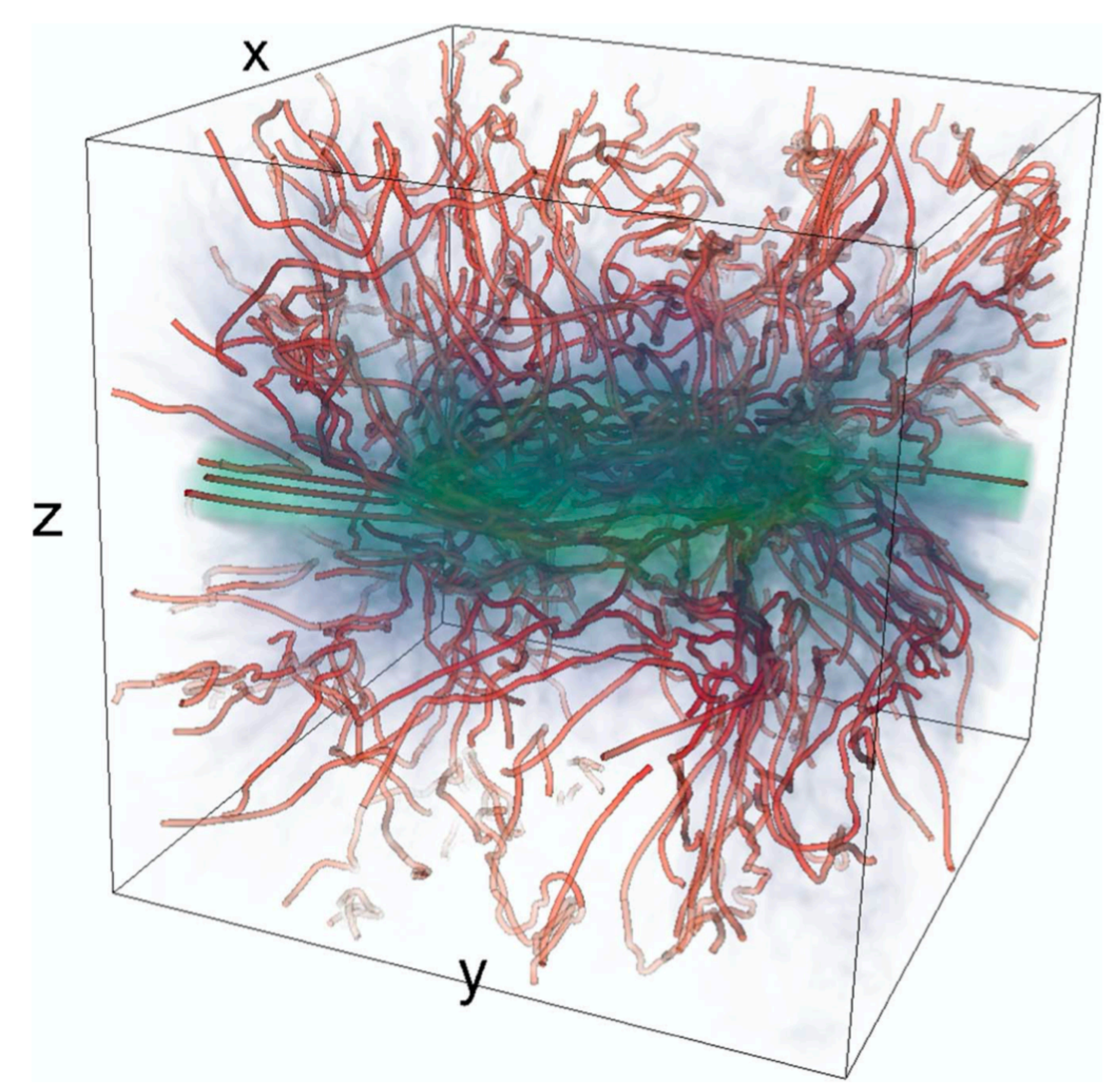
DENSITY SHIFTS B-FIELD-CLOUD ALIGNMENT



Chen et al. 2016 =>

relation between cloud and B-field orientation has a density dependence. The transition density at which field changes from parallel to perpendicular depends on the B-field strength.

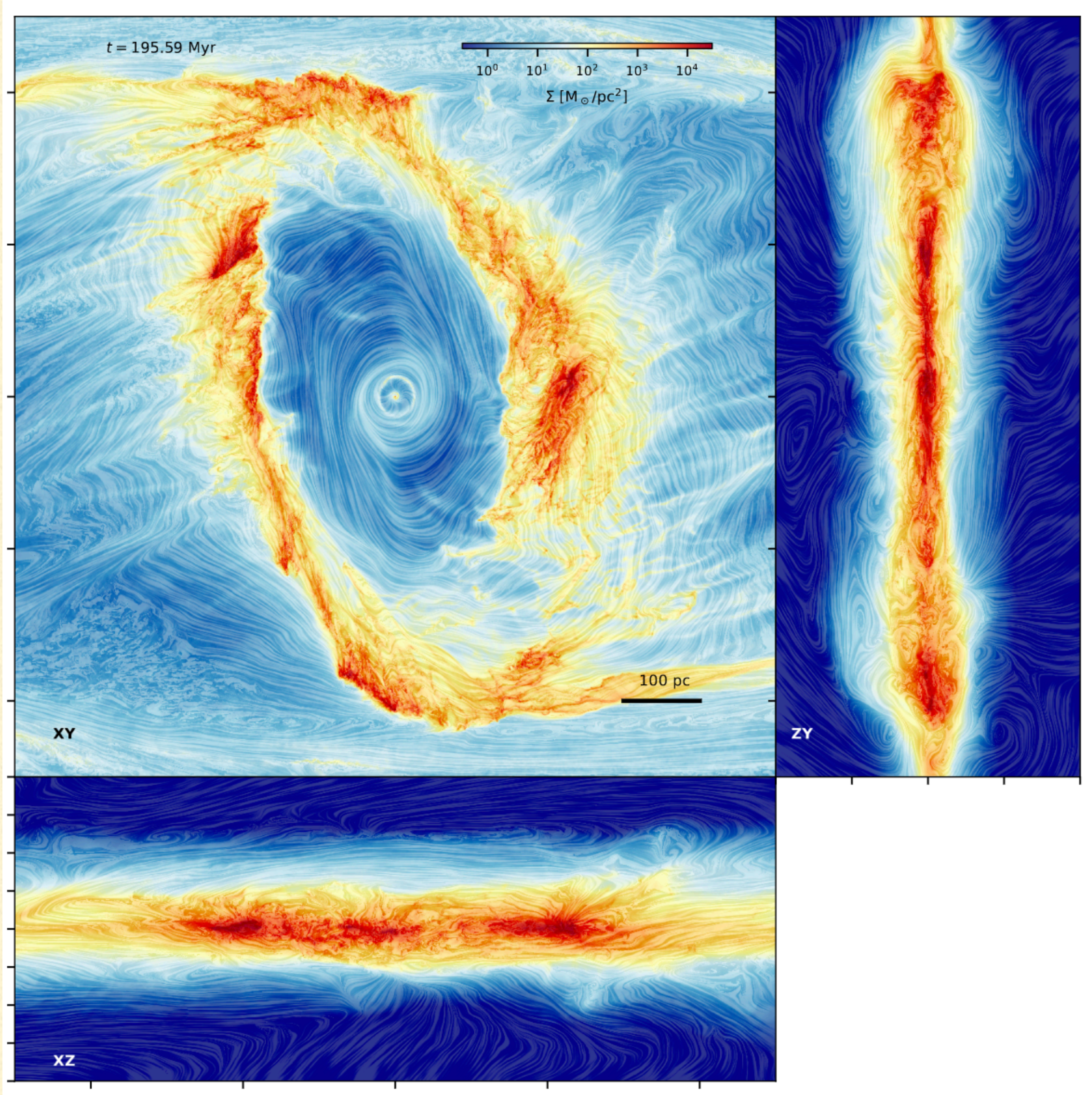
IMPACT OF B-FIELDS IN NUCLEAR RINGS



3D magnetic field structure in model B100 at t = 250 Myr

=> "large-scale magnetic fields tend to suppress star formation in nuclear rings."

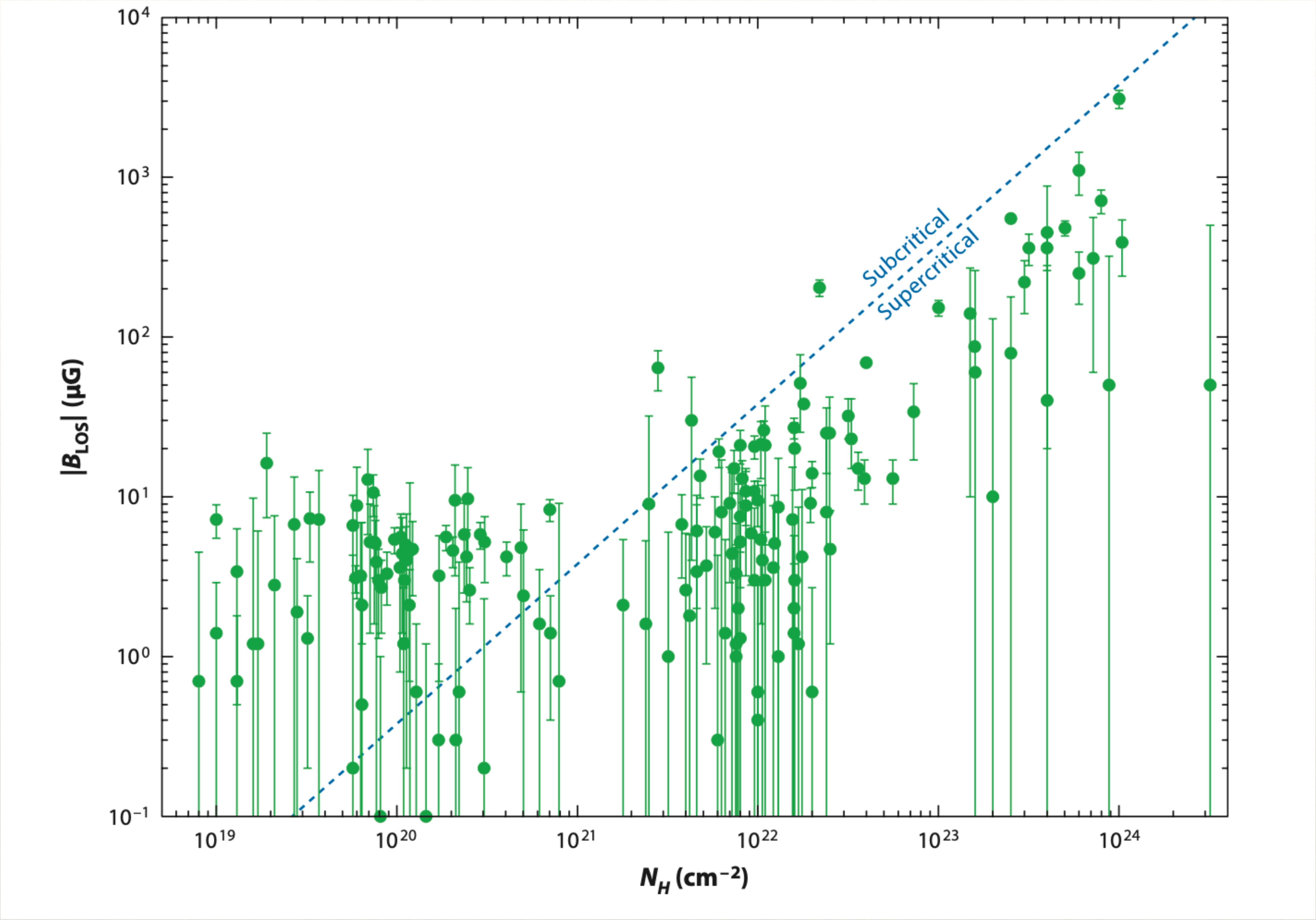
Moon et al. 2023



=> "Magnetic fields play a non-negligible dynamical role"

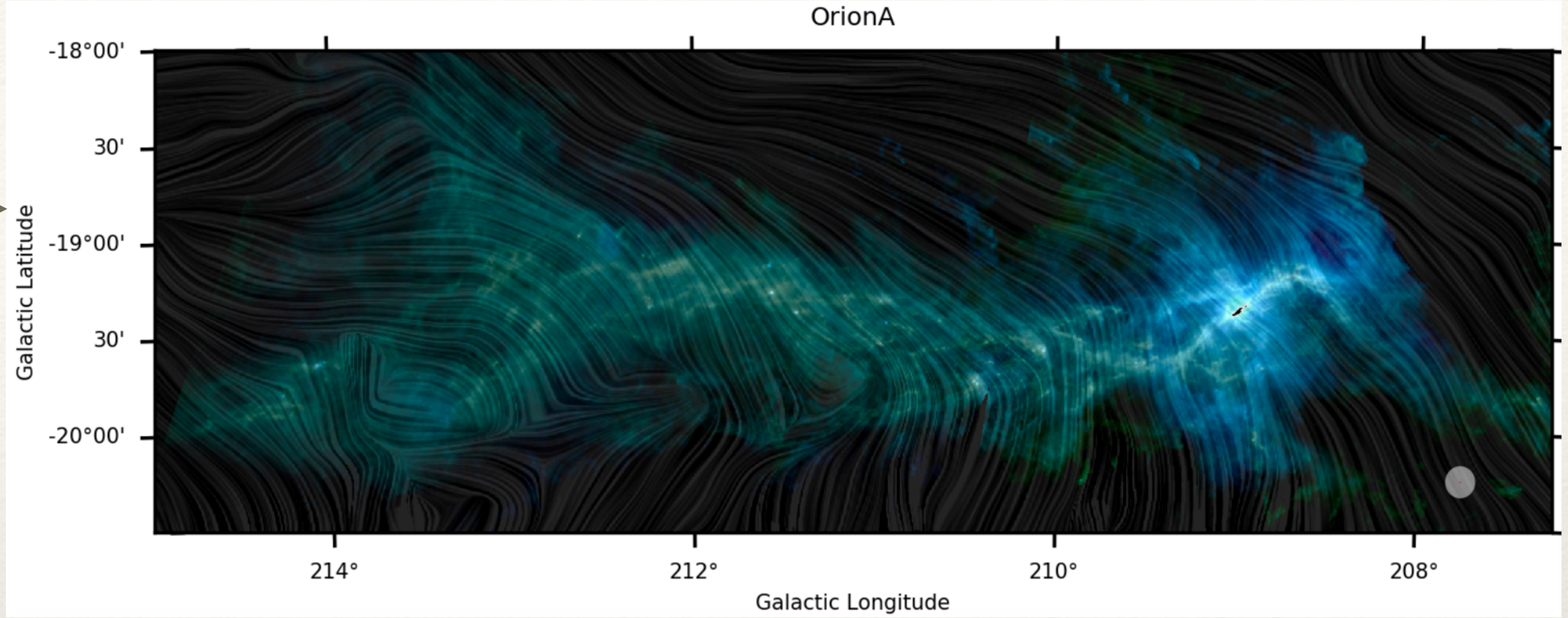
Tress et al. 2024

ISM Magnetic Fields

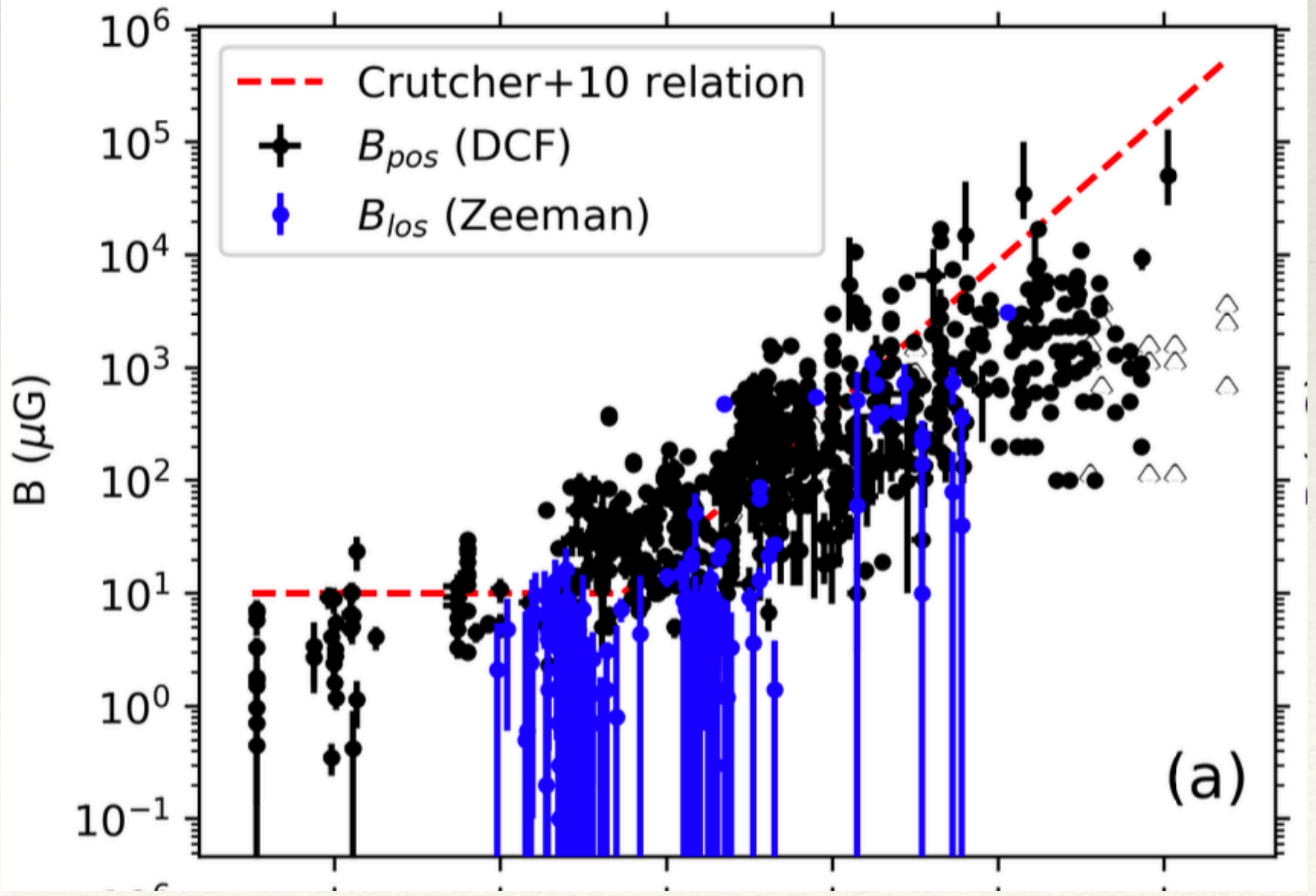


Crutcher et al. 2012

"no definitive evidence for magnetic fields dominating gravity in molecular clouds"



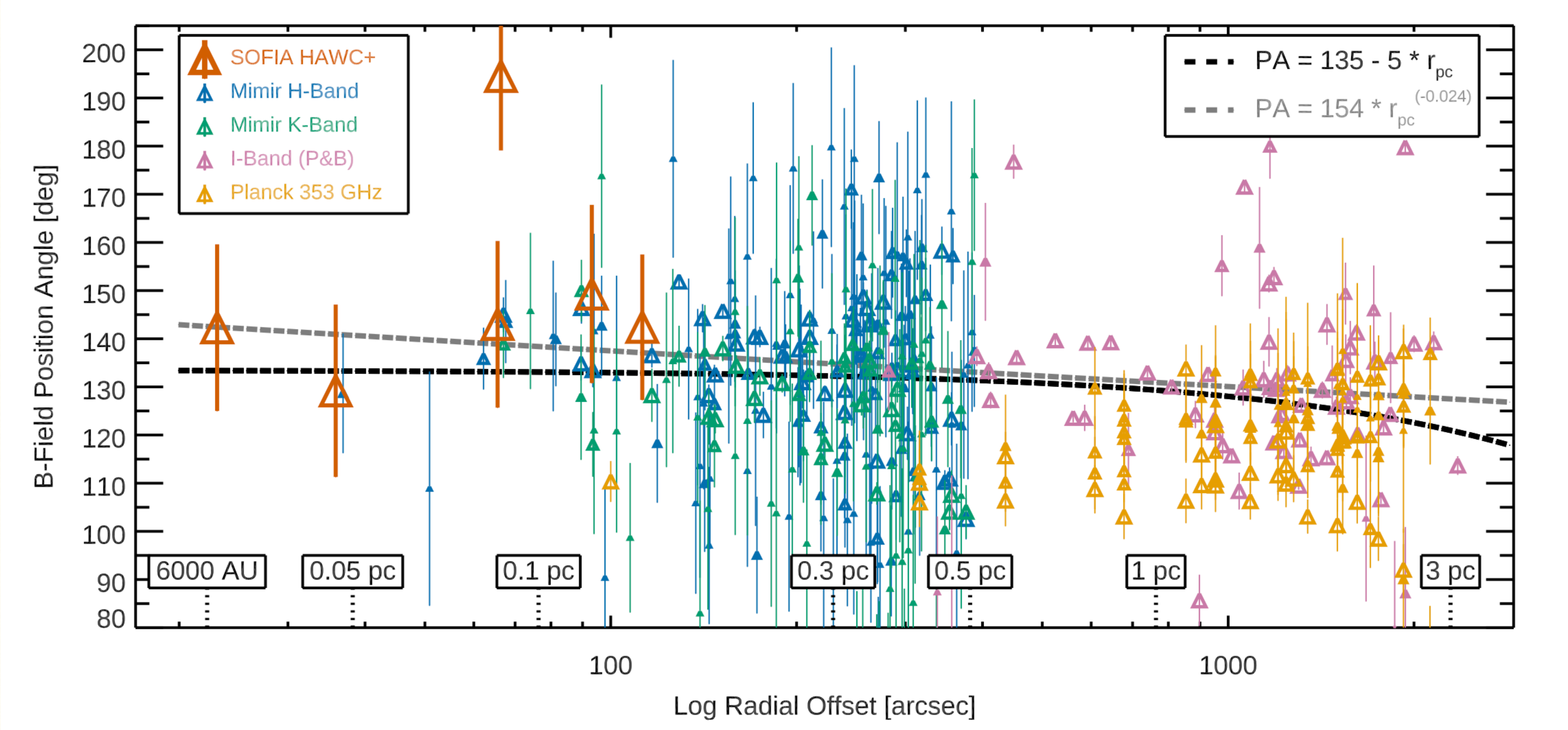
Planck 353 GHz, Soler et al. 2020



Pattle et al. 2023, Liu et al. 2022b

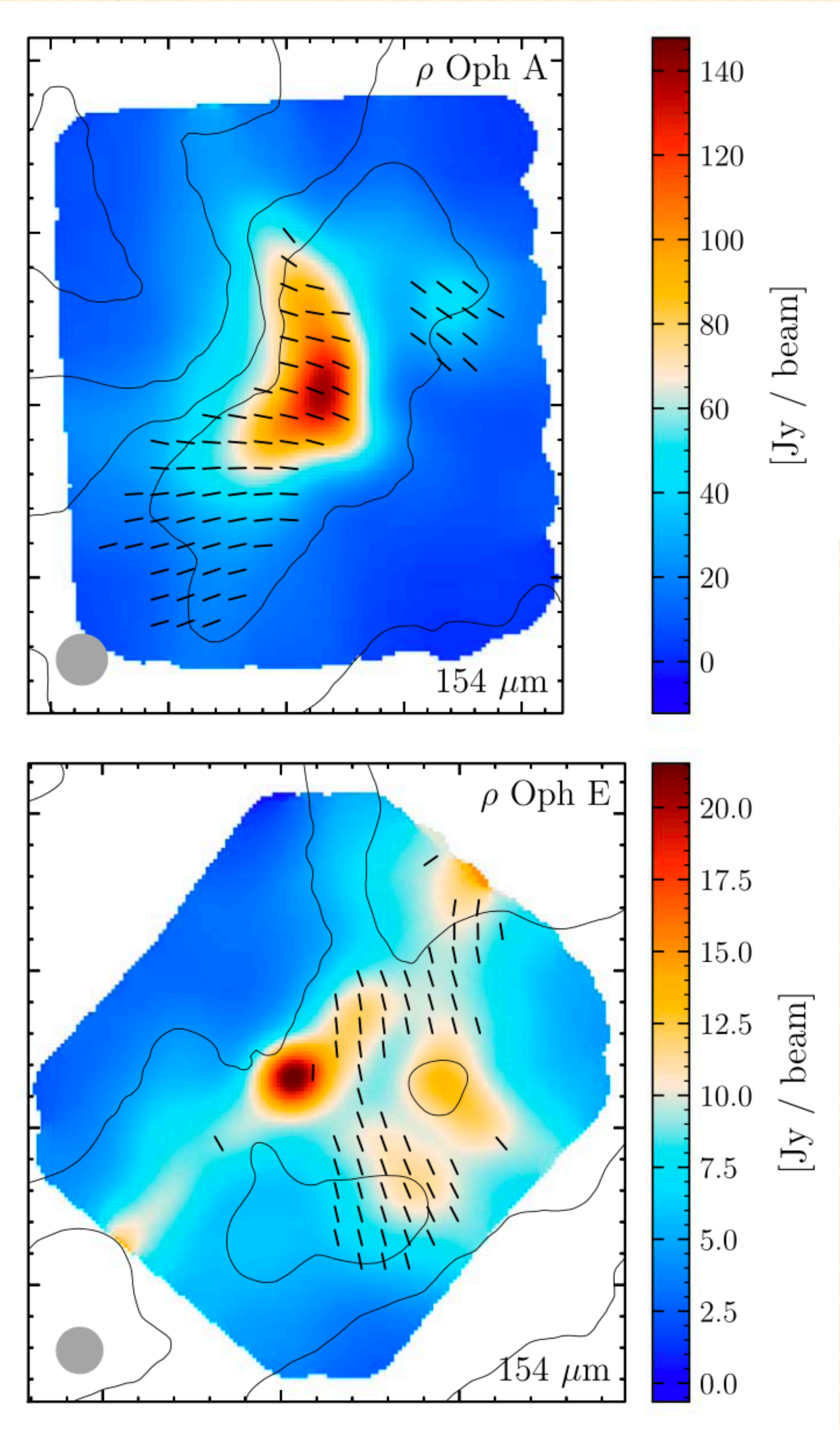
SOFIA/HAWC+ IN CONTEXT

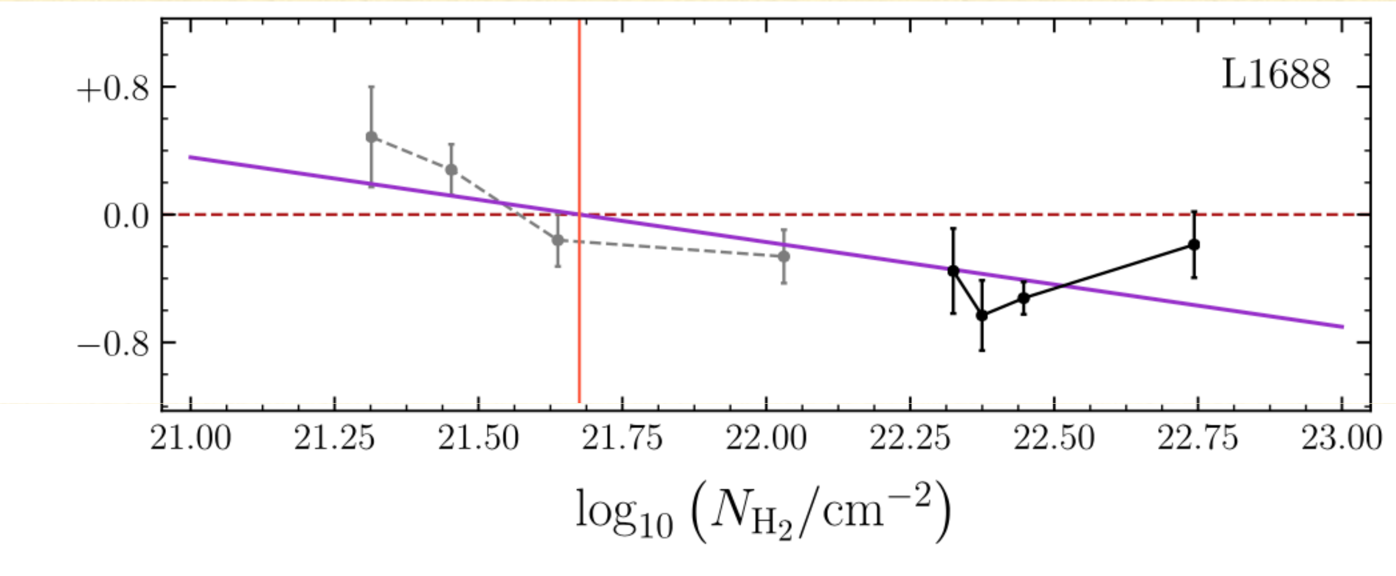
HAWC+ EARLY RESULTS



Clemens et al. 2018, GF-9

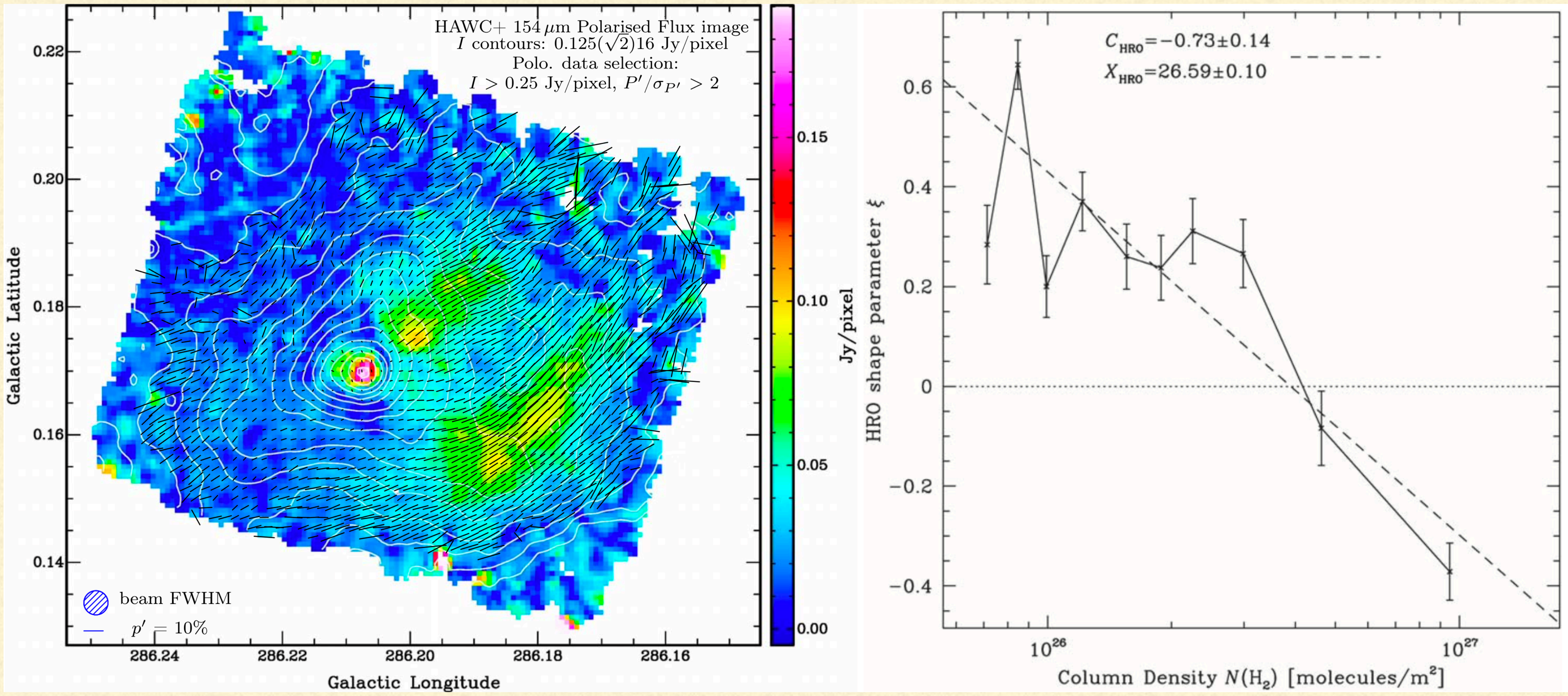
RELATIVE ALIGNMENT IN CLOUDS





Lee et al. 2021

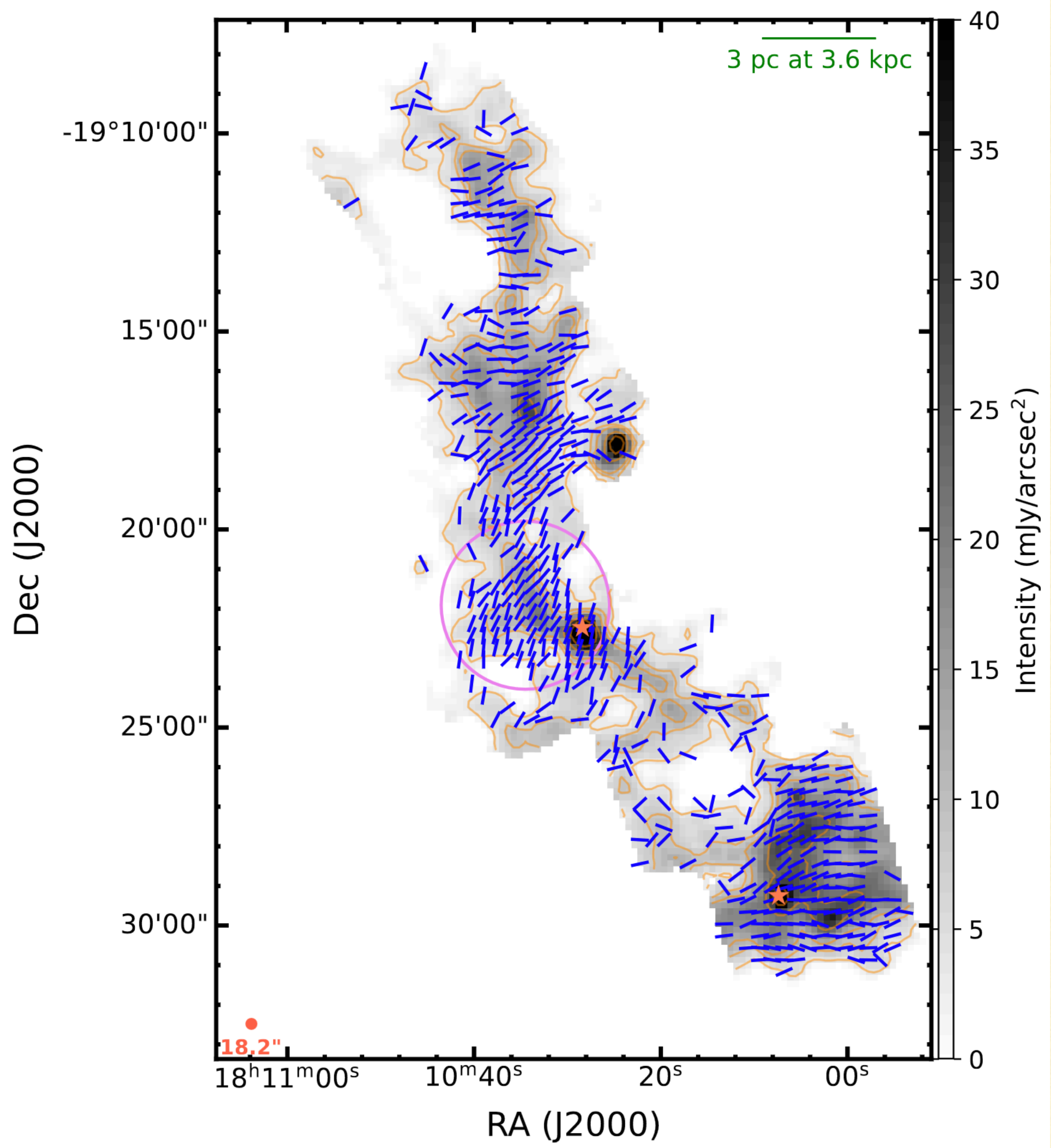
Finer resolution SOFIA data align with Planck results



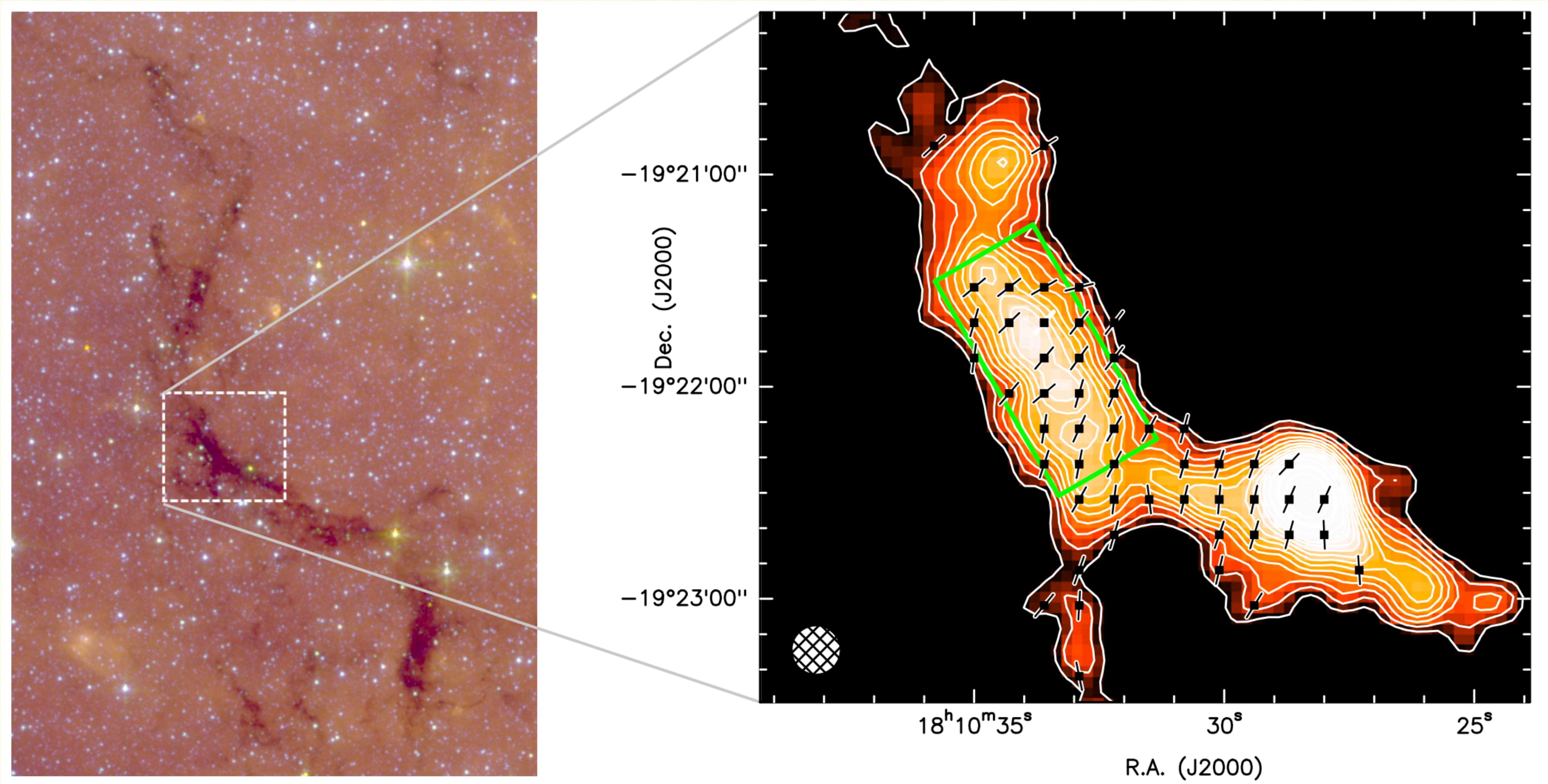
Barnes et al. 2023

Santos et al. 2019, Lee et al. 2021

TRANSFORMATIONAL SCIENCE WITH HAWC+

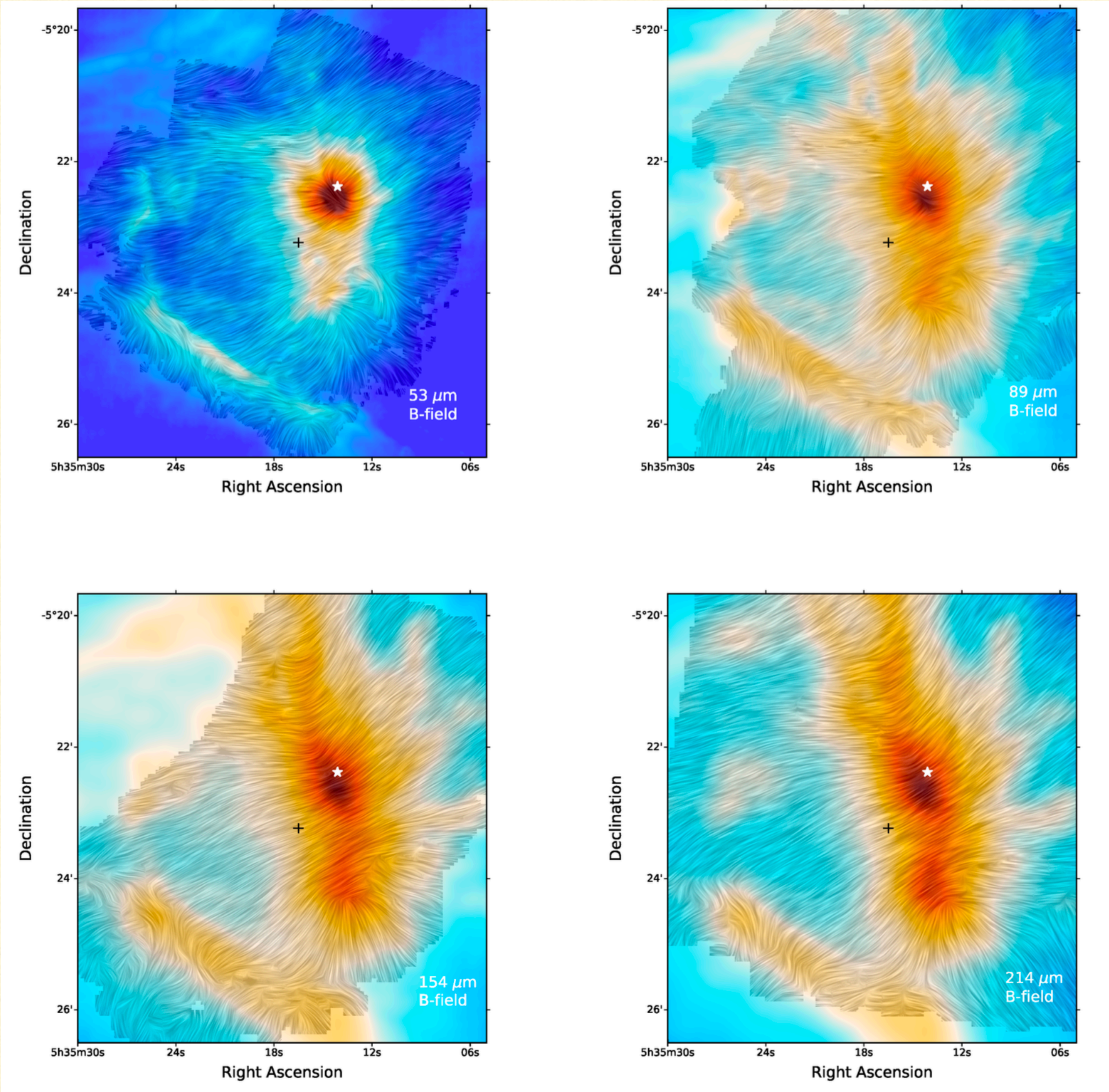


Ngoc et al. 2023



Pillai et al. 2015

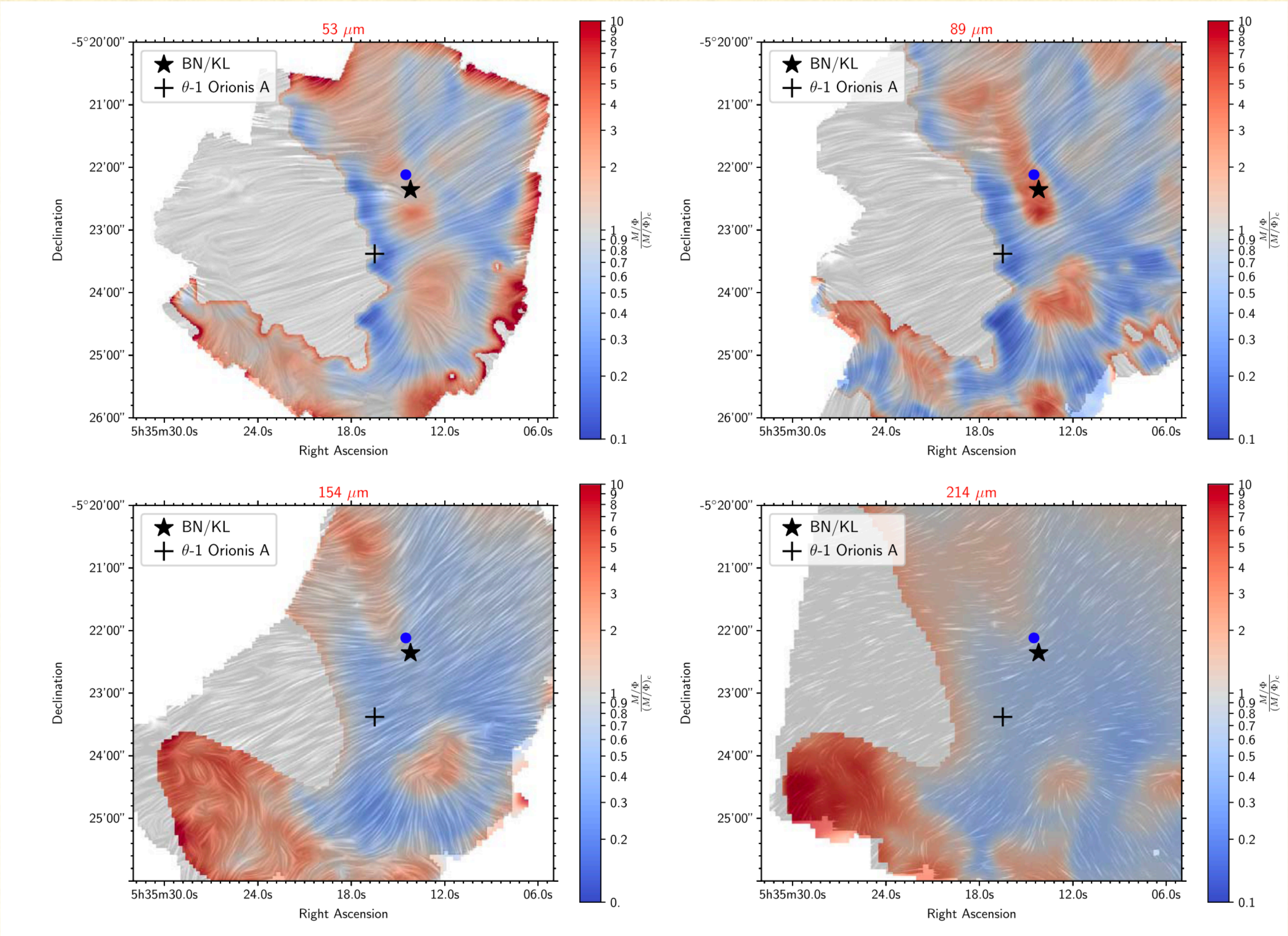
MULTI-WAVELENGTH POLARIMETRY



- Longer Wavelengths (154 & 214 μm) reveals gravity dominated hour-glass structures
- Short Wavelengths (53 & 89 μm) reveal feedback effects

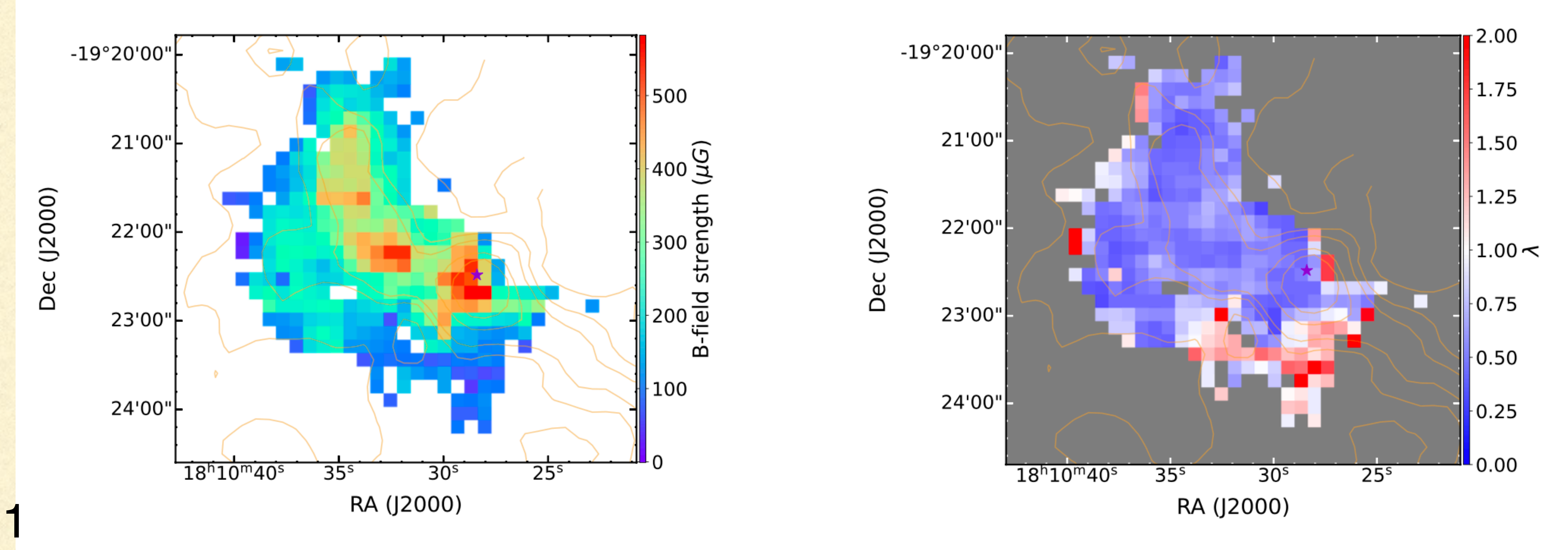
Chuss et al. 2019

MASS-TO-MAGNETIC FLUX RATIO DISTRIBUTION



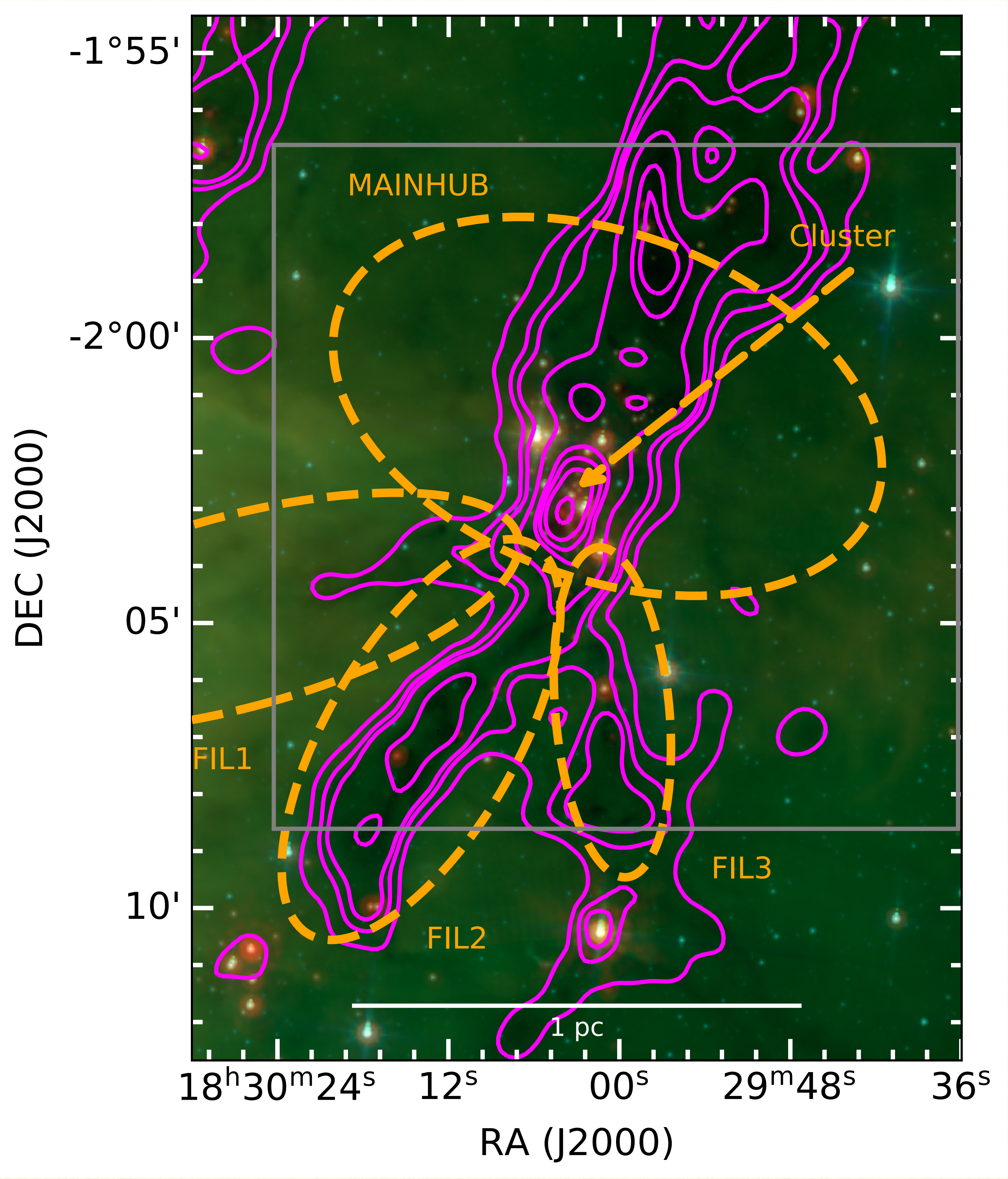
Guerra et al. 2021 in OMC1

Can distinguish sub-critical from super-critical regions within a cloud

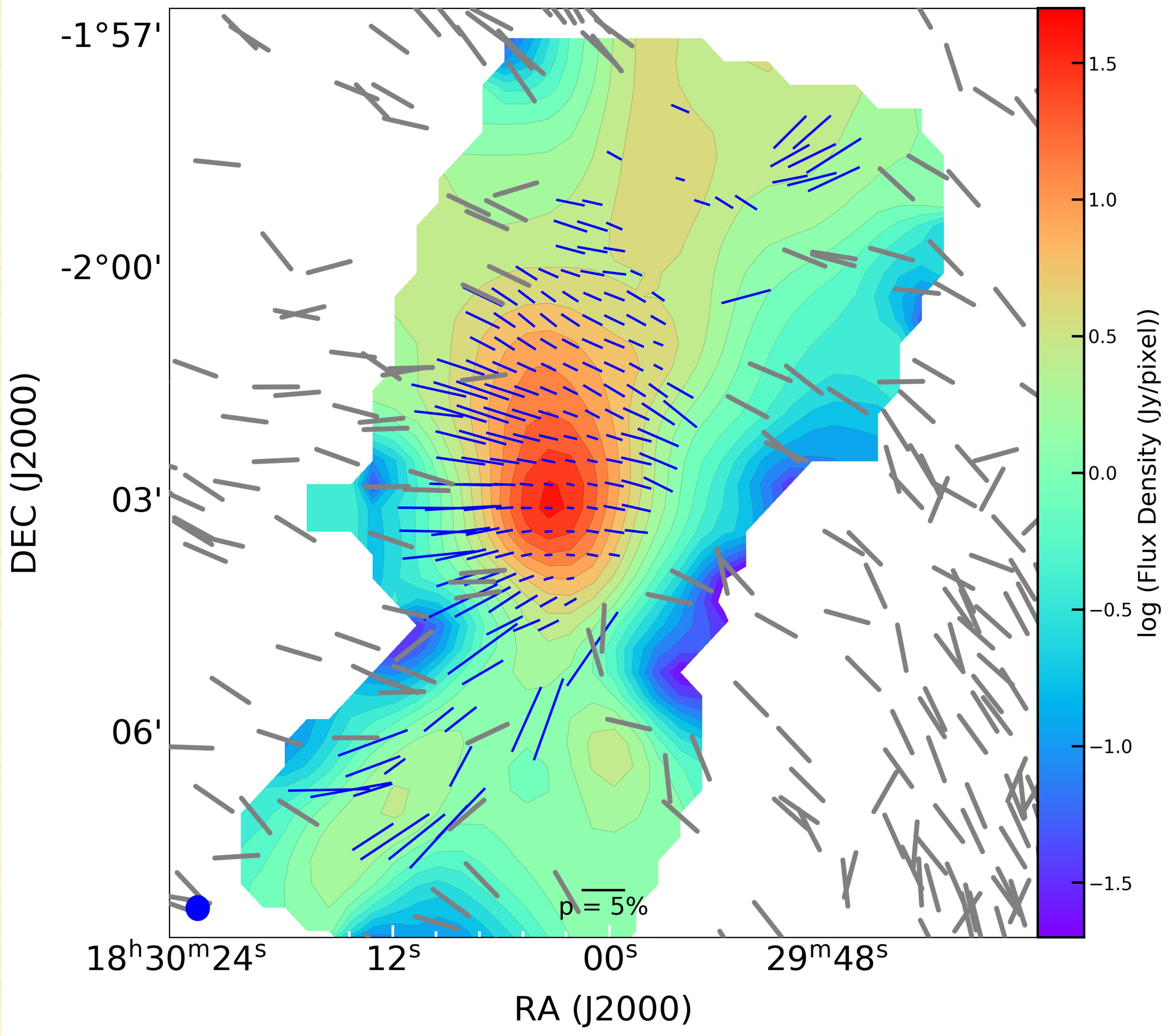


Ngoc et al. 2023 in IRDC G11

B-FIELD IN A CLUSTER FORMING FILAMENT



column density distribution reveals 3 filaments merge onto one hub



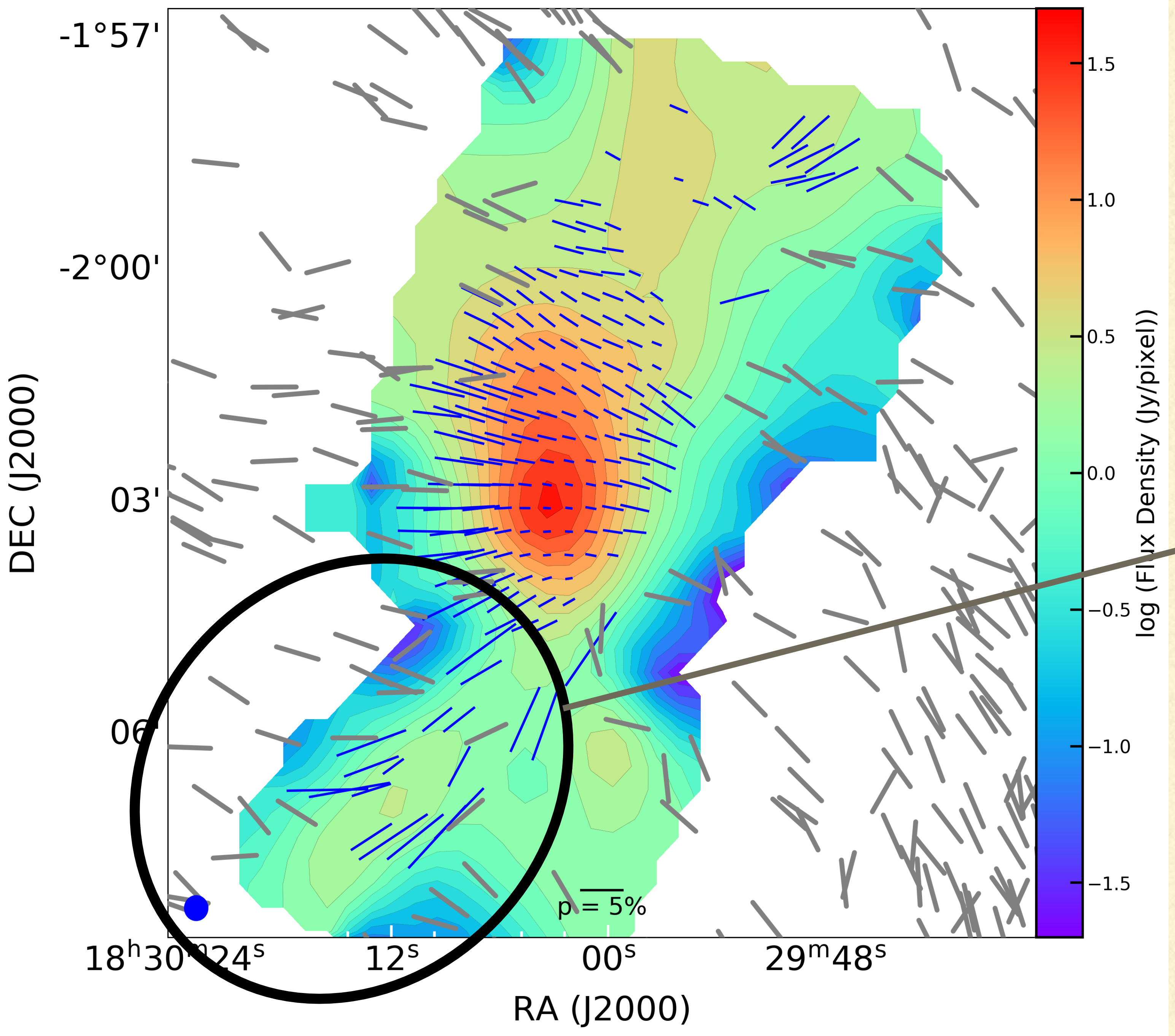
Pillai et al. 2020

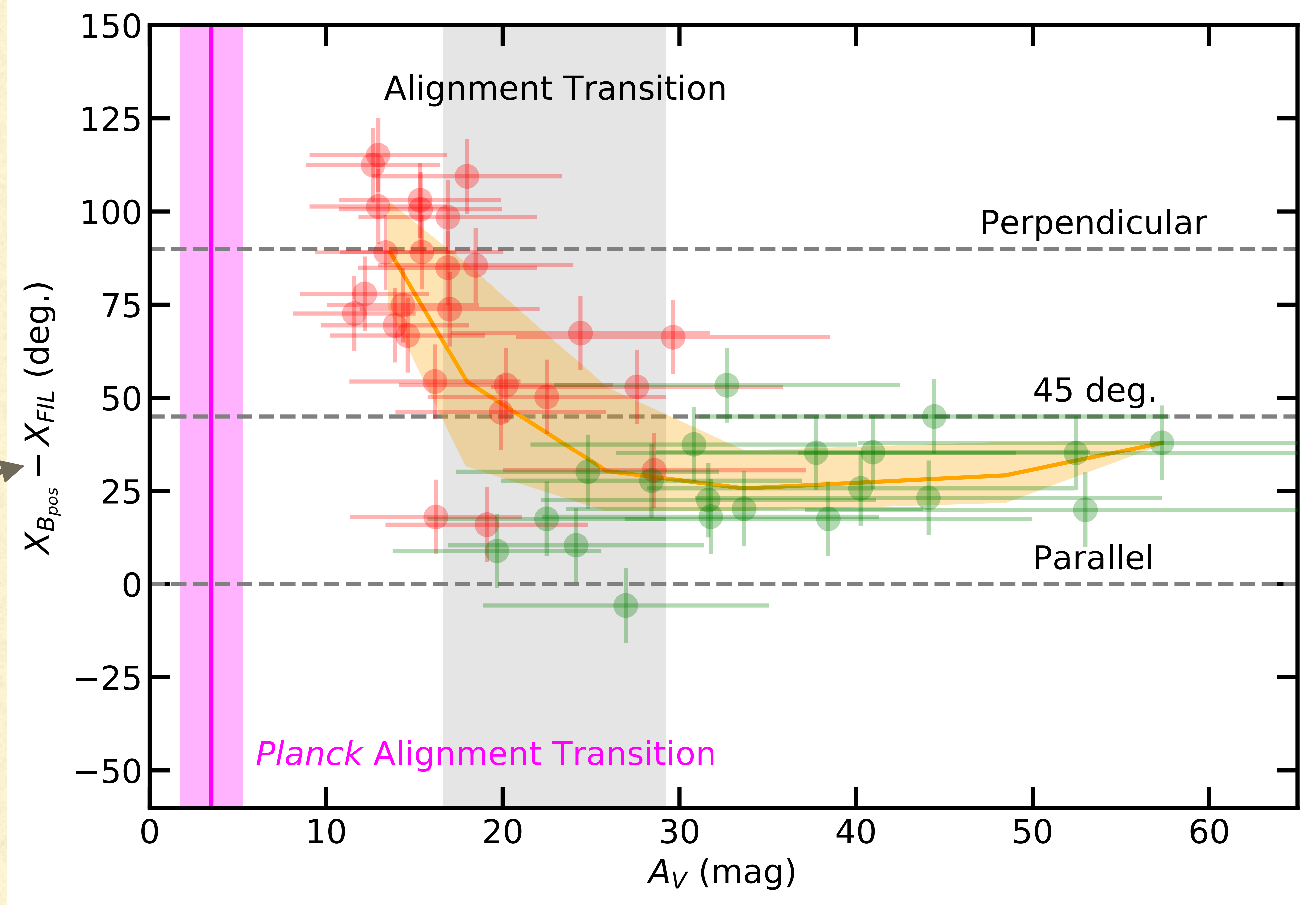
NIR–based starlight polarimetry on large scales (gray vectors, Sugitani et al. 2011)

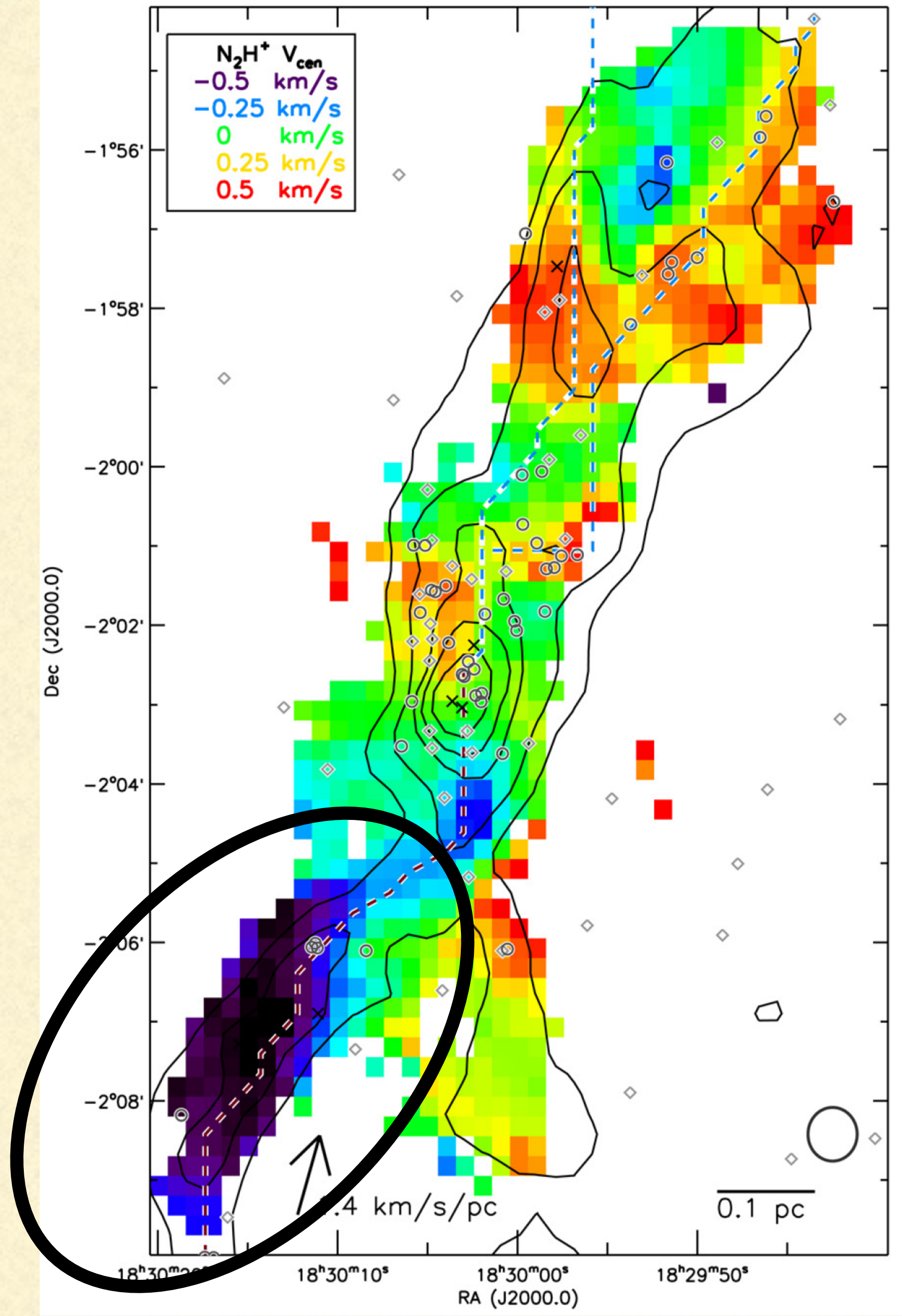
+

SOFIA 217 μm dust continuum polarimetry on smaller scales (blue vectors)

B-FIELD MORPHOLOGY TRANSITIONS







Kirk et al. 2013

background field perpendicular to this filament, while field in filament is parallel to filament

=> field dragged along by gravitational flow at high density   Pillai et al. 2020

DUST POLARIZATION PHYSICS - POLARIS

Spitzer IRAC 3.6/4.5/5.8 μm
NASA/JPL-Caltech

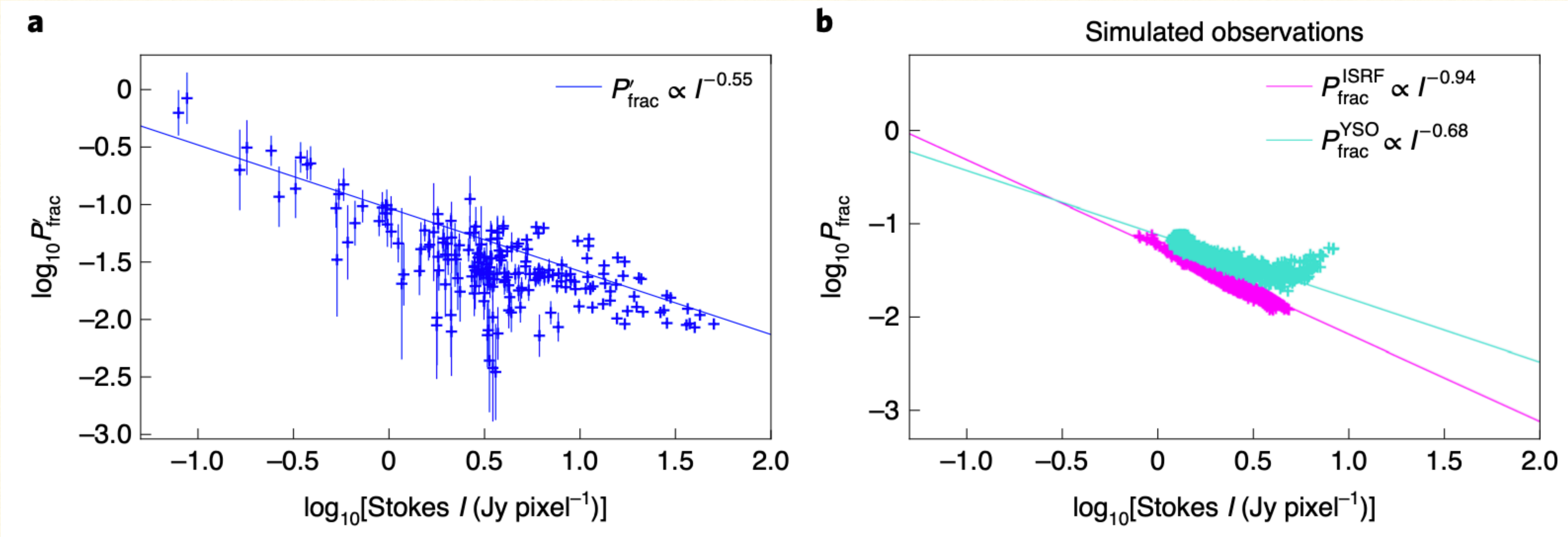
Well characterized Cluster Luminosity Distribution

+

Well characterized H_2 column density structure (Herschel based, Herschel Gould Belt Survey)

+

POLARIS



Observed Fractional Polarization Distribution

Simulated Polarized Dust Emission

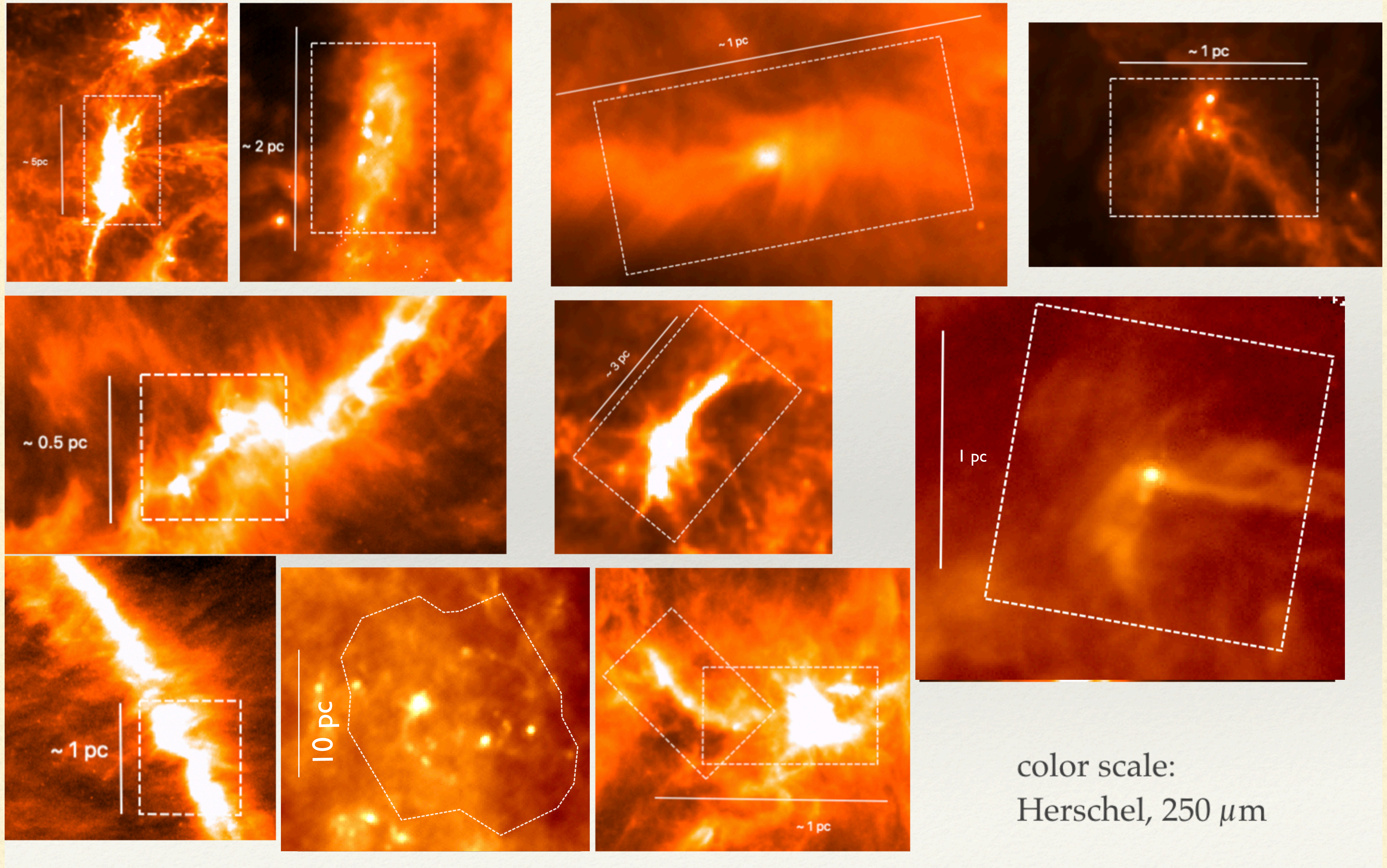
Modeling HAWC+ Observations reveal that internal radiation from protoclusters can keep dust grains aligned deep into cores
(Pillai,Clemens,**Reissl** et al. 2020)

HAWC+ MW LEGACY SURVEYS

SIMPLIFI:
HAWC+ SURVEY OF NEARBY CLOUDS

PI: Thushara G.S. Pillai

Study of Interstellar Magnetic Polarization: A Legacy Investigation of Filaments (SIMPLIFI)



Resolves (≤ 0.1 pc) observations of representative filamentary clouds and cores that captures both the larger cloud scale as well as clump scale magnetic field structure

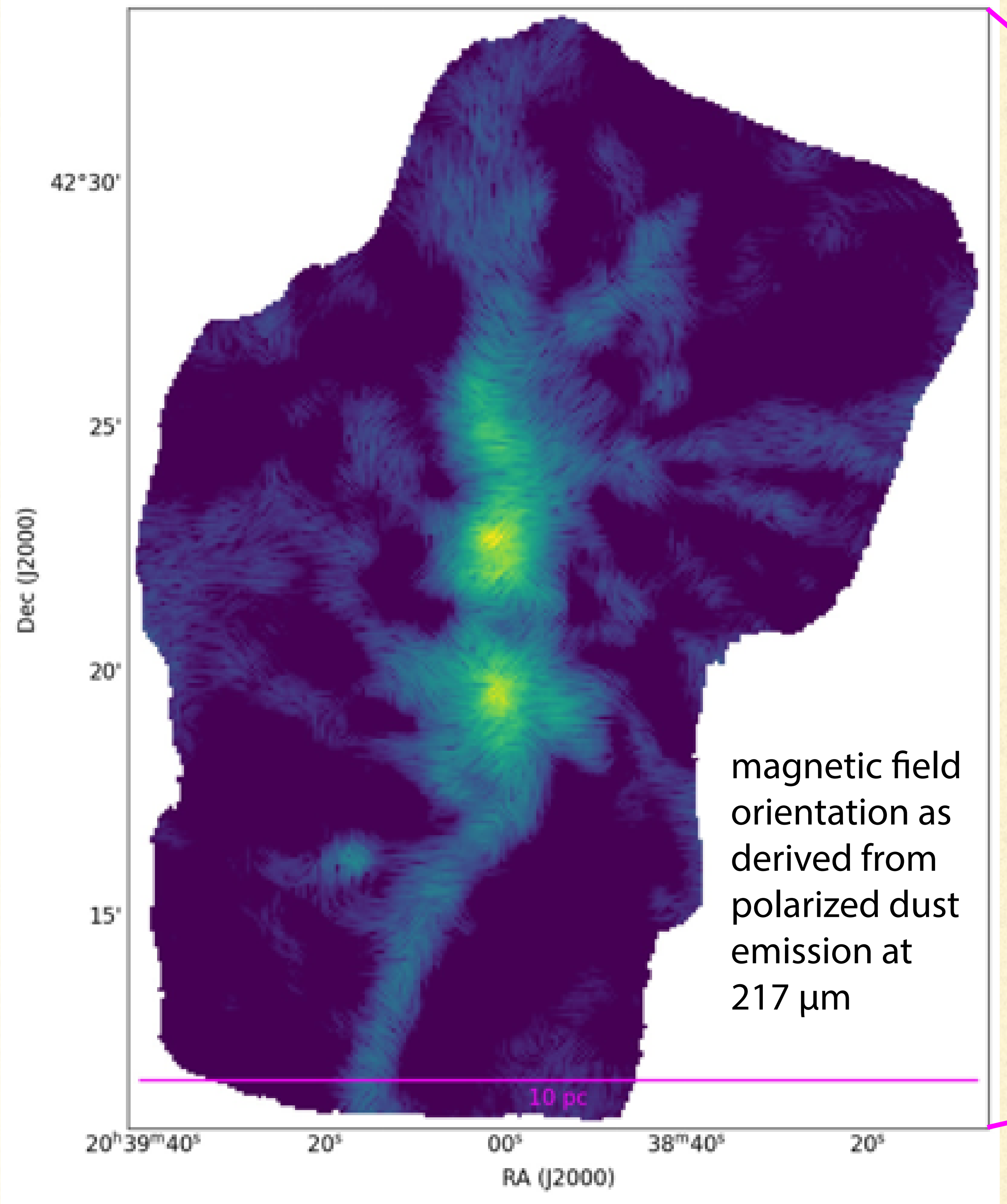
Nearby filamentary molecular clouds:

=> clouds with m/l from ~10 to $>10^3\ M_\odot/pc$

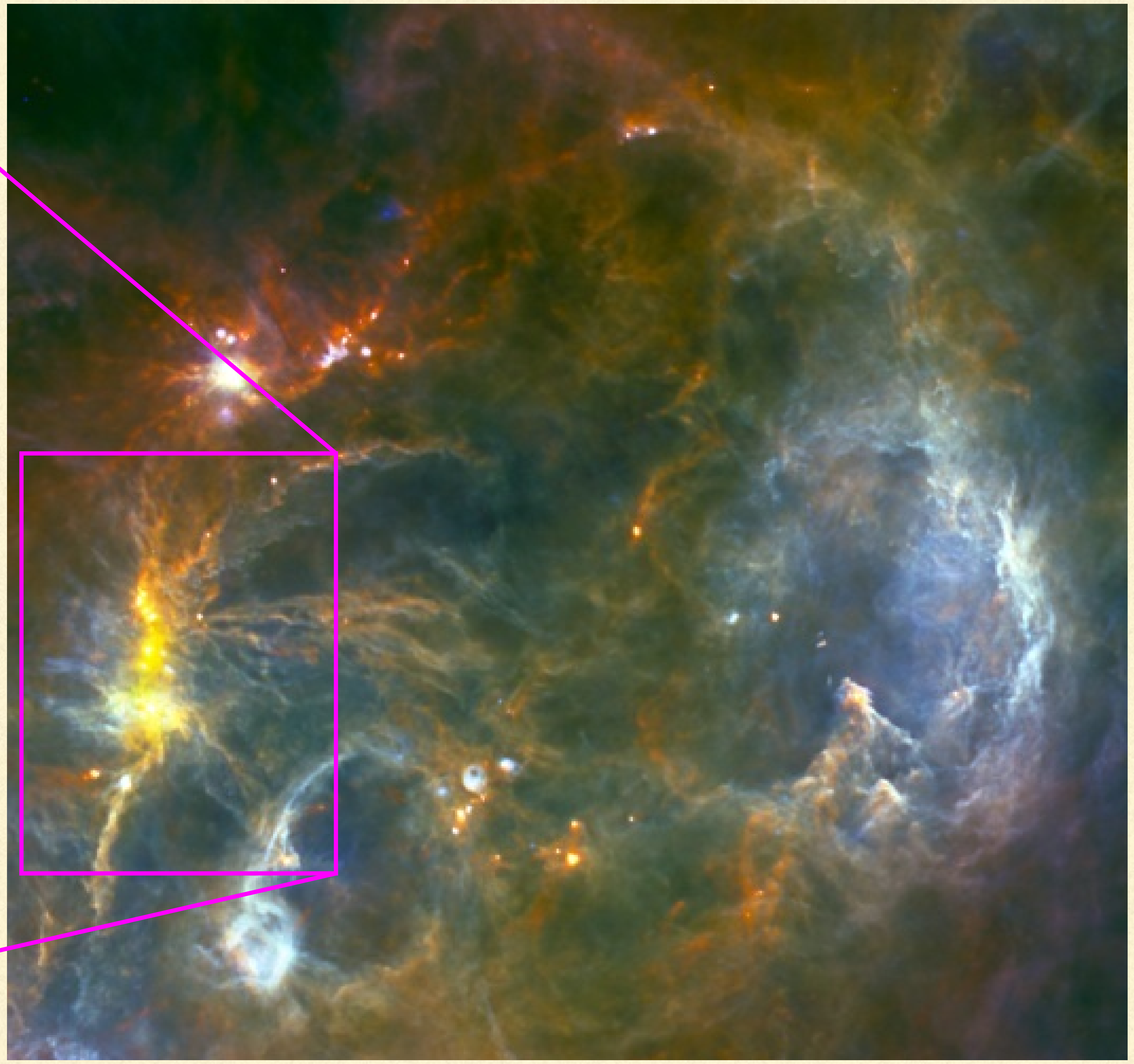
==> Quiescent and Star-Forming filaments

DR2 | SIMPLIFI

SIMPLIFI Project on SOFIA



Cygnus X observed by HOBYS Project on Herschel

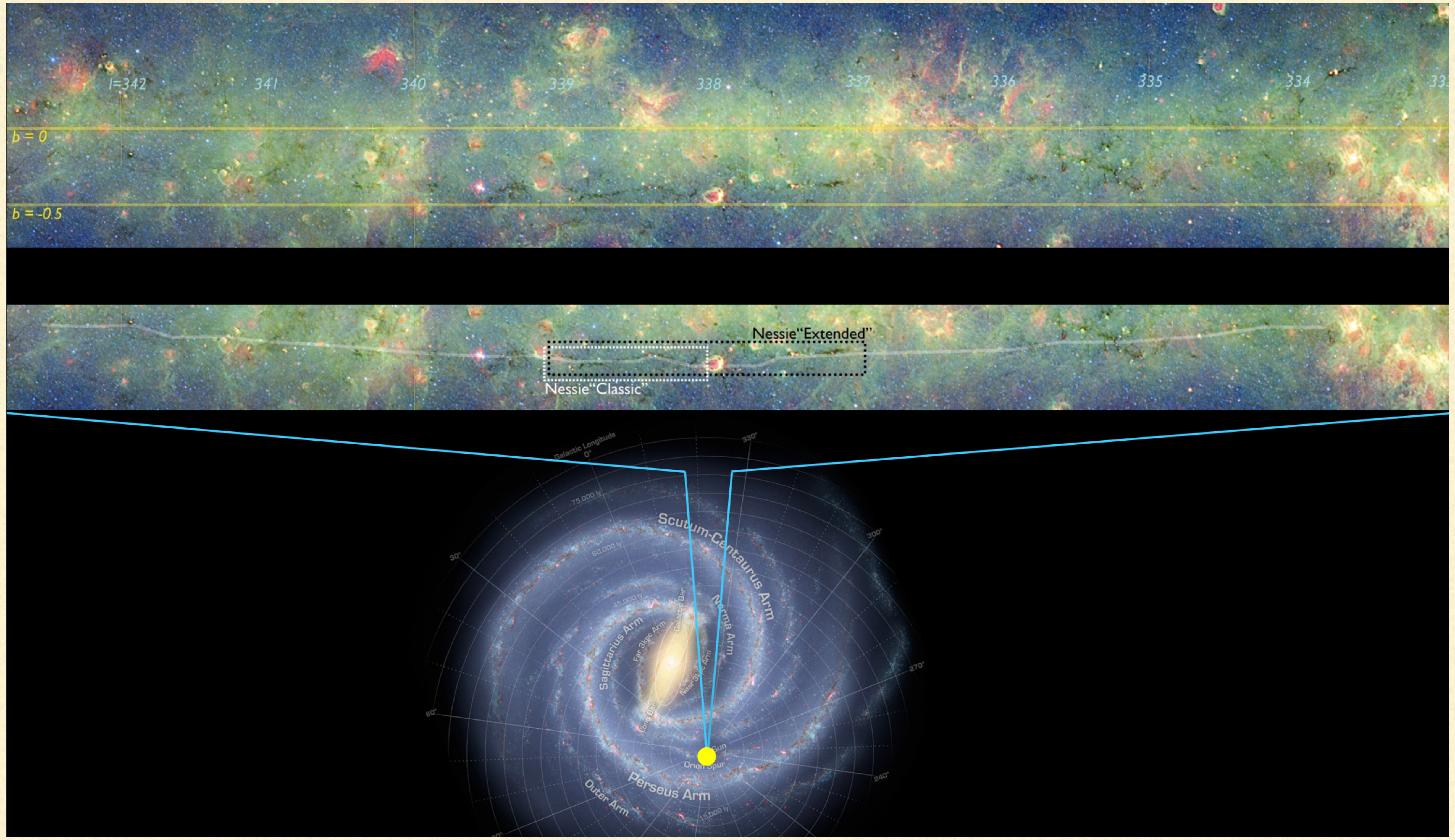


Heyer et al., Pillai et al., Kumar et al. in prep.

FIELDMAPS:
HAWC+ SURVEY OF GALACTIC BONES

PI: Ian Stephens

GALACTIC BONES

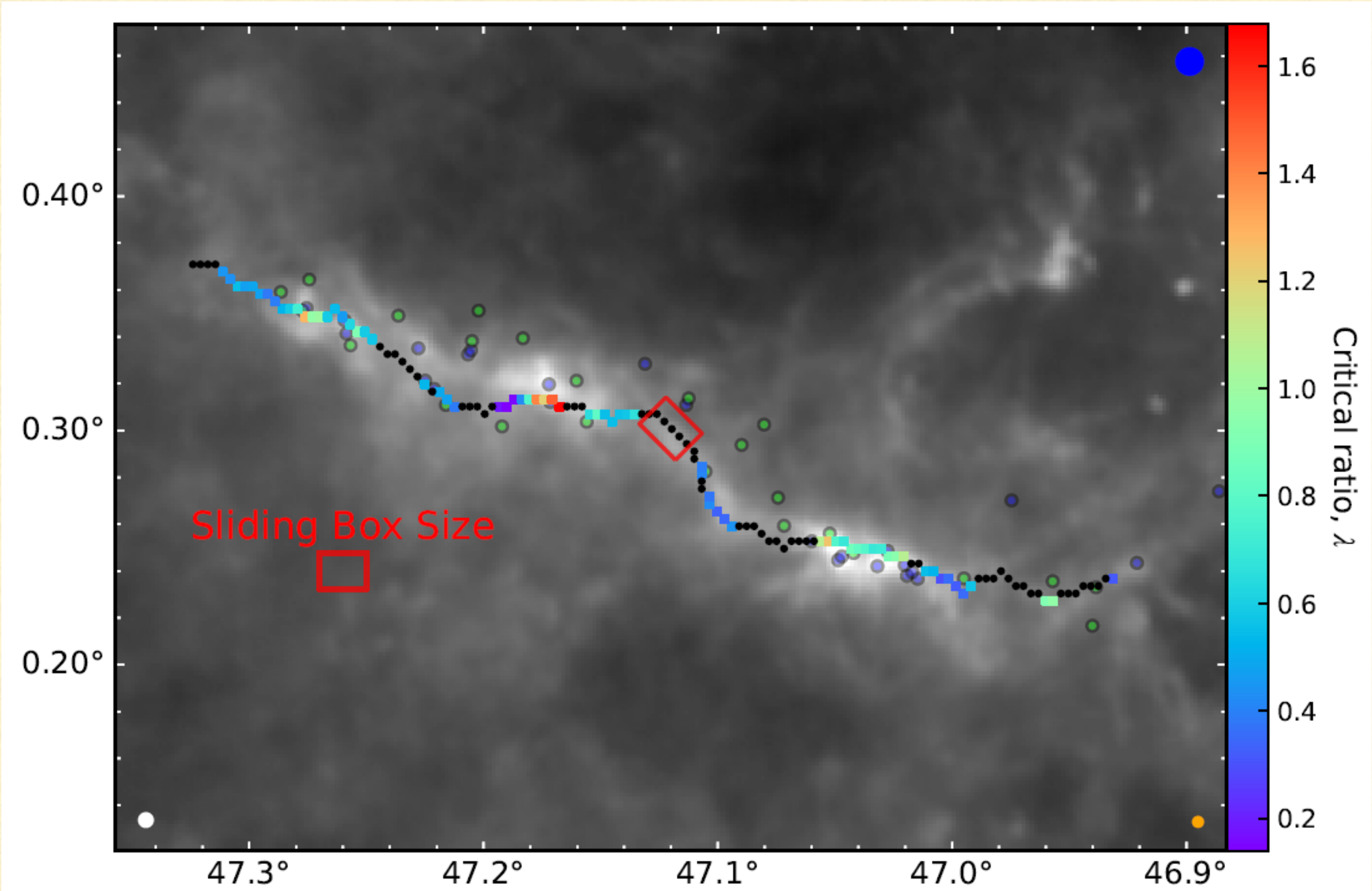


Goodman et al. 2014

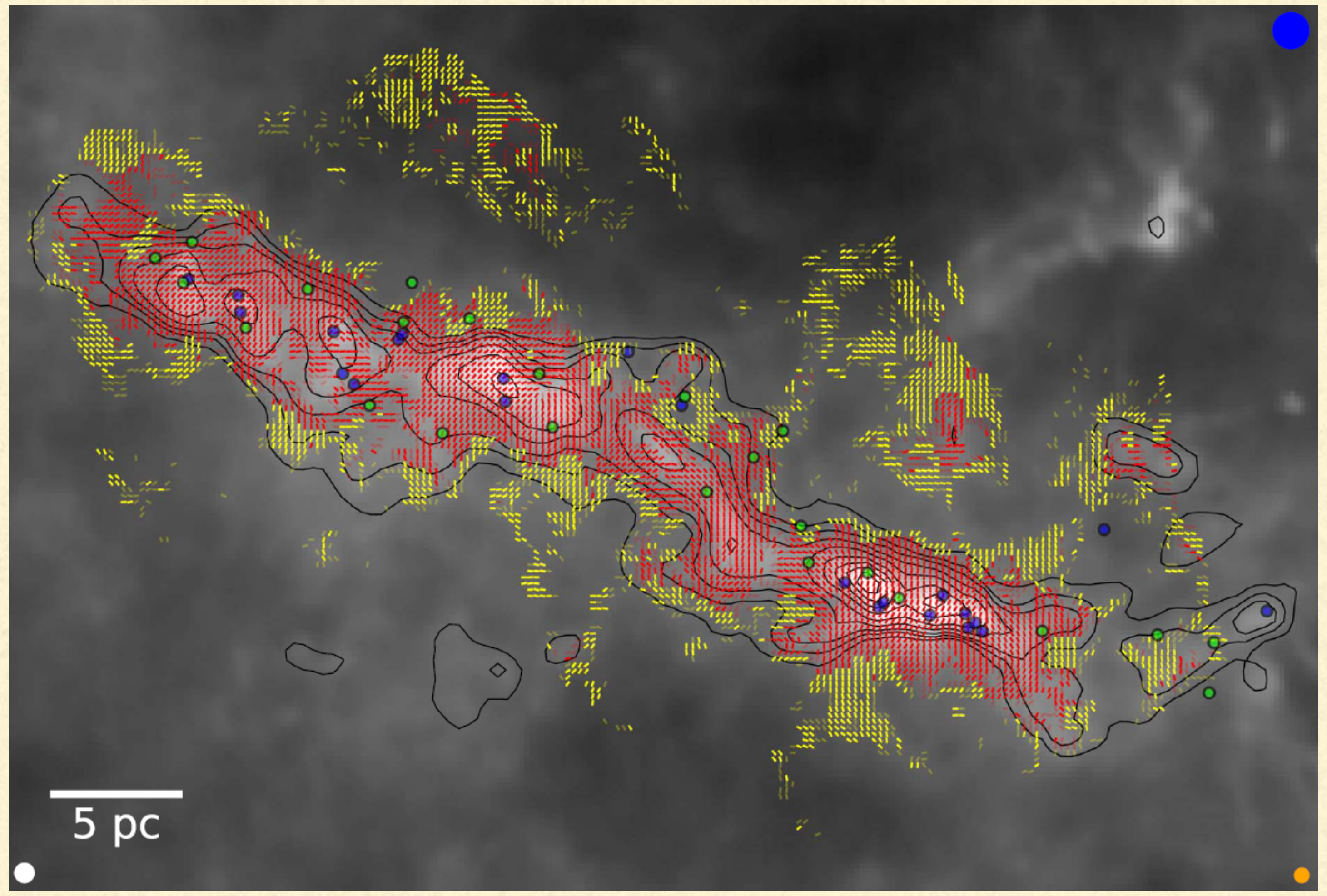
"Bones" – Goodman+2014, Zucker+ 2015

- Largely contiguous in the mid-IR
- Parallel to Galactic plane within 30 degrees
- Within 20 pc of the physical mid-plane
- Within 10 km/s of spiral arm velocity
- Coherent velocity structure
- Large aspect ratio (greater than 50:1)

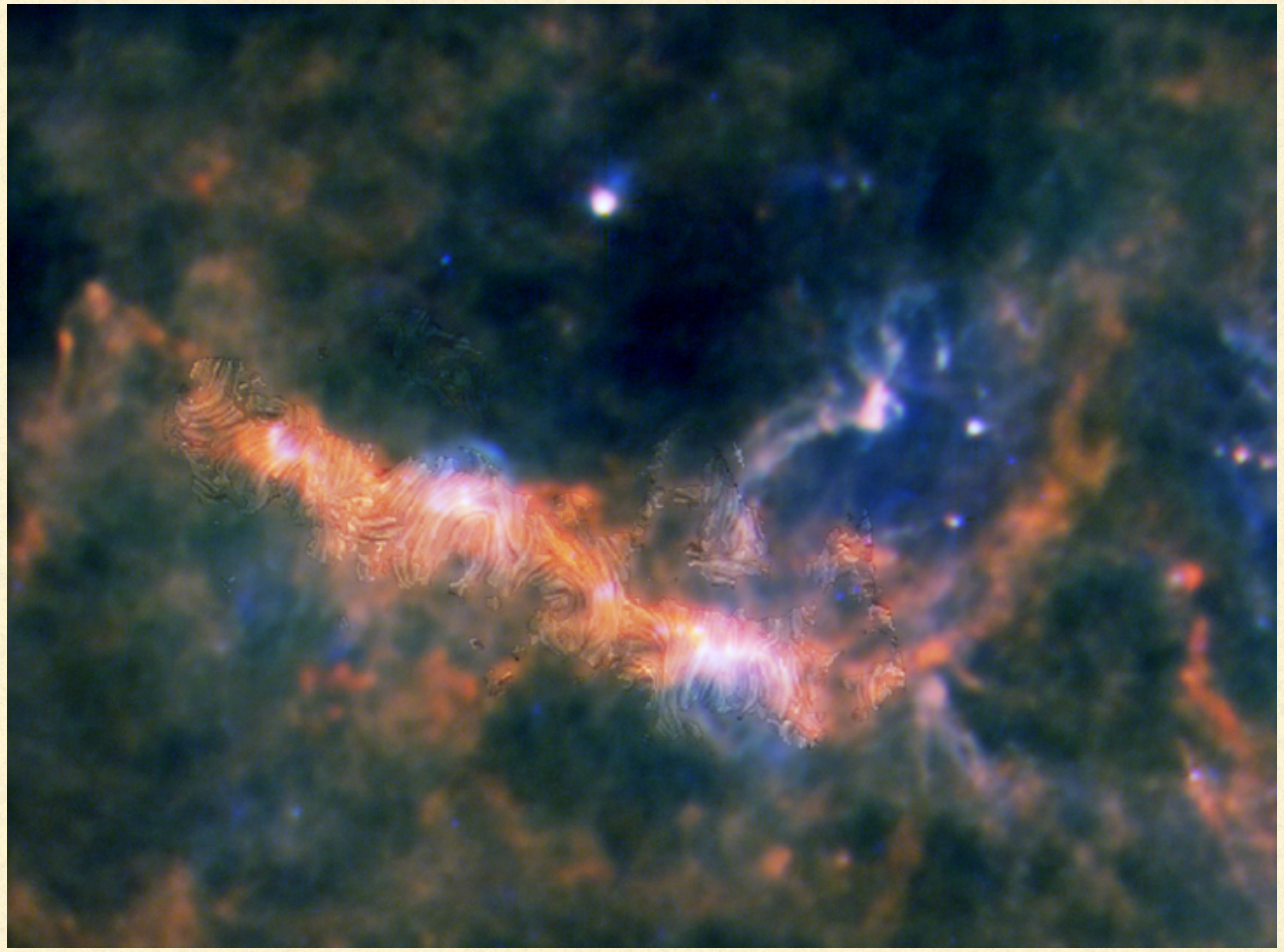
G47 RESULTS



Magnetic criticality according to DCF measurements along the spine of filament G47 using NH_3 and ^{13}CO J=2-1

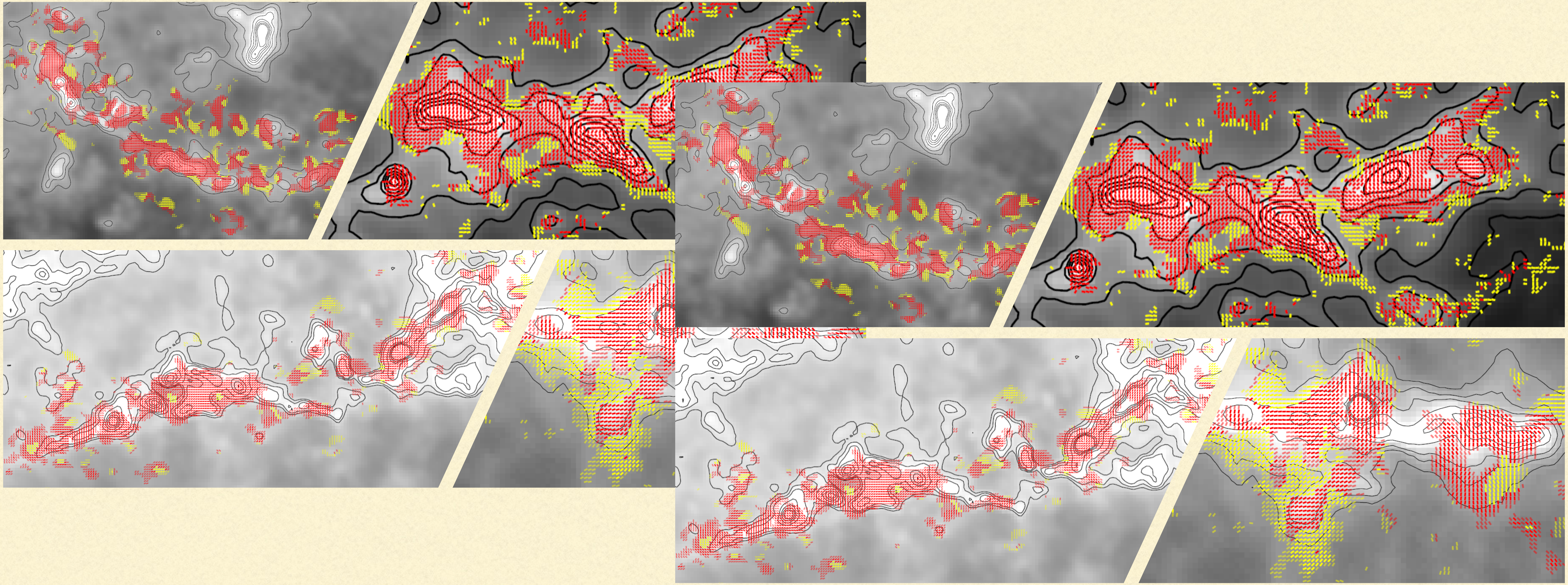


Magnetic field vectors across the entire G47 “bone” with identified young stellar objects (circles)



Stephens I. et al. 2022, ApJL, 926, L6)

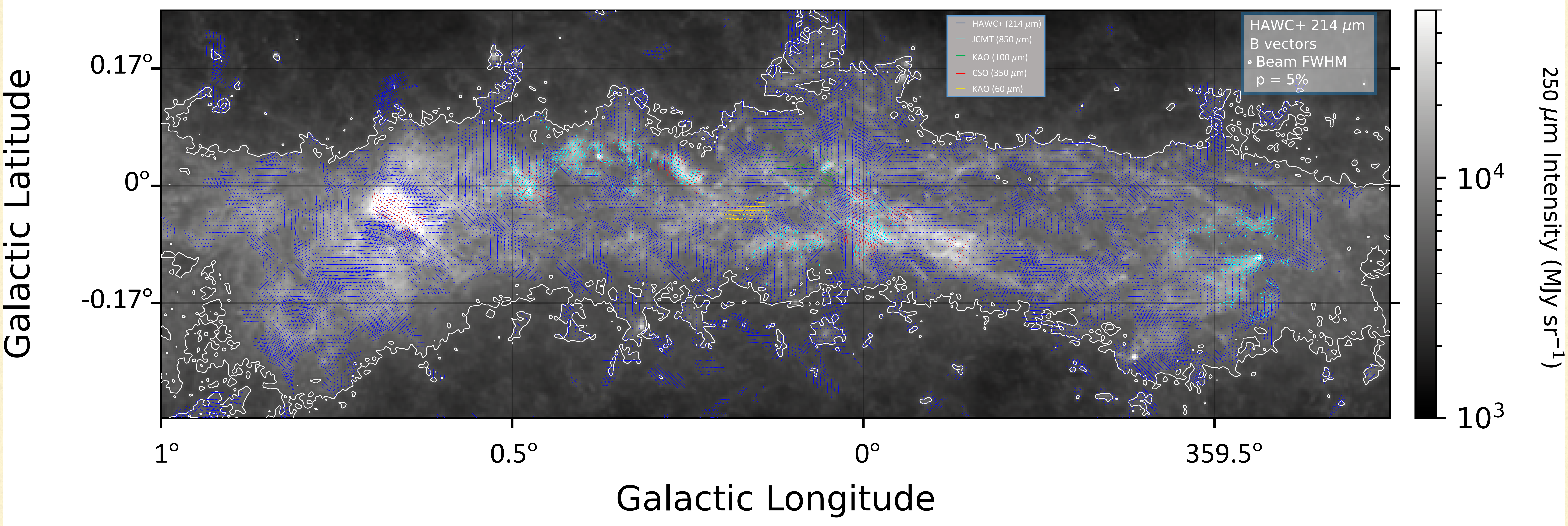
FIELDMAPS GALLERY



FIREPLACE:
HAWC+ SURVEY OF THE CMZ

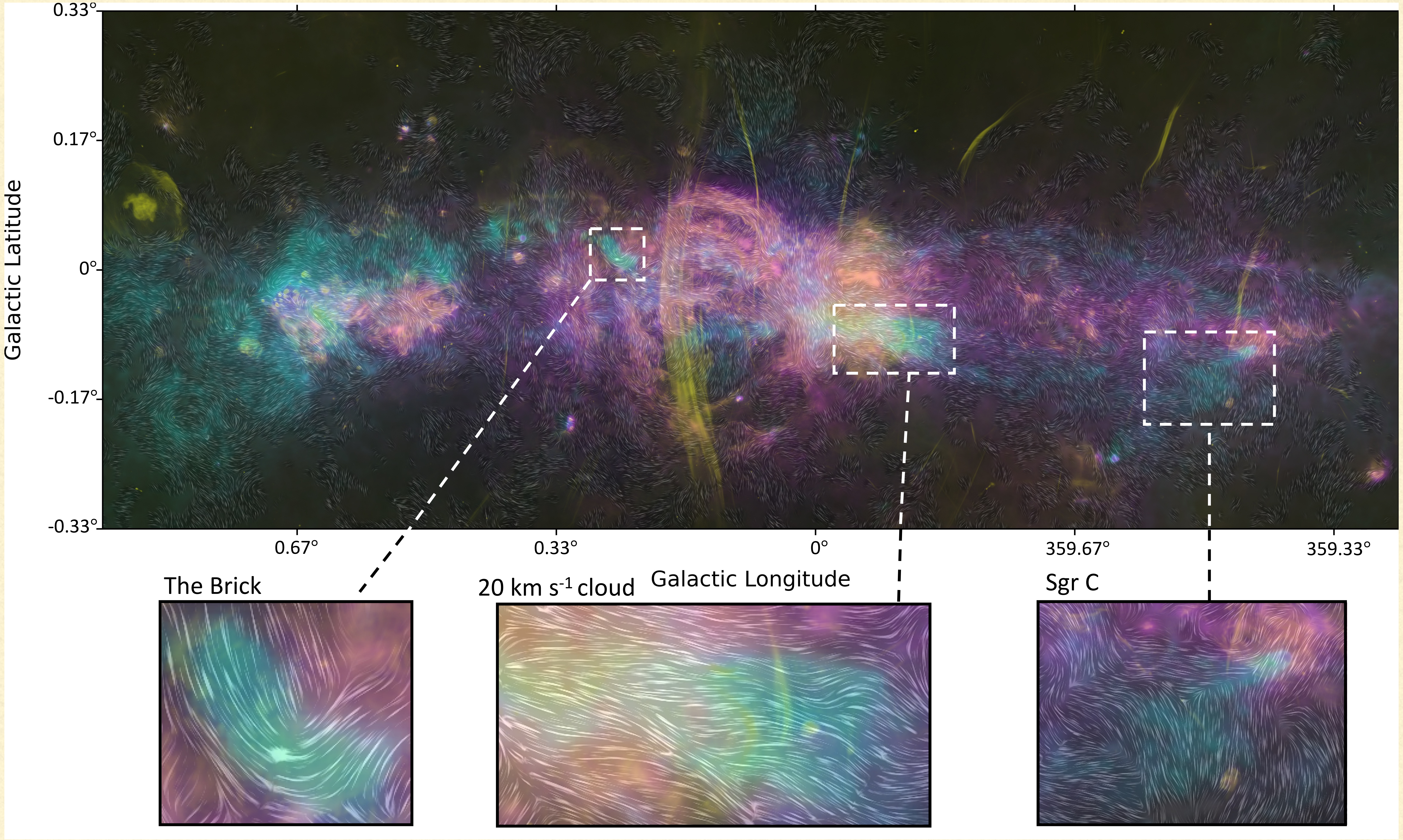
PI: Dave Chuss

FIREPLACE



Pare et al. 2024

FIREPLACE



Pare et al. 2024

FINAL THOUGHTS

SUMMARY

High resolution and sensitivity SOFIA HACW+ observations

- Greatly transforms dust polarimetry to map magnetic fields in detail.
- Tracks magnetic field transitions, from parallel to perpendicular, indicating evolving substructures.
- Identifies gravity-dominated areas where magnetic fields align with gas movements in critical regions.
- Links core magnetic field characteristics to star formation processes, underscoring magnetic influence.
- Explores magnetic fields over large scales in spiral arms and extreme environments of our galaxy.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Every new generation of eyes sees a new version of our galaxy, the Milky Way.
The New York Times