Investigating magnetic field properties across NGC 2024 in Orion B

X-ray: NASA/CXC/PSU/K.Getman, E.Feigelson, M.Kuhn & the MYStIX team; Infrared:NASA/JPL-Caltech

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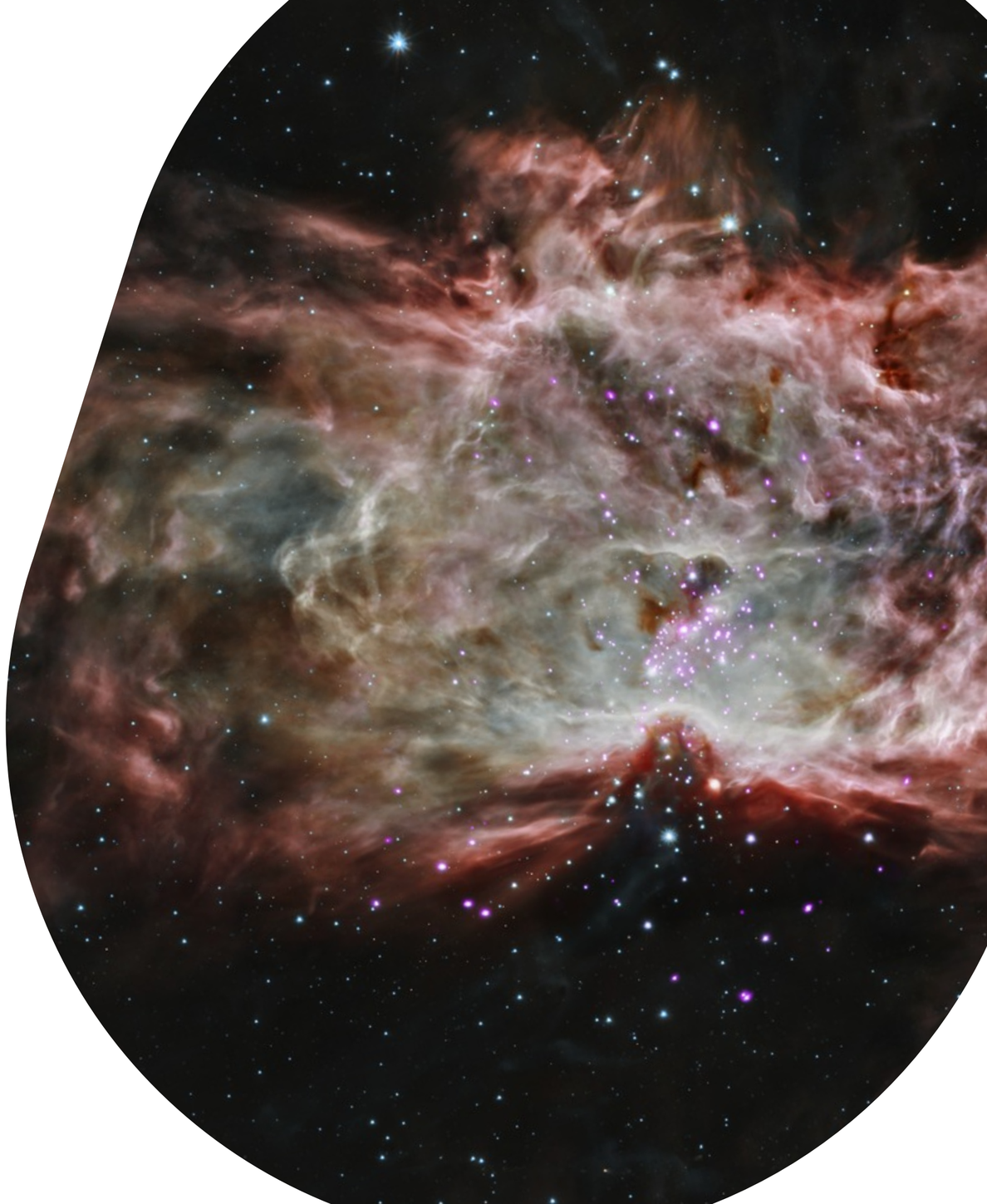
814. WE-Heraeus Seminar:
Heritage of SOFIA – Scientific Highlights and Future Perspectives

OVERVIEW

- INTRODUCTION
- NGC 2024
- POS B FIELD
- OBSERVATIONS
- RESULTS
- SUMMARY

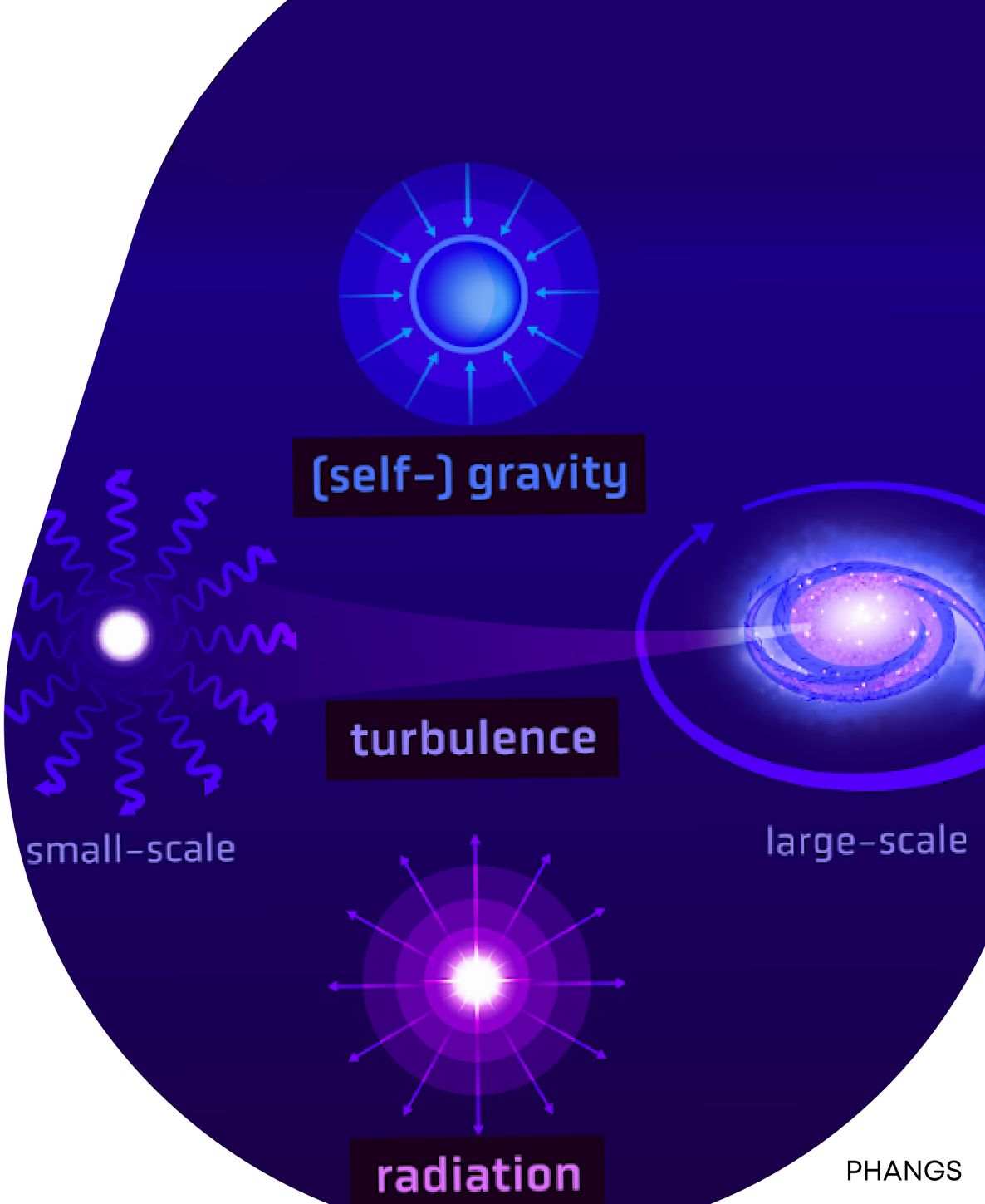


INTRODUCTION

STAR FORMATION IS INEFFICIENT

ISM IS MAGNETIZED

A CONSTANT BATTLE BETWEEN PROCESSES OF TURBULENCE, THE IMPACT OF THE MAGNETIC FIELD, STELLAR FEEDBACK AND SELF-GRAVITY



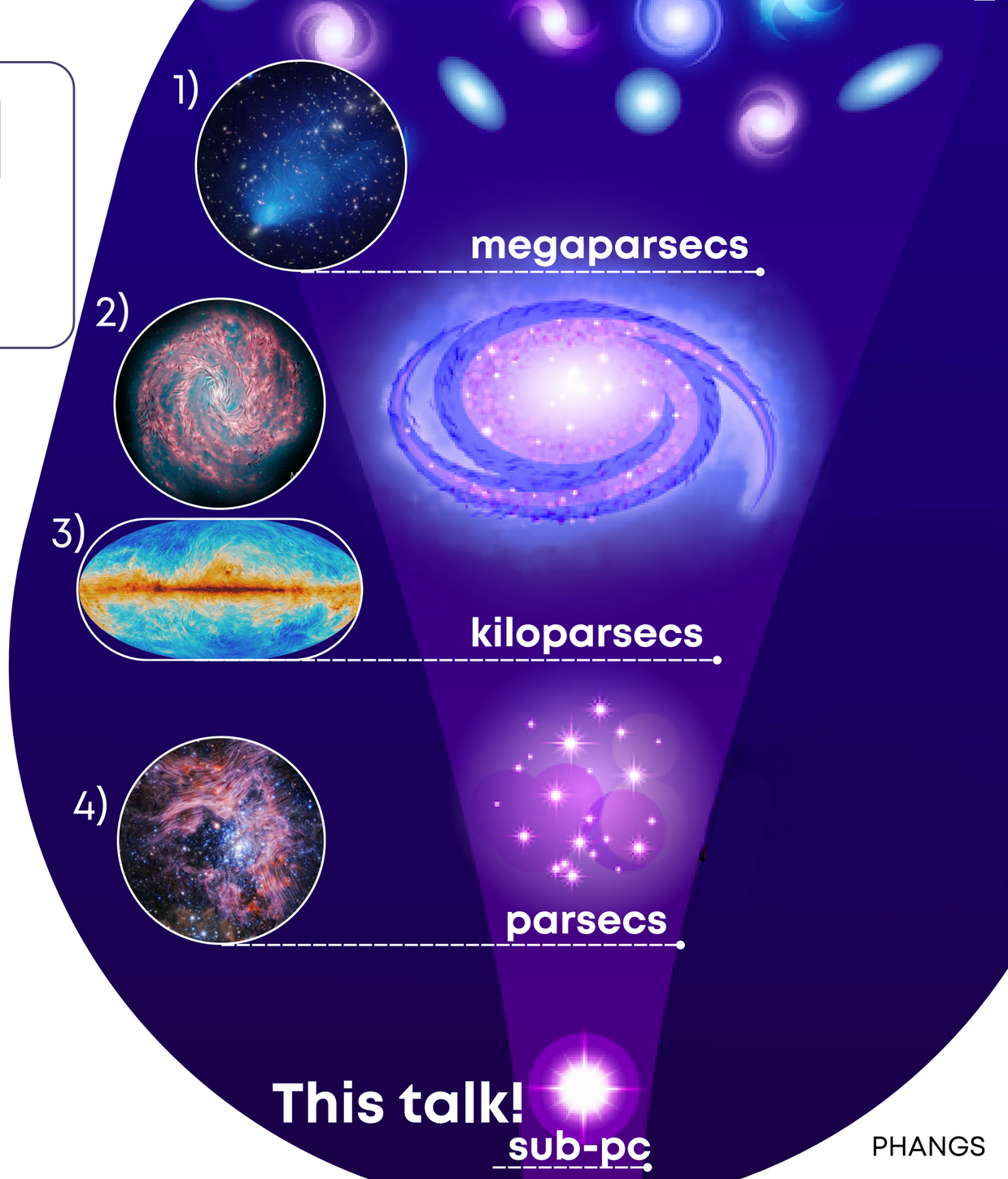
Magnetic (B-) field is everywhere!

1) El Gordo cluster; Hu et al., 2024, Nature communications

2) M83. SALSA NASA, SOFIA, HAWC+, Alejandro S. Borlaff; JPL-Caltech, ESA, Hubble), Borlaff et al., 2023, Lopez-Rodriguez et al., 2022

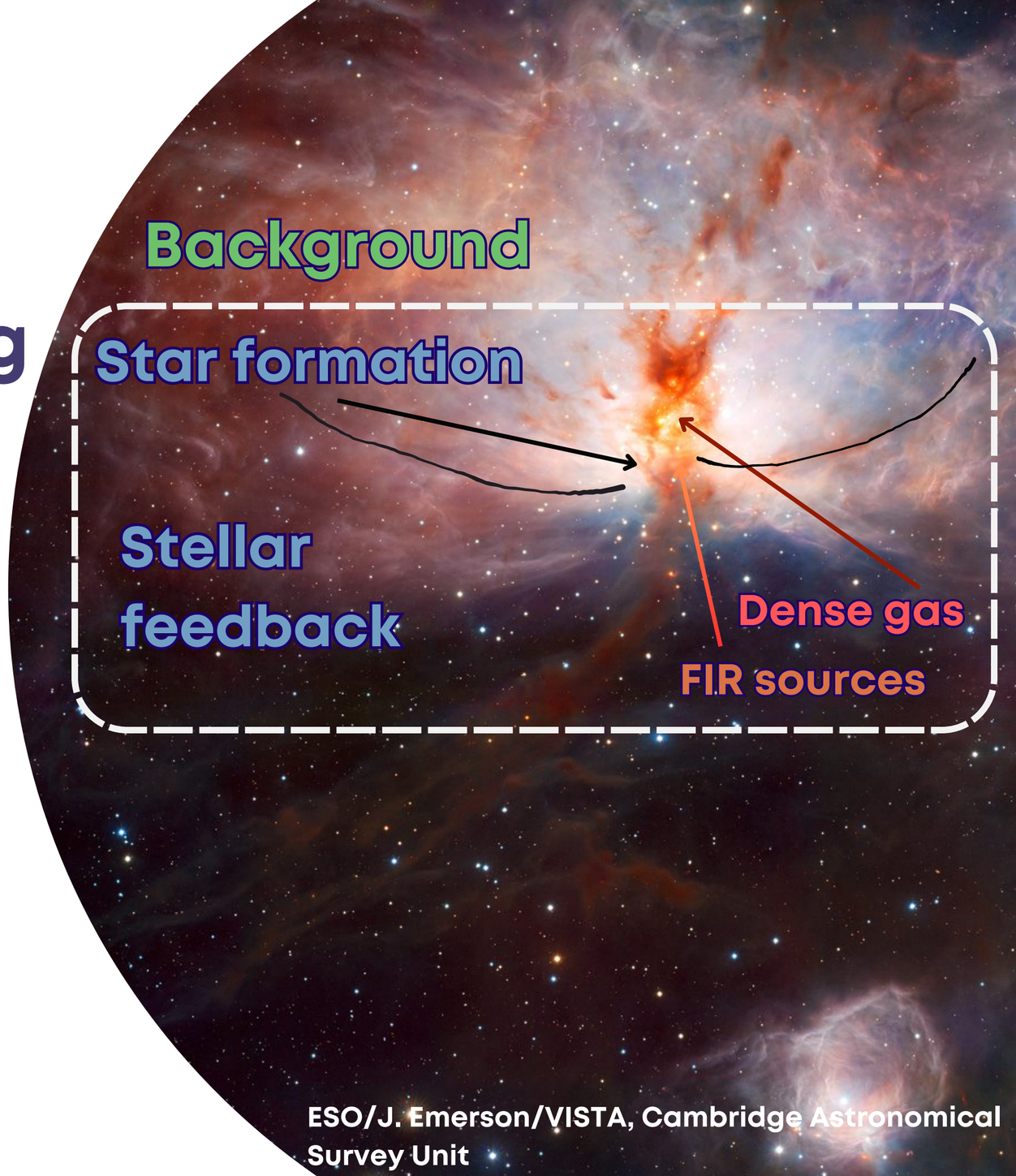
3) Planck Colaboration

4) 30 Doradus; Tram et al., 2023



NGC 2024

- A massive star-forming region in Orion B.
- Distance of 410 pc.
- Filamentary structure
- HII region.



ESO/J. Emerson/VISTA, Cambridge Astronomical Survey Unit

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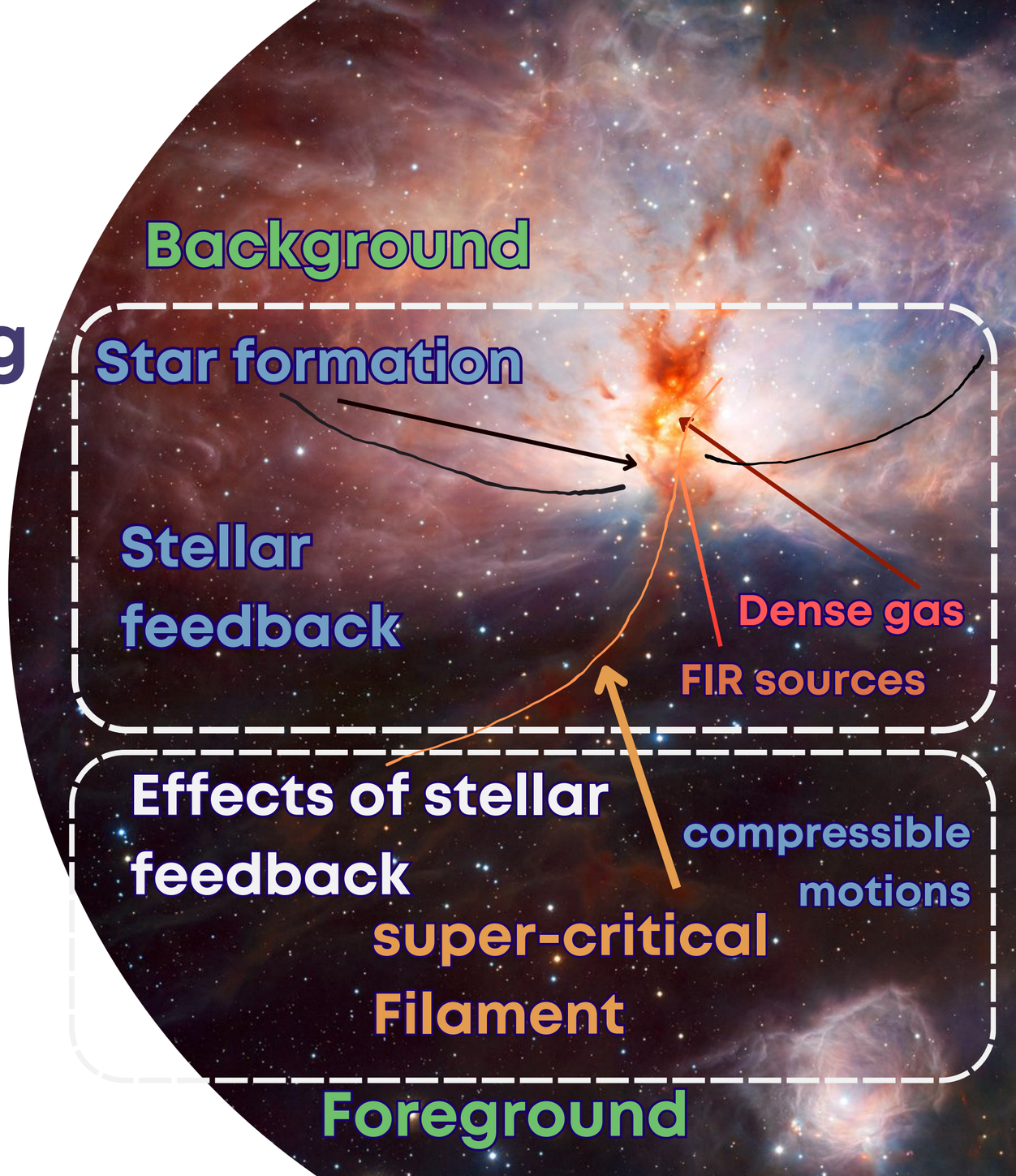


NGC 2024

A massive star-forming region in Orion B.

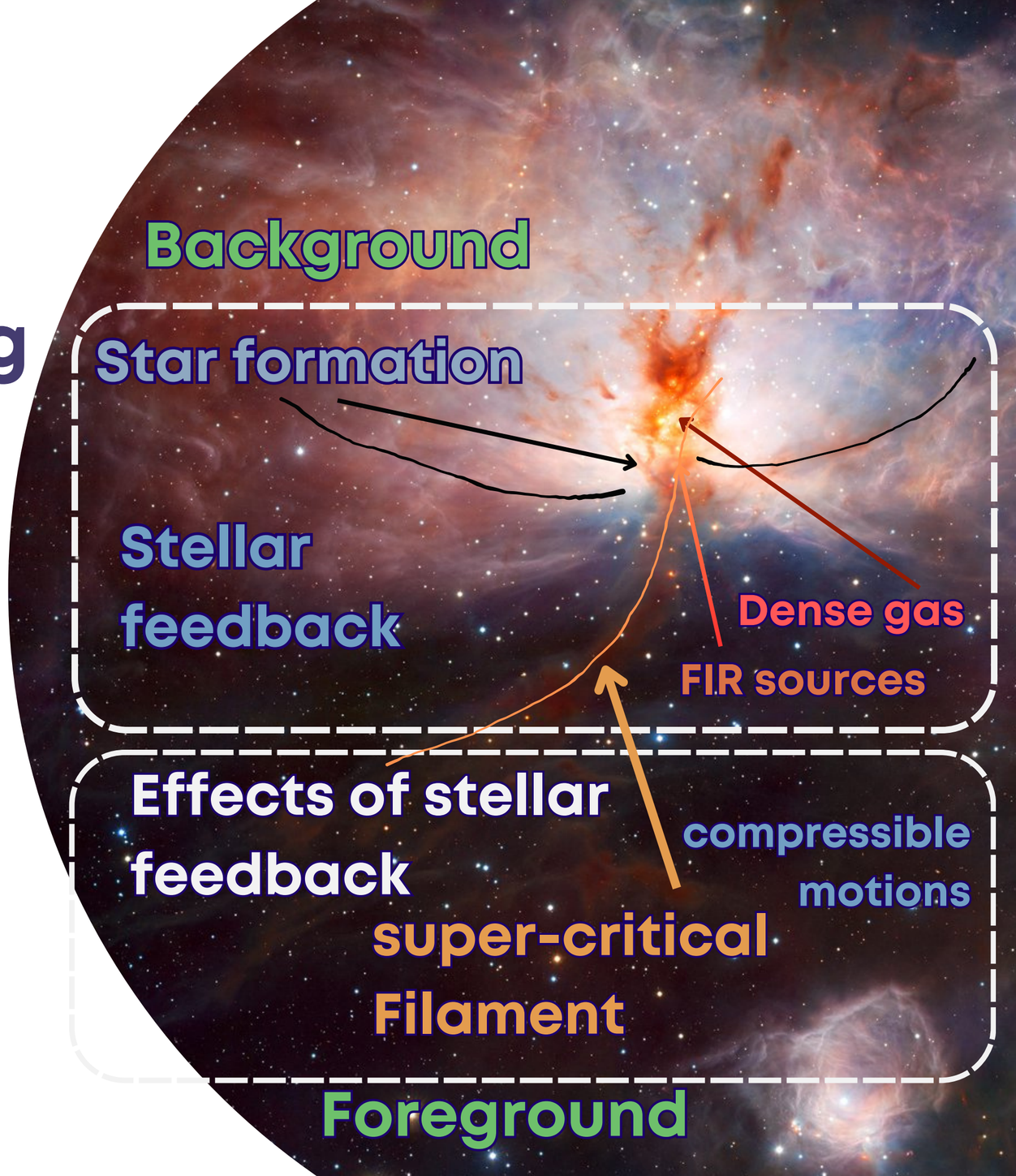
Distance of 410 pc.

Filamentary structure

HII region.

GOALS

Morphology and strength of the B field in NGC 2024.



POS B-FIELD AND HOW TO MEASURE IT

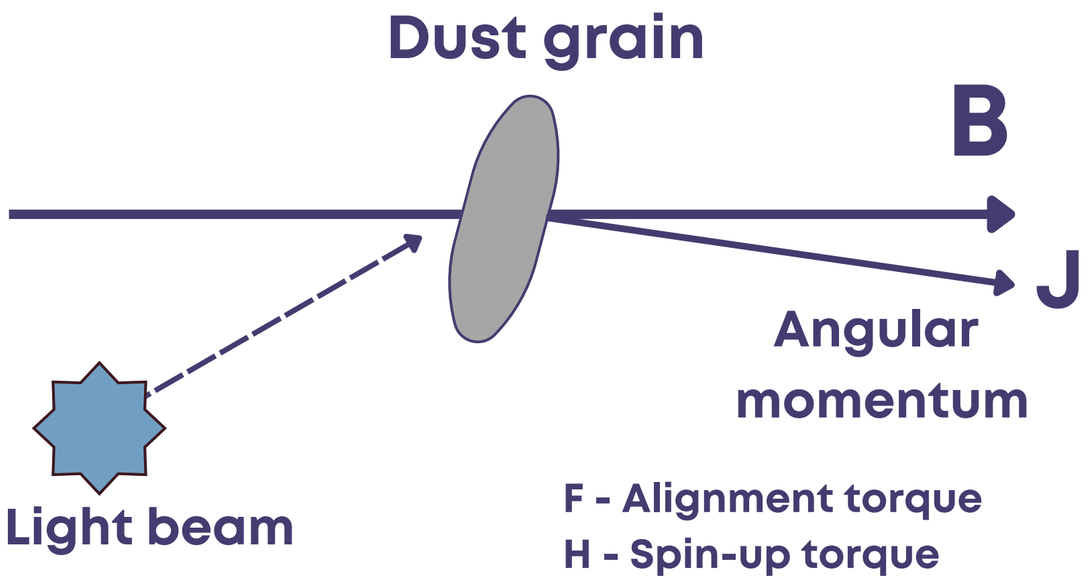
DUST EMISSION IS POLARIZED

RADIATIVE ALIGNMENT TORQUES

Polarization is perpendicular to the POS magnetic field.

see Pattle et al., 2023

Sketch adapted from Andersson et al., 2015



Hoang & Lazarian et al., 2014;
Andersson et al., 2015

POS B-FIELD AND HOW TO MEASURE IT

Small-scale turbulence impacts direction of the B-field.

$$B_{\mathrm{pos}} \approx 9.3 \cdot \sqrt{n_{\mathrm{H_2}}} \cdot \frac{\Delta v}{\widehat{\sigma}_{\mathrm{c}}(\varphi)}\ [\mu\mathrm{G}]$$

Davis & Greenstein et al., 1951;
Chandrasekhar & Fermi et al., 1953

Compressible nature of the ISM.
Magneto-hydrodynamic waves.
Entropy modes.

$$B_{\mathrm{pos}} \approx 1.8 \cdot \sqrt{n_{\mathrm{H_2}}} \cdot \frac{\Delta v}{\sqrt{\widehat{\sigma}_{\mathrm{c}}(\varphi)}}\ [\mu\mathrm{G}]$$

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

Measure

1. Gas number density (cm-3)
2. Turbulent FWHM (km/s)
3. Spatial dispersion of direction of B-field (deg)

OBSERVATIONS

FAR INFRARED

SOFIA
HAWC+

PI: D. Lis

Dust polarization

Stokes parameters

154 and 216 microns

MILLIMETER

IRAM 30m
EMIR

ORION B Large Program

PI: J. Pety, M. Gerin

Molecular emission

CN and HCO+

Team's webpage!

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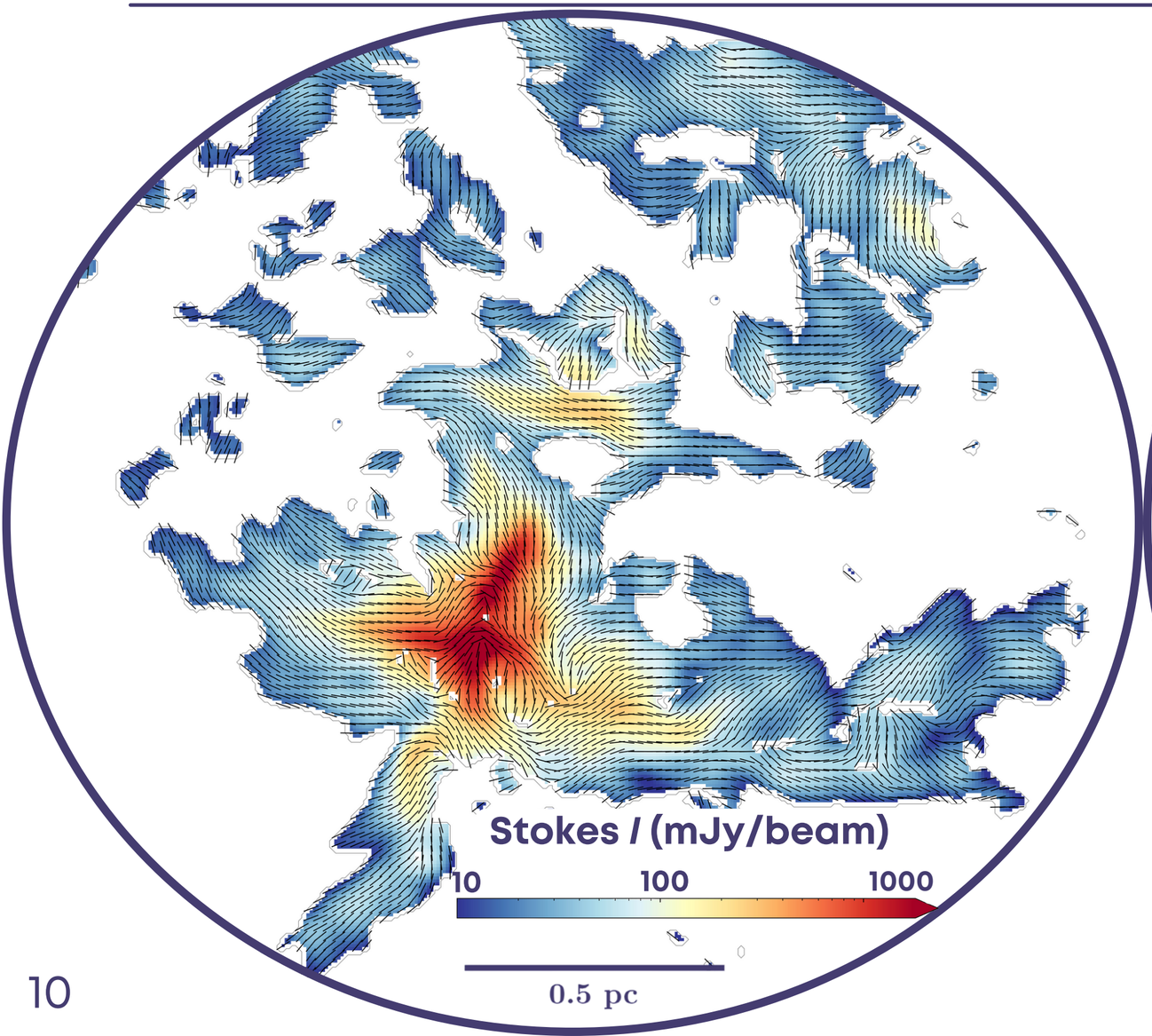
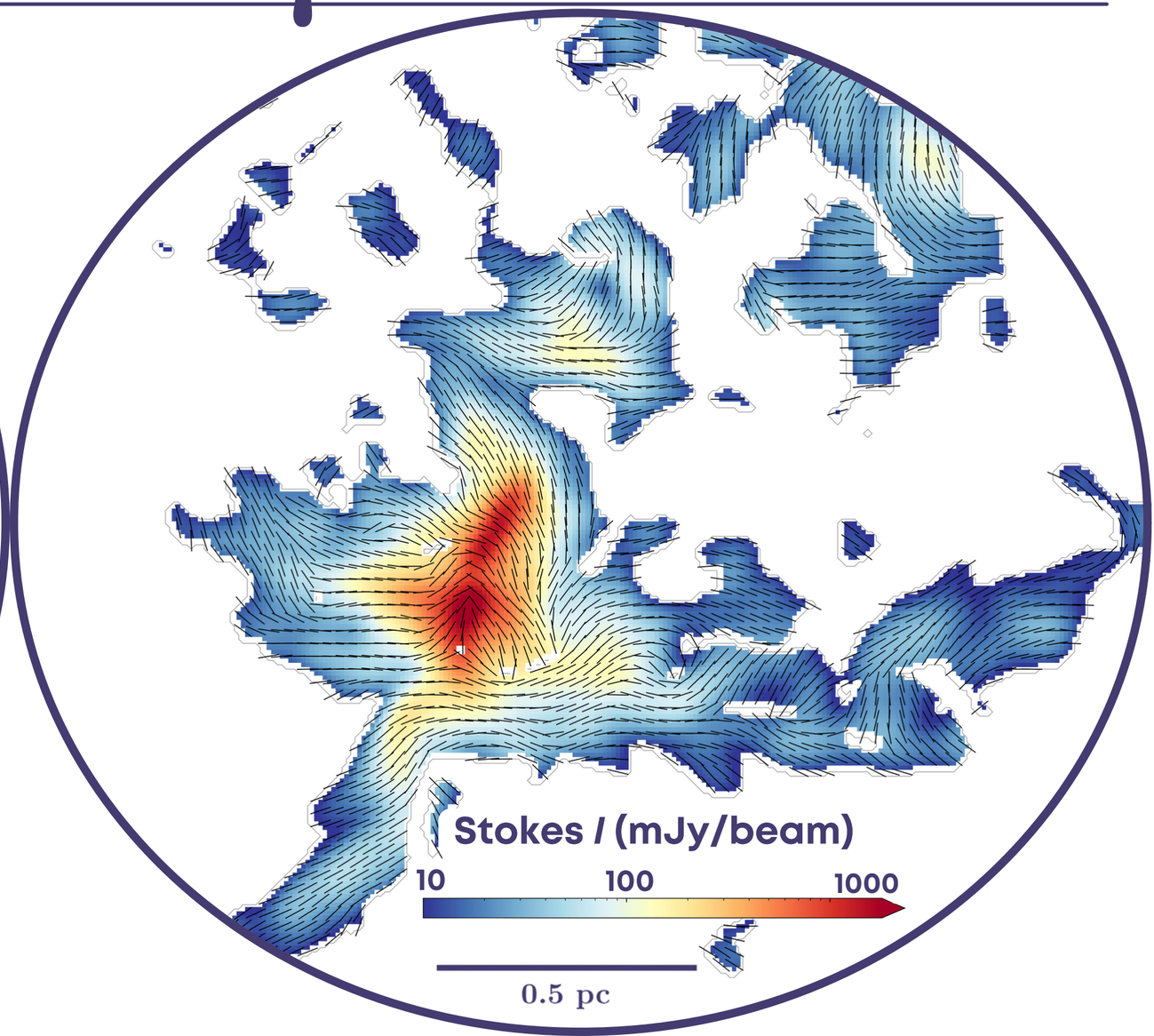
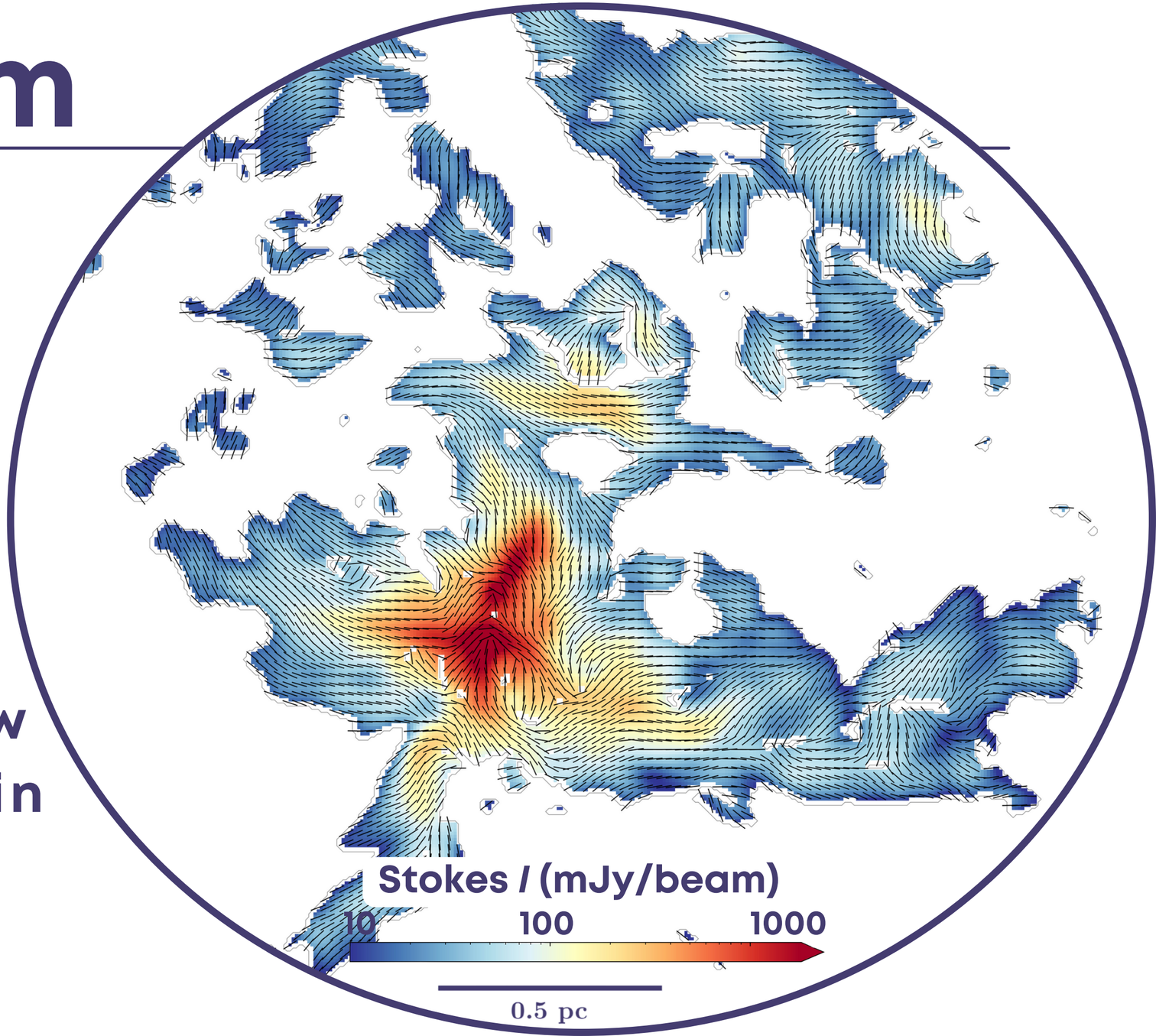
SOFIA 154 AND 214 μm





SOFIA 154 μm

- B-field is highly ordered
- B-field follows the morphology of the gas
- Bands D and E show similar properties in some regions of NGC 2024



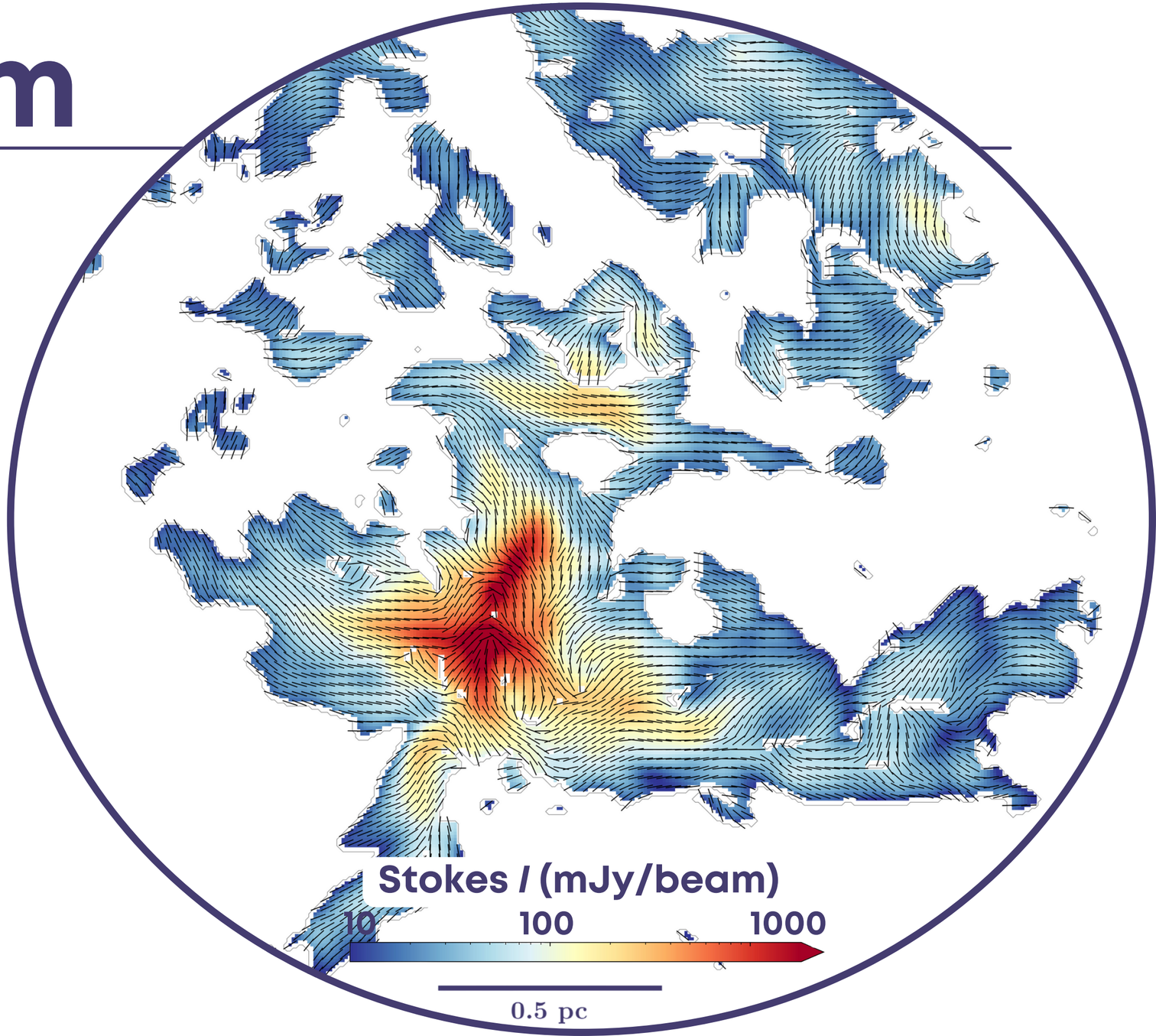
SOFIA 154 μm

Remove the large-scale contribution of B-field

1) Sliding window

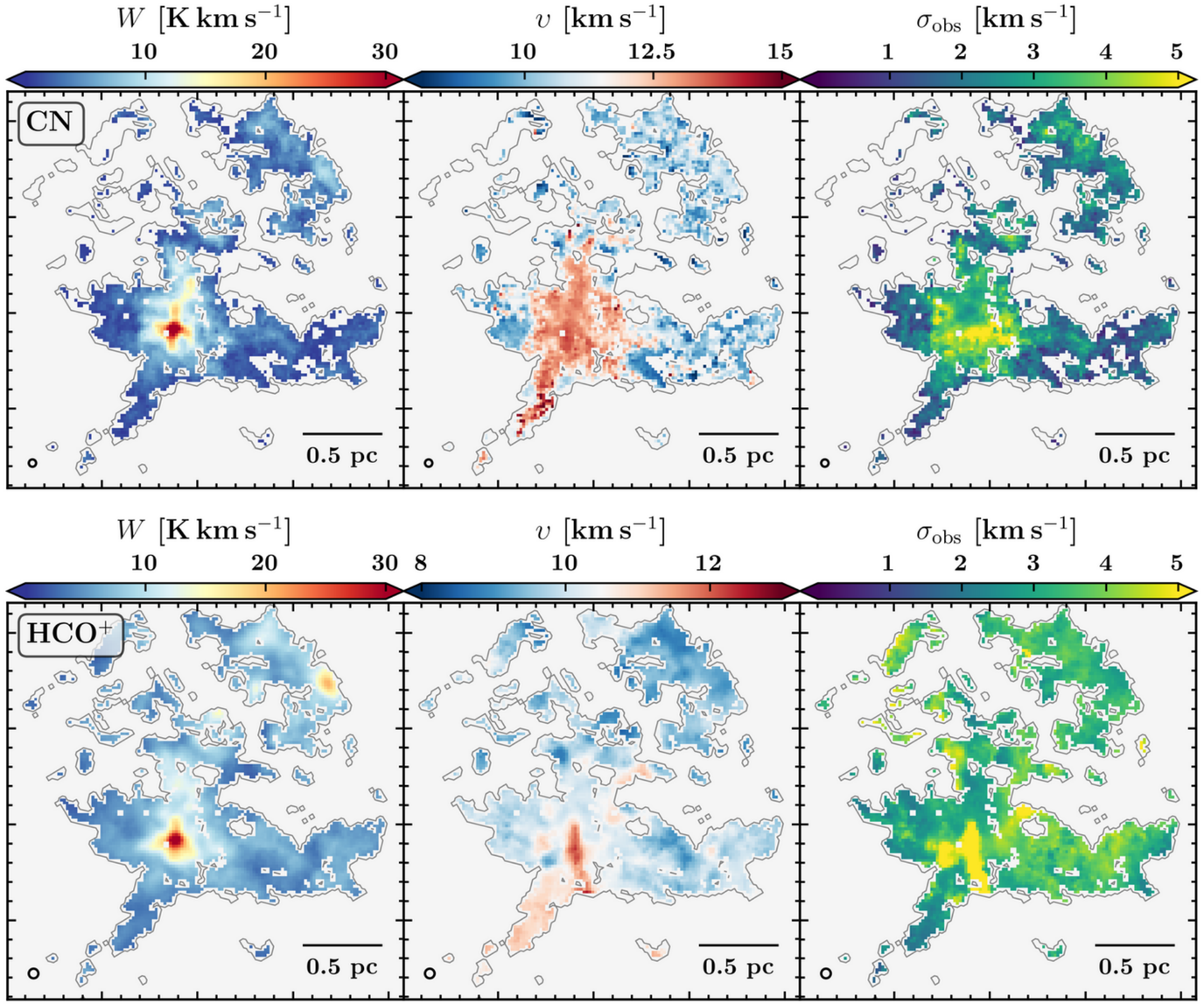
2) Histogram analysis

Consistent results rms of ~ 5 deg



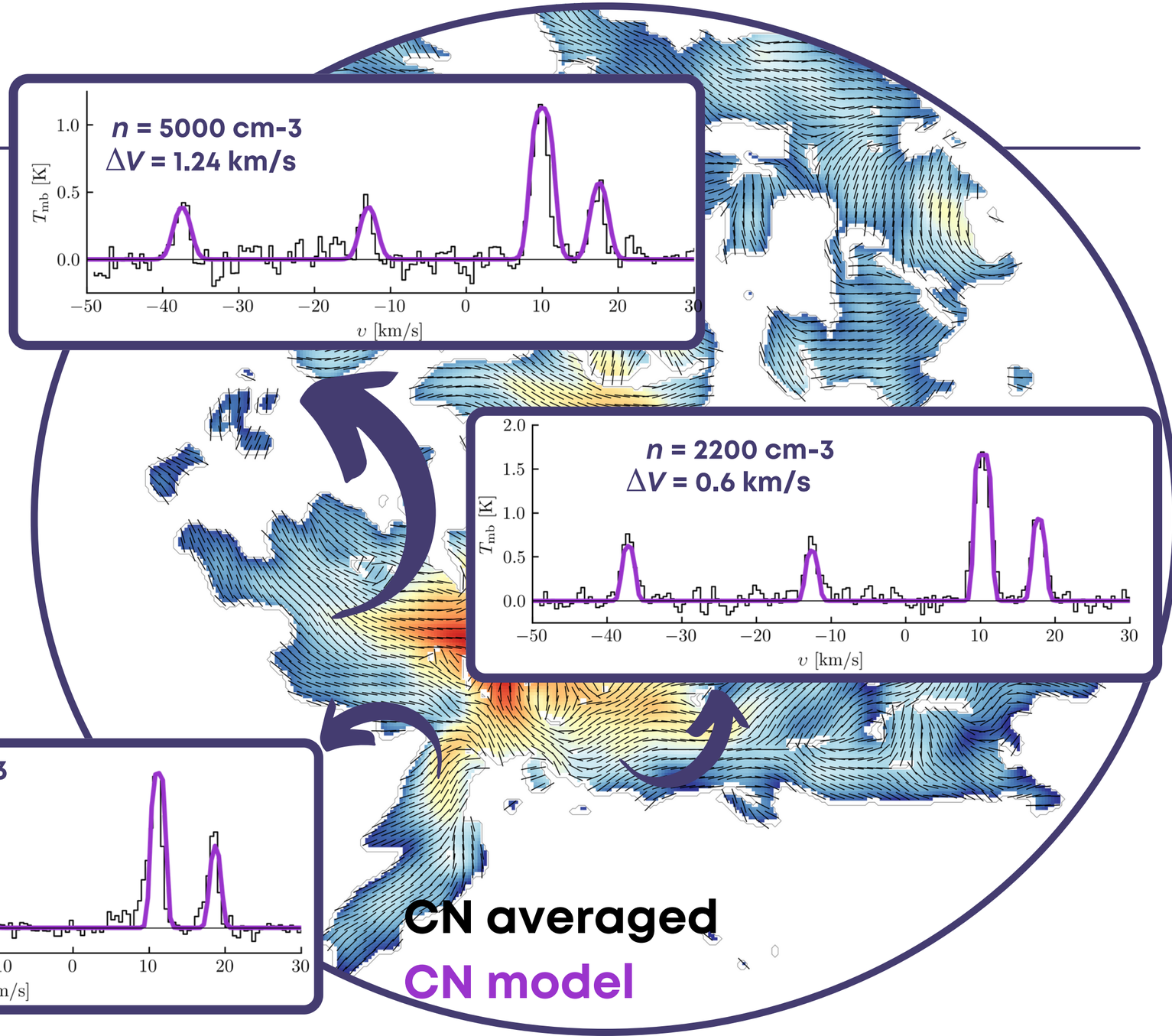
Molecular gas in NGC 2024

- Tracers of UV-illuminated gas (Gratier et al., 2018, Bron et al., 2018)
  - Cyanide, CN
  - Formyl cation, HCO+
- Multiple velocity components
- Opacity effects
- CN has a hyperfine structure
- non-LTE radiative transfer
- SpectralRadex (van der Tak et al., 2007, Holdship et al., 2021)



Modeling

- Line widths are generally consistent
- Gas number densities consistent between CN and HCO+ at the edges of HII
- The broadest lines found on the east of NGC 2024 Filament has the highest density

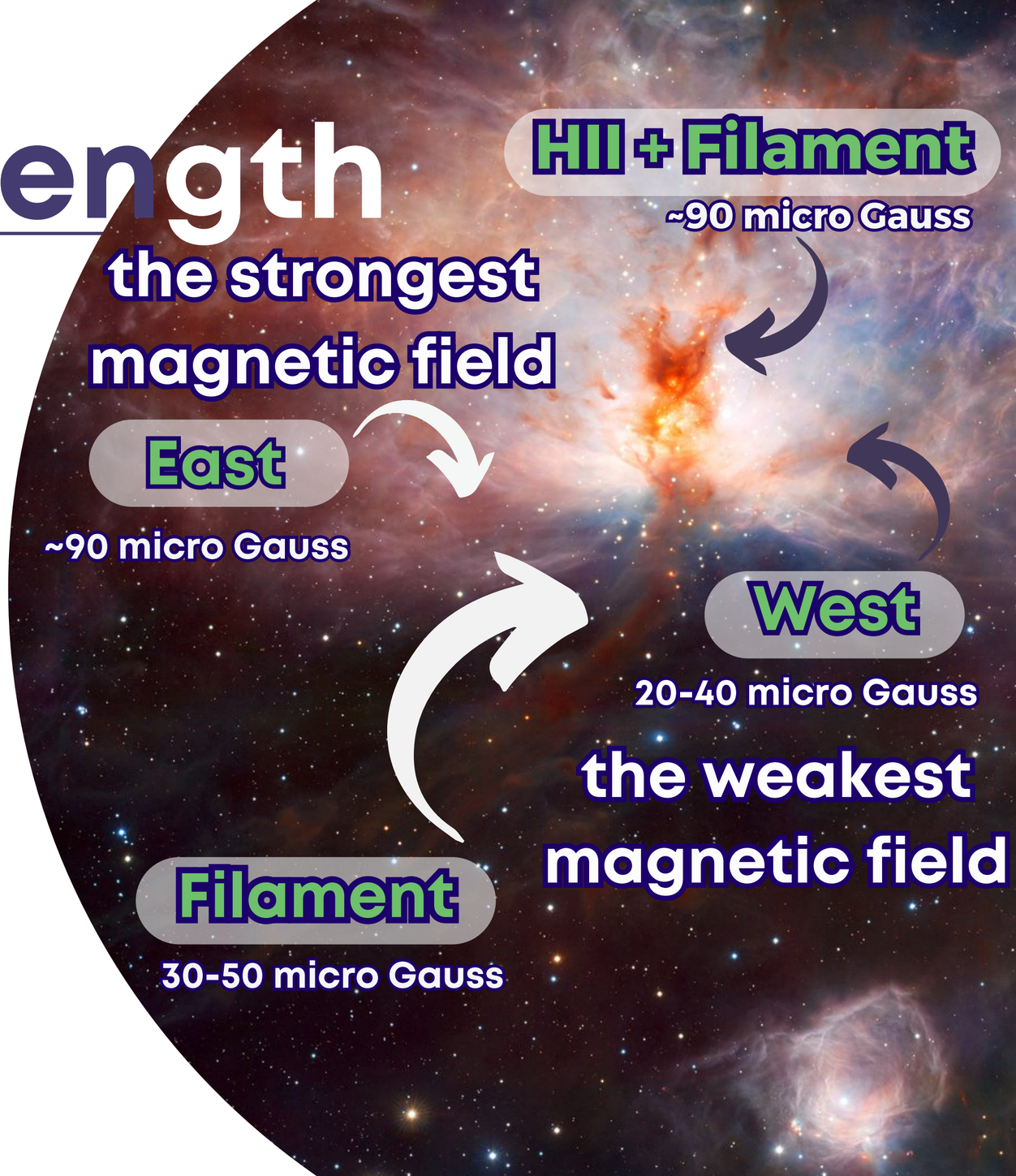


POS B-field strength

Varies across NGC 2024
20-90 micro Gauss

Decreases from east to west

Possible change of direction of B-field?

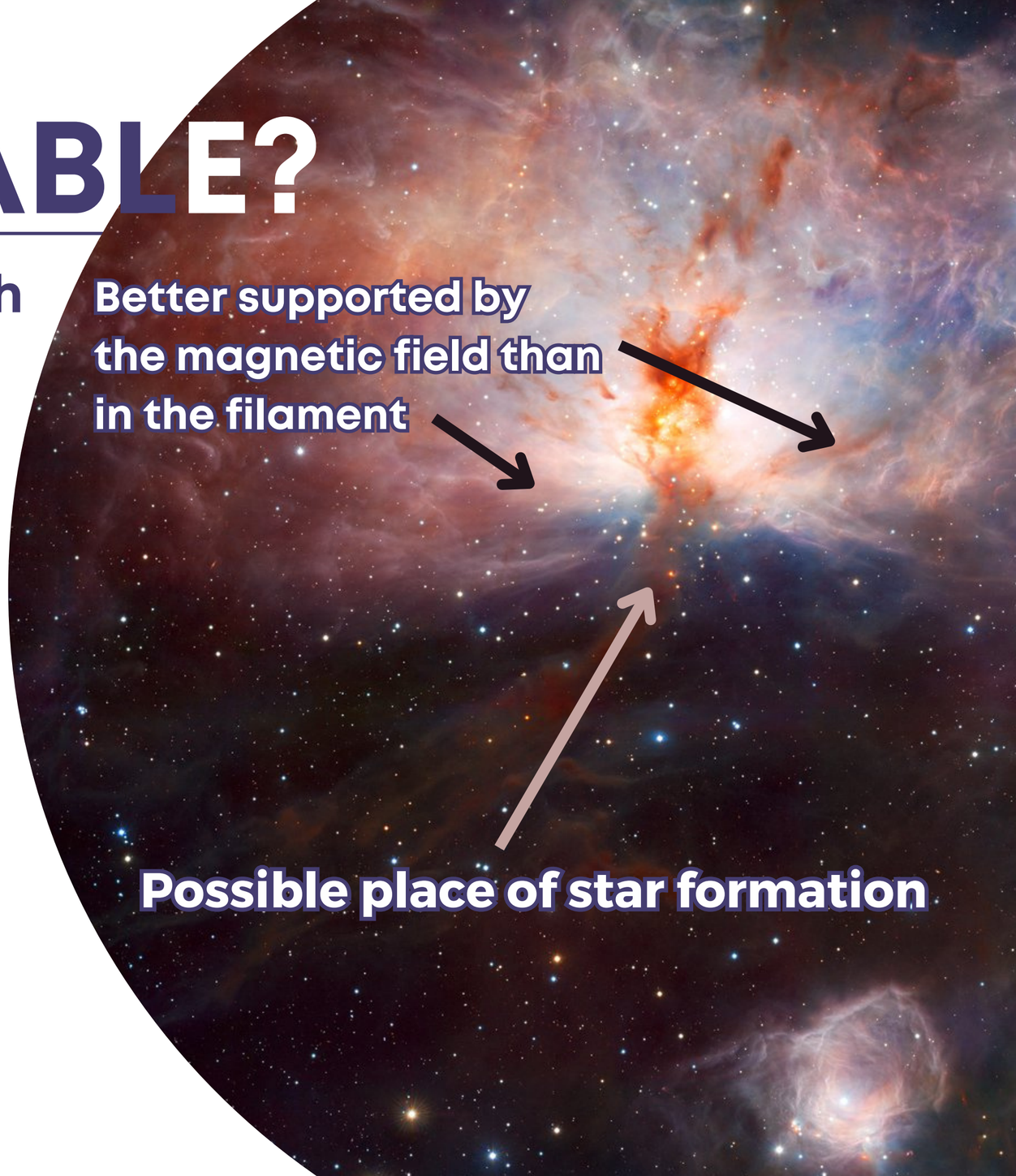


IS THE GAS STABLE?

Mass-to-flux ratio, Alfven Mach number, plasma-beta

Gas is highly turbulent in NGC 2024

Transition to super-criticality
Young HII region
Selection of lines



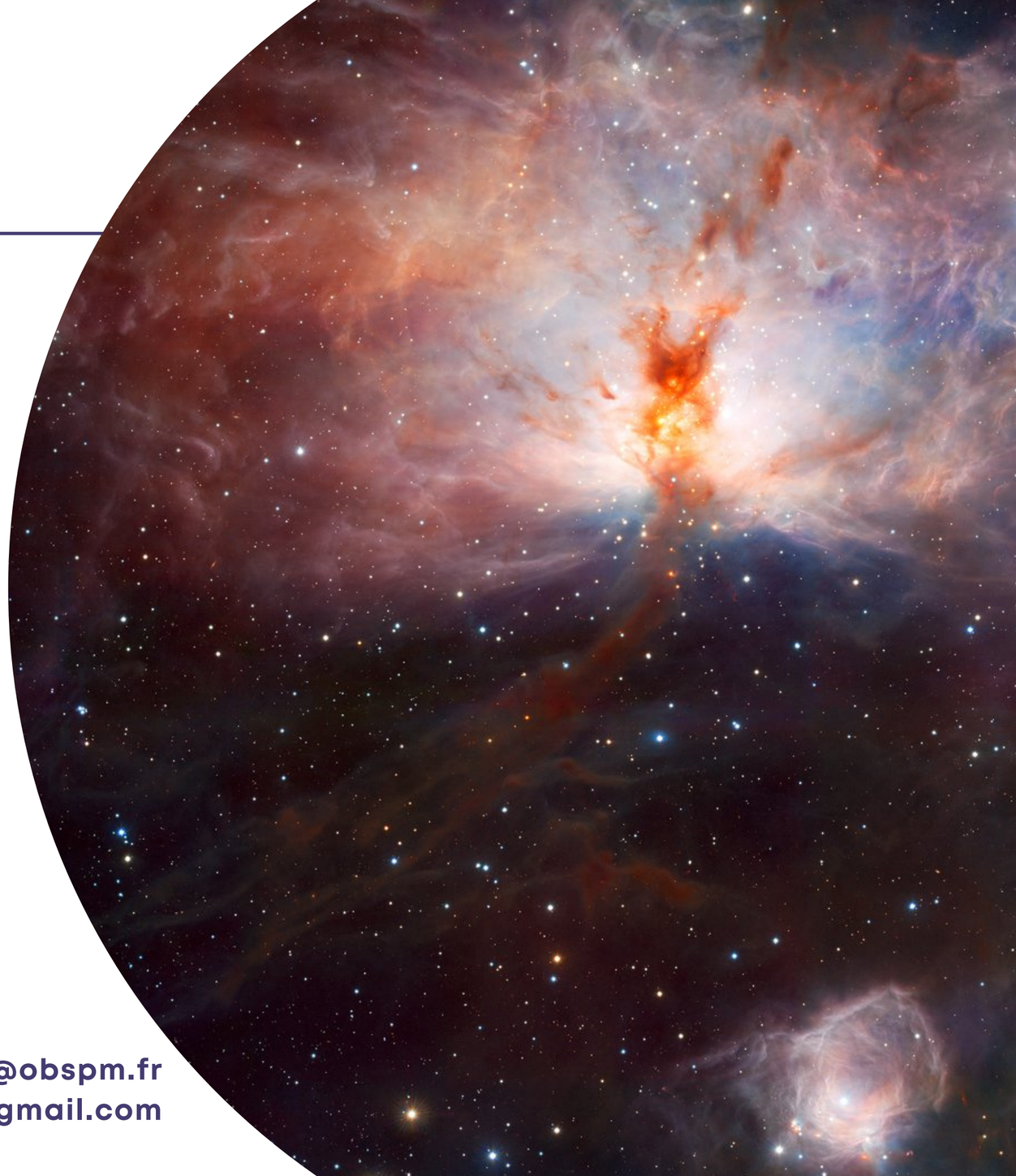
SUMMARY

SOFIA FIR dust polarization to measure magnetic field in NGC 2024

B-field shows an ordered structure in NGC 2024

20-90 micro Gauss

B-field has an important role in regulating star formation



Bešlić+2024

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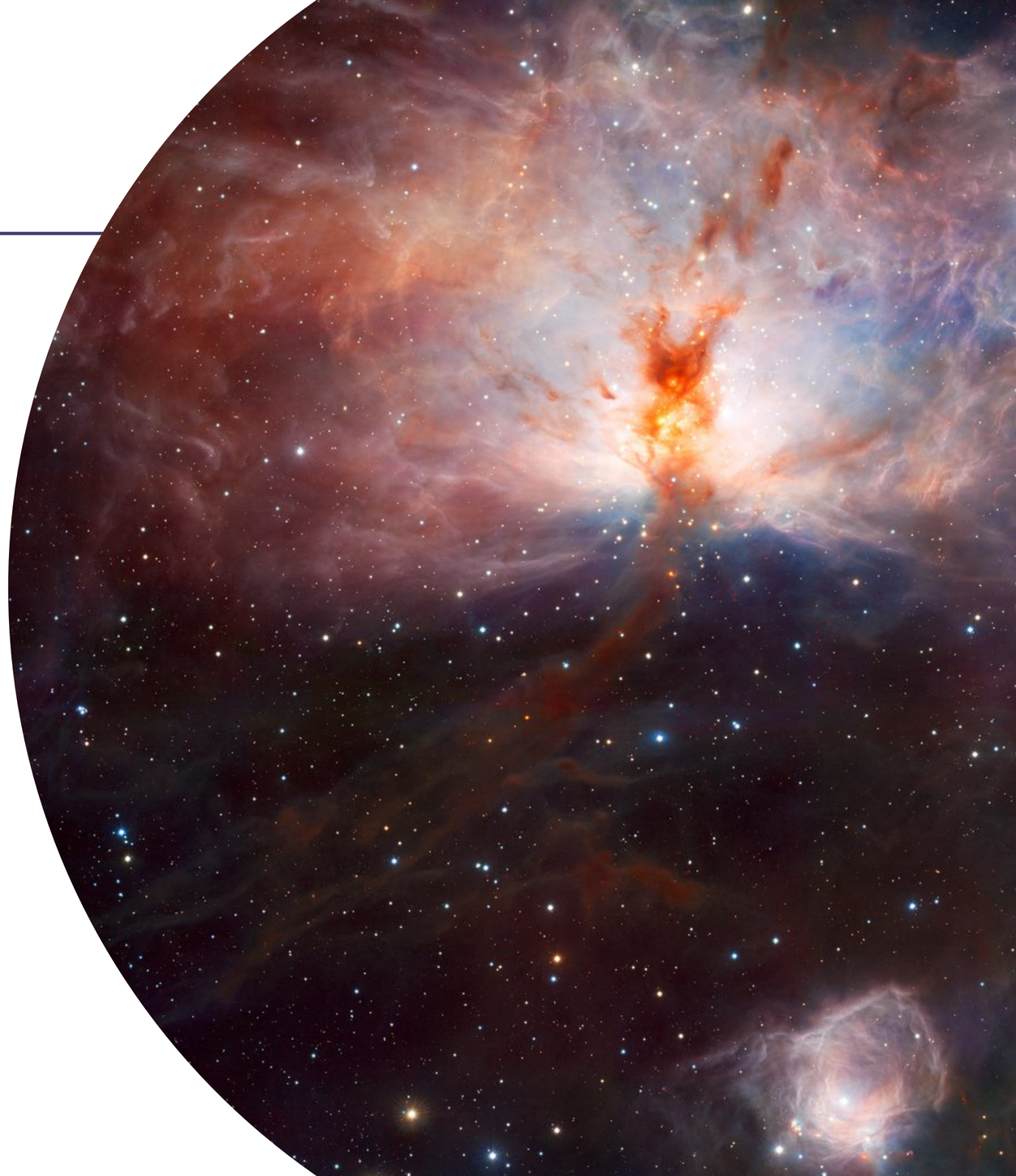
FUTURE WORK

- Multiwavelength dust polarization analysis
- Grain alignment and polarization fraction in NGC 2024
- Investigation of the outflow in NGC 2024



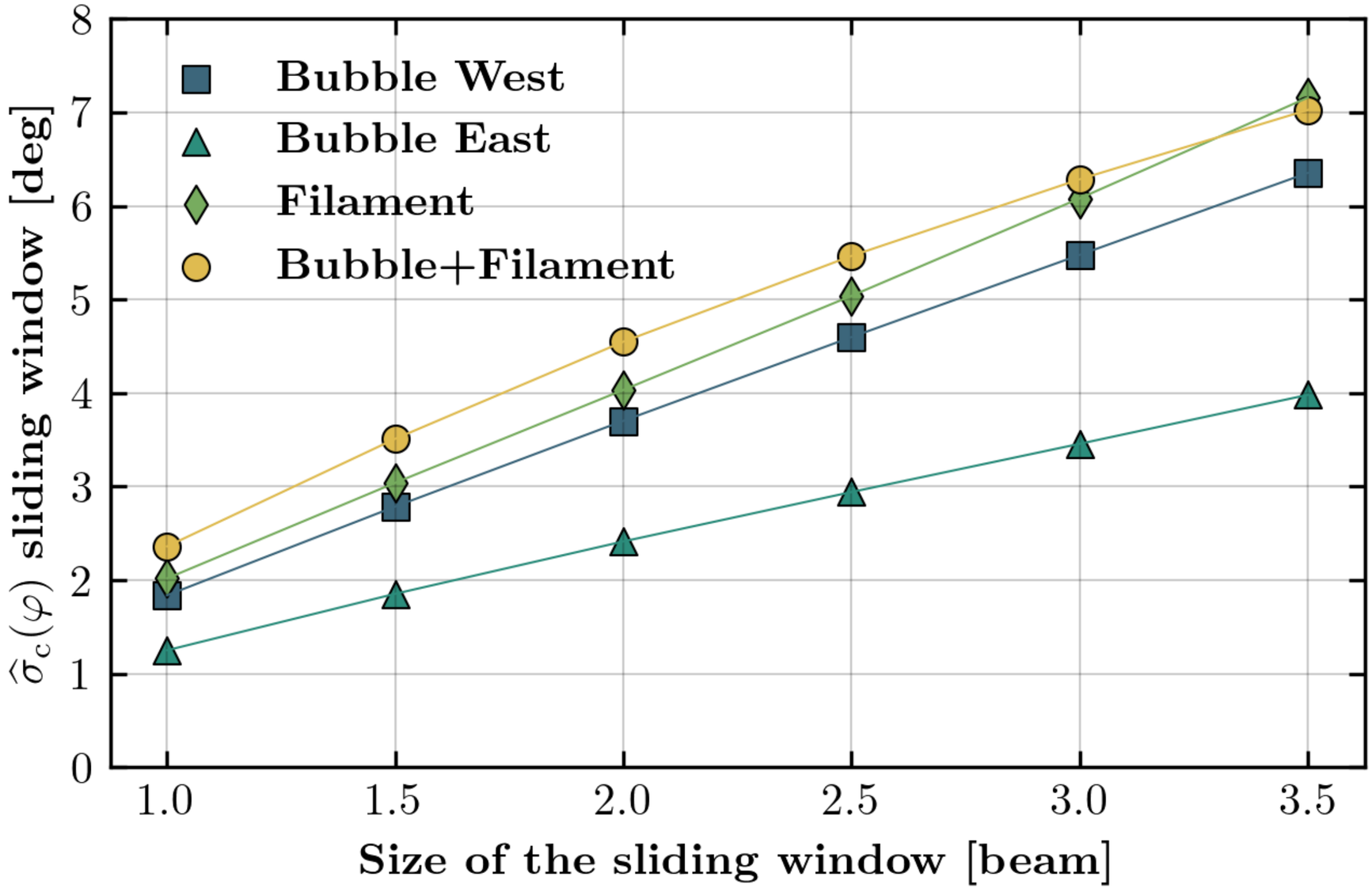
Bešlić+2024

Sliding window

$$z = \frac{1}{L}\sum_{l=1}^{L} e^{2i\varphi(l)}$$

$$\widehat{m}_{\mathrm{c}}(\varphi) = \frac{1}{2}\arctan\frac{b}{a},$$

$$\widehat{\sigma}_{\mathrm{c}}(\varphi) = \sqrt{\frac{1}{2}(1-|z|)}.$$

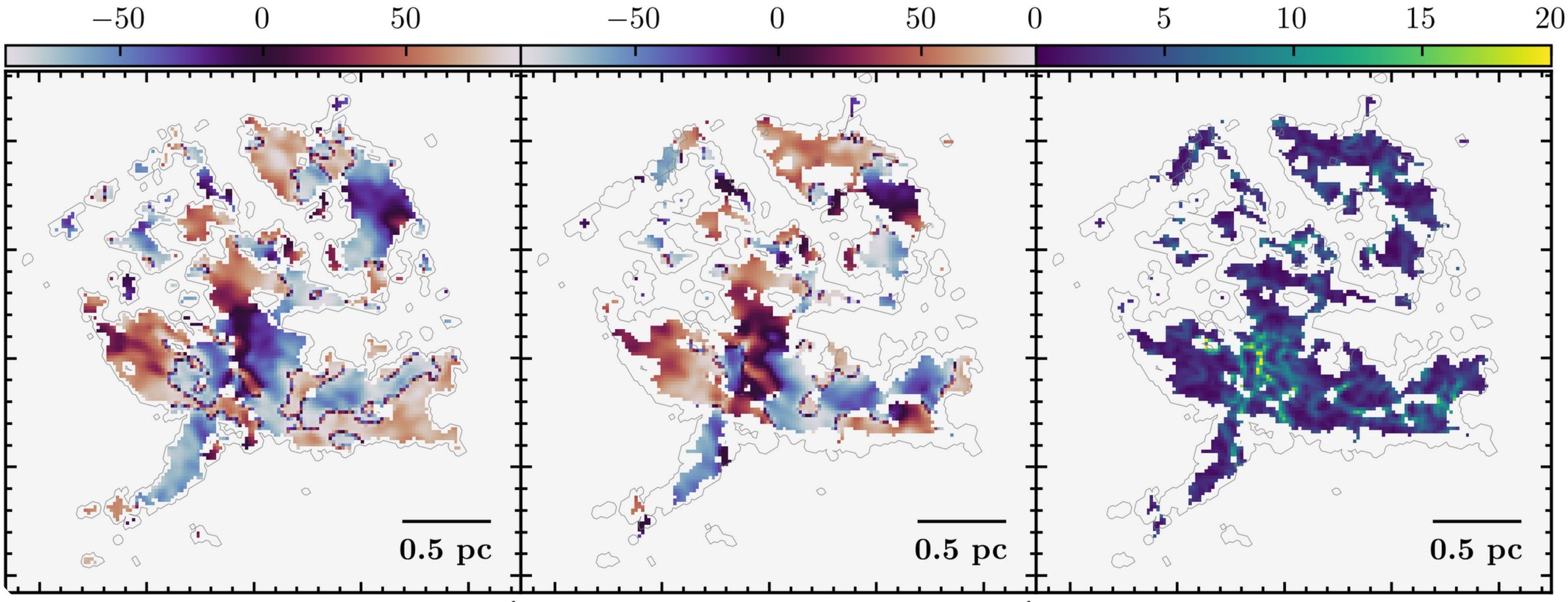


Sliding window

Angle

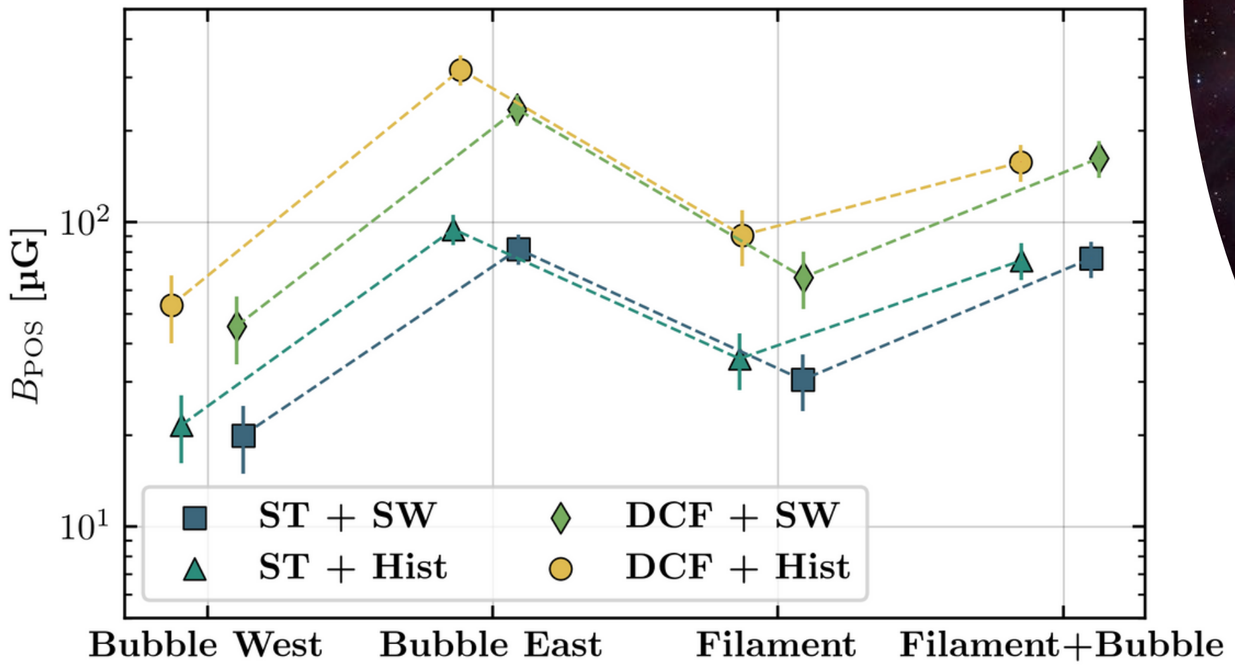
Circ mean

Circ standard deviation



POS B-field strength

B-field strength derived from ST is generally lower than the DCF. Angle dispersion measurements consistent between sliding window and histogram analysis.



HII + Filament

~90 micro Gauss

the strongest magnetic field

East

~90 micro Gauss

West

20-40 micro Gauss

the weakest magnetic field

Filament

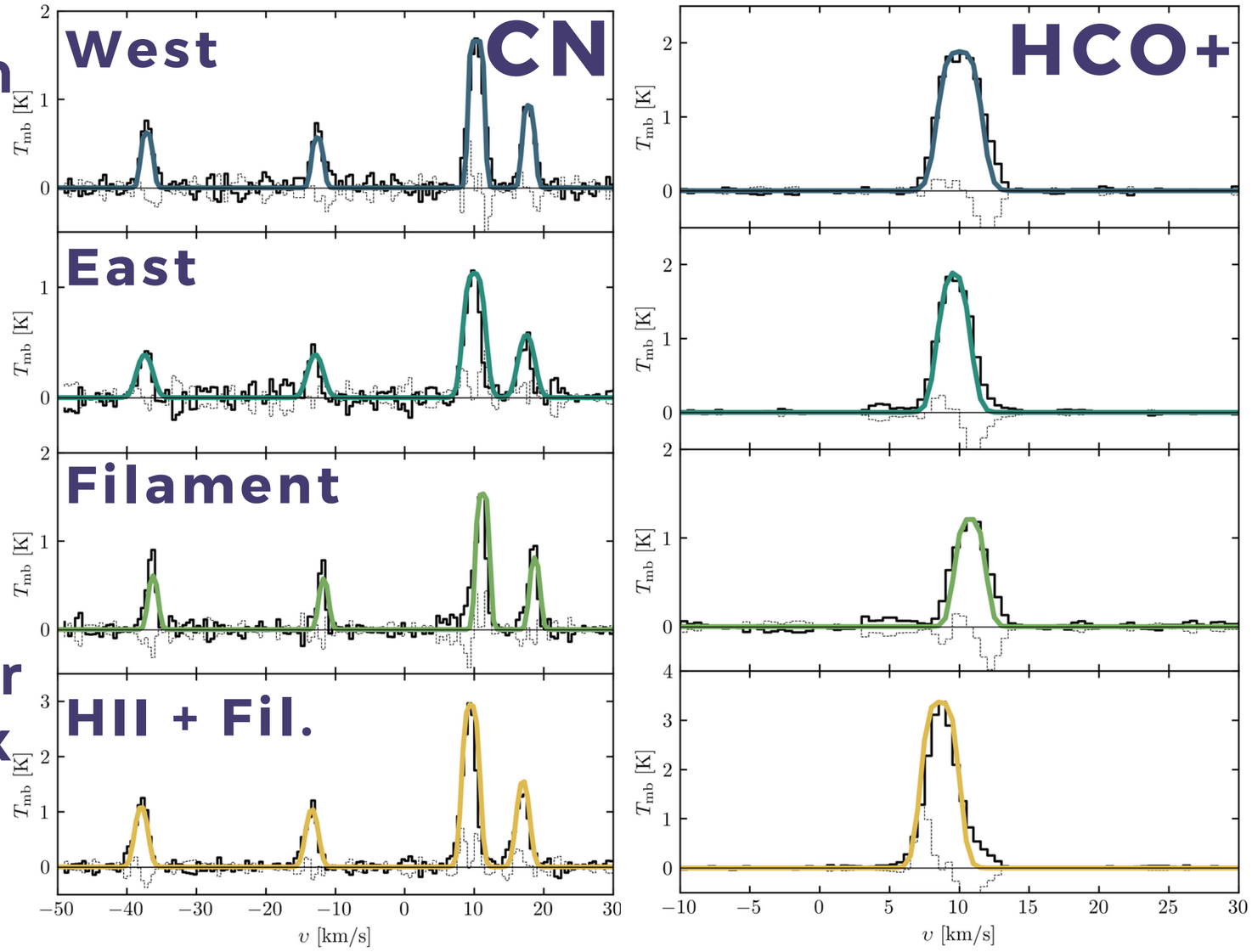
30-50 micro Gauss

Molecular gas in NGC 2024

Line width inferred from modeling their excitation

Input: Tkin, Column density
Collision partners: e-, ortho and para H2, e- density

Output: opacity, number density, line width, peak temperature



Orion Constellation

The region studied in this work

Orion’s belt

N

Credit:
Zdeněk Bardon/ESO

ORION B

Team's webpage!

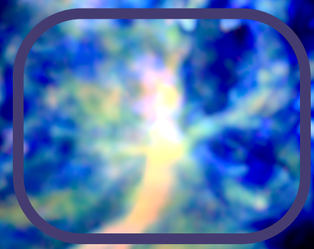
Facts

5 square degrees
~1000 hours
0.05 pc, 10^4 AU
30 molecular lines

Data

~820 000 pixels
~240 000 spectral channels
Astronomers and data scientists

The region studied in this work



CO composite
Image credit: J. Pety, Pety et al., 2017