INSTITUT DE CIÈNCIES DE L'ESPAI

CSIC IEEC

B-fields Orion Protostellar Survey: Magnetized Envelopes in Orion

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BOPS Team: C. Hull, Q. Zhang, M. Lopez ...

Outline

- 1. Introduction
- 2. Observation
- 3. Results
- 4. Summary and Conclusions

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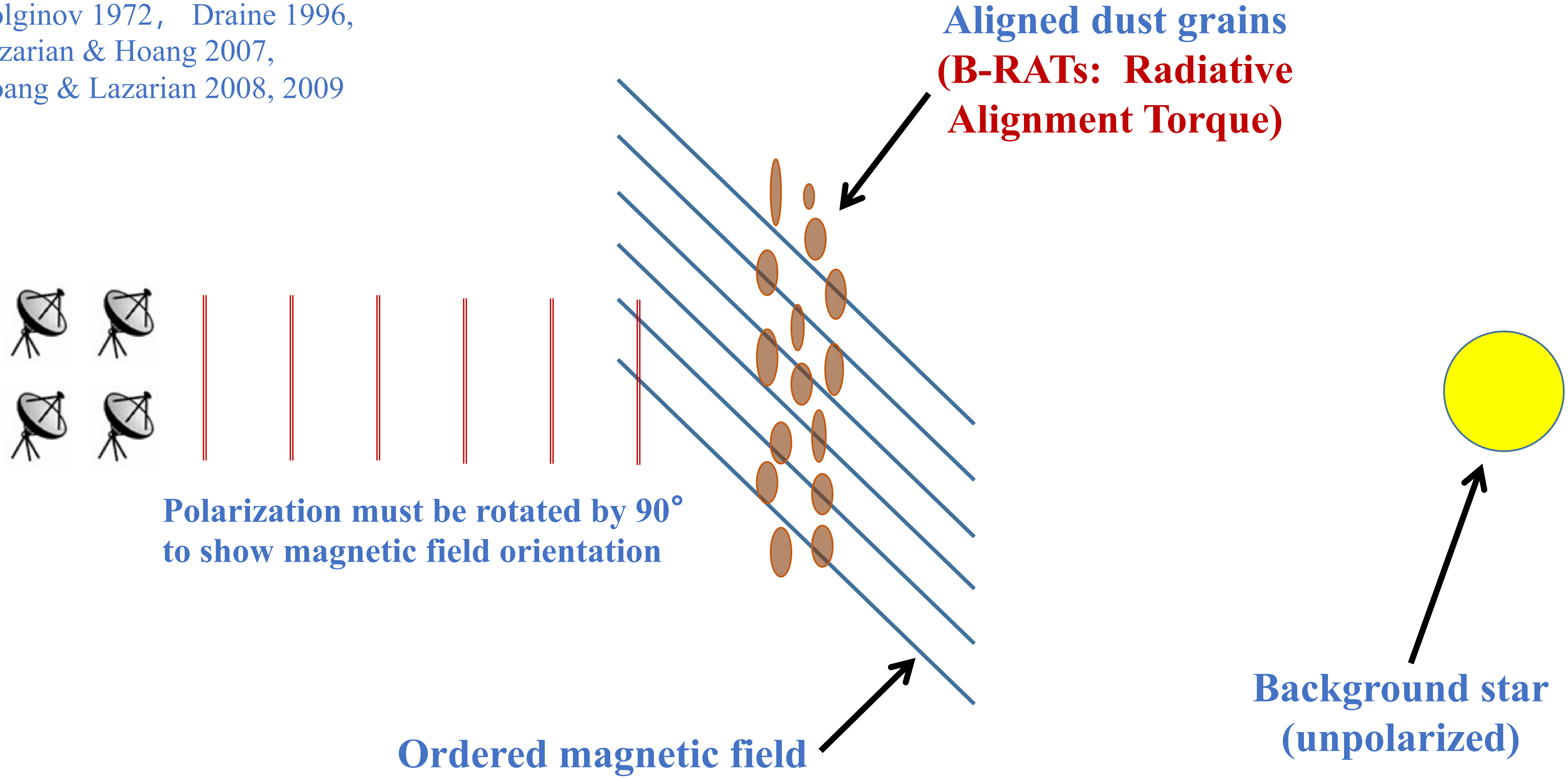
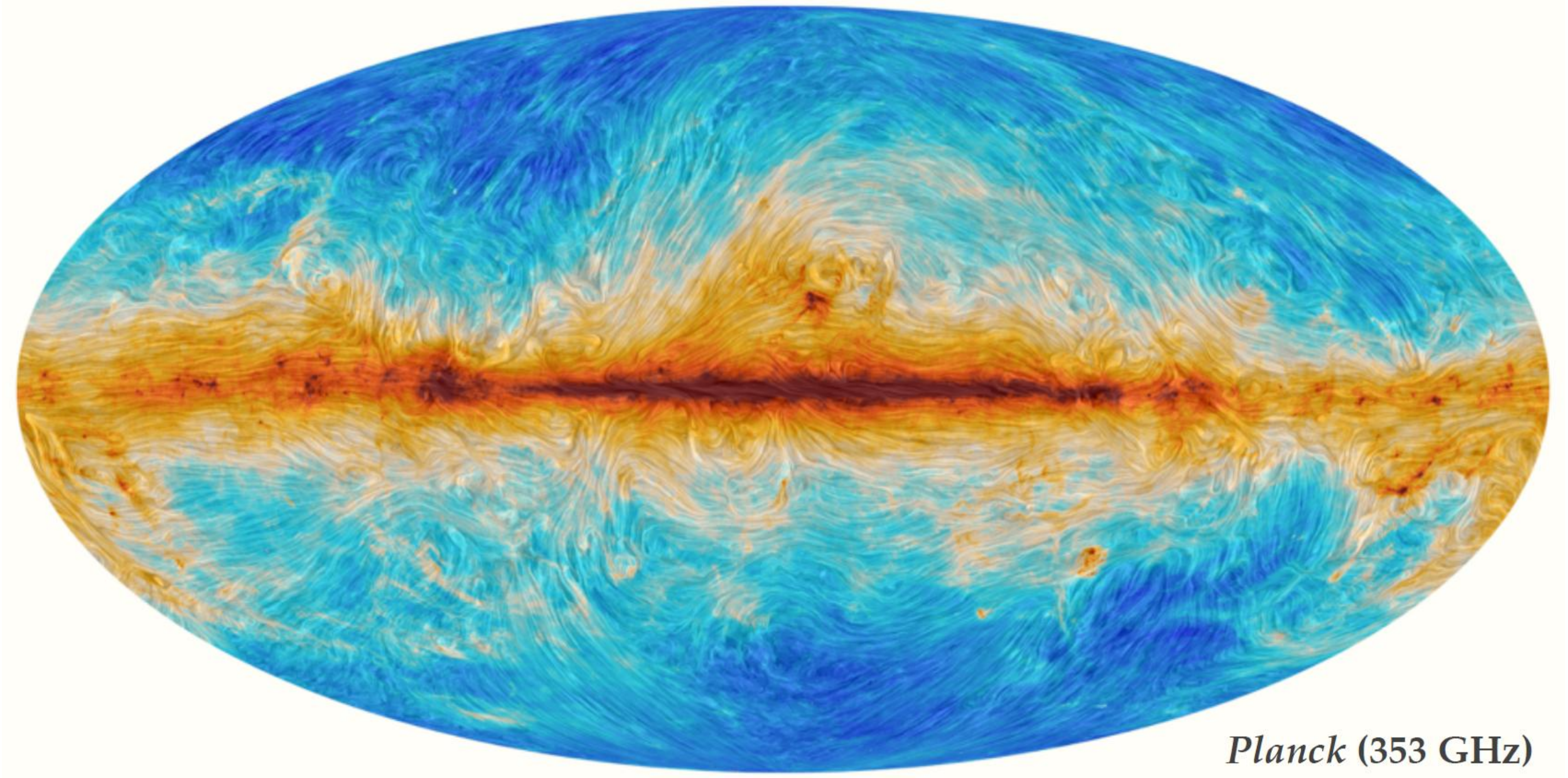
Polarization (dust emission)

Dolginov 1972， Draine 1996,
Lazarian & Hoang 2007,
Hoang & Lazarian 2008, 2009



B-Field on Large Scales



From Planck Collaboration

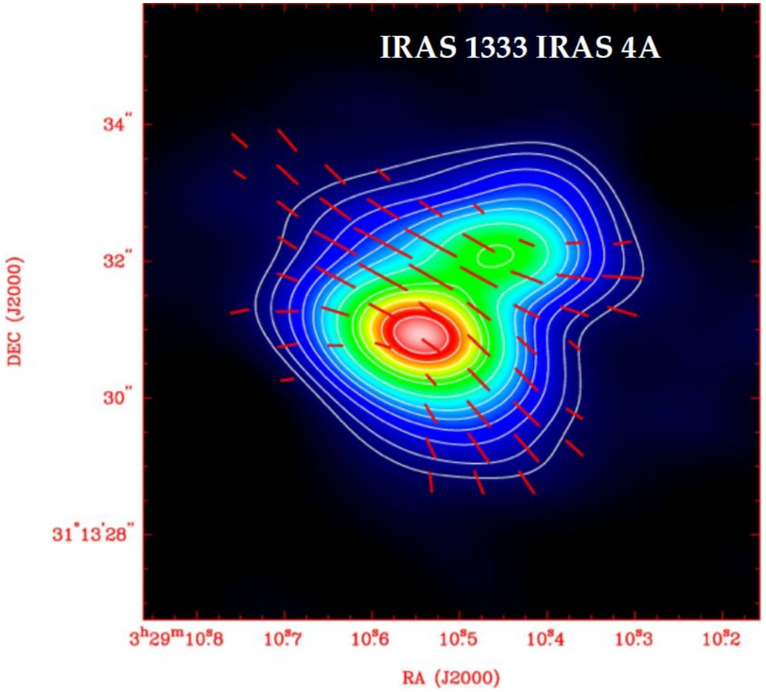
Planck observations at pc scales

(1) Lower-density filamentary sub-structure tend to be parallel to the B-field;

(2) Magnetic fields in dense gas tend to be perpendicular to filament axis.

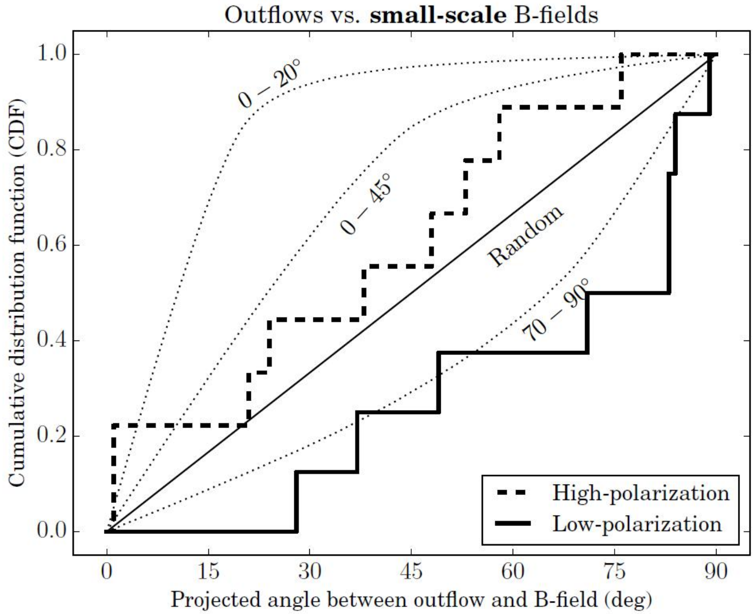
B-Field on Small Scales

- Small scales (10^2~10^3 au): complex morphology



Girart et al. 2006

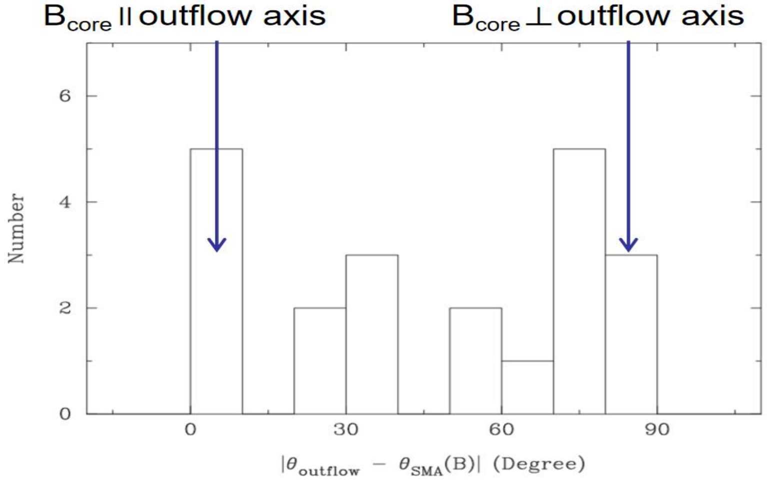
Low-mass



Hull et al. 2014

High-mass

Outflows *vs* **small-scale** B-fields



Zhang et al. 2014

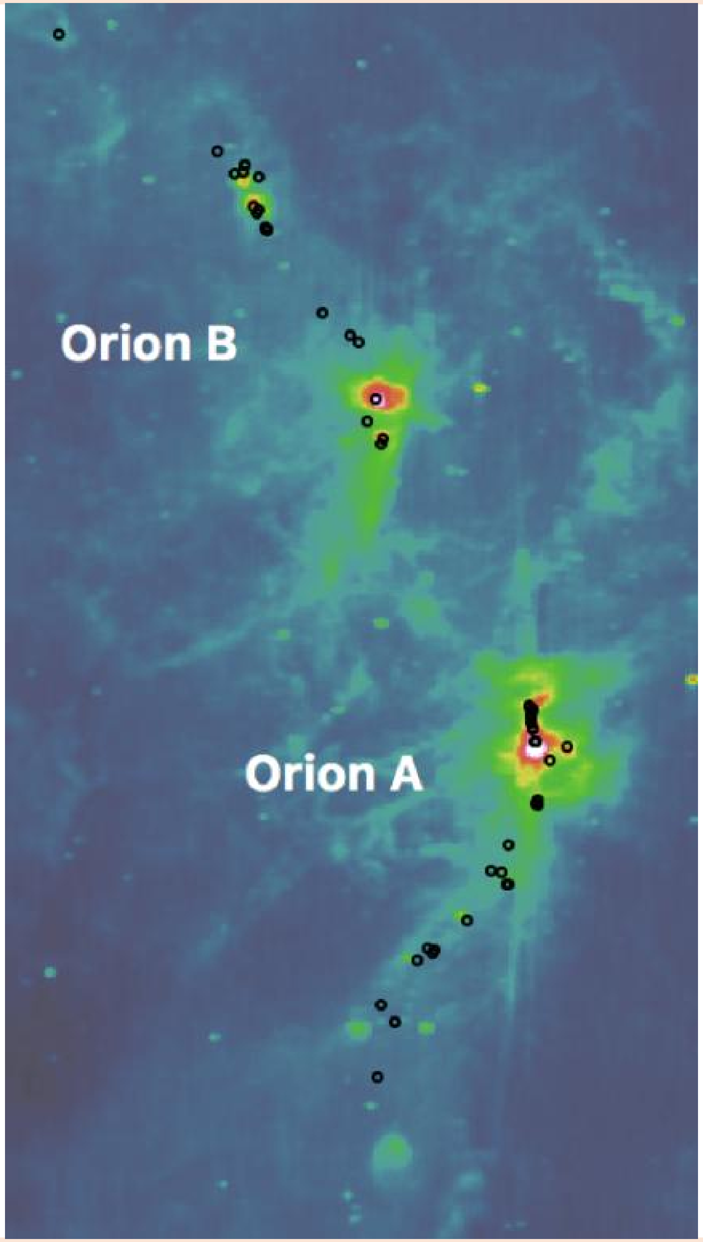
1. Different evolutionary stages,
2. Different observational spatial resolutions, and
3. Different star-forming conditions

Why Orion?

- Requires a survey of sources in a single region that has typical star-forming conditions

- OMC has a typical mode of Galactic star formation, with following advantages (e.g. Kounkel et al. 2017) :
  1. It is more dynamic than low-mass star-forming regions
  2. It is the closest massive star-forming region (412±6 pc)
  3. It is a well-studied part of a large molecular cloud complex
  4. It has the largest population of Class 0 protostars within 500 pc

- BOPS: B-Field Orion Protostellar Survey (PI: Ian Stephens)
  - Band 7 polarization survey
  - 58 young protostellar objects
  - Scales: 400~2,000 au



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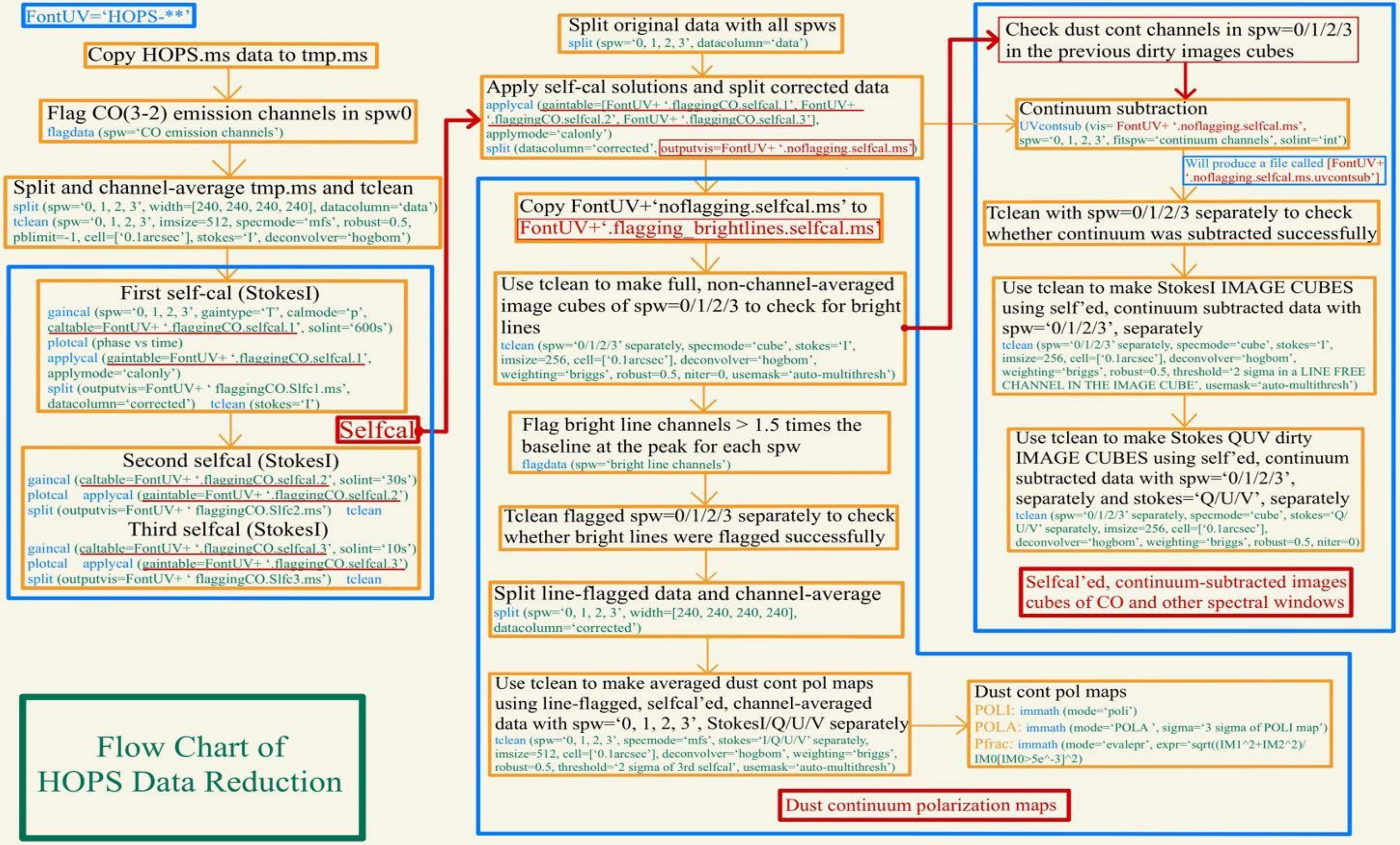
Observation

- 1. Time: 13.5h (ALMA, 12m Array, 43 antennas)

- 2. Resolution: 1´´ (~400 au)

- 3. Continuum spectral setup:
  - Spw1----Center freq: 345.79599 GHz, Bandwidth: 468.75 MHz [^{12}CO (3-2)]
  - Spw2----Center freq: 348.50000 GHz, Bandwidth: 1875.00 MHz
  - Spw3----Center freq: 334.50000 GHz, Bandwidth: 1875.00 MHz
  - Spw4----Center freq: 336.50000 GHz, Bandwidth: 1875.00 MHz [C^{17}O (3-2)]

Data Reduction



Data Reduction

In CASA 5.4:

- 1. Self-calibration: improve the quality of images
  - tclean set: deconvolver--hogbom, weighting--briggs, robust--0.5
  - 3 iterations

- 2. Dust continuum and polarized emission
  - apply self-calibration solutions to the original data
  - flag bright line channels
  - tclean set: deconvolver--hogbom, weighting--briggs, robust--0.5

- 3. Image cubes
  - apply self-calibration solutions to the original data
  - subtract continuum channels
  - tclean set: deconvolver--hogbom, weighting--briggs, robust--0.5

Polarization intensity:

$$P = \sqrt{Q^2 + U^2 - \sigma^2_{Q/U}}$$

Polarization angle:

$$\theta = 0.5 \cdot arctan(U/Q)$$

Fractional Polarization:

$$P_{frac} = P/I$$

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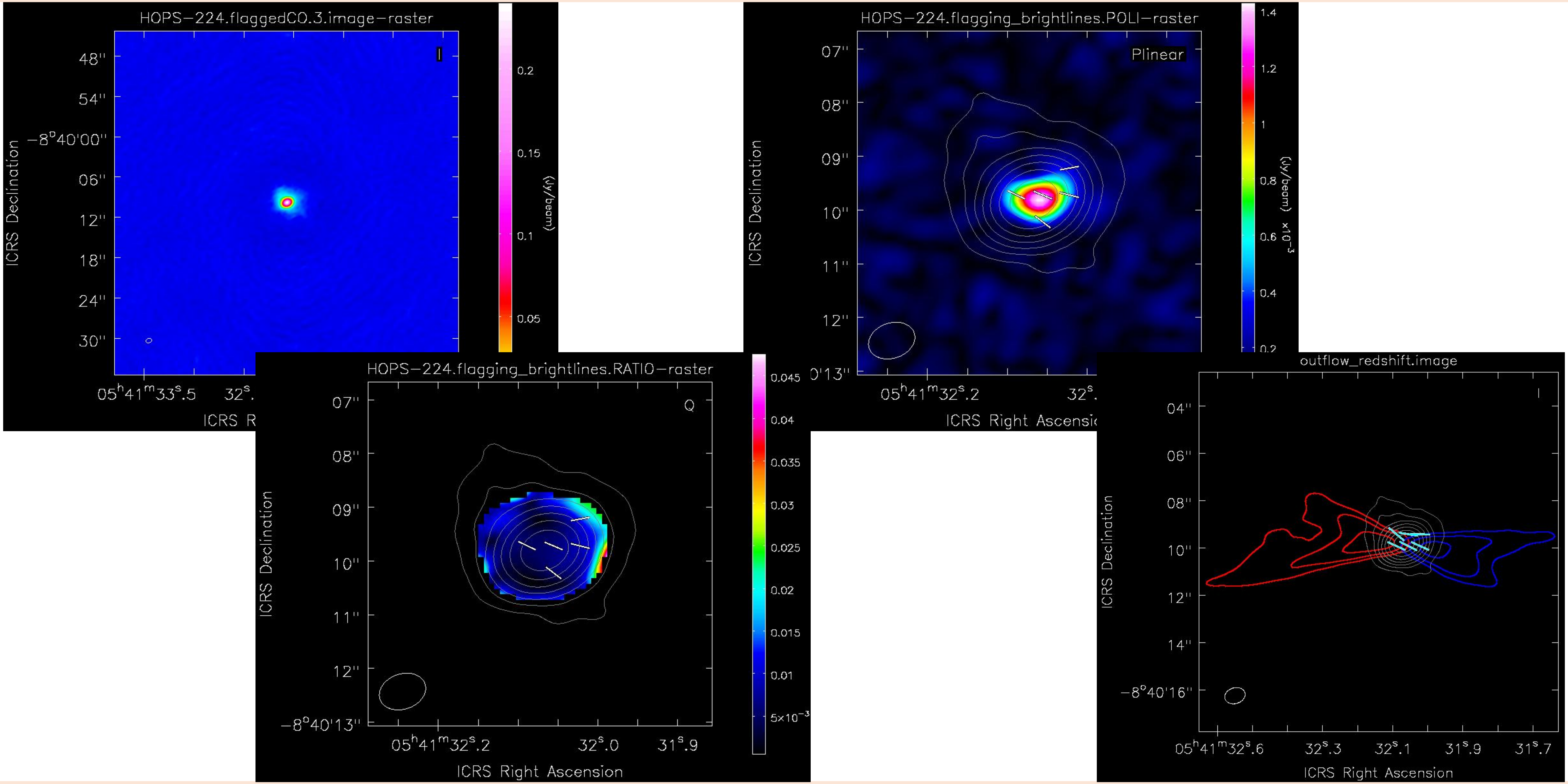
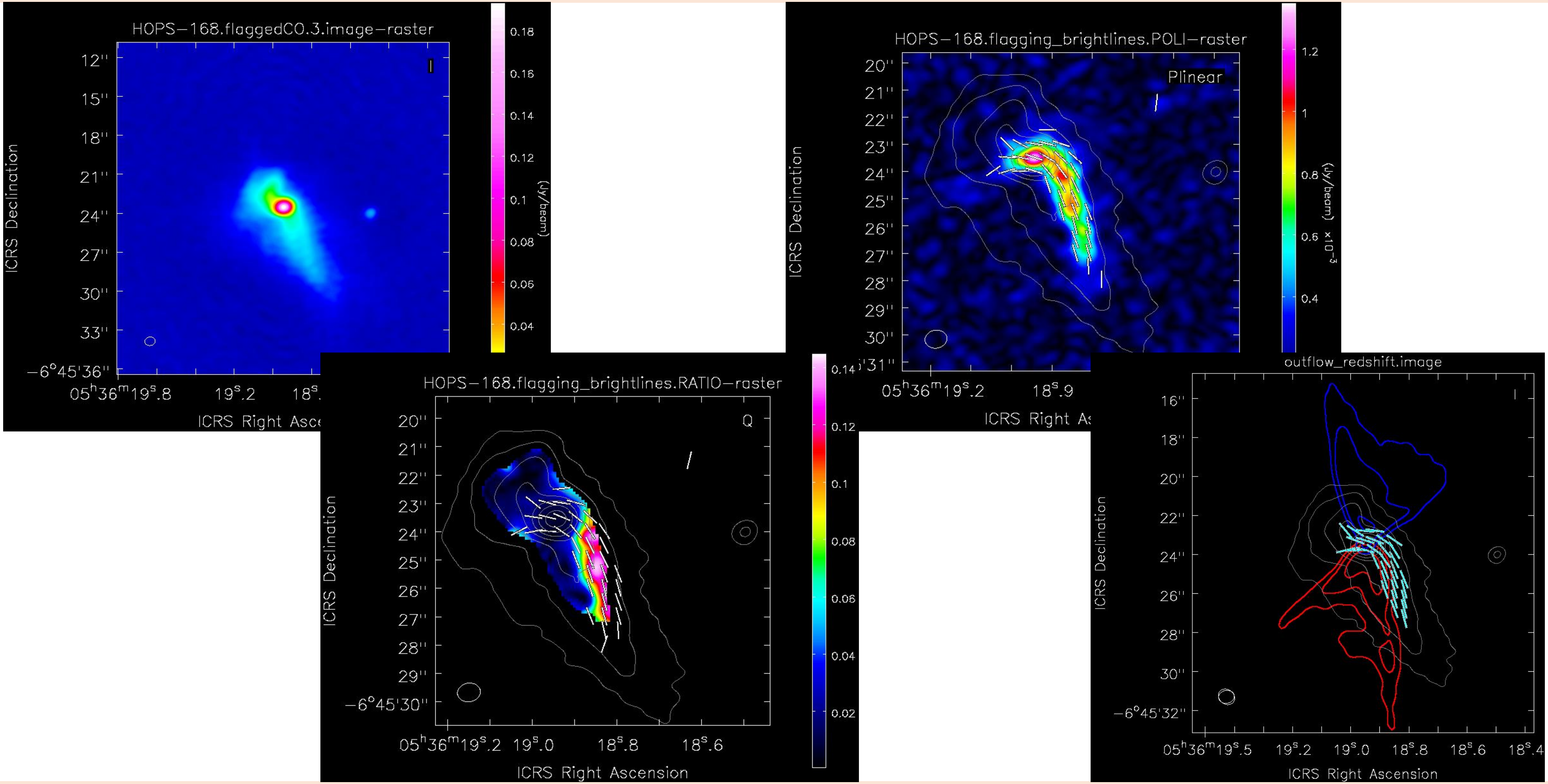
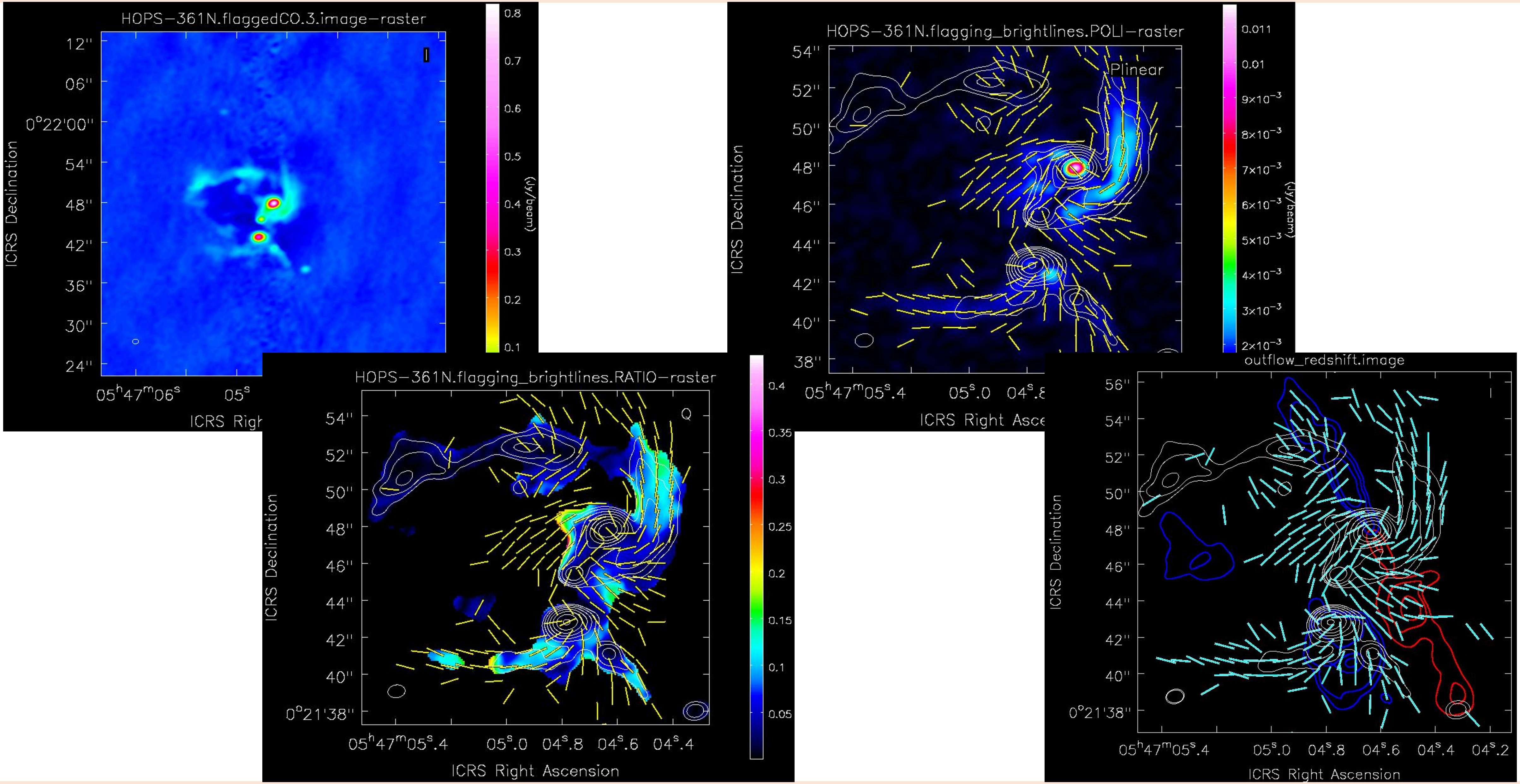
Point Source



Extended Source

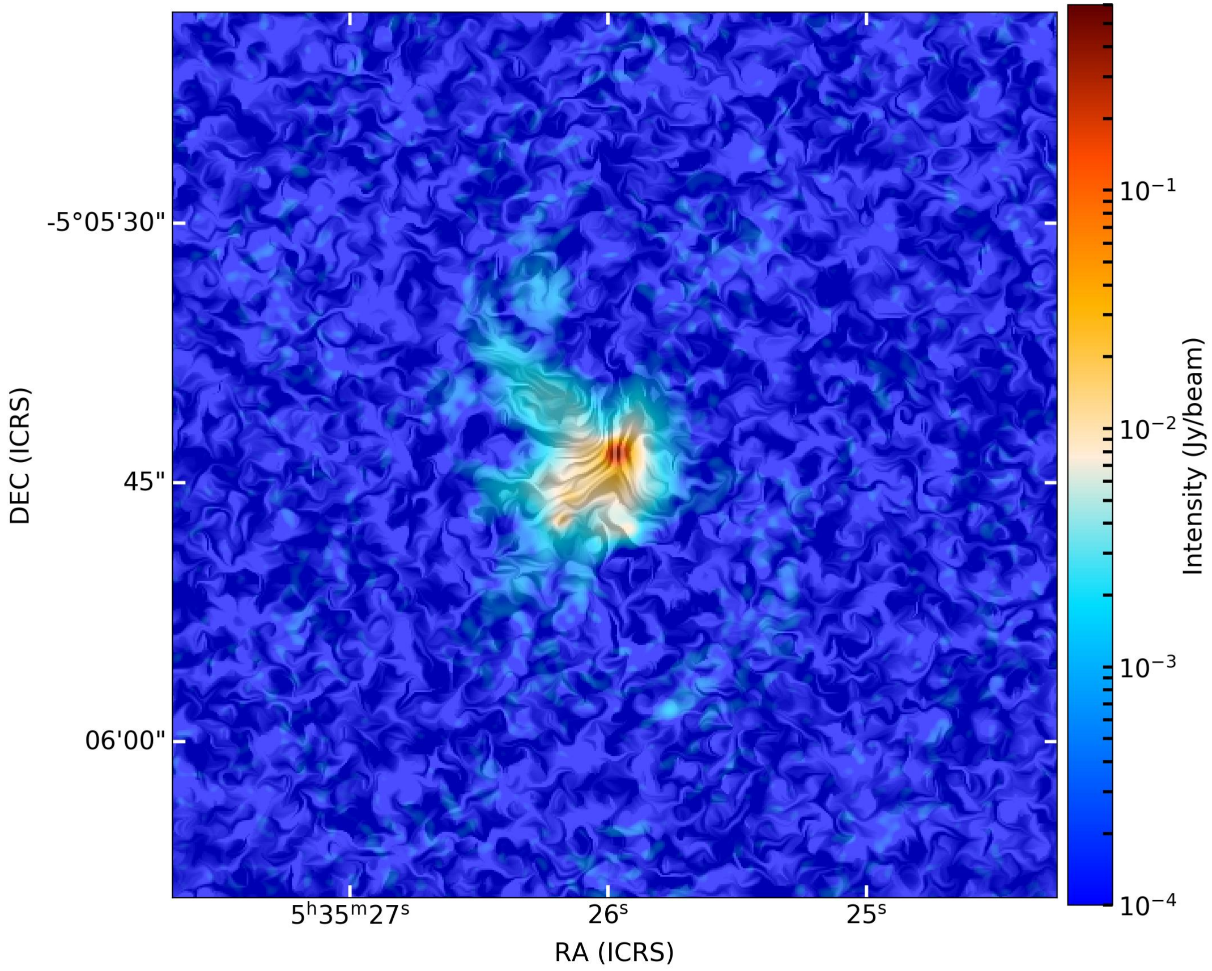


Binary

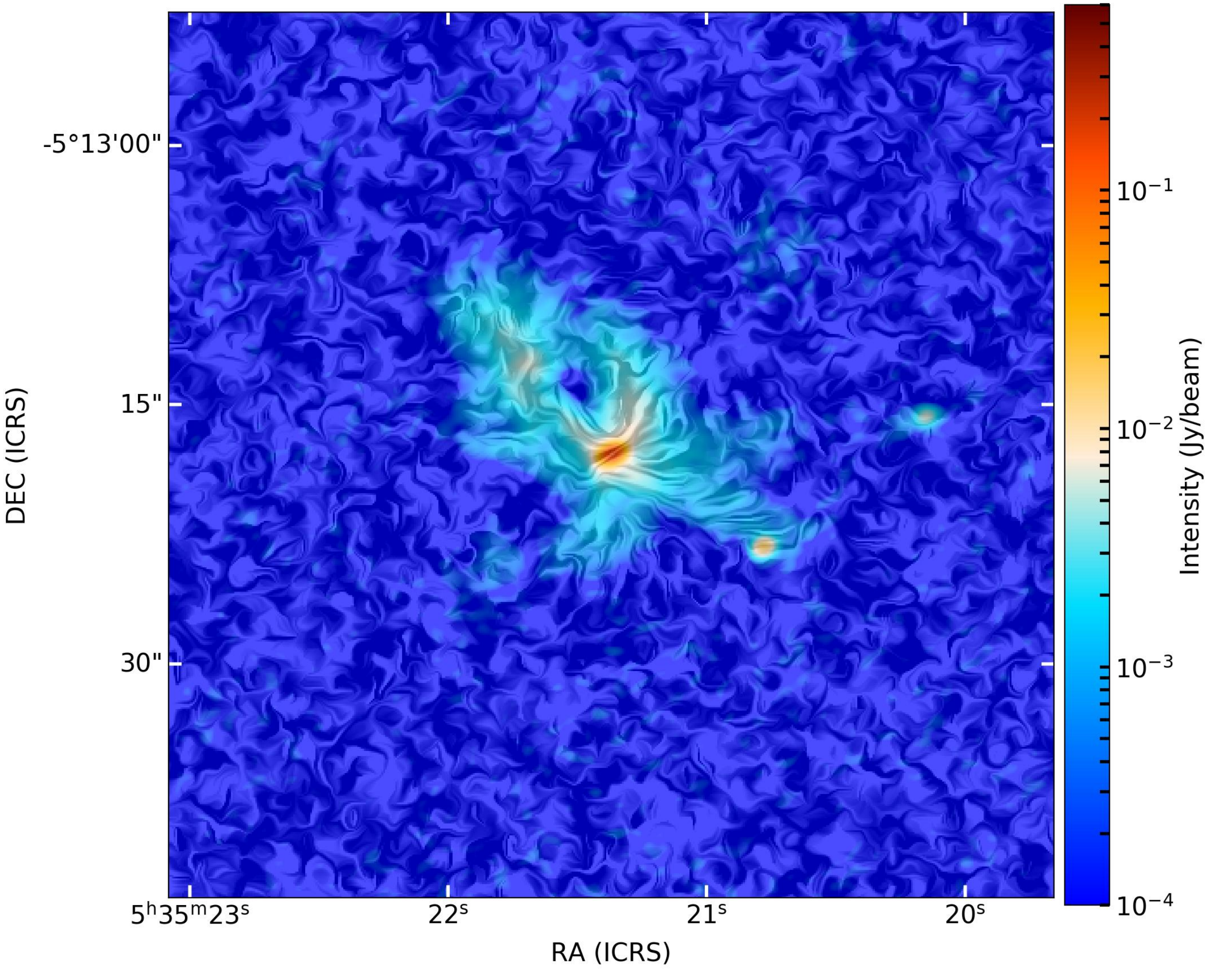

HOPS−361N.flaggedCO.3.image−raster
ICRS Declination
ICRS Right Ascension
(Jy/beam)
I
HOPS−361N.flagging_brightlines.POLI−raster
Plinear
HOPS−361N.flagging_brightlines.RATIO−raster
Q
outflow_redshift.image
0°21'38"
05h47m05s.4
05s.0
04s.8
04s.6
04s.4
04s.2

B-field on Scales of ~10^3 au

HH270IRS



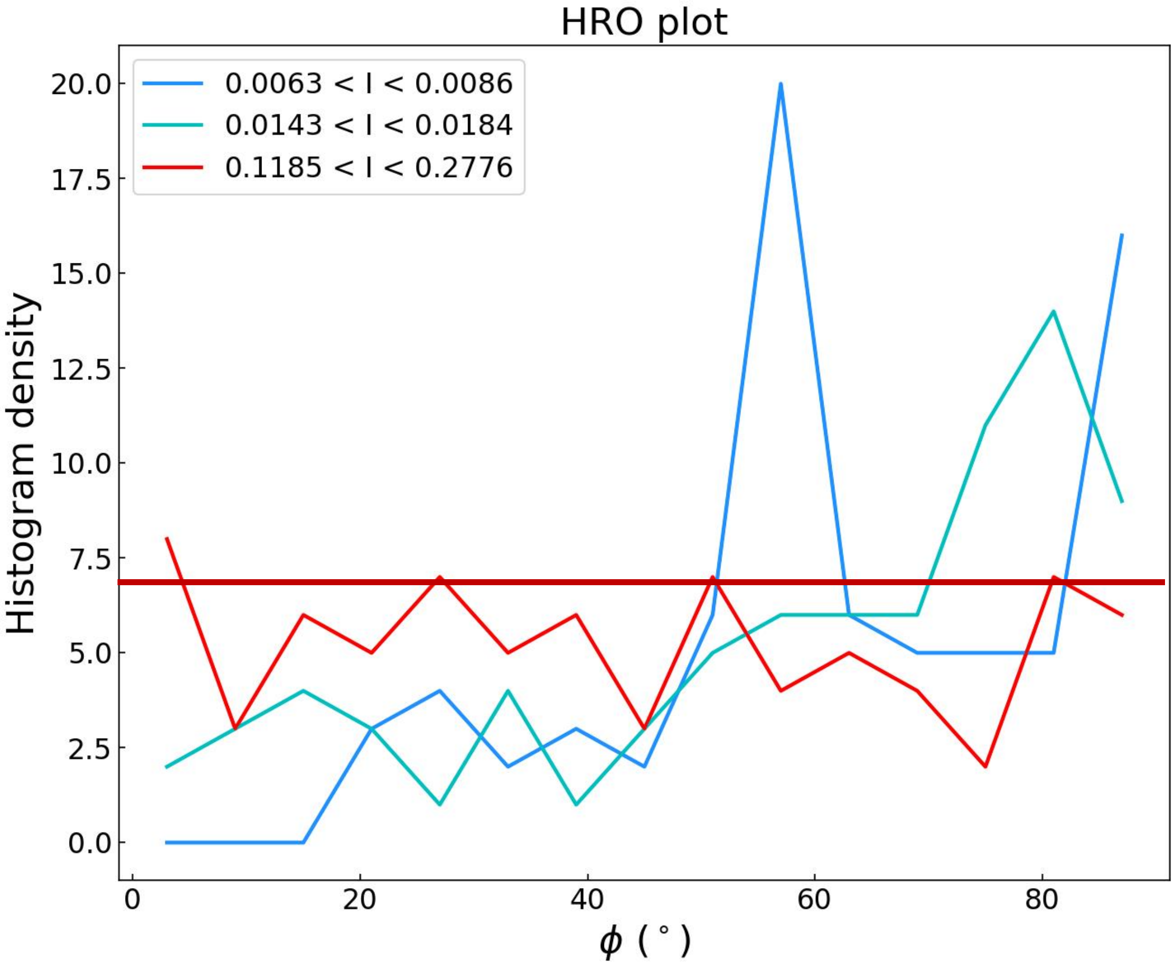
HOPS-409



B-field tend to be aligned with intensity structure.

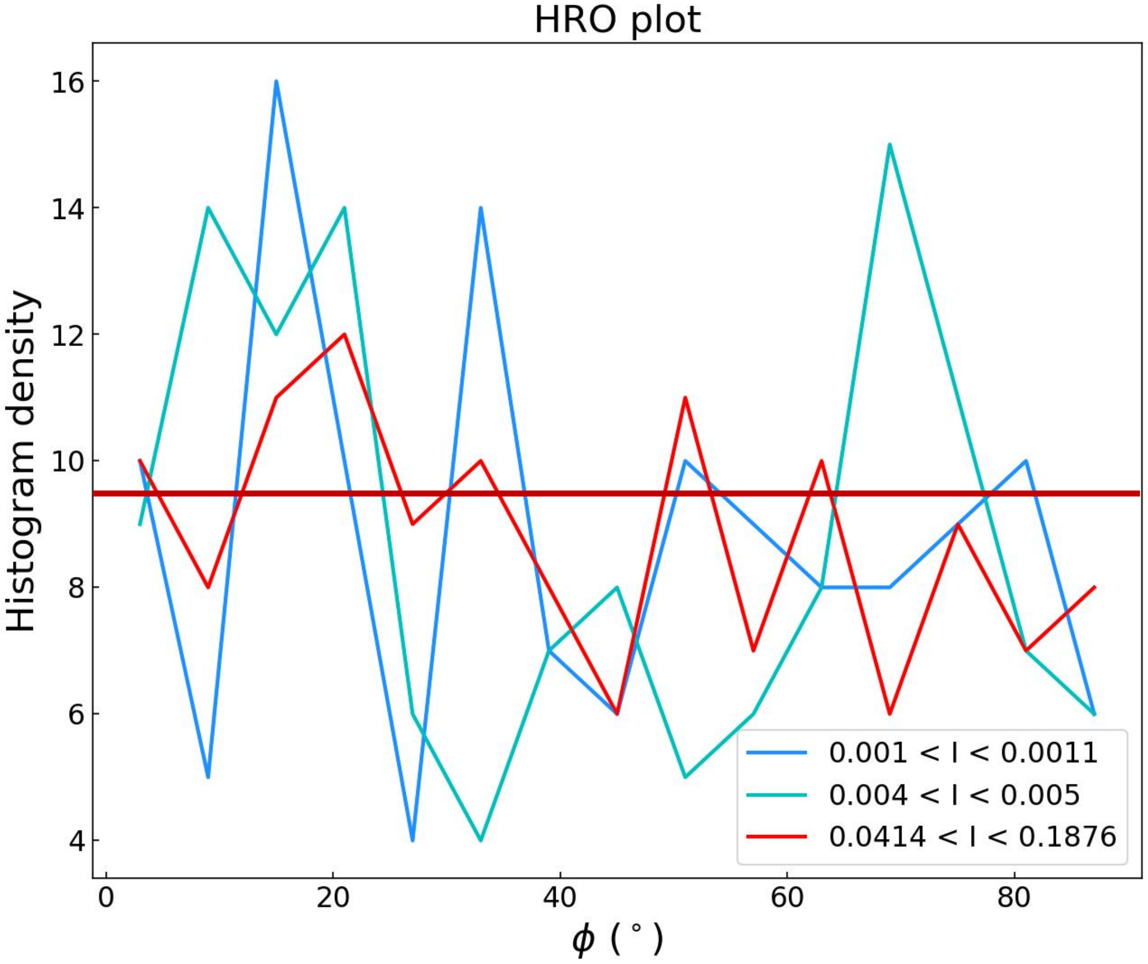
B-field on Scales of ~10^3 au

HH270IRS



Low- and intermidiate intensity: perpendicular
High-intensity: randomly align

HOPS-409

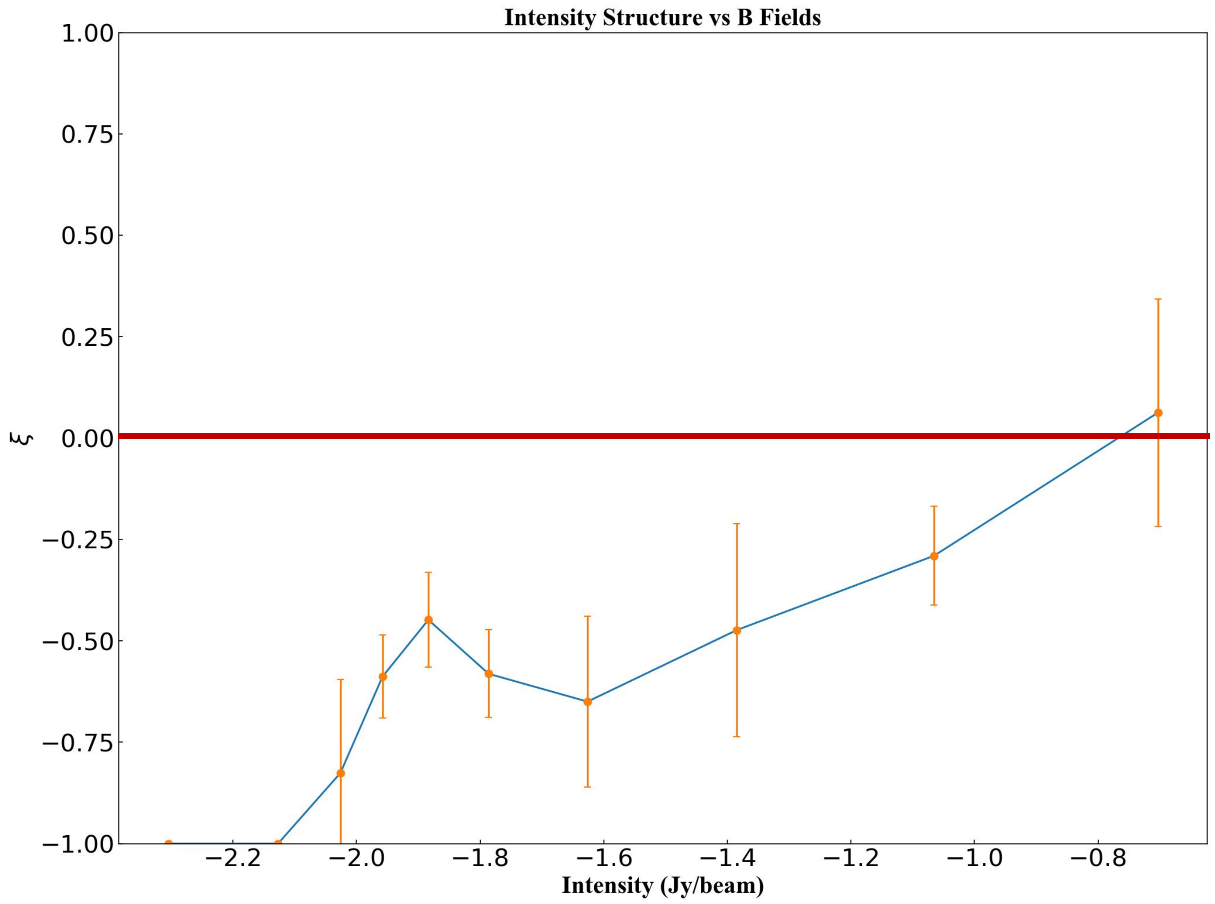


Each bin: weakly parallel

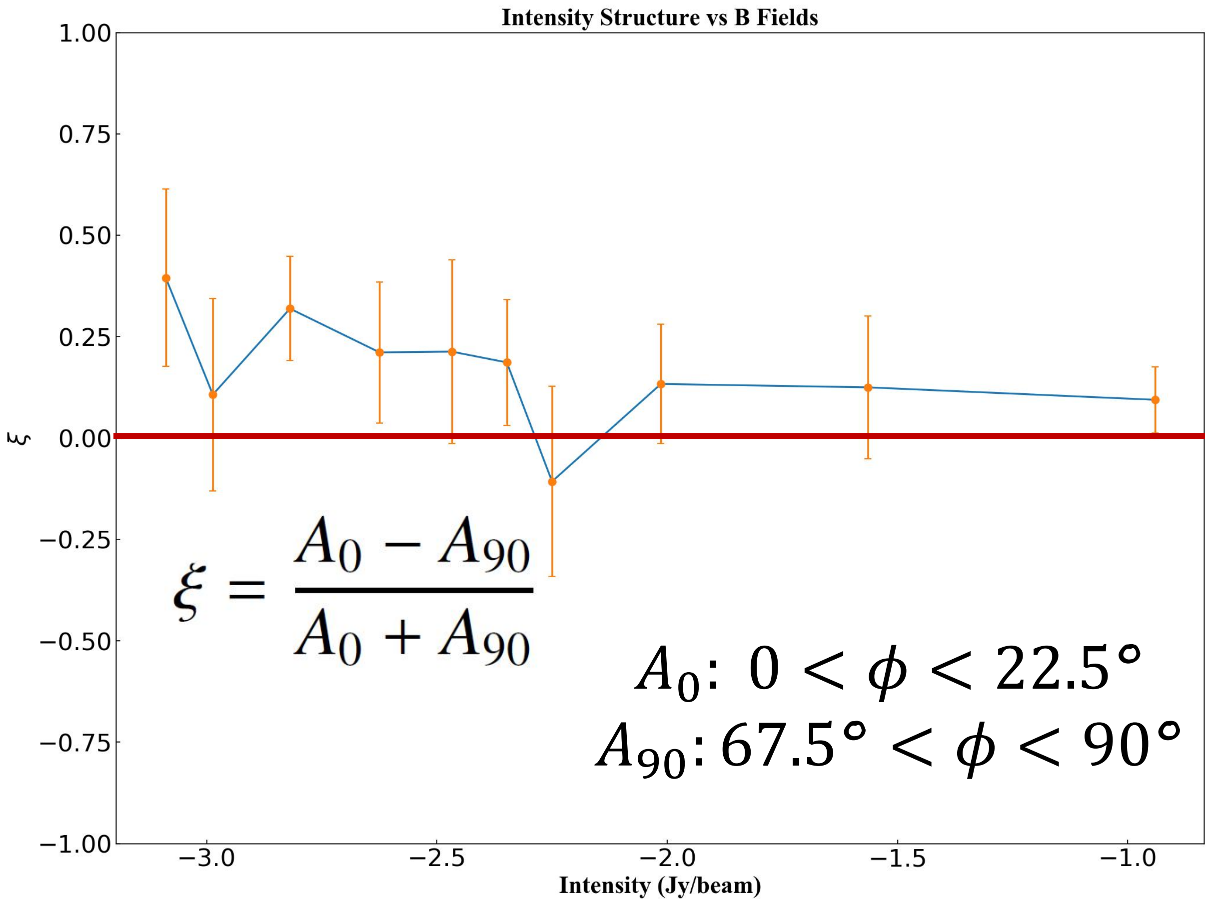
Soler et al., 2017

B-field on Scales of ~10³ au

HH270IRS



HOPS-361N



$$\xi = \frac{A_0 - A_{90}}{A_0 + A_{90}}$$

A_0: $0 < \phi < 22.5°$

A_{90}: $67.5° < \phi < 90°$

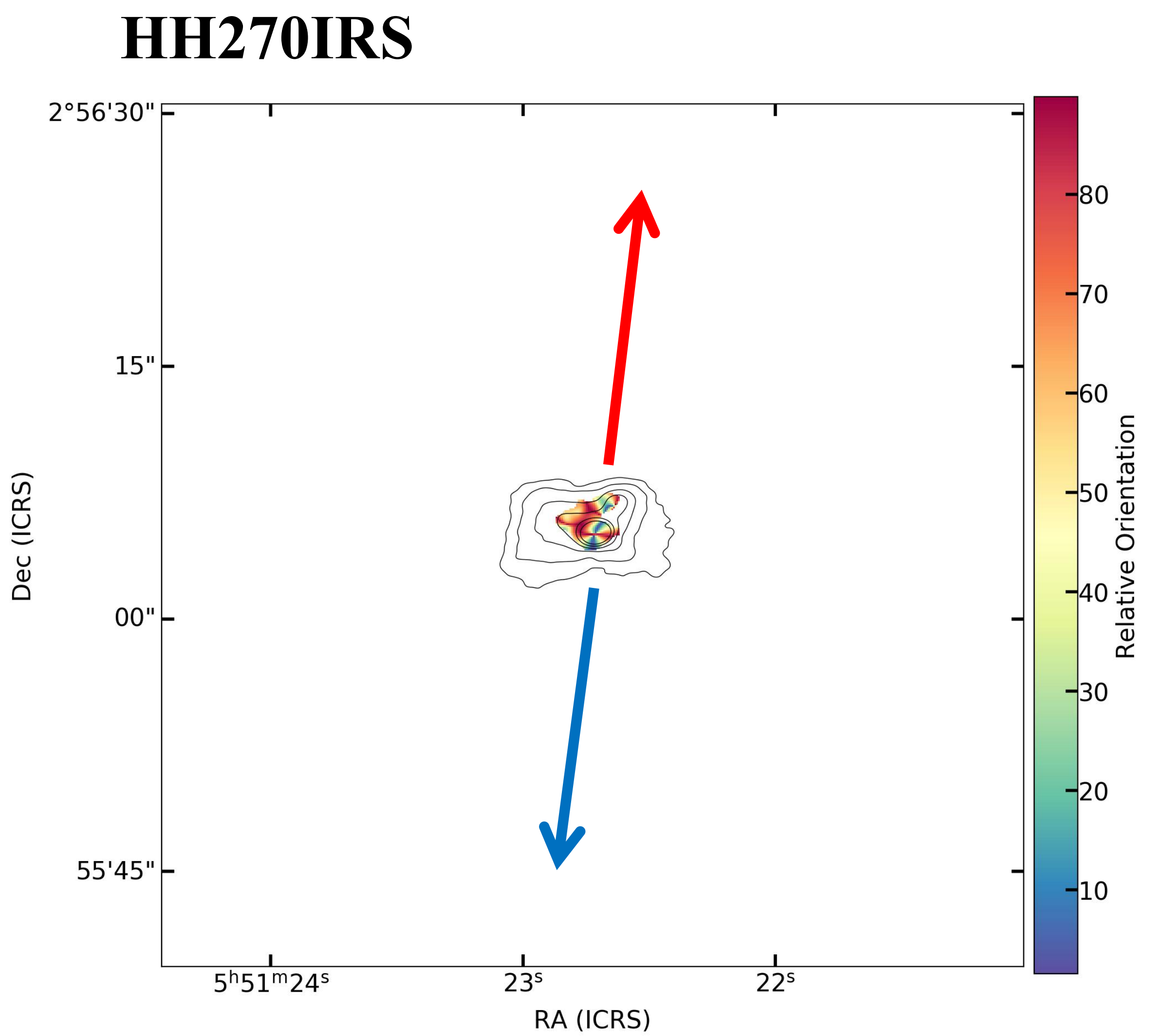
Low- and intermidiate intensity: perpendicular

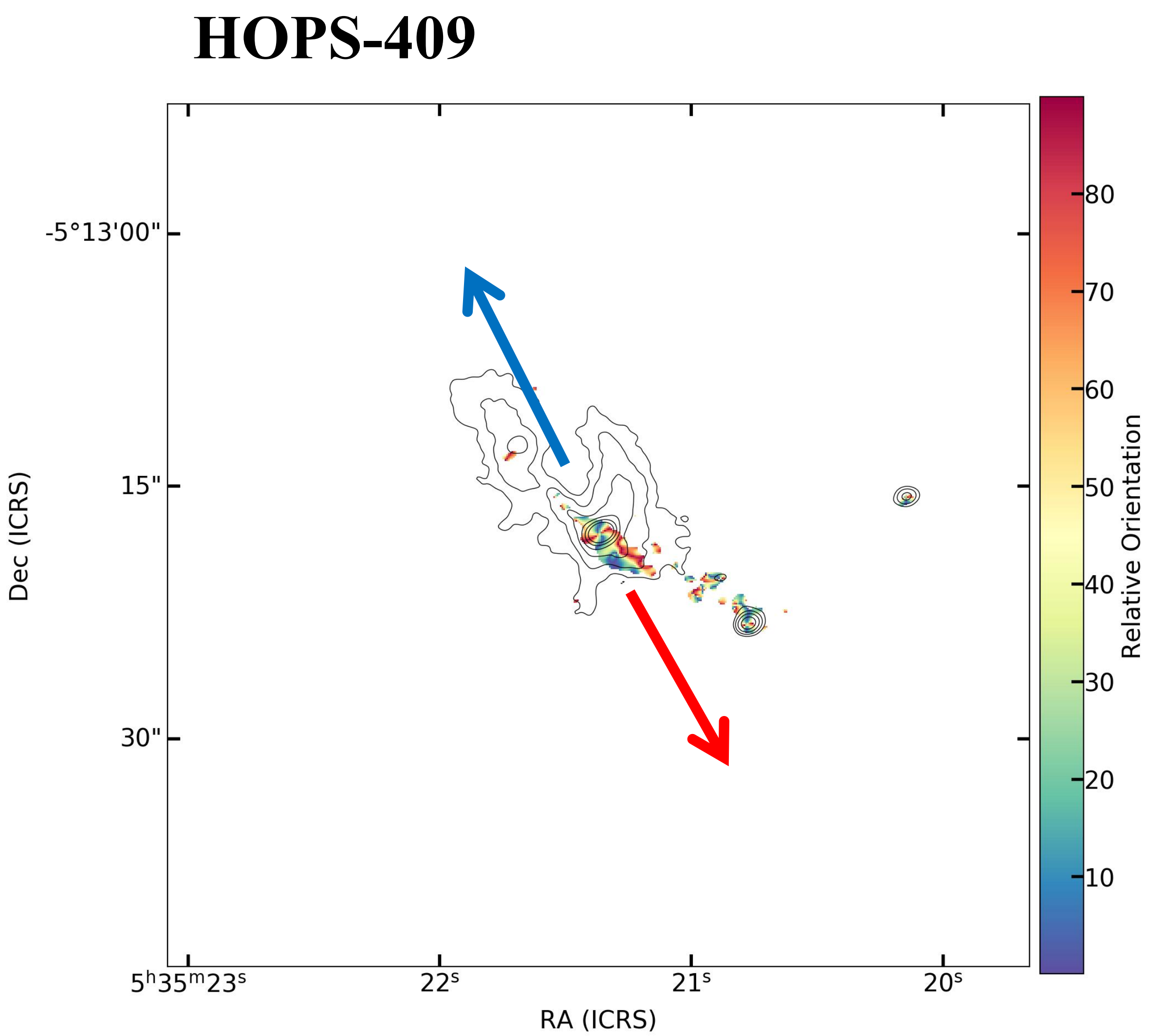
High-intensity: randomly align

Each bin: weakly parallel

Soler et al., 2017

B-field on Scales of ~10^3 au

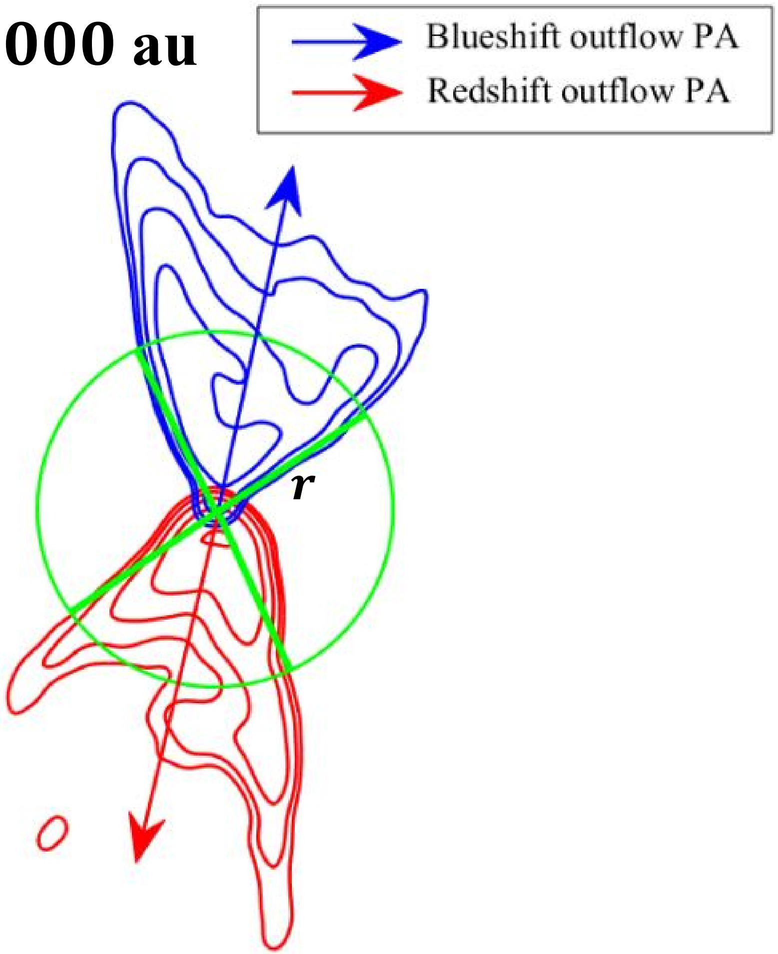




B-field is coupled with outflows, ... (in progress)

while in other regions, B-field tend to be perpendicular to the intensity structure.

$r = 1000$ au



Estimate the outflow direction:

1. Connect the source center and the two edges of outflows;

2. Take the bisector of the angle intersected by two peak-edge lines as the outflow position angle.

3. Take the average of redshift and blueshift position angles as the outflow direction.

B-field Direction

- Total-intensity-weighted PA of polarization: $\langle \chi \rangle = 0.5 \cdot \arctan\left(\frac{\sum_i (U_i I_i) / \sum_i \mathrm{I}_i}{\sum_i (Q_i I_i) / \sum_i \mathrm{I}_i}\right)$

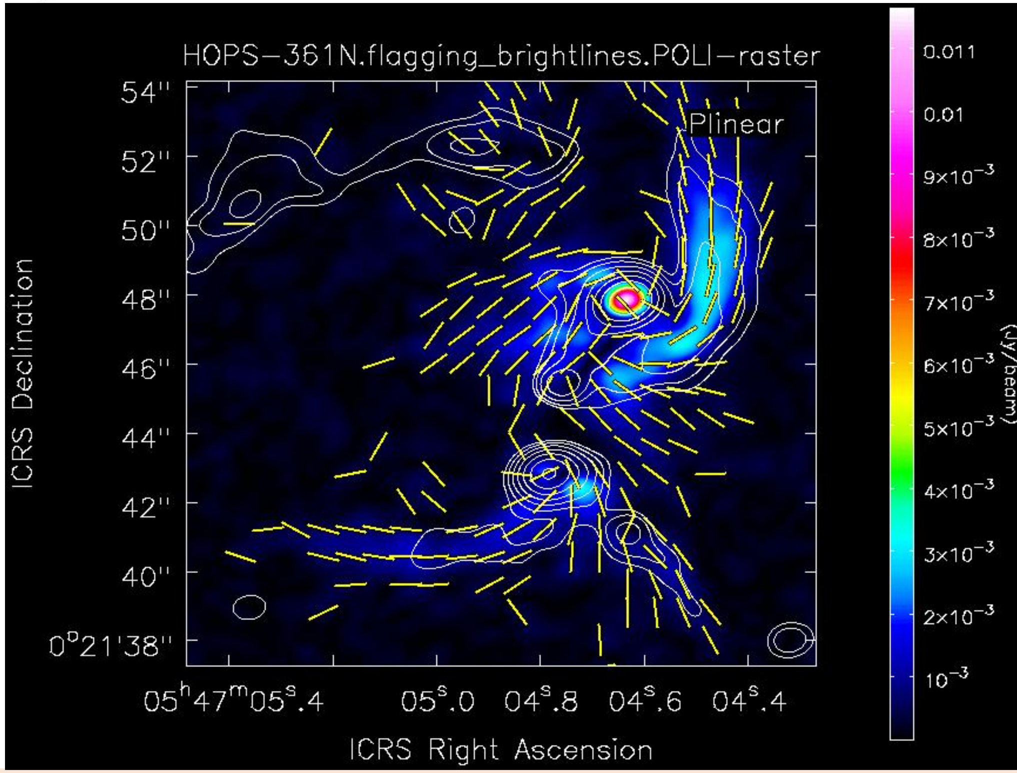
  (C. Hull et al. 2013, 2014)

- Error-weighted PA of polarization: $\Delta_{\chi_i} = \sqrt{\left(\frac{\partial \chi_i}{\partial Q_i}\right)^2 \cdot \Delta_Q^2 + \left(\frac{\partial \chi_i}{\partial U_i}\right)^2 \cdot \Delta_U^2}$ $\quad \Delta_{\chi_i} = \Delta Q / (2\sqrt{Q_i^2 + U_i^2})$

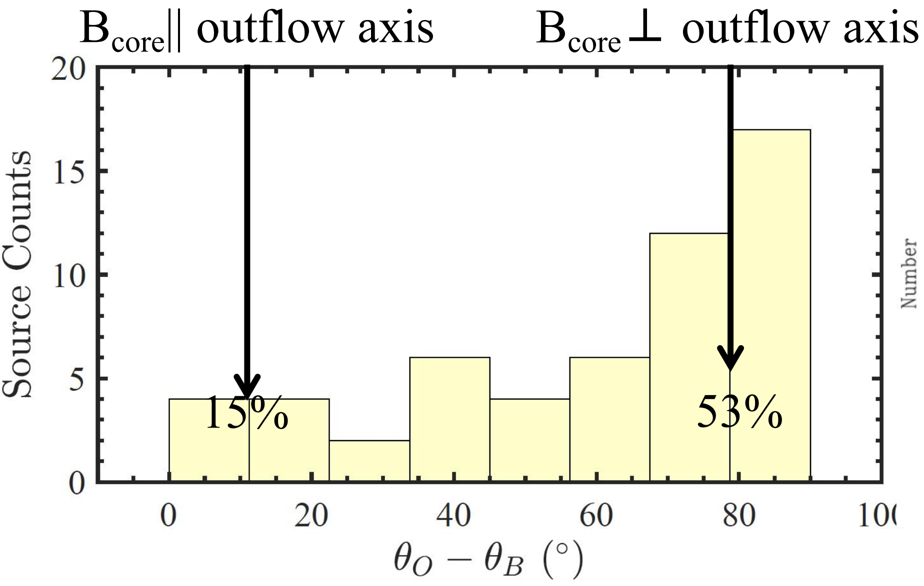
$$\langle Q \rangle_{\Delta_\chi} = \frac{\sum_i Q_i / \Delta_{\chi_i}^2}{\sum_i 1/\Delta_{\chi_i}^2}, \qquad \langle U \rangle_{\Delta_\chi} = \frac{\sum_i U_i / \Delta_{\chi_i}^2}{\sum_i 1/\Delta_{\chi_i}^2}$$

$$\langle \chi \rangle = 0.5 \cdot \arctan\left(\frac{\langle U \rangle_{\Delta_\chi}}{\langle Q \rangle_{\Delta_\chi}}\right)$$

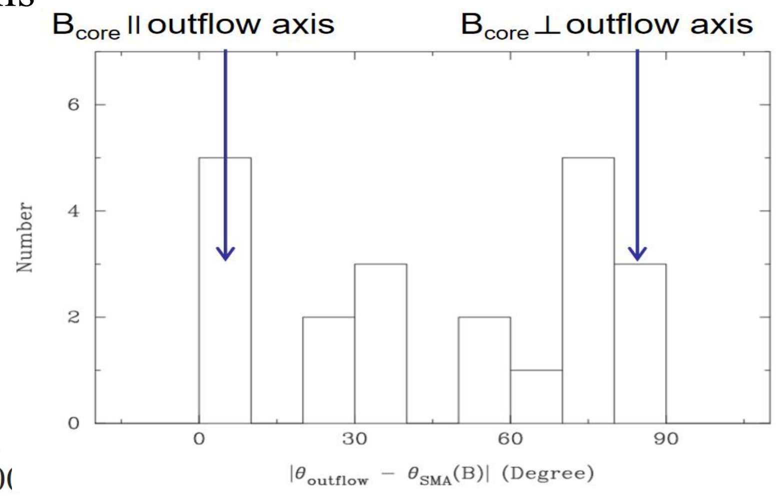
- Weighted polarization angle rotates by 90° to infer B-field direction.



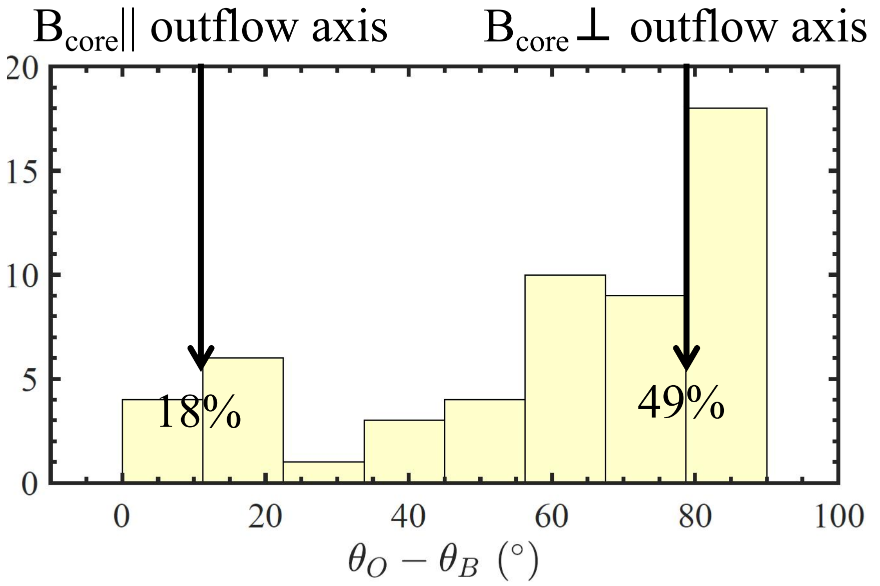
Outflow VS B-Field (Scales: $10^2 \sim 10^3$ au)



Intensity-weighted



(Zhang et al. 2014)



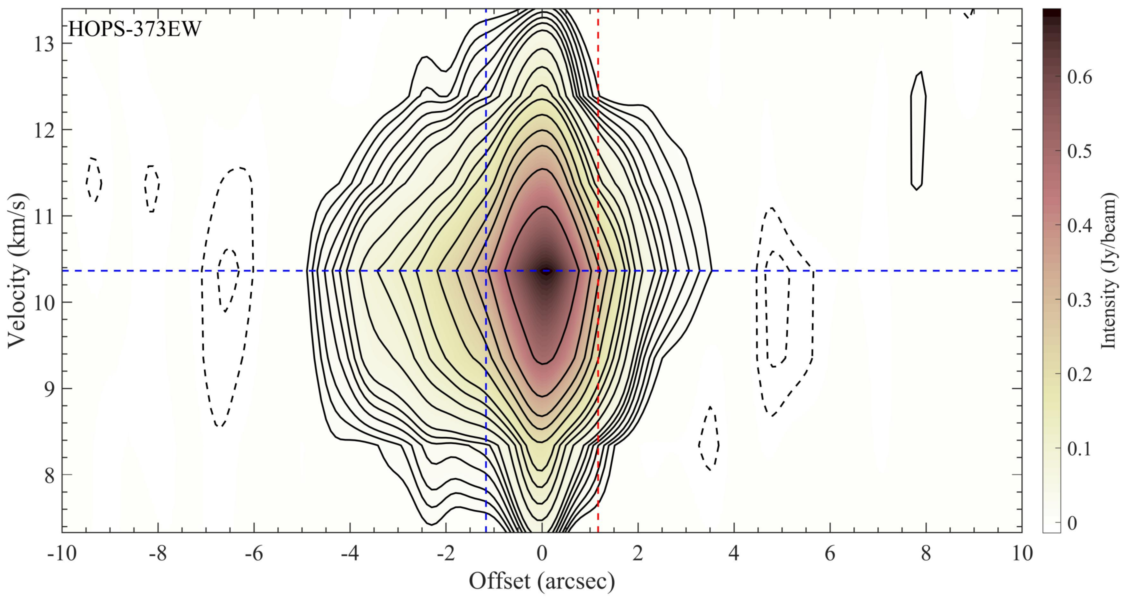
Error-weighted

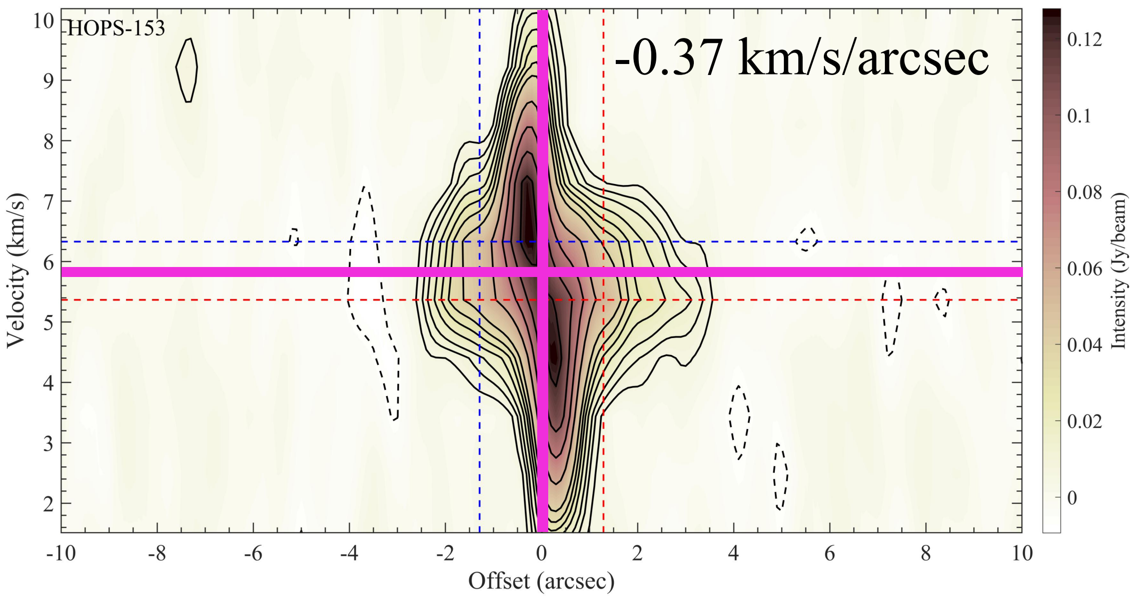
Weak correlation: ~50% of the sources show that B-field tend to be perpendicular to the outflow.

B-field may have an impact in setting the angular momentum of embeded envelopes and outflows.

Envelope Rotation

- The velocity field of the envelope is traced by $C^{17}O$ (3-2)
- P-V diagram: shows the infall and rotation motion of the envelope
  - direction: ⊥outflow
  - center: peak position





- Absolute velocity gradient (1 source are thought to be starless core, 2 sources do not have clear outflows)

  =0: do not have clear rotation (30/55)   ≠ 0: envelope rotation (25/55)

Velocity Gradient (VG)

- For 25 sources with clear envelope rotation, their velocity gradients are calculated from the moment 1 map using least squares fitting the following function:

$$v_{lsr} = v_\alpha \Delta\alpha + v_\delta \Delta\delta + v_0$$

- the direction and magnitude of velocity gradient in each pixel is calculate by:

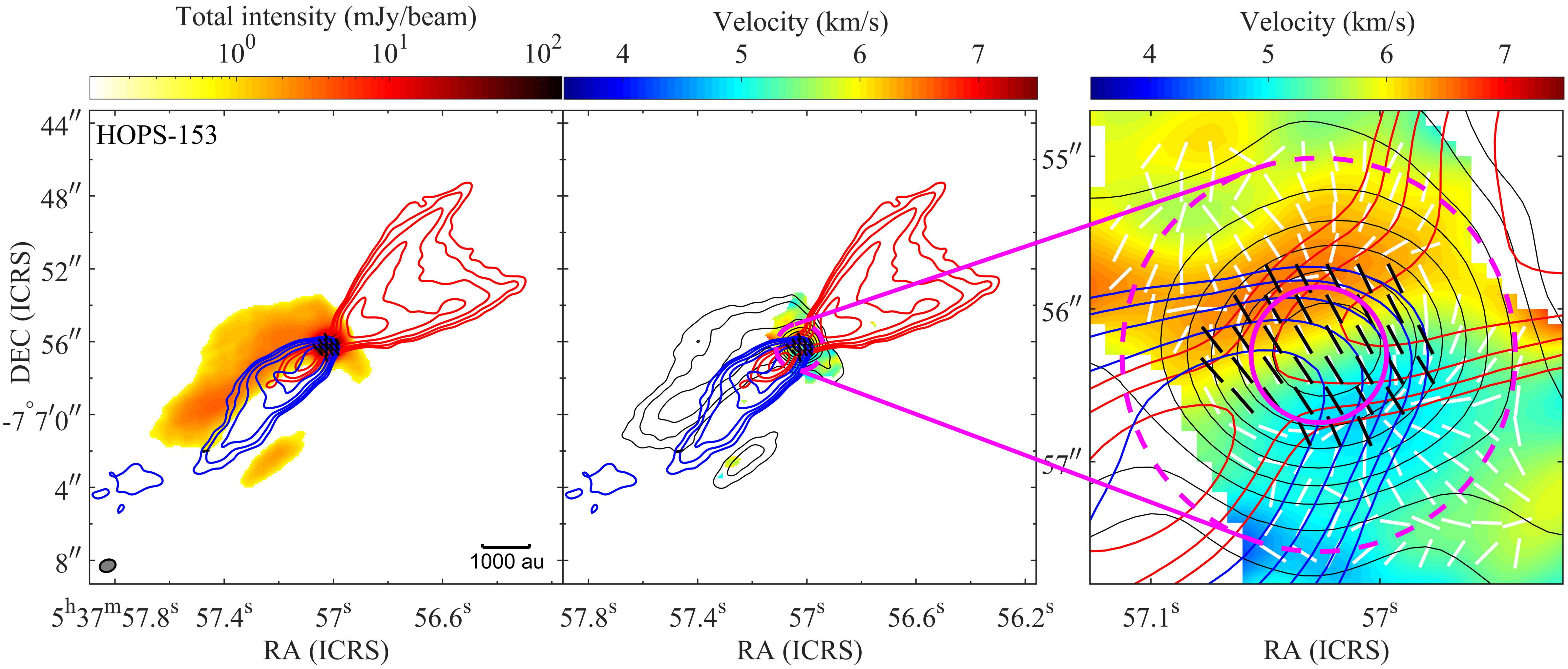
$$\theta_v = arctan(v_\delta / v_\alpha), \qquad W_v = \sqrt{v_\alpha^2 + v_\delta^2}$$

- Then PA of VG is weighted by $W(i\,,j) = \sqrt{v_i^2(i,j) + v_j^2(i,j)}$:

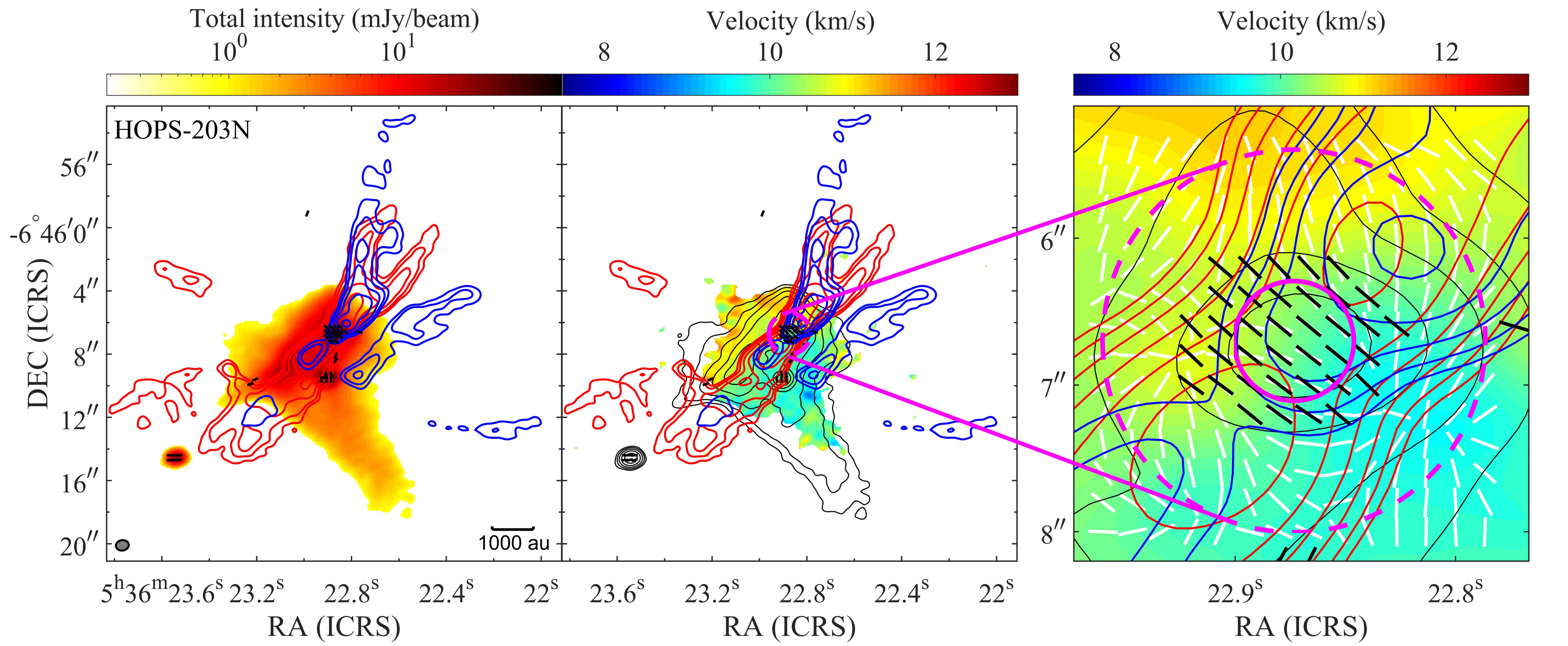
$$\langle\theta_v\rangle_w = \sum_{ij}[\theta_{VG}(i,j) \cdot W^2(i,j)] \big/ \sum_{ij} W^2(i,j)$$

- Velocity gradient *vs* outflow direction：
  - Type I: Perpendicular (67.5°≤$|\theta_{outflow}-\theta_{VG}|$≤90°): 17/55
  - Type II: Random alignment ($|\theta_{outflow}-\theta_{VG}|$≤67.5°): 8/55
  - Type III: Non-distinct rotation: 30/55

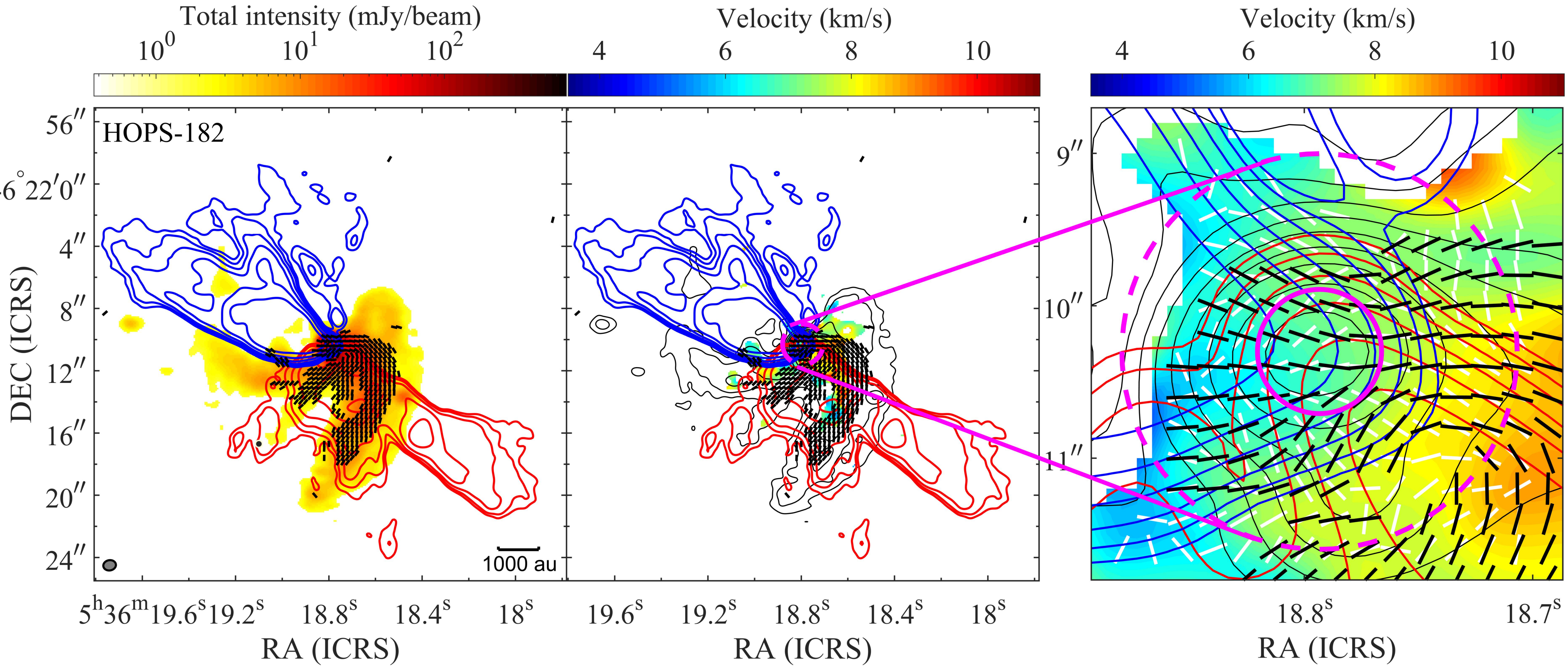
Type I: Velocity Gradient ⊥ Outflow Direction (17/55)



Type I: Velocity Gradient ⊥ Outflow Direction (17/55)



Type II: Velocity Gradient Random Alignment with Outflow Direction (8/55)



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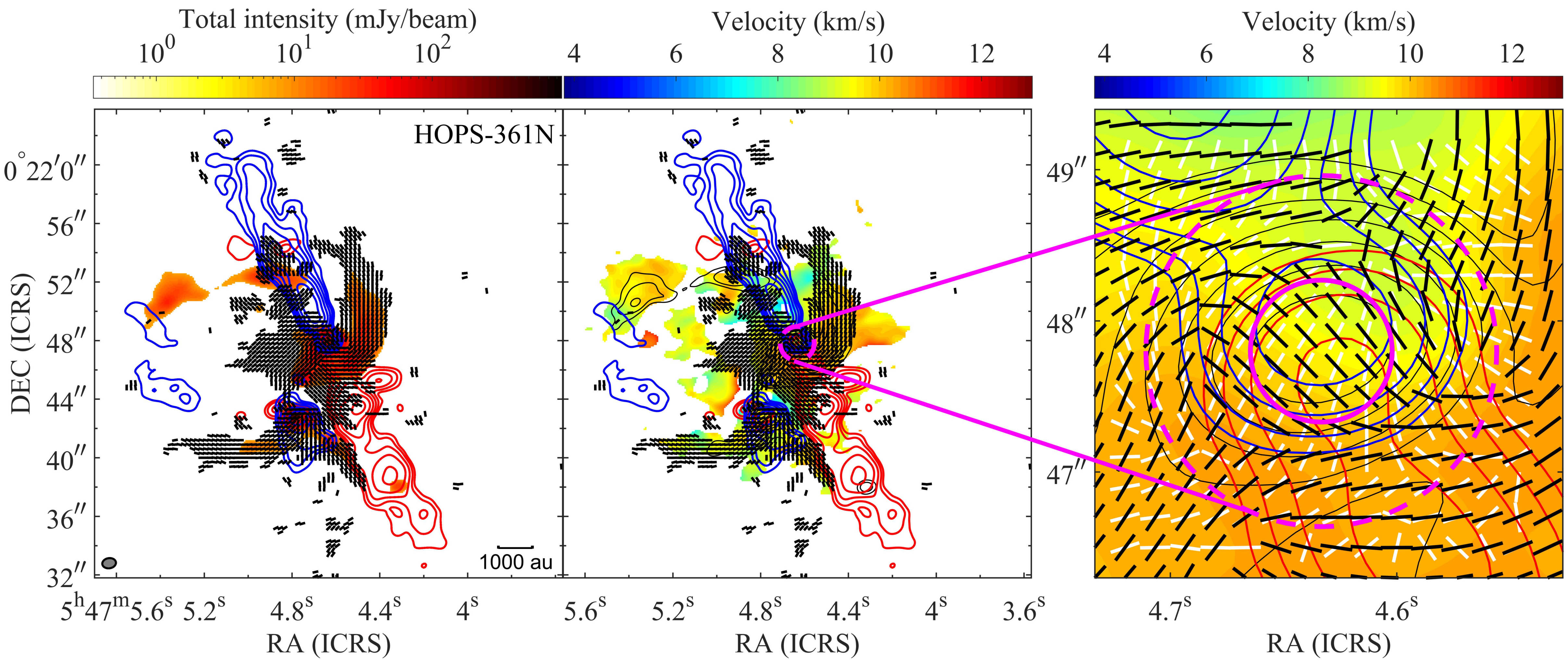
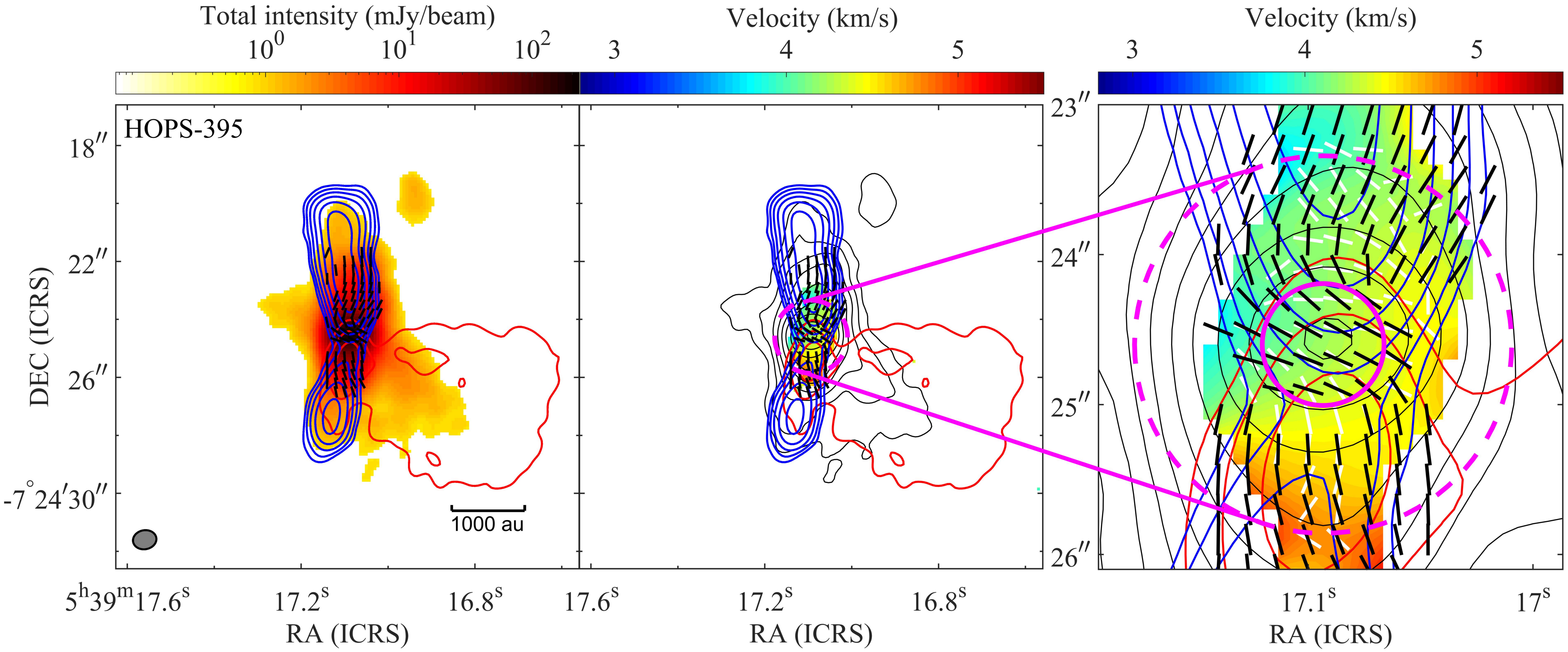


Type III: Non-Distinct Velocity Gradient (30/55)

B-field shows hourglass structure (20% of the sources)



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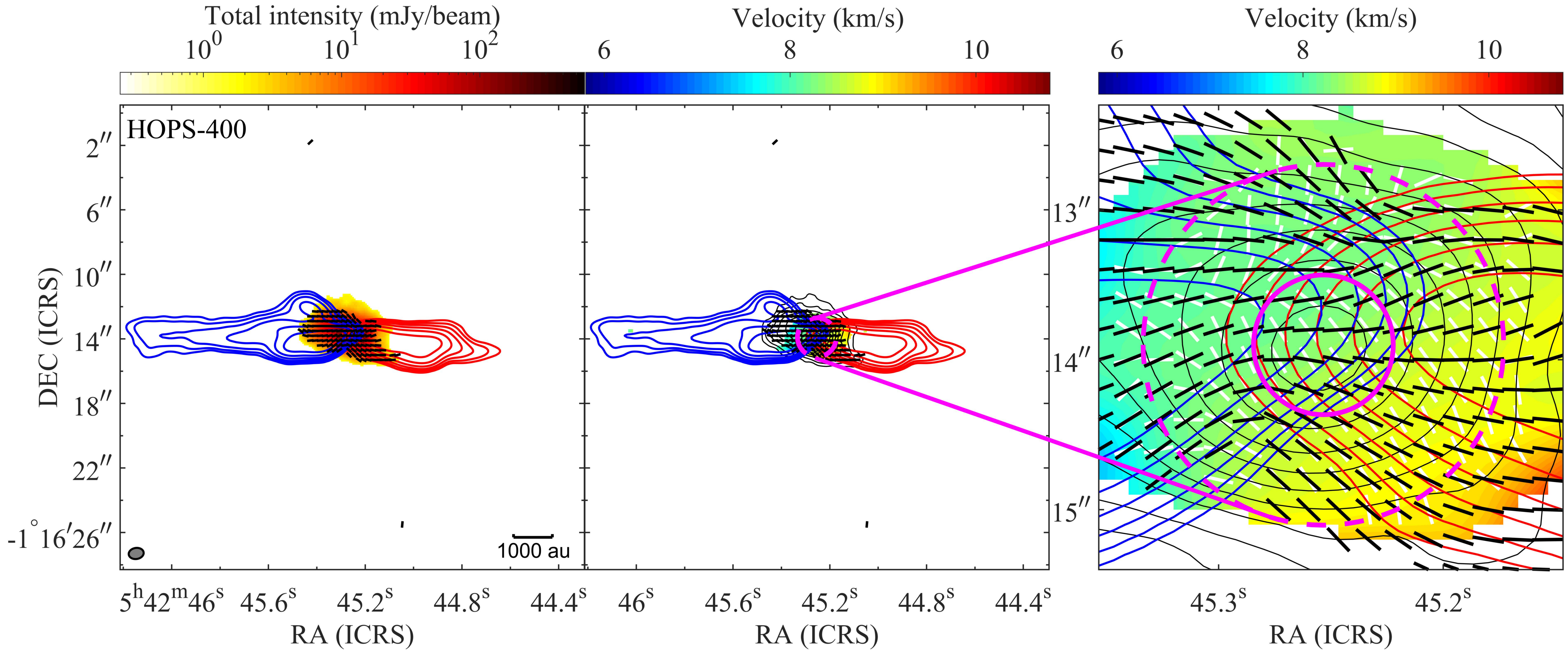
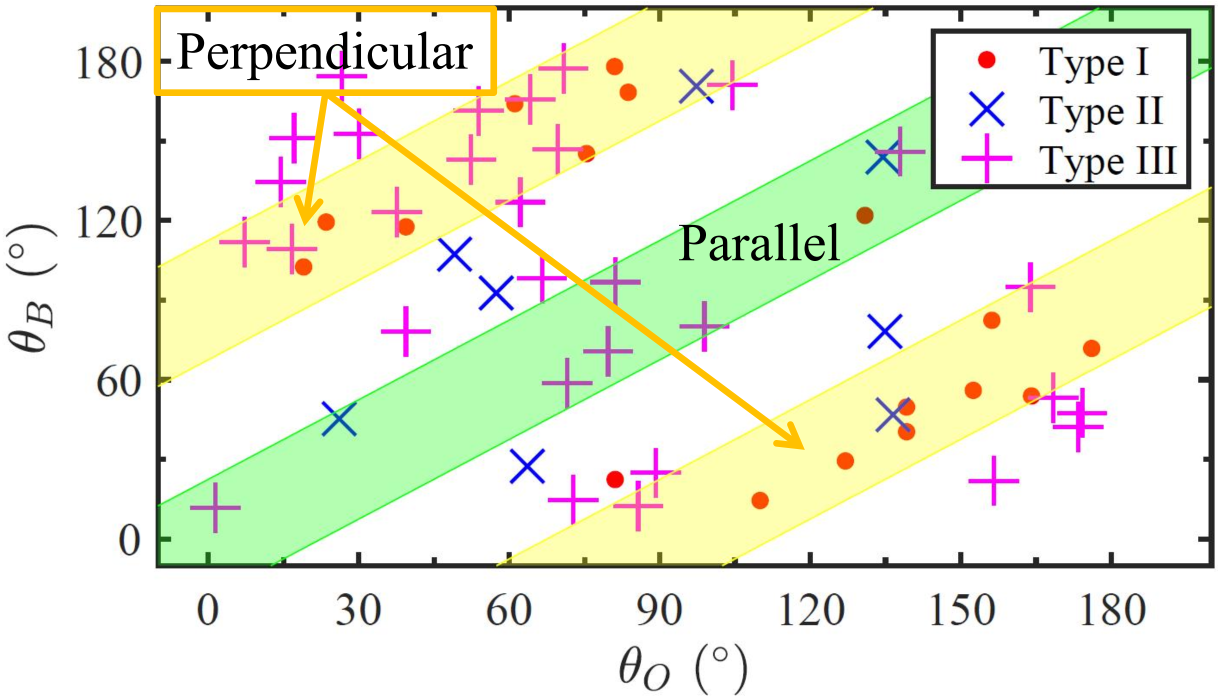
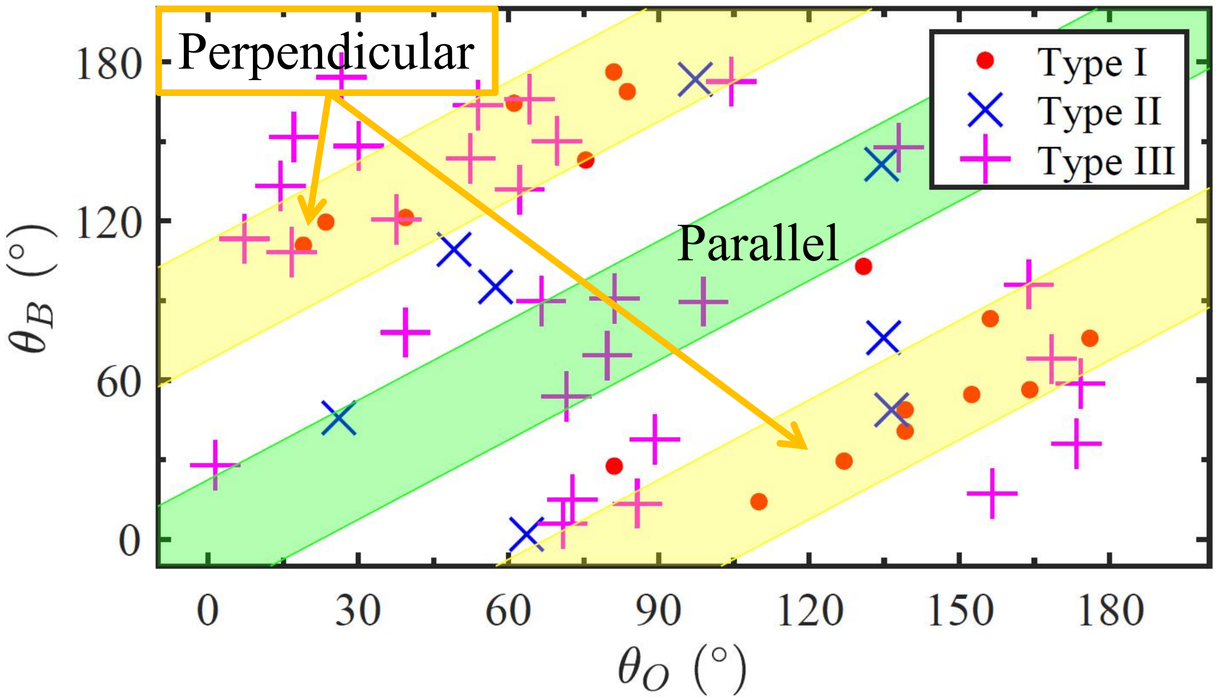


Relative Orientation between B-field and Outflow (Scale: 1000 au)

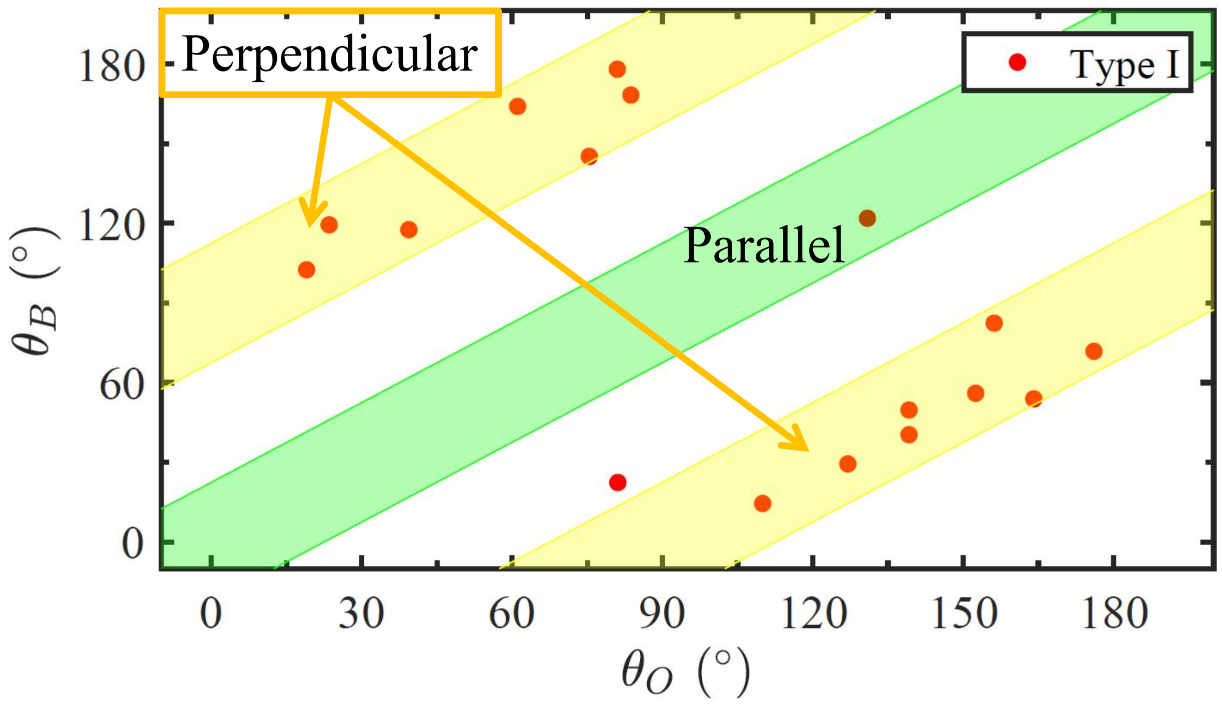


Error-weighted



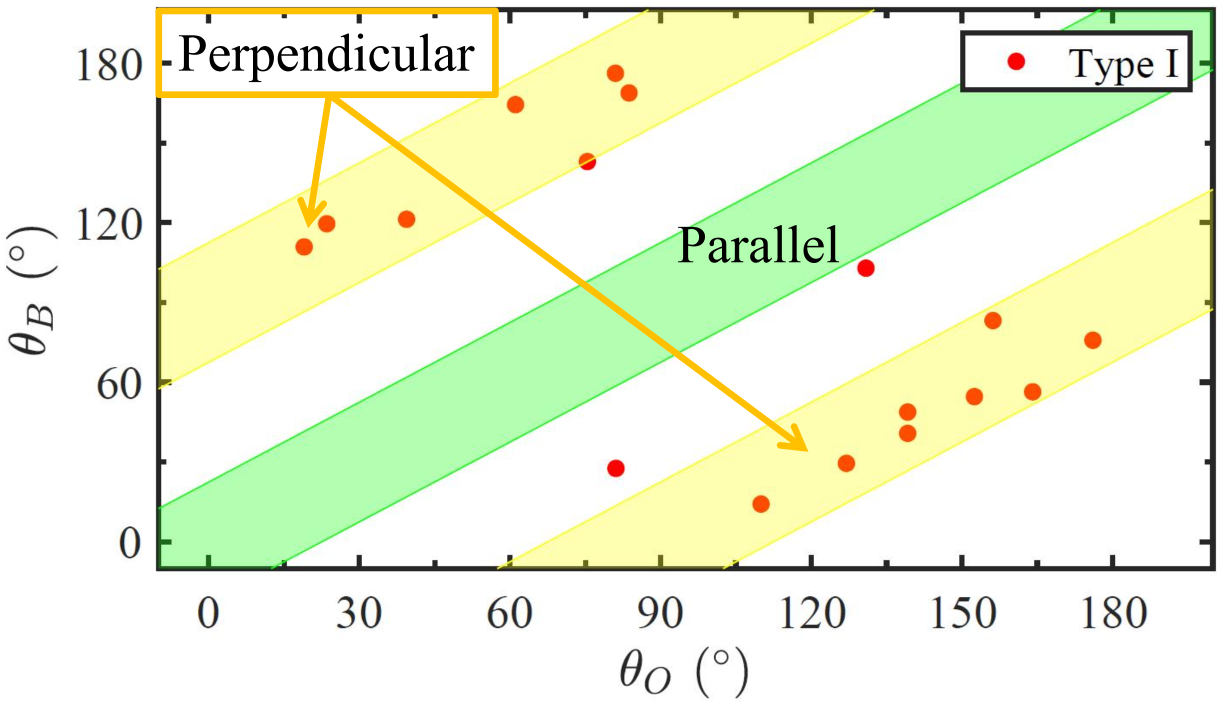
Intensity-weighted

Relative Orientation between B-field and Outflow (Scale: 1000 au)



Error-weighted

15/17=88.2%



Intensity-weighted

15/17=88.2%

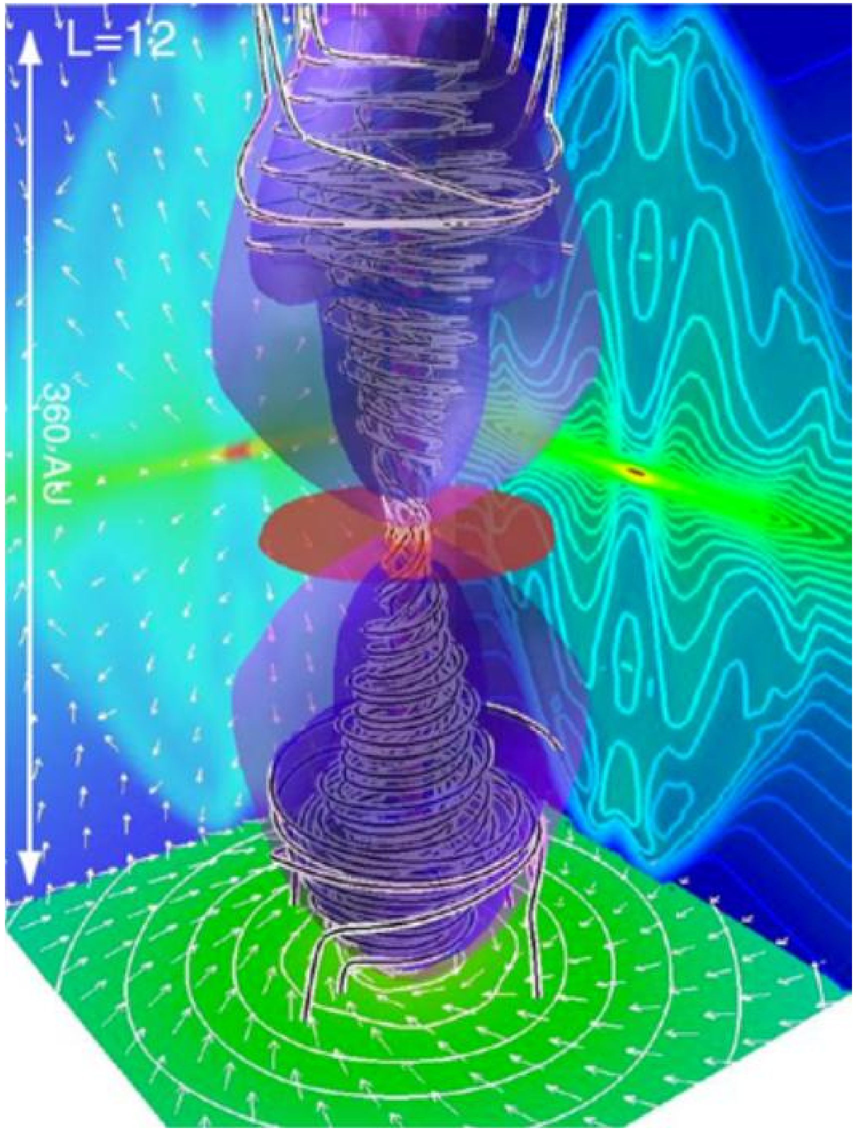
B-field tend to be perpendicular to the outflow direction!

Possible explanation: Toroidal B-field (Scale: 1000 au)

- 1. The pinched geometry of the B-field around the core center, strengthens the B-field and carries away angular momentum;

- 2. Envelope rotation draggs of field lines to produce toroidal B-field component.

- 3. Under the condition of velocity gradient ⊥ outflow direction, B-field tend to be perpendicular to the outflow direction.



Machida et al. 2007

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Conclusion

B-field VS intensity structure

1. Most sources show a complex B-field morphology, B-field is preferentially aligned with intensity structure along the outflow direction, while in other region:

   -- Less extended sources: B-filed tend to be perpendicular to the intensity structure;

   -- Much extended and binary sources:B-field tend to be randomly aligned with intensity structure.

2. B-field and outflow show a weak correlation that B-field tends to be perpendicular to outflows, and ...

3. When the envelope's velocity gradient $\perp$ outflow, B-field is stronglytend correlated with outflow and tend to be perpendicular to the outflow ------> Toroidal!