Laying the groundwork for future ALMA direct magnetic field detection in protostellar environments

ISMS Conference Talk
June 20, 2017

Erin Cox
University of Illinois

Protostar Classification

Class 0

Youngest
Most embedded

Class I

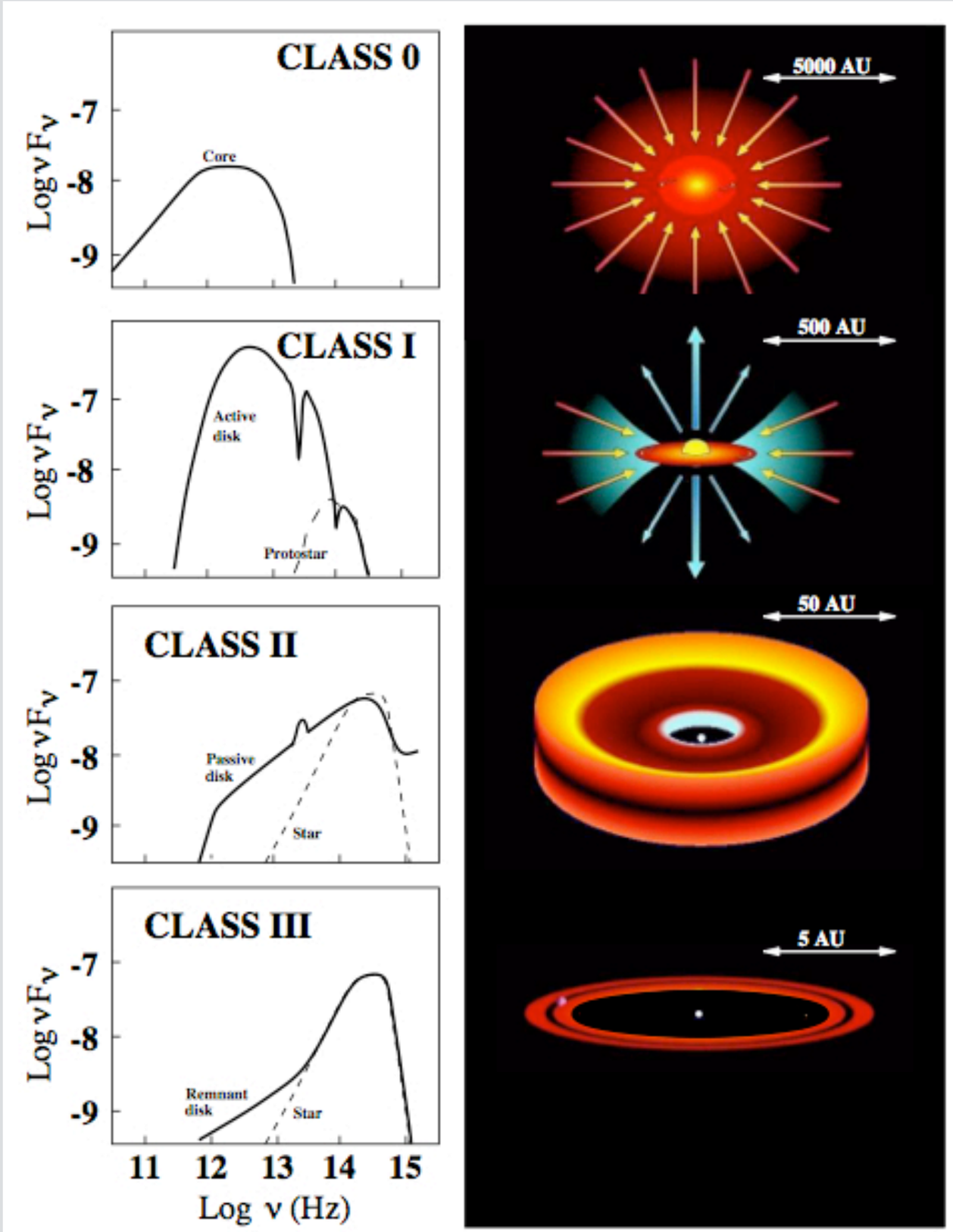
Older, ~1 Myr
Starting to shed envelope

Class II

Prominent disk
Very little envelope left

Class III

Oldest (not quite MS)
Tenuous disk left



https://ismlandmarks.files.wordpress.com/2013/05/isella.jpg

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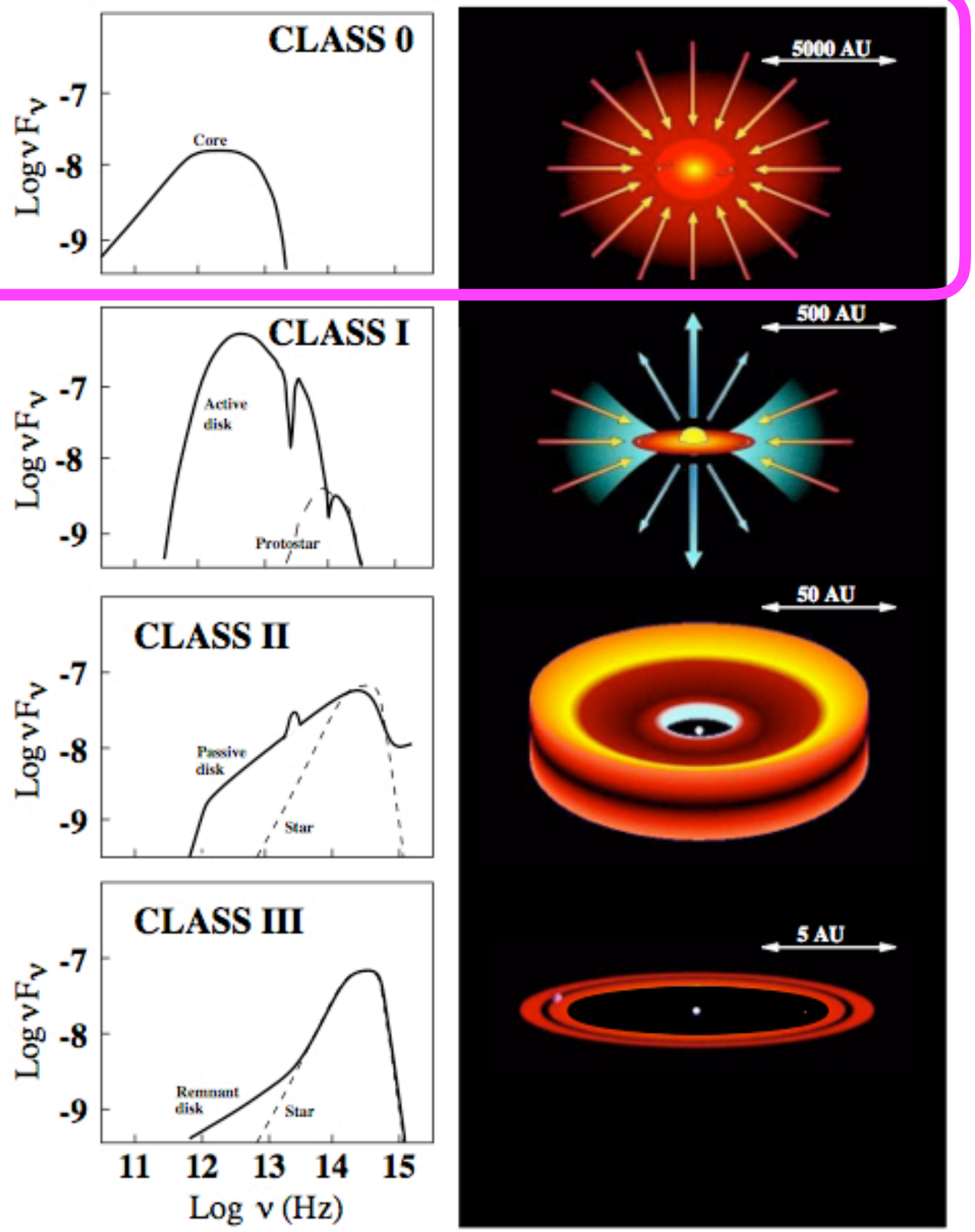

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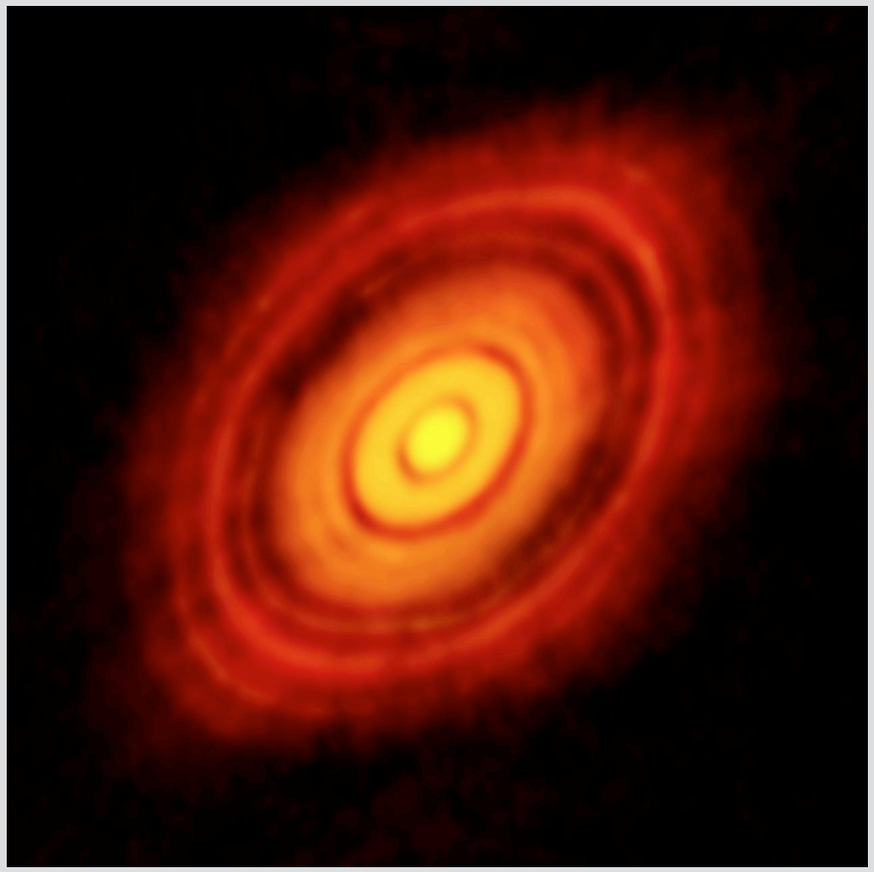
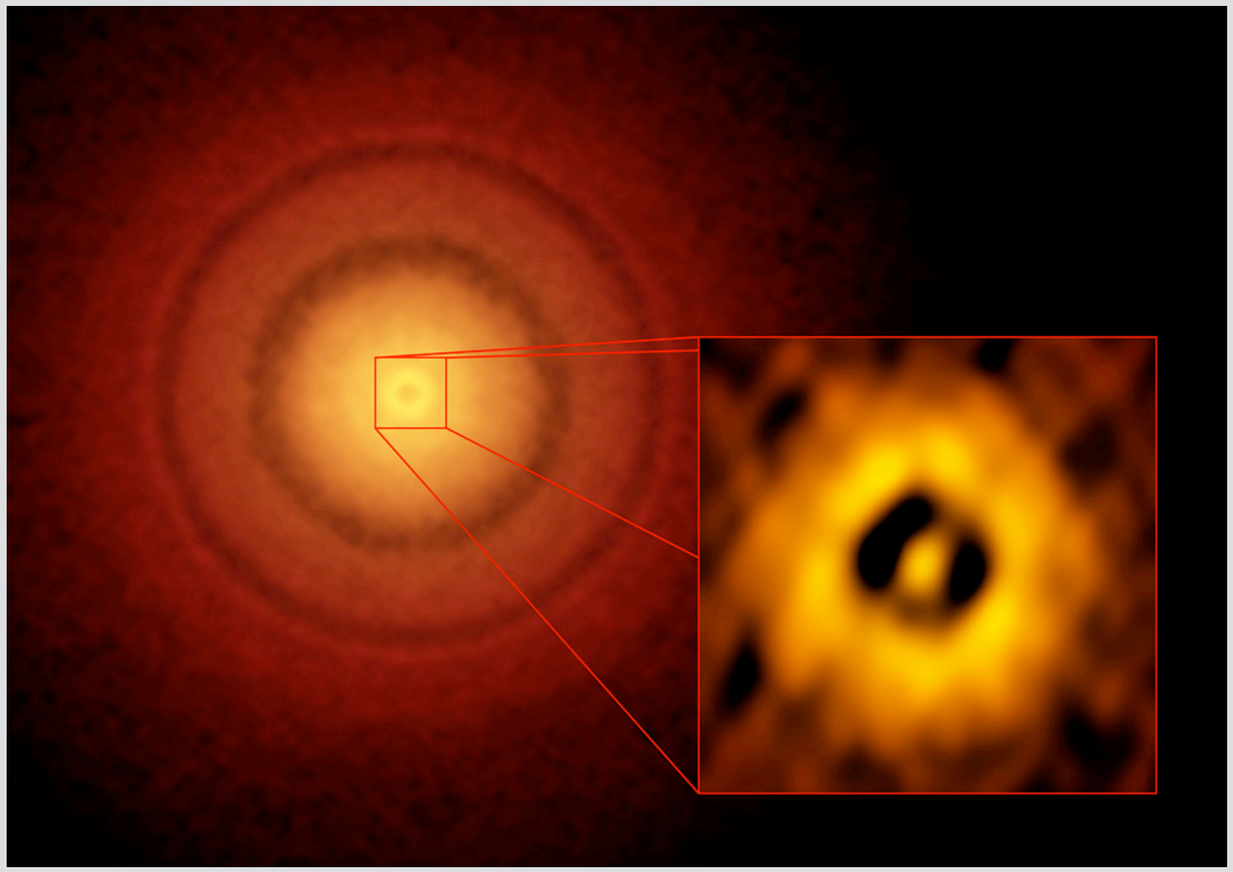
Disks

- Way for material to lose angular momentum
- Avenue for mass accretion onto protostar
- Where planets will form

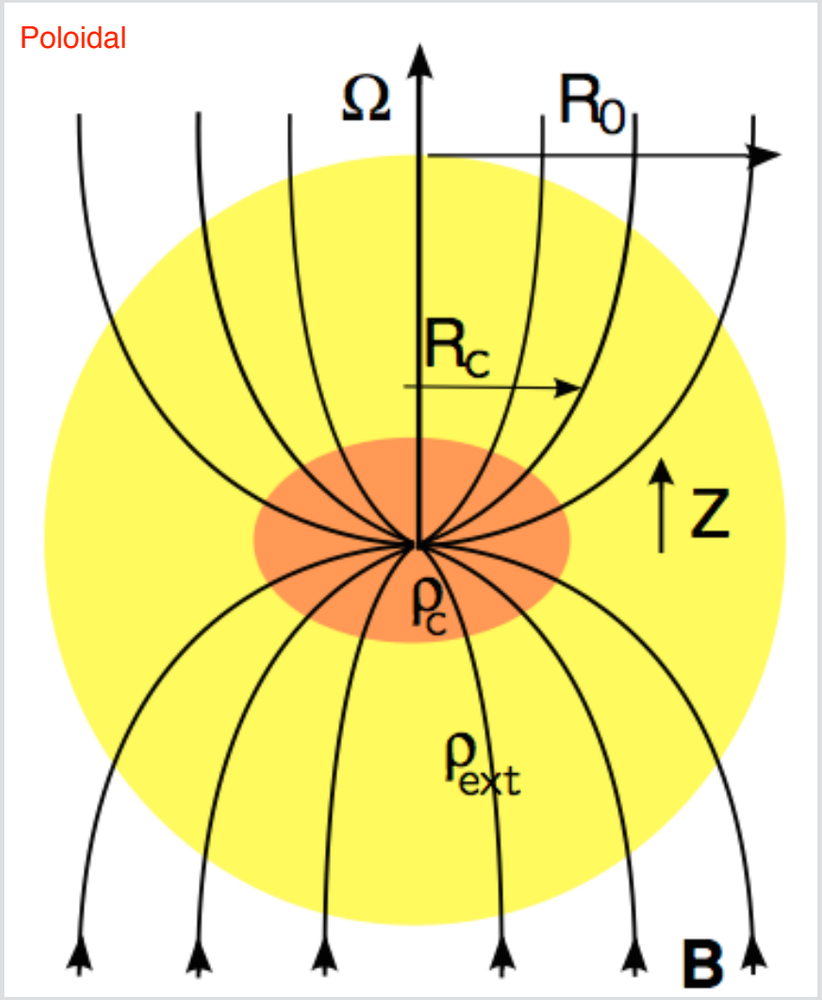


ALMA Partnership 2015

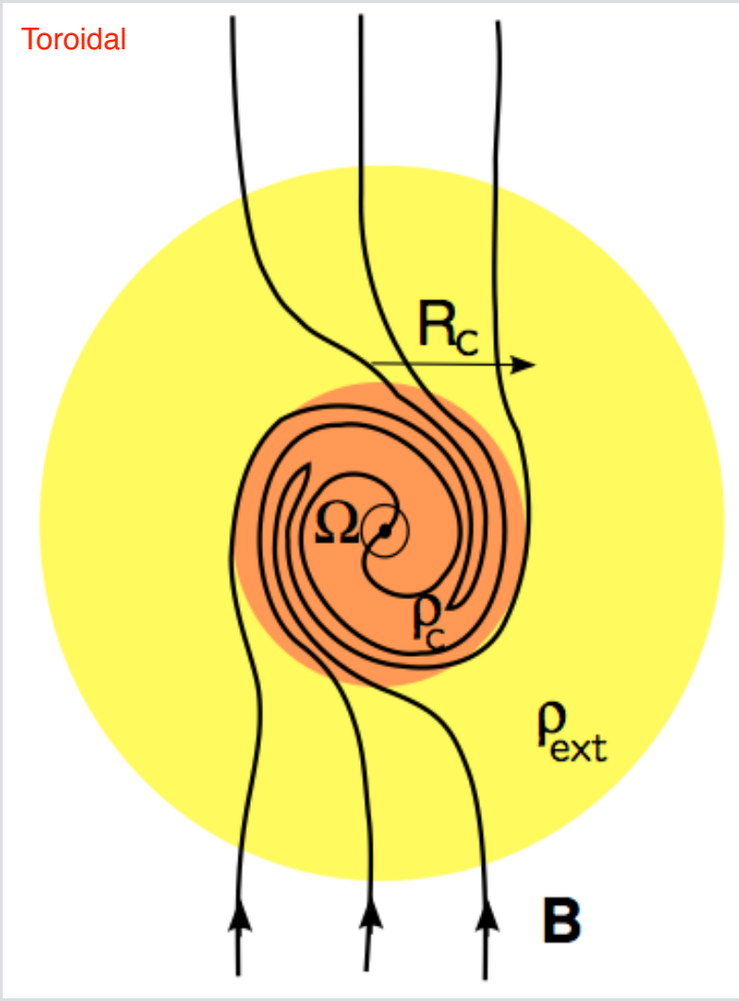


http://www.sci-news.com/astronomy/alma-planet-forming-disk-twhydrae-03748.html

Magnetic braking in Class 0



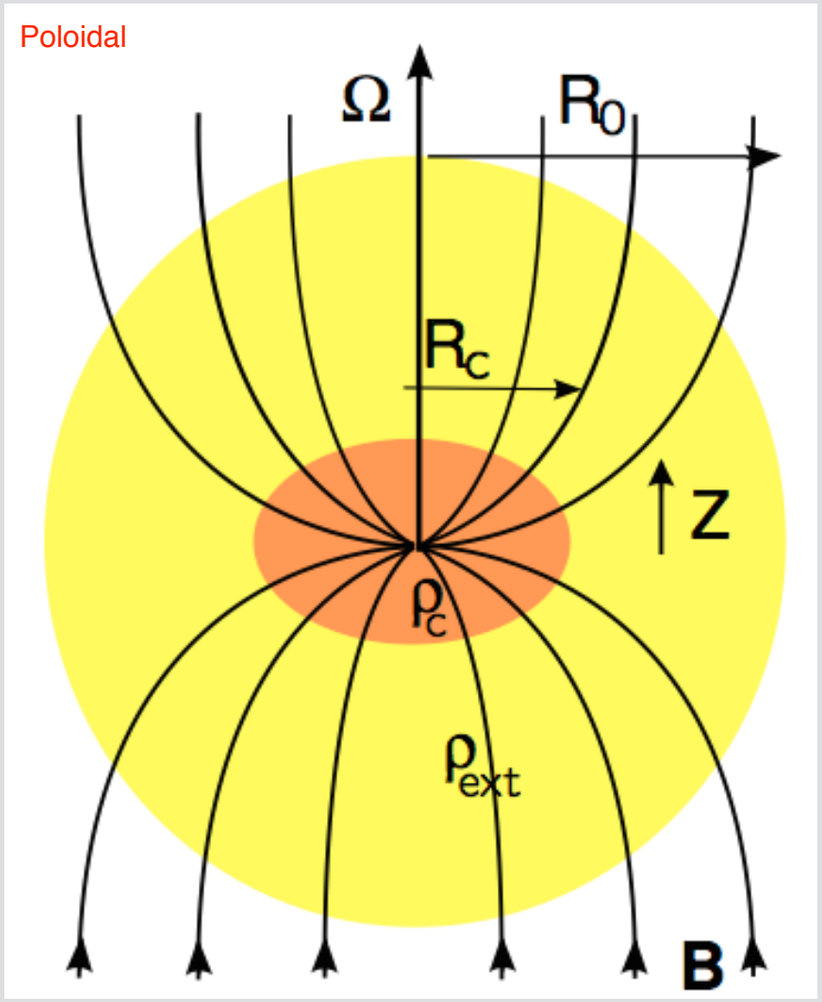
- Magnetic fields can hinder disk growth in youngest protostars
- Poloidal fields (left) are efficient at magnetic braking
- Toroidal fields (right) are inefficient at magnetic braking



Joos+ 2012

Magnetic braking in Class 0

Axes parallel



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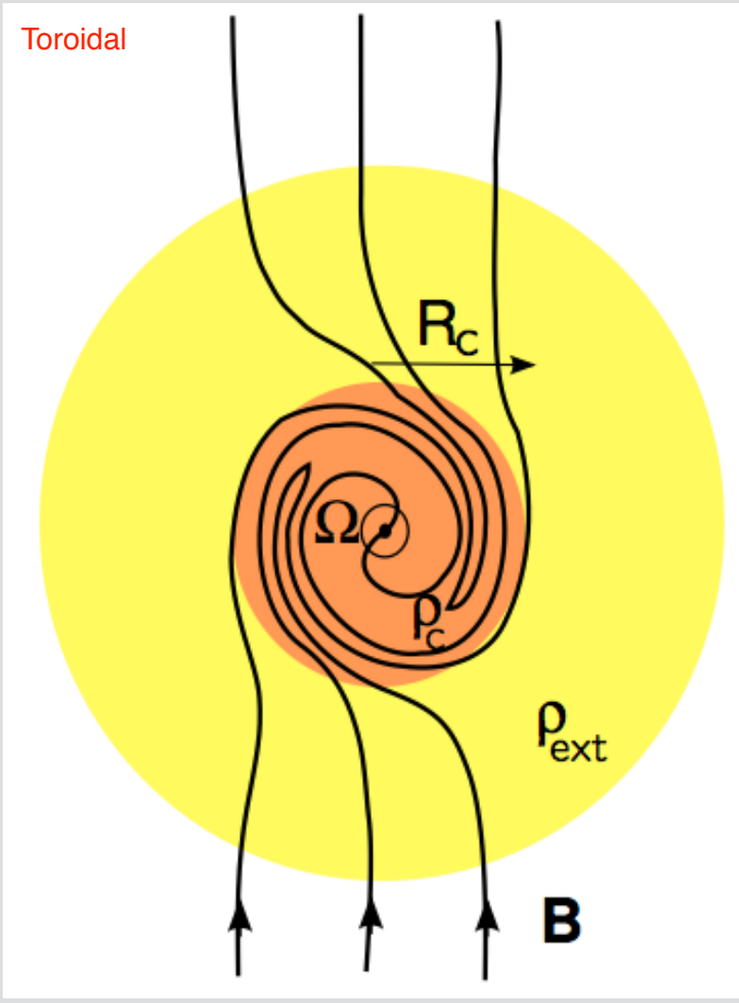
Axes perpendicular



Joos+ 2012

Determining the magnetic field

- Millimeter/centimeter-wave dust continuum polarimetry
- Goldreich-Kylafis Effect
- Zeeman spectroscopy of paramagnetic molecules

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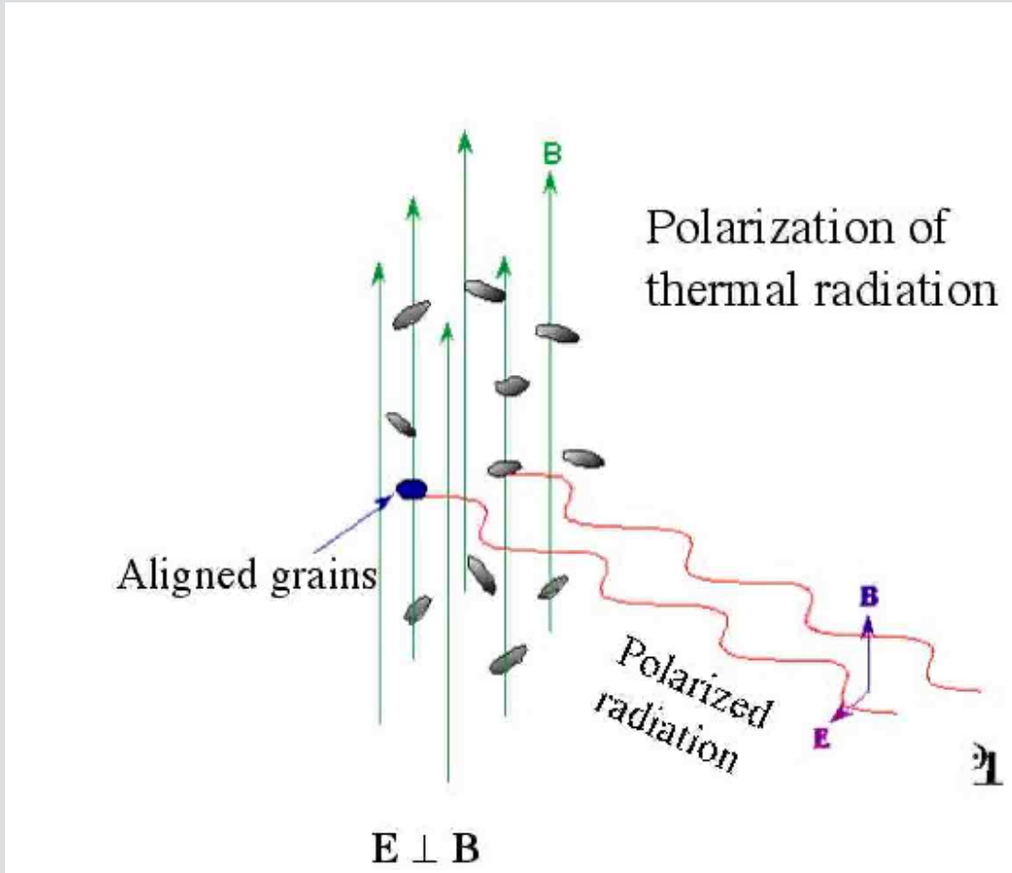

(Lazarian 2007)

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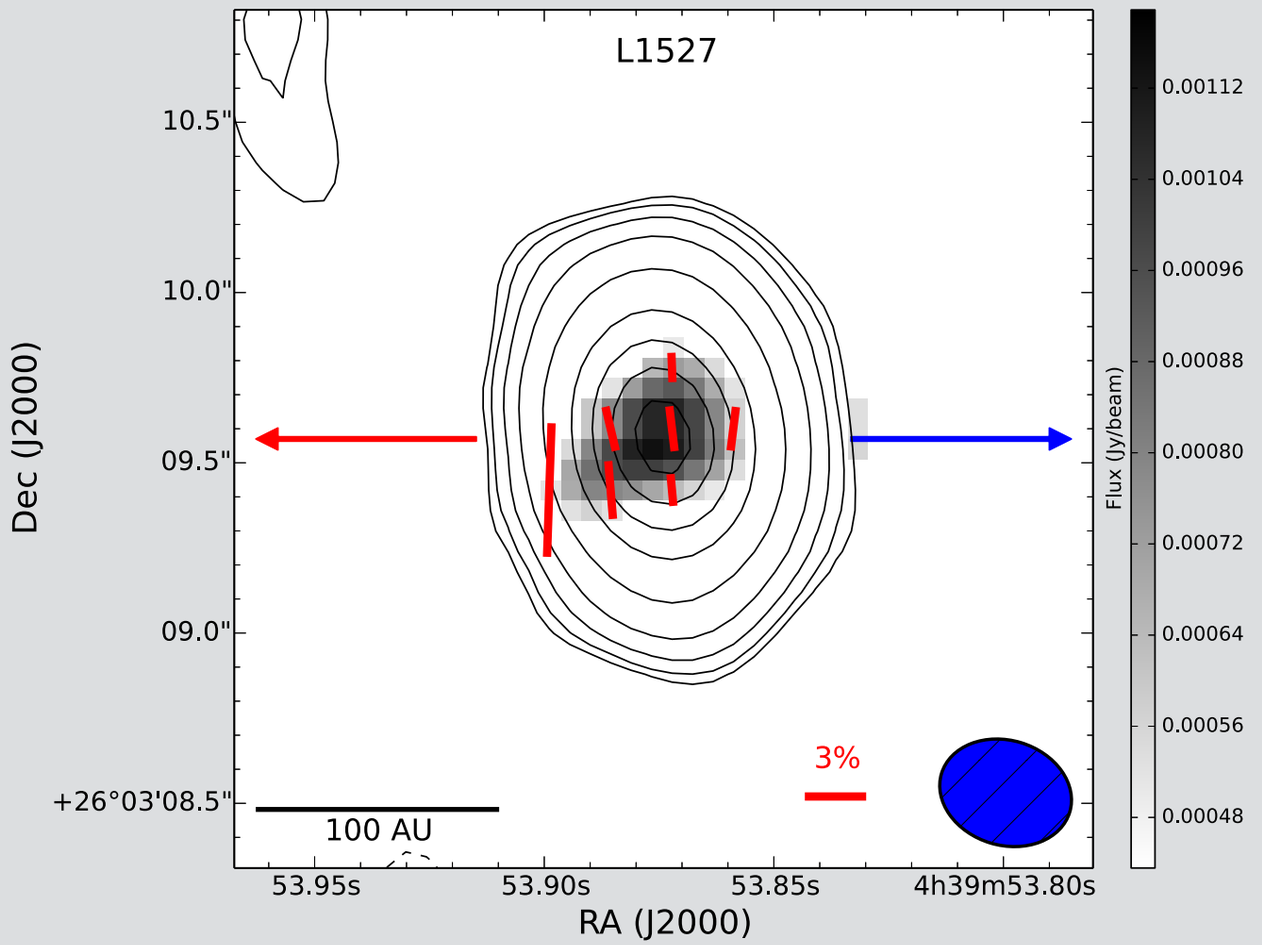

Segura-Cox+ 2015

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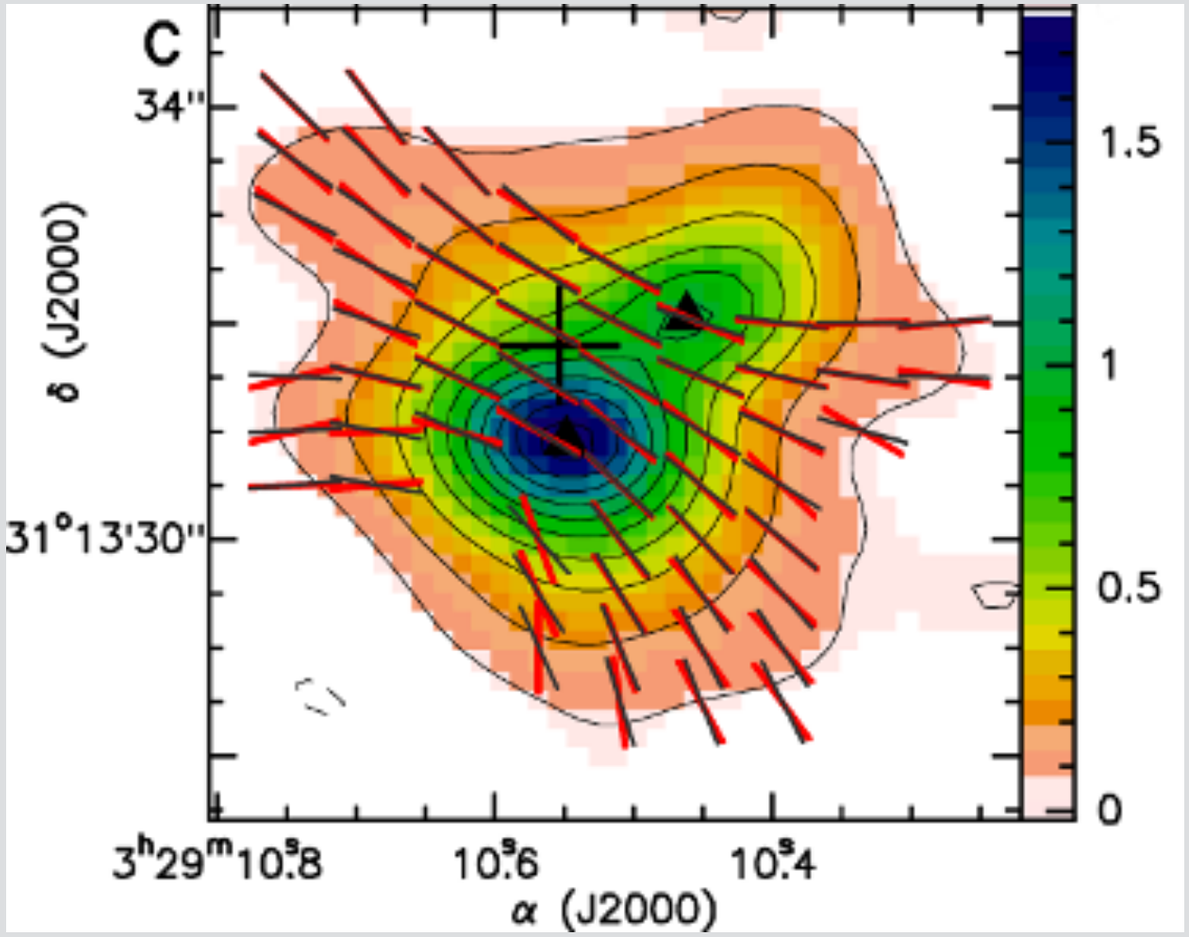

Girart+ 2006

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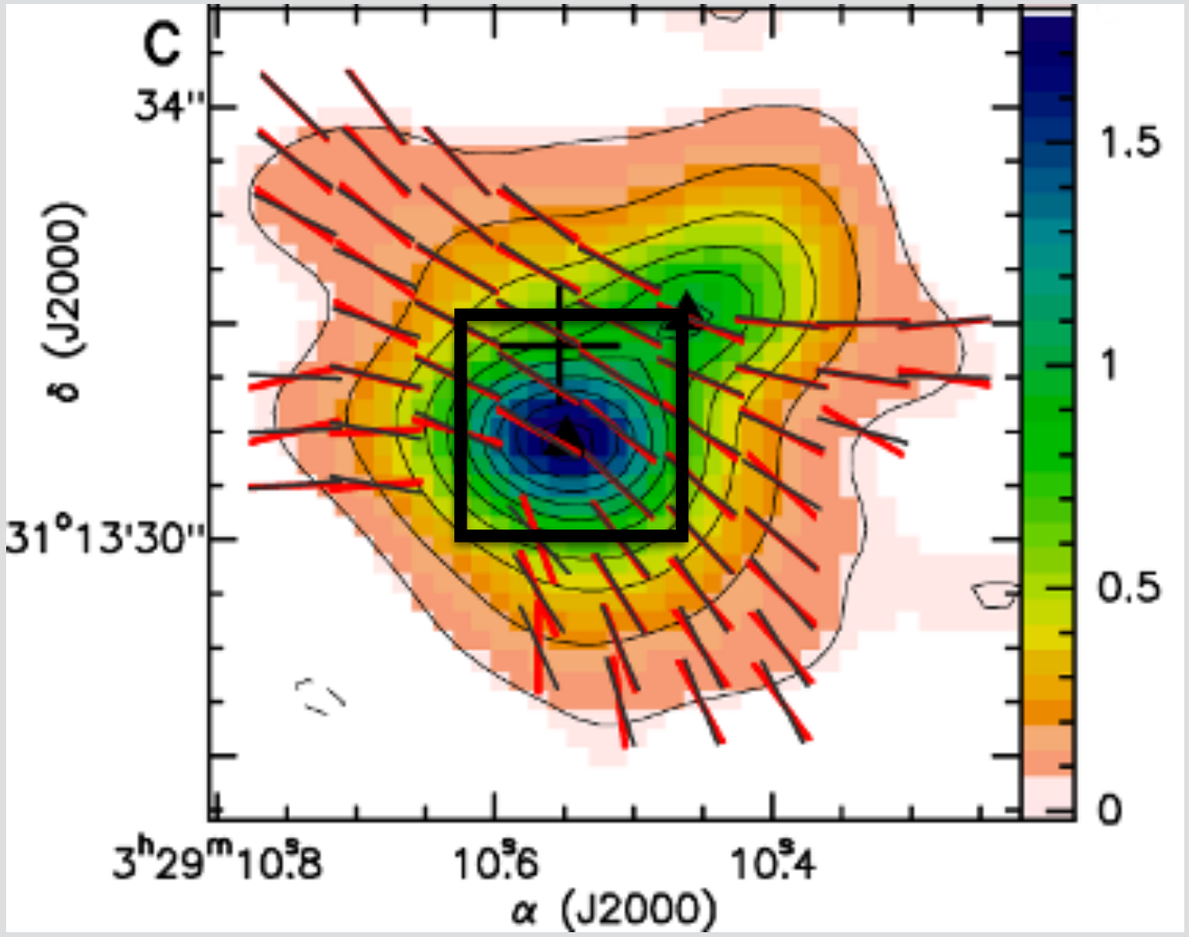

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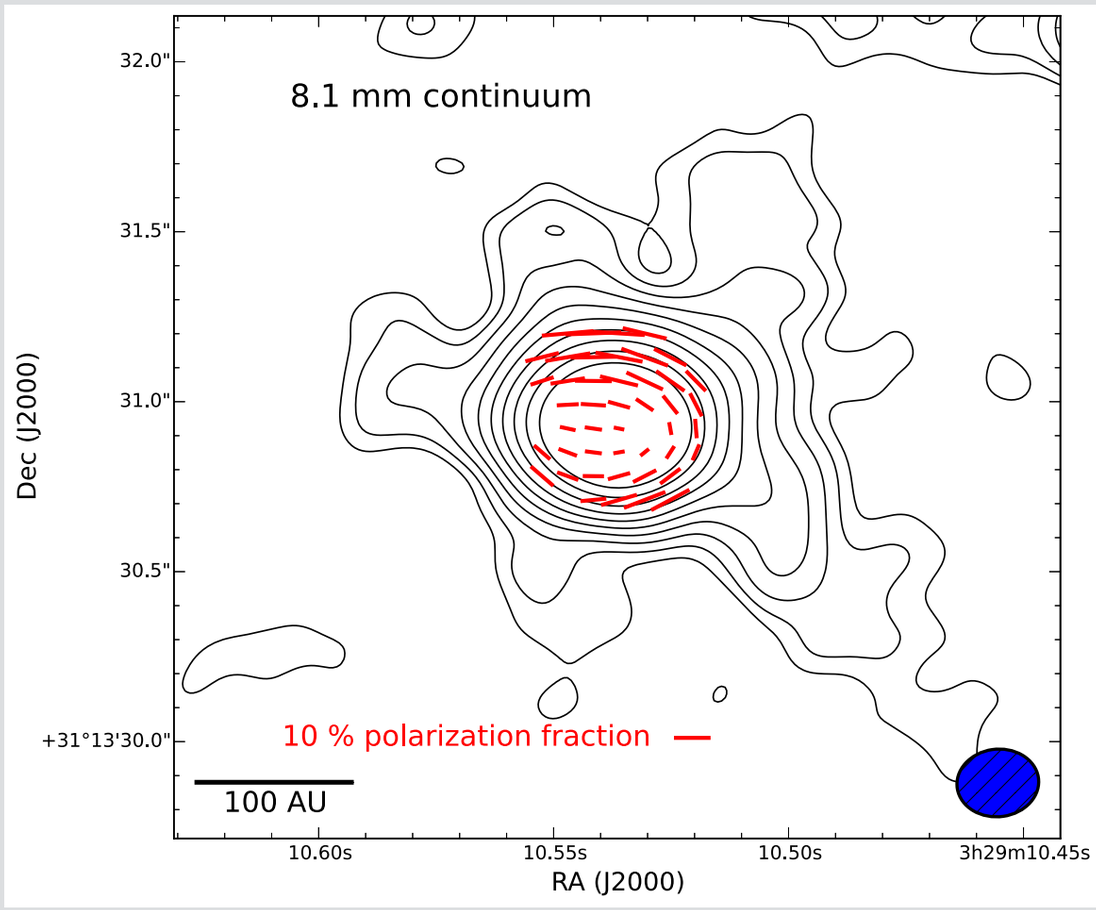

Cox+ 2015

Determining the magnetic field

- **Millimeter/centimeter-wave dust continuum polarimetry**
- Goldreich-Kylafis Effect
- Zeeman spectroscopy of paramagnetic molecules

Issues

- Scattering contributions?
- Only plane-of-sky
- No information re: B field strength

Determining the magnetic field

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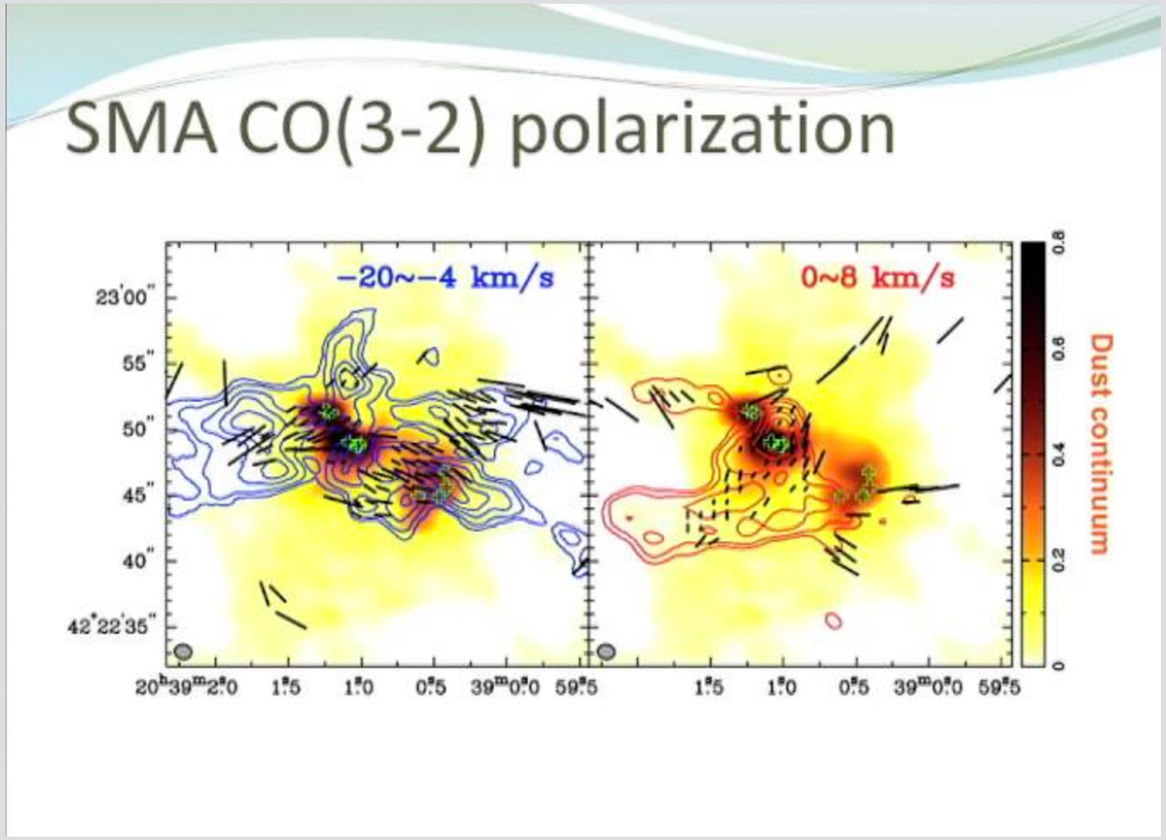

DR21(OH), Shih-Peng Lai (2015)

Determining the magnetic field

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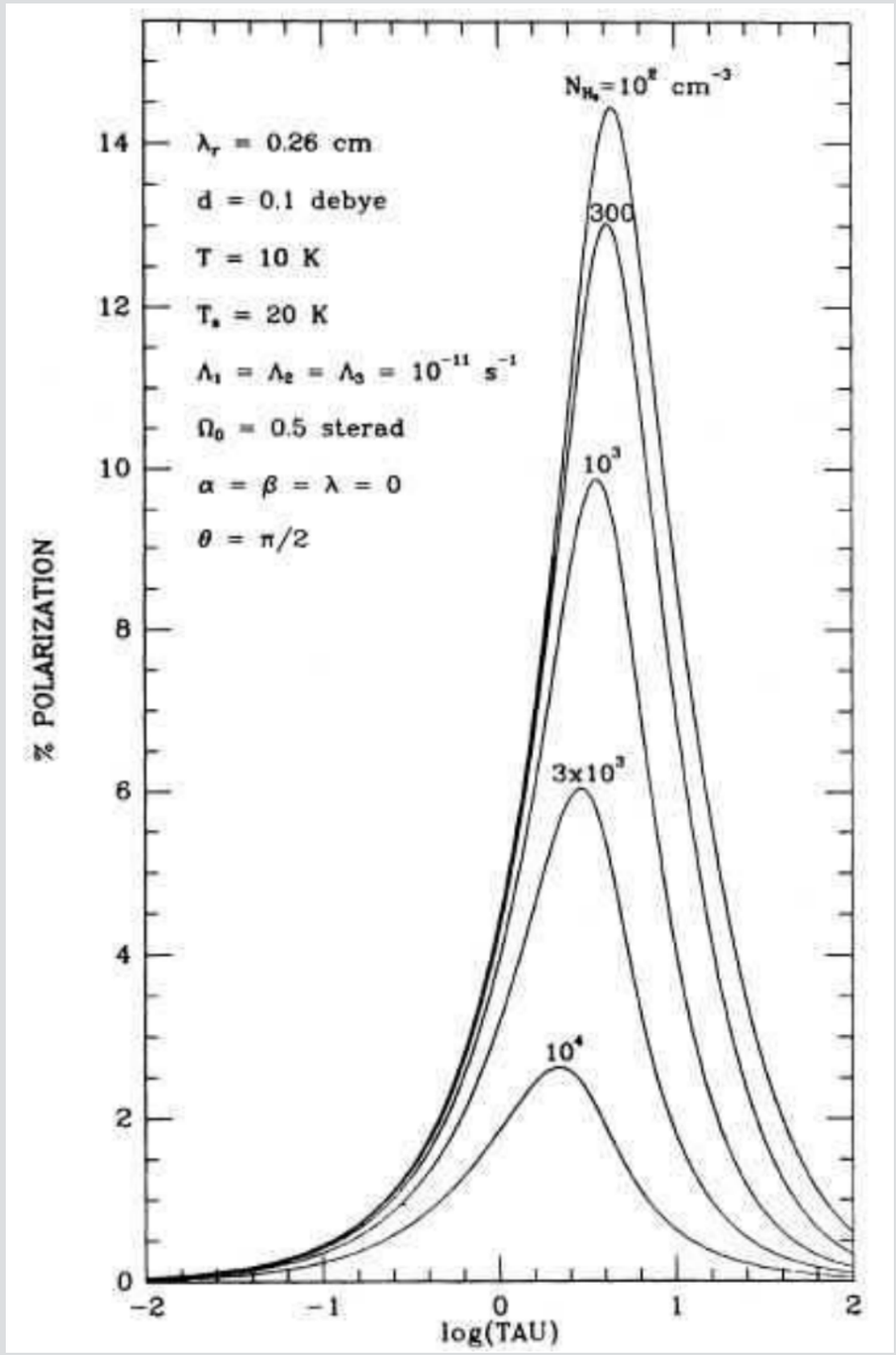

Kylafis, 1983

Determining the magnetic field

- Millimeter/centimeter-wave dust continuum polarimetry
- **Goldreich-Kylafis Effect**
- Zeeman spectroscopy of paramagnetic molecules

Issues

- Predictions are model-dependent
- Only plane-of-sky
- B-field angle uncertain to 90 degrees

Determining the magnetic field

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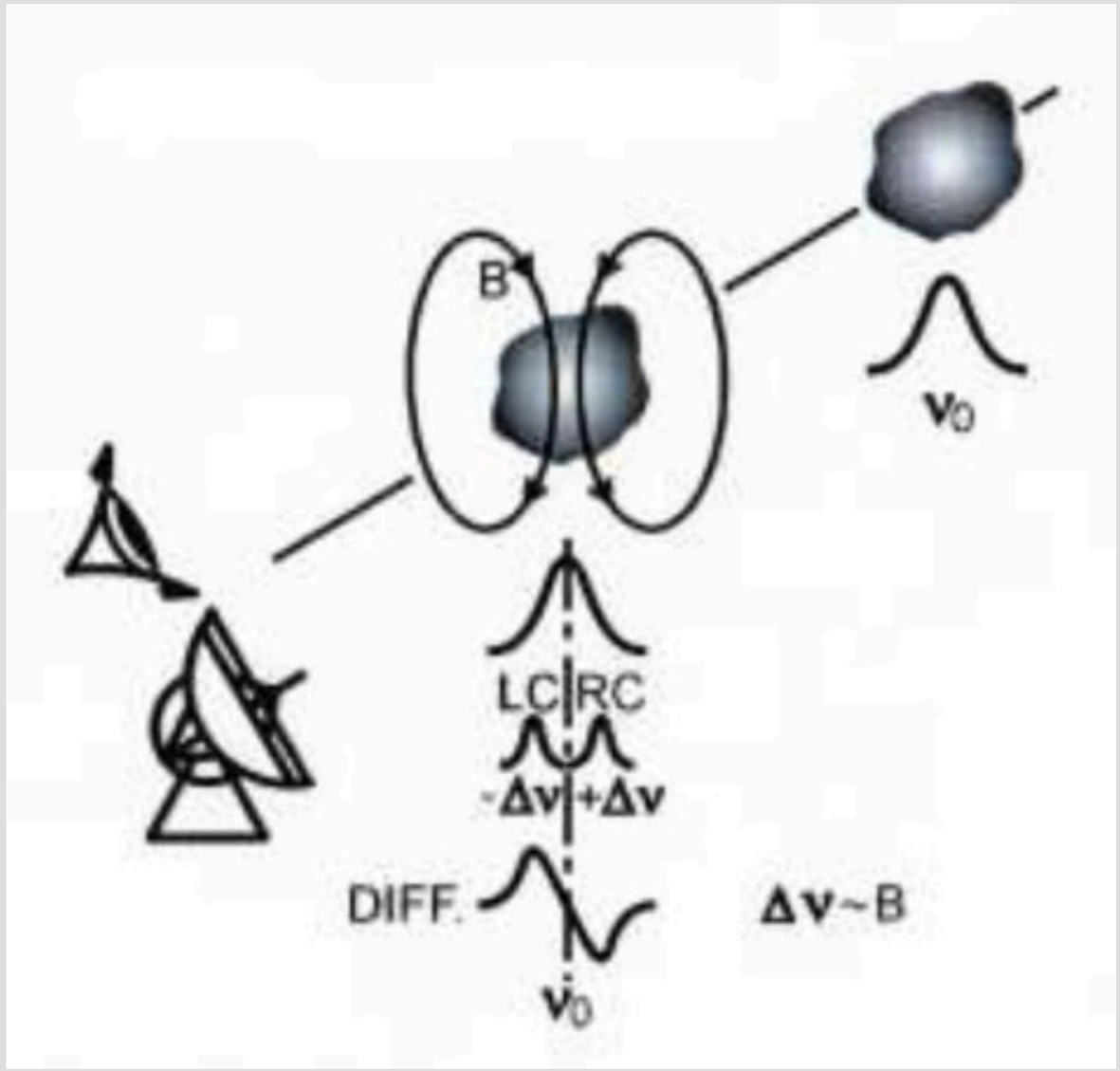

https://ned.ipac.caltech.edu/level5/Sept13/Beck/Figures/figure4.jpg

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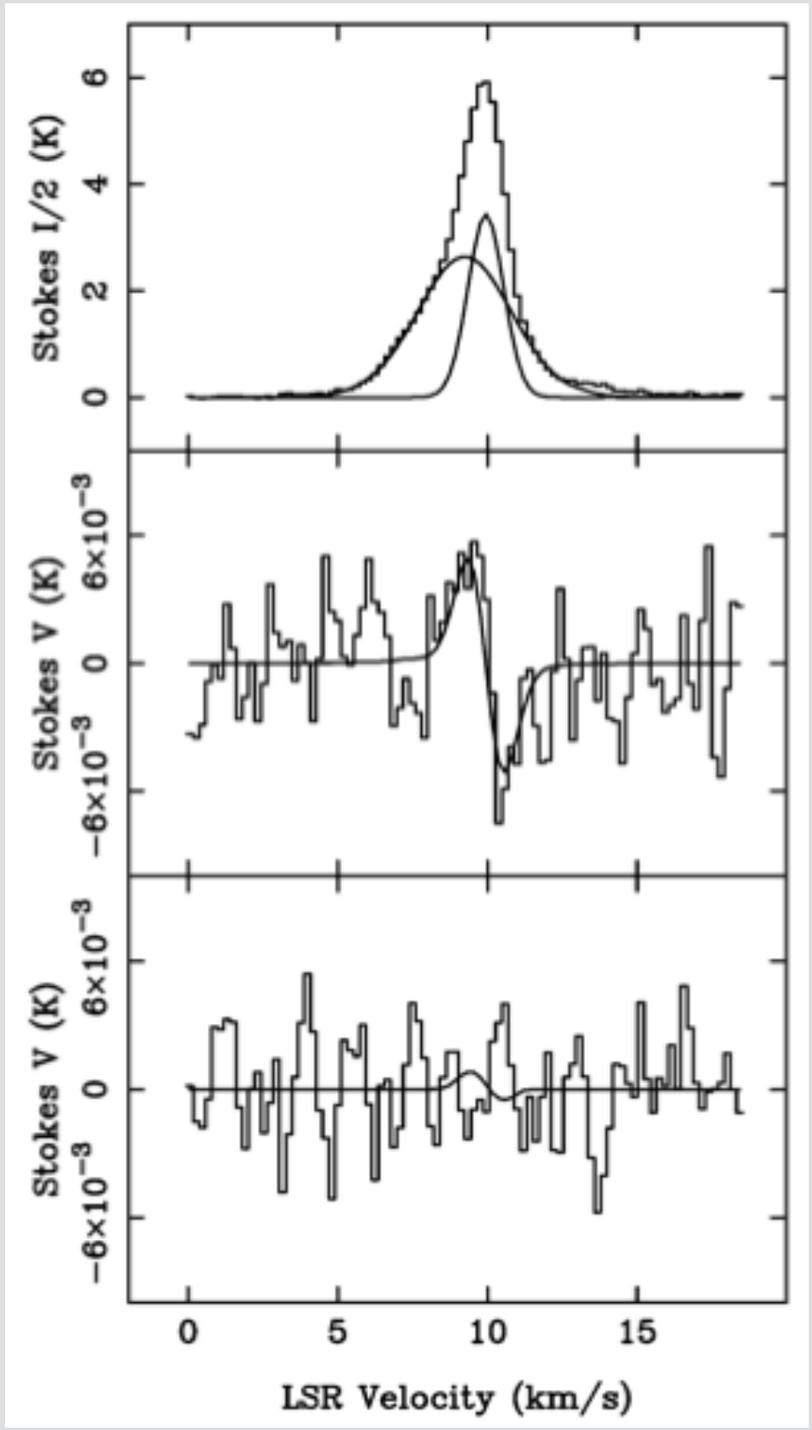


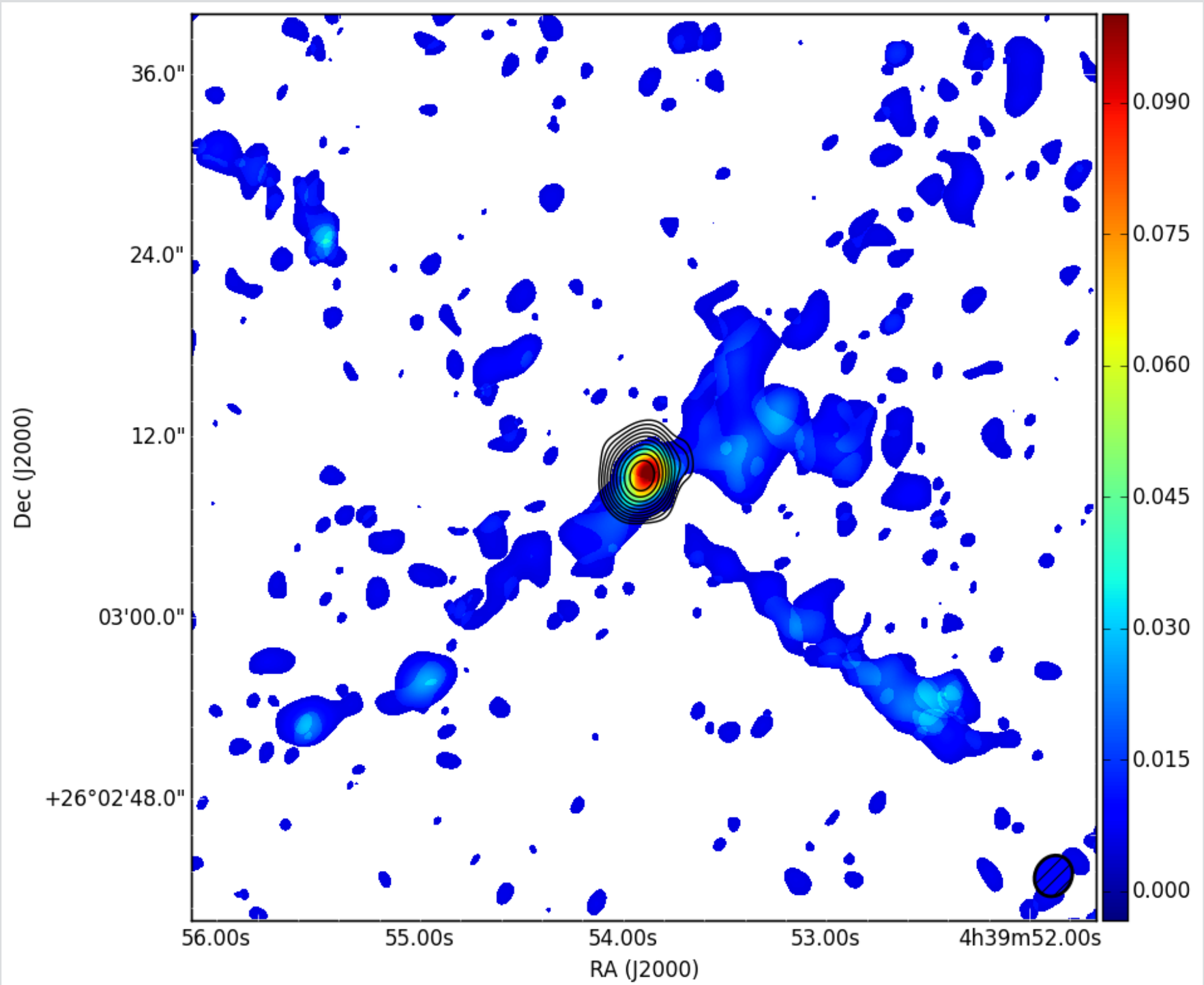
Crutcher+ 1999

High Resolution imaging of paramagnetic lines with ALMA

- Survey structure
  - Snapshot of 10 millimeter-bright sources in mainly Taurus, Oph, and Perseus at Band 3.
  - ~2-3'' resolution ~ 300-900 AU resolution
  - 3 mm continuum + 5 transitions of 4 paramagnetic molecules

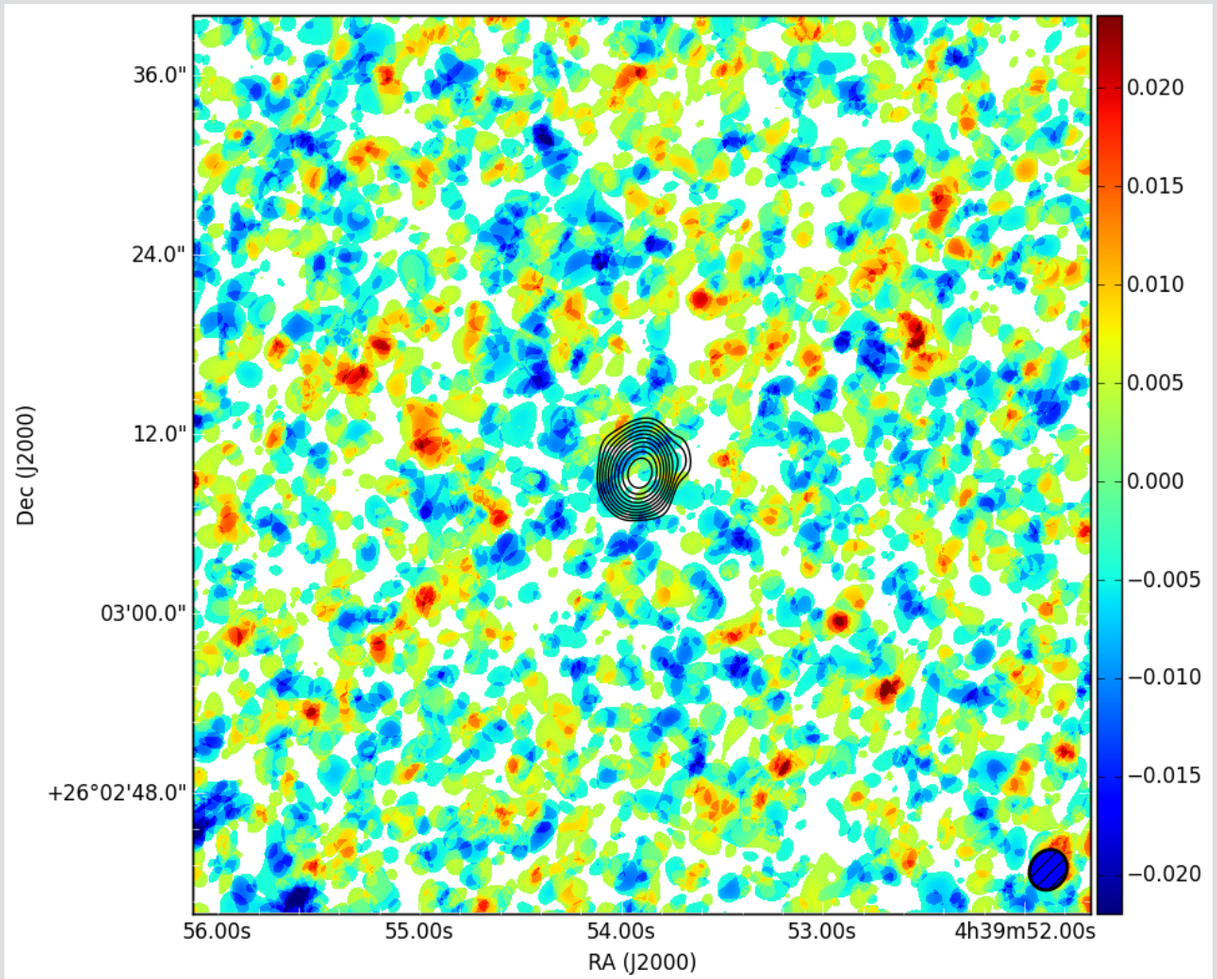
Species	Frequency (GHz)	Zeeman coeff. Z (Hz/μG)
SO(3Σ; $\nu = 0$; $3(2) \rightarrow 2(1)$)	99.29987	1.043
SO(3Σ; $\nu = 0$, $4(5) \rightarrow 4(4)$)	100.02964	...
CN($\nu = 0$; $N = 1 \rightarrow 0$; $J = 1/2 \rightarrow 1/2$; $F = 1/2 \rightarrow 3/2$)	113.14416	2.18
CCS($N = 9 \rightarrow 8$, $J = 8 \rightarrow 7$)	113.41020	...
C_4H($J = 12 \rightarrow 11$)	114.22104	...

L1527 SO 3∑ 3——>2

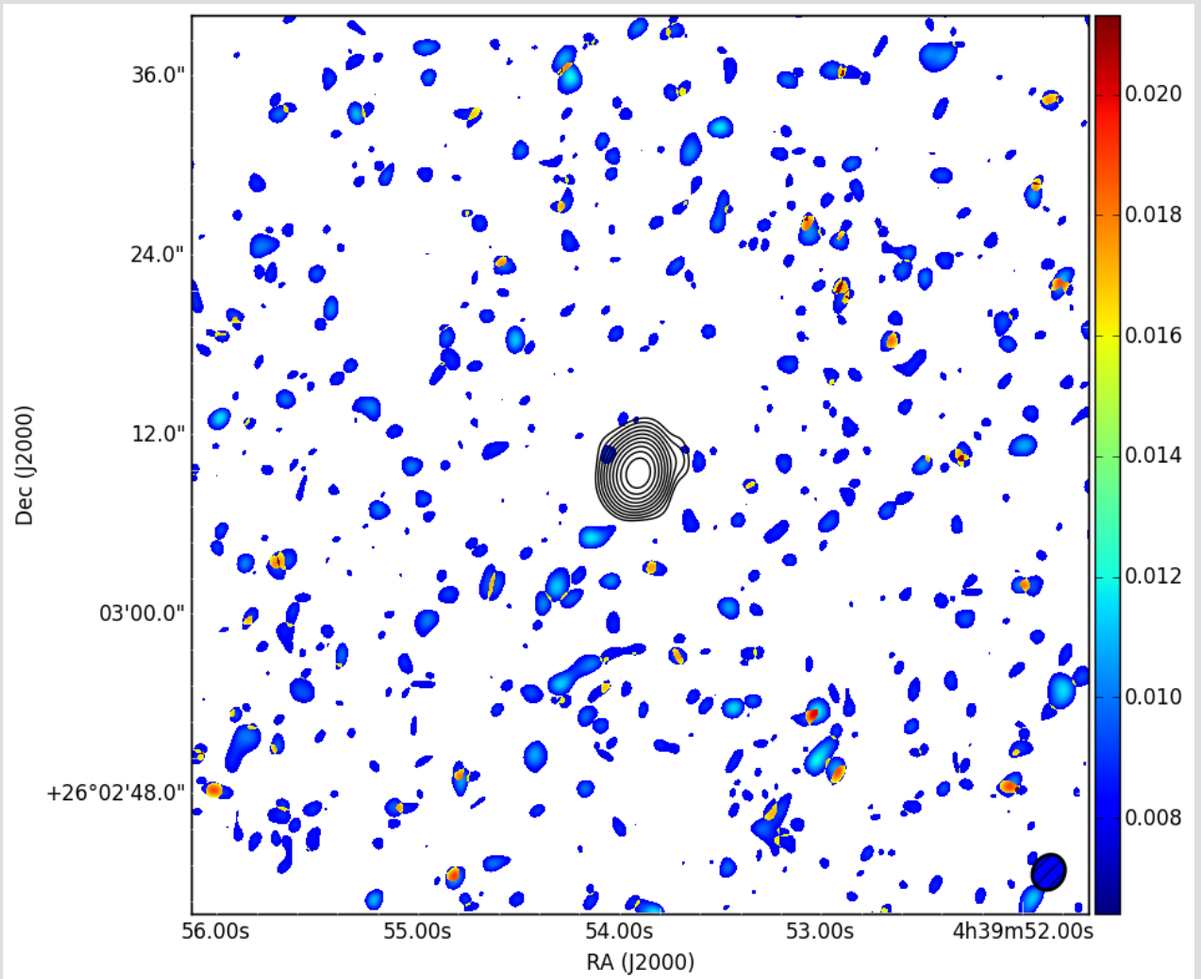

36.0"
24.0"
12.0"
03'00.0"
+26°02'48.0"
Dec (J2000)
56.00s
55.00s
54.00s
53.00s
4h39m52.00s
RA (J2000)
0.090
0.075
0.060
0.045
0.030
0.015
0.000

L1527

SO 3∑ 4—>4

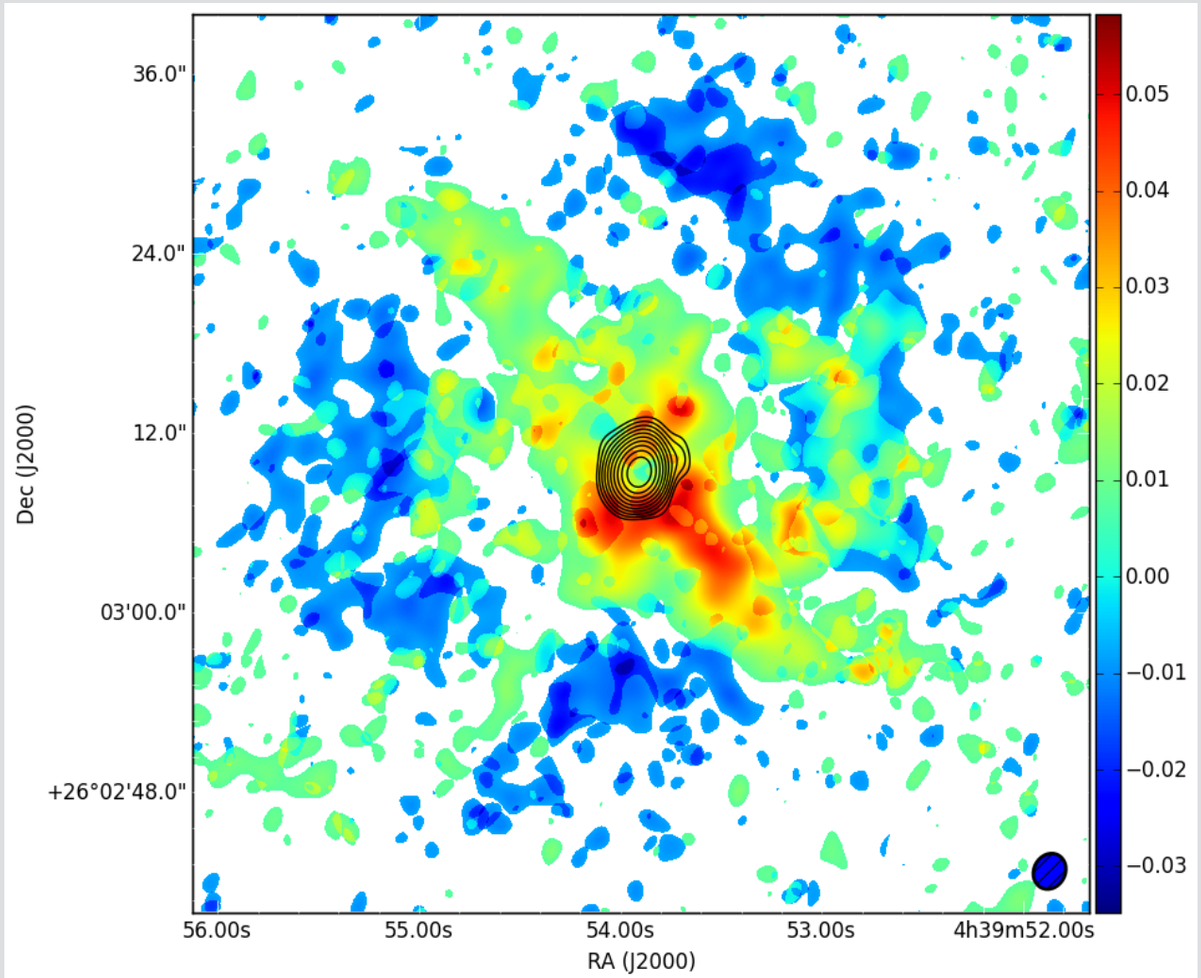


CCS

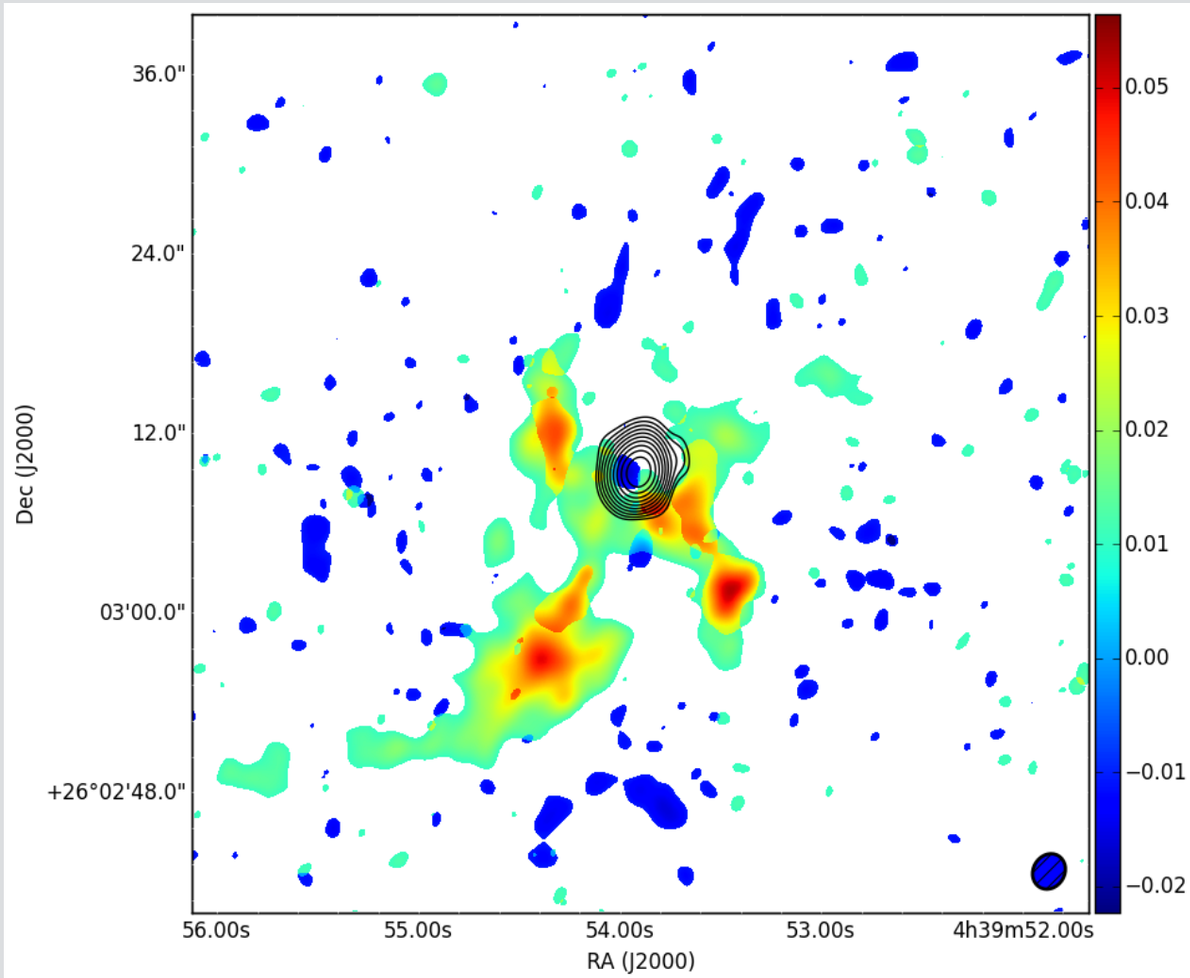


L1527

CN


36.0"
24.0"
12.0"
03'00.0"
+26°02'48.0"
Dec (J2000)
56.00s
55.00s
54.00s
53.00s
4h39m52.00s
RA (J2000)
0.05
0.04
0.03
0.02
0.01
0.00
−0.01
−0.02
−0.03

C4H


36.0"
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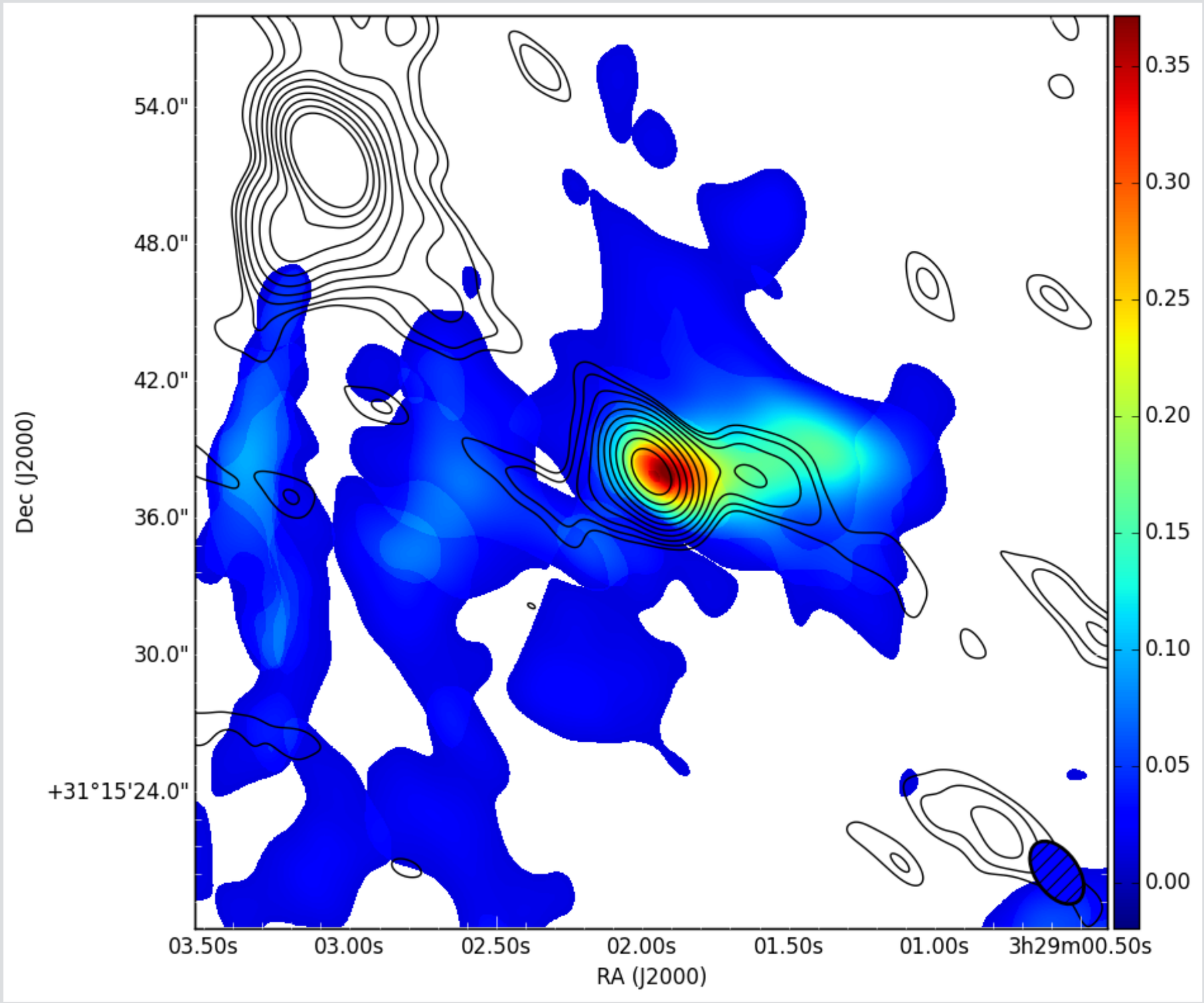
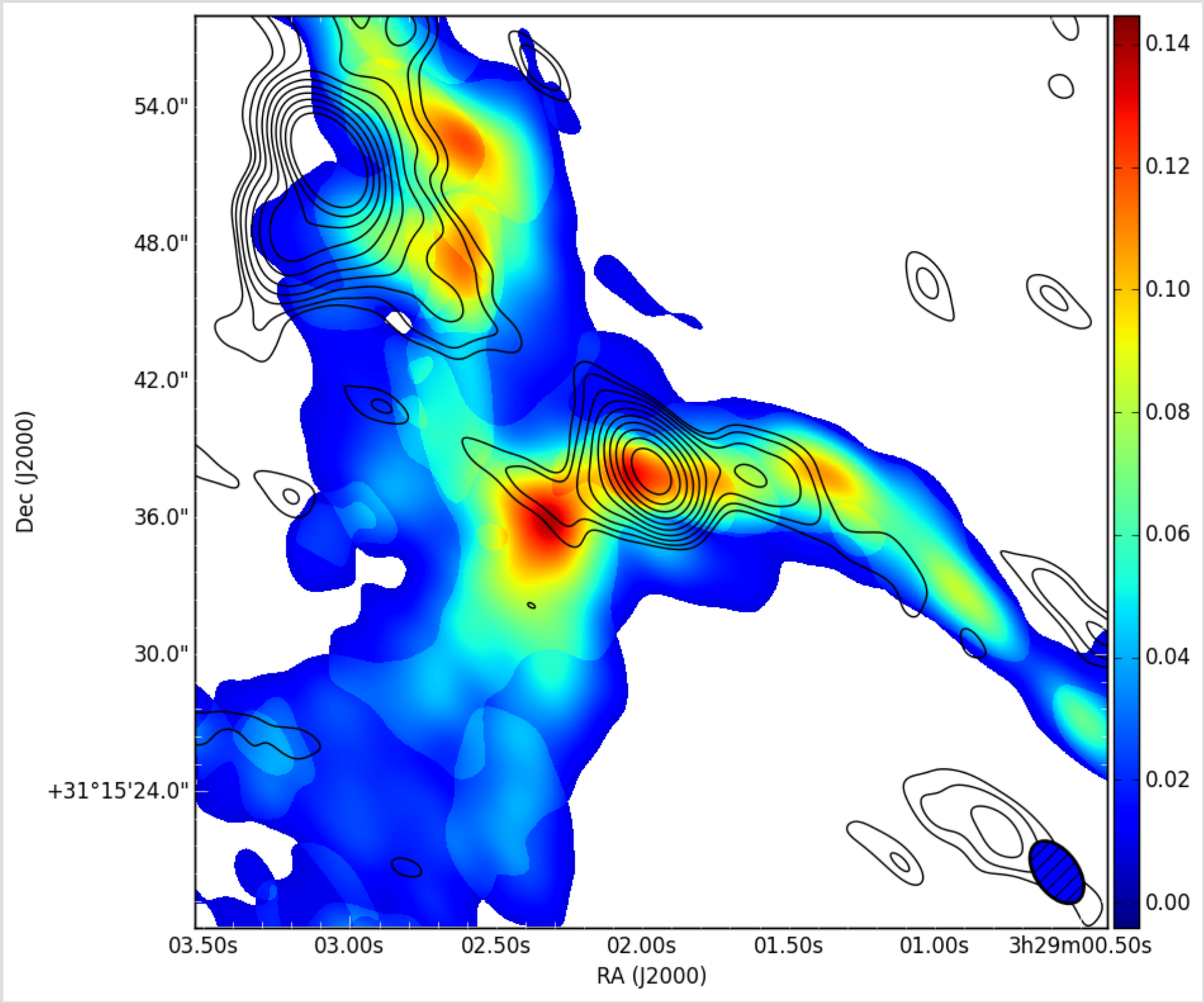
Dec (J2000)
56.00s
55.00s
54.00s
53.00s
4h39m52.00s
RA (J2000)
0.05
0.04
0.03
0.02
0.01
0.00
−0.01
−0.02

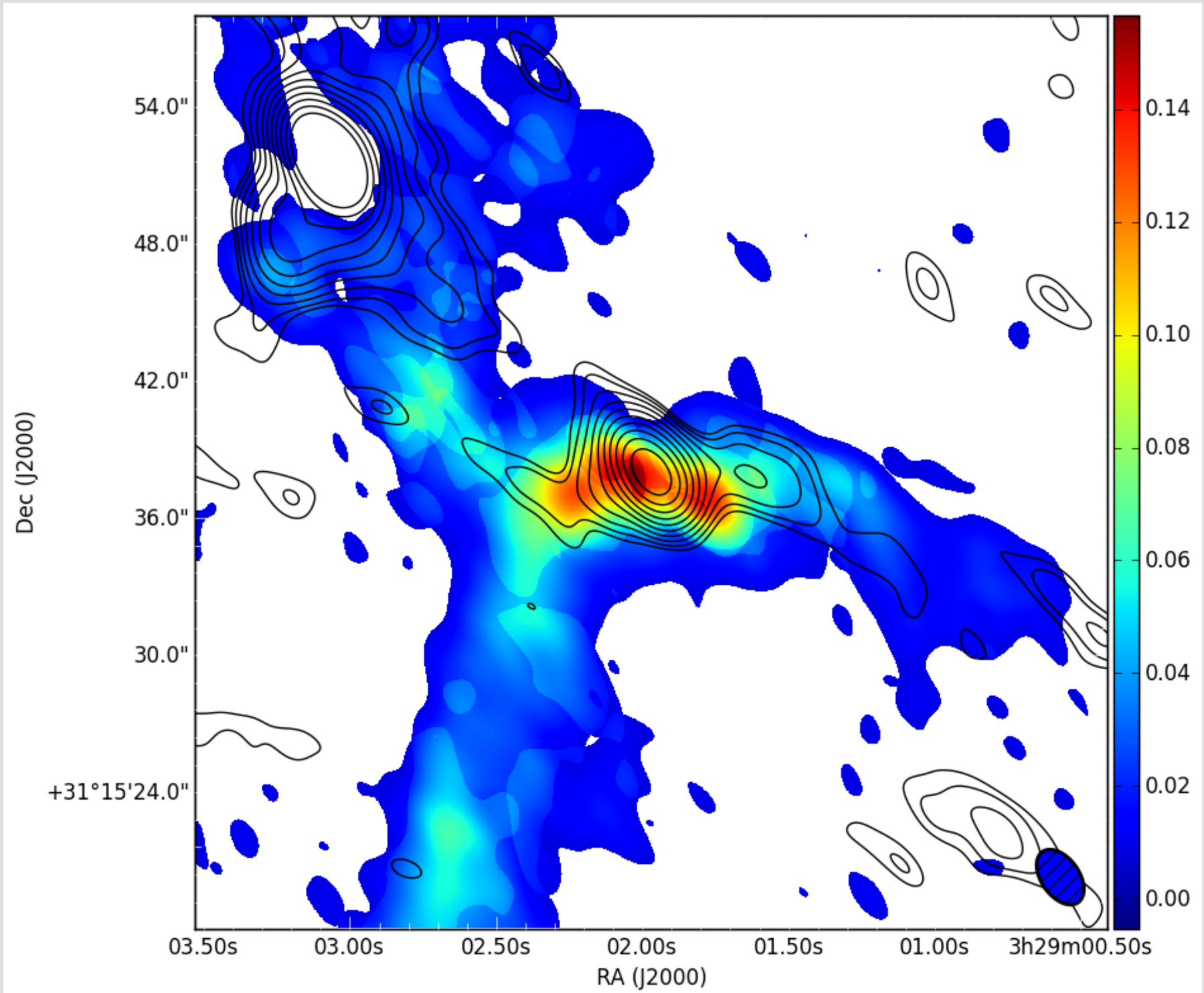
SVS13C SO 3∑ 3——>2



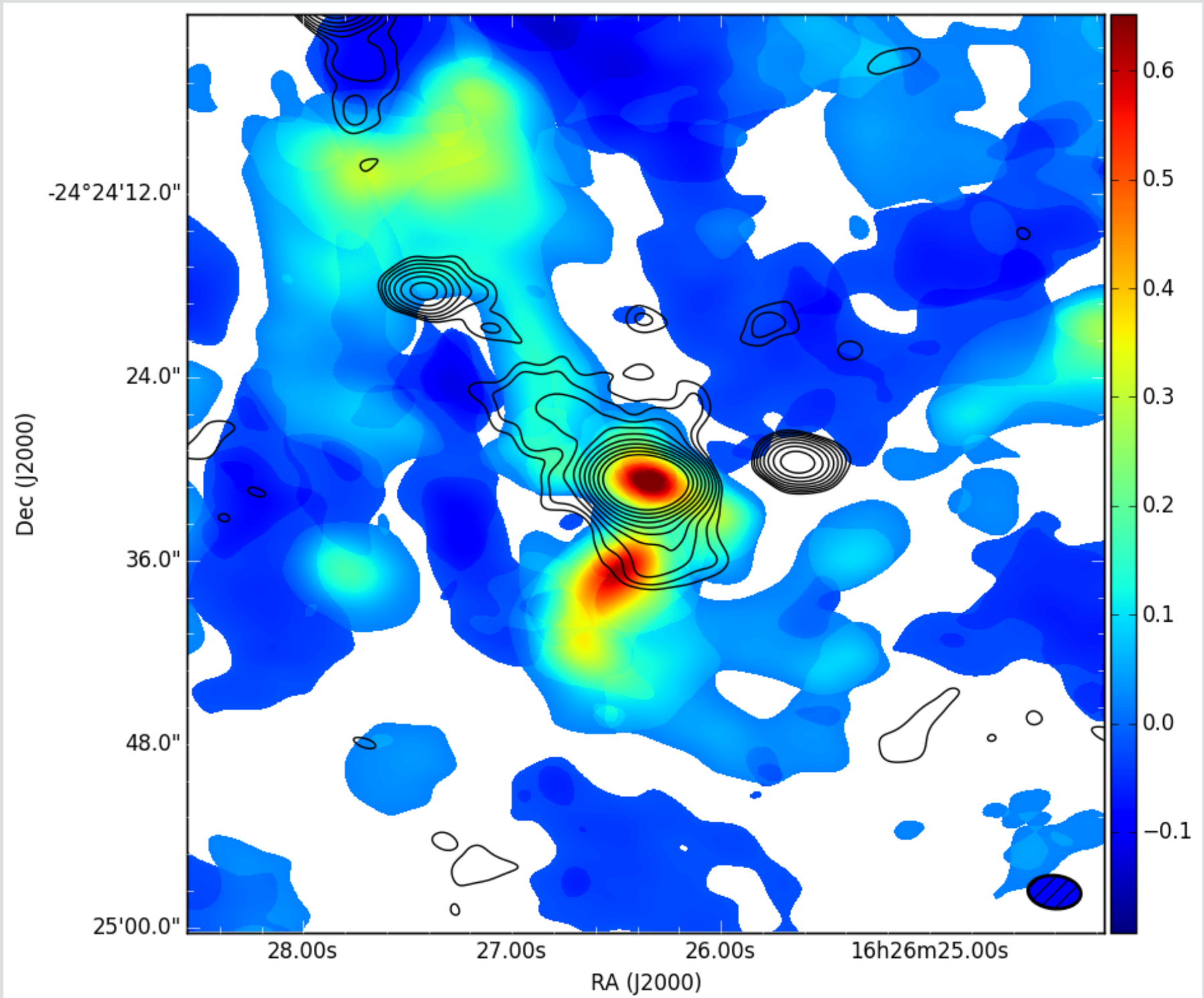
SVS13C SO 3∑ 4—>4



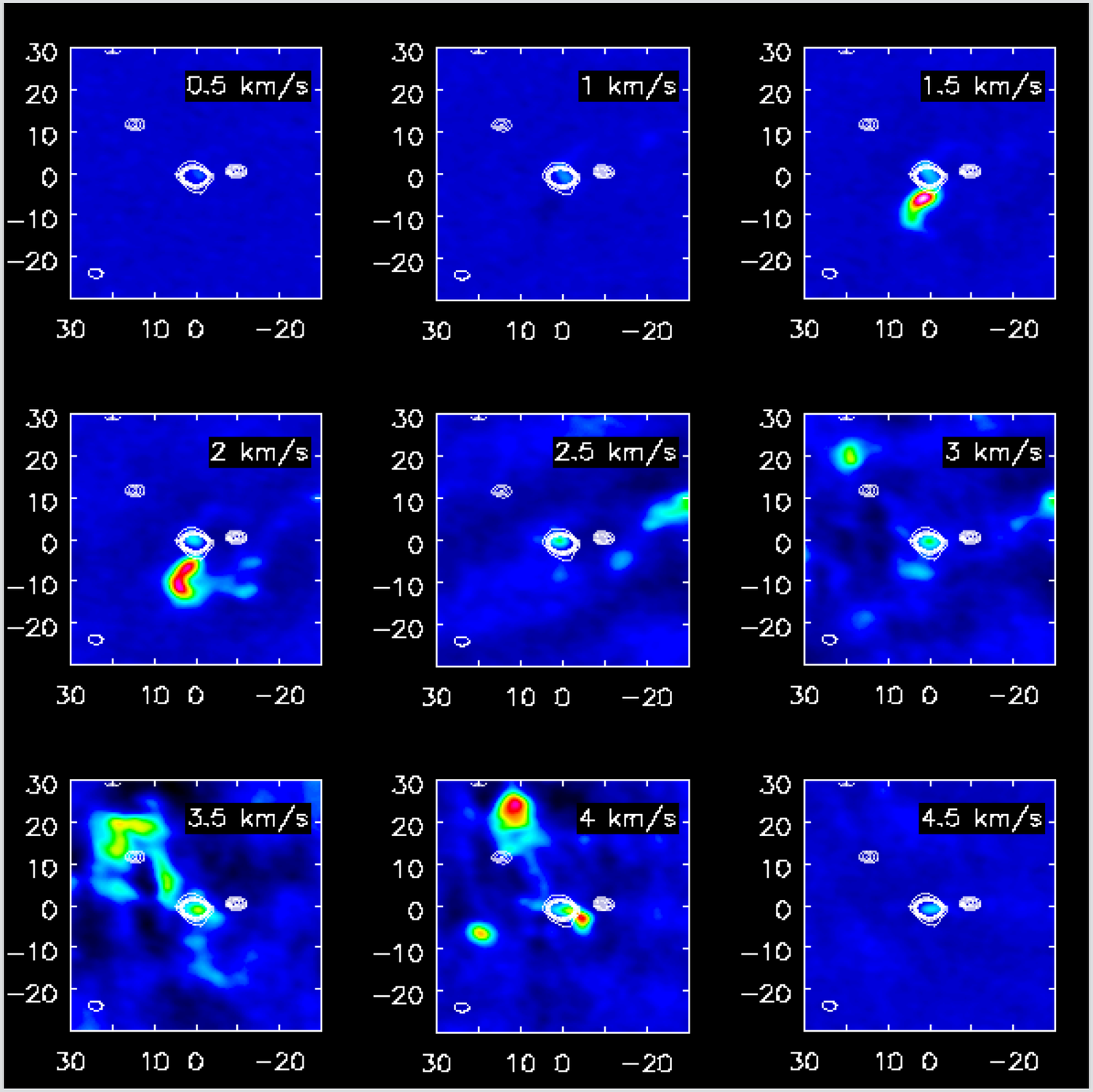
SVS13C CN


54.0"
48.0"
42.0"
36.0"
30.0"
+31°15'24.0"
Dec (J2000)
03.50s
03.00s
02.50s
02.00s
01.50s
01.00s
3h29m00.50s
RA (J2000)
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00

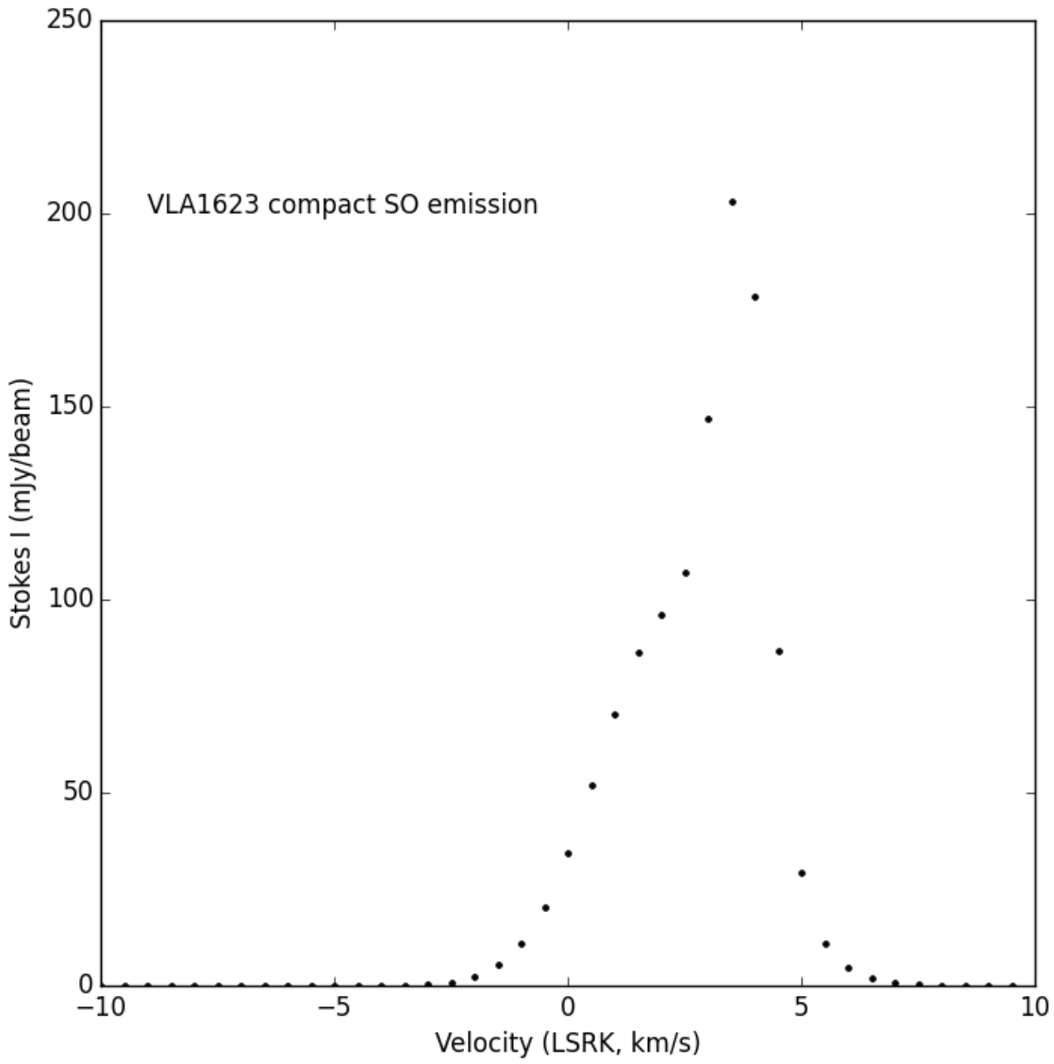
VLA 1623 SO 3∑ 3——>2

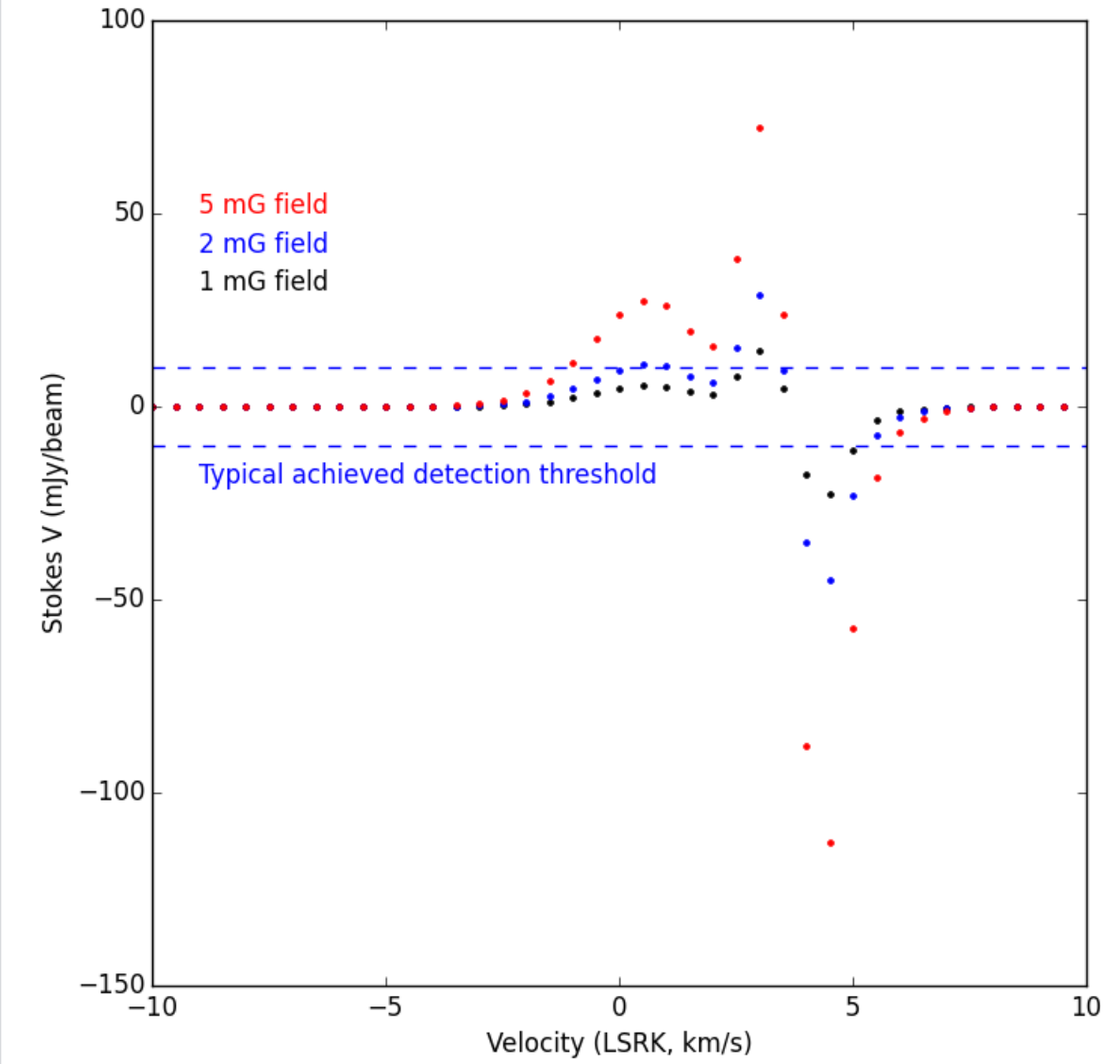


VLA 1623 SO 3∑ 3——>2



Test Case: VLA 1623





Take Away Points

- Paramagnetic molecules found close to central protostar
    - In disk or near base of outflow?
    - Look for velocity gradient in lines.
- Need follow-up Zeeman observations to determine LOS magnetic field strength