Thermal Dust Polarization Toward Star Formation Regions

--An Evolving Role of the Magnetic Field from Large to Small Scales from High Angular Resolution Observations

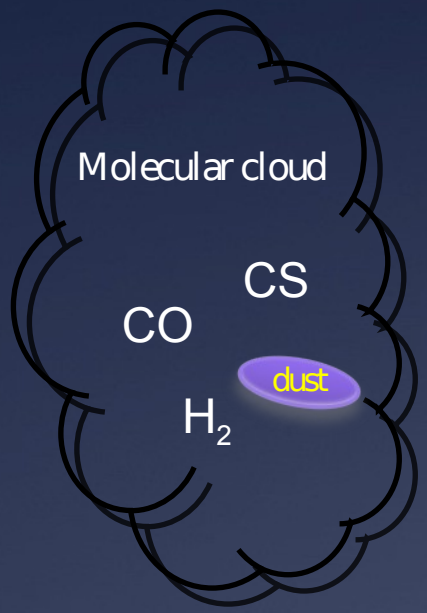
Ya-Wen Tang
Laboratoire d'Astrophysique de Bordeaux; CNRS, France

Paul T. P. Ho
Institute of Astronomy and Astrophysics, Academia Sinica, Taipei, Taiwan (ASIAA)
Patrick Koch (ASIAA)
Josep M. Girart (CSIC-IEEC, Spain)
Ramprasad Rao (ASIAA)
Shih-Ping Lai (NTHU,ASIAA)

Outline

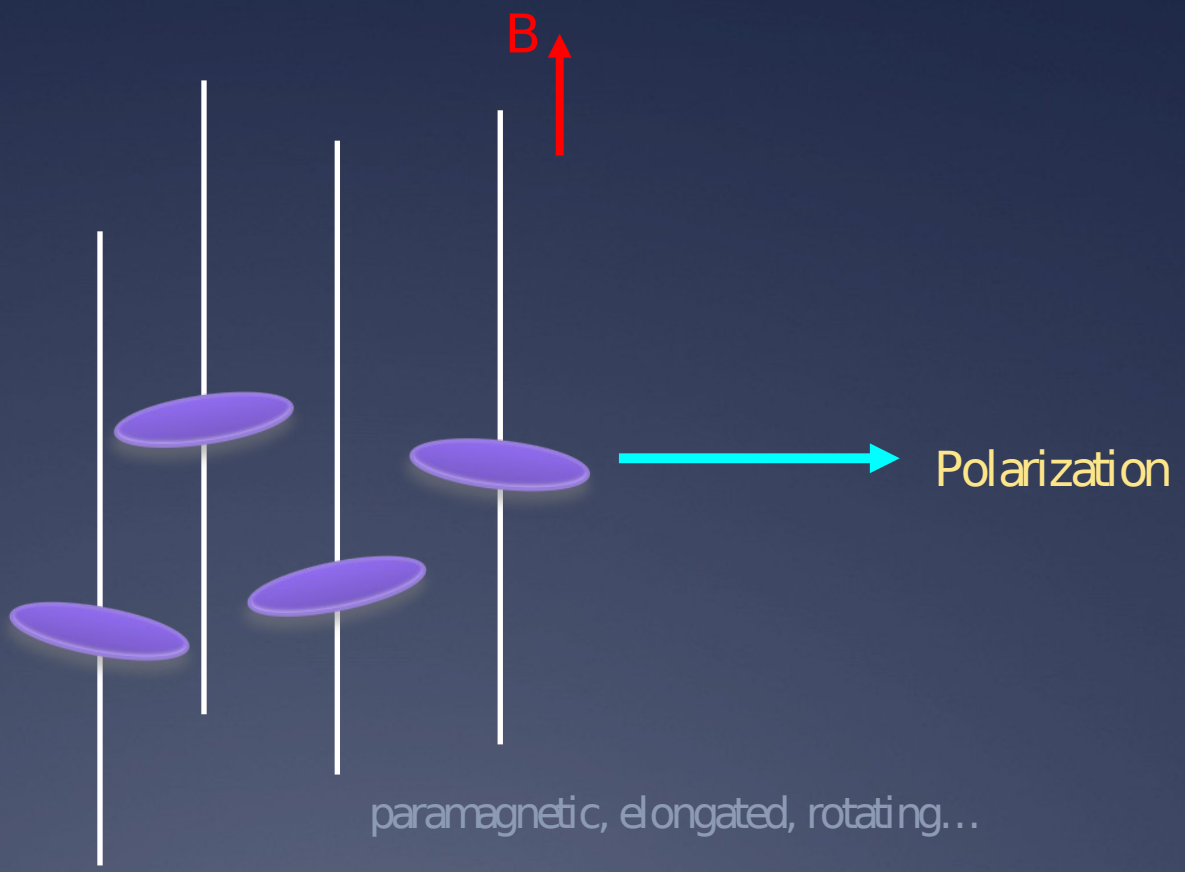
- Observation
  - Method: thermal dust polarization
  - Interferometer: the Submillimeter Array
- B field from pc to 0.05 pc scale
- B field shaped by gravity?
  - Collapsing core W51 e2
- Conclusion

Method: linear polarization from the thermal dust emission



n_{H_2} ~ $10^{4\text{-}7}$ (cm^{-3})

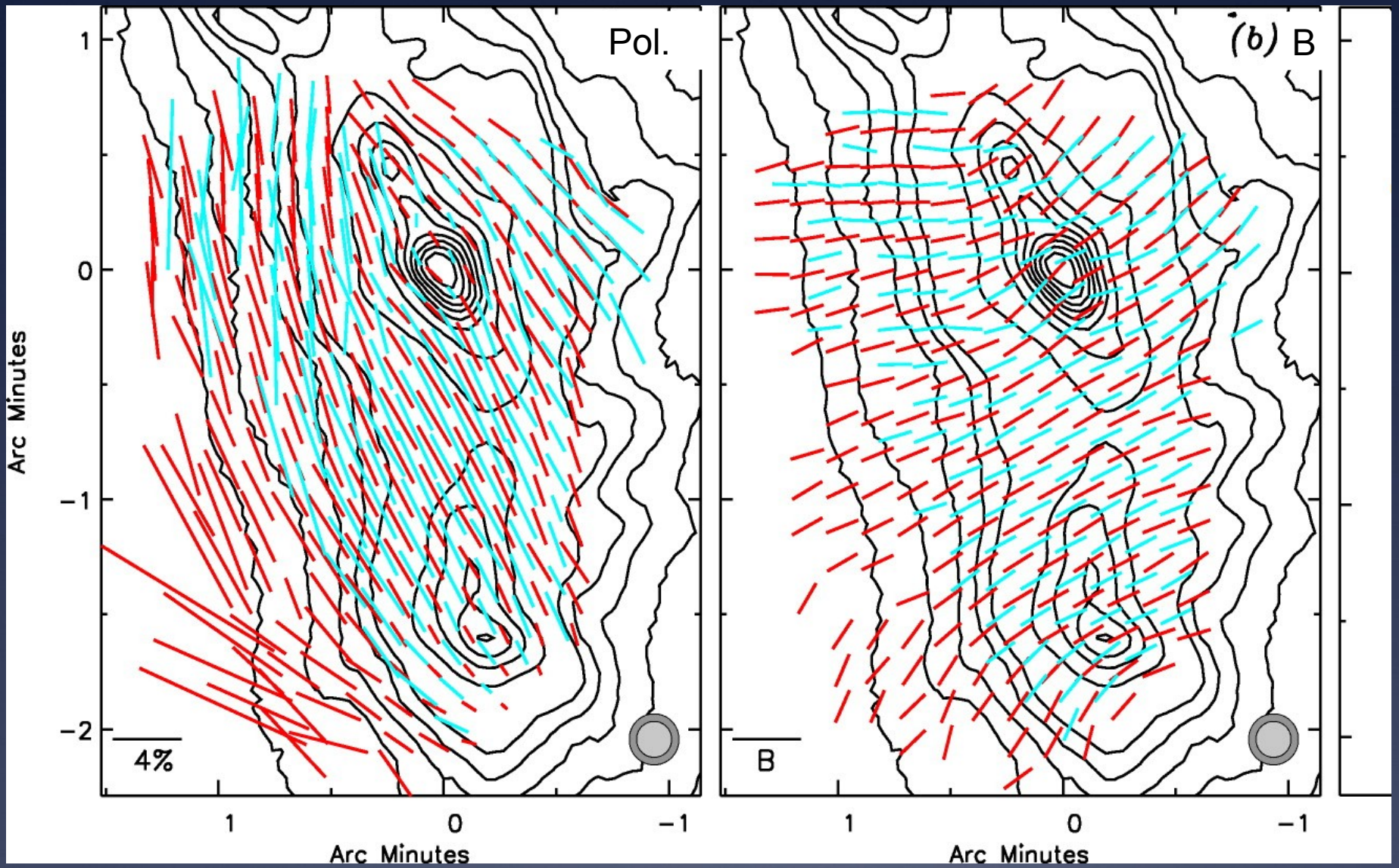
T ~ 10 (K)



Talk by Koang Thiem on Thursday

Method: FIR linear polarization

OMC-1

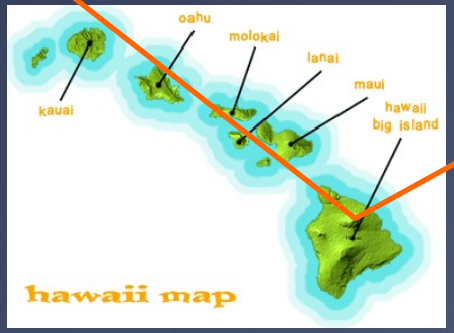


0.3 pc

Vaillancourt et al. 2008

Observations

Sub-Millimeter Array (SMA)

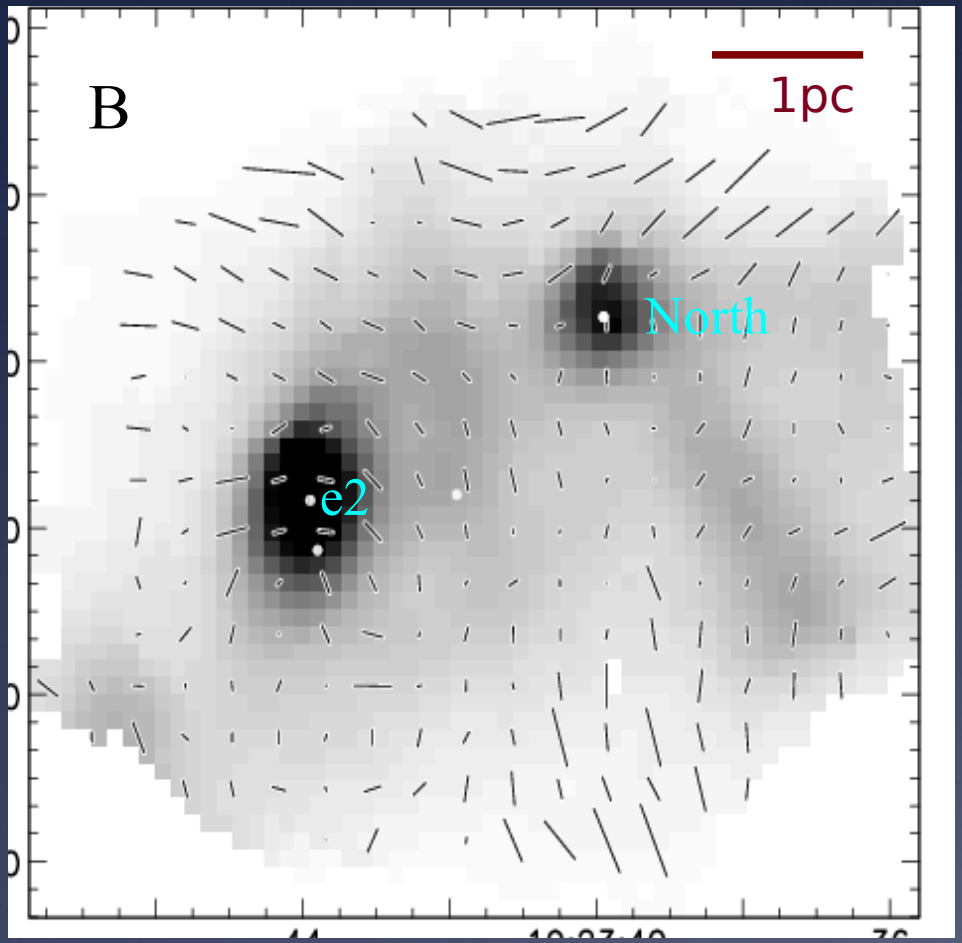


- 8 x 6-m antennae
- Frequency: 345 GHz (870 micron)
  - ➔trace thermal dust emission
- Quarter-wave plates
  - ➔ measure dual polarization
  - ➔Stokes I, Q, U & V
- Angular resolution: ~1"
- Sigma PA ~ a few degree

Outline

- Observation
  - Method: thermal dust polarization
  - Interferometer: the Submillimeter Array
- B field from pc to 0.05 pc scale
- B field shaped by gravity?
  - Collapsing cores W51 e2/e8 and W51 North
  - Orion BN/KL
- Conclusion

W51 e2/e8 and North

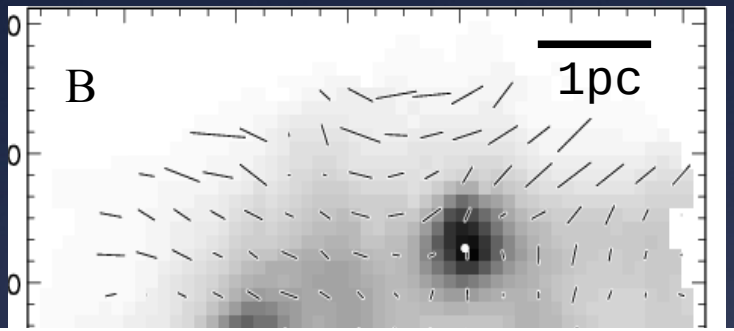


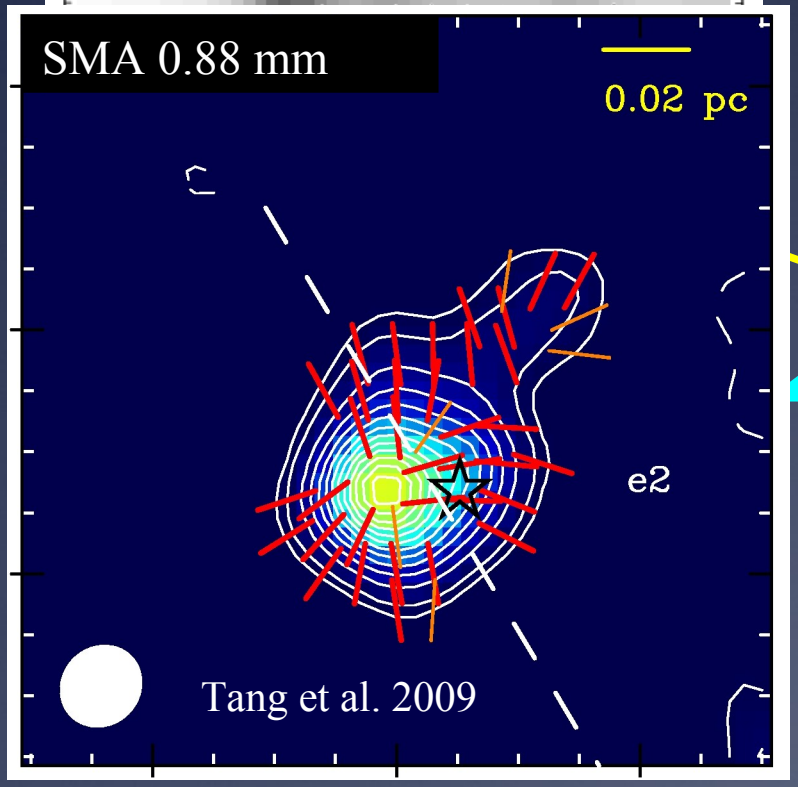
- SCUBA POL at 0.85 mm
- W51A is active in star formation
- B field lines do not show a single coherent structure

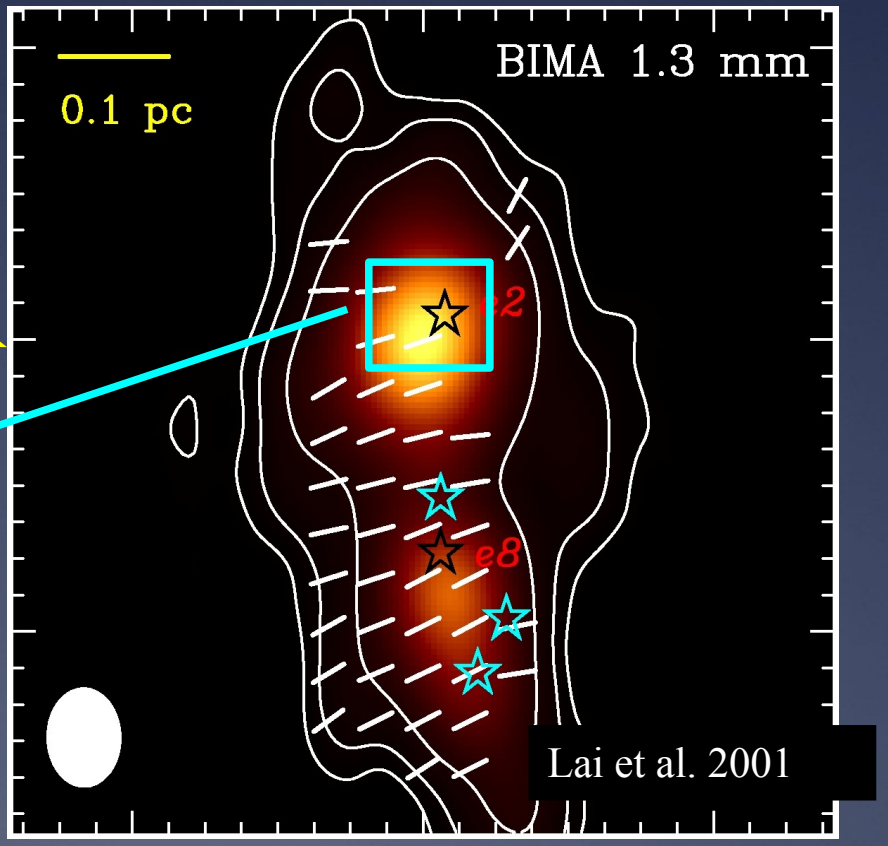
Chrysostomou et al. 2002

W51 e2/e8

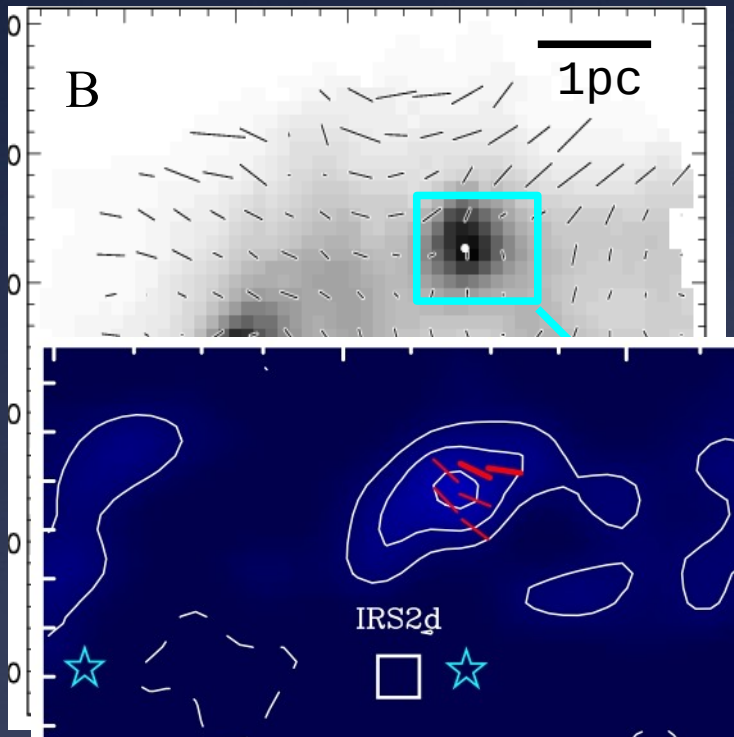
- B field in 0.5 pc envelope is uniform → stable at this scale
- B field at 0.02 pc scale is furthur resolved



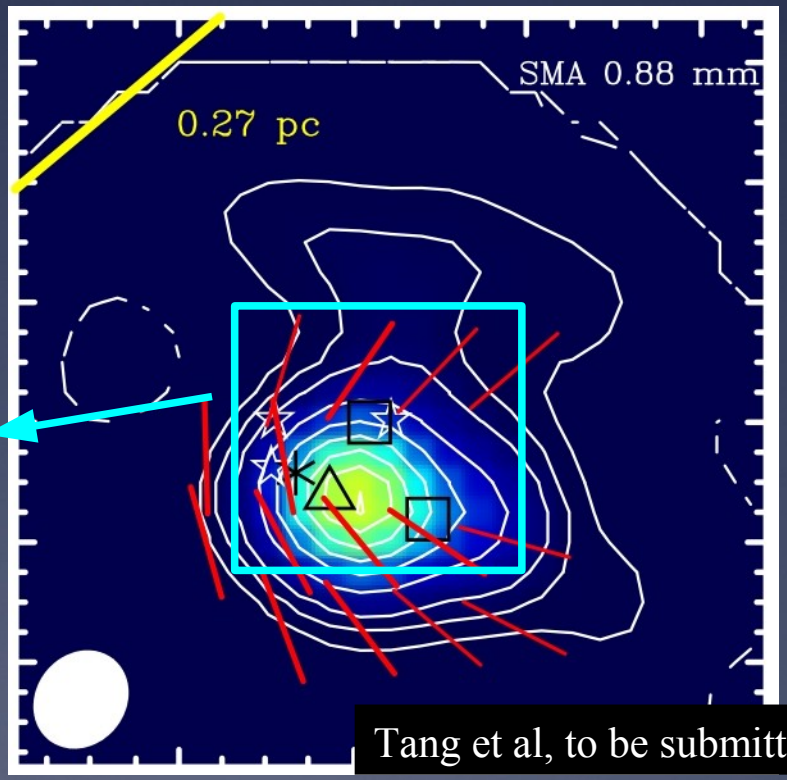




W51 North

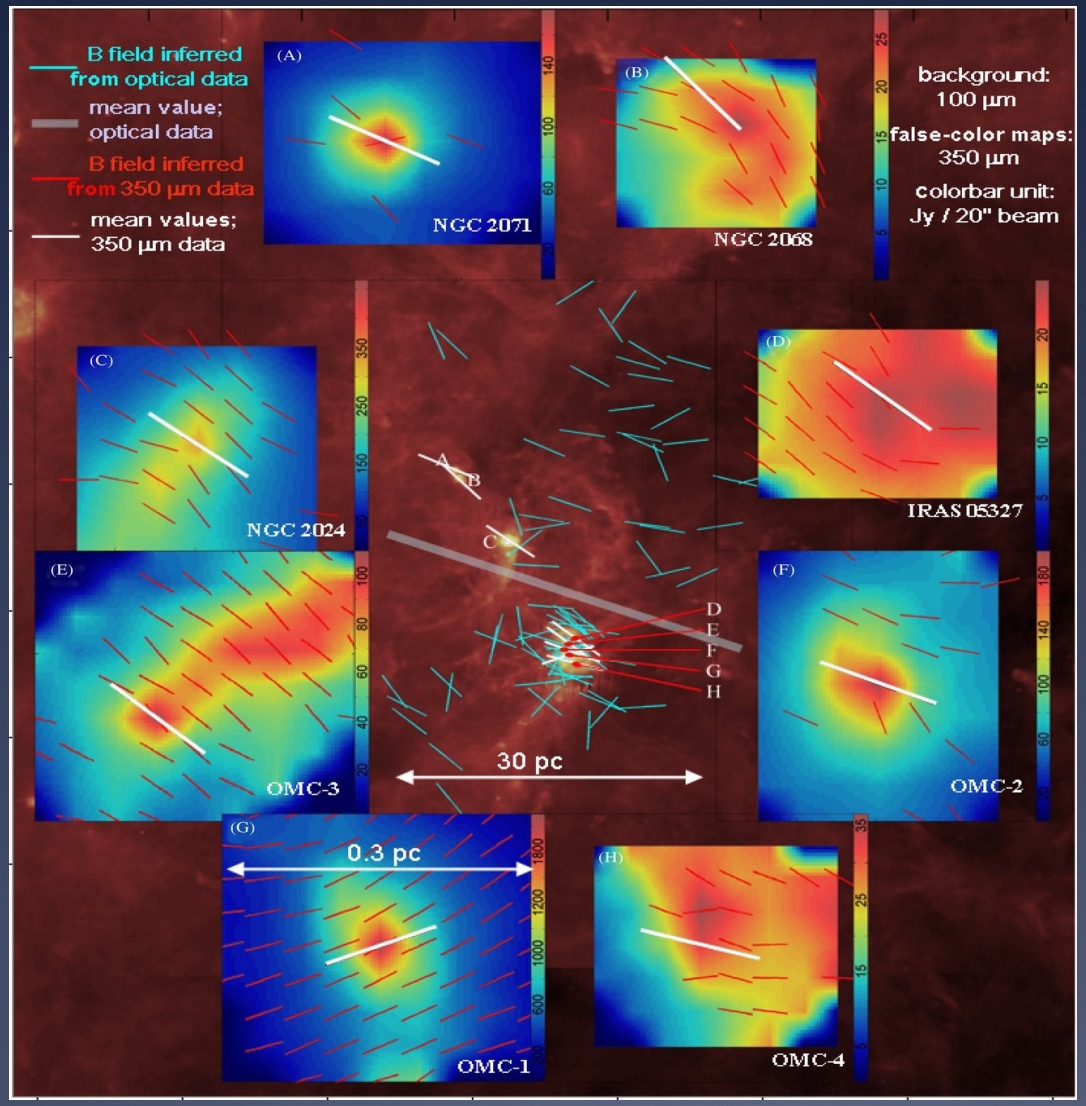


- B field is much more complex as resolved in the core scale !



Tang et al, to be submitted

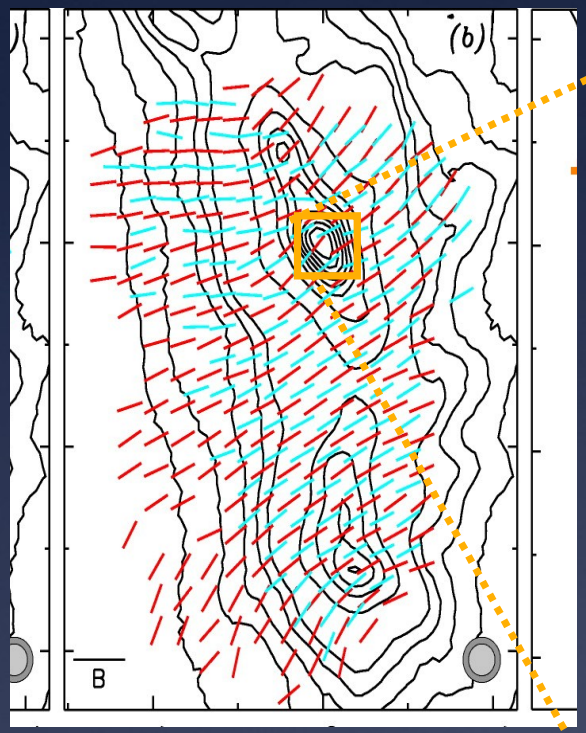
Orion Molecular Cloud



Li et al. 2009

Orion BN/KL: B field, zooming in with 2 mpc resolution

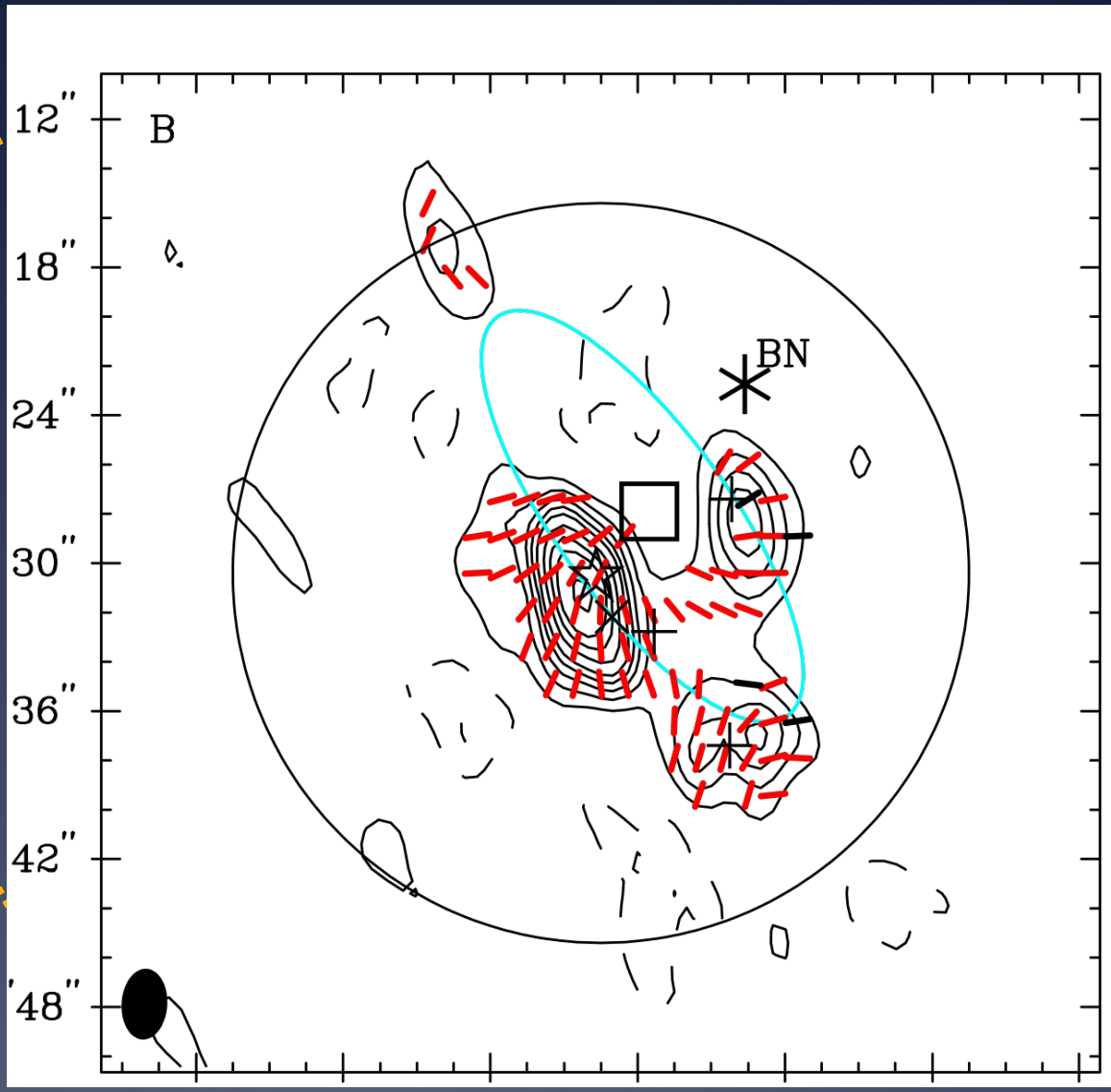
SHARP 350, 450 μm



0.26 pc

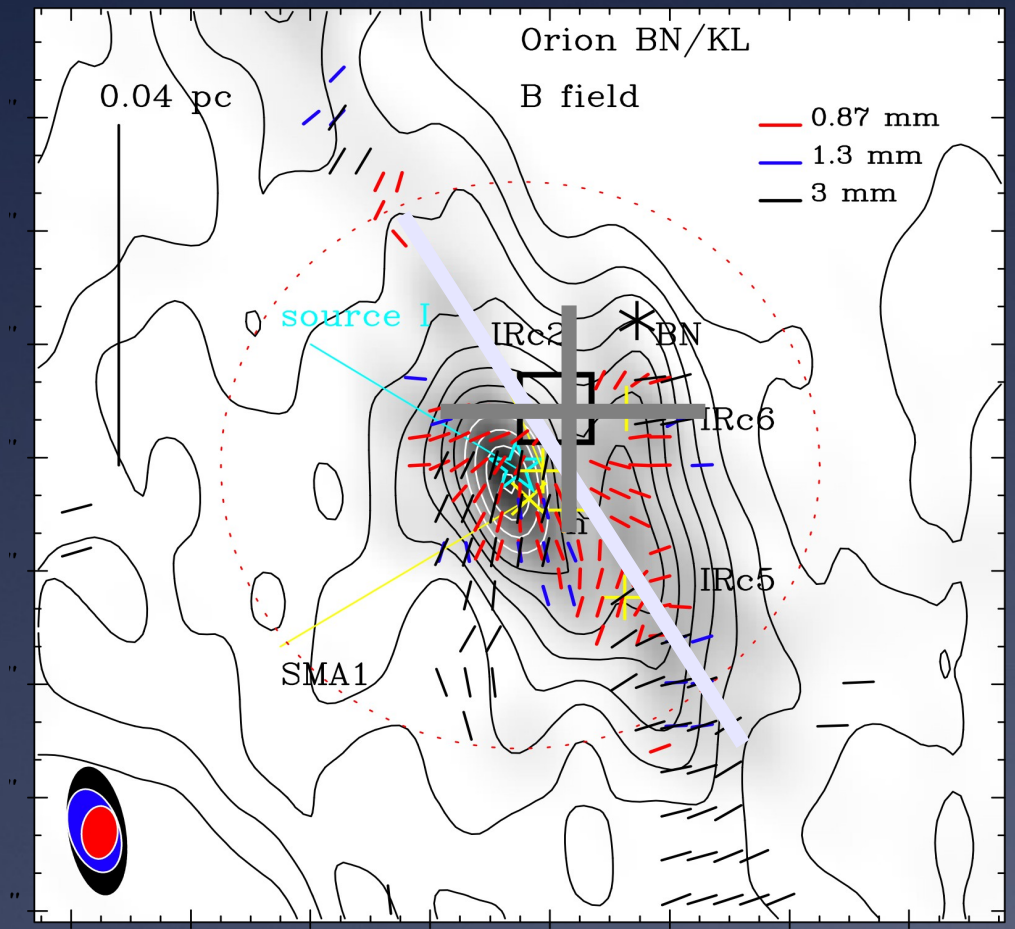
Vaillancourt et al. 2008

- B field varies significantly and smoothly across the dust ridge



Tang et al., ApJ, 2010

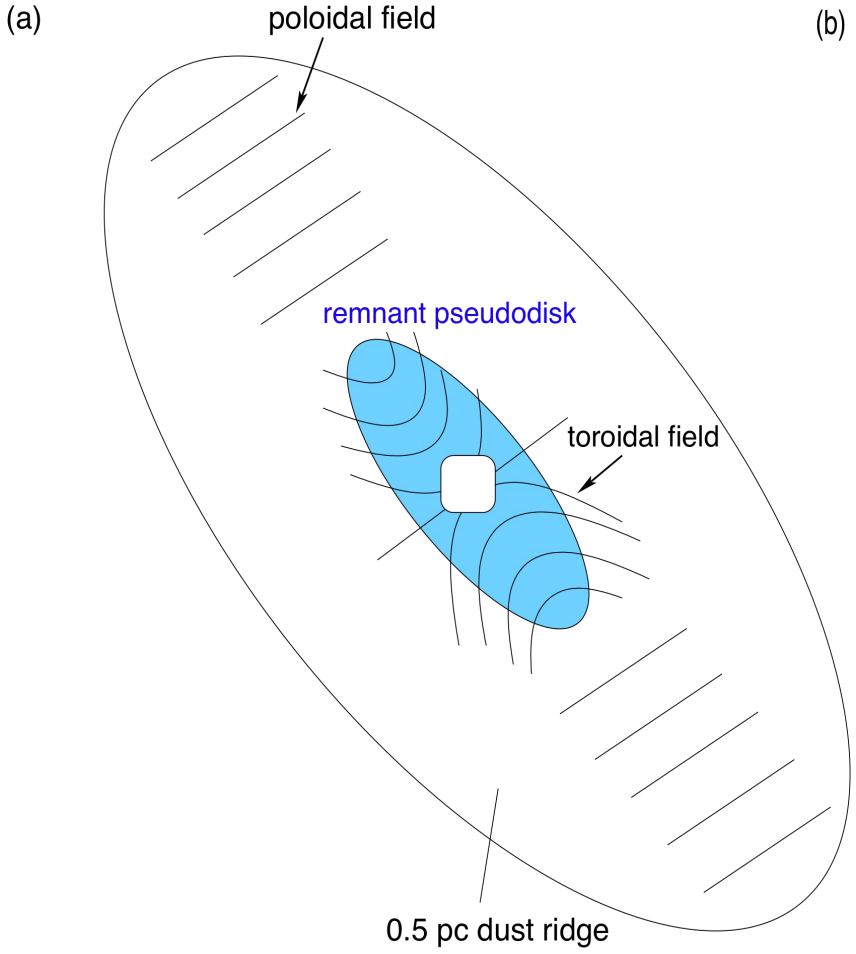
Orion BN /KL



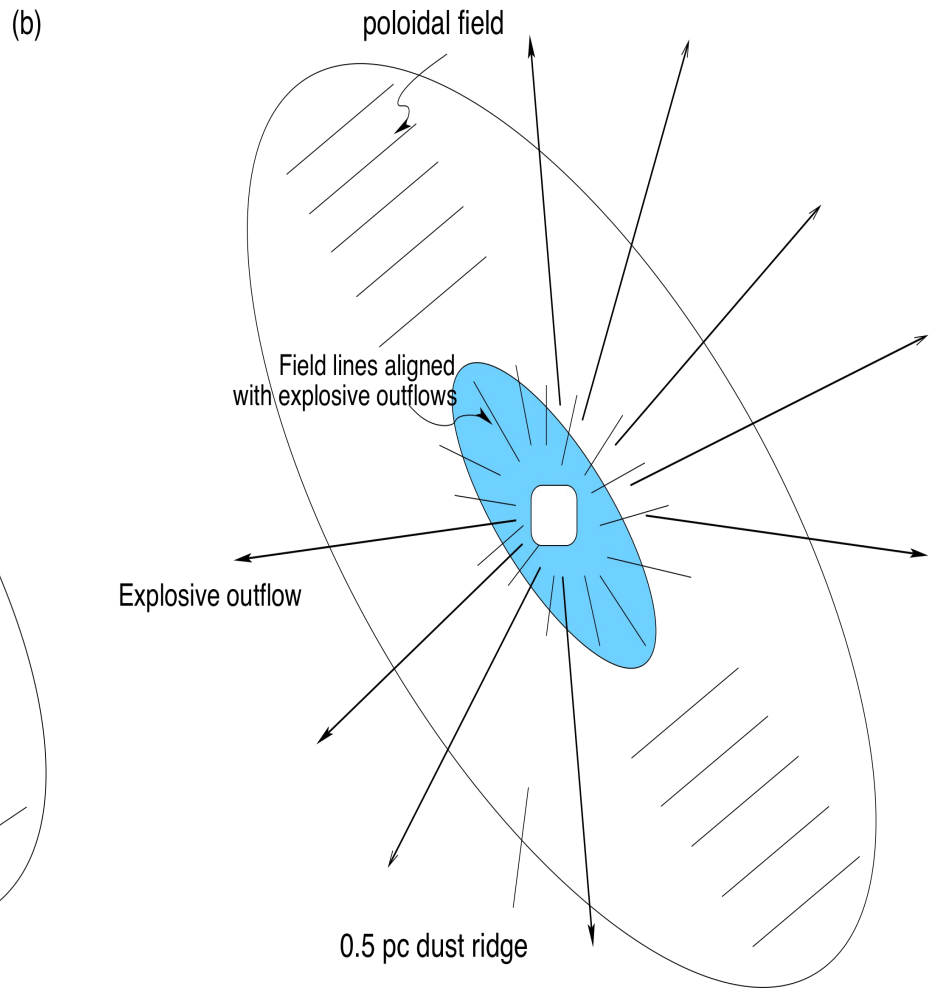
Tang et al., ApJ, 2010

Check for symmetry
- pure radial ?
- symmetry plane ?

Possible Interpretation



- Poloidal and toroidal field
- Magnetized pseudo-disk
- contraction

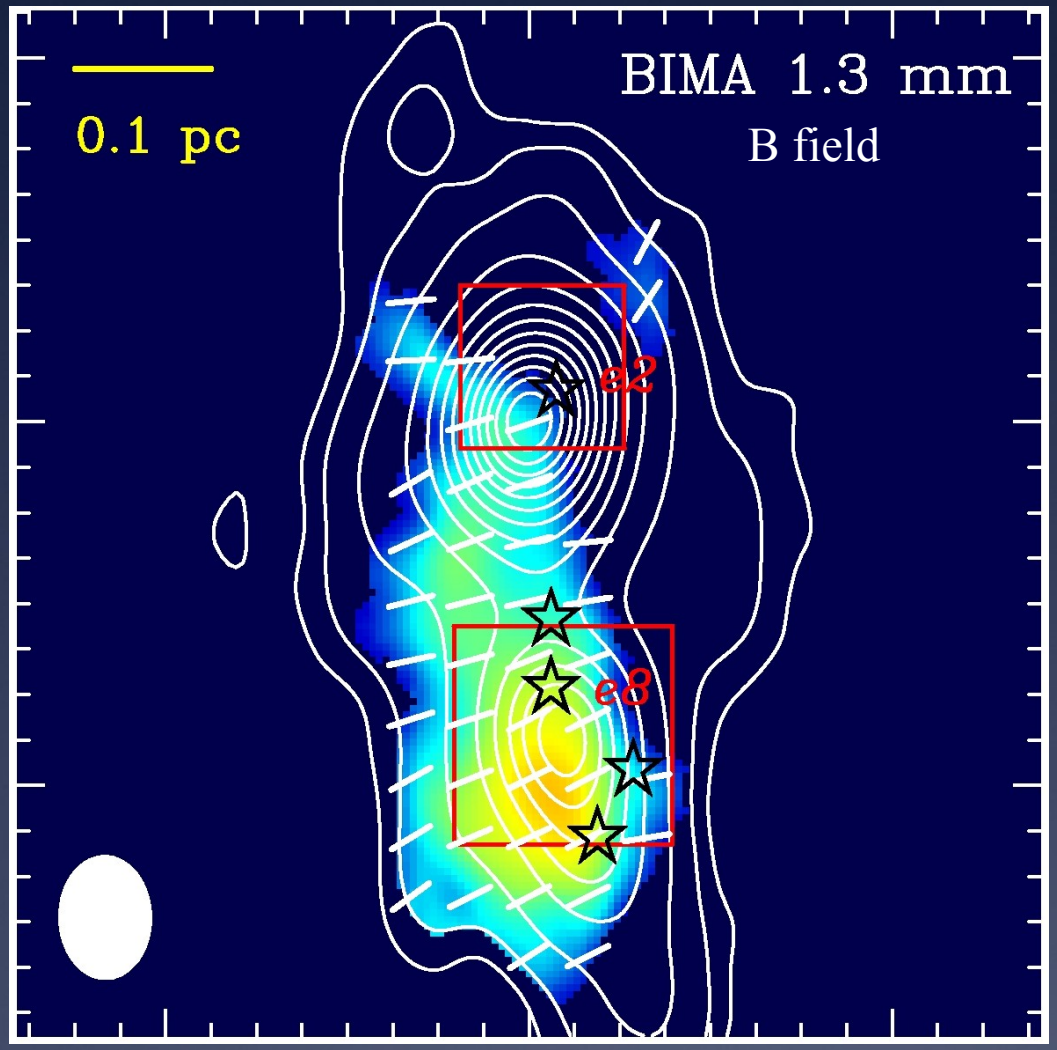


- B field lines being shaped by the explosive outflow

Outline

- Observation
  - Method: thermal dust polarization
  - Interferometer: the Submillimeter Array
- B field from pc to 0.05 pc scale
- B field shaped by gravity?
  - Collapsing cores W51 e2/e8 and W51 North
  - Orion BN/KL
- Conclusion

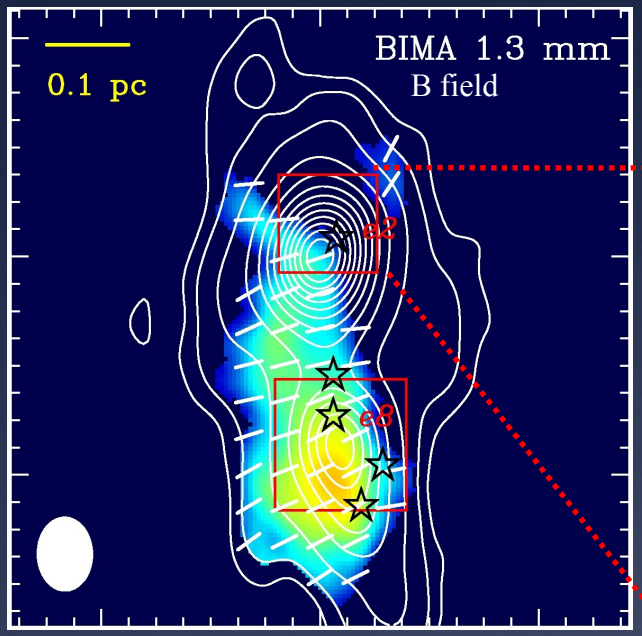
Results: W51 e2/e8



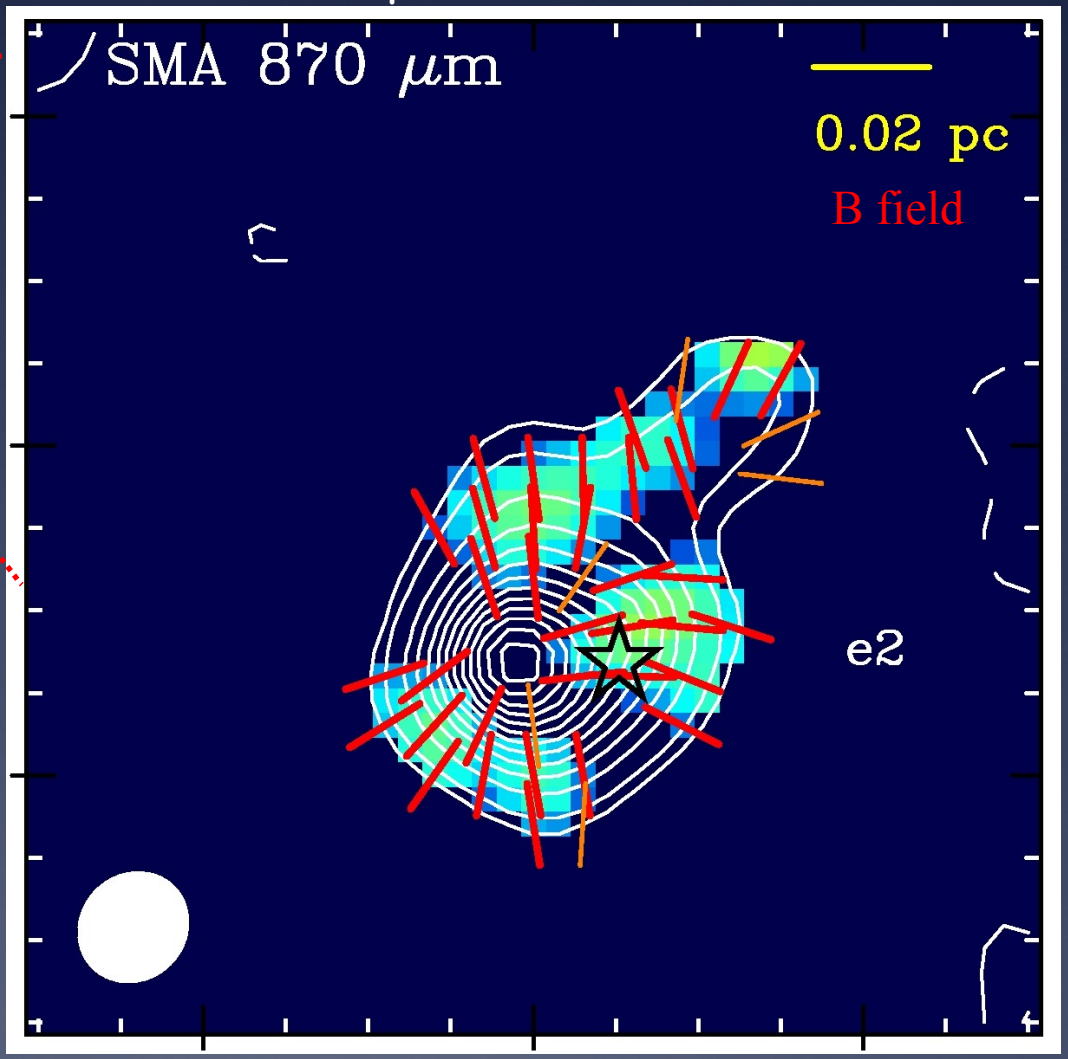
Lai et al. 2001

Contours: continuum emission
Color scale: polarized emission

Results: W51 e2/e8

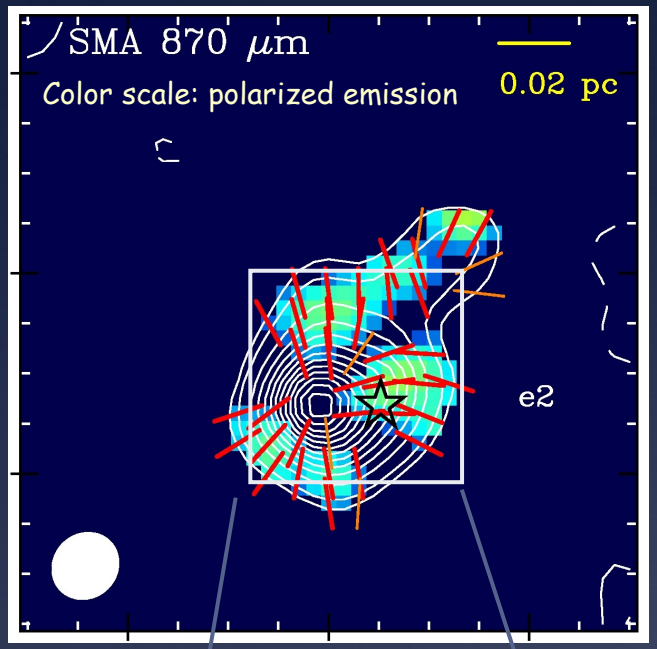


Contours: continuum emission
Color scale: polarized emission Tang et al. 2009b

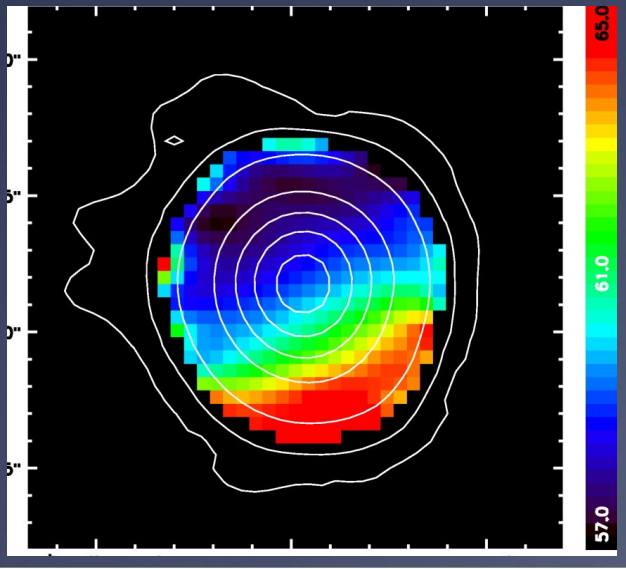


In e2, the depolarization previously seen at 3" is apparently due to more complex underlying structures

Discussion: W51 e2



Tang et al. 2009b ApJ



- In e2, depolarization zone is nearly parallel to the rotating plane of the ionized accretion flow traced by H53a

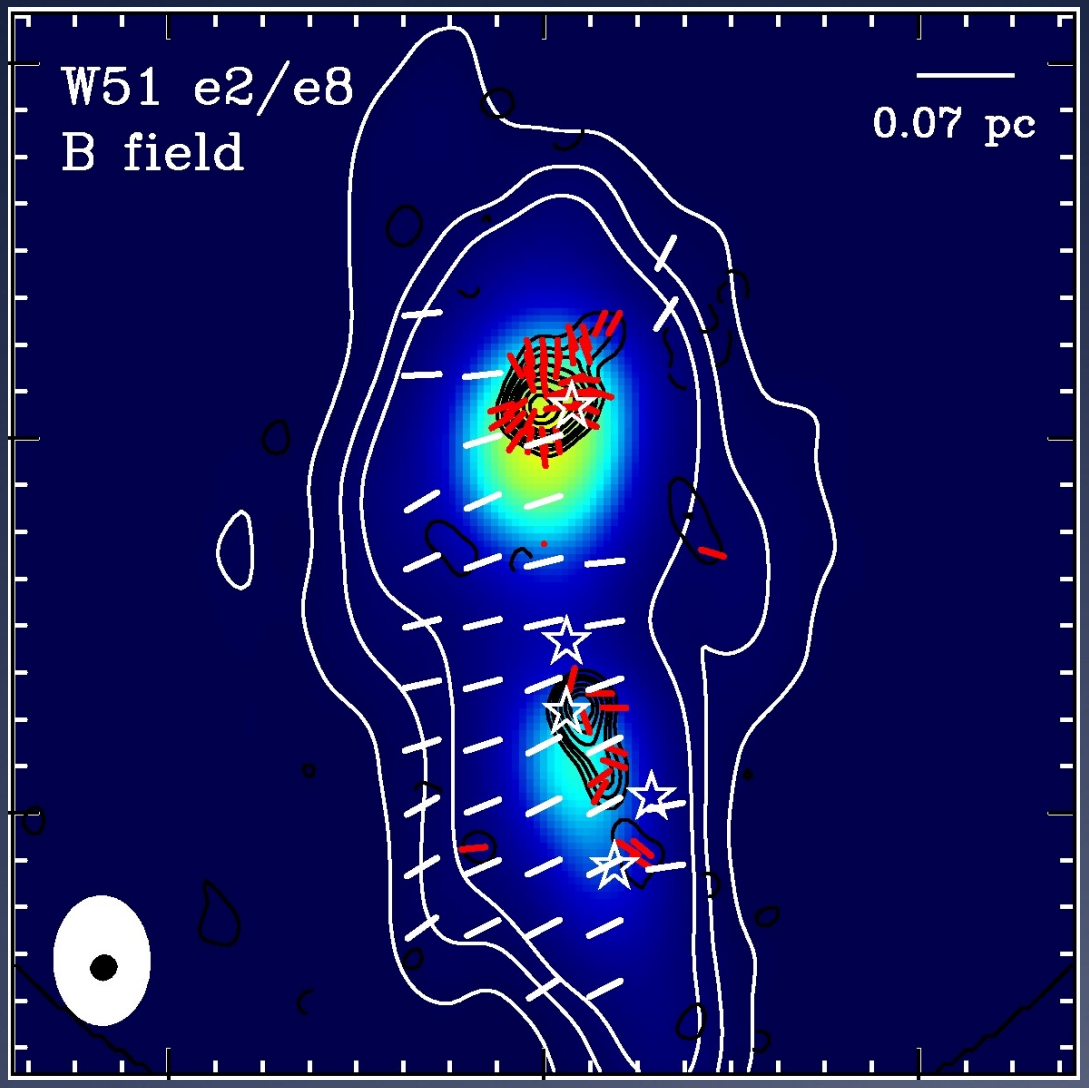
  ➔ B field lines are most likely dragged inward along with accretion and appear to be hourglass like, as in low mass cases (NGC 1333 IRAS4A; Girart 2006).

- Furthermore, clear collapsing signatures were seen in kinematics inferred from molecular lines in e2 and possibly also e8.

  ➔e2 and e8 are super-critical cores.

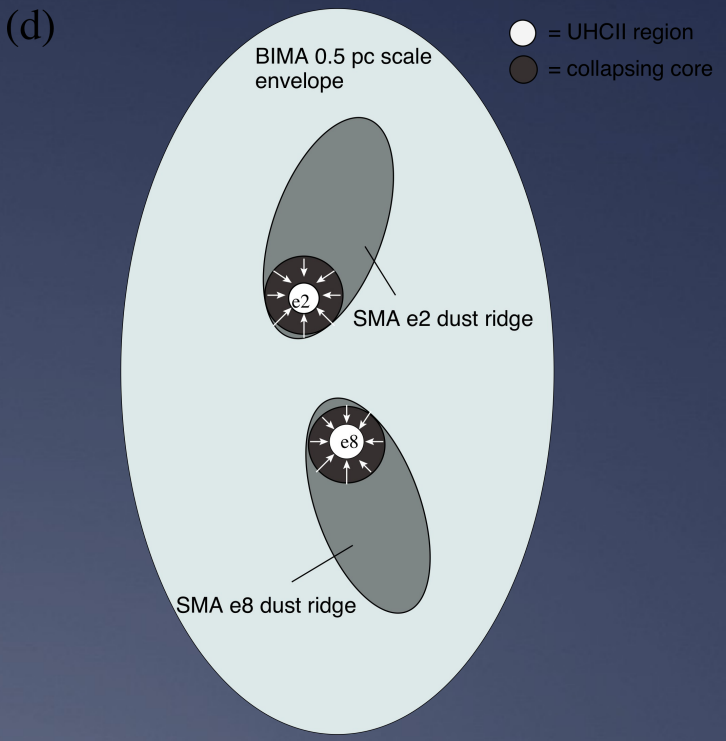
H53a recombination line (Keto & Klaassen 2008)
Contour: integrated intensity
Color scale: velocity in km/s

W51 e2/e8



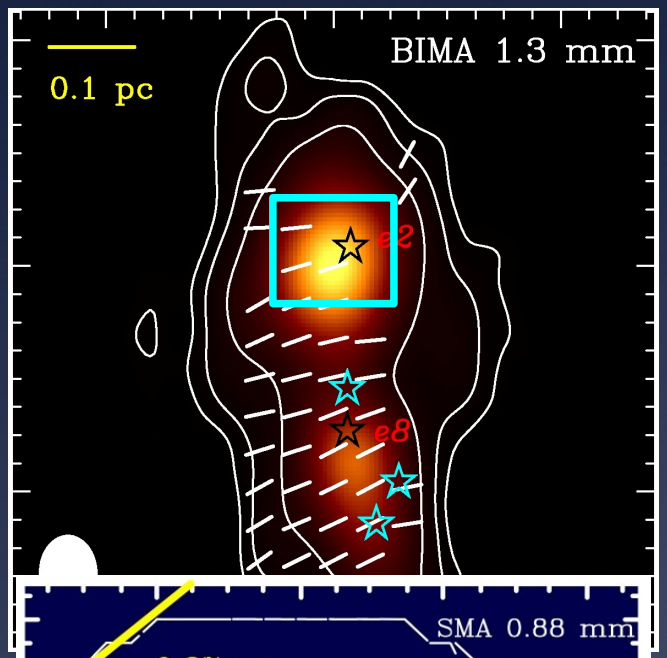
Super-critical cores formed inside a stable envelope

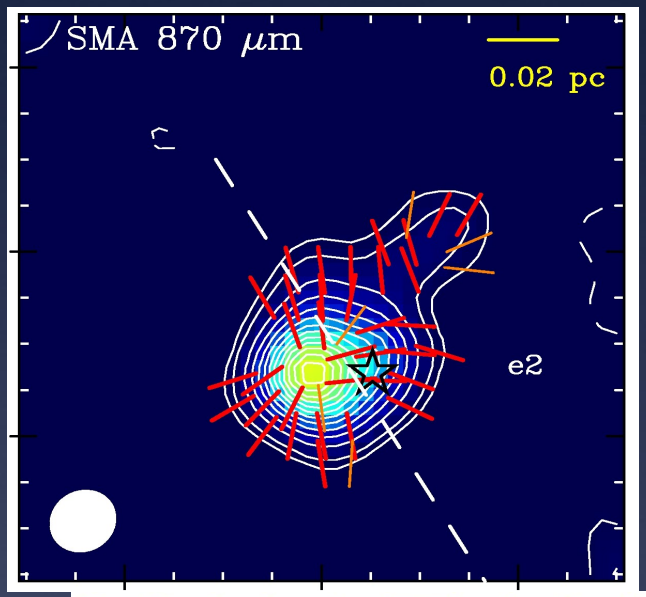
➔ supporting magnetic fragmentation scenario (Lizano 1989; Shu 2004)

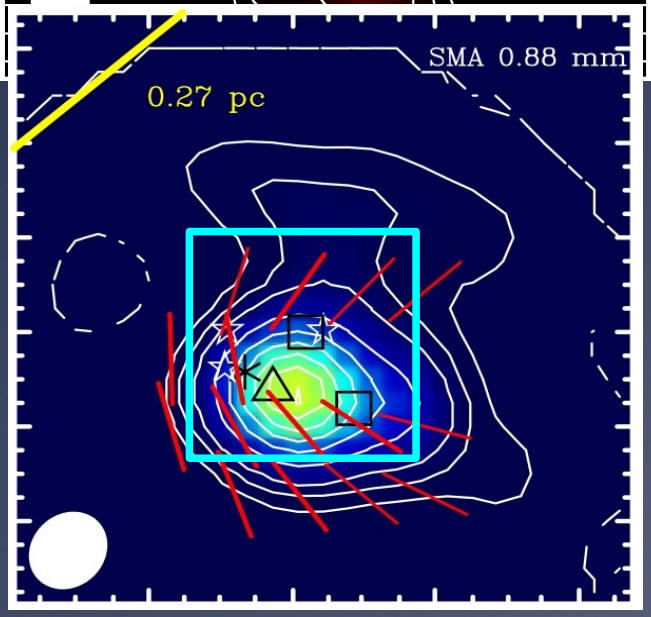


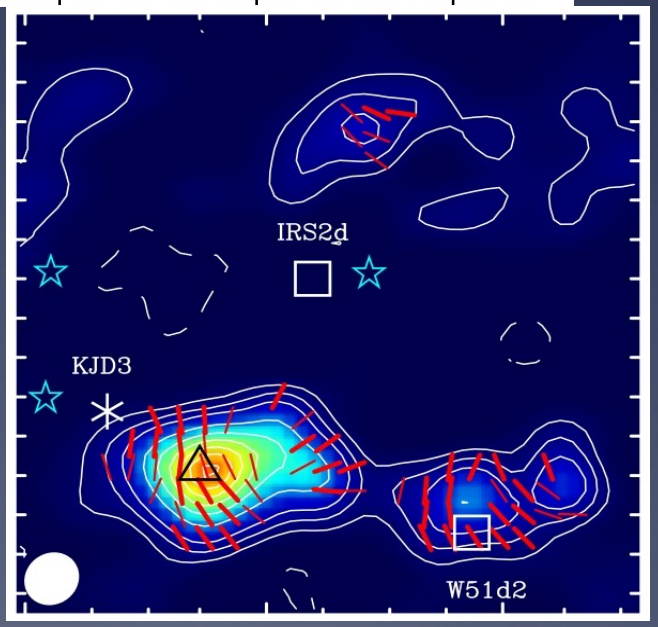
Tang et al. 2009b, ApJ

W51 e2/e8 and North

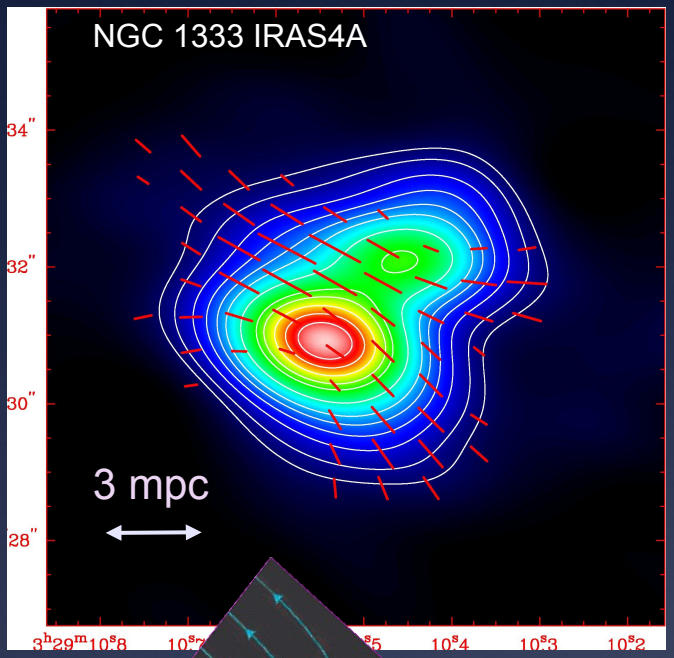


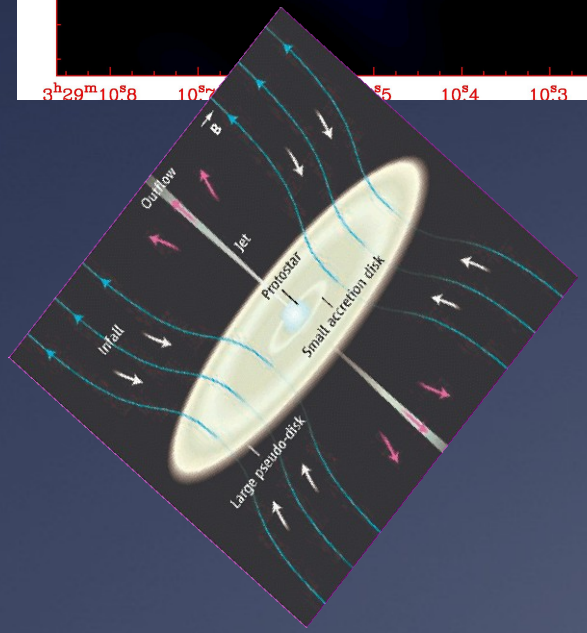




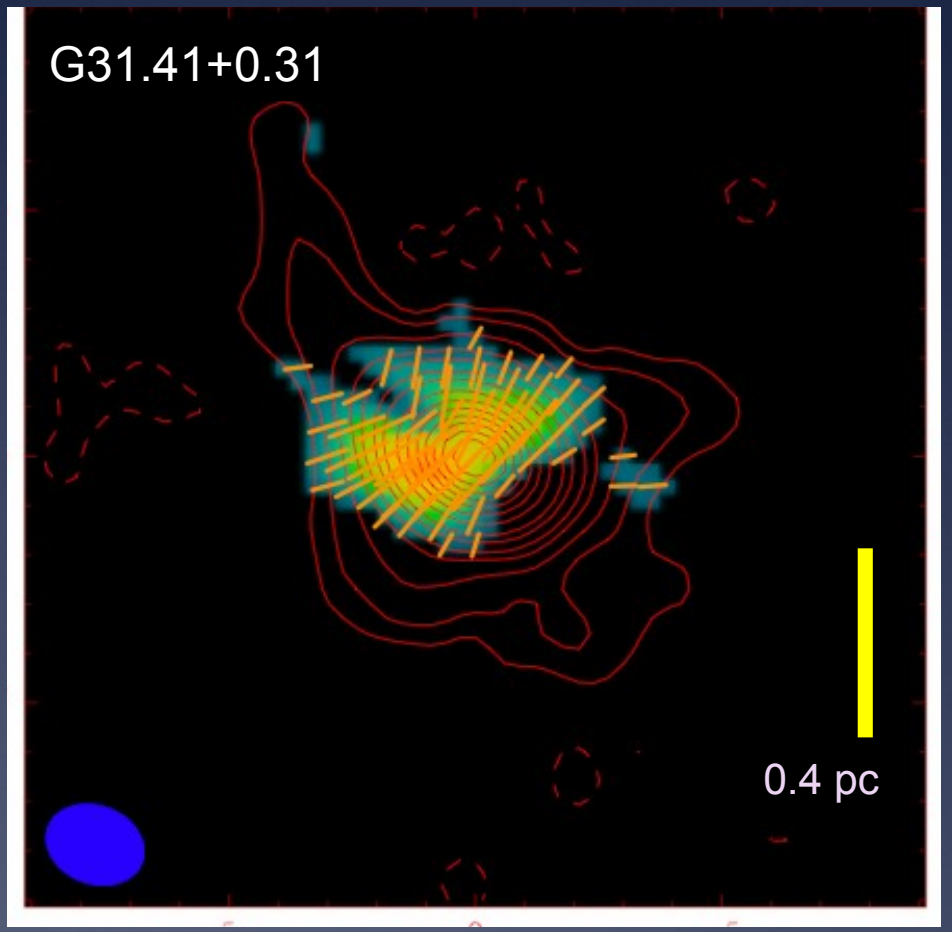


Low mass star formation



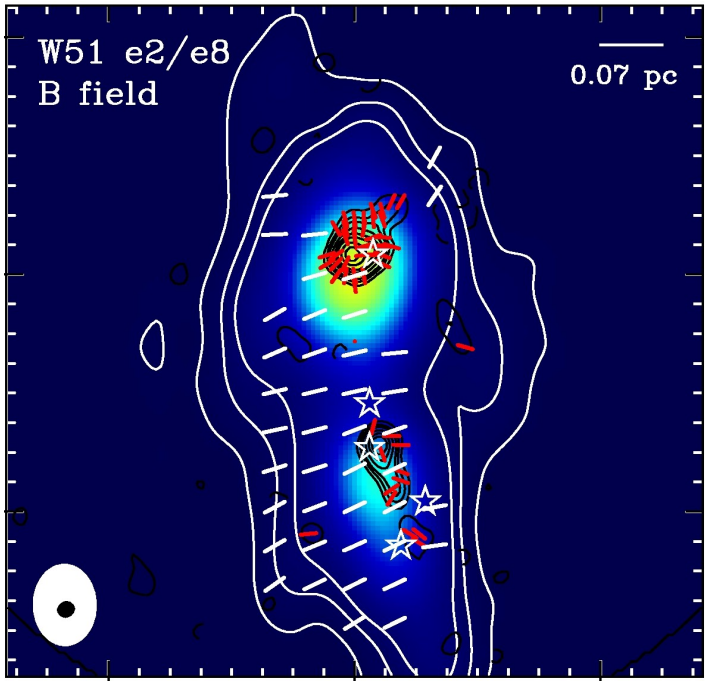


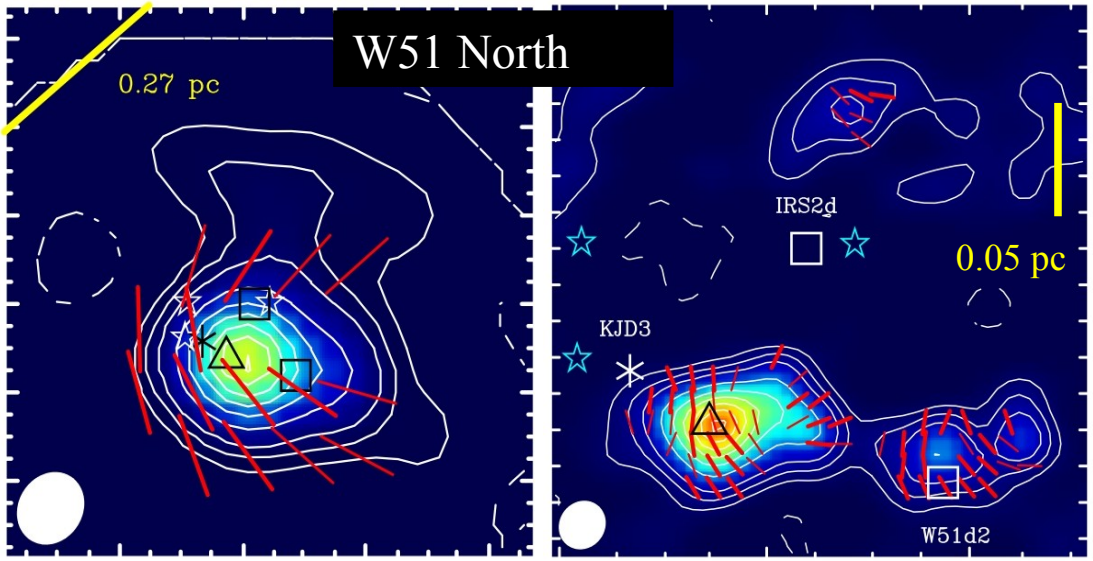
Girart et al. 2006; 2009

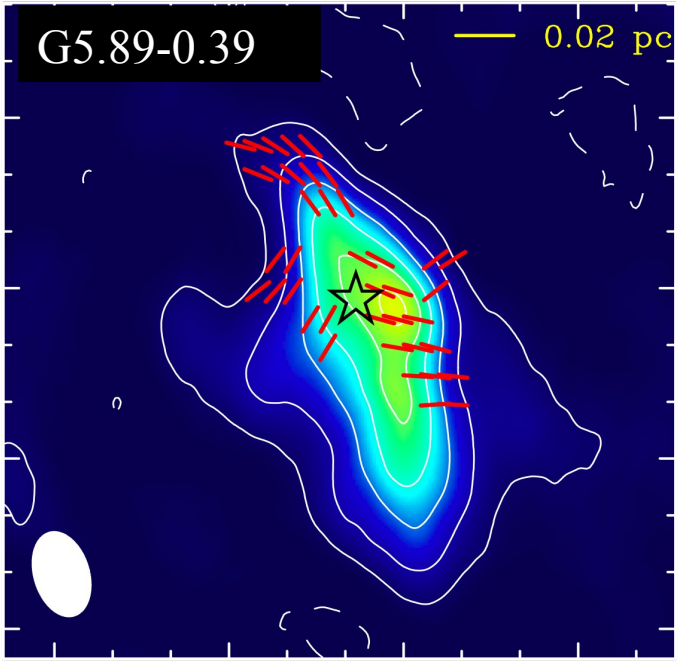


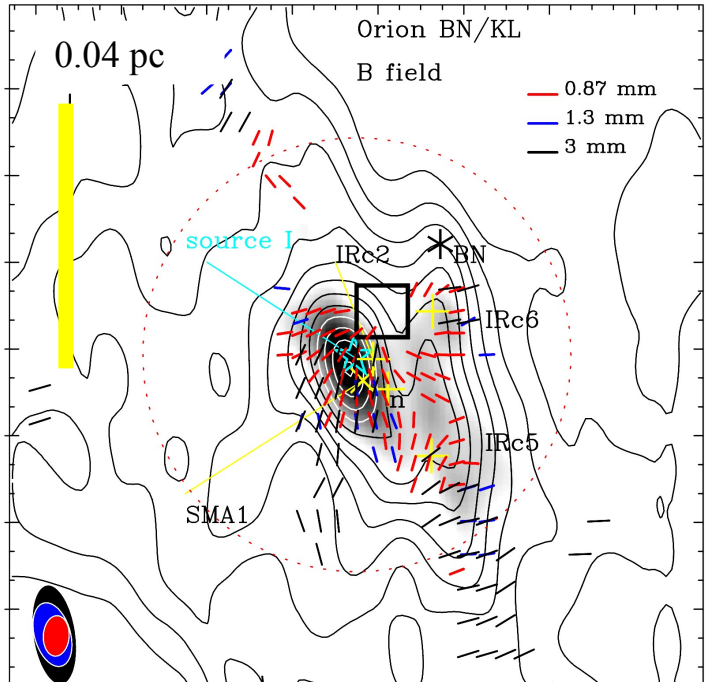
Massive star formation

Polarization observed with high angular resolution in massive star forming cores









Conclusion

- The role of B field varies with scales
  - Uniform B field in w51 e2/e8 and Orion BN/KL at 0.5 pc scale
  - Pinched B field morphology in w51 e2 and w51 north at 0.02 pc scale
- Depolarization near the intensity peak is partly due to more complicated underlying structures