Measuring magnetic fields in the synchrotron protostellar jet in W3(H2O)

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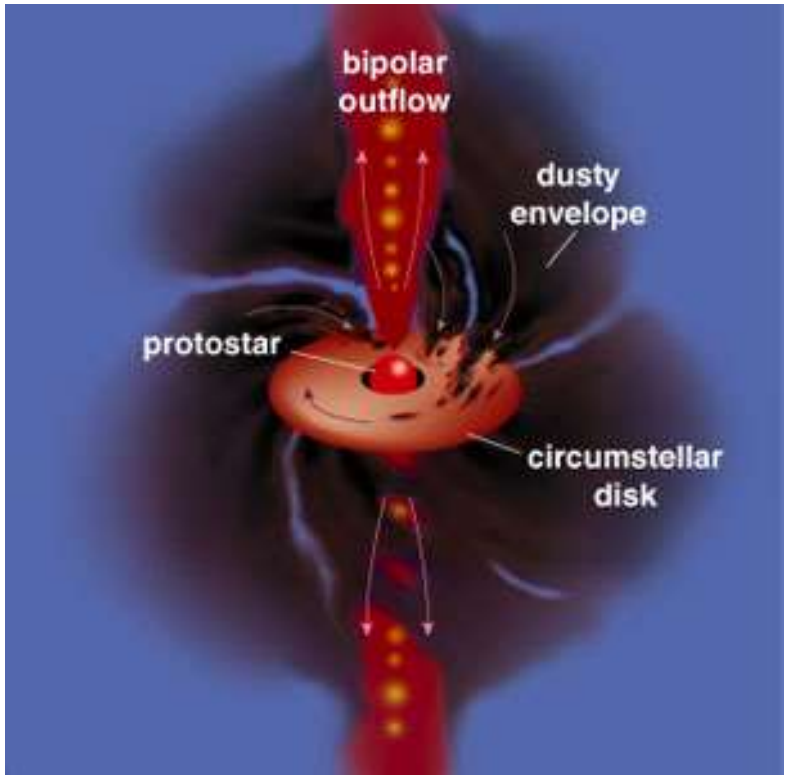
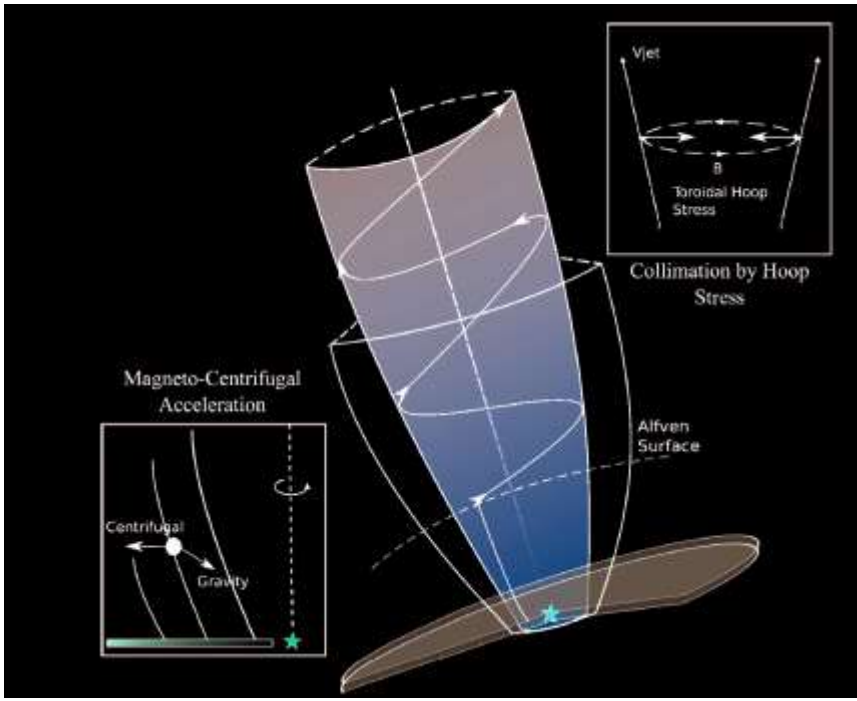
Role of Magnetic fields in jet launch



- observational data on the spatial scales required to assess their role in the mass-loss process is scarce.

- Magnetic fields are invoked to launch, drive, and shape protostellar jets



Adapted from Blandford & Payne 1982

Jets from HMYSOs are ionized

- Shocks
  - *thermal* bremsstrahlung emission
- H-ionizing flux at ZAMS (HII regions)
  - *thermal* bremsstrahlung emission
- (Mildly) relativistic electrons gyrating in magnetic fields
  - ***Synchrotron*** emission

The target: the massive SFR W3(H_2O)

SYNCHROTRON EMISSION FROM THE H_2O MASER SOURCE IN W3(OH)

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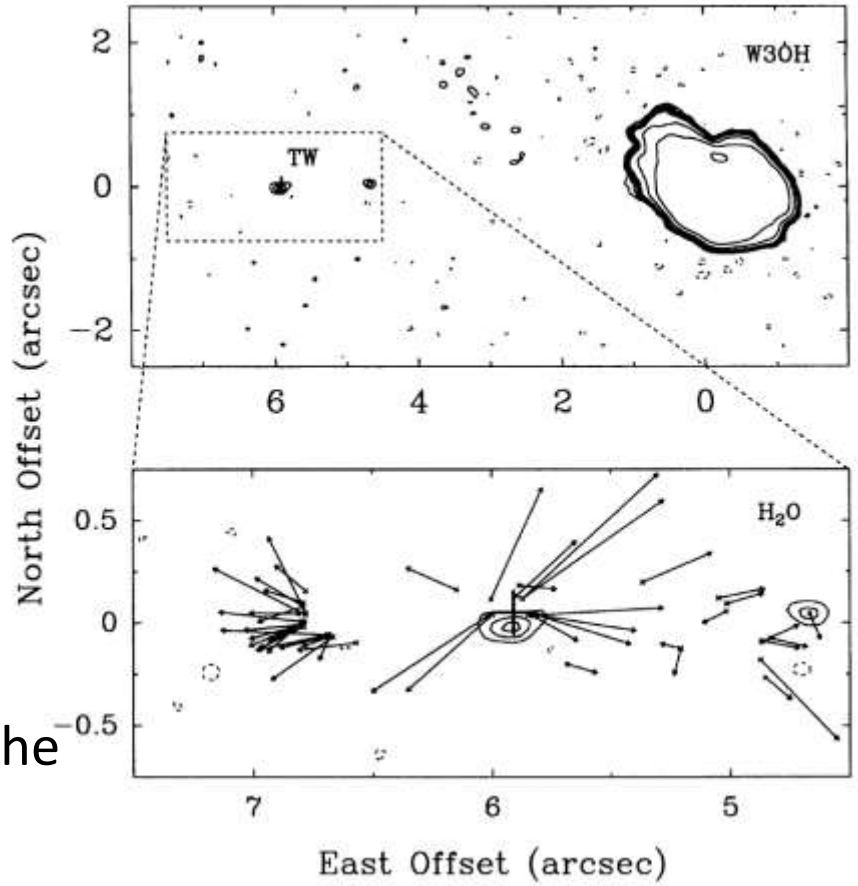


- ✓ synchrotron jet from a massive protostar
  - ➢ **B** must play a role in driving this jet
- ✓ strongly polarized H_2O maser source
  - ➢ VLBI can be used to map **B** at the highest angular resolution

Observations and data analysis

Full-stokes (I,Q,U,V) observations with the VLBA of the 22 GHz H_2O maser line

Linear polarization:

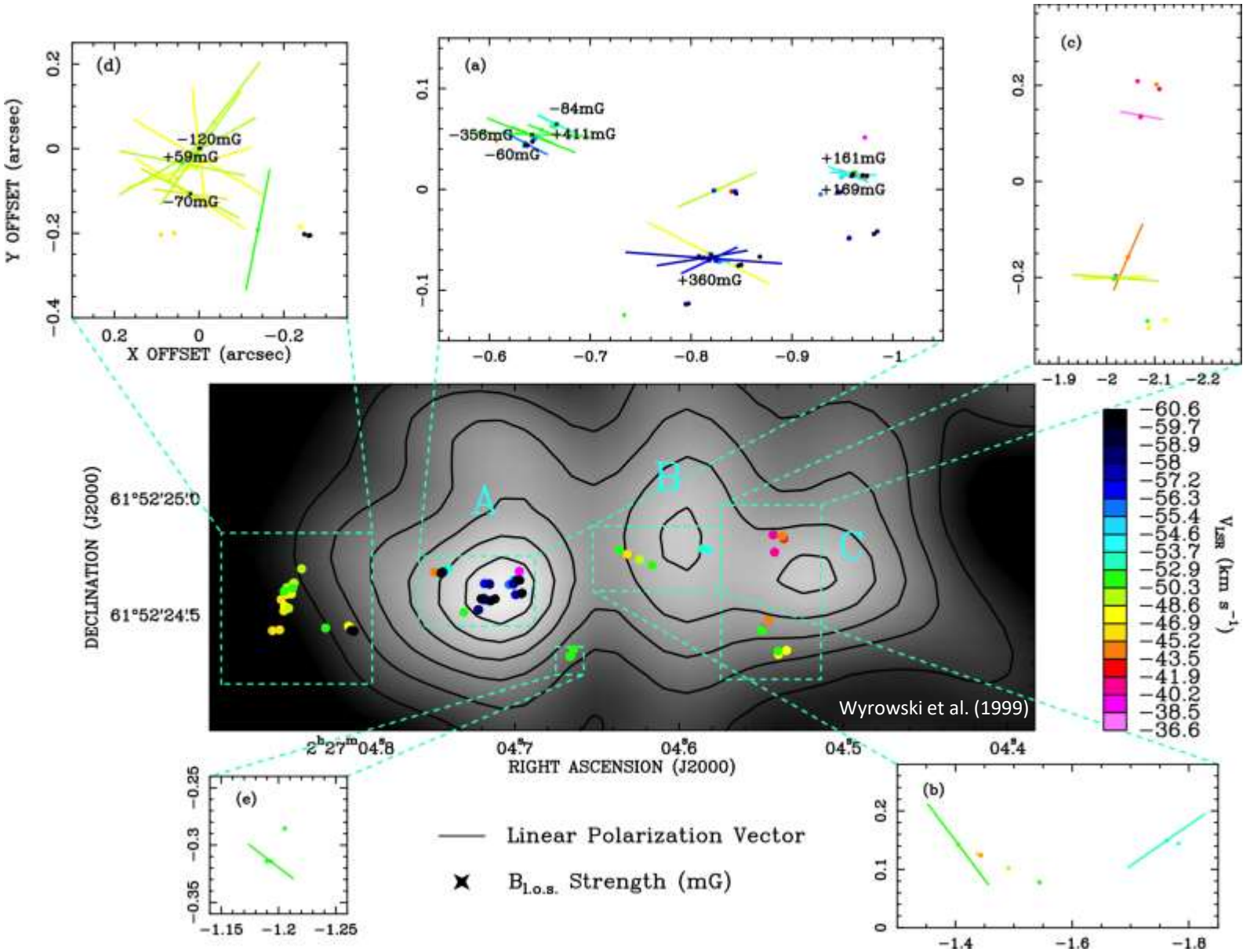
- Velocity cubes: Stokes *I*, *Q*, *U* (**Dv=0.2 km/s**)
- Polarized intensity: *POLI* = sqrt(□$Q^2 + U^2$)
- Polarization angle: *POLA* = 1/2 × *atan*(*U*/*Q*))
  - **B-orientation:**

    B_{sky} = POLA (±90°) (Goldreich 1973)

Circular polarization (Zeeman splitting):

- Velocity cubes: Stokes *I* and *V* (**Dv=0.03 km/s**)
- Circular polarization fraction: $P_V = (V_{max} - V_{min})/I_{max}$
  - **B-strength: B[Gauss]=P_v Δv[km/s] / α cosθ**

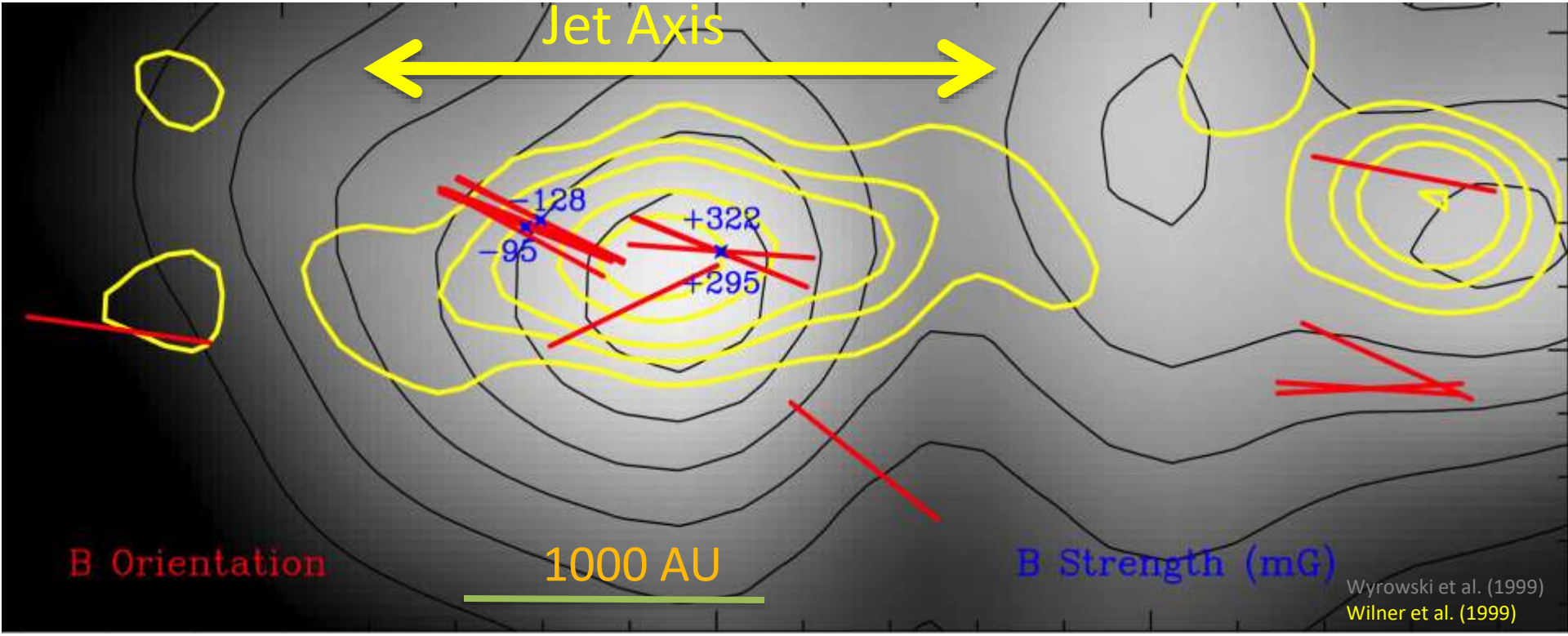
I. Measurements of fractional Polarization



148 masers
40 polarized
P_I=1-40%
P_V = 0.2-1.6%

II. Measurements of the Magnetic Field

(Including only masers with *PI*<5%)

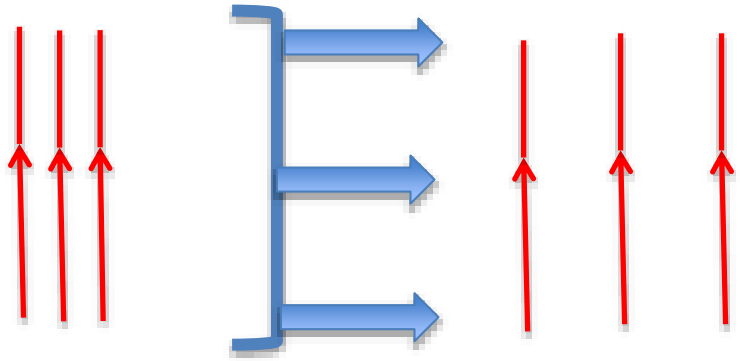


B~100-300 mG.

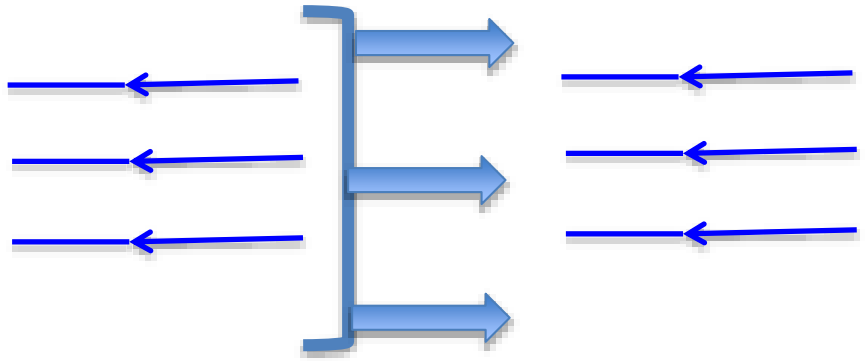
What's the origin of such a strong magnetic field?

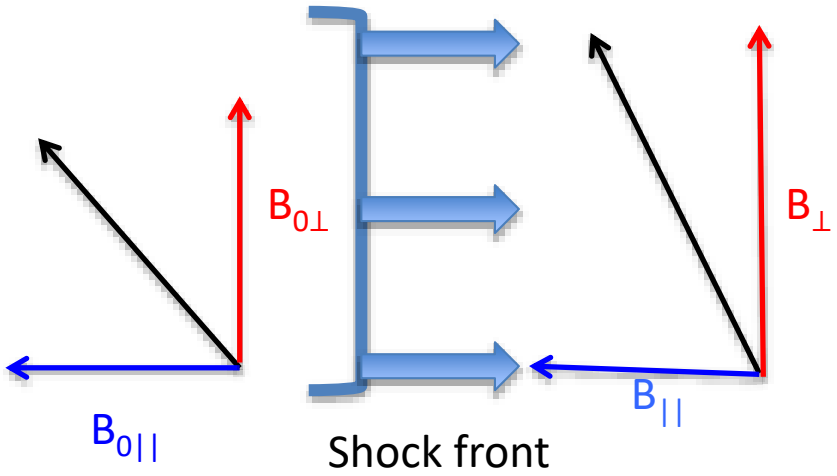
H_2O masers emerge behind shocks

B parallel to the shock front is ***compressed***



B perpendicular to the shock front is ***unaffected***





$B_{||} = B_{0||}$,

$B_{\perp} = B_{0\perp}\, n_s/n_0$

(n_s = post-shock density n_0 = pre-shock density)

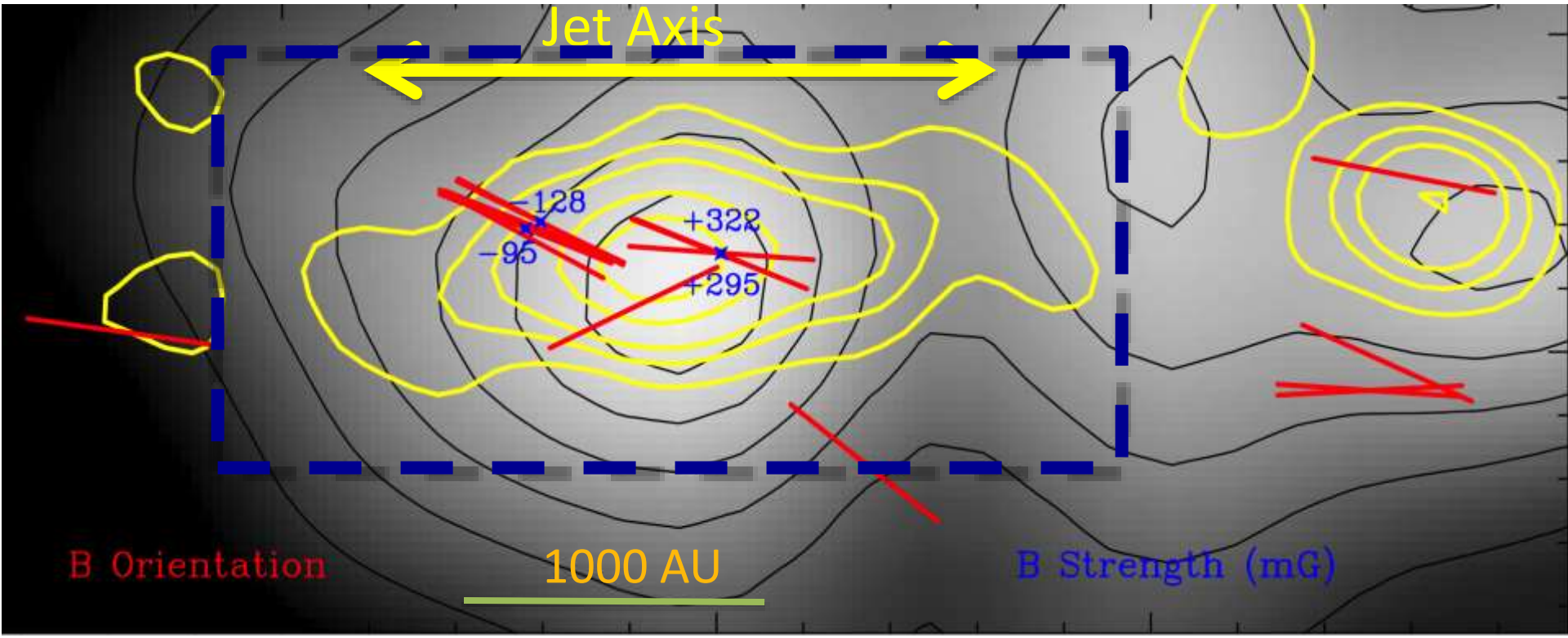
$n_0 = 10^7$ cm^{-3}, $n_s = 10^9$ cm^{-3}

$B_{\perp}$ = 100-300 mG

======> $\boldsymbol{B_{0\perp} = 1\text{-}3}$ **mG**

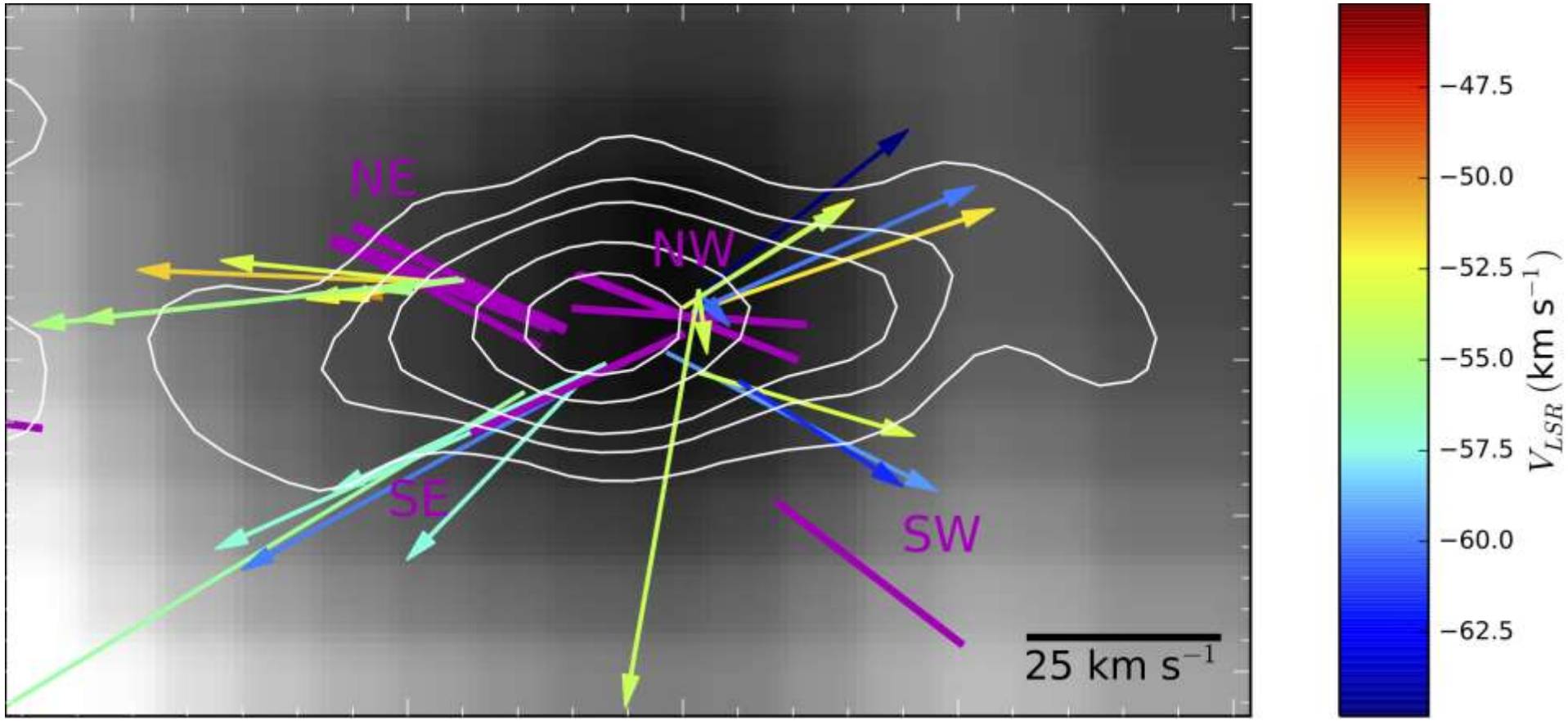
$B_{0||}$?

III. Gas dynamics and magnetic field structure



B~100-300 mG.

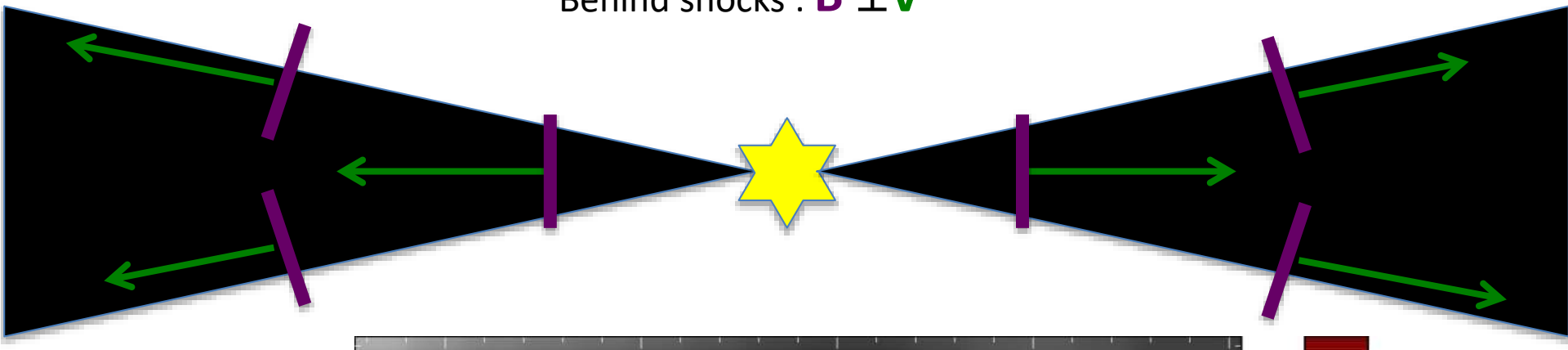
III. Gas dynamics and magnetic field structure



The magnetic field and the velocity vectors are apparently misaligned

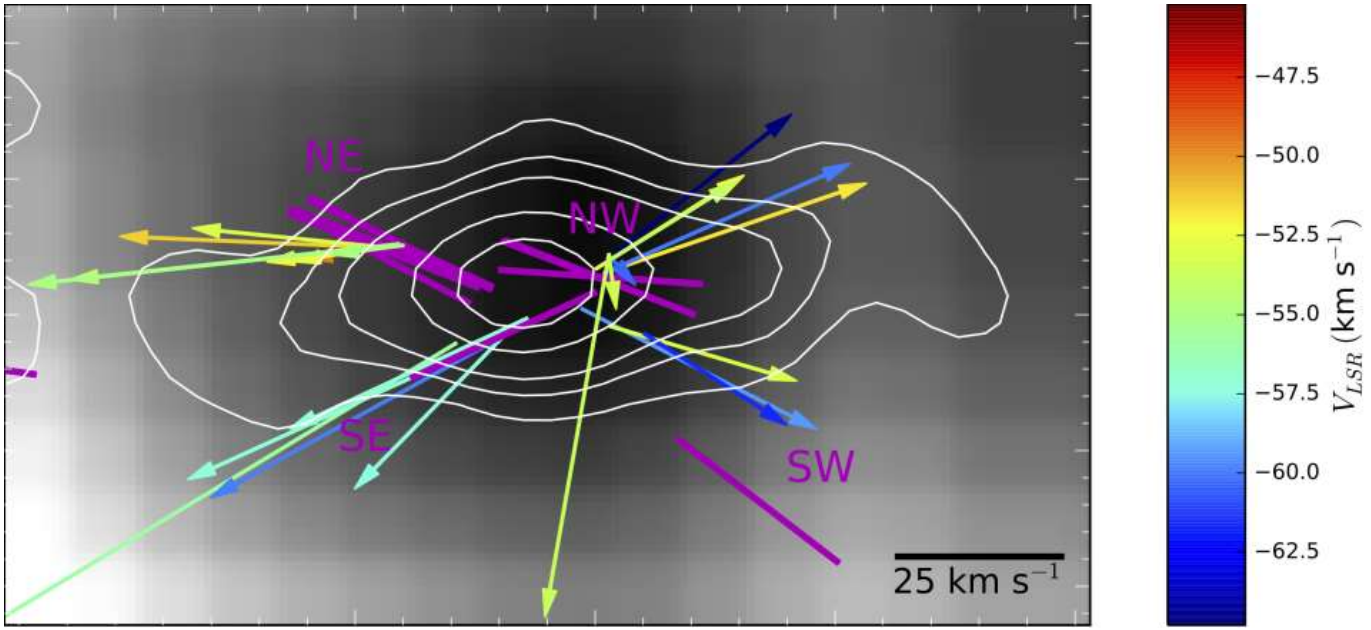
What's the origin of such a misalignment?

Behind shocks : **B** ⊥ **V**



$\Phi_{th} = 90^{o}$

$\Phi_{obs} < 90^{o}$?



.....possibly 3-D effects.....

$$B_{\text{l.o.s.}} = B\cos(\theta), \quad B_{\text{sky}} = B\sin(\theta),$$

$$B_{\text{sky}_\parallel} = B\sin(\theta)\cos(\phi), \quad B_{\text{sky}_\perp} = B\sin(\theta)\sin(\phi).$$

$$B_\parallel \equiv B_{\text{sky}_\parallel} = B\sin(\theta)\cos(\phi),$$

$$B_\perp = \sqrt{(B_{\text{l.o.s.}})^2 + (B_{\text{sky}_\perp})^2} = \sqrt{(B\cos(\theta))^2 + (B\sin(\theta)\sin(\phi))^2}.$$

$$B_\perp / B_\parallel = \sqrt{\cot^2(\theta)/\cos^2(\phi) + \tan^2(\phi)}.$$

$B_\perp / B_{||} \sim 10$ =➔ **Φ_{3d} ~85°**

$B_\perp$ = 100-300 mG => $B_{||}$~10-30mG

$B_{||}$ = **$B_{0||}$=10-30 mG**

Conclusions

1. In the pre-shock gas, the magnetic field starts with a dominant component *parallel* to the outflow velocity.

   $B_{0\perp}$ = 1-3 mG ; $B_{0||}$=10-30 mG

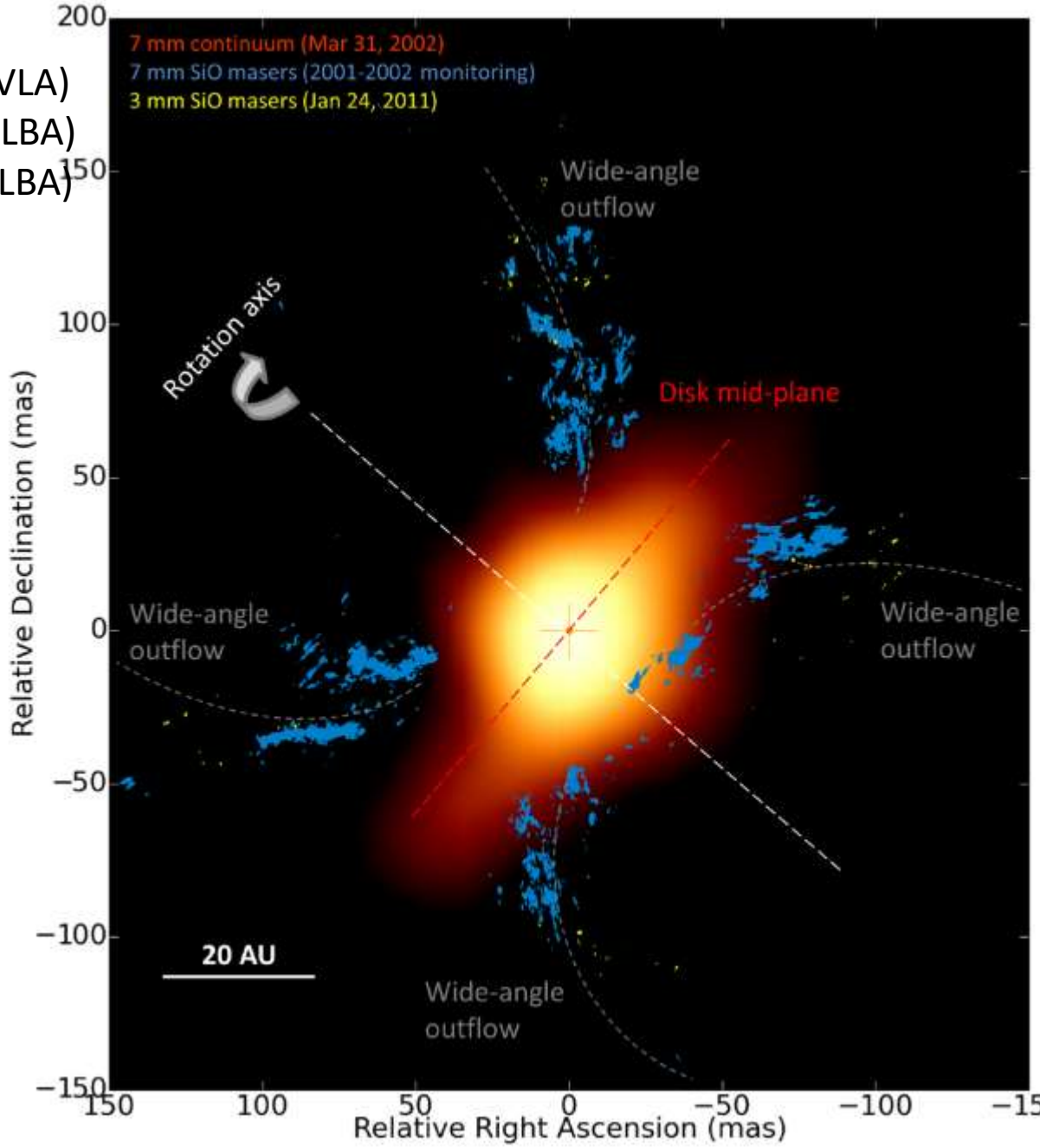
2. In the post-shock gas, it becomes mainly dominated by the component perpendicular to the shock velocity.

   $B_{\perp}$ = 100-300 mG ; $B_{||}$=10-30 mG

Magnetic fields can be dynamical important in driving the gas outflowing from a high-mass protostar.

Disk-wind from the massive YSO Orion Source I

7mm cont (JVLA)
7mm SiO v=1,2 (VLBA)
3mm SiO v=1 (VLBA)



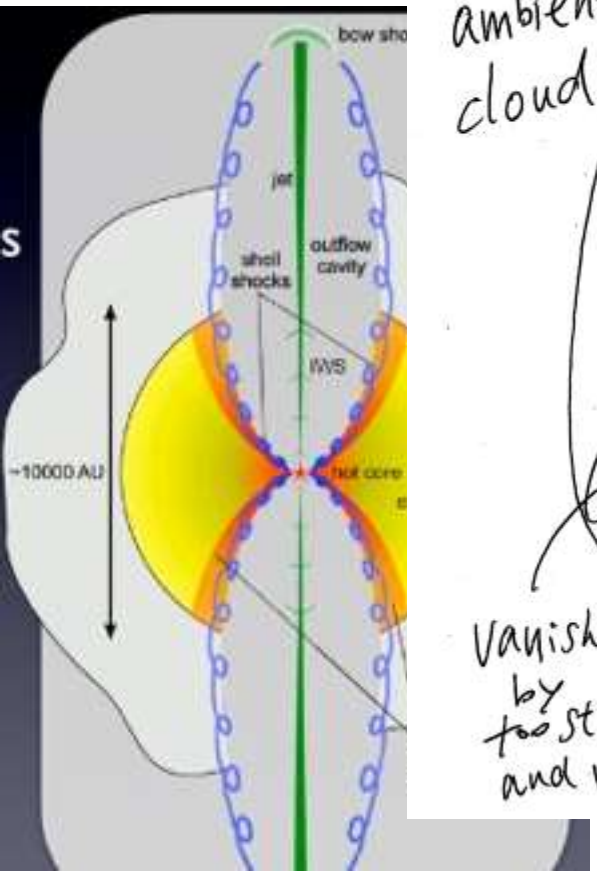
Issaoun, Goddi, et al. 2017:arxiv

Observations

- Target: W3(H_2O)
- Transition: 6_{16}-5_{23} of H_2O (rest frequency: 22.23508 GHz)
- Array: NRAO Very Long Baseline Array (VLBA)
- Date: August 18th 2006
- Observation time : 12 h.
- Spectral setup: BW=2 MHz, Dv≈ 27 km/s.
- Three correlation passes:
    1. 128 channels, D*v*=15.6 kHz (0.2 km/s) and full polarization: RR, LL, RL, LR (used to measure linear polarization)
    2. 1024 channels, D*v*=1.95 kHz (0.03 km/s), polarization: RR
    3. 1024 channels, D*v*=1.95 kHz (0.03 km/s), polarization: LL (used to measure circular polarization or Zeeman splitting)

Masers as tracers of B

We report full polarimetric VLBA observations of H_2O masers towards W3(H_2O). Their linearly polarized emission provides clues on the orientation of the local magnetic field (on the plane of the sky), while the measurement of the Zeeman splitting provides its strength (along the line-of-sight).



ambient cloud

global outflow

weak shocks

vanished by too strong shock and molecular dissociation?