Magnetic field and gas, a sticky couple: observations and models to quantify magnetic braking

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Collaborators:

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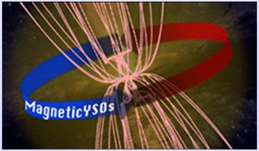

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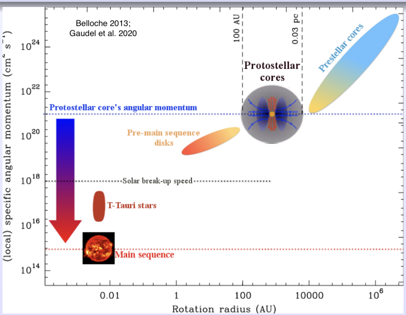
Low-mass SF

Theoretical problem(s):

- angular momentum must be dissipated



- $\sim$ 5 orders of magnitude

Low-mass SF

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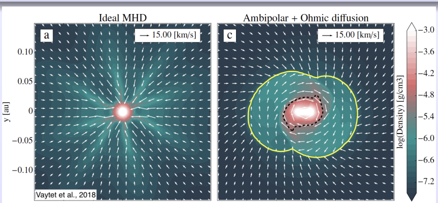
Solutions?

- magnetic braking



Low-mass SF

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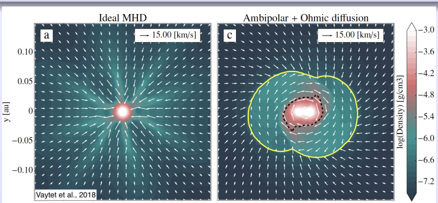
- magnetic braking "catastrophe"

Solutions?

- magnetic braking
- non-ideal MHD



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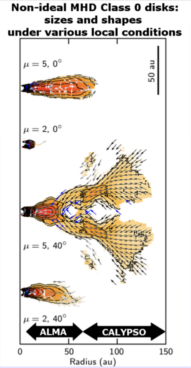

Actual observation:

- disc smaller than 60 au in Class O (Maury+2019,Sheehan+2022)

Motivation

- Test efficiency of the magnetic braking.
- Observe B-field morphology.
- Constrain B-field – gas coupling.
  - constrain ionization.
- Observe features due to magnetic braking.
  - Gas kinematics.

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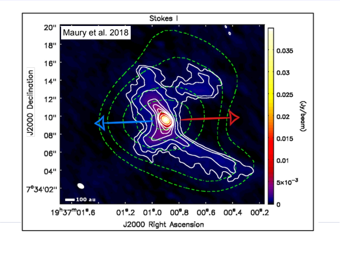
B335

ALMA molecular lines observations (Cabedo+2022;arXiv:2204.10043)

- to measure ionization of the gas (χ_e)
- to measure Cosmic Rays (CRs) ionization rate (ξ)

B335; ideal laboratory

- d $\sim$ 165 pc (Watson 2020).
- isolated Class O protostar (Keene et al. 1983).
- no disk kinematic signature (Kurono et al. 2013).
- "hourglass" B-field morphology (Maury et al. 2018).



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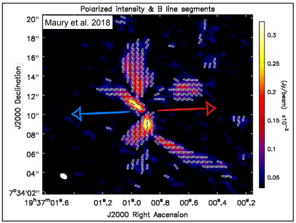
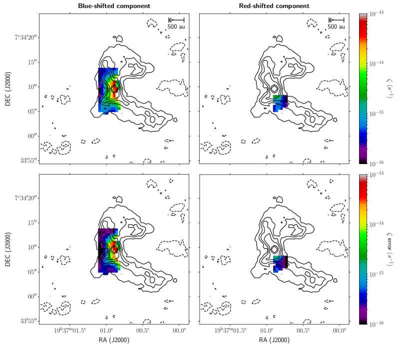
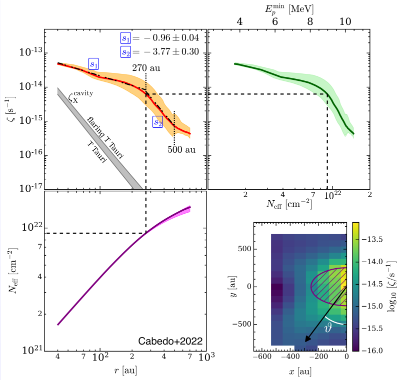


B335; CR ionization rate





- high gas ionization at <500 au due to locally produce CRs.
- organized B-field due to strong coupling with infalling material.
- Strong coupling reinforces the magnetically regulated scenario (Maury+2018).

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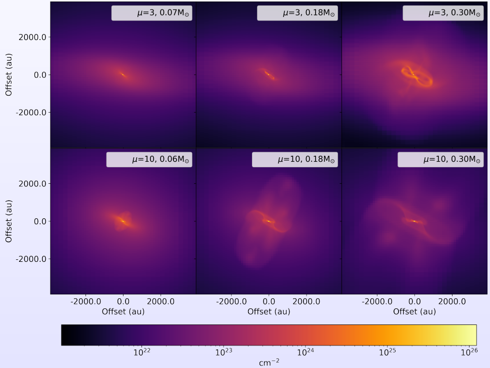
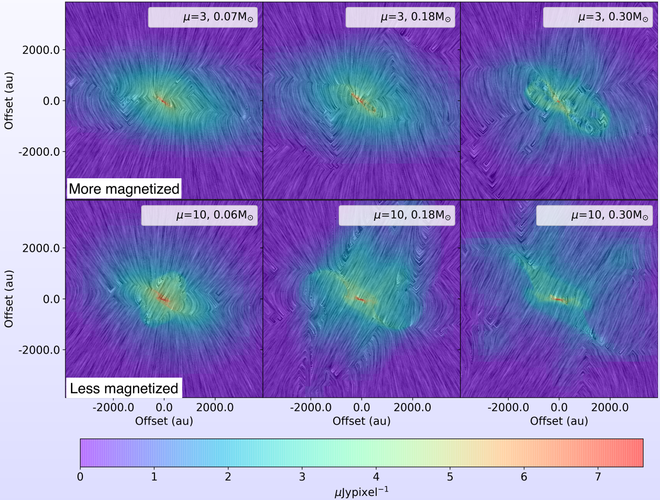
Models



- Hennebelle et al. 2020
- RAMSES non-ideal MHD low-mass collapsing cores
- 1 $M_\odot$
- edge-on orientation
- 8000 au scales
- similar physical characteristic except for the magnetic field.

ID	μ	β_{rot}	θ	$\mathcal{M}$	time (Kyr)	$mass_{sink}$ ($M_\odot$)	r_{disc} (au)
R2-100	3.33	0.04	30°	0	62.08	0.06	21.97
R2-300	3.33	0.04	30°	0	67.80	0.18	21.59
R2-700	3.33	0.04	30°	0	80.40	0.30	21.40
R3-100	10.00	0.04	30°	0	53.52	0.07	148.04
R3-840	10.00	0.04	30°	0	63.83	0.18	68.85
R3-2380	10.00	0.04	30°	0	81.43	0.30	48.68

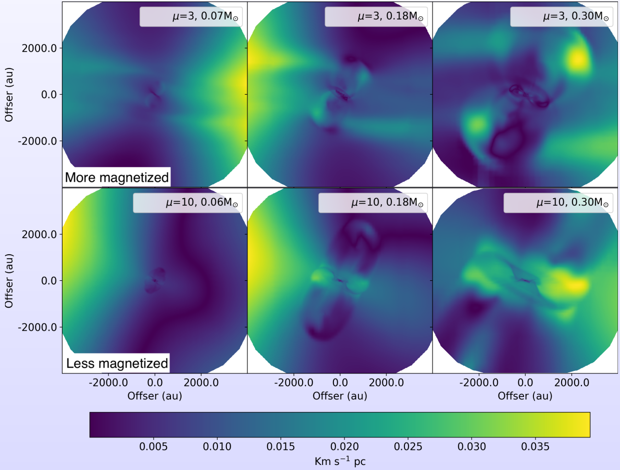
Magnetic field morphology



- Polarised dust thermal emission
- 860μm (360 GHz)

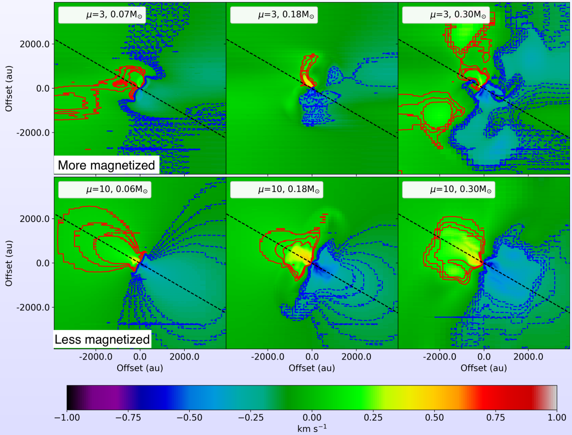
Specific Angular Momentum (SAM)

$$\left\{ jm^h_{ij} = \quad r^h_{ij} v^{ijh}; \quad jm_{ij} = \frac{\sum \rho^h_{ij} jm^h_{ij}}{\sum \rho^h_{ij}} \quad \text{for h} = 0, ..., 5000 \text{ au}, \right.$$



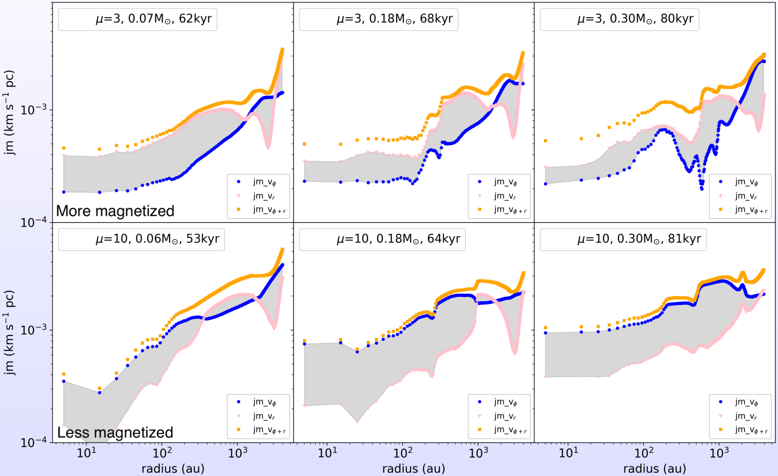
Synthetic observation

First moment map / Intensity weighted velocity



- POLARIS
- $C^{18}O$ (2-1)
- d 250 pc
- spec.res. 0.12 km s^{-1}
- ranged $\pm$ 6 km s^{-1}

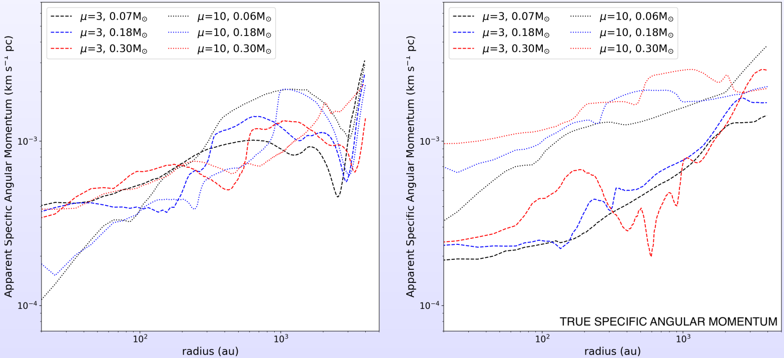
SAM & ASAM profiles (MODEL)



- SAM computed from rotational vel. comp. **True angular momentum**
- ASAM computed from radial vel. comp.
- ASAM computed from total vel.

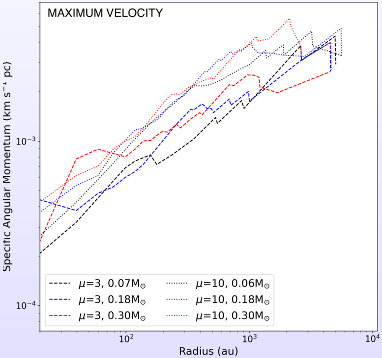
Infall & rotation (MODEL)

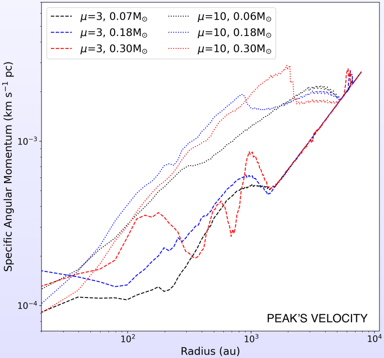
Radial component (ASAM) / rotation component (SAM)



- SAM profiles are split
- No major differences in ASAM profiles

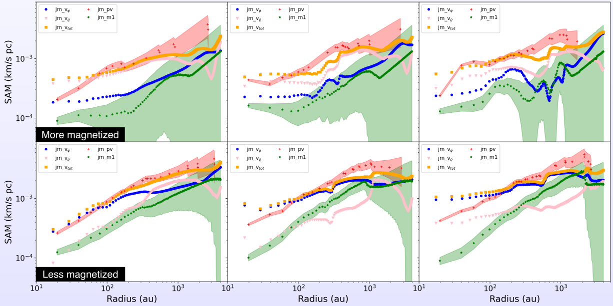
SAM (SYNTHETIC OBSERVATION)





- in both cases the profiles are separated according to their mass-to-flux ratio rather than to evolutionary stage.

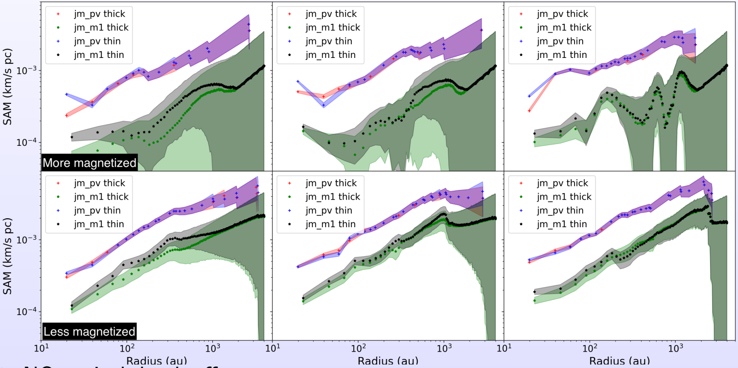
Model VS synthetic observation



Model	d(r,g)	d(b,g)	d(b,r)	d(o,r)	d(o,g)
R2 100	0.094	0.017	0.079	0.062	0.042
R2 300	0.083	0.033	0.063	0.035	0.059
R2 700	0.061	0.044	0.060	0.027	0.068
R3 100	0.105	0.034	0.088	0.041	0.080
R3 840	0.085	0.017	0.075	0.044	0.045
R3 2380	0.104	0.034	0.089	0.072	0.059

- Peak Velocity SAM ≈ true SAM.

$C^{18}O$ / $C^{17}O$



- NO optical depth effects.
- Slightly higher SAM of the optically thin molecule emission seen in the peak velocity.

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Conclusion

- B335 show high CRs ionization rate, increasing at small envelope radii, suggesting local acceleration of CRs.
- Large ionization fraction suggest an efficient coupling between B-field and the gas in the inner envelope of B335.

Conclusion

- More magnetized model show larger dissipation of SAM as we approach the protostar, showing a dominance of the radial component of velocity at smaller radii.
- $C^{18}O$ (2-1) velocity field shows clear different depending on the level of magnetization, reproducing the behavior of the true angular momentum.
- Specific angular momentum computed with maximum velocity (PV-diagram method), appear to plot not only rotational velocity but also radial components, especially in the innermost radii.
- Intensity weighted velocity (first moment method) best approximates the rotational velocity component, especially in a strongly magnetised environment.

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