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

N. Añez-López
Cold Cores

May 24-26, 2023

Co-Authors and collaborators:
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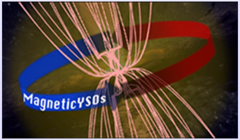

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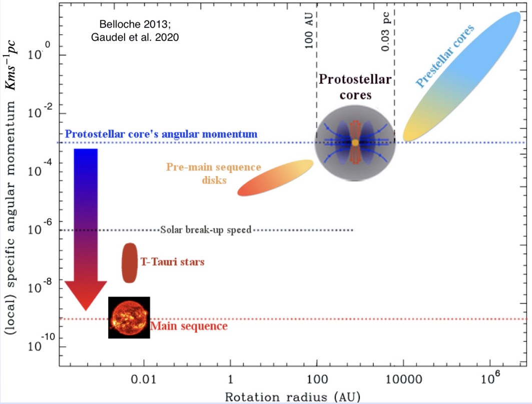
Angular momentum must be redistributed

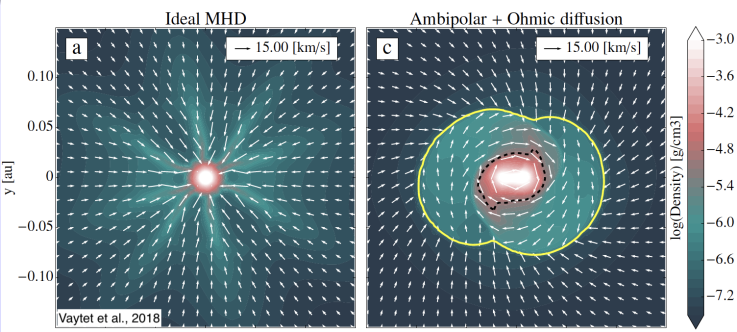


- AM PC/MS $\sim 10^5$
- centrifugal force would balance gravity

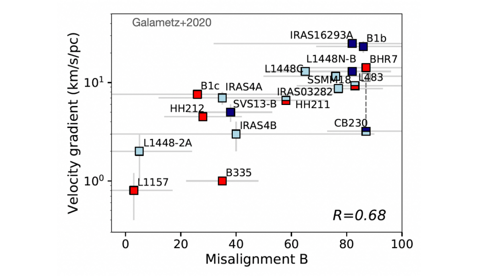
Magnetic braking

Solutions?

- Magnetic field can redistribute angular momentum through Alfvén waves. "Magnetic braking"
- Regulation mechanism has to be included to avoid the magnetic braking "catastrophe"



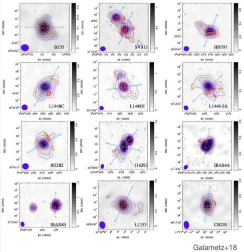
Others solution to magnetic braking catastrophe



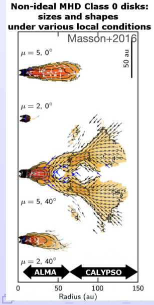
See Joos+2012; Gray+2018 as well

- correlation between misalignment and velocity gradient
- turbulence proposed as solution to magnetic braking catastrophe: as diffusivity arising from turbulent magnetic re-connection

Sizes of the protostellar disks



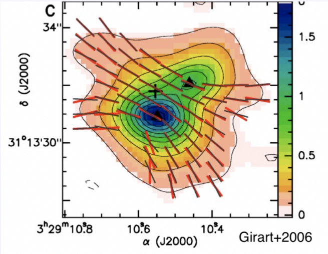
- Magnetic field is ubiquitous.
- Observation toward Class 0 at 100-5000 au scales
- ex.: SMA 850 μm (Galametz+18)



- Most of Class 0 harbor a disk (CALYPSO survey, Maury+2019),
- majority are only found at radii < 60 au (Maury+2019;Sheehan+2022),
- which is difficult to reconcile with purely hydro-dynamical models (Lebreuilly+2021)

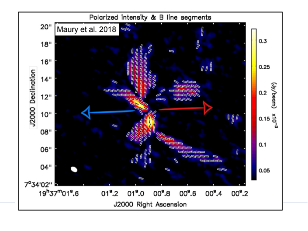
Indications of the coupling

IRAS4A



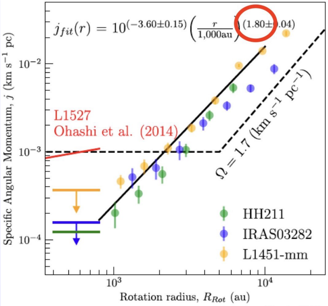
- Infalling material pinch magnetic field
- where B-field is pinched, there will be a decrease in AM

B335

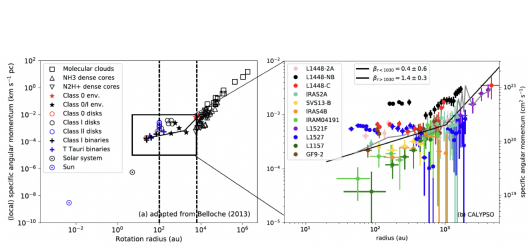


- More severe magnetic braking is expected around the equatorial plane.

Specific angular momentum observations



Pineda+2019



Gaudel+2020

AM observation shows different behavior at inner radius < 1000au.
Magnetic braking ?

Main goal

- Observe features due to magnetic braking by analyzing gas kinematics
- Test efficiency of the magnetic braking.

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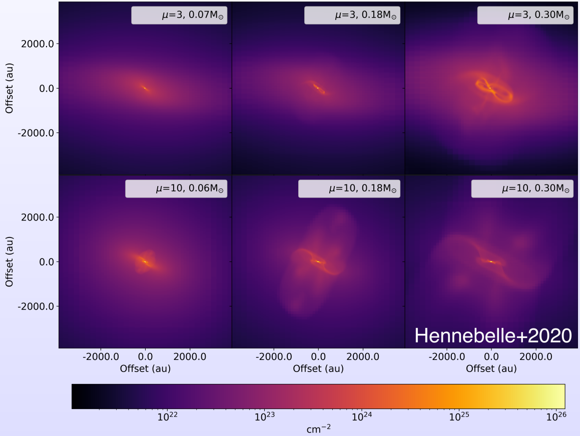
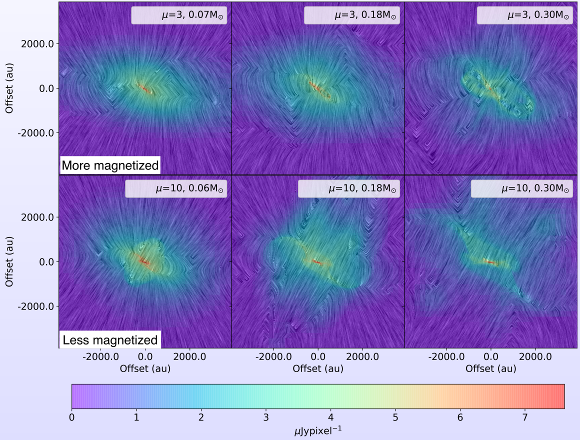
Models



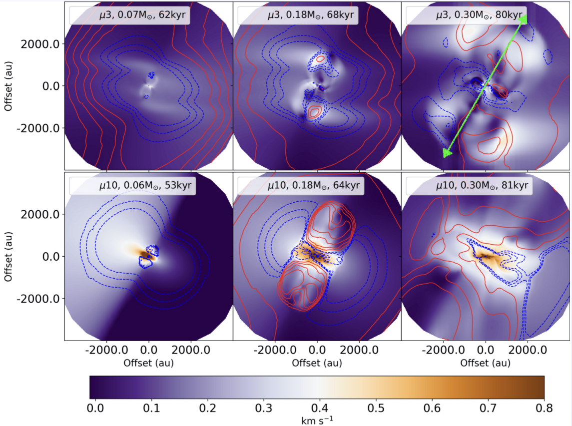
- RAMSES non-ideal MHD low-mass collapsing cores
- total mass 1 $M_{\odot}$
- edge-on orientation (z-x plane)
- 8000 au scales (out of 16000 au)
- initial uniform density
- β_{rot}, θ, ... similar initial condition
- sink at the geometric center

Magnetic field morphology



- B-field is initially uniform
- Polarized dust thermal emission using POLARIS at 860μm (360 GHz)
- assuming dust grain aligned by b-field

Rotational and radial velocity components

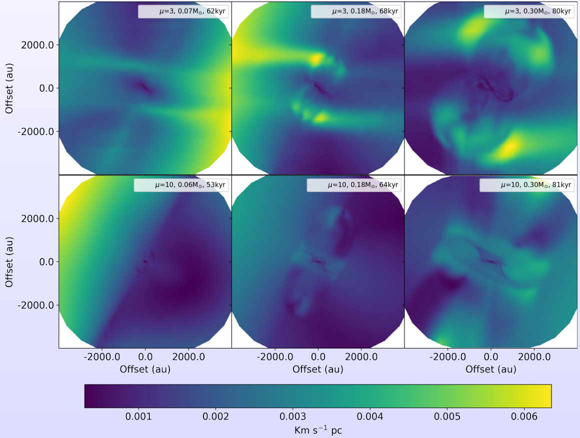


- velocity integrated along LOS
- V_{φ} in color
- V_{ϱ} in contours

Starting from the same AM distribution, very different behavior

Specific Angular Momentum of the model

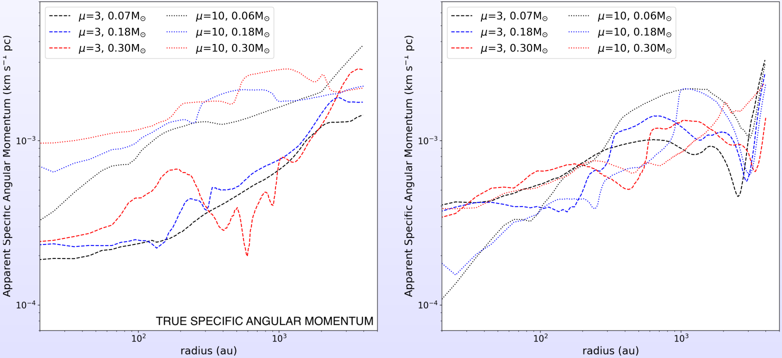
$$\begin{cases} jm^h_{ij} = \quad r^h_{ij} v^{ijh}; \quad jm_{ij} = \quad \frac{\sum \rho^h_{ij} jm^h_{ij}}{\sum \rho^h_{ij}} \quad \text{for h} = 0, ..., 5000 \text{ au}, \end{cases}$$



- SAM integrated along LOS

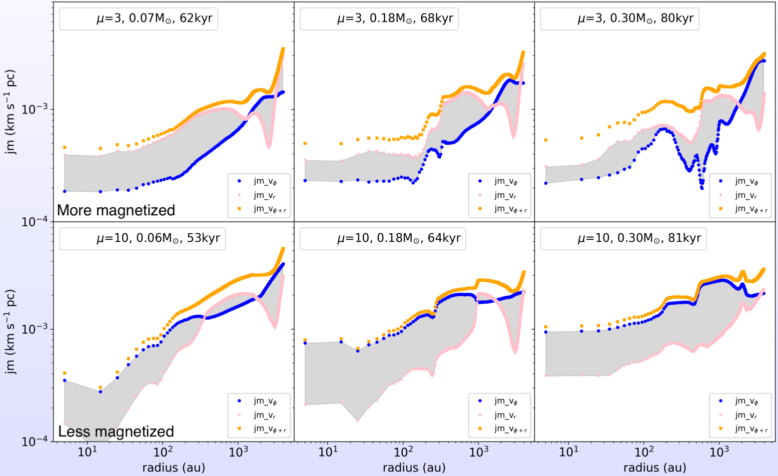
Specific Angular Momentum radial profile

Rotation component (SAM) / Radial component (ASAM)



Starting from the same AM, more magnetized model show much less magnitude

SAM & ASAM profiles



- μ=3 model: kinematics dominated by infall
- μ=10 model: kinematics dominated by rotation

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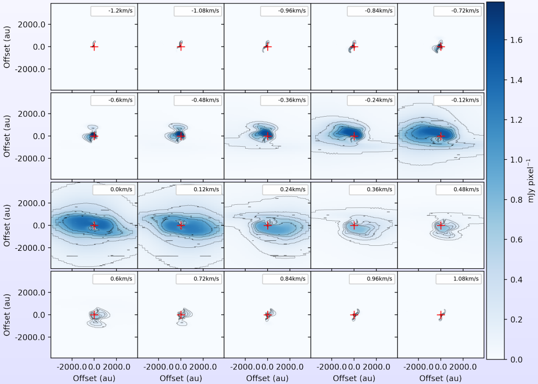
$C^{18}O$ (2-1) Synthetic observation

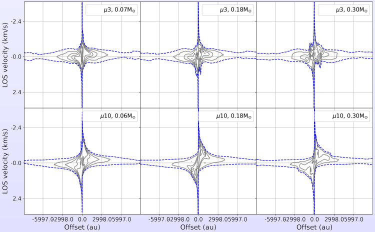


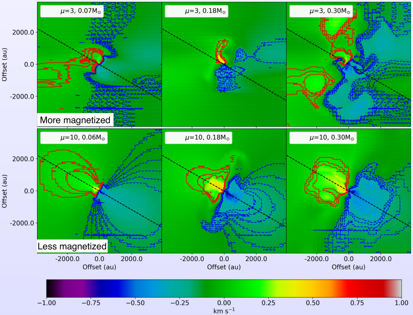
- POLARIS (Reissl+2016; Brauer+2017)
- $C^{18}O$ (2-1)
- $E_{up} = 15.81$ K
- spec.res. 0.12 km s^{-1}
- ranged $\pm$ 7 km s^{-1}

$C^{18}O$: widely used to trace kinematics

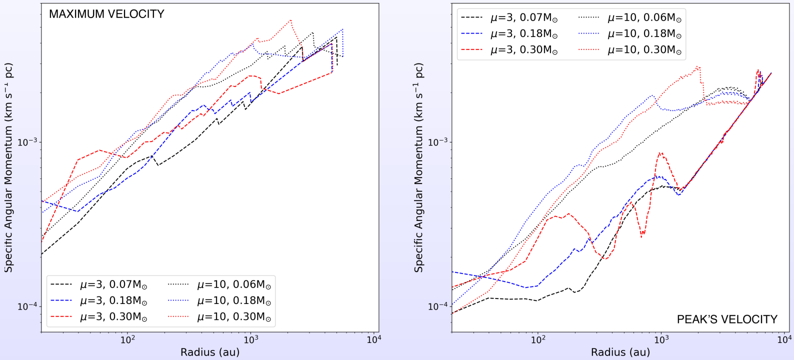
How observers do it?

Maximum velocity / Peak‘s velocity



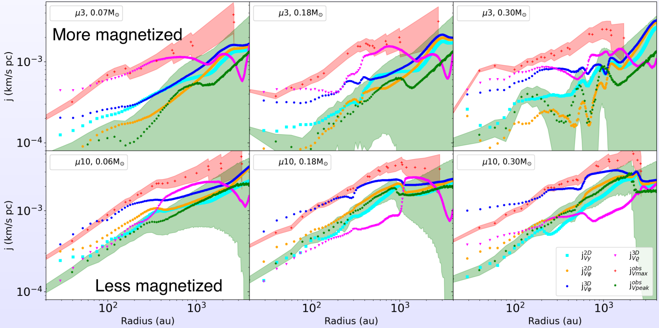


SAM in synthetic observation

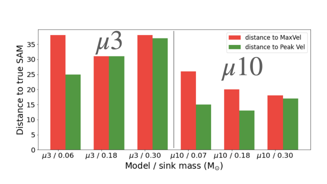


- Left: SAM from maximum velocity computed from pv-diagrams through the equatorial plane.
- Right: SAM from peak's velocity from first moment maps through equatorial plane.

Model VS synthetic observation

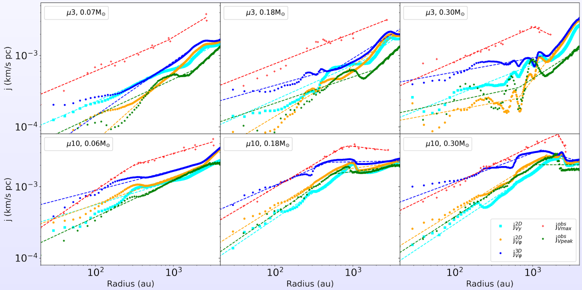


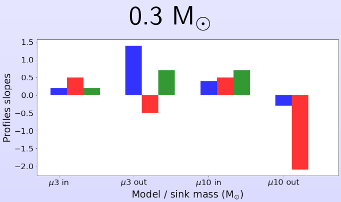
3D



Peak's velocity capture the SAM trend

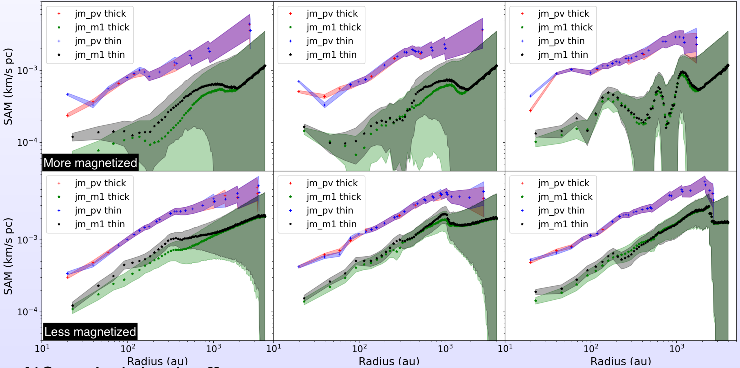
Radial profiles slope





Peak's velocity catch inner and outer slope

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



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

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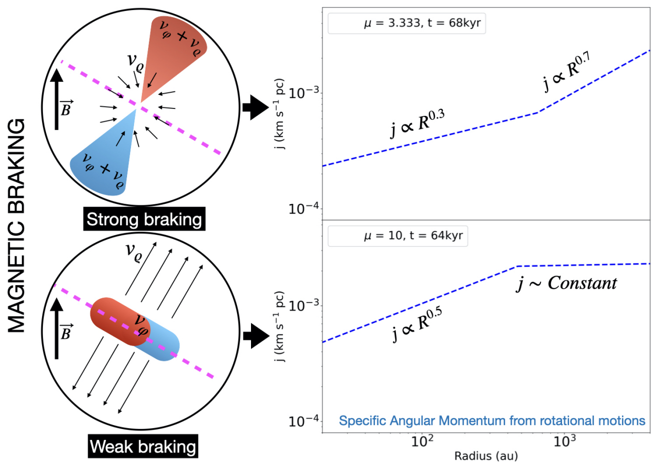
Specific Angular Momentum in non-Ideal MHD models



Is possible to catch the signature of magnetic braking

Conclusion

- The magnetization level of the models have a great impact on the characteristics of the radial and rotational velocity components, which is reflected in the specific angular momentum.
- More magnetized model show very efficient redistribution of SAM toward the outside, mostly affecting the gas kinematics at scales from $\sim$1000 to $\sim$4000 au
- A higher magnetization also results in predominant radial motions at the small envelope radii, < 1000 au.
- $C^{18}O$ (2-1) velocity field can distinguish the more magnetized model from the less magnetized model and, is capable of recovering the trend of the specific angular momentum.
- Peak's velocity best approximates the rotational velocity component, especially in a strongly magnetized environment.

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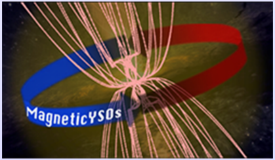
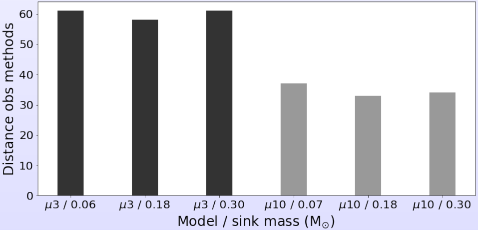


THANK YOU!

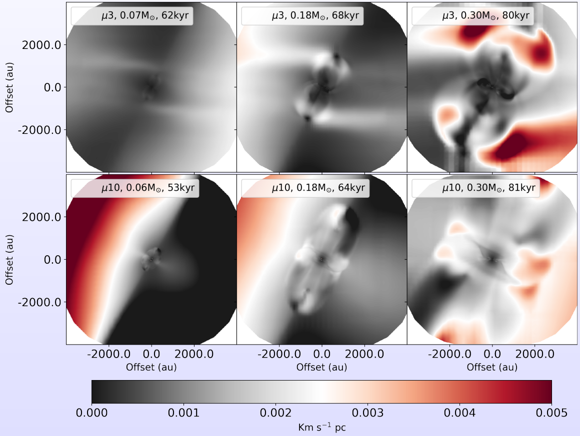
Normalized Euclidean Distances

	Rot. Vs Rad.	3D Vs 2D		Synthetic Observation (SO) Vs 3D				Synthetic Observation (SO) Vs 2D				SO Vs SO
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
ID ($M_\odot$)	$(j^{3D}_{v\varphi}, j^{3D}_{v\varrho})$	$(j^{3D}_{v\varphi}, j^{2D}_{v\varphi})$	$(j^{3D}_{v\varphi}, j^{2D}_{v_y})$	$(j^{obs}_{vmax}, j^{3D}_{v\varphi})$	$(j^{obs}_{vmax}, j^{3D}_{v\varrho})$	$(j^{obs}_{vpeak}, j^{3D}_{v\varphi})$	$(j^{obs}_{vpeak}, j^{3D}_{v\varrho})$	$(j^{obs}_{vmax}, j^{2D}_{v\varphi})$	$(j^{obs}_{vmax}, j^{2D}_{v_y})$	$(j^{obs}_{vpeak}, j^{2D}_{v\varphi})$	$(j^{obs}_{vpeak}, j^{2D}_{v_y})$	$(j^{obs}_{vmax}, j^{obs}_{vpeak})$
μ3(0.06)	9.5	10	8	38	2	25	16	48	47	15	17	61
μ3(0.18)	15	11	7	31	1.6	31	17	42	40	22	24	58
μ3(0.30)	23	14	9	38	11	37	15	48	58	24	29	61
μ10(0.07)	13	16	6	26	4	15	2	39	33	1	9	37
μ10(0.18)	20	12	8	20	11	13	7	34	29	1	6	33
μ10(0.30)	31	15	9	18	43	17	14	35	28	2	8	34

How similar are both observational method?

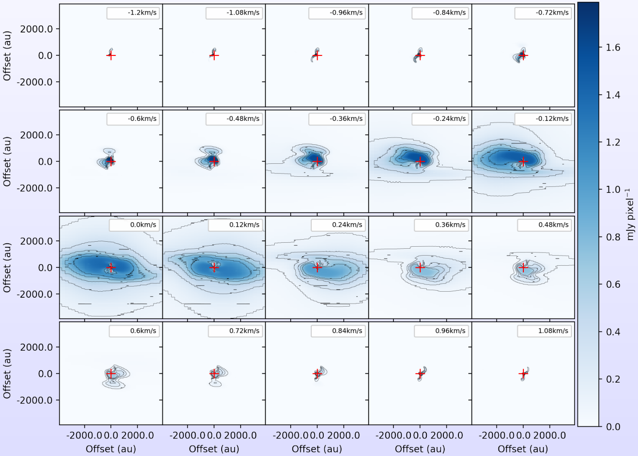


Specific Angular Momentum 2D

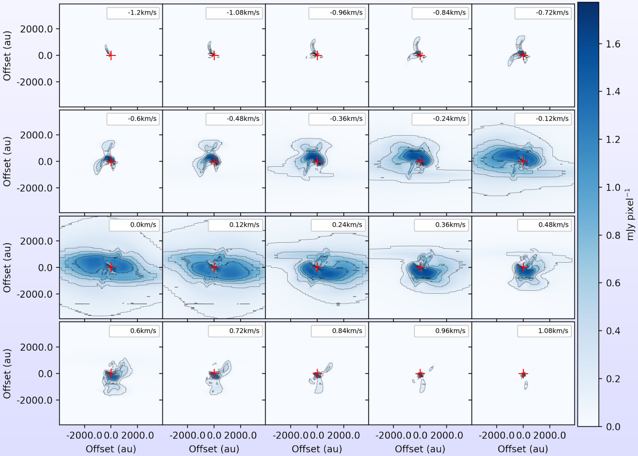


- Projected $V_\varphi \times$ radius in the POS
- similar distribution than 3D,
- lower values than 3D

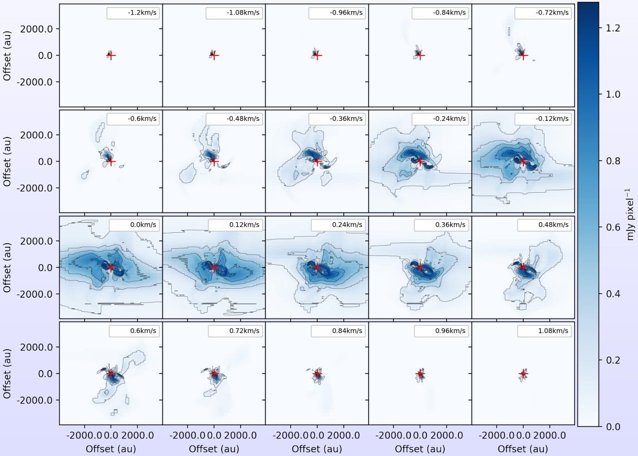
Chanel's map $\mu 3$ $0.07 M_{\odot}$



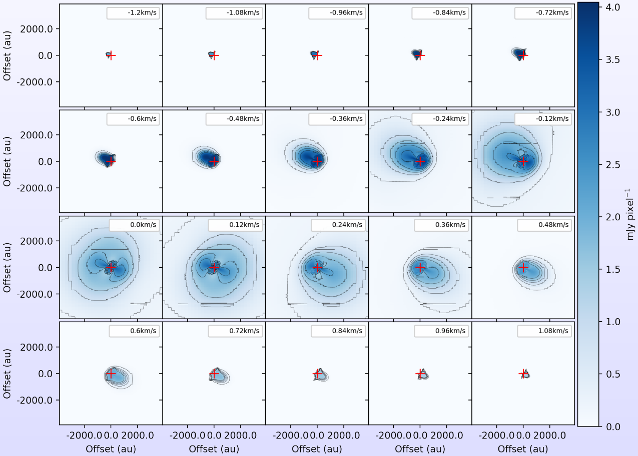
Chanel's map $\mu3$ $0.18M_\odot$



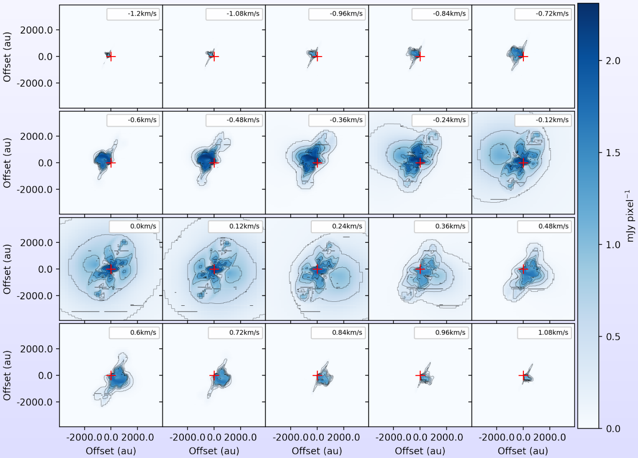
Chanel's map $\mu 3$ 0.30M$_\odot$



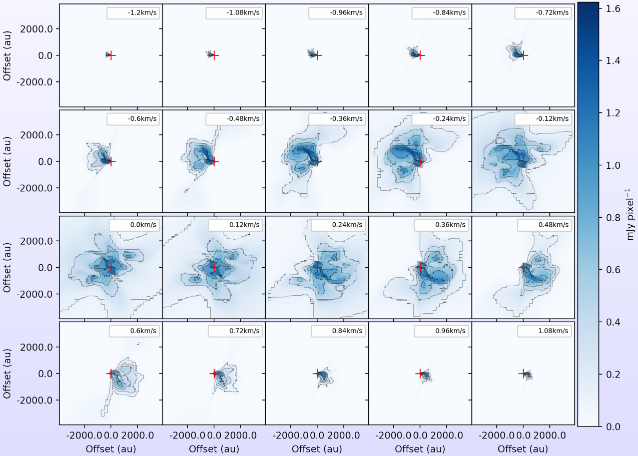
Chanel's map $\mu 10$ $0.06 M_{\odot}$



Chanel's map $\mu10$ 0.18$M_\odot$



Chanel's map μ10 0.30M$_\odot$



Testing asymmetry