

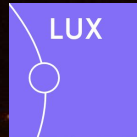
Feedback of protostellar ejections on planetary formation

Nathan Maindon¹, Sylvie Cabrit^{1,2}, Zakaria Meliani¹, Guillaume Pineau des Forêts^{1,3}

¹LUX, Observatoire de Paris, Université PSL, Sorbonne Université, CNRS, 75014 Paris, France

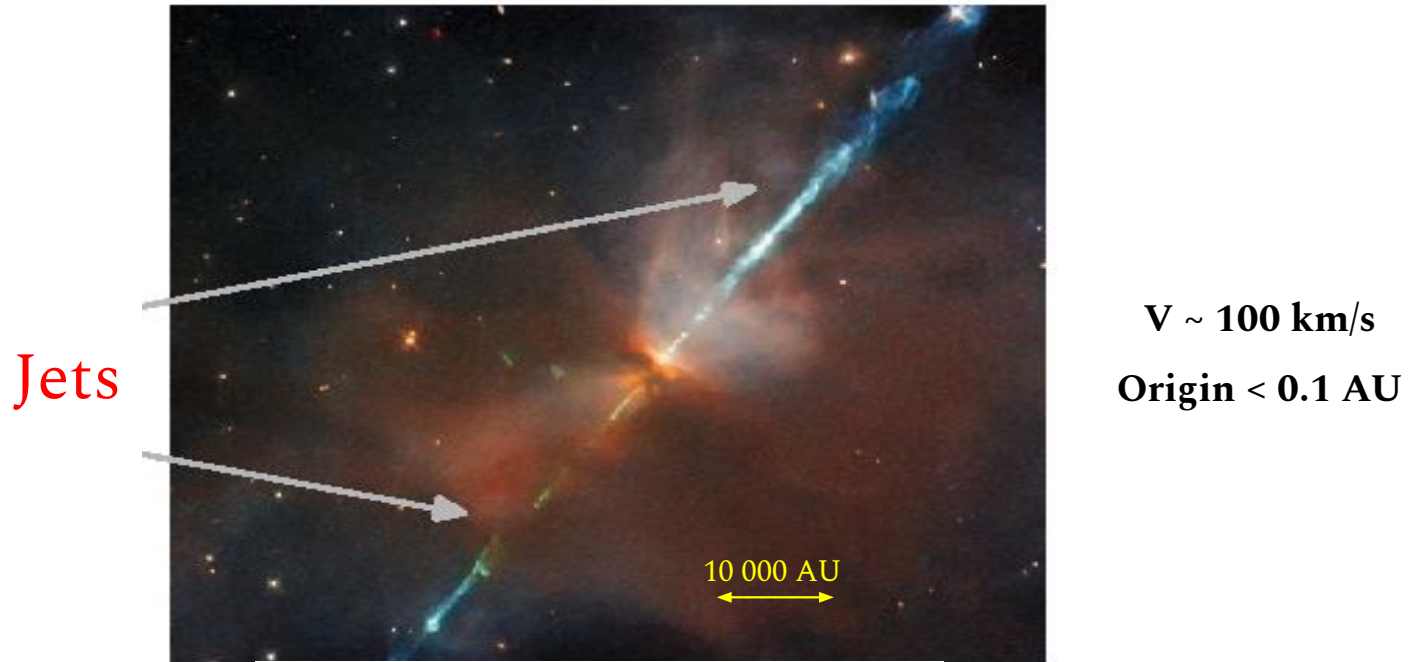
²Univ. Grenoble-Alpes, CNRS, IPAG, 38000 Grenoble, France

³Univ. Paris-Saclay, CNRS, Institut d'Astrophysique Spatiale, 91405 Orsay, France



Accreting young stellar objects drive fast jets

Strongly accreting : $\dot{M}_{\text{accretion}} = 10^{-8} - 10^{-6} M_{\odot} \cdot \text{yr}^{-1}$

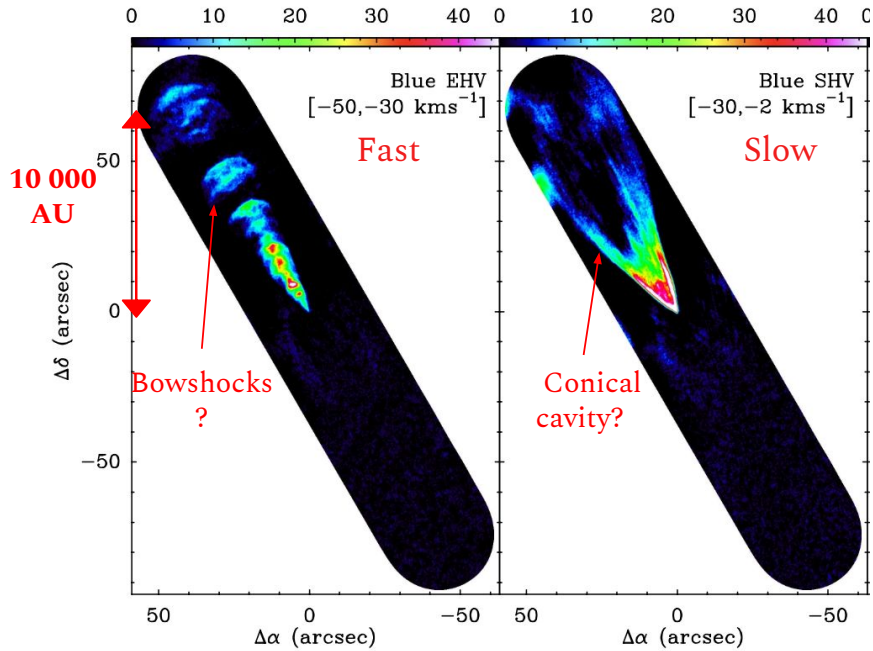


HH 111

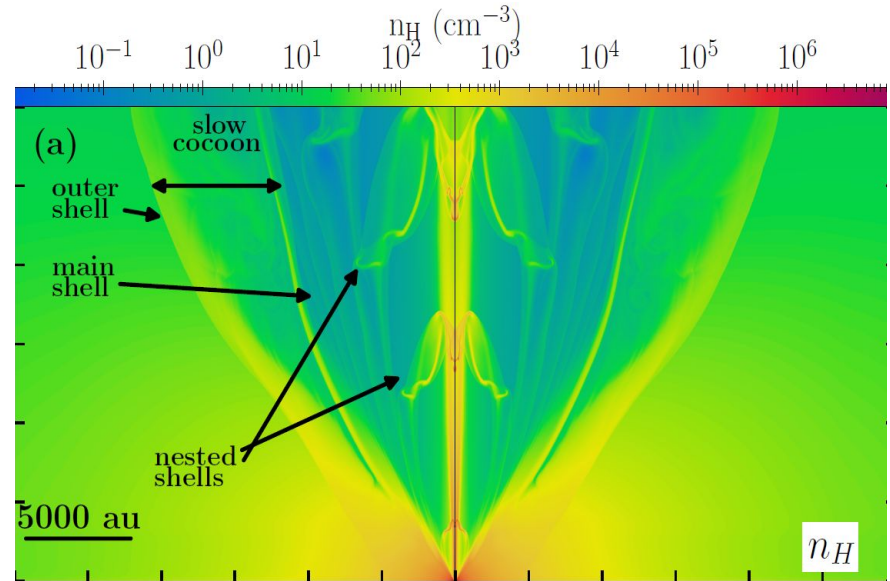
© ESA/Hubble & NASA, B. Nisini

$$\dot{M}_{\text{jet}} \approx 0.1 \dot{M}_{\text{accretion}}$$

Jet bowshocks drag LARGE SCALE molecular outflows

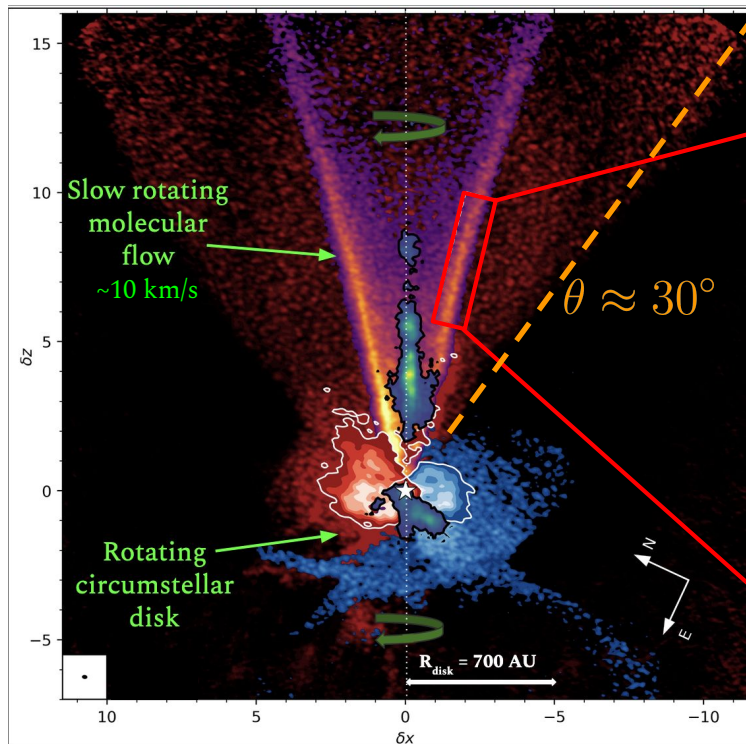


IRAS 04166+2706 (Tafalla et al., 2025)



Large scale simulations of variable jets
in a stratified medium (AMR-VAC)
Rabenanahary et al., 2022

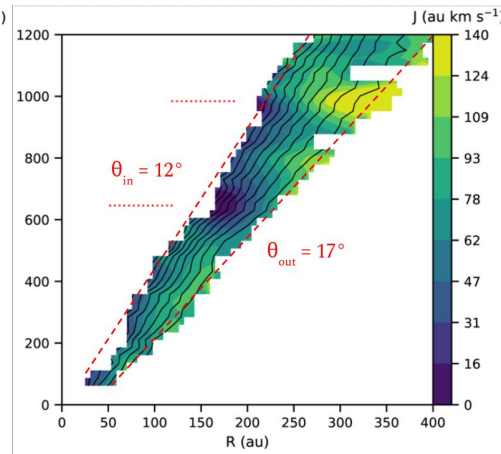
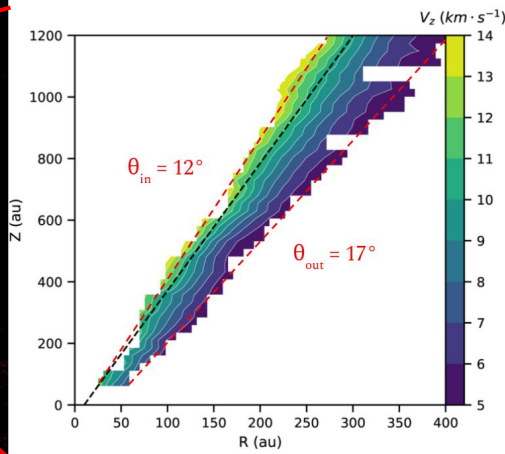
Molecular outflows also observed at smaller scale



ALMA CO(2-1) DeValon+2020

Observables :

- (1) V_z (5 – 15 km/s) (2) J (30 – 80 AU.km/s)
(angular momentum)



(3) $\dot{M}_{\text{OBS}}(\text{CO}) \approx \dot{M}_{\text{acc}}$

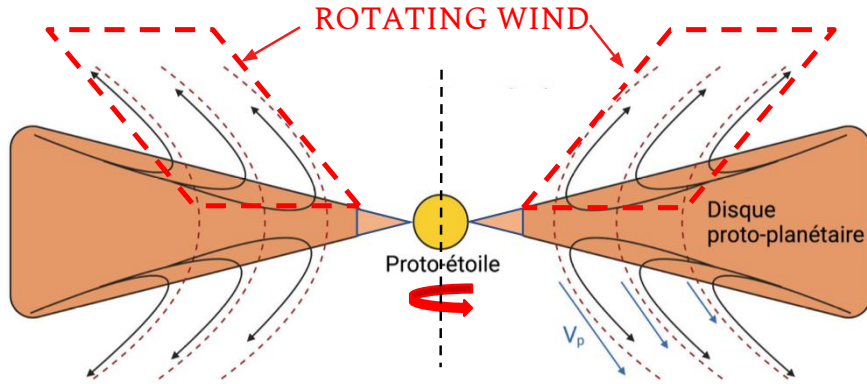
$R_0(\text{CO}) \leq 10 \text{ AU}$: planet forming region !

What triggers such **massive** molecular outflows ?

“Competing” models for the origin of inner rotating molecular outflows

1- MHD winds
(Blandford & Payne, 1982)

Extracts J, can drive accretion



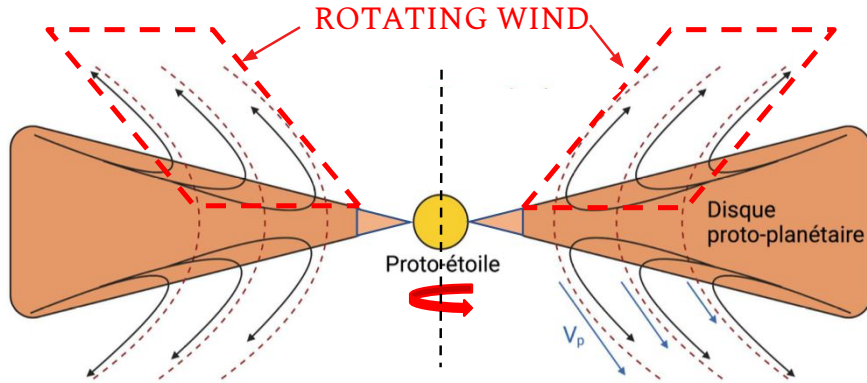
— Streamlines
---- Magnetic field lines

$$\dot{M}_{wind} \approx \dot{M}_{obs}(CO)$$

“Competing” models for the origin of inner rotating molecular outflows

1- MHD winds
(Blandford & Payne, 1982)

Extracts J , can drive accretion



— Streamlines

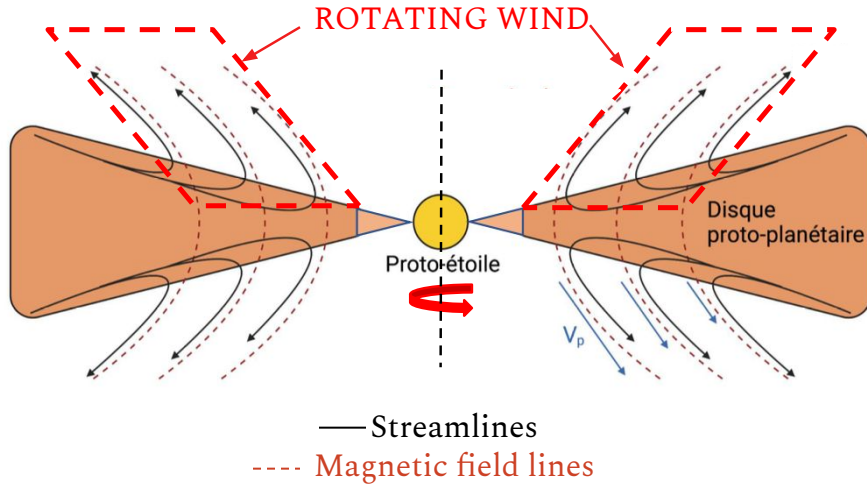
---- Magnetic field lines

- **Rotating** CO outflows not (yet) detected in all accreting sources
- B-field strength poorly constrained

“Competing” models for the origin of inner rotating molecular outflows

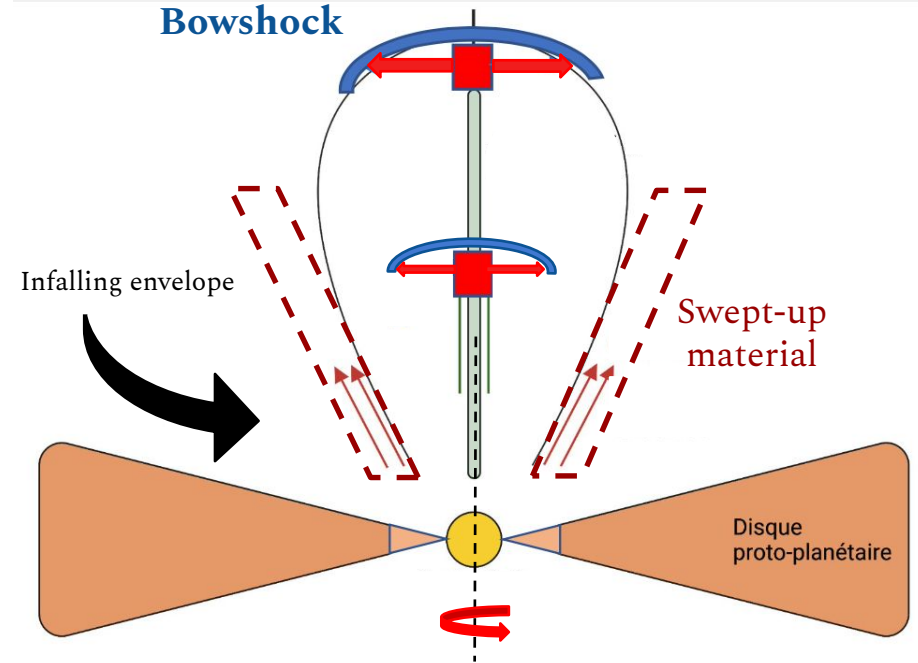
1- MHD winds (Blandford & Payne, 1982)

Extracts J , can drive accretion



- **Rotating** CO outflows not (yet) detected in all accreting sources
- B-field strength poorly constrained

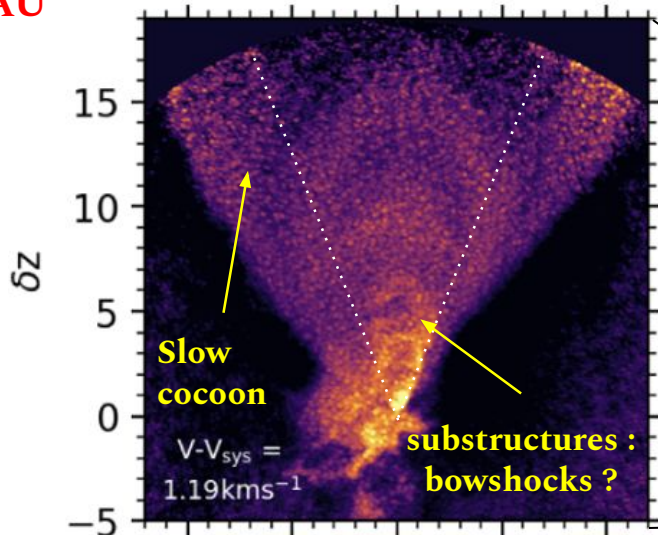
2- Entrainment by jet bowshocks



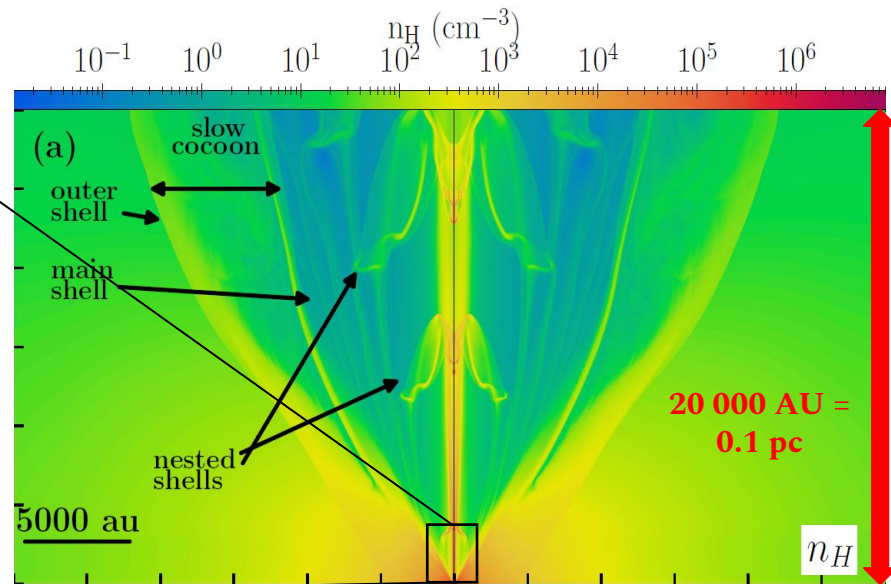
Why the “jet entrainment” model?

Promising resemblance with SMALL-SCALE flow observations

3 000 AU



DG Tau B (Class I/II)
De Valon, Dougados, Cabrit+2020



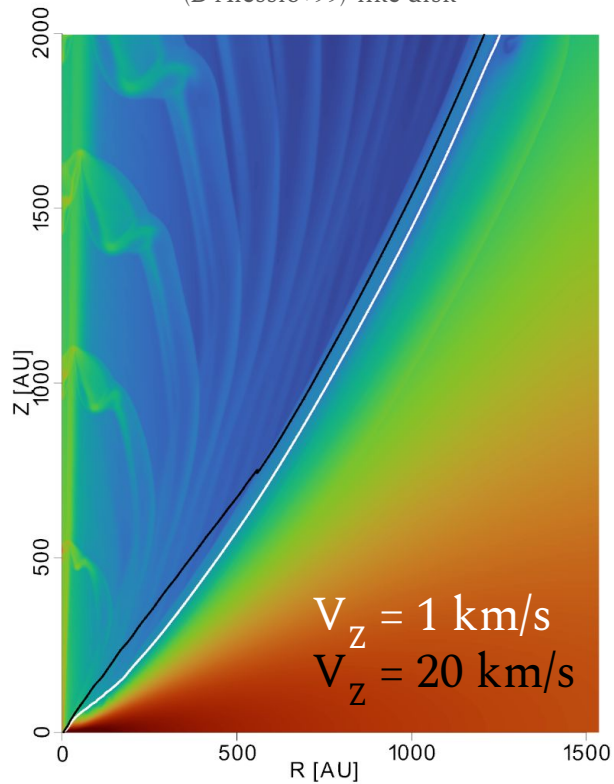
Need to **increase resolution on small scales** and **add rotating disk and/or infalling envelope**

Outcome of the simulations

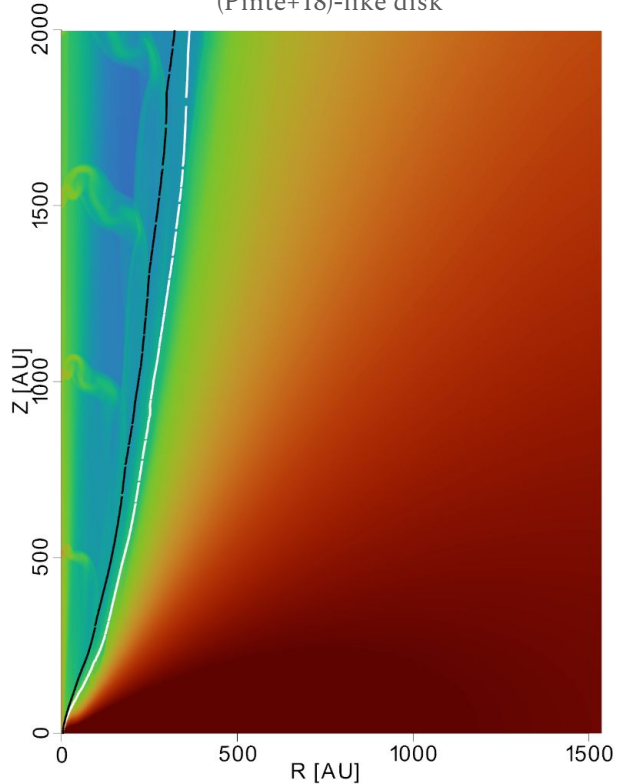
Non-definitive results

Disk-only:
(Eqs. from Nelson et al., 2013)

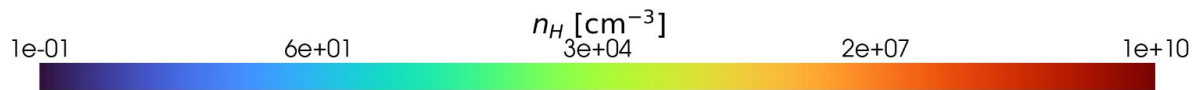
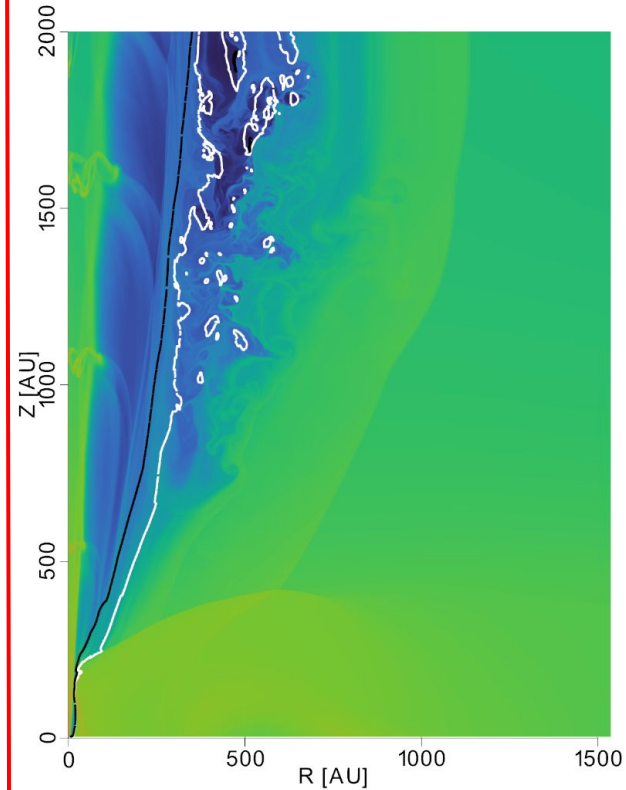
(D'Alessio+99)-like disk



(Pinte+18)-like disk

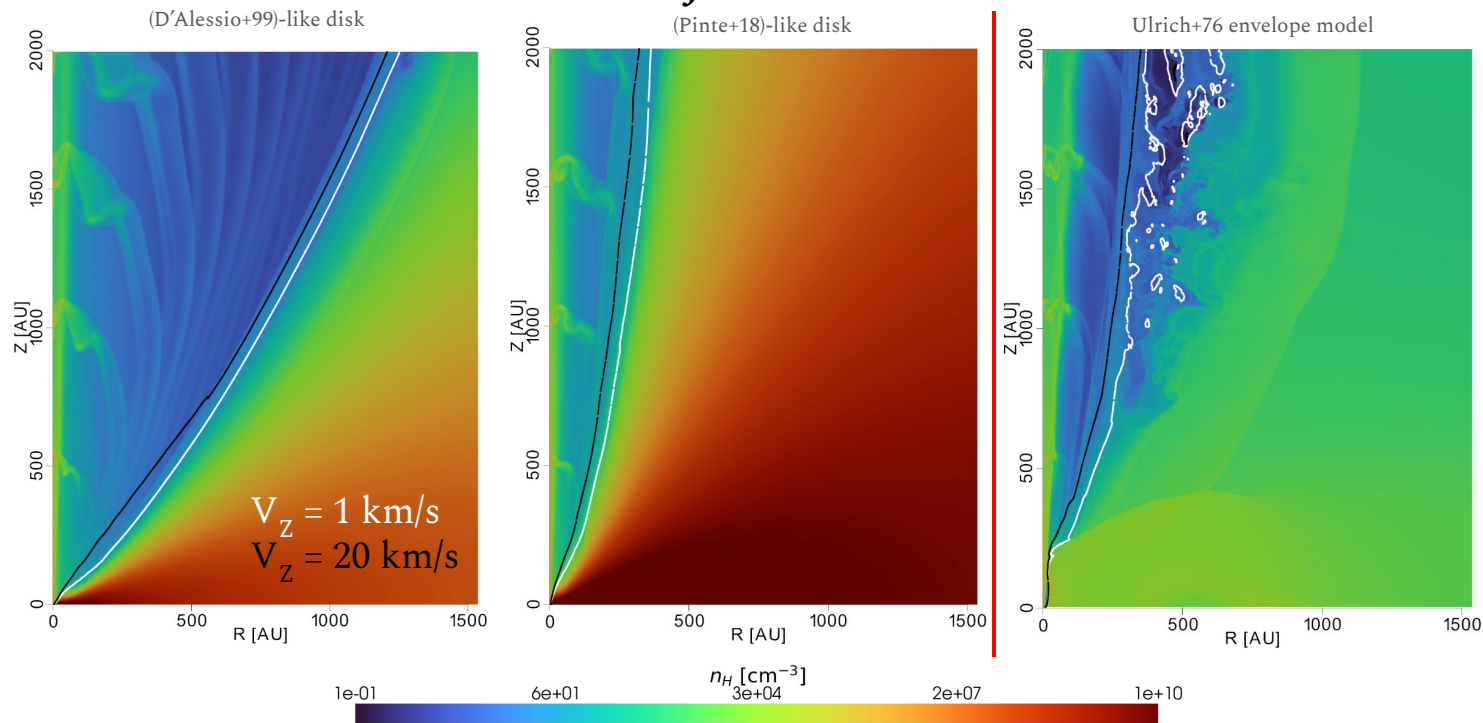


Envelope-only:
Ulrich+76 envelope model



Outcome of the simulations

Non-definitive results



Morphologic and kinematic similarities

Mass flux much smaller than in observations : $\dot{M}_{\text{simu}}/\dot{M}_{\text{obs}}(\text{CO}) = 10^{-3}$

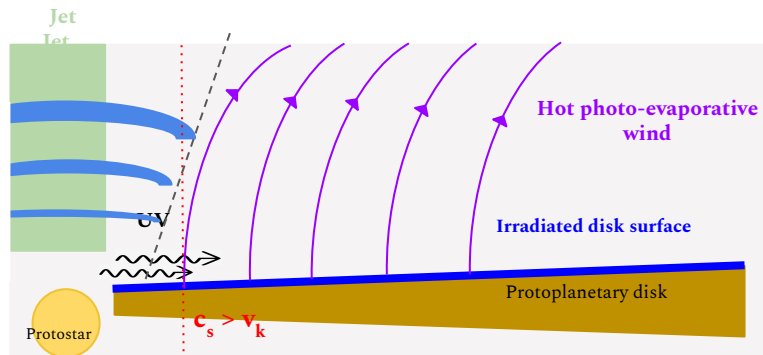
Next step :Interaction of jet bowshocks with PE winds

Adding effect of stellar irradiation (PLUTO code):

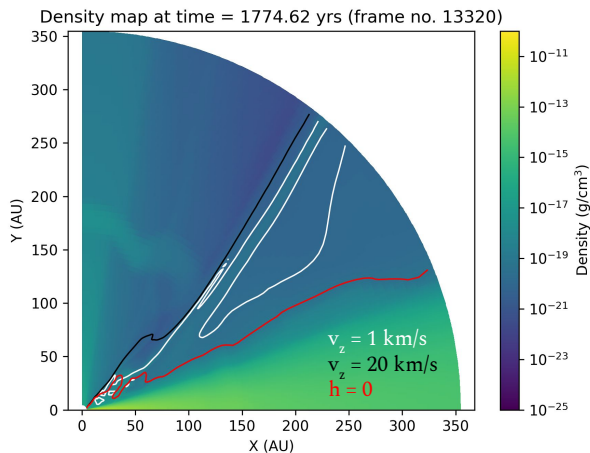
with R. Nakatani (Università degli Studi di Milano)

FUV (Acc. shock) + EUV + X-Rays (coronal activity)

→ Generation of a photo-evaporated wind



Solving out-of-equilibrium chemistry (10 species) & cooling

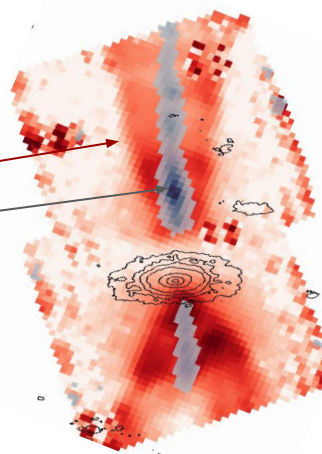


DG Tau B

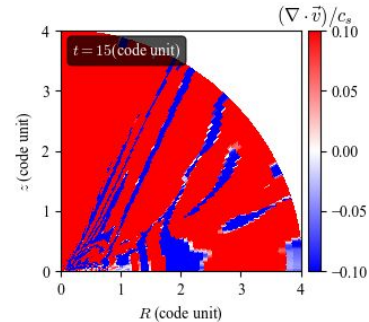
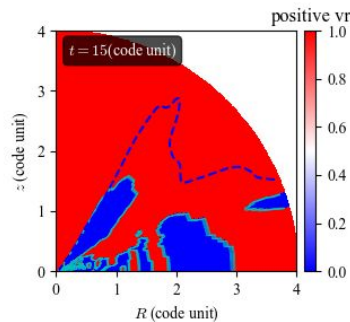
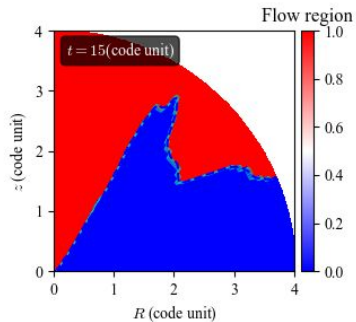
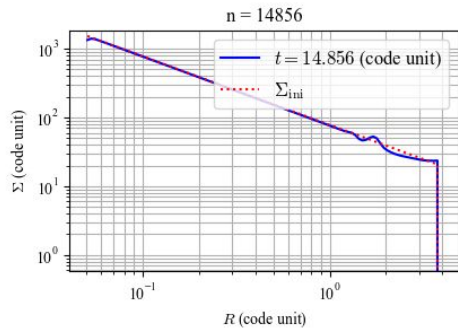
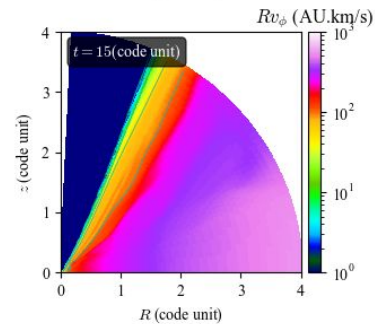
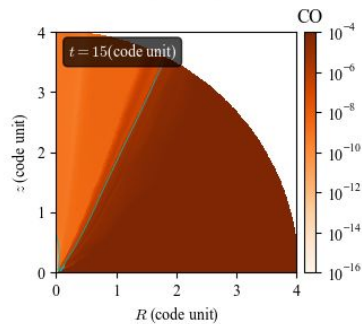
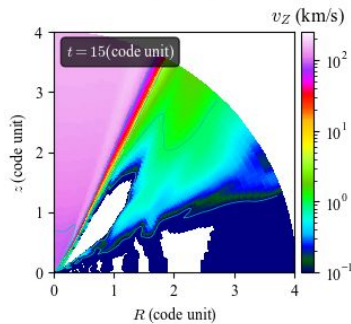
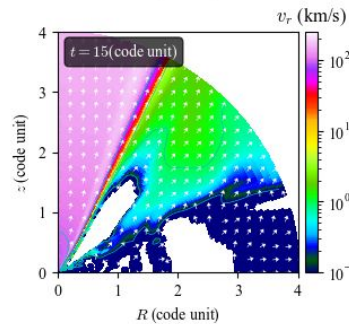
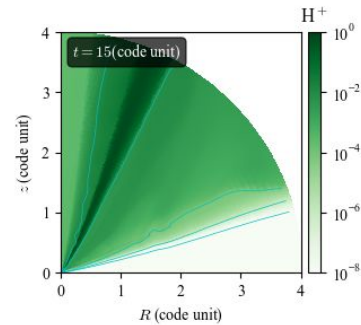
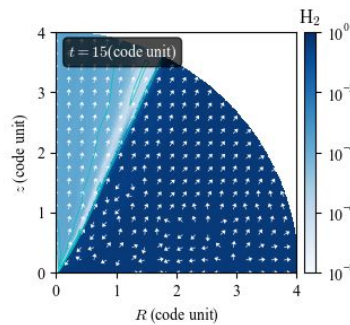
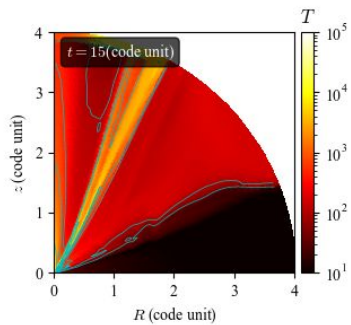
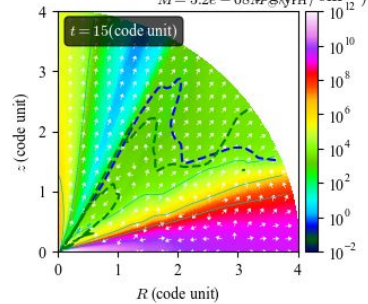
JWST observations

Flot
Jet

*Delabrosse,
Dougados,
Cabrit+2024*



$$\dot{M} = 5.2e-08 M_{\odot} / \text{cm}^{-3}$$



Thank you for listening !