Nathan Maindon

HH 46/47, NIRCAM - Crédits: NASA, ESA, CSA -Joseph DePasquale, Anton M. Koekemoer

5th Hel.A.S. MHD Summer School - Ioannina, 20/09/24

PhD subject : Feedback of protostellar ejections on planetary formation
(To be started on October 1st 2024)

Supervisors : Sylvie CABRIT (LERMA-OBSPM), Guillaume PINEAU DES FORÊTS (IAS-Saclay)

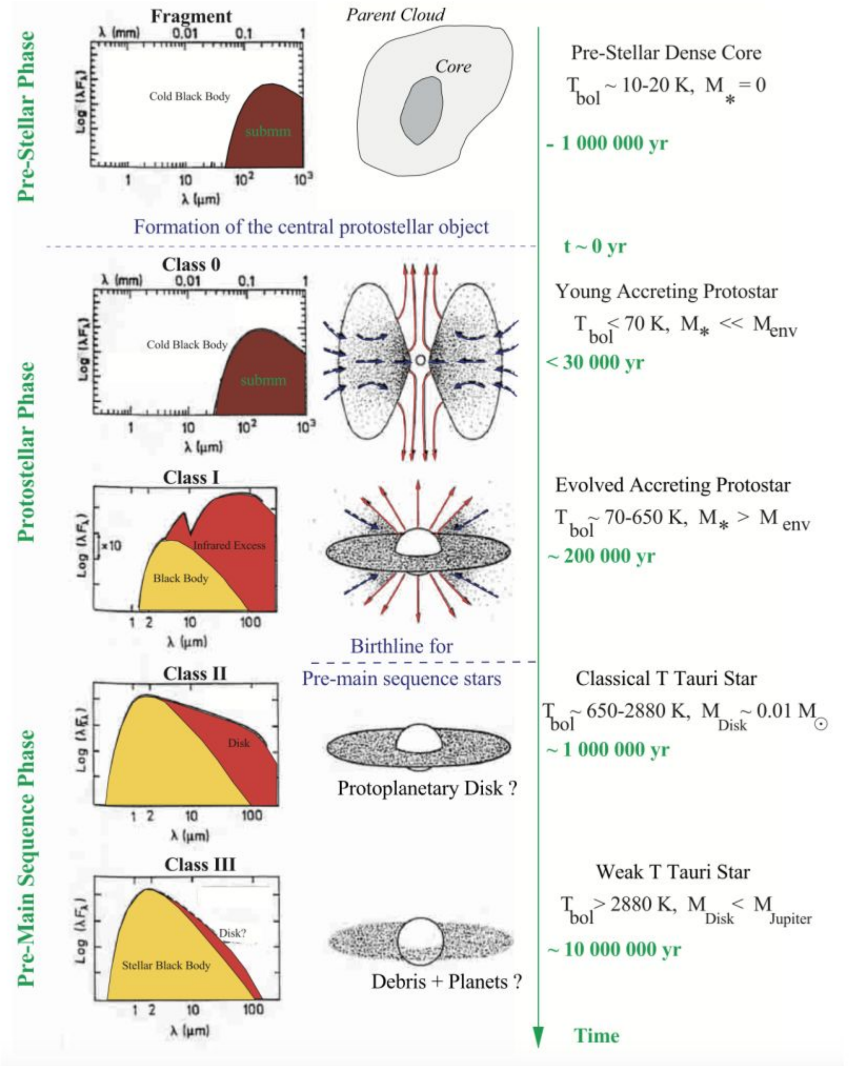
Context of star formation

Cf. talk of Kostas Tassis yesterday

Diverse interactions between magnetic field and matter of the protostellar object

This thesis: focused on **T-Tauri stars**

=> Kelvin-Helmholtz mechanism
(gravitational collapse, slowed down by internal and radiative pressures)
No nuclear reactions yet : $T<T_{fus}(H)$



Credits:F. Lévrier (ENS-PSL)

Ejections in T-Tauri stars: “Herbig-Haro objects”

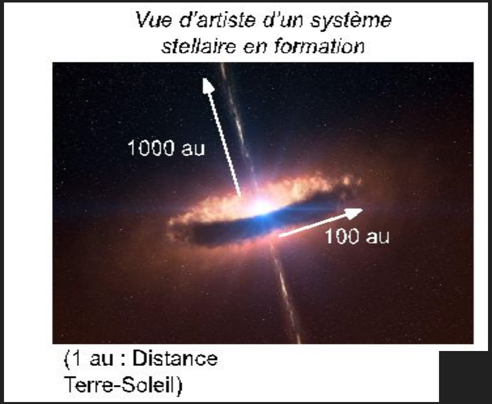
- Collapse of an interstellar cloud
- Formation of a gas/dust disk
-Accretion on the star

Atomic jets:
10 000 K, 100 km/s
Origin < 0.1 AU

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

Molecular flows (CO):
30 K, 10 km/s
Origin 1-30 AU

$\dot{M} \approx \dot{M}_{accretion}$



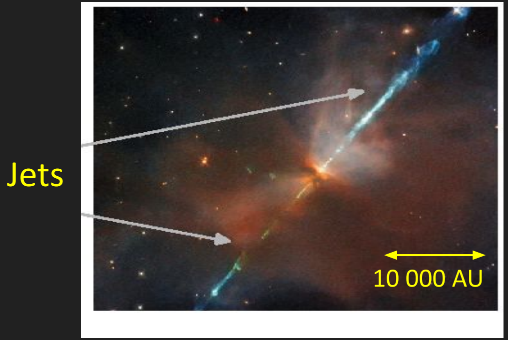


Image de HH111, HST/Nisini+2021

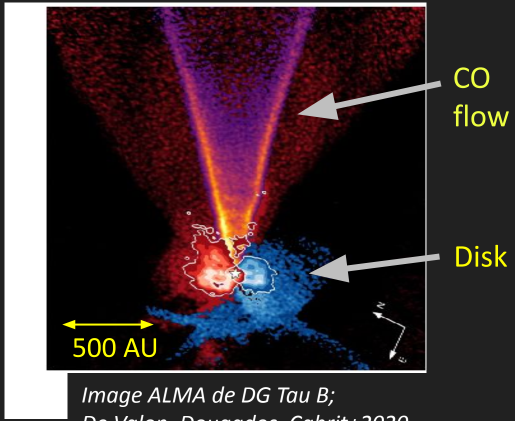


Image ALMA de DG Tau B;
De Valon, Dougados, Cabrit+2020

Question : What is the **origin** of the observed **molecular flows**?
What **impact** do these flows have on **planetary formation?**

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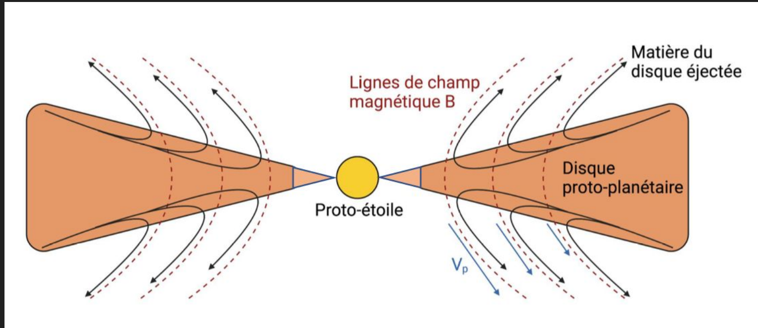
TWO COMPETING MODELS

1) MHD magneto-centrifugal disk wind ?

Recently preferred, on the basis of ALMA observations:
- Coherent rotation, ejection speed, mass fluxes
- Magnetic braking would explain accretion from disk onto the star

Major MHD effects on planetary formation and migration ?

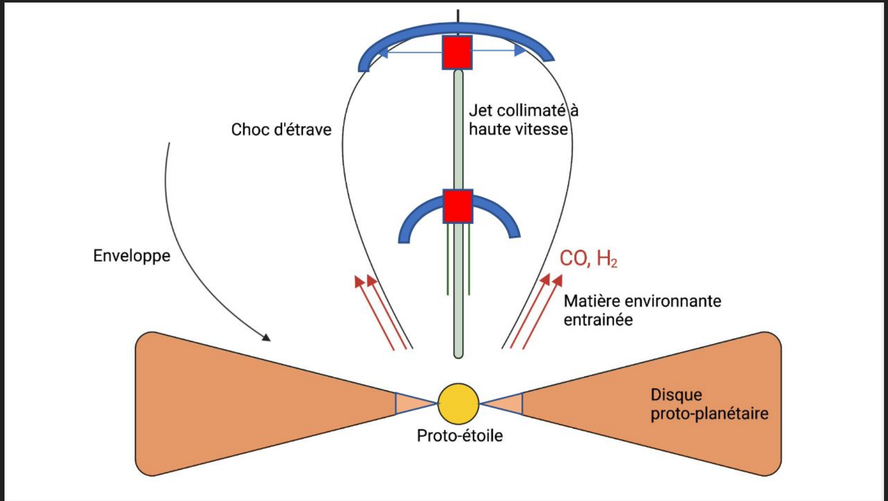
Problems: - fineness of the CO cavity (r << R_{disk})
- **Ejections are not systematic, whereas this wind should be !**



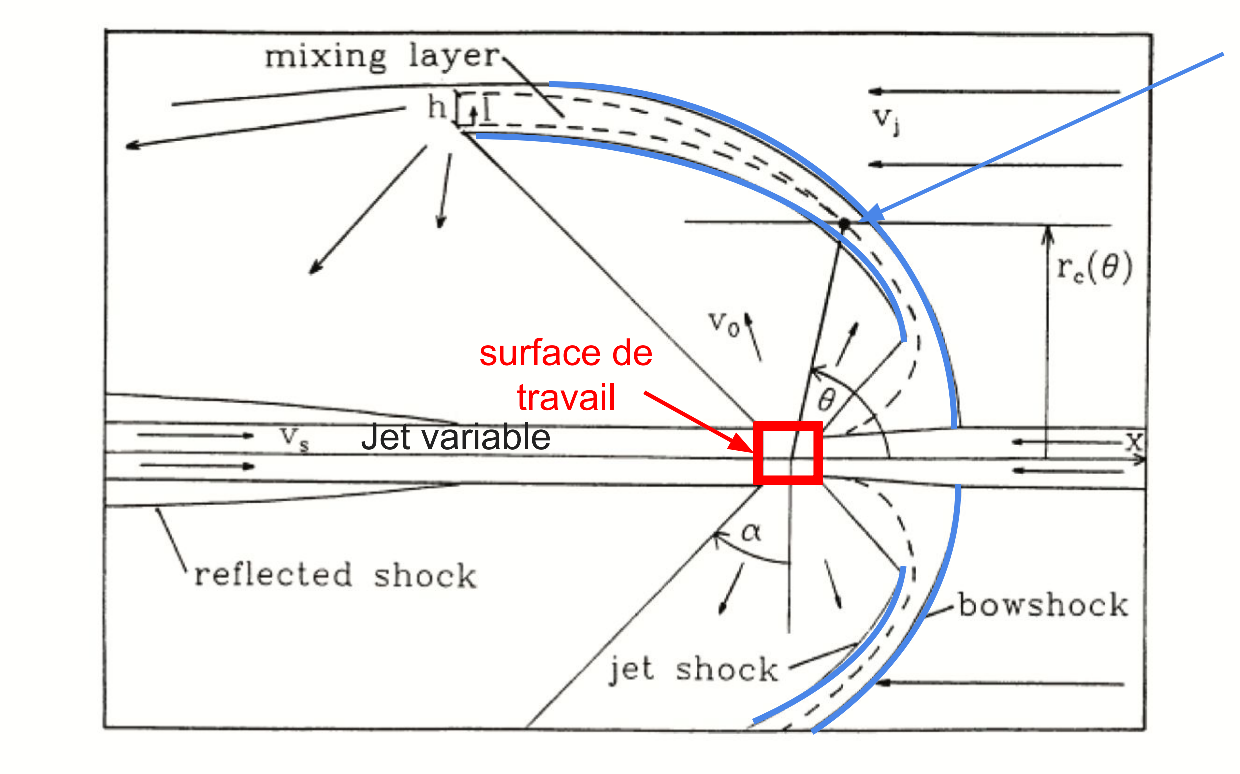
2) Matter dragged by the atomic jets' bow shocks?

Alternative scenario: goal of this PhD

- Variability of the atomic jet (speed, mass flux):
- Generating bow shocks as it hits the disk and the envelope
- Could explain rarity of the phenomenon (+ fineness ?)



Quick overview of the bow shock



Ejecta participates in the formation of the observed cavity

Promising latest model: ***Rabenanahary, et al. 2022***

First simulations of variable jets in a stratified environment, up to 10 ^{4} years (with Z. Meliani)

Code: AMR-VAC

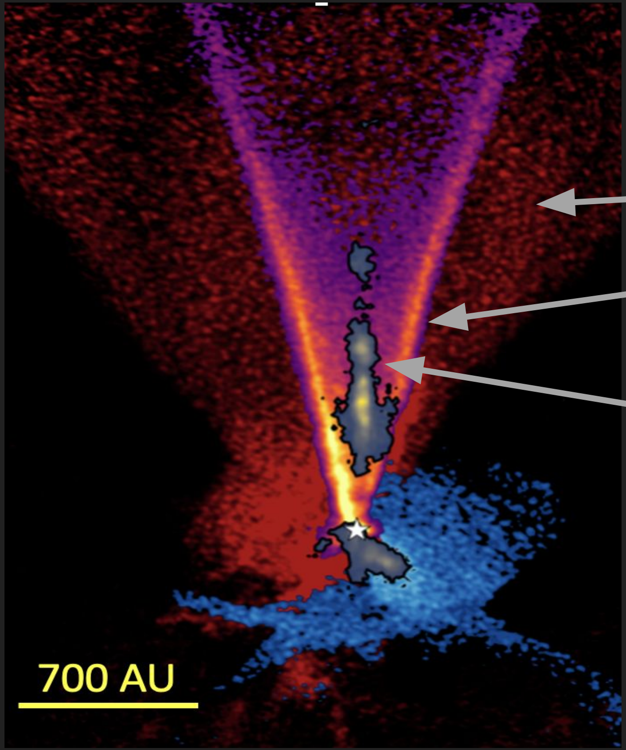


Image ALMA de DG Tau B;
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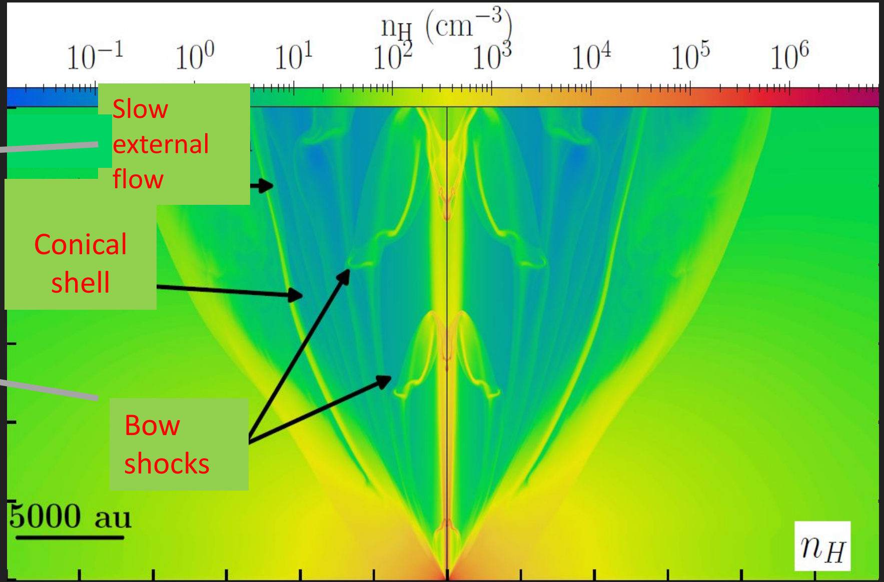


Yet too many hypothesis:

- -Static environment, with no rotation
- -No chemistry
- -No disk
- -Scales >> 1000 au

Numerical Simulations

MHD : AMR-VAC

Parmi d'autres applications et problèmes, le module d'hydrodynamique de MPI-AMRVAC en particulier permet de résoudre les équations d'Euler avec termes sources traduisant :

— **la conservation de la masse :**

$$\partial_t \rho + \nabla.(\rho \vec{v}) = M_p, \quad \text{(III.1)}$$

— **la conservation de l'impulsion :**

$$\partial_t (\rho \vec{v}) + \nabla.\left(\rho \vec{u}\vec{v} + p\vec{I}\right) = \vec{F}_p, \quad \text{(III.2)}$$

— **la conservation de l'énergie :**

$$\partial_t (e) + \nabla.((e+p)\,\vec{v}) = E_p, \quad \text{(III.3)}$$

où ρ est la densité totale du fluide, p est la pression thermique; $\vec{v}$ est le champ eulérien de vitesse du fluide; M_p, $\vec{F}_p$, et E_p traduisent respectivement les termes sources des trois équations de conservations; $\vec{I}$ est le tenseur identité; et $e = \frac{p}{\gamma_{\rm ad}-1} + \frac{\rho u^2}{2}$ est la densité totale en énergie du gaz, avec $\gamma_{\rm ad}$ l'indice adiabatique. Dans un gaz parfait avec trois degrés de liberté, $\gamma_{\rm ad} = 5/3$ (gaz monoatomique); tandis que dans un gaz isotherme, $\gamma_{\rm ad} = 1$.

From the thesis of M. Rabenanahary (2022)

Adaptive mesh

Chemistry: Kimya (UNAM)

UNAM Team :pioneer in the coupling chemistry-HD of 2D/3D reactive flows (chemical characteristic time >> dynamic time: out of equilibrium)

KIMYA, a Code for Solving Chemical Reaction Networks in Astrophysics Revista Mexicana de Astronomía y Astrofísica Vol. 54, pp. 409-422 (2018)

Downwind method (more stable and fast), up to 15-30 chemical species

Goals of the thesis:

1) Develop the first realistic simulations of the jet/disk interaction < 1000 au

- with rotation + disk + collapsing residual envelope
- Simplified out-of-eq chemistry (H^+, H, H_2, CO) + associated radiative cooling

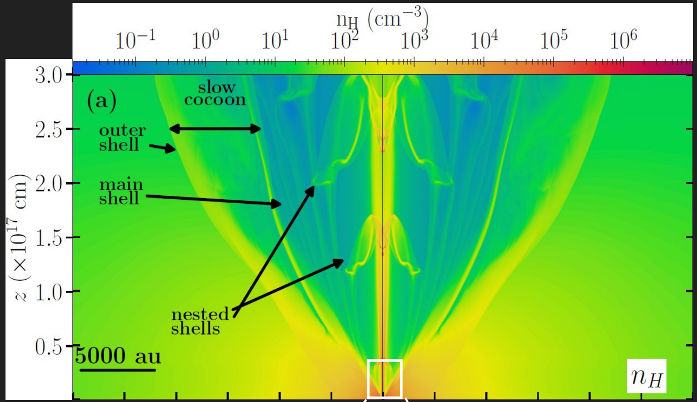
2) Compare to our observations

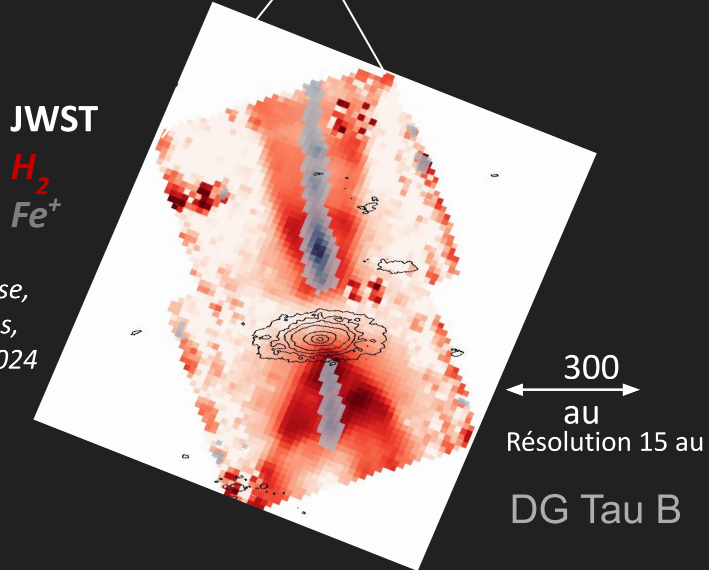
- JWST : H_2 (2000 K): Shocks tracers
- ALMA: cold CO : Rotation, dragged mass

=> Discrimination *versus* MHD disk wind

3) Impact on planetary formation

- Shocks on the disk + species depletion
- Negligible MHD effects, or not?





Delabrosse, Dougados, Cabrit+2024

Thanks for listening !