High-mass turbulent core collapse with ambipolar diffusion and hybrid radiative transfer

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Massive stars (> 8 solar masses) form in turbulent, magnetized regions. Because of their strong radiative pressure stopping accretion in 1D models, numerical efforts have been focused on radiative transfer. Spherical symmetry has been broken in multidimensional simulations, and disk accretion (2D, Yorke+02) then accretion via radiative Rayleigh-Taylor instabilities (3D, Rosen+16), have emerged.

I have been implementing a hybrid radiative transfer method in the RAMSES code to treat the stellar irradiation separately from the diffuse medium emission, allowing to capture better the radiation anisotropy and coupling with the gas. I will use it to investigate the main accretion mode during massive star formation (Mignon-Risse+20).

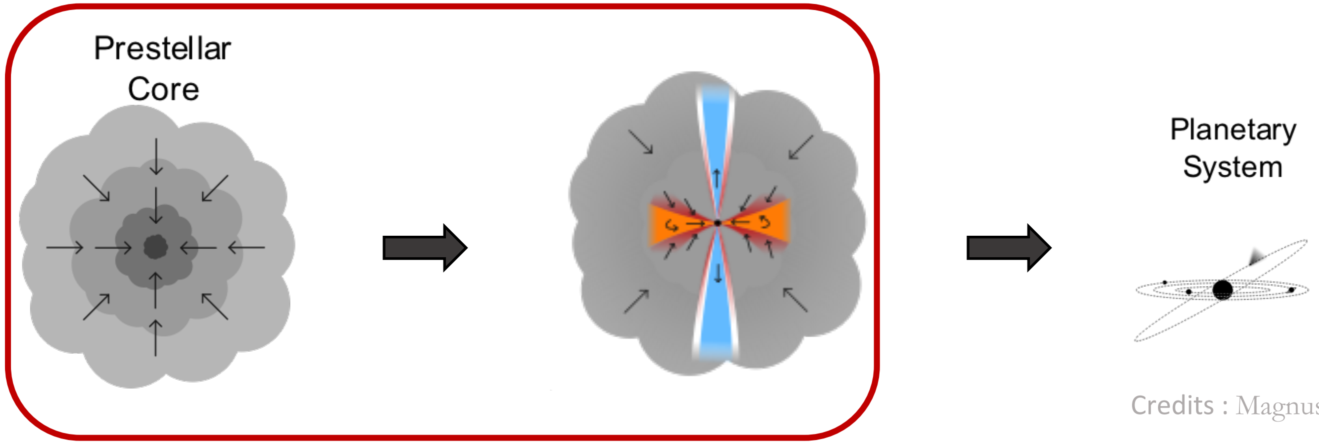
I will then include turbulence and (non-ideal) MHD to determine the launching mechanisms of their bipolar outflows. I will finally provide observable quantities such as disk and outflows properties (e.g. opening angles) for comparison with ALMA observations.

1. Context of the research

Massive stars are

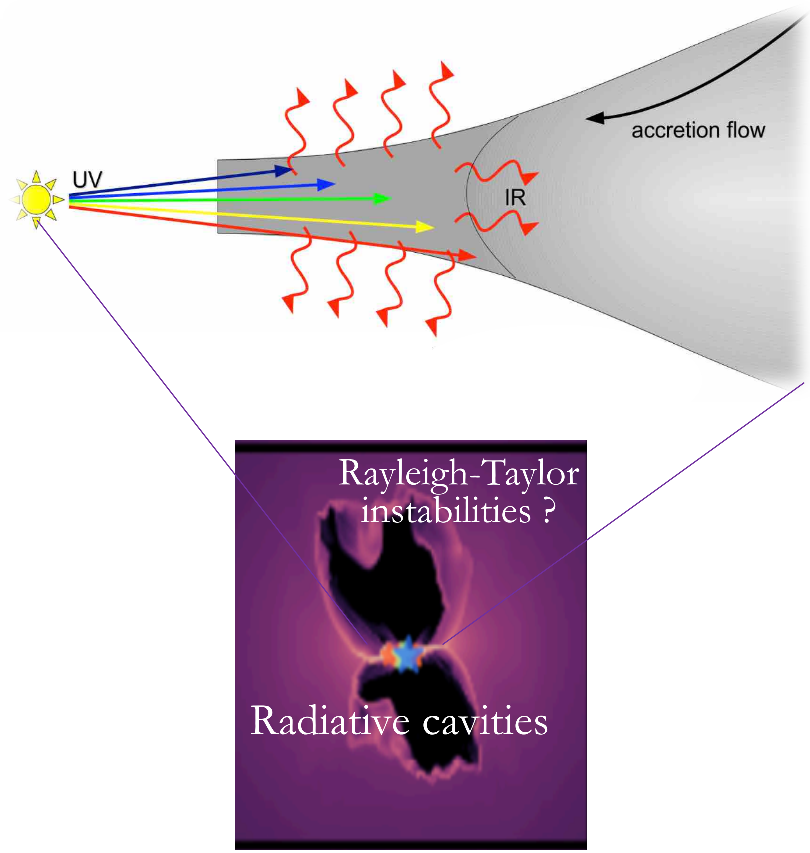
- **Massive** $M > 8\ M_{\odot}$
- **Luminous** $L > 10^5\ L_{\odot}$

But do they form like low-mass stars ?



Credits : Magnus Vilhelm Persson

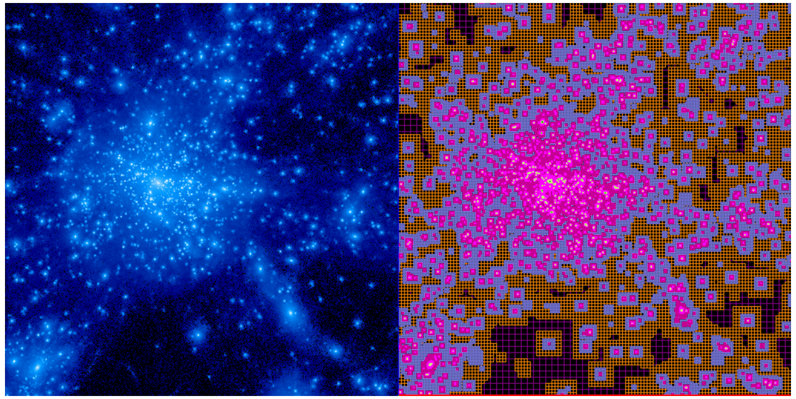
- Disk accretion and/or Rayleigh-Taylor instabilities ?
- Radiative or magnetic outflows ?



Essential questions:		
Accretion		Ejection
	Multiplicity	

RAMSES (Teyssier+02) :

- High-performance code
- Adaptive mesh refinement, Fortran, MPI



- Non-ideal MHD, self-gravity, N-body
- Diffusion radiative transfer, ~~irradiation~~
- Stellar irradiation module for cosmology

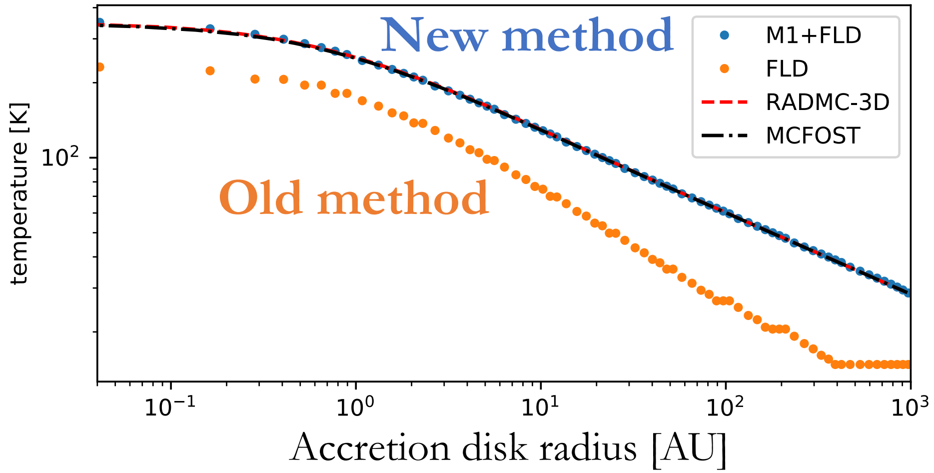
Hybrid method for irradiation (Mignon-Risse+20) :

✓ Coupling of the two modules

✓ Dust sublimation

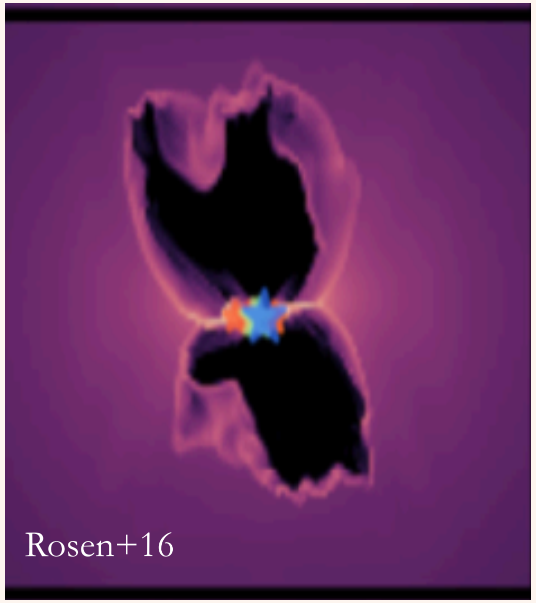
Tests vs Monte-Carlo radiative transfer codes

- Radiative force x100 (Owen+14)
- Gaz temperature more accurate

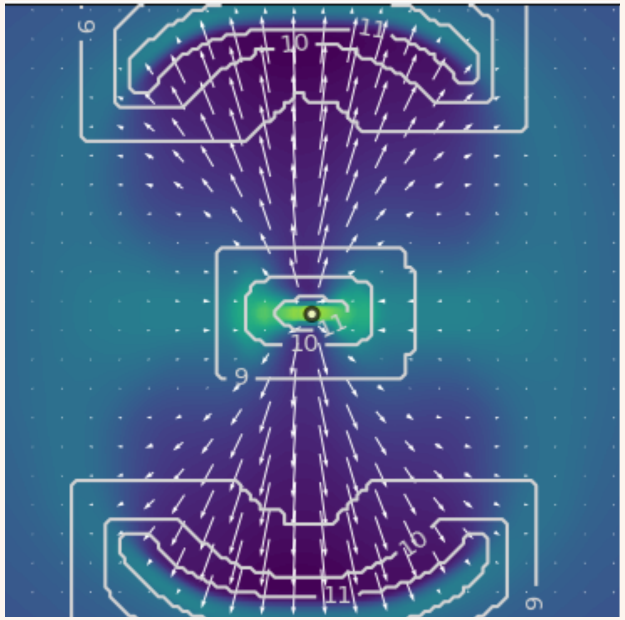


What is the accretion dominant process ?

Methods: Hydrodynamics + Irradiation



- ~~No Rayleigh-Taylor instability~~
  - 1st proof at same resolution,
    comparable RT method,
    theoretical arguments
- Large disk (~1000AU)



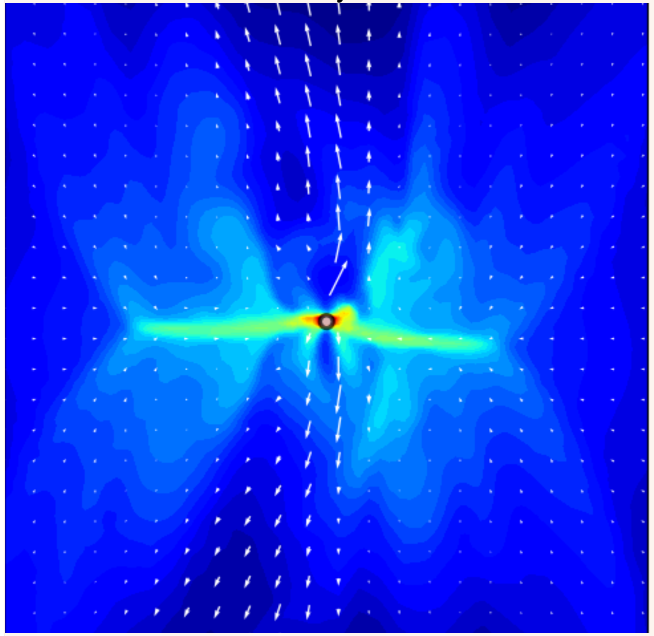
(Mignon-Risse+20)

3. Results

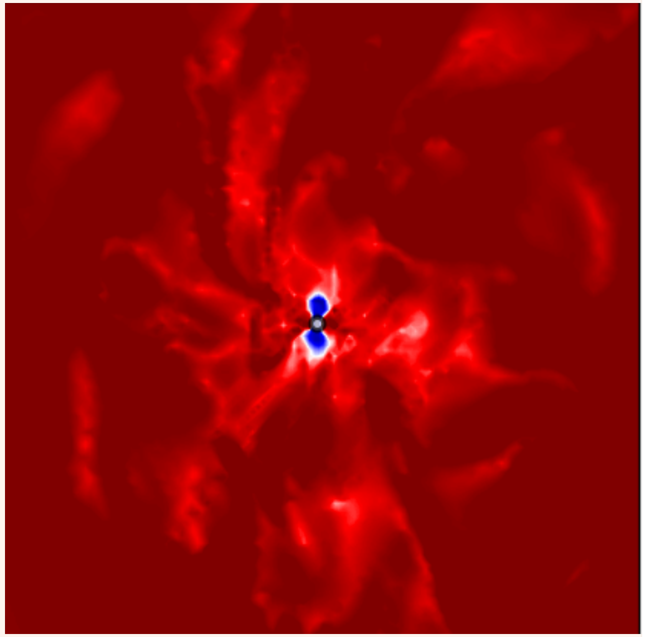
Magnetic or radiative ejections?

First simulations with irradiation
+ non-ideal MHD (+ turbulence)

Density slice



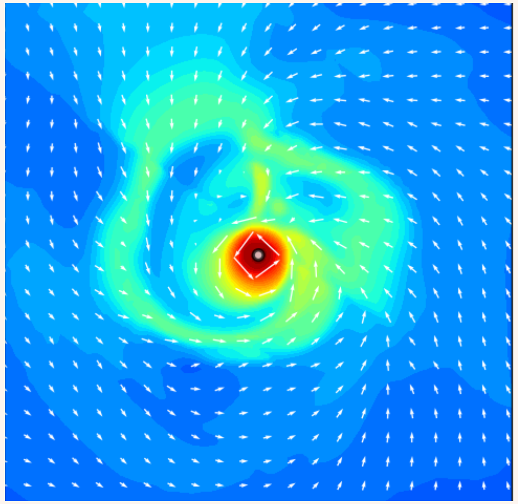
Lorentz force/Radiative



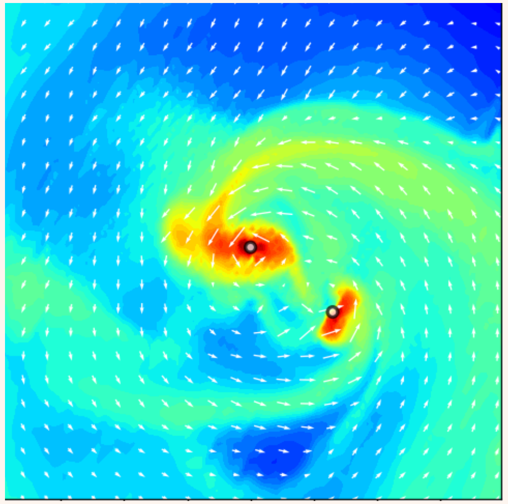
Magnetic origin

Disks & Multiplicity

No turbulence



with turbulence

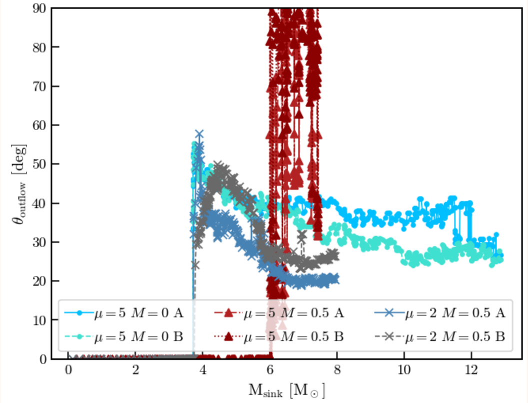


Small disk ~100 AU
Single star

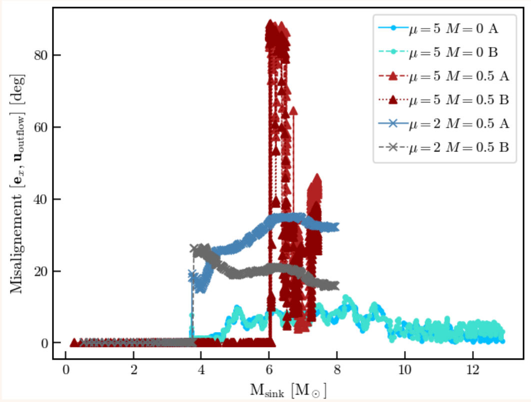
~300-1000 AU
Binary system

Obs : 20-2000AU (Kraus+10, Johnston+15)

Outflow opening angle



Misalignement with B



(Mignon-Risse et al., in prep)

Impact

• Disk-mediated accretion, like low-mass stars
Mignon-Risse+20 https://arxiv.org/pdf/1601.02816.pdf

• Outflows are mainly driven magnetically

• Opening angle 20-40°

• Disk misaligned with large-scale magnetic fields

• Outflows tend to align with large-scale magnetic fields
Mignon-Risse et al, in prep.

Prospects

• High-resolution to capture jets
(Kölligan+18)

• Inclusion of photoionization, can disrupt the magnetic fields topology
(Peters+11)

• Dust dynamics, major contributor to opacities