Chocs d'accrétion sur les étoiles jeunes:

l'apport de la simulation numérique et des expériences

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and with the collaboration of S. Orlando, S. Bonito et al. (O. Palermo),
M. Kozlova et al. (PALS)

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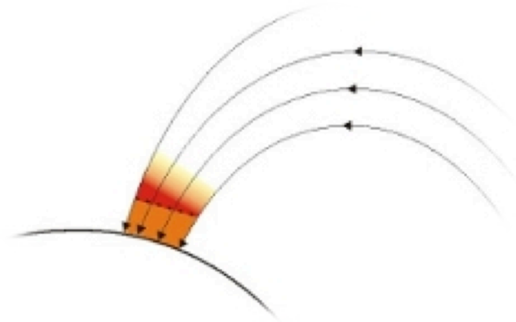


General goal

How to understand accretion process with :

- Numerical simulations (1D and 3D) on the structure & dynamics of accretion shocks
- Comparaison with observations (RT : 1D and 3D)
- Experimental benchmarks

Context : Topology of accretion flows

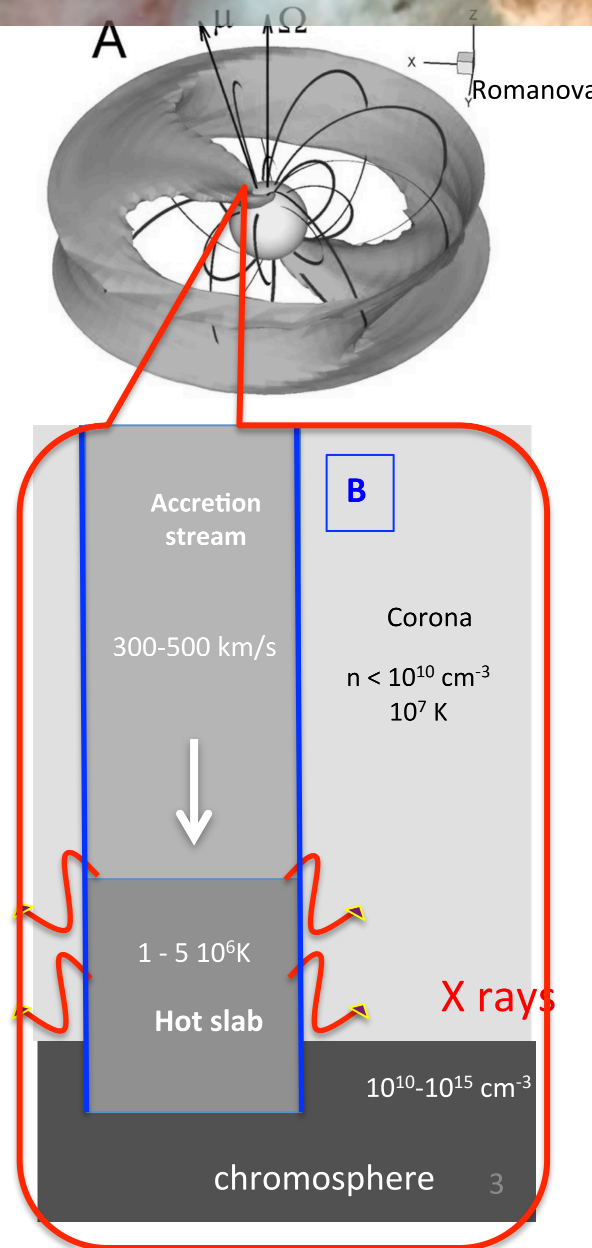
cf Bouvier & Donati talks

- Magnetic field lines connect photosphere to the stellar disk (~ 500 – 1000 G)

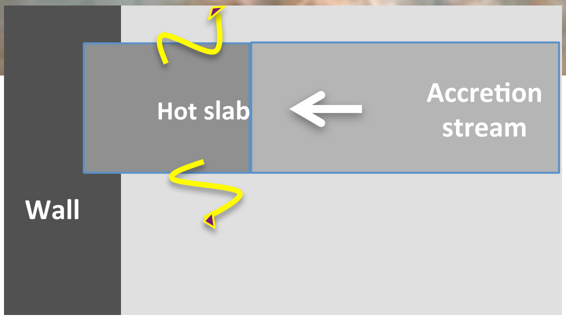
- Accretion in funneled streams :
  V ~ 300 – 500 km/s (free fall)

- Hot and dense post shock:
  1–5 10^6 (X rays), n> 10^{11}cm^3

Accretion rate deduced from L_{acc} & models

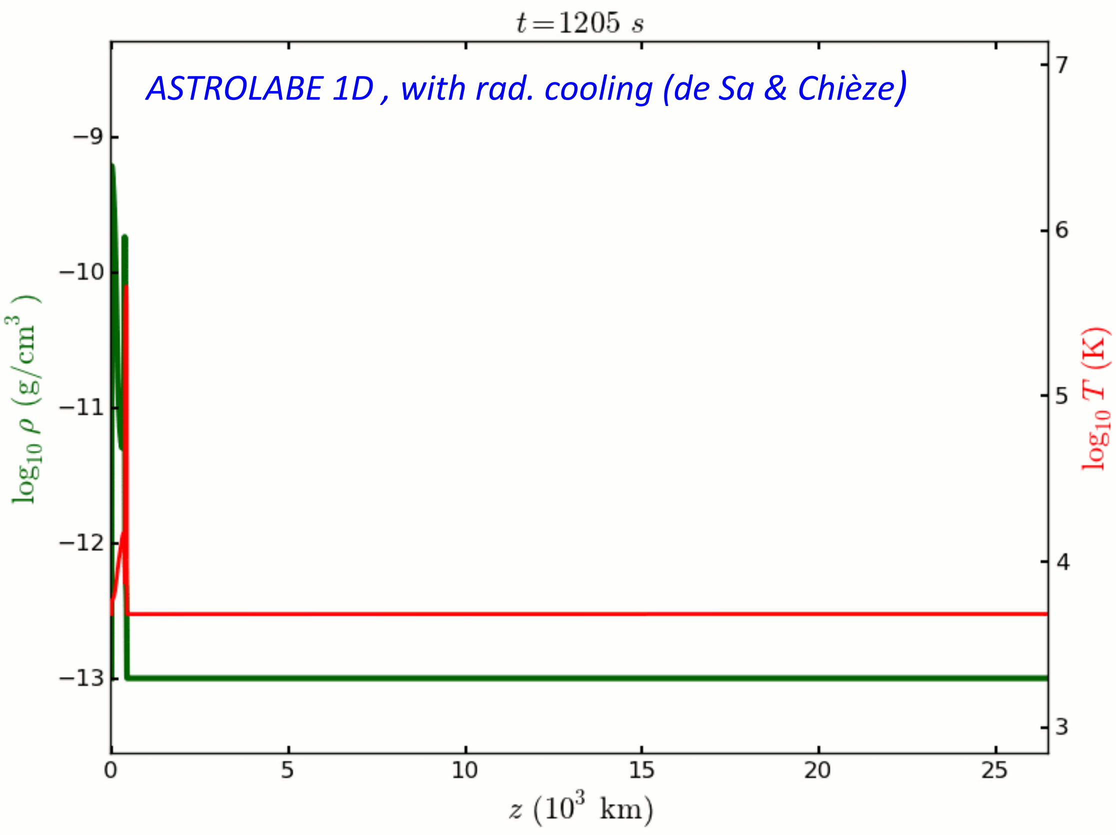


QPO : quasi periodic oscillations



Matter falls on to the chromosphere **(here a wall)**

1) accretion shock forms first on the chromosphere (ie wall, z=0)
2) A hot slab grows with time with a reverse shock on the top



3) Strong cooling, in the regime of cooling instabilities
4) The slab crashes

5) A new cycle starts

Period ~ 400 s, height of the column : 20000 km

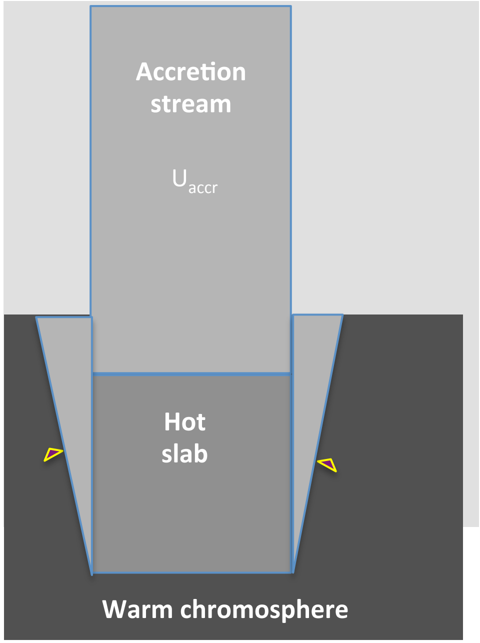
Main difficulties

No observational evidence of QPO

Too weak flux in UV lines like CIV

Accretion rate deduced from X ray observations lower than expected

May be the scenario is like this?



A warm column hidden by lateral "dense" plasma

=> less observable X rays

The main questions

How deep is located the accretion shock?

How extended is the radiative precursor?

Is the flow subject to cooling-driven instabilities in some parameter regime?

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What is the accretion rate ?

How does the shock diameter influence its spectral properties?

What is the emitted spectrum as a function of angle and frequency?

THE MAIN QUESTIONS

How deep is located the accretion shock?
How extended is the radiative precursor?
Is the flow subject to cooling-driven instabilities in some parameter regime?
What is the effect of magnetic field in this picture?

How does the shock diameter influence its spectral properties?
What is the emitted spectrum as a function of angle and frequency?

Requires Radiative Magneto Hydro simulations (RMHD)

Requires detailed radiative transfer simulations

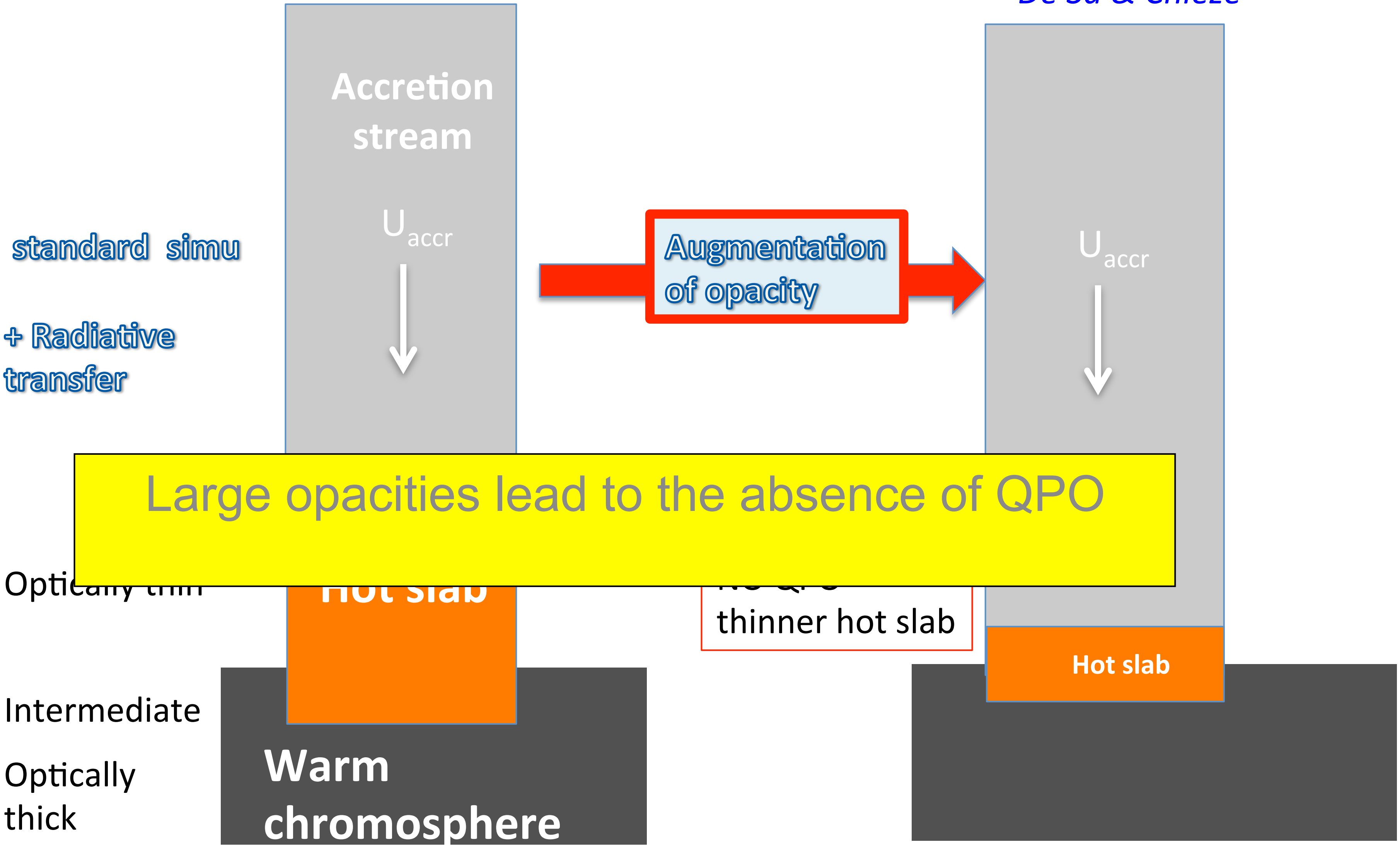
To be validated, for instance with experiments

-> eligible models constrained by observations

This also requires physics !

1D radiative simulations with ASTROLABE

De Sa & Chièze



Period : 170 s, height 8000 km

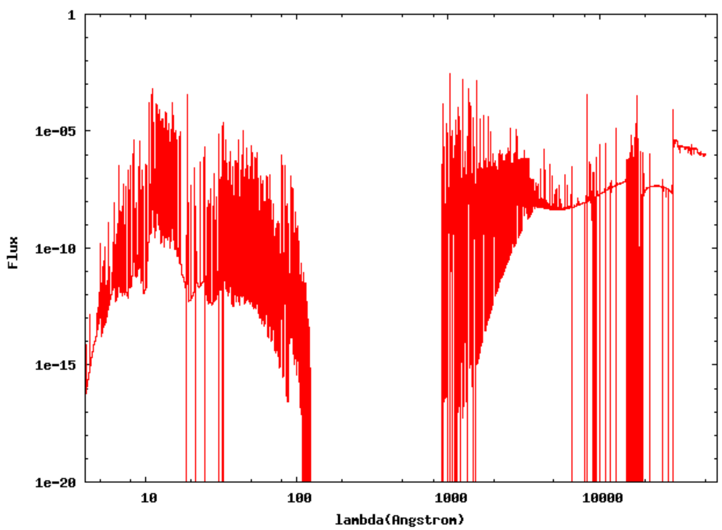
Period : 0 s, height 2 km !!!

The key role played by the opacities

A wide range or [ρ, T] for opacities : [10^3-10^7K ; 10^{-16}-10^{-8} g/cm^3)

new opacities: calculated , merging Molecular opacities (Ferguson) and atomic opacities

De Sa, Stehlé, Hubeny, Lanz, Delahaye, Alexander.



SYNSPEC spectra : correct order of mag. of Lx is correct few 10^{30} erg/s (2 -27.5 A) (Brickhouse , ApJ 2010)

Stehlé, Lanz, Hubeny

Very different behaviour from X Ray, UV, Visible

=> Multi group RMHD !!

Gonzalez's talk

\+ NLTE opacities !!

What we learned from 1D ?

- Chromospheric heating should be included for fine and self consistent studies
- Conditions vary from LTE at the base to coronal on the top
- Time dependent ionisation (coupled to hydro)
- Radiative transfer is important
- Radiative precursor ? (need of multi-groups)

2D-3D MHD simulations

2D MHD simulation with PLUTO

Radiative cooling

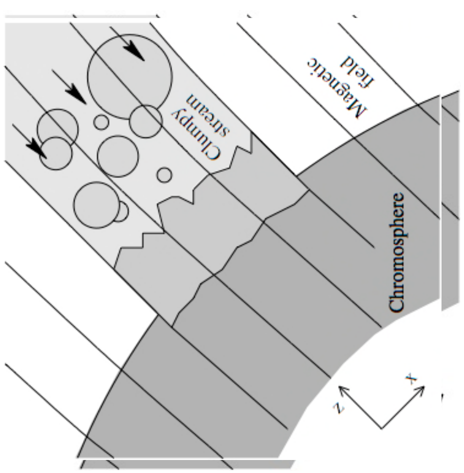
Clumpy incoming flow

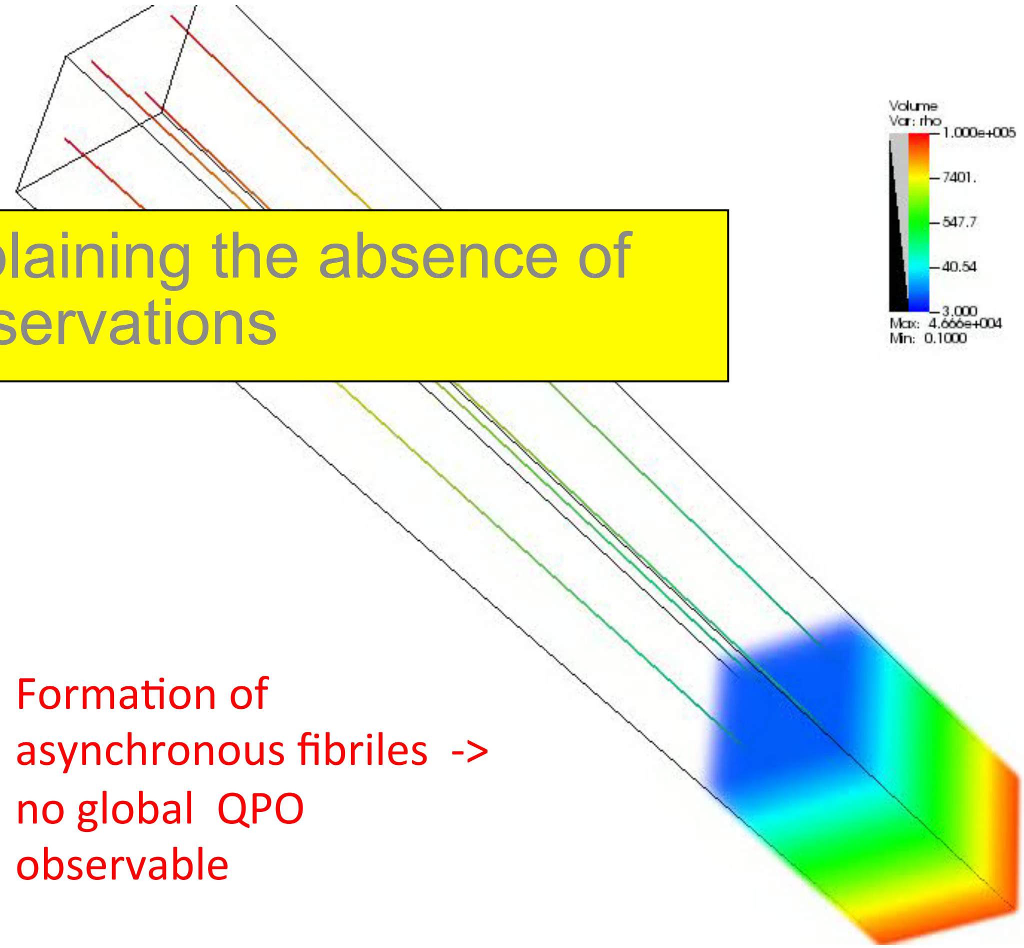
(*overdense large clumps*)

v = 5

B= 5

Another scenario explaining the absence of QPO observations



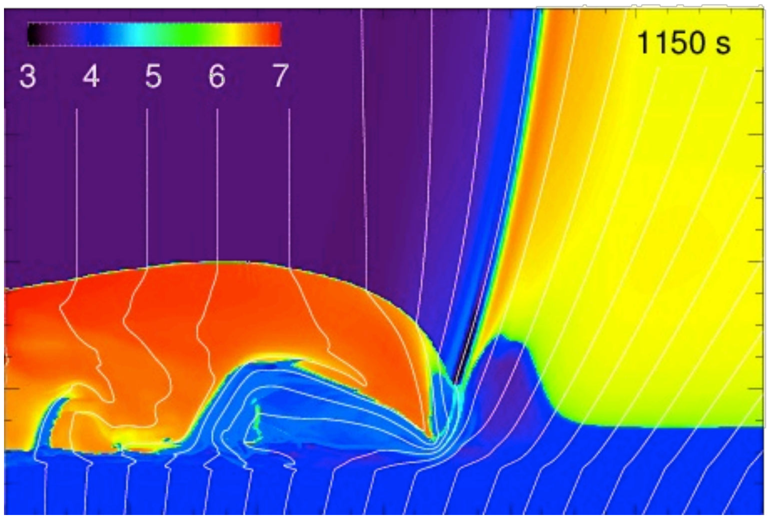


Formation of asynchronous fibriles -> no global QPO observable

Matsakos, Chièze et al. 2013

Larger scale 2D simulationss

PLUTO 2D MHD simulation, Orlando et al. 2013, Bonito et al 2014

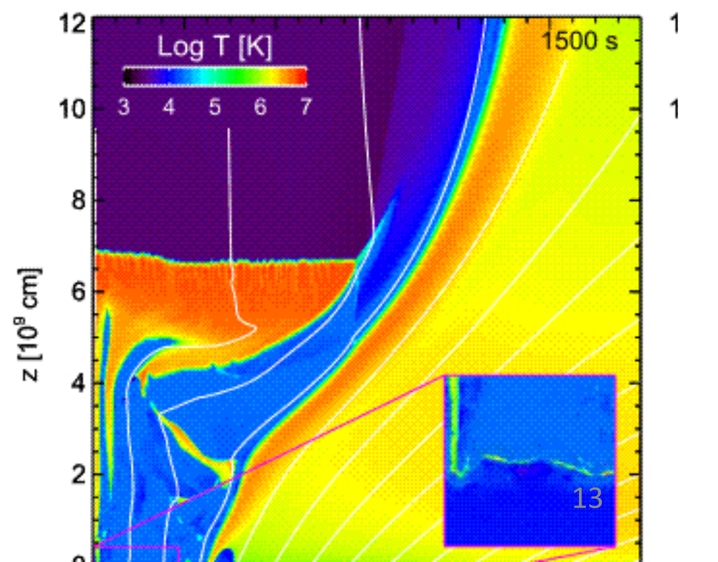


Global simulations of the column in its surrounding : magnetic field play a dramatic role.

low B (50 G), uniform field lines perpendicular to chromosphere

A lack of confinement of the shock,

- > oscillations are smoothed

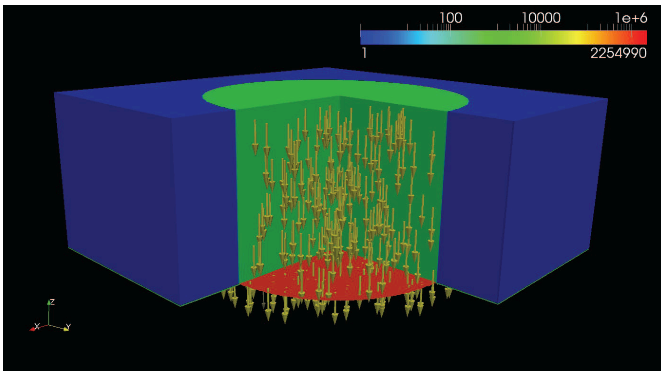


3D Radiative Transfer

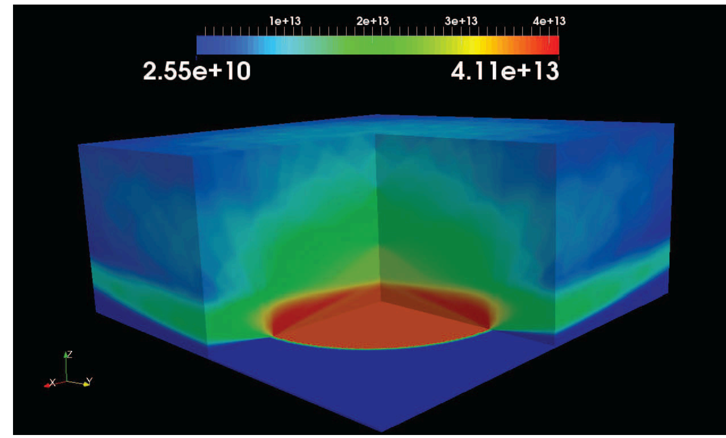
Ibgui, Hubeny, Lanz, Stehlé

A post processor to compare with observations and test the scenario.

IRIS a new generic 3D RT code (short characteristics)



gray radiation flux emitted by the RHD accretion structure (IRIS)



☞flux at the side walls of the same order of magnitude as the axial flux

Benchmark to check the description of RT in RHM codes like HERACLES

IRIS today : LTE transfer
in progress : parallelisation ; then NLTE

Prospects for 2D/3D simulations

Various reasons to explain the absence of QPO and the "low" X ray emission

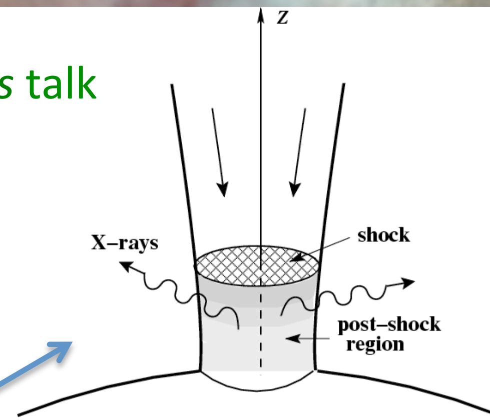
Need of :

3D RMHD with NLTE opacity and time dependent ionisation & multigroup !!!

Post-processed by a 3D RT code using NLTE opacities

Experiments

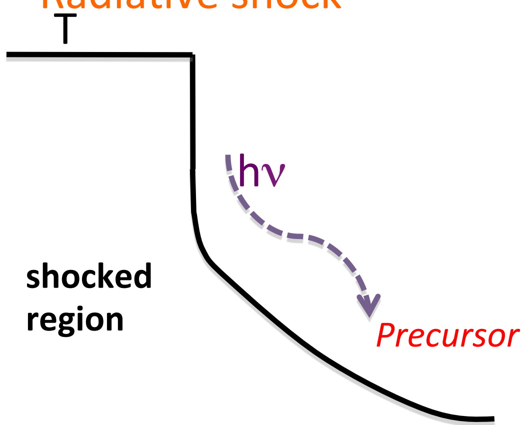
cf Jean Pierre's talk



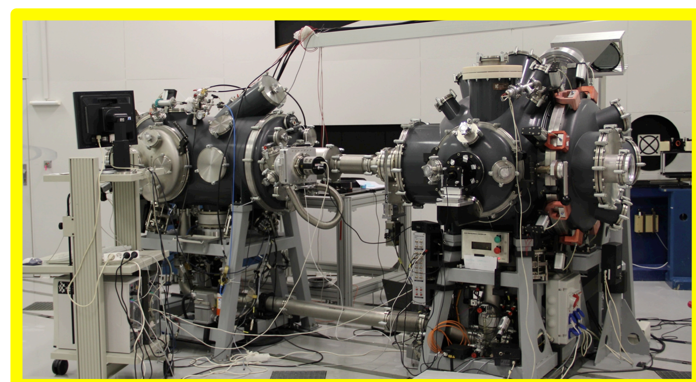
To understand the physics of shocks in general in conditions where radiation is coupled to hydro, like for accretion shocks

To test the ability of radiative hydro codes to reproduce experiments .

Radiative shock



PALS laser facility in Prague : 0.3 ns, 1kJ



Experiments

GENERAL CONTEXT

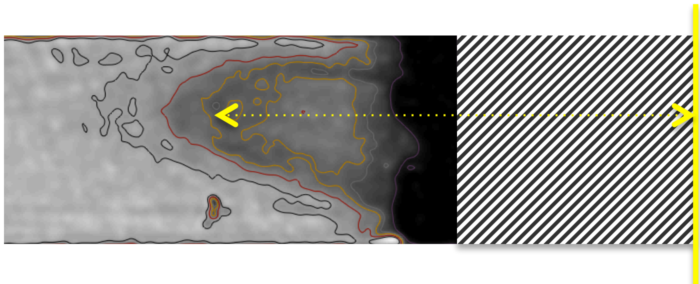
- 50-150 km/s achieved on kJ lasers , duration few 10 ns, Xe at 0.1-0.3 bar
- Studies of the post shock (Rochester) or the precursor (elsewhere) , but never both together
- Agreement with HERACLES (also used for astrophysics) for the precursor
- Transverse Radiative losses effects on the structure

Several diagnostics needed … a long way towards an unambiguous benchmark experiment

ACH

- F
  agreement with IRIS
- First XUV radiography of both post-shock and precursor together

400 μm
Xe, 0.3 bar



t= 20 ns, ~ 1mm => v = 50 km/s ; detached shock

PERSPECTIVES

- Focus on the X ray signatures of the shock
- Test of hydro and of Rad. Transfer (IRIS)

Final perspectives for accretion shocks

SCHEDULED :

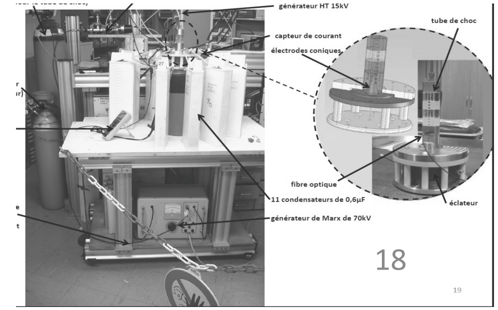
- 2D RMHD of accretion shocks
- NLTE version of IRIS (Radiative transfer) and comparison with observations

LONG TERM perspectives : FEEDBACKS

- Is the accretion shock able to induce a hot wind from the stellar surface?
- What is the entropy flux entering the star?
- What is the exact temperature of the incoming flow ?

SCHEDULED EXPERIMENTS

- Spectroscopic signatures of laser generated Radiative Shocks at PALS and ORION
- Radiatively cooled Shocks on pulsed power devices (Ecole Polytechnique : J. Larour)
- Experiment at LULI : collision of a magnetized plume on a wall (A. Ciardi , LERMA)



OBSERVATIONS

- Multi wavelengths + resolution :
  e-ELT, ATHENA, SPIROU …