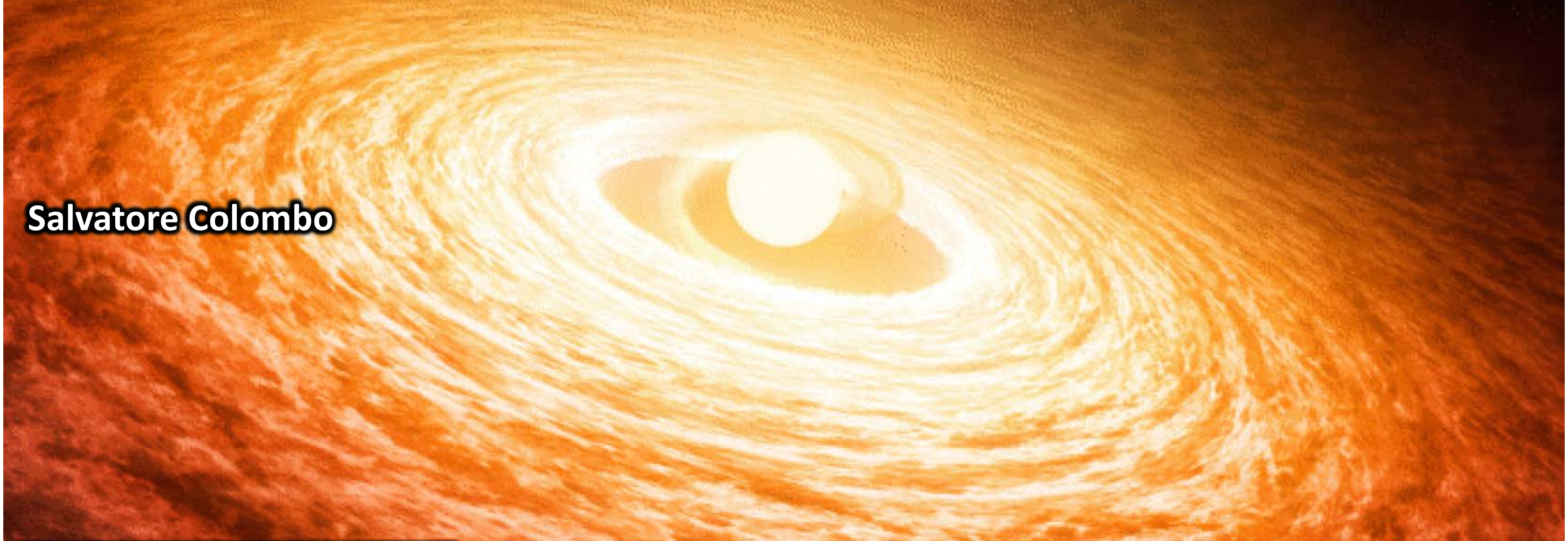
Radiation hydrodynamics modeling of accretion on classical T Tauri Stars



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PNPS Programme National de Physique Stellaire
CNRS INSU Observer & comprendre

Radiation Hydrodynamics Modeling of accretion on Classical T Tauri Stars

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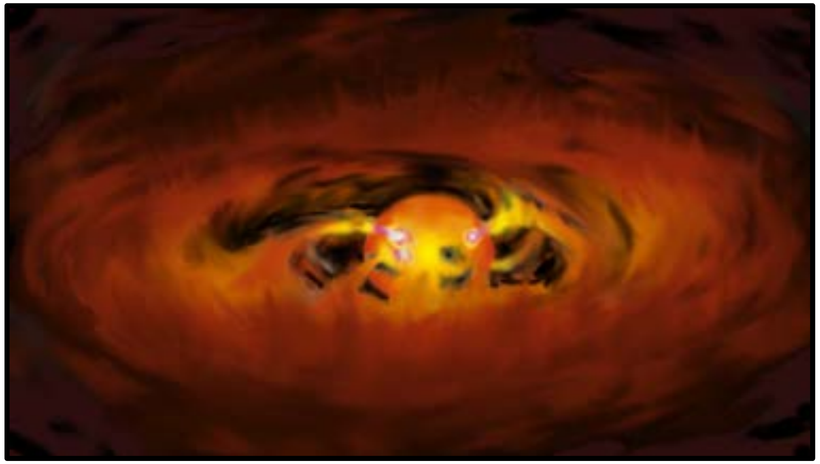
Colombo et al. (2019 a): Colombo, Ibgui, Orlando, Rodriguez et al. "Non-LTE radiation hydrodynamics in PLUTO", A&A, 631, A41, 2019

Colombo et al. (2019 b): Colombo, Ibgui, Orlando, Rodriguez et al. "Effects of radiation in accretion regions of classical T Tauri stars. Pre-heating of accretion column in non-LTE regime", A&A, 631, A41, 2019

Outline



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1) Accretion on Classical T Tauri Stars (CTTSs).
   Why radiation feedback ?
   Why non-LTE radiation ?

2) non-LTE radiation hydrodynamics (RHD) in PLUTO

3) our model of non-LTE RHD accretion on a CTTS

4) Influence of accretion conditions on the radiation feedback

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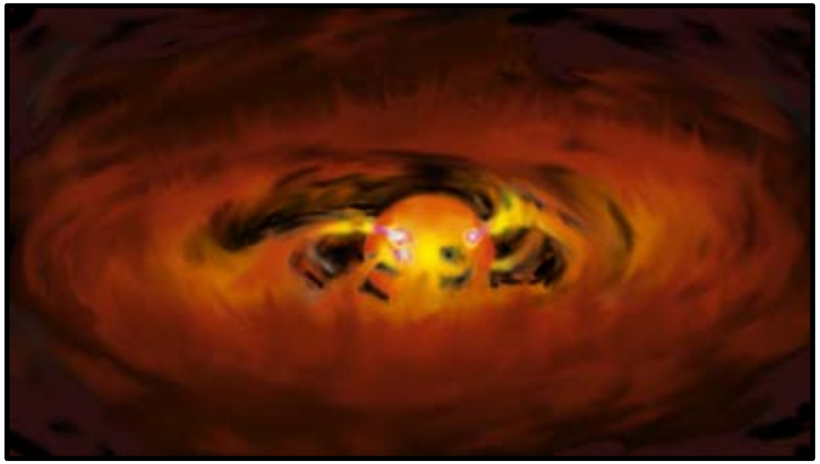
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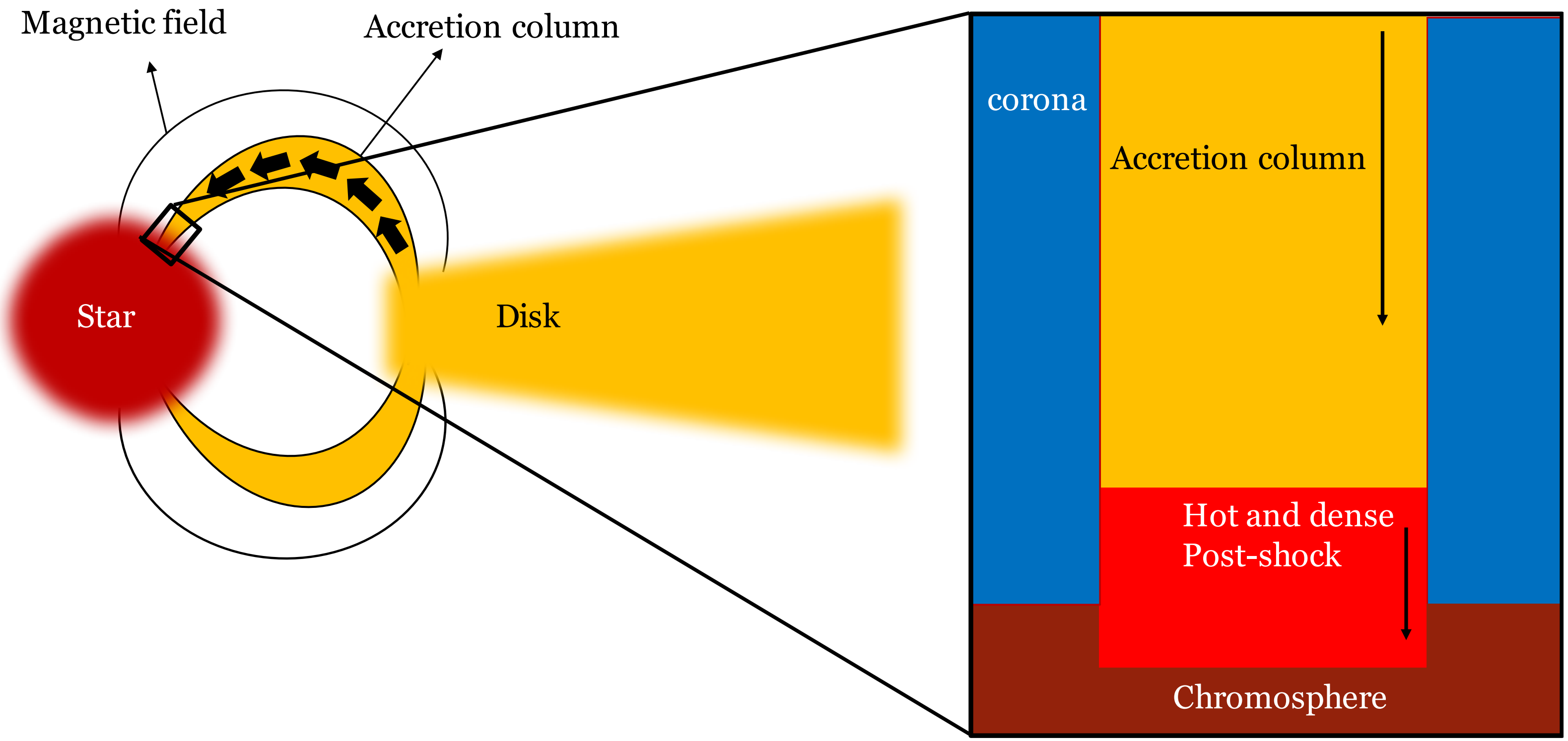
Accretion on Classical T Tauri Stars



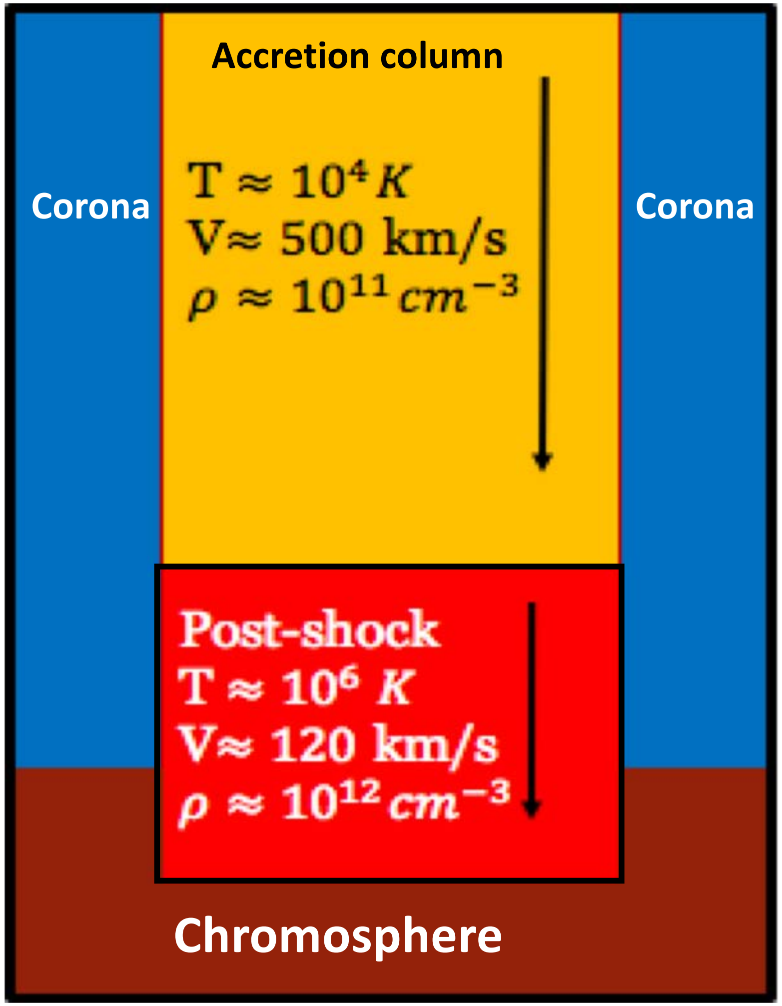
State of the art

Several model developed in the last 10 years (Sacco et al. 2008, Orlando et al, 2010, 2013, Matsakos et al. 2013, Colombo et al. 2016):

- 1D, 2D, 3D, HD/MHD
- Radiative losses from optically thin plasma
- NO radiative GAIN from matter

Results:

- Dynamics
- Stability and structure of the post-shock plasma
- Comparison with observations

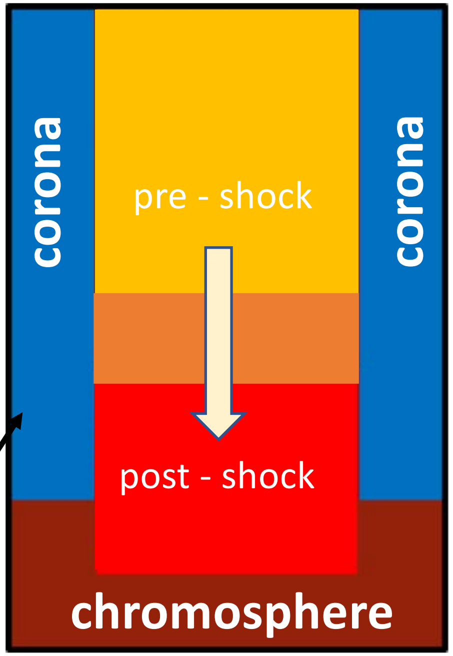


Why radiation feedback?

- Optically **thin** and **thick** plasma components coexist.

- The impact region emits in X-ray. The chromosphere around and the downfalling plasma above may be thick at these wavelengths (Bonito et al 2014, Revet et al. 2017)

The radiation may heat up the plasma before the shock forming a **precursor region** (Costa et al. 2017) emitting in UV



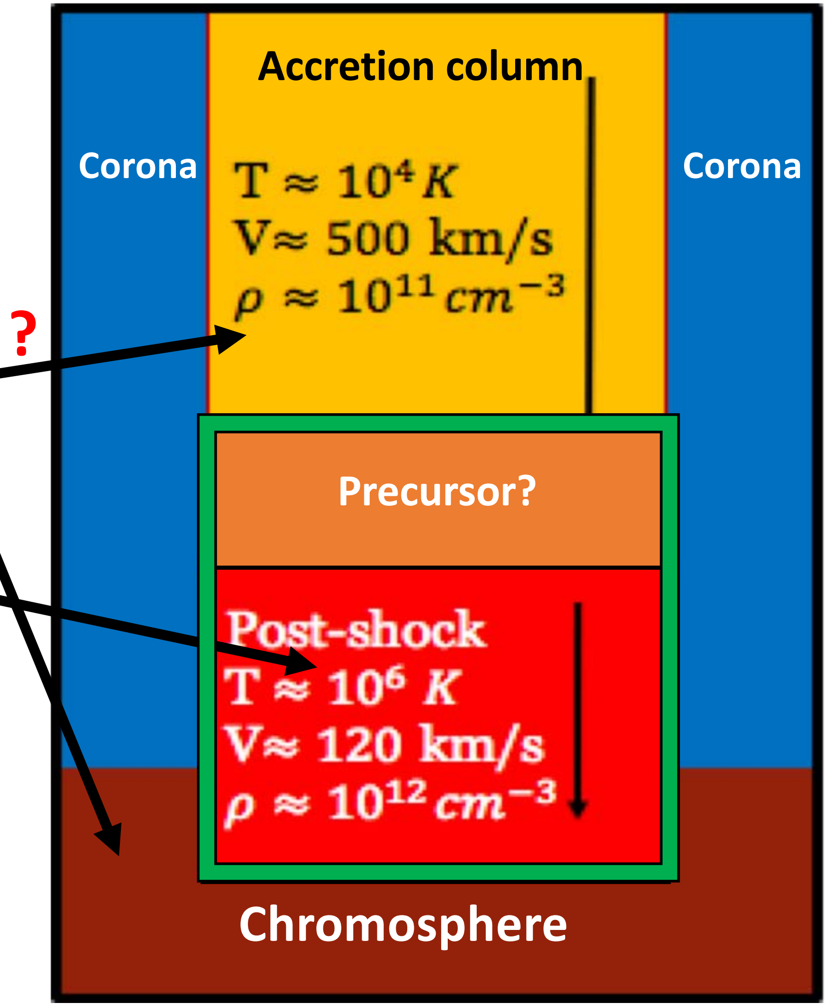
We need non-LTE

- The post-shock region is in **non-LTE**

- (emissivities, opacities)$_{NLTE}$ **Optically thick**

  $\neq$ (atomic models R. Rodriguez+ 2018)

  (emissivities, opacities)$_{LTE}$ **Optically thin**



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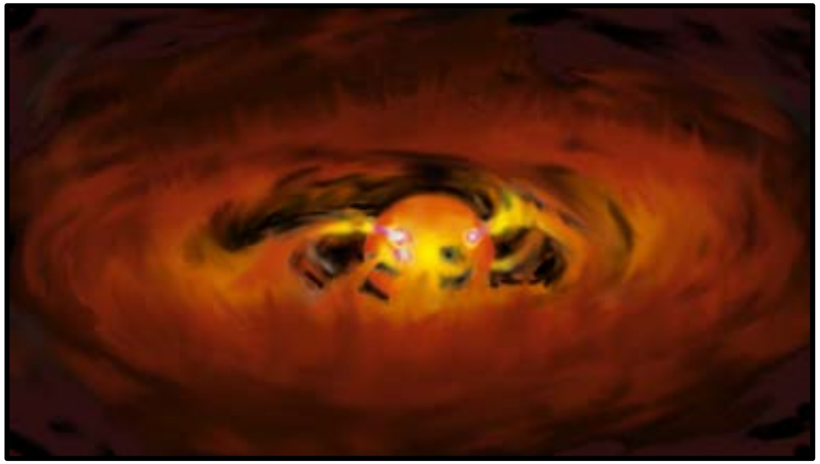

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Radiation hydrodynamics in the PLUTO code

- 3D Radiation module implemented in PLUTO by Kolb et al. (2013)
- Local Thermodynamic Equilibrium (LTE)
- Flux Limited Diffusion (FLD)

The non-LTE RHD equations

$$\frac{\partial \rho}{\partial t} + \boldsymbol{\nabla} \cdot (\rho\, \boldsymbol{u}) = 0$$

$$\frac{\partial \rho \boldsymbol{u}}{\partial t} + \boldsymbol{\nabla} \cdot (\rho \boldsymbol{u}\boldsymbol{u}) + \nabla p = \rho \boldsymbol{g} + \frac{\boldsymbol{k_R \rho}}{\boldsymbol{c}} \boldsymbol{F}$$

$$\frac{\partial \epsilon}{\partial t} + \boldsymbol{\nabla} \cdot [\,(\epsilon + p)\, \boldsymbol{u}\,] = \rho \boldsymbol{u} \cdot \boldsymbol{g} + \frac{\boldsymbol{k_R \rho}}{\boldsymbol{c}} \boldsymbol{F} \cdot \mathbf{u} + \nabla \cdot F_c - L + k_P \rho c E$$

$$\frac{\partial E}{\partial t} + \boldsymbol{\nabla} \cdot \boldsymbol{F} = L - k_P \rho c E$$

$$p = \rho \frac{k_B T}{\mu m_H} \qquad \boldsymbol{F} = -\lambda \frac{c}{k_R \rho} \nabla E$$

$$\epsilon = e + \frac{1}{2} \rho \boldsymbol{u}^2 \qquad e = \rho c_V T$$

The model in PLUTO (Colombo et al. 2019 a) takes into account the :

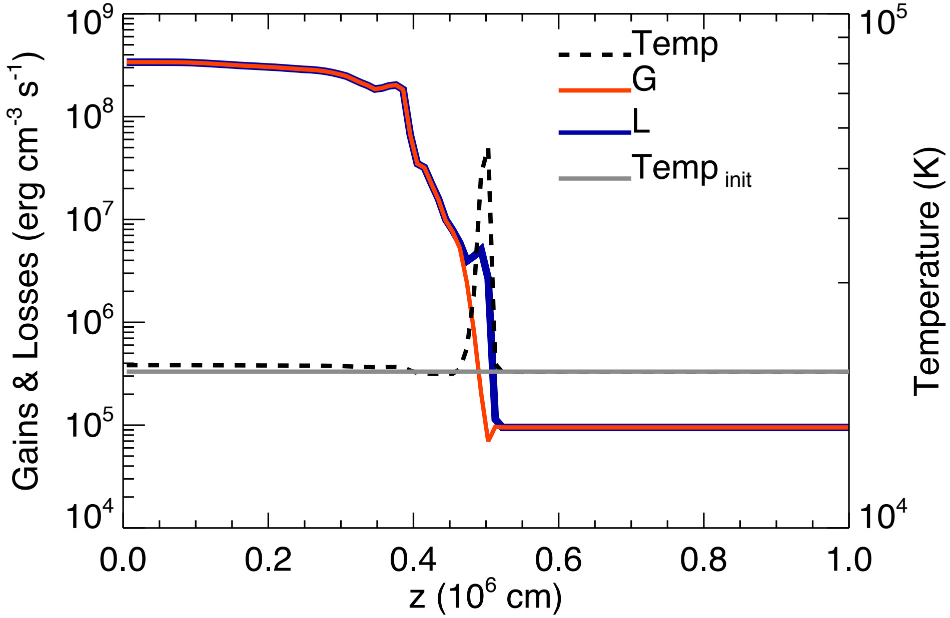
- Gravity
- Thermal conduction
- Non-LTE radiation effects:
  - Gain of radiation energy by matter
  - Loss of radiation energy by matter

$\boldsymbol{k_P}$, $\boldsymbol{k_R}$, and $\boldsymbol{L}$ databases are calculated in a **non-LTE** regime (Rodriguez, R. et al. 2018)

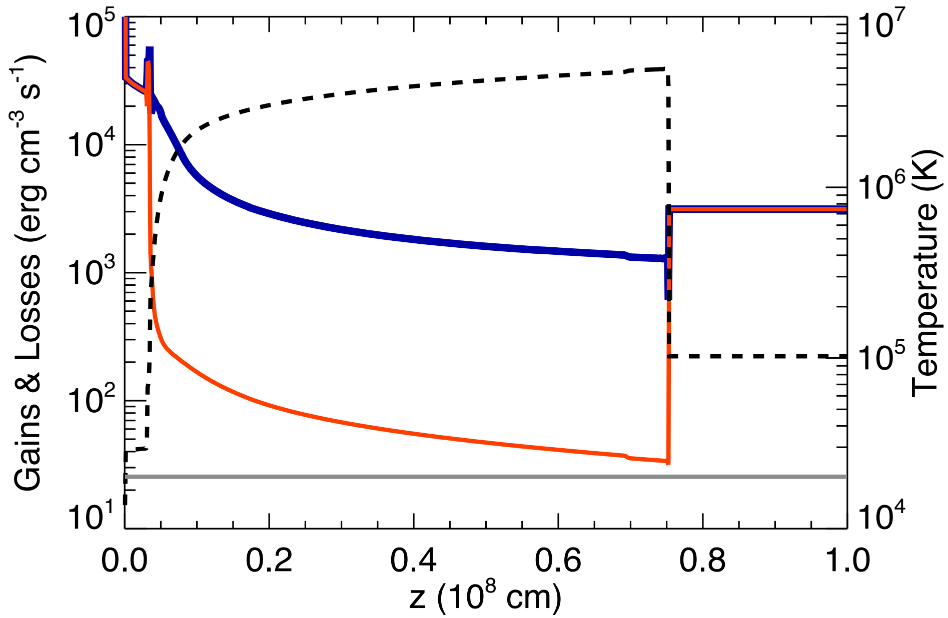
LTE vs non-LTE

Colombo et al., 2019a

LTE



Non-LTE



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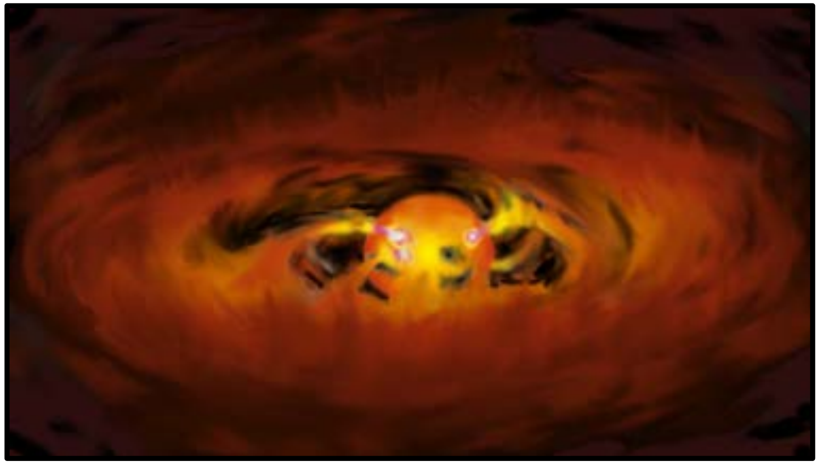

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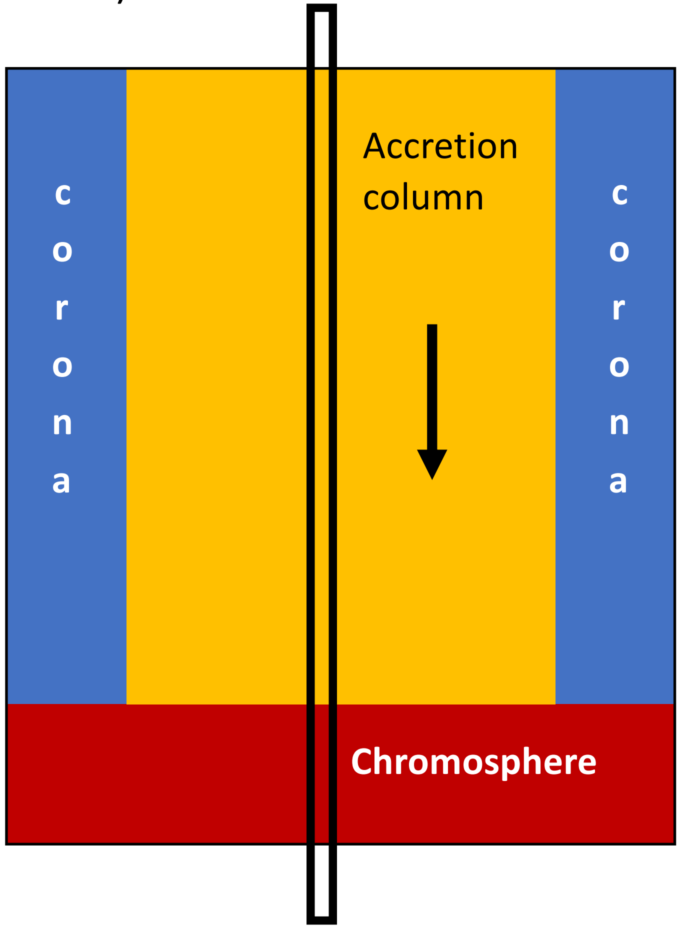
The accretion model

Colombo et al. (2019b)

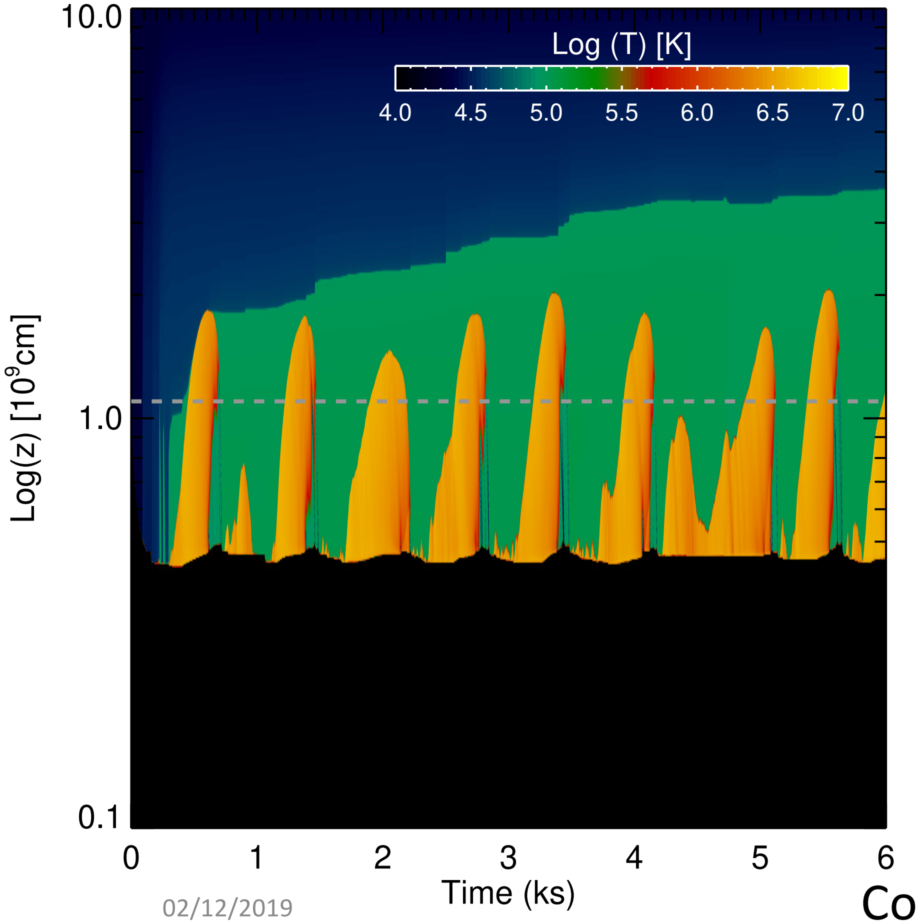
- RHD quasi-1D model ($\beta \ll 1$)
- Isothermal chromosphere $\mathrm{T} = 2{\times}10^4 K$
- Accretion column density $n = 10^{11}$ cm^{-3}
- Impact velocity 500 km/s



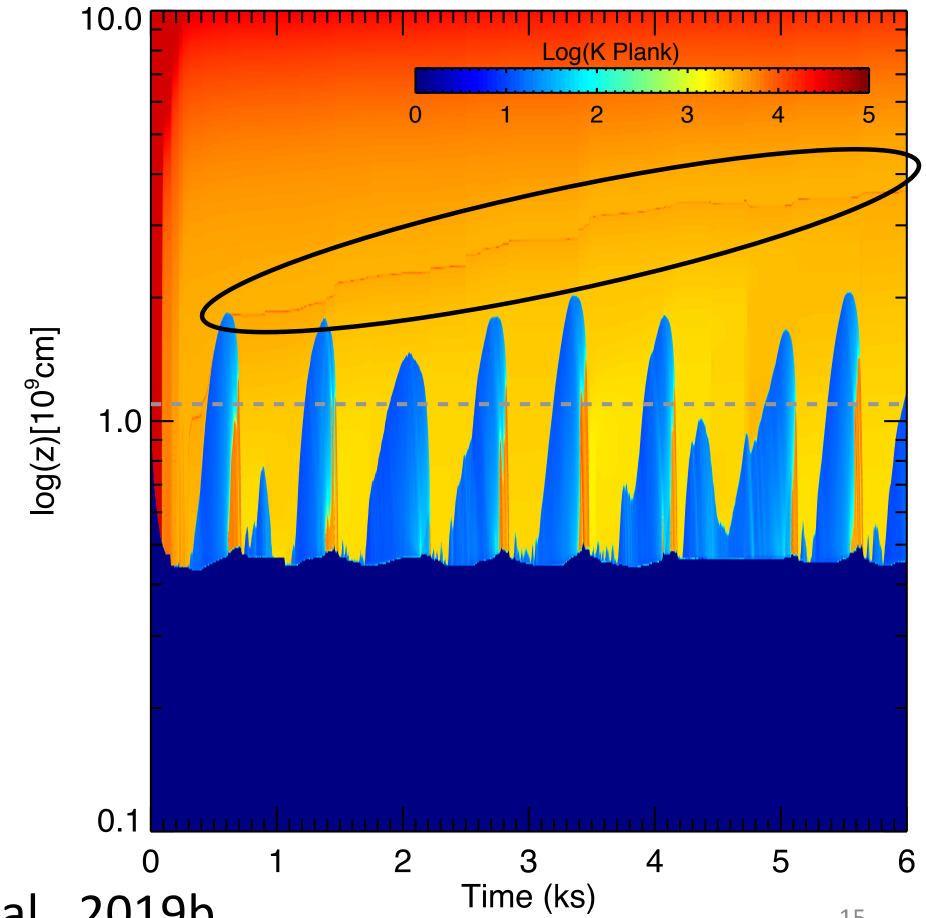
Helium effects

$\mathbf{Gain} = k_p\, \rho\, c\, E$

Temperature (K)



Planck opacity (cm^2 g^{-1})



Colombo et al., 2019b

Summary (Colombo et al. 2019a, 2019b)

Non-LTE RHD modeling of an accretion column on a CTTS :

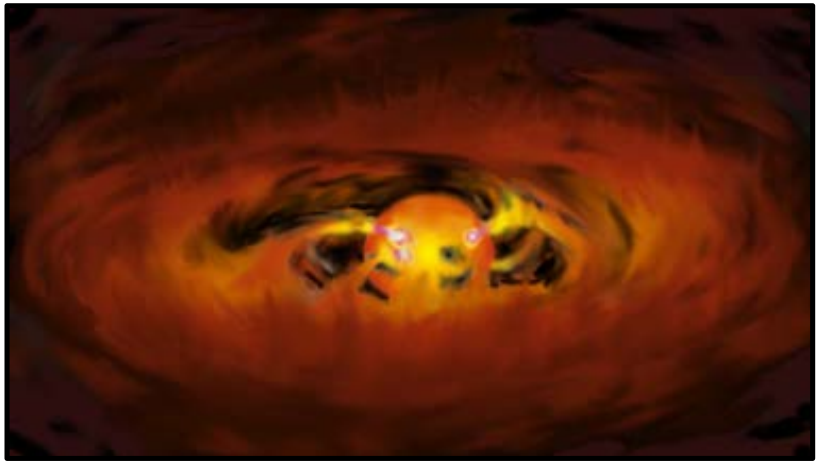
- part of the accretion shock radiation is **absorbed** by the accretion column,
- plasma heated-up : hot **precursor** T ~ 10^5 K,
- precursor: **new source of UV emission**.

☞precursor must be considered to

interpret observed UV lines;

infer **mass accretion rates** from UV observations.

Outline



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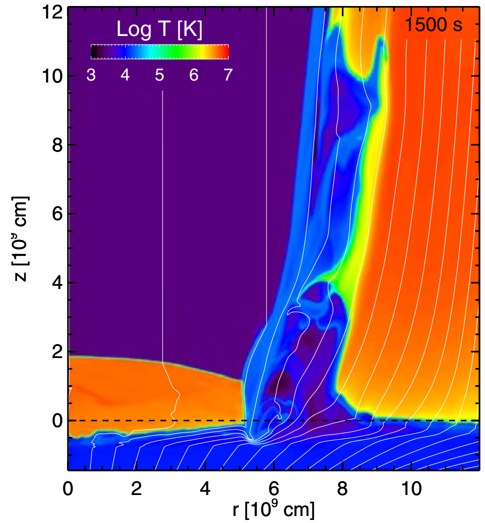
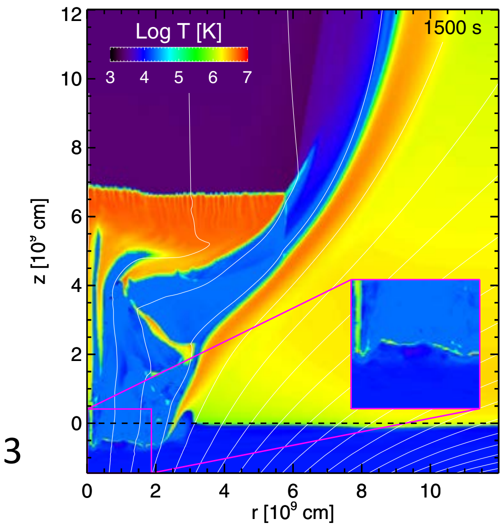
Future perspectives

- Exploring the role of radiation and magnetic field, with multi-D RMHD simulations.



- Comparison with observations
  (Synthetic Spectra)



Orlando et al. 2013
A&A 559, A127