The Meudon PDR code on MHD simulations

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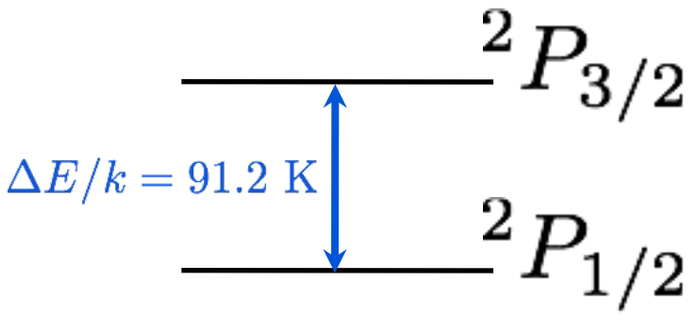
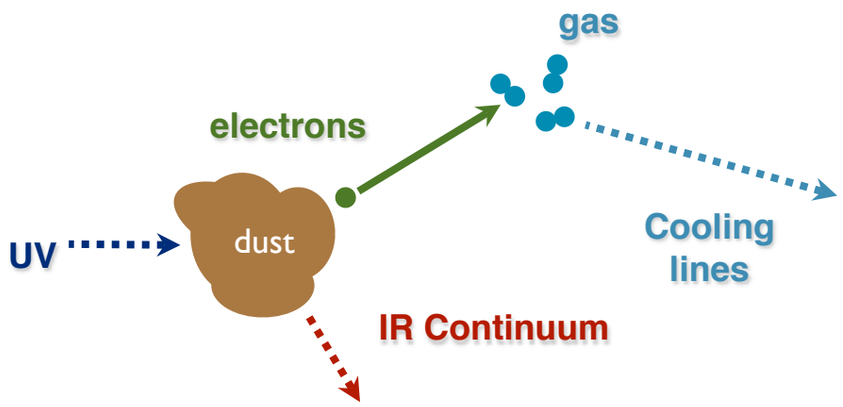
A case study : The [CII] 158 µm line



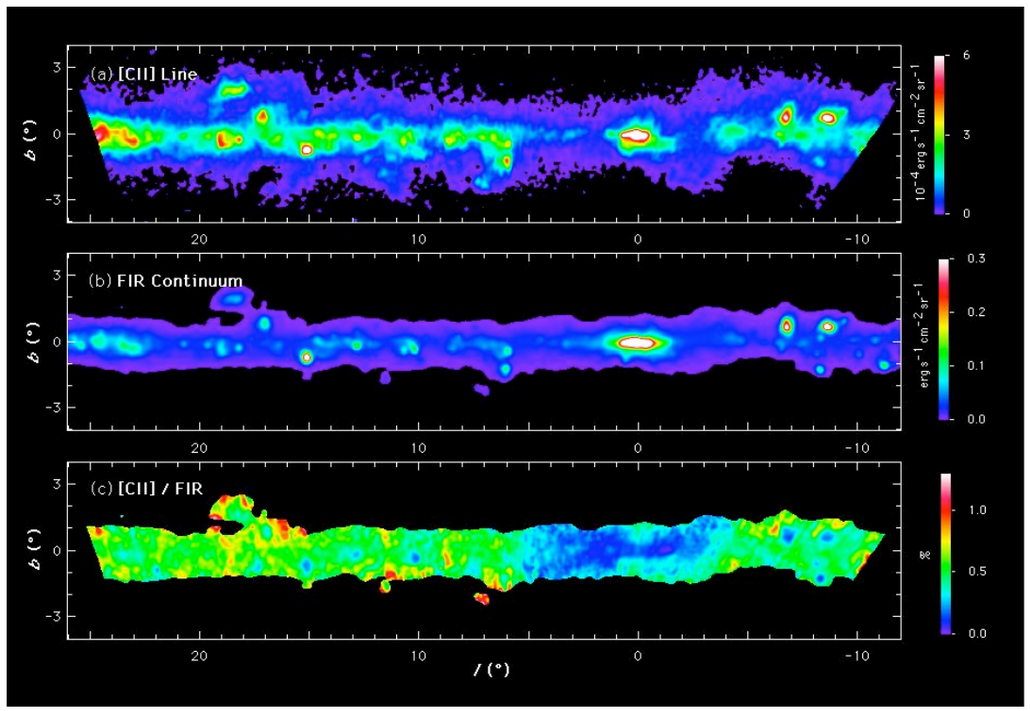
Fine structure of the ground state of C+



UV to IR energy transfer via photoelectric effect

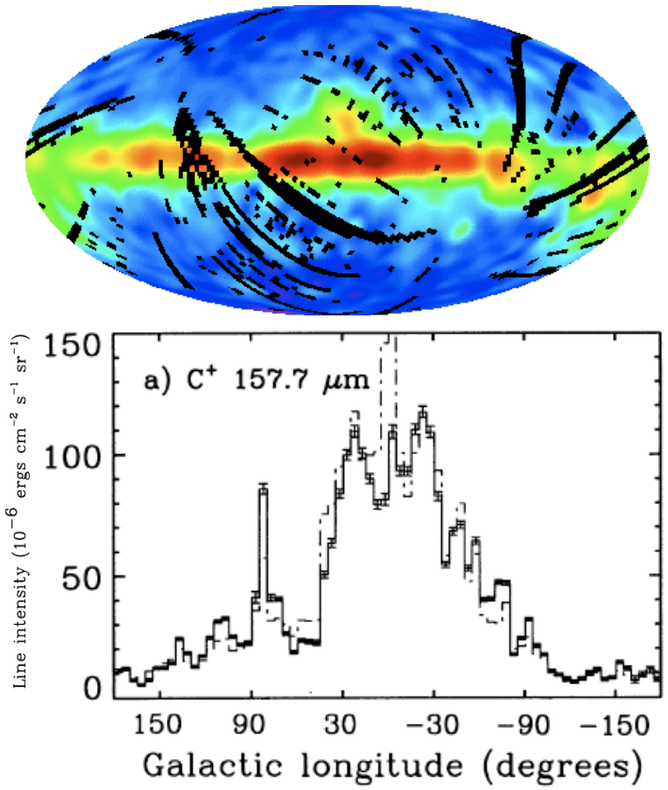
SPICA / SAFARI (Joint JAXA / ESA)

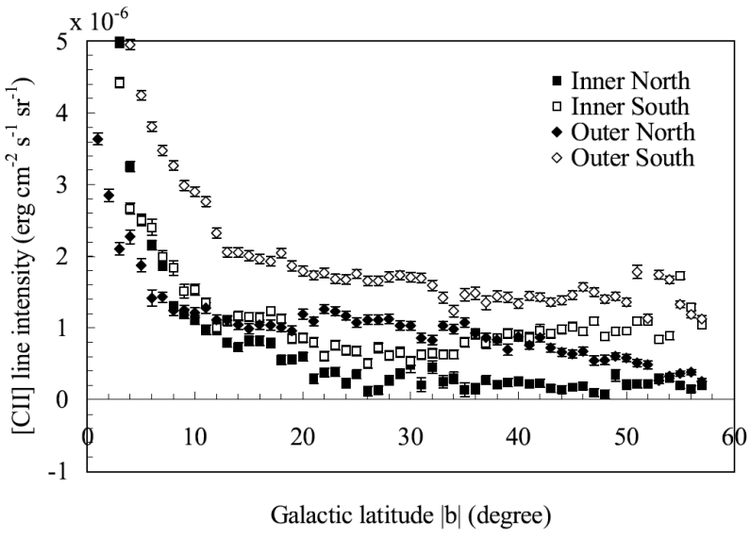
- Carbon ionization potential : 11.3 eV
- One of the dominant cooling lines of interstellar gas
- Early stages of star formation
- 0.3% of the bolometric FIR emission of the Galaxy *(Wright et al. 91)*
- Seen "everywhere"



Nakagawa et al. 98 (BICE)

Bennett et al. 94 (COBE / FIRAS)





Makiuti et al. 2002 (FILM / IRTS)

A very crude method

Technical stuff

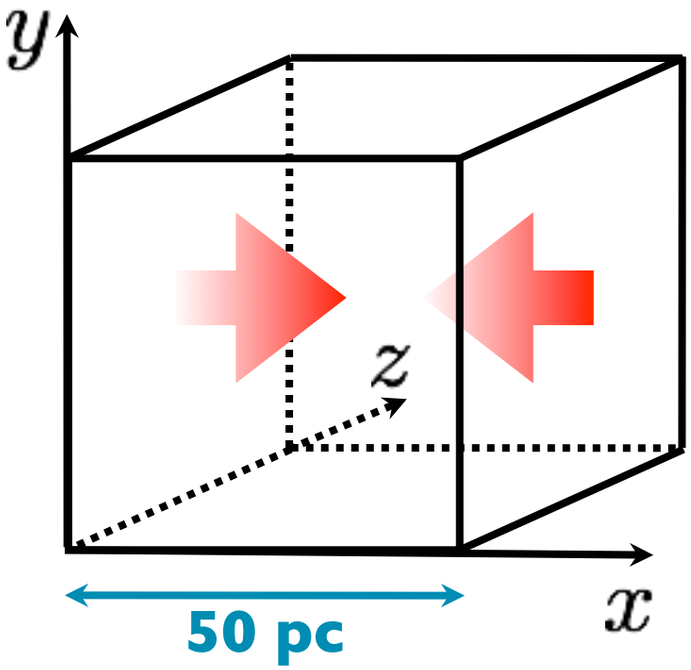
- Sample lines of sight in the MHD simulation cubes
- Extract "clouds" by applying a simple density threshold
- Use these as input density profiles in the Meudon PDR code

Scientific stuff

- Derive 158 μm line intensity vs. HI column density
- Estimate Total gas vs HI relationship
- Build line emission map from simulated cube
- Estimate time required to map the sky area covered

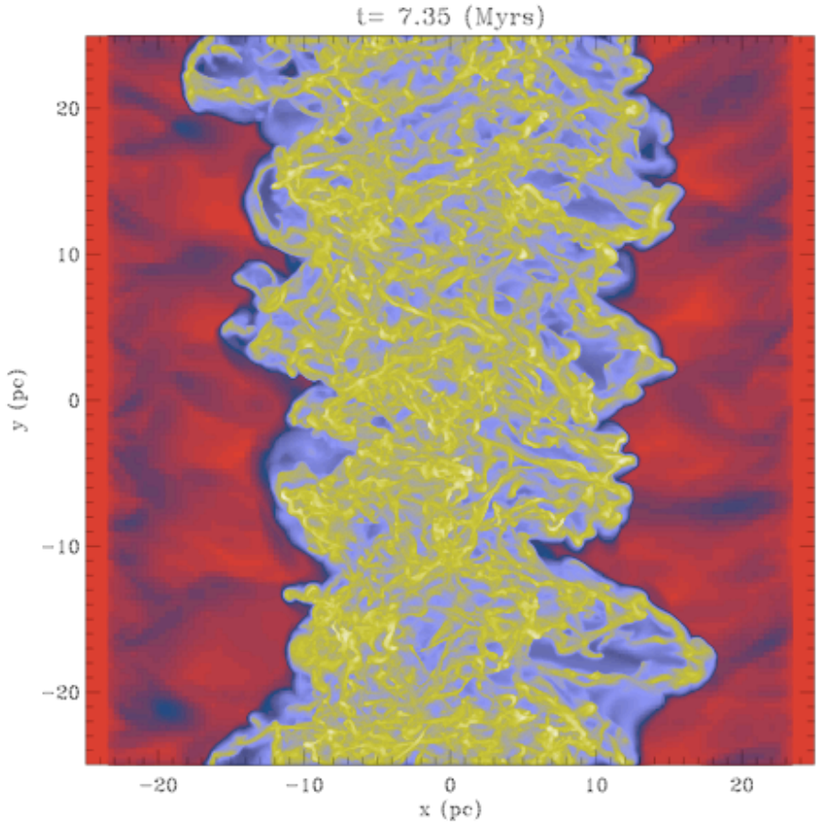
Compressible MHD turbulence simulations

Hennebelle et al. 2008

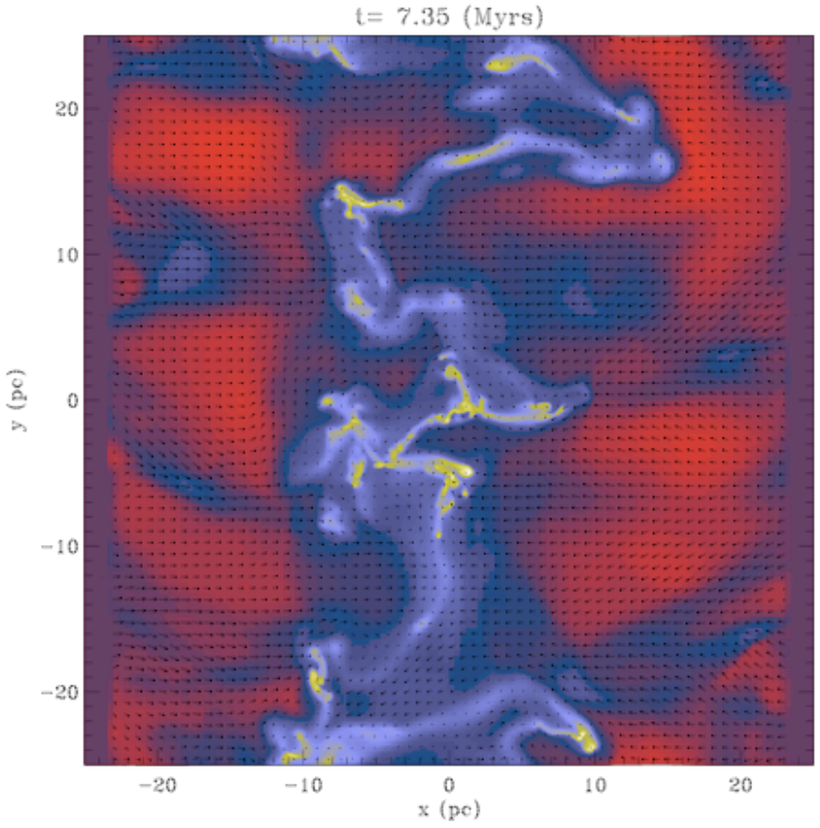


- RAMSES code (Teysier 2002, Fromang et al. 2006)
- Adaptive Mesh Refinement with up to 14 levels
- Converging flows of warm (10,000 K) atomic gas
- Periodic boundary conditions on remaining 4 sides
- Includes magnetic field, atomic cooling and self-gravity consistently
- Covers scales 0.05 pc - 50 pc
- Heavy computation : ~30,000 CPU hours ; 10 to 100 GB

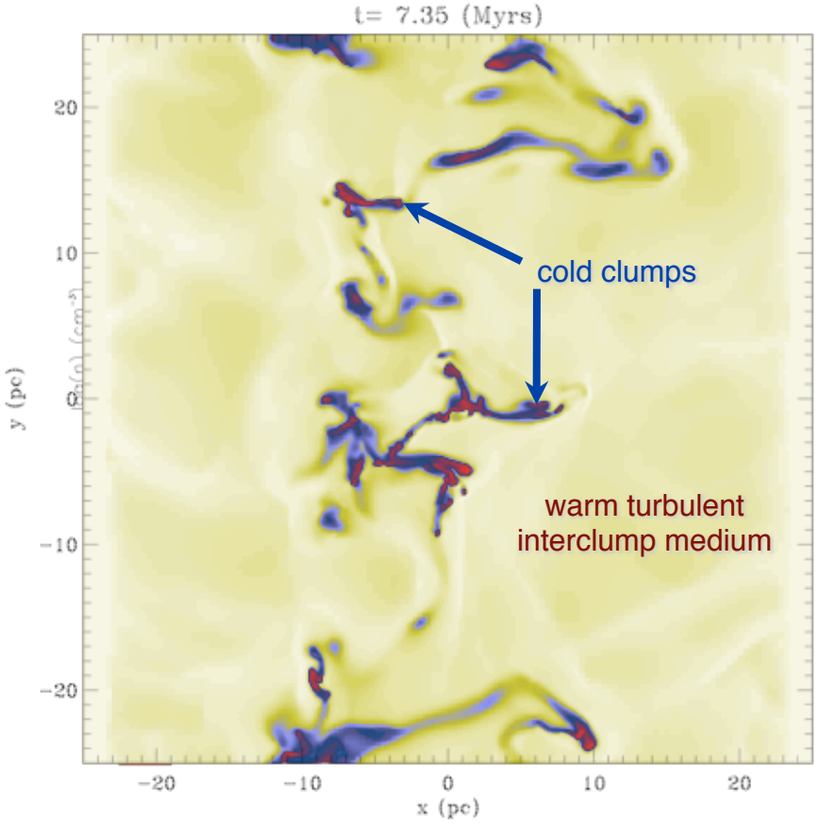
X-Y column density



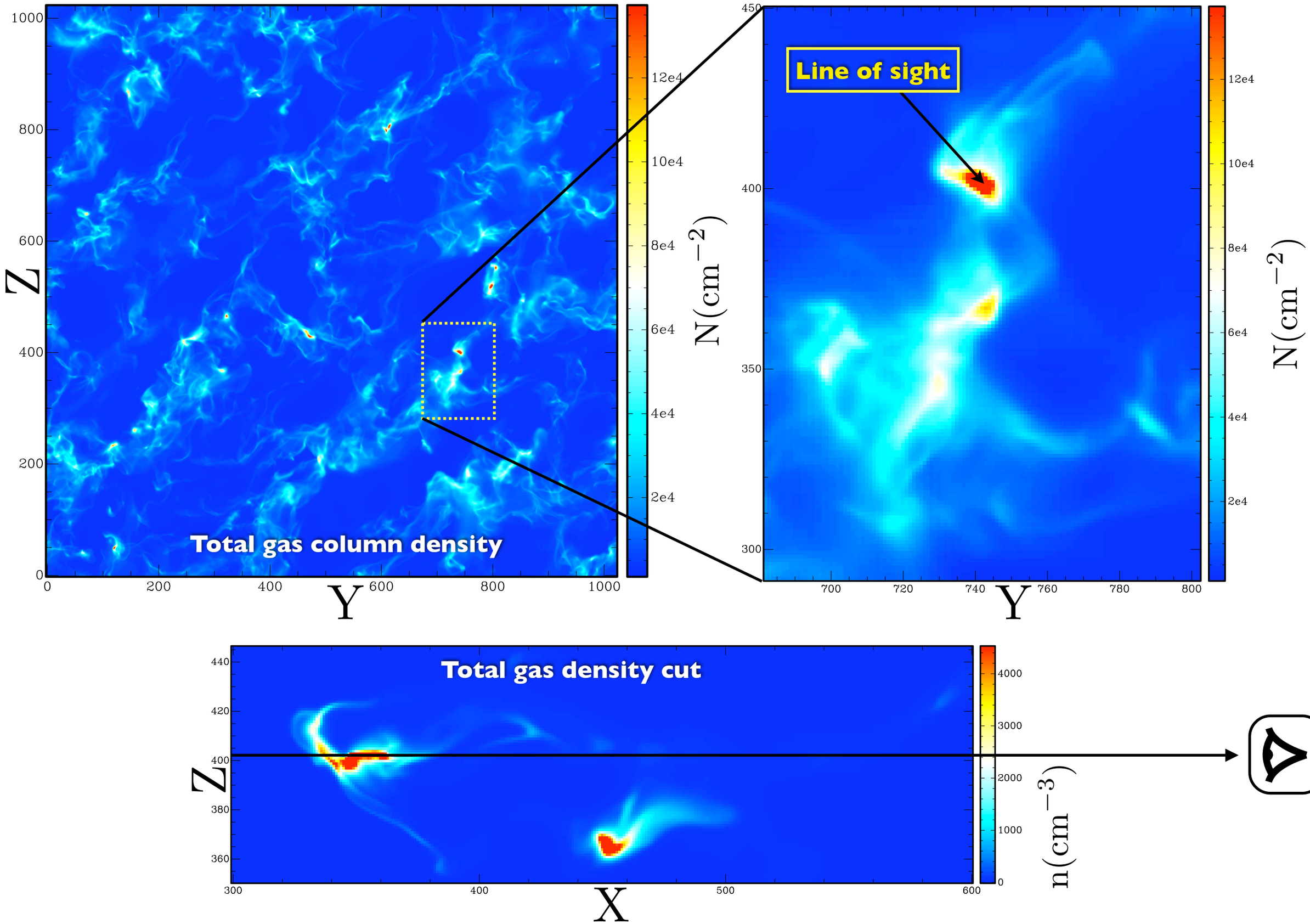
X-Y density cut



X-Y temperature cut



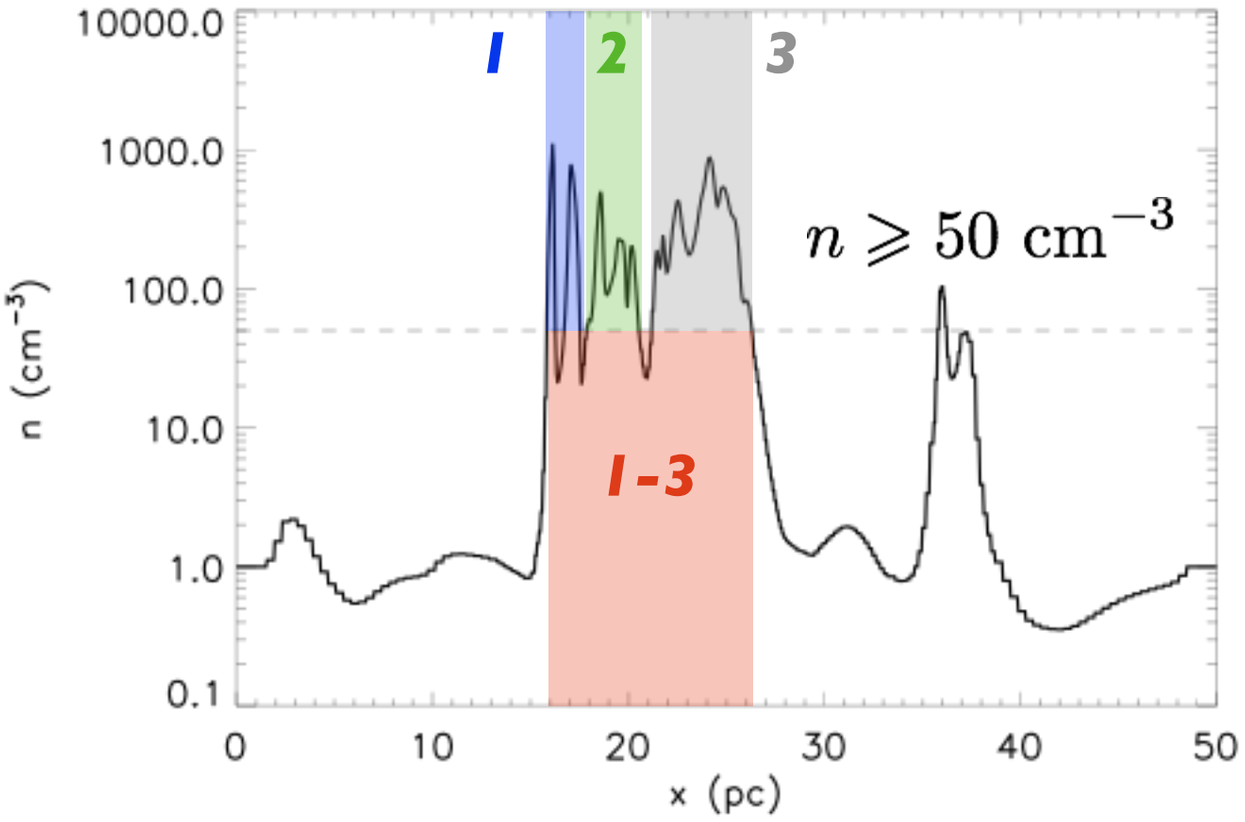
Density structures along the line of sight



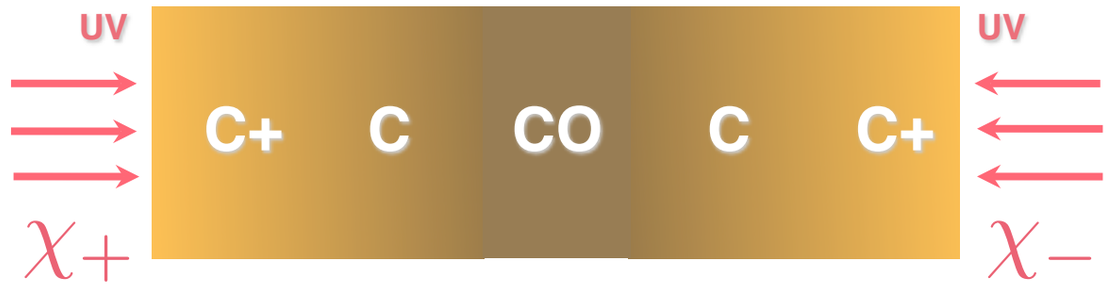
Applying the PDR code on clumps

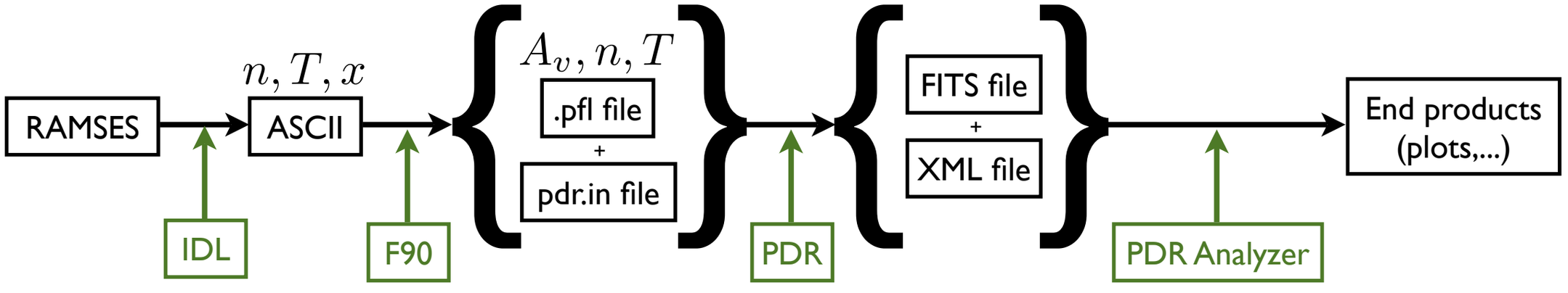
Convergence issues in low density regions → Apply code on overdensities only

Heavy computations : a few hours per "clump" → Grid computation would be ideal

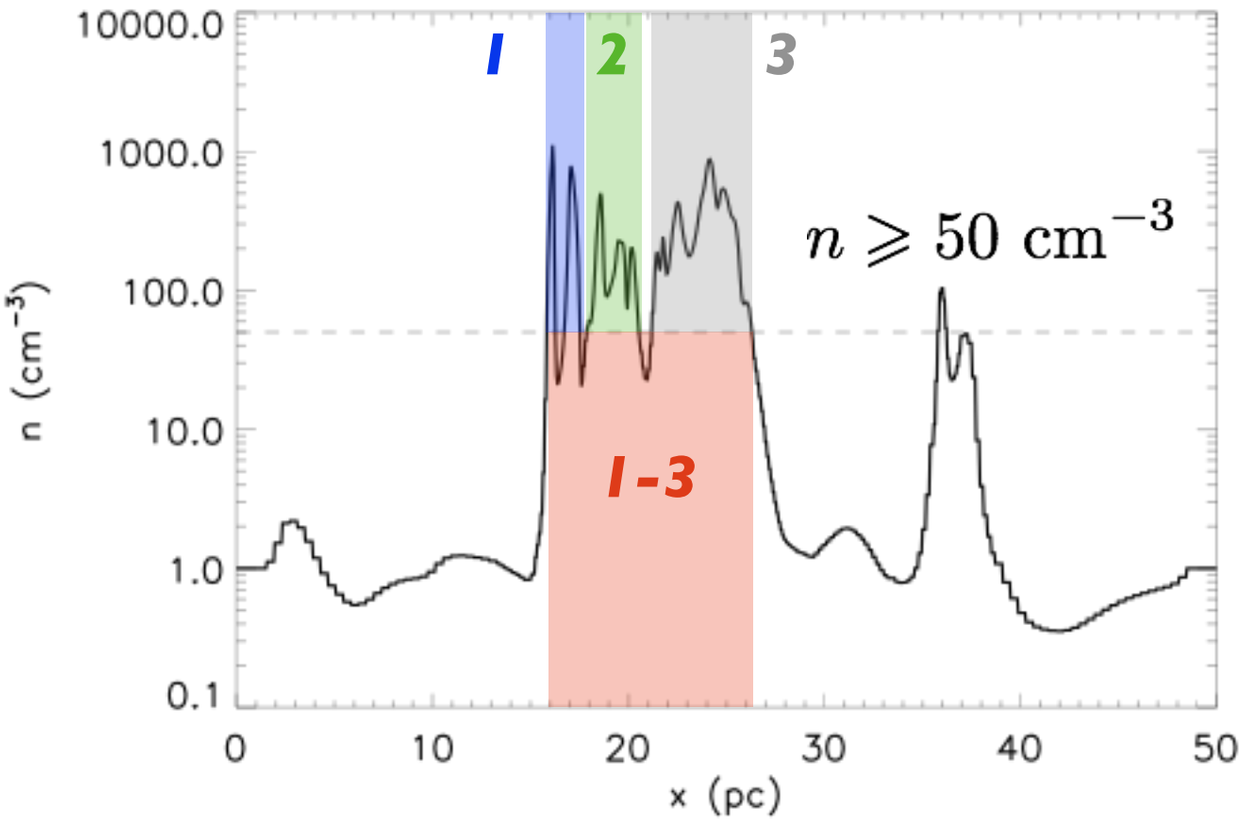


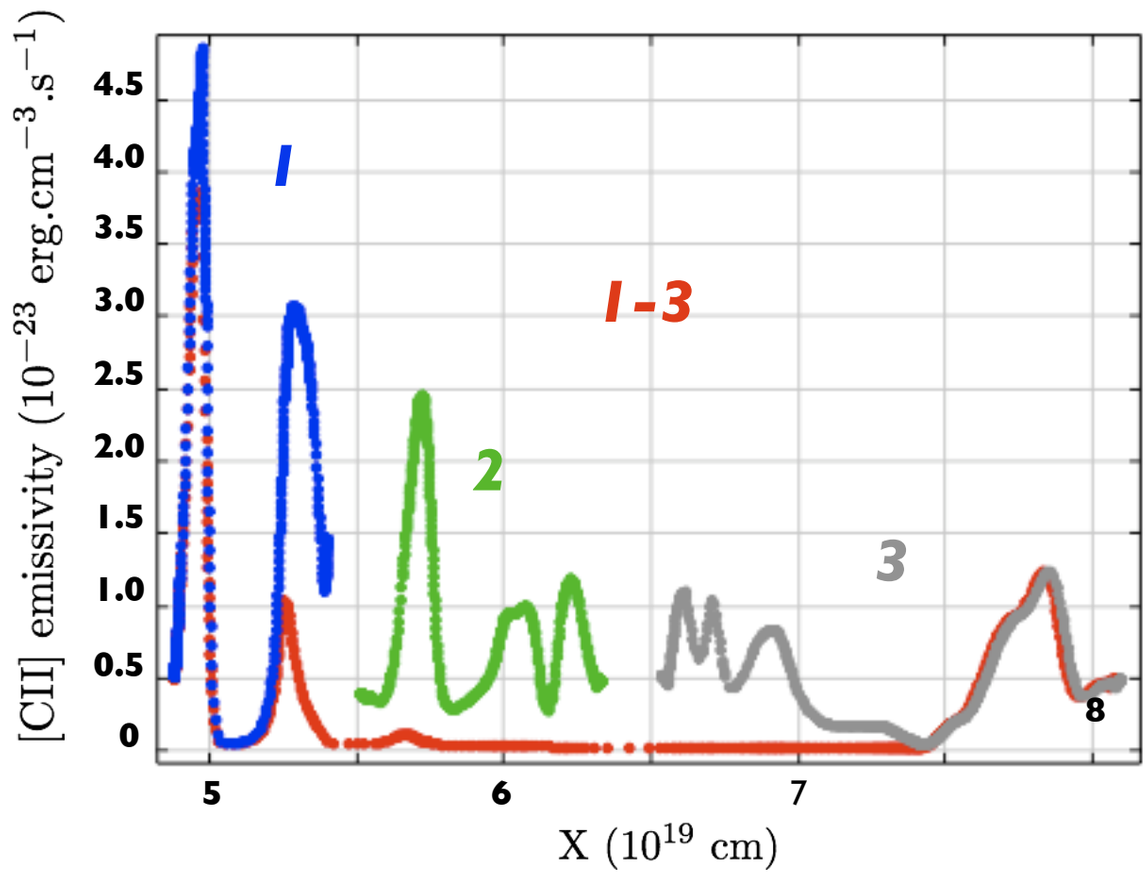
For each "clump" 1 to 3 and full 1-3 region





Simulation results





HI column density

$$N_1 + N_2 + N_3 = 3.70\ 10^{20}\mathrm{cm}^{-2}$$

$$N_{1-3} = 1.70\ 10^{20}\mathrm{cm}^{-2}$$

Integrated emissivity of the [CII] line

$$I_1 + I_2 + I_3 = 1.88\ 10^{-5}\mathrm{erg.cm}^{-2}.\mathrm{s}^{-1}.\mathrm{sr}^{-1}$$

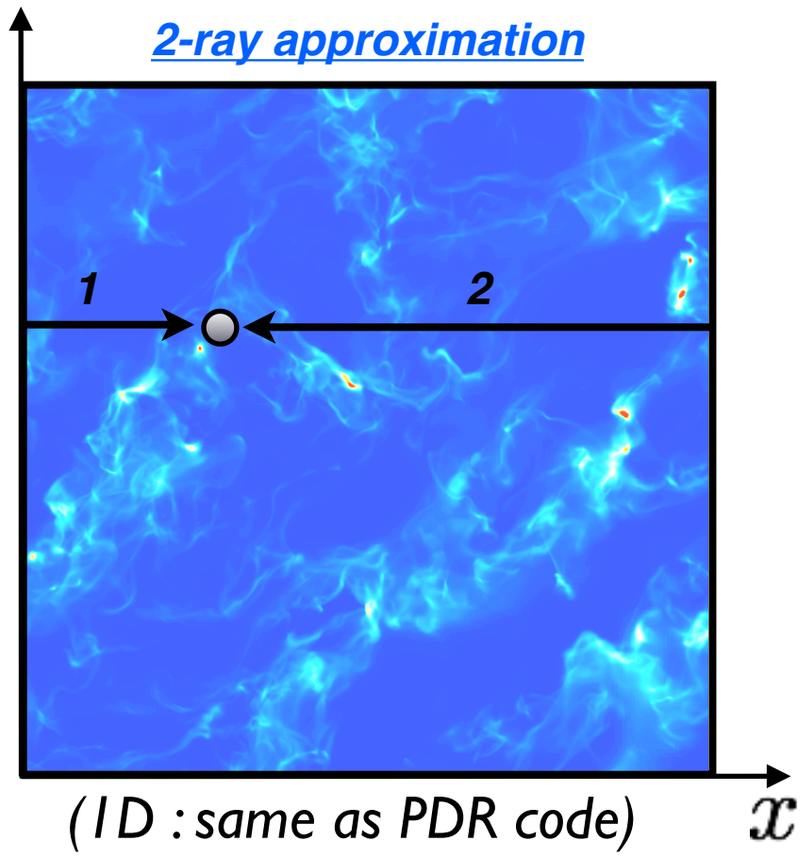
$$I_{1-3} = 7.21\ 10^{-6}\mathrm{erg.cm}^{-2}.\mathrm{s}^{-1}.\mathrm{sr}^{-1}$$

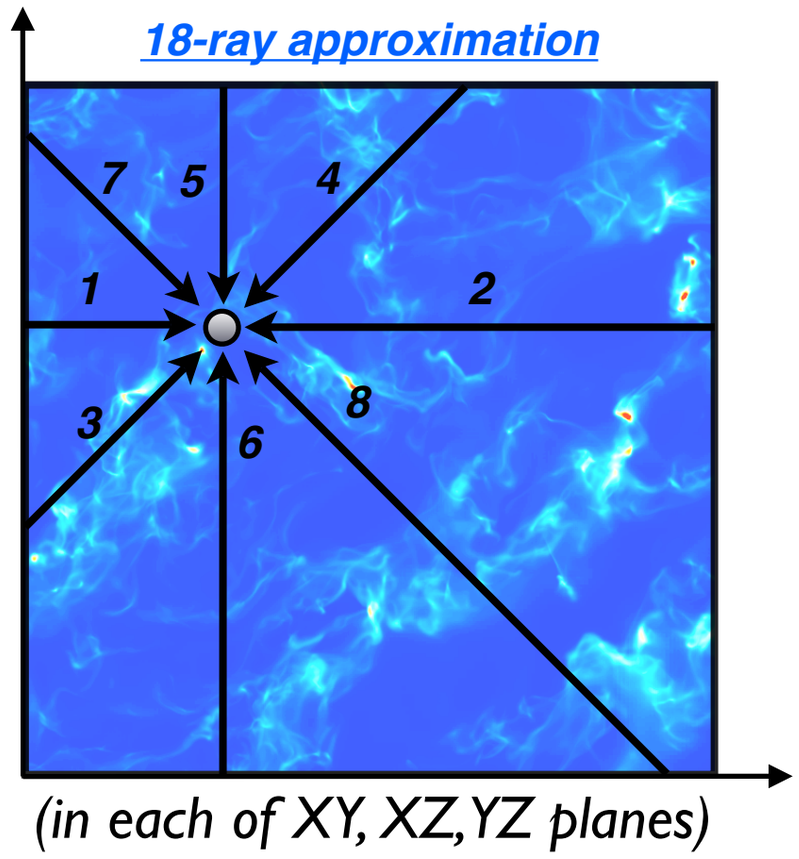
1D geometry unrealistic ⇒ 3D PDR code badly needed

Illumination of clouds

- "Fractal" nature of ISM clouds / Simulated density structures
- Each point may be illuminated from many directions
- At each point, from each line of sight, compute visual extinction
- Minimum value taken to be "actual" extinction

$$A_{v_i} = 5.3\ 10^{22} \times \left(\frac{\mathrm{N_i}}{1\ \mathrm{cm}^{-2}} \right) \quad \Rightarrow \quad A_v = \min \{ A_{v_i} \}$$

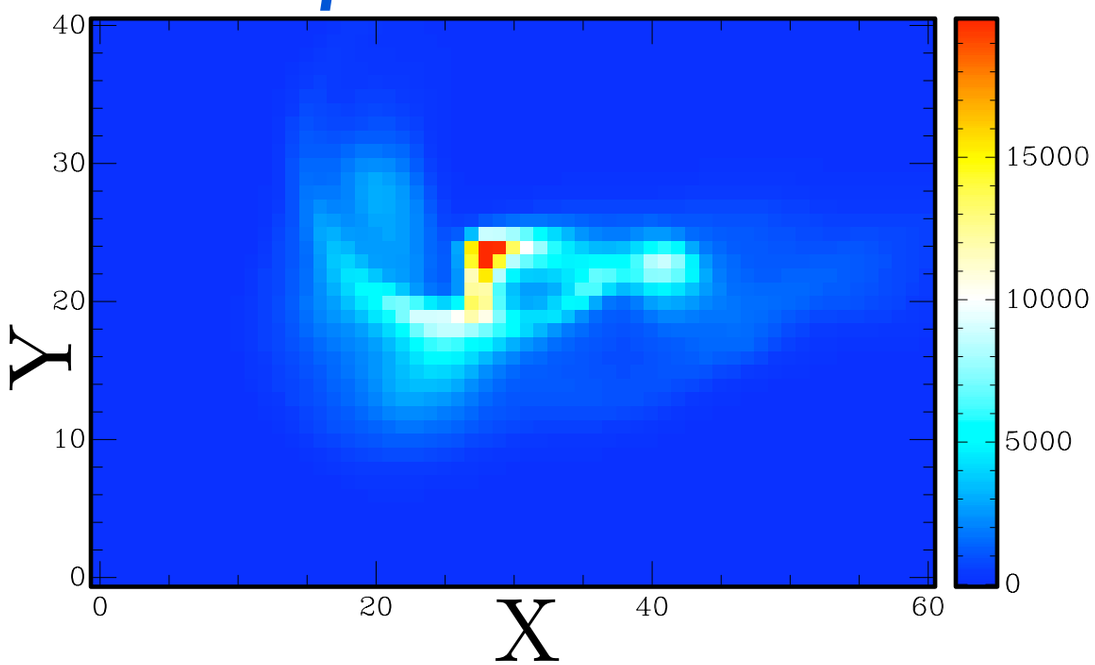


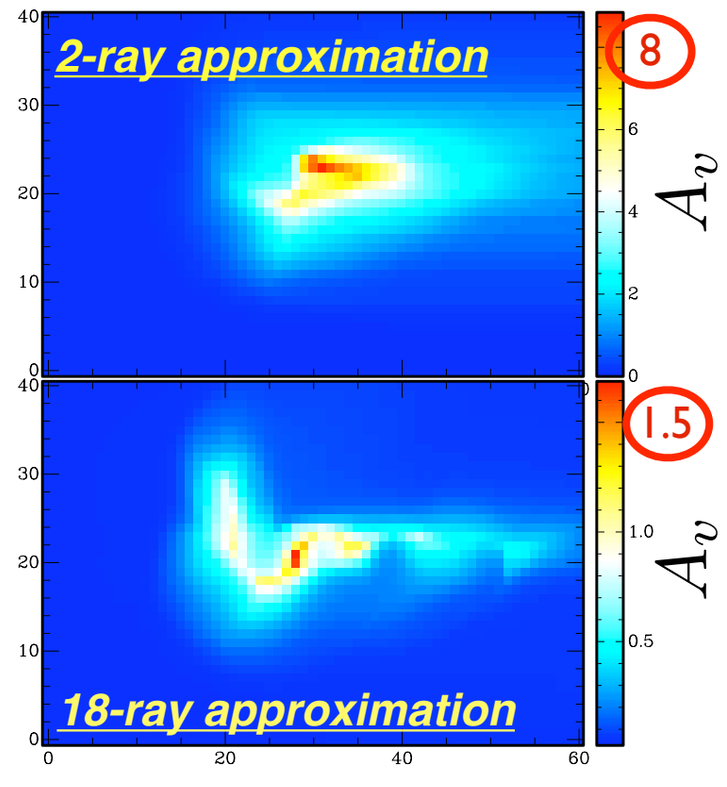


Do this as post-processing
Use it for incoming field in PDR code

Illumination of clouds : results

Example on a 2D cut

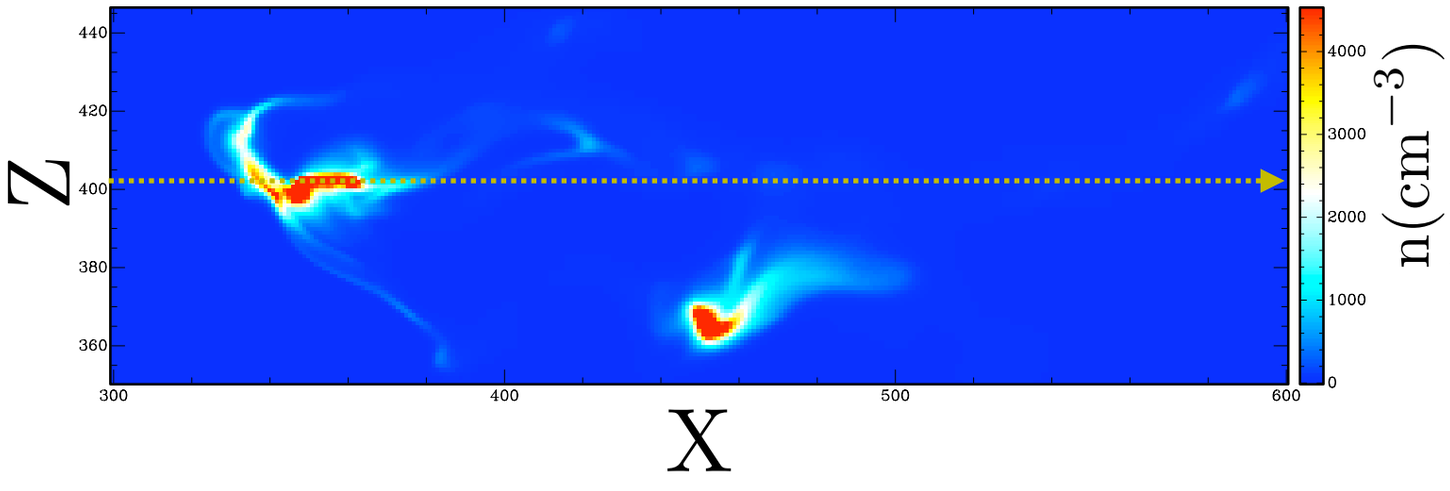




Note effect on :

- Total extinction
- Morphology

Example on a single line of sight



Exctintion up to 20 times lower