COLUMN DENSITY ESTIMATION: TREE-BASED METHOD IMPLEMENTATION

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ABSTRACT

The radiative transfer plays a crucial role in many astrophysical processes. In particular the physics of dense gas requires the accurate calculation of the UV radiation that regulates the physics and the chemistry within the molecular cloud. The numerical modelization needs the calculation of column densities in any direction for each resolution element. We present our tree-based method for estimating column densities and the attenuation factor for the UV field. This method is suitable for parallel computing and no communication is needed between different CPUs. It has been implemented into the RAMSES AMR code (Teyssier 2002). We present the results of two tests and a discussion on the accuracy and the performance of this method.
We show that the UV screening affects mainly the dense parts of molecular clouds, changing locally the Jeans mass and therefore affecting the fragmentation.

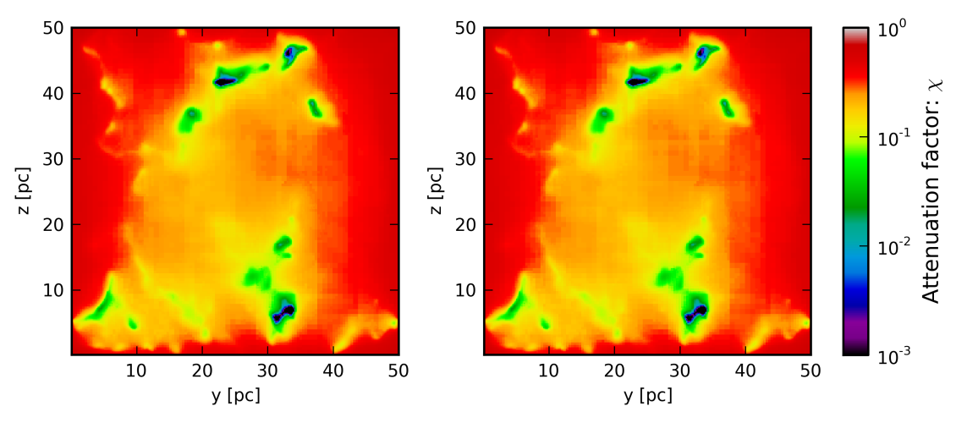
INTRODUCTION

In physical problems, in particular in the turbulent medium, the radiative problem does not have a simple solution. If we consider N resolution elements, we will have to deal with calculations of the order of $N^{5/3}$, which is extremely expensive in terms of CPU time for relatively large simulations and not practical in parallel computing. Approached methods must therefore be used. Recently some efforts have been done in this direction (Clark *et al.* 2012) .

Our tree-based method is based on the fact that any distant cell subtends a small angle and its contribution to the screening will be diluted.

PRECALCULATION MODULE

In order to optimize the calculations, we have implemented a precalculation module for the geometrical corrections based on the fact that *octs* are self-similar. We define a standard cube, knowing that for each shell there at at most 5 cells in each direction. We use up to two correction levels depending on the oct configuration. The matrix that contains the corrective factors and the boolean matrix that tells us if there is a contribution to the column density are calculated just once at the beginning of the simulation.



Extinction map calculated with the tree-based method ($7 \times 12 = 84$ directions) for a slice at the center of the box. Left: all the calculation is done *in situ*. Right: using the precalculation module.

Method	$t_{sim}/t_{w/o}$	
6 dir	1.1	
$3 \times 4 = 12$ dir	7.9	
$3 \times 4 = 12$ dir prec	**1.6**	∼ **5** times faster
$5 \times 8 = 40$ dir	15.8	
$5 \times 8 = 40$ dir prec	**2.4**	∼ **6.6** times faster
$7 \times 12 = 84$ dir	26.3	
$7 \times 12 = 84$ dir prec	**3.3**	∼ **8** times faster

CONCLUSIONS

- We have implemented a tree-based method in the AMR code RAMSES with the following advantages:

-No communication between CPUs is needed.

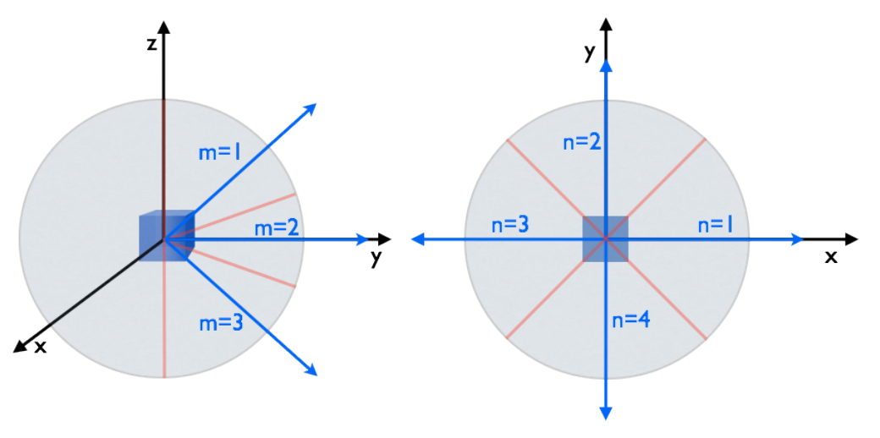
-Computational cost of order $N\log N$ (Barnes & Hut 1989).

-The code is up to 8 times faster when the precalculation module is used.

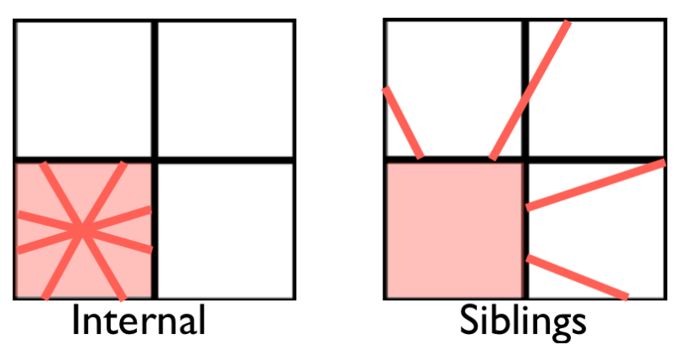
- For a realistic cloud the mean error for the column densities is $\sim 50\%$, while for the screening the difference between the reference and our estimation is better than 10%.
- The UV screening affects mainly the dense parts of the cloud, where dense cores form, protecting them from the UV heating and diminishing locally the Jeans mass.

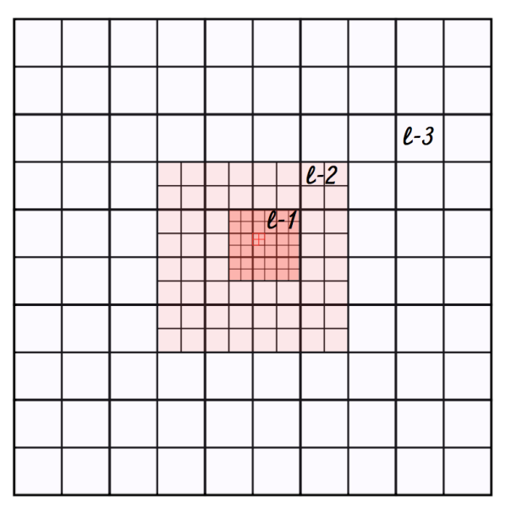
METHOD

We define directions in spherical coordinates, centered at the *target cell* where we want to estimate the screening. The discretization is done in order to cover equal solid angles.



We separate the contributions to the column density in three regions: the *target cell* itself, the sibling cells that belong to the same oct and the outer region.





For the outer region we define concentric cubic shells, where the resolution decreases with distance.

Then, as the tree structure is walked over the resolution levels, we calculate the contribution to the column density in each direction seen by any *leaf cell*.
It is important to notice that for any direction not aligned with the cartesian directions the calculation of the distance crossed through the treated cell is not trivial.

For the tests we present column density maps integrated along x, y, and z calculated with respect to the respective midplane. We present the extinction maps χ, that corresponds to mean extinction as seen by the cells in the midplanes, defined as:

$$\boxed{\chi = \langle e^{-\tau(\theta,\phi)} \rangle_{4\pi\mathrm{sr}}\ ; \qquad \tau(\theta,\phi) = \sigma N(\theta,\phi)}$$ where $\sigma = 2 \times 10^{-21}\mathrm{cm}^2$ (Draine & Bertoldi 1996).

UNIFORM SPHERICAL CLOUD

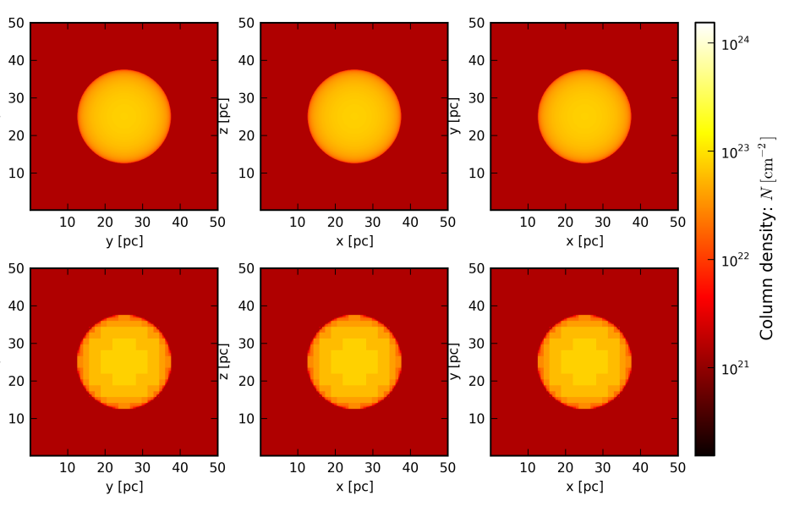


Fig1

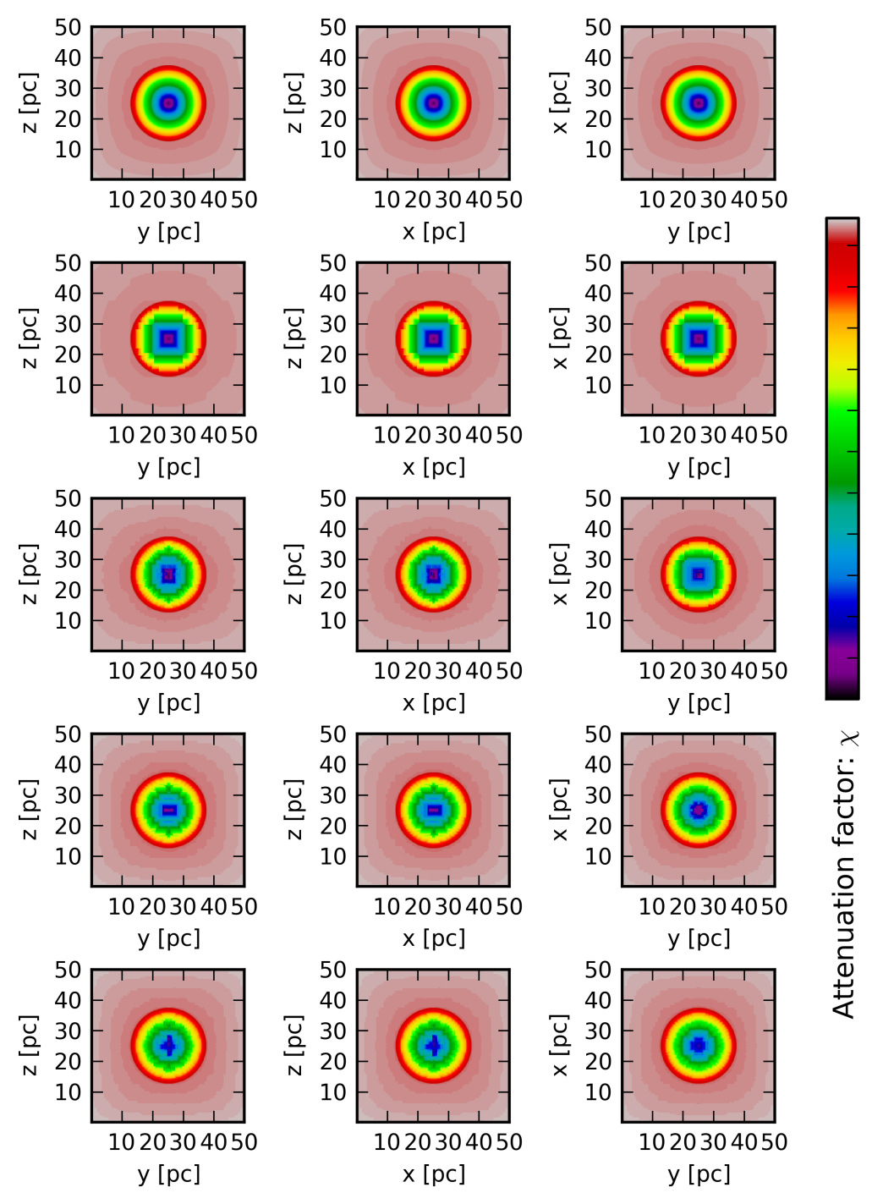


Fig 2

Fig 1: Column density maps. Top: reference calculated with a ray-tracing method. Bottom: estimation done with the tree-based method.
Fig 2: Extinction maps. From top to bottom: reference, estimation calculated with the tree-based method for 6, 12, 40 and 84 directions.

TURBULENT CLOUD

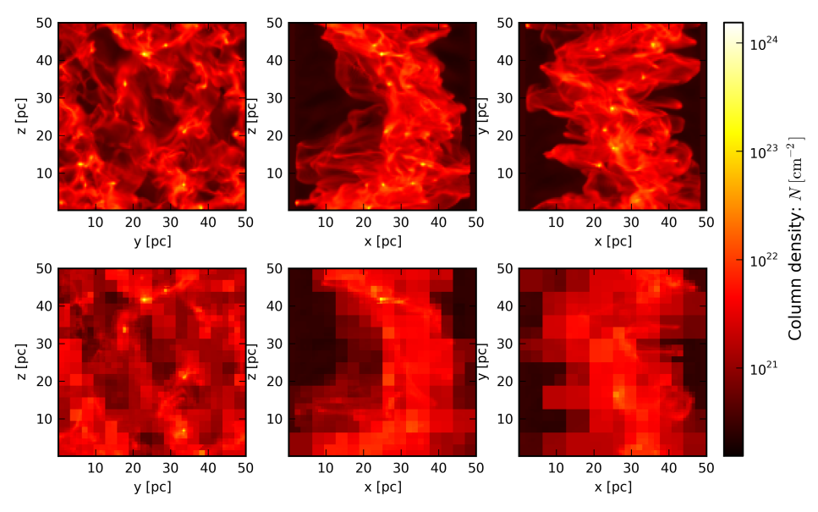


Fig3

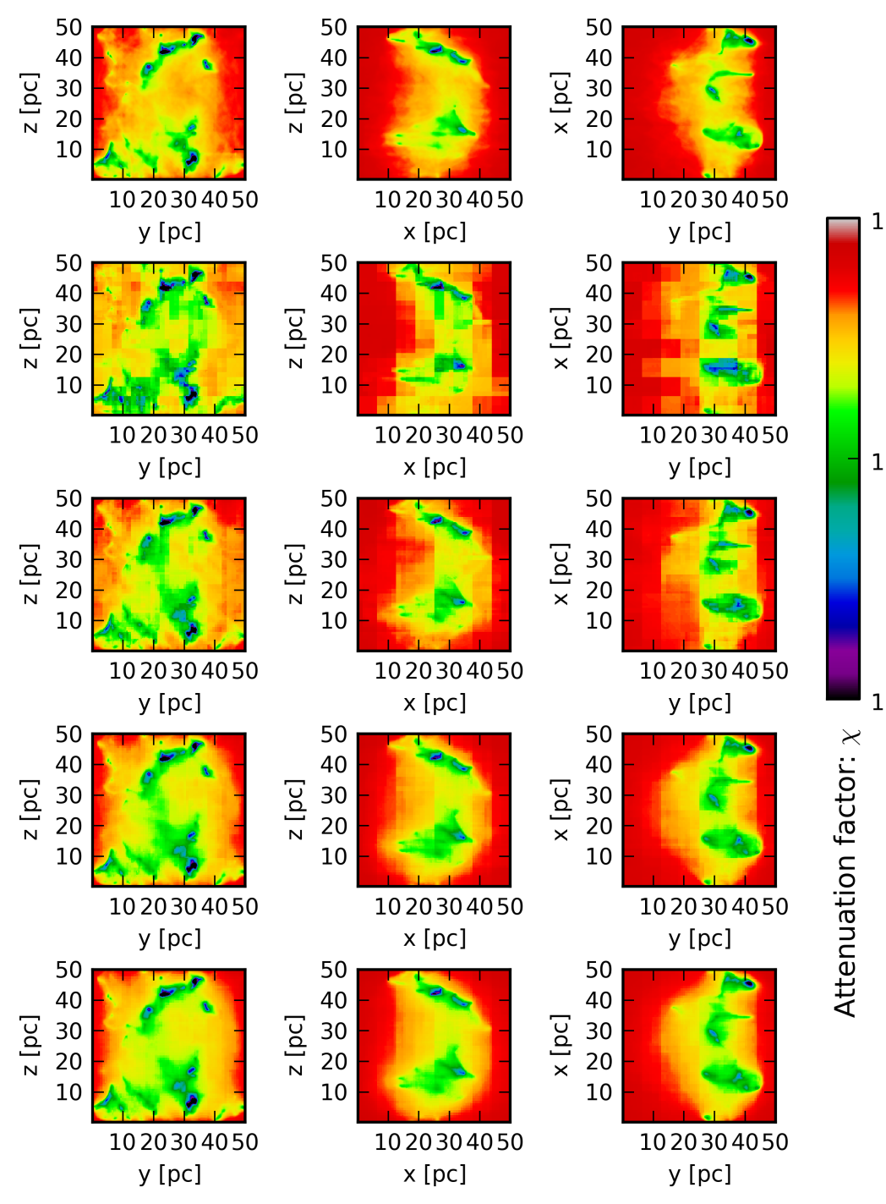
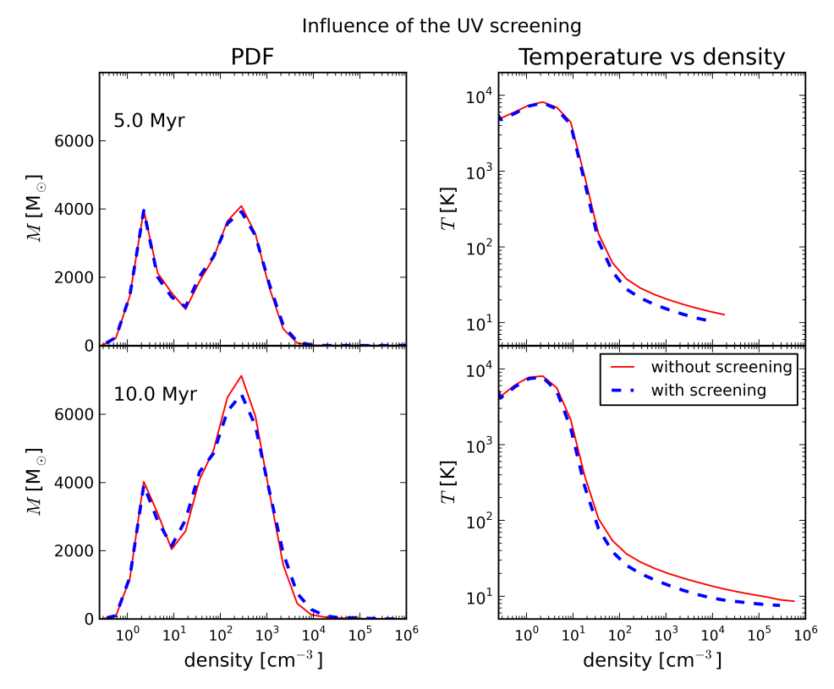


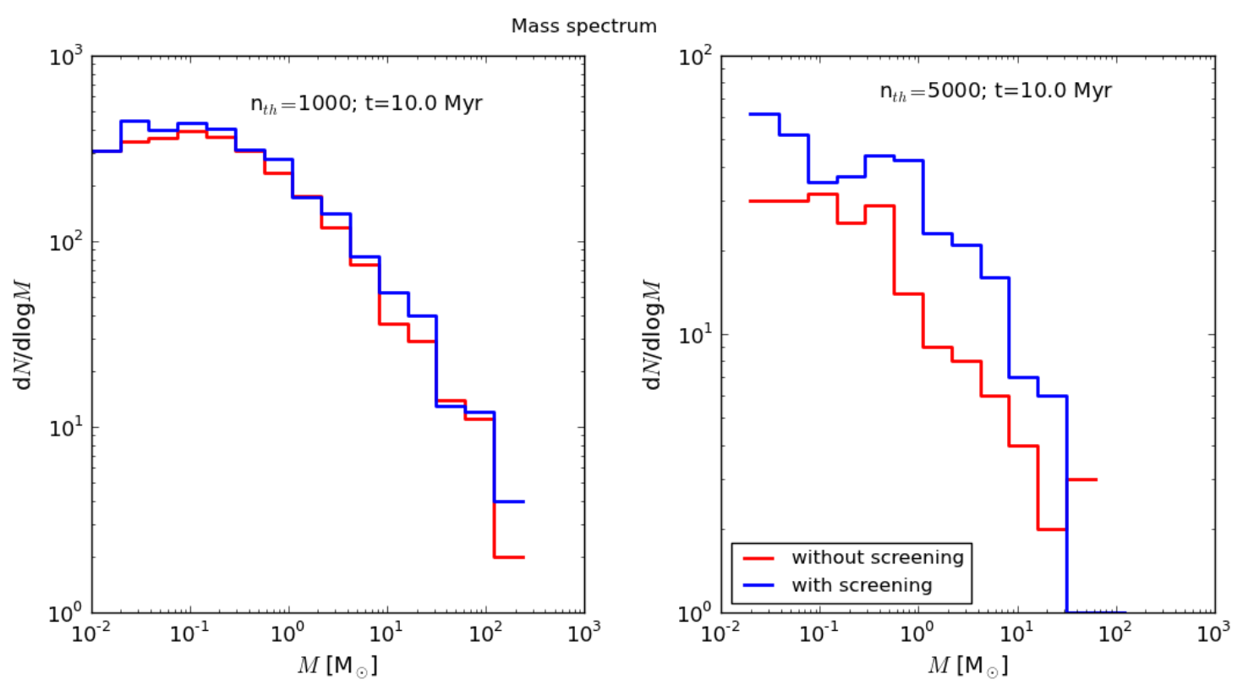
Fig4

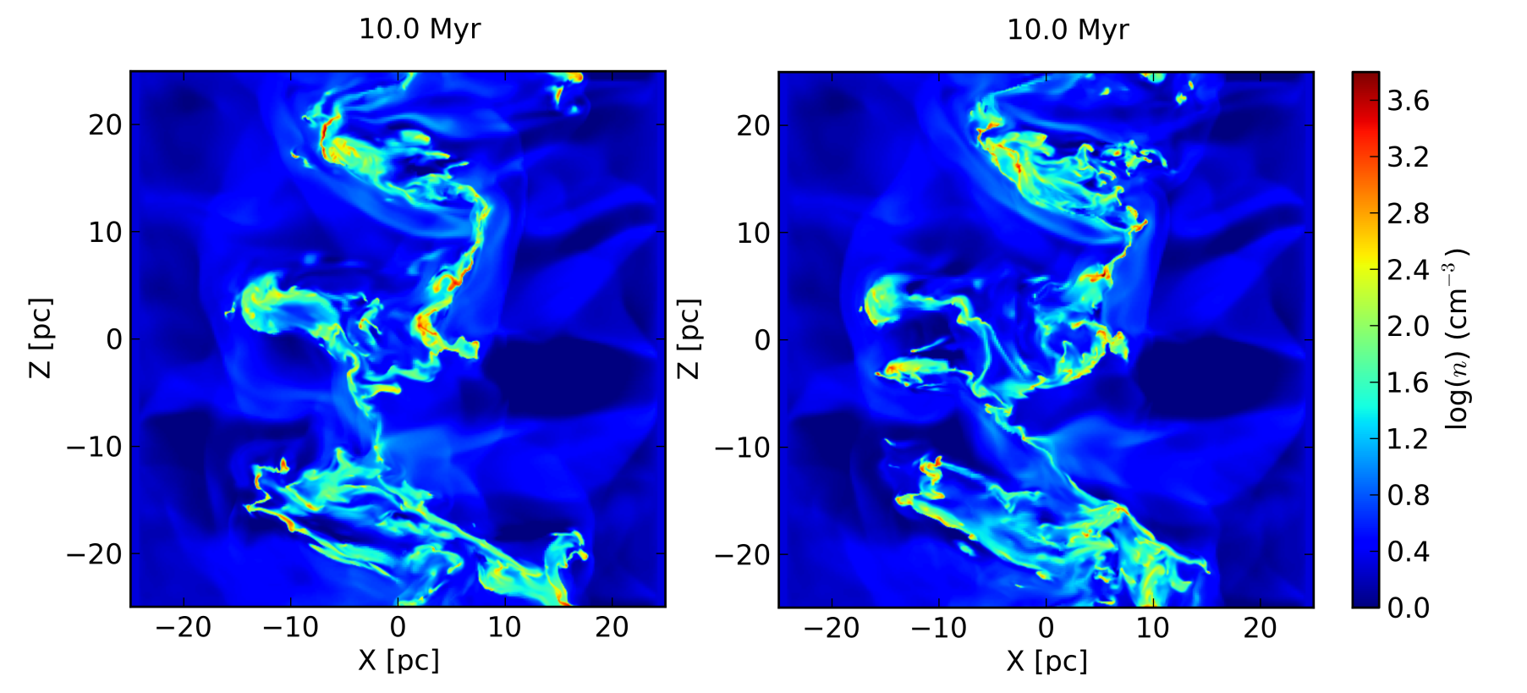
Fig 3: Column density maps. Top: reference calculated with a ray-tracing method. Bottom: estimation done with the tree-based method.
Fig 4: Extinction maps. From top to bottom: reference, estimation calculated with the tree-based method for 6, 12, 40 and 84 directions.

APPLICATION

We consider two colliding streams of warm atomic gas (Audit & Henebelle 2005), heated by the interstellar radiation field (ISRF). The standard atomic cooling curve, which is reasonably accurate up to densities of a few 10^3 cm^{-3}, spontaneously leads to a multi-phase medium (Field *et al.* 1969).
We analyze the influence of the UV screening on the core formation in colliding flows.







Left: PDF and T per density bin. Center: Mass spectrum at $t = 10$ Myr for two simulations. Right: slice at the midplane showing the difference in fragmentation induced by the screening: left: without screening, right: with screening.

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