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# A REIONISATION SCENARIO FROM HII REGIONS MERGERS HISTORIES

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**Abstract.** We describe a methodology to analyse the reionisation in numerical simulations. We particularly focus on the merger history of HII regions during the process. For this purpose, we identified the HII regions using a *friend-of-friend* algorithm and then derived the merger tree of these regions. By investigating the properties of evolving ionised regions thanks to the merger tree, we propose a typical scenario of the reionisation.

Keywords: Reionisation, HII regions, first stars, Methods: numerical

## 1 Introduction

Recent progress in numerical simulations (see Trac & Gnedin 2009 for a complete review of these models) permit us to add radiative transfer runs on hydrodynamics data. In this context, one challenge is to describe the chrono-geometry of the reionisation process through cosmological simulations. This will be an helpful tool in order to overtake forthcoming observations with new large-area radio interferometers like SKA (`http://www.skatelescope.org/`) and LOFAR (`http://lofar.org/`).

We aim here at investigating the time sequence of the reionisation in simulations. For this purpose, we adopt an alternative method by tracking the HII regions and derivating their merger tree. As a result, we embrace a 'local' perspective with histories of reionisation instead of 'global' rationale commonly used. We apply this technique to a large-scale cosmological simulation of reionisation and propose a scenario in this context.

## 2 Methodology

### 2.1 Simulation

This work was developed on a numerical simulation of reionisation fully described in Aubert & Teyssier (2010). The hydrodynamic of the gas is performed with the RAMSES code (Teyssier 2002) and the radiative transfer is post-processed with the ATON code (Aubert & Teyssier 2008). The simulation is a comoving 50 Mpc/h box produced on a $1024^3$ coarse grid. The simulation is performed from $z \sim 14$ to $z \sim 6$ when the reionisation is achieved.

### 2.2 Friend-of-friend algorithm

The first step of our purpose is the identification of individual HII regions in each snapshots of the simulation. The rule we adopt is that each cell of our cosmological box with a ionisation fraction $x > 0.5$ is considered as ionised. Then, when we encounter a ionised cell we allocate to it an identification number corresponding to the ionised region being tested. With the help of a *friend-of-friend* algorithm we allocate to the ionised nearest neighbors of this cell the identification of the HII regions being explored. We are thus able to separate all the ionised region and to keep track of each of them with the identification number.

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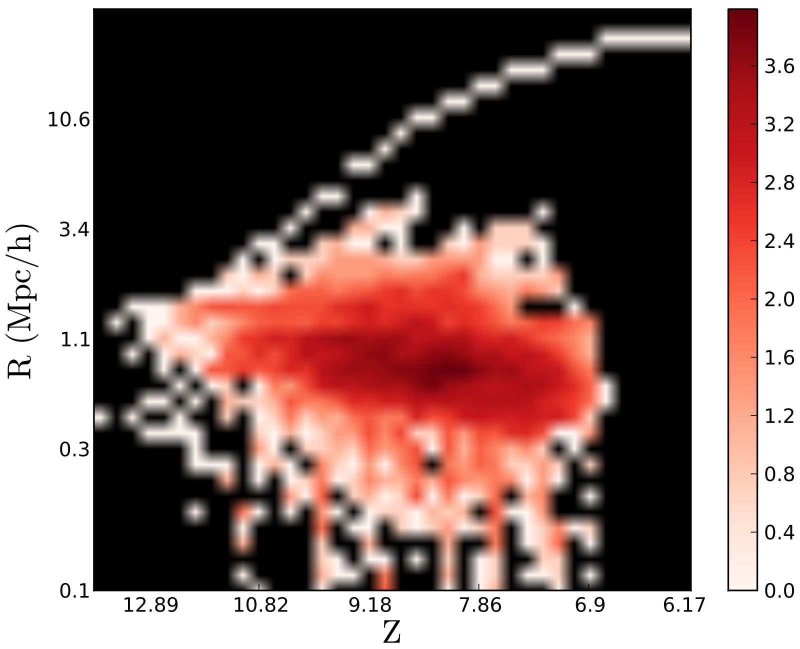


**Fig. 1.** Redshift radius distribution of HII regions. The color code is an arbitrary logarithm scale of the number of counts.

### 2.3 Merger tree

The second step is the derivation of the merger tree of these regions to follow them with time. In order to follow the evolution of the properties of each HII region we track the evolution of its identification number. In practice, we extract where are located the cells of an HII region at time $t$ and look at the identification number that they received at time $t+1$. We then link the two identification number between the two snapshots. We repeat this process for all the HII regions and between all the snapshots of the simulation.

## 3 Results

### 3.1 HII regions size

By firstly focusing on the size distribution of HII region with redshift (figure 1), we find that the typical radius of ionised patches is $\sim 1$ Mpc/h during the entire period simulated. Moreover, we observe that HII regions reach rarely a radius above 3 Mpc/h. We also find the emergence of a single dominant HII region in size which appear early in the simulated reionisation. We are able to follow this particular region with the merger tree and we will show that it has a key role in our reionisation scenario. Intuitively, the ionised regions reach the critical value of 3 Mpc/h in radius before merging with the main one.

### 3.2 Analysing the merger tree

Thanks to the merger tree we can investigate some properties related to the HII regions. We summarize them below:

- The number of new HII regions between two snapshots.
- The number of ionised regions resulting from mergers between two snapshots.
- The number of parents involved for an HII region resulting from mergers.
- The number of mergers that occurs between two snapshots.

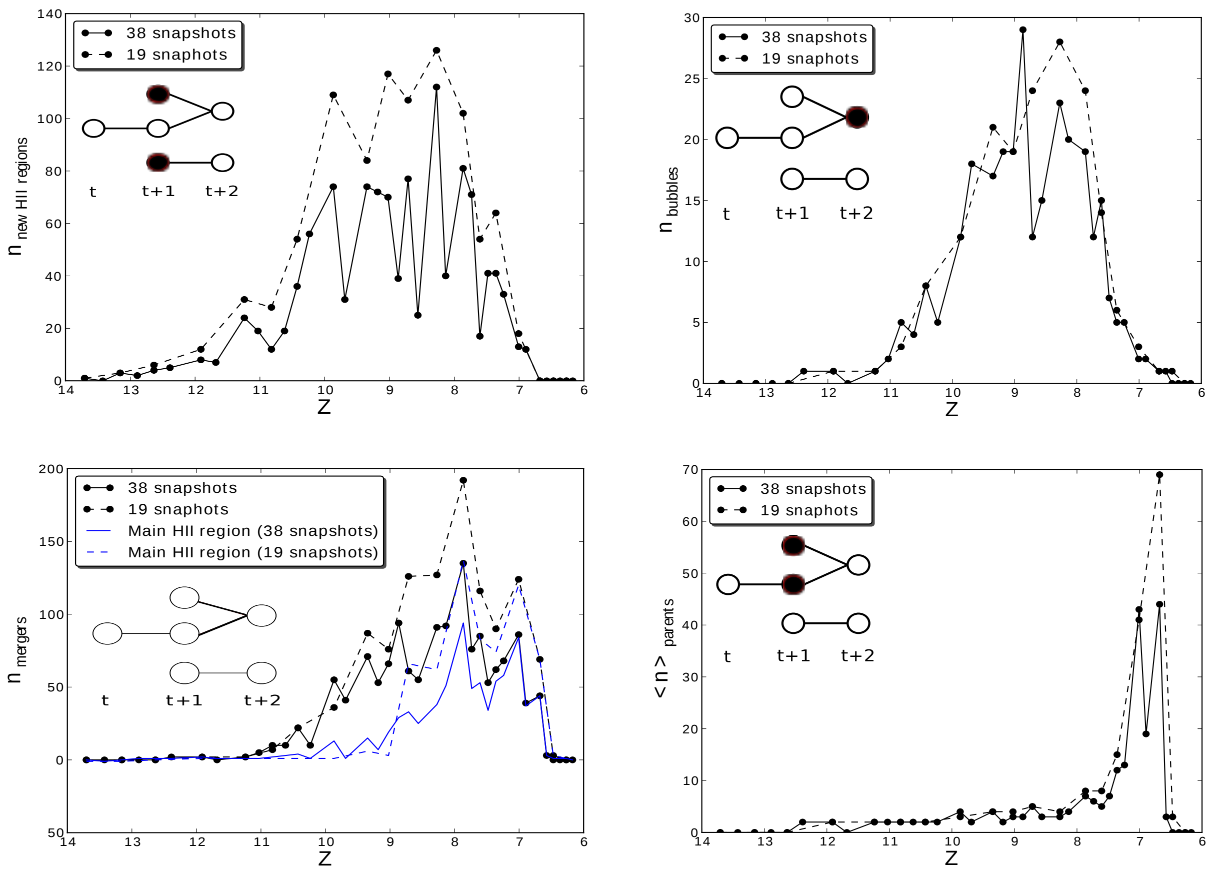


**Fig. 2.** The redshift evolution of the typical properties investigated by the merger tree. The number of new HII regions (*top left*), the number of HII regions resulting from merger (*top right*), the number of mergers that occur between two snapshots (*bottom left*) and the average number of parents for HII regions resulting from mergers (*bottom right*). We represent also the number of mergers involving the main HII region with the blue line in the *bottom left* panel. Each little diagram represent the typical HII regions considered.

In figure 2 we can see the redshift evolution of these properties for two snapshots sampling (for the 38 snapshots of our simulation and by taking one snapshot over two which correspond to 19 snapshots).

We see that the merger process is concentrated between $z \sim 11$ and $z \sim 7$ by looking at the *top right* and *bottom left* panel of figure 2. From $z \sim 9$ mergers are dominated by the main HII regions and at $z \sim 7$ this region is responsible of all the mergers (*bottom left* of figure 2).

We remark that there is a significant number of birth of HII regions up to $z \sim 7$ (*top left*). But at the same time the merger process is also very marked. An explanation is that the merger seems to be localized in a certain region of space. These concentrated merger would build the main HII region in a clustered area.

In the *bottom right* panel we see that the averaged number of parents for ionised regions resulting from mergers growth dramatically. This would be the moment where the main HII region merge very efficiently with the other remaining. This moment could be seen as the end of the reionisation in terms of HII regions.

### *3.3 A reionisation scenario*

From the properties analysed in the previous section, we are able to propose a reionisation scenario in terms of HII regions in the context of our simulation. We propose to summarize here the main key period that emerge from the curve in figure 2:

- Between $14 > z > 12$ the first sources begin to appear in the simulated volume.

- Between $12 > z > 11$ the sources birth is marked but the merger process between them is not efficient.
- Between $11 > z > 8.5$ the first merger appear locally and lead to the construction of a main HII region in size.
- At $z \sim 8$, the space is saturated in terms of isolated HII regions. This is the typical turning point where the merger process dominate the HII regions formation rate.
- Between $8 > z > 7$ there is a intense period of merger mainly dominated by the main region.
- At $z \sim 7$, the main HII region finally merge with the others remaining. This can be seen as the redshift of reionisation in terms of HII regions.

## 4 Conclusions

By applying a new technique to characterize the chronology and the geometry of reionisation, we have determined some key period in the course of the process. We have also proposed a scenario for the particular case of our simulation. In the future, we will apply systematically this technique in order to understand how the physical 'ingredients' in the simulation will influence the chrono-morphology of the reionisation. Finally, the merger tree developed promise to be an helpful tool for other kind of work like the reionisation around particular objects in the simulations. We will in forthcoming work use it to characterize the 'HII region object' in regard to the cosmological environment where it is expanding.

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