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HOW DID Z=0 GALAXIES IONIZE THEIR ENVIRONMENT DURING THE REIONIZATION EPOCH ?

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Abstract.
Cosmological simulations of reionization are analyzed in order to assess the reionization history of individual galaxies. A catalog of the evolution of the HII region properties is calculated with a merger tree of HII regions. It is assumed that a galaxy experiences a reionization in isolation until its related HII region merge with another one equal or greater in volume. The lifetime of HII regions related to galaxies and their volume before their fusion with the UV background are calculated. We find that the later a galaxy appears, the smallest is its lifetime and its volume before being incorporated into the UV background. We then use an average mass accretion history of dark matter halo model (AMAH model) to calculate the mass of the galaxies today at $z = 0$. We can thus link the past reionization properties of their related HII regions with the mass of the galaxy observed today. We find that the more a galaxy is massive today, the earliest it appears and the largest its lifetime and volume are before it sees another I-front coming from another galaxy.

Keywords: Reionization, HII regions , first stars - Methods: numerical

1 Introduction

The reionization period is the moment in the history of the Universe that sees the first galaxies ionizing their environment until $z \sim 11 - 6$ (see respectively Komatsu et al. 2009 and Fan et al. 2006) when the whole IGM is transformed into a plasma. One key challenge is to understand how the reionization proceeds locally around individual galaxies instead of focusing on the global transition. It could be a starting point in order to understand how did occur the reionization of our own galaxy or the reionization of the Local Group (see Ocvirk & Aubert 2011 and Iliev et al. 2011 for example). In that spirit, we propose in that work to assess the "local reionization history" of individual galaxies in cosmological simulation of reionization. The basic idea is to evaluate how long can be a galaxy reionized by itself without any contribution from another I-front and what volume a galaxy is able to ionize alone depending on the cosmic time of apparition of the galaxy.

2 Methodology

2.1 merger tree of HII regions

In order to follow the HII regions properties with redshift we built the merger tree of the ionized regions appeared during simulations. The methodology is fully described in Chardin et al. (2012) and is basically performed in two steps: Firstly, the identification of the HII region in all snapshots of a given simulation with a friends-of-friends algorithm (FOF) is performed and secondly the link between the identification number of the regions is done between all the snapshots and for all HII regions. We adopt the criterion that says that a cell is ionized if its ionization fraction $x \geq 0.5$.

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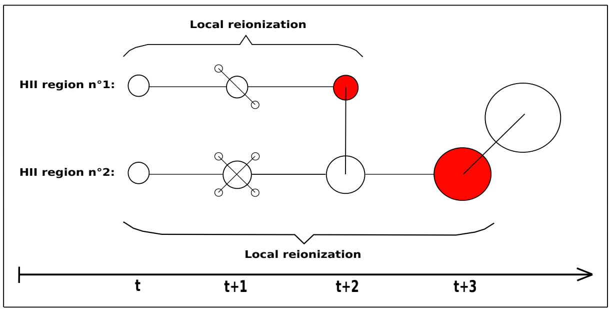


Fig. 1. Illustration of the follow up of the 'local reionization history' fro two distinct HII regions. Red items symbolize that the HII region undergoes a major merger after what the local reionisation history is finished.

2.2 follow up of local reionization histories

Thanks to the merger tree, we built a catalog of HII regions extracted from simulations. For each HII region, the catalog allows to follow its volume at any instant of the simulation, the number of merger with the region and the total volume of the regions that merge with it. We also have access to the mass of the most massive dark matter halo progenitor inside the region at each instant. In that work we want to investigate how long can be a galaxy been reionized in isolation without any influence of neighboring galaxies depending on their cosmic apparition time. To address this question we adopt the definition which says that a galaxy ends its local reionization history when its related HII region merges with regions with a total volume equal or greater than the current volume of the region (see figure 1 for a schematic view of that definition).

2.3 Local reionization seen at $z = 0$

In order to make predictions about the past reionization history of galaxies observed today, we propose to calculate the mass M_0 that would have the dark matter halo progenitors inside the HII regions at $z = 0$. For this purpose, we use the average mass accretion history (AMAH) of dark matter halos model of McBride et al. (2009) to extrapolate the mass of a halo at redshift z to $z = 0$.

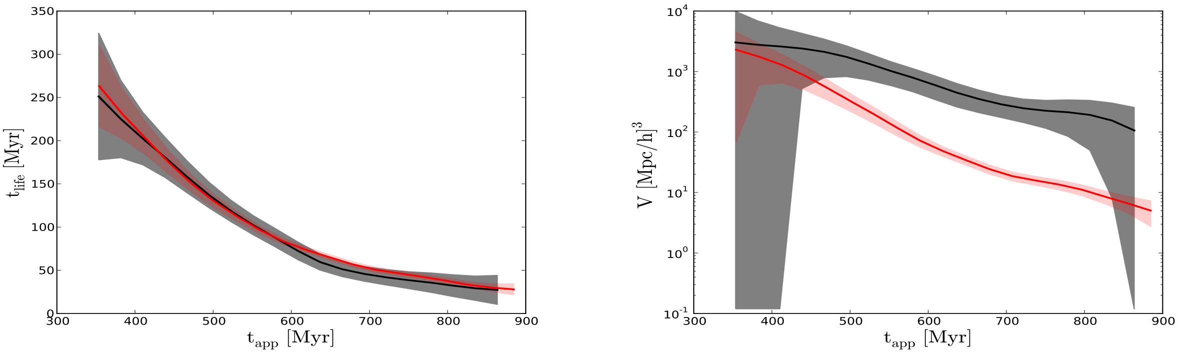
2.4 simulations

We propose in this work to apply the merger tree methodology on two simulations of cosmic reionization. We performed a simulation where the stellar particles generated with the RAMSES code (Teyssier 2002) act as ionizing sources with a constant emissivity. Alternately, we performed a model where the dark matter halos extracted from the density fields are assumed as ionizing sources with an emissivity proportional to the halo masses. In all cases the radiative transfer is done with the ATON code (Aubert & Teyssier 2008) and the emissivities are tuned to obtain a reionization redshift at $z \sim 6$. One box size of 200 Mph/h is considered with a coarse resolution of 1024^3 with 3 additional levels of refinements for the hydrodynamic step. Radiative transfer is treated as a post-processing step and has been performed at the same resolution as the hydrodynamic coarse grid (i.e. 1024^3). The full details of the simulations can be found in section 3 of Chardin et al. (2012) (models S200 and H200).

3 Results

3.1 Global evolution

The figure 2 shows the evolution of the mean lifetime t_{life} and the mean volume (at the 3σ uncertainty) of the HII regions before seeing the UV background as a function of their cosmic time of apparition t_{app}. The curves are calculated for both ionizing source models according to the caption of the figure. We observe in both model that t_{life} and the corresponding volume decreases with t_{app}. This tendency is not surprising considering that the later an ionizing source appears during the reionization, the less neutral is the IGM. It then leads to a more accentuated proximity effect between the HII regions and a higher merging rate of the regions. On the contrary,



(a) (b)

Fig. 2. (a) Mean evolution of the lifetime of the HII regions before their fusion with the UV background as a function of the apparition time of the regions. (b) Mean evolution of the volume of the HII regions before their fusion with the UV background as a function of the apparition time of the regions. The black and red curve stand respectively for the mean value of the Star and Halo model at the 3σ uncertainty.

early regions can expand during ~ 250 Myr with a volume that can reach until a few 10^3 [Mpc/h]^3 because they appear in a mostly neutral environment.

Otherwise, it is surprising to note that whatever the ionizing source model considered, the mean curves are relatively similar. We expected to find smaller t_{life} in the halo-based model compared to the star model. Indeed, the greater number of halos compared to stars particles leads to a higher number of HII regions that could merge more quickly than in the star prescription. In regards to our results it alternately seems that the I-fronts velocities of the regions is slower in the halo model in order to match the global ionization history of the star-based model. This is although confirmed with the volume of the regions that are smaller in the halo model than in the star-based one.

3.2 Reionization seen at $z = 0$

Figure 3 shows the the evolution of the mean lifetime t_{life} and the mean volume (at the 3σ uncertainty) of the HII regions before seeing the UV background as a function of the mass M_0 at $z = 0$ of the dark matter halo progenitor of the region. The curves are calculated for both ionizing source models according to the caption of the figure.

It is reassuring to note the same trends in both models : the more a halo is massive today, the larger is the lifetime and the volume that the related HII regions can reach before merging with another ionized region. This tendency is natural since the more massive halos at $z = 0$ are the ones appeared the most early and thus in the most neutral environment. In other words the smallest galaxies observed today are the ones appeared late in the reionization epoch and are rapidly swallowed by large HII regions associated to massive galaxies observed today.

We can note that the faster I-fronts in the star-based model lead to a same volume reached by the HII region than in the halo prescription but with a shorter lifetime before seeing the UV background.

In order to make predictions on the past reionization of MW and M31, our results suggests that an object of $\sim 3 \times 10^{11} M_\odot$ should have reionized its close environment in isolation for $\sim 90 \pm 30$ Myrs within a sphere of a typical radius of ~ 2.7 Mpc/h. These results are in agreement with the study of Ocvirk et al. (2013) where constrained simulations of the Local Group show that the reionization of a Milky Way halo ($\sim 3 \times 10^{11} M_\odot$) is done in isolation for 130 Myrs in their photon-rich H43 model (the closest to our emissivity model). However, Ocvirk et al. (2013) found a maximal extent of ~ 1 Mpc/h for the related HII region which is under our estimations. For the exceptional case of the Local Group, with the proximity of MW and M31, it is thus difficult to bring closer our statistical results and those obtained from constrained simulation of the reionization of the Local Group.

However, thinking of the whole Local group as a massive object of a few $\sim \times 10^{12} M_\odot$, our results suggests an HII region extension of a few Mpc before encountering another front. This is a volume large enough to

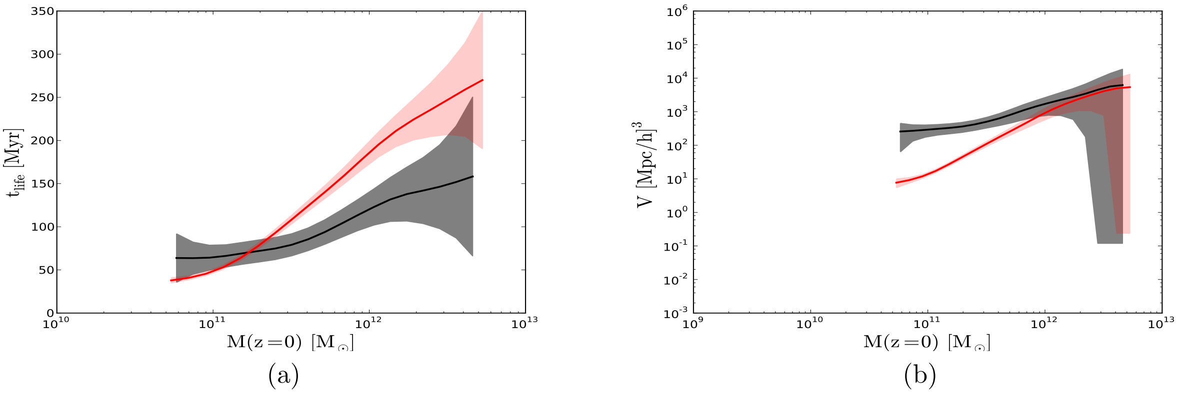


Fig. 3. (a) Mean evolution of the lifetime of the HII regions before their fusion with the UV background as a function of the mass of their dark matter halo progenitor at z=0. (b) Mean evolution of the volume of the HII regions before their fusion with the UV background as a function of the mass of their dark matter halo progenitor at z=0. The black and red curve stand respectively for the mean value of the Star and Halo model at the 3σ uncertainty.

encompass the whole Local Group. In other words, statistically the Local Group could have been reionized by only its own source content whithout any influence from another front coming from a Virgo-like cluster for example.

4 Conclusions

We have addressed questions related to the reionization history of individual galaxies in numerical simulations of reionization. We used a merger tree of the HII regions in order to follow the duration of the local reionization and the volume that can be reionized by a or a couple of halos. We found that the later an ionizing source appears, the smaller are the lifetime and the volume of its associated HII region before encountering an other I-front. We then tried to link these local reionization histories with the local Universe. We found that a more massive is a galaxy today, the earlier it appears during the reionization and the larger is its local reionization duration and volume. Statistically, we found that MW and M31 reionized in isolation during about 100 Myrs which is consitent with constrained simulation of the reionization of the Local Group. We also found that the whole Local Group would have been reionized by its inner source content without any influence coming from a Virgo-like cluster. These results have to be compared to more constrained simulation at the scale of galaxies in the future. It could be done by using the merger tree approach in a systematic manner.

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