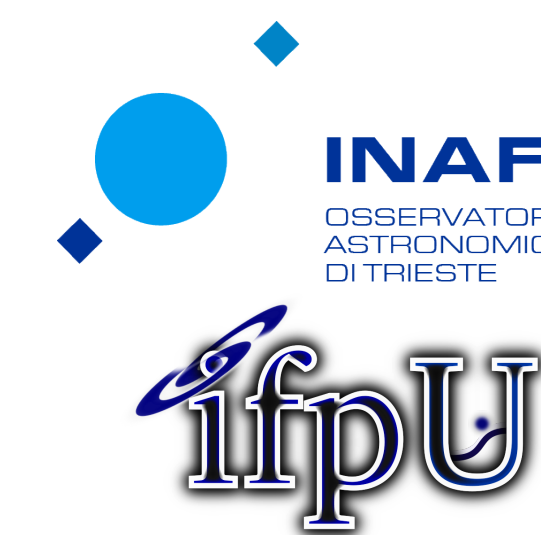


Probing quasar lifetimes with proximate 21-cm forest absorption

Tomáš Šoltinský (tomas.soltinsky@inaf.it), James Bolton, Margherita Molaro, Nina Hatch,
Martin G. Haehnelt, Laura C. Keating, Girish Kulkarni, Ewald Puchwein

Istituto Nazionale di Astrofisica - Osservatorio Astronomico di Trieste (INAF-OATs), Trieste, Italy
National Astronomical Meeting 2025, Durham, UK



Ly α forest vs 21-cm forest

- Both signals are series of absorption features in spectra of distant quasars arising from the intervening neutral hydrogen in the intergalactic medium (IGM) due to the Ly α (restframe wavelength of 1216 Å, observed at IF-UV) and hyperfine (restframe wavelength of 21.1 cm, observed at radio) line.
- They can be used to probe the Epoch of Reionization (EoR) - the cosmological era after the first galaxies formed and their radiation ionized and heated the material in the universe
- If hydrogen is even slightly neutral, it becomes opaque to the Ly α photons, hence during the EoR the Ly α forest can be observed only close to the quasars which ionize their surroundings with radiation they emit $\Rightarrow$ this is known as Ly α forest proximity zone
- On the contrary, the 21-cm forest is strongest in cold and neutral hydrogen gas, and hence is complimentary to the Ly α forest signal
- For the first time, we explore this proximity zone effect on the 21-cm forest

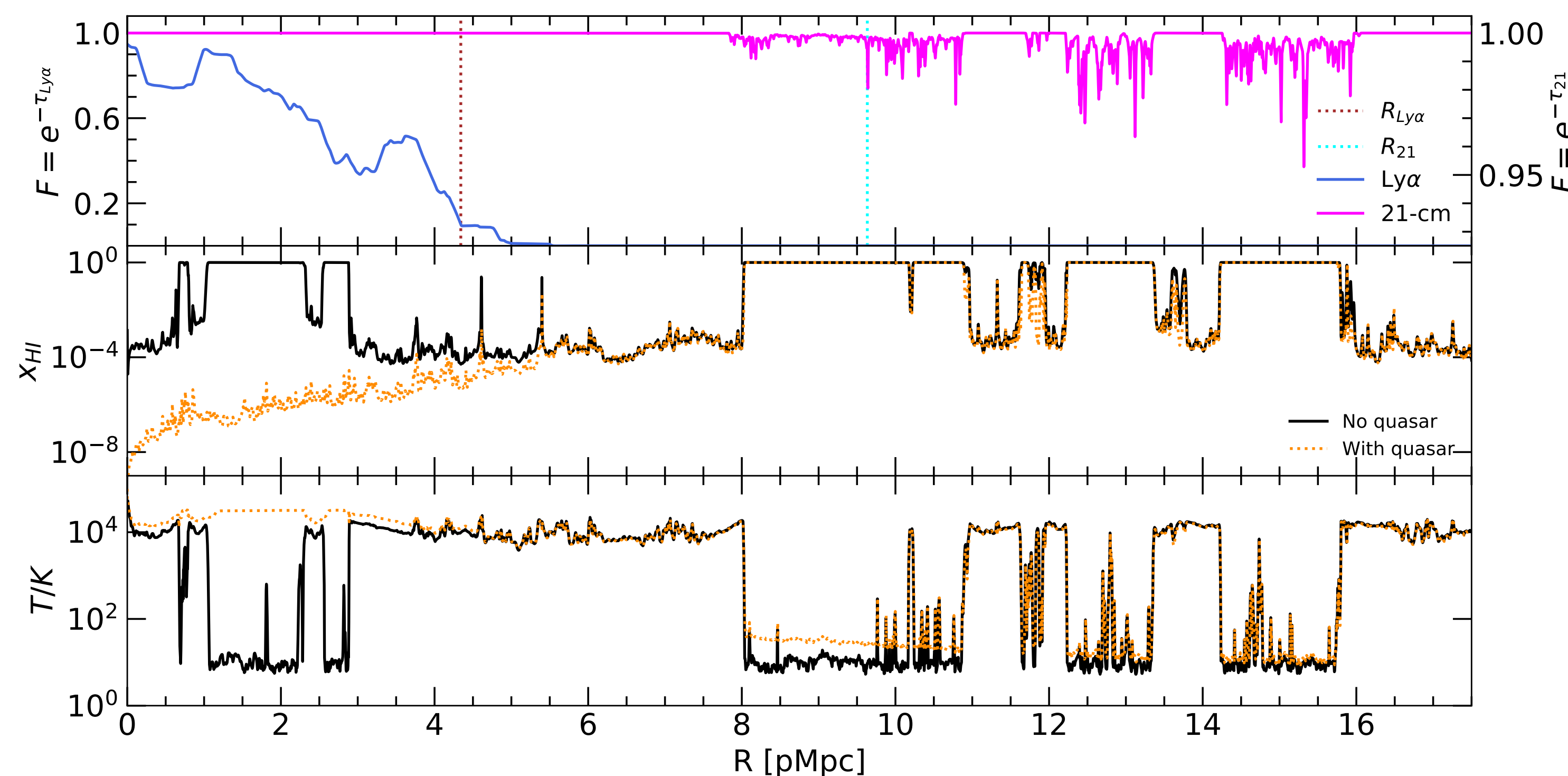


Figure: Top: Smoothed Ly α (blue) and 21-cm (fuchsia) forest spectra close to a 10 Myr old quasar. Middle: Neutral hydrogen fraction profile before the quasar turns on (solid black) and after it shines for 10 Myr (dotted orange). Bottom: Same as the middle panel but for the gas temperature.

Proximity zones

- The figure shows the neutral hydrogen fraction and temperature profiles before the quasar was turned on (solid black) and after it radiated over 10 Myr (dotted orange) - the gas surrounding the quasar is heated up and ionized
- $R_{Ly\alpha}$ is mainly given by the ionization state of the gas and hence UV photons emitted by the quasar
- Vertical dotted lines in the top panel indicate Ly α , $R_{Ly\alpha}$ (red), and 21-cm, R_{21} (cyan), proximity zone sizes defined as the closest point to the quasar where the smoothed flux goes below 10% (Fan et al. 2006, ApJ, 132, 1, 117) and 99%, respectively
- R_{21} is mainly given by the neutral gas temperature and hence X-ray radiation from the quasar

Model

- Sherwood-relics simulation suite (Puchwein et al. 2023, MNRAS, 519, 4, 6162)
- $\Downarrow$
- A set of hybrid hydrodynamic-Radiative Transfer high resolution cosmological simulations of the EoR
- 1D multifrequency Radiative Transfer simulations (Bolton & Haehnelt 2007, MNRAS, 374, 2, 493)
- $\Downarrow$
- Track the propagation of photons emitted by a quasar and how they affect the surrounding gas
-
- Lightbulb model - the quasar is turned on and its luminosity stays constant
 - Flickering model - part of the quasar radiation is periodically turned ON/OFF

Time evolution of the proximity zones

Both the Ly α and 21-cm forest proximity zones expand when the quasar is ON as the gas is ionized and heated

- During the quasar OFF phase the hydrogen...
- ...has enough time to recombine and become partially neutral $\Downarrow$ Ly α proximity zone shrinks
 - ...does not have enough time to adiabatically cool $\Downarrow$ 21-cm proximity zone does not decrease

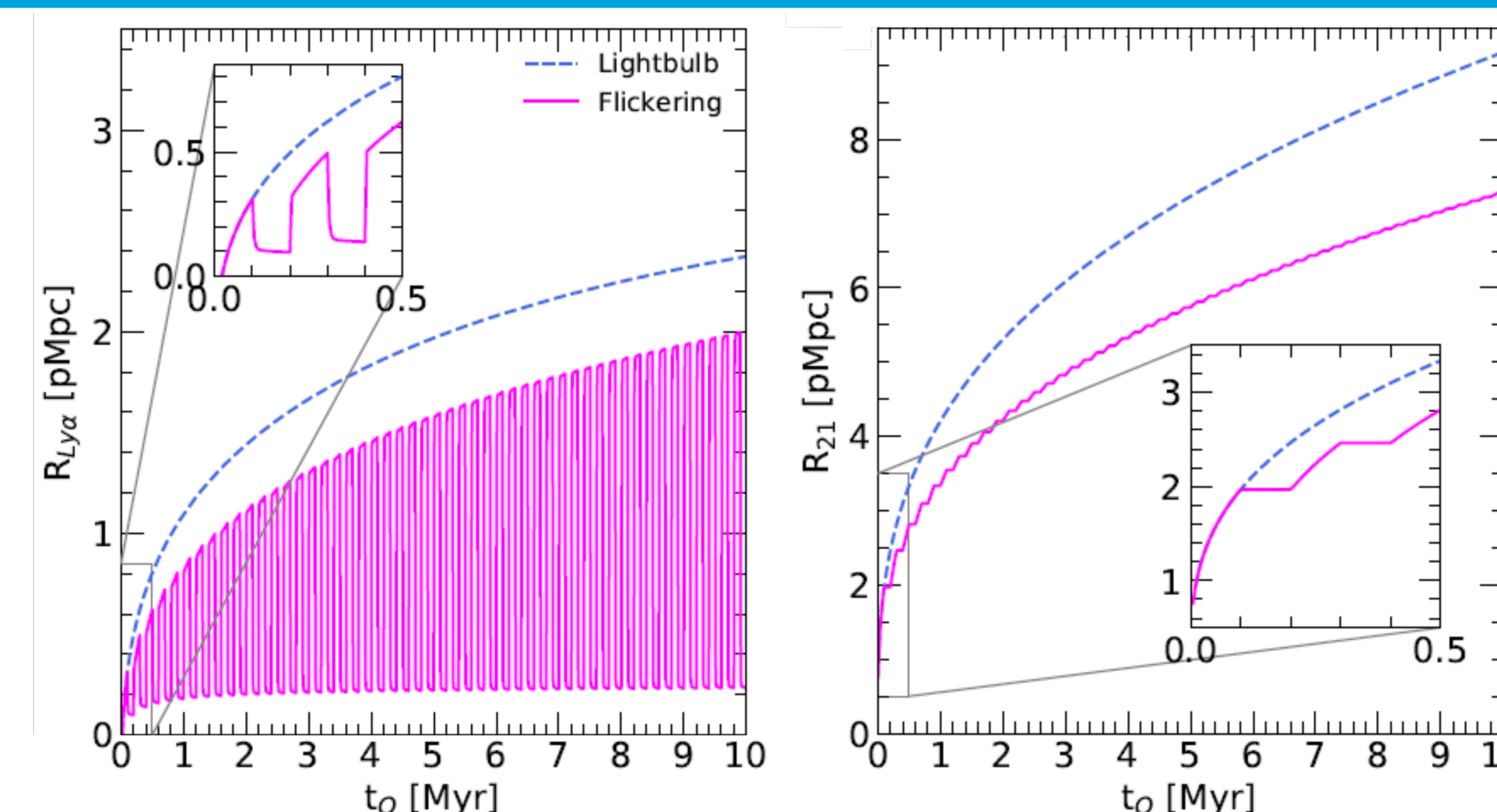


Figure: Ly α (left) and 21-cm (right) forest proximity zone sizes evolution with quasar lifetime in the lightbulb (dashed blue) and flickering (solid fuchsia) model in initially homogeneous cold and neutral IGM.

More details in Šoltinský et al. 2023, MNRAS, 519, 2, 3027



Young quasar vs old but flickering

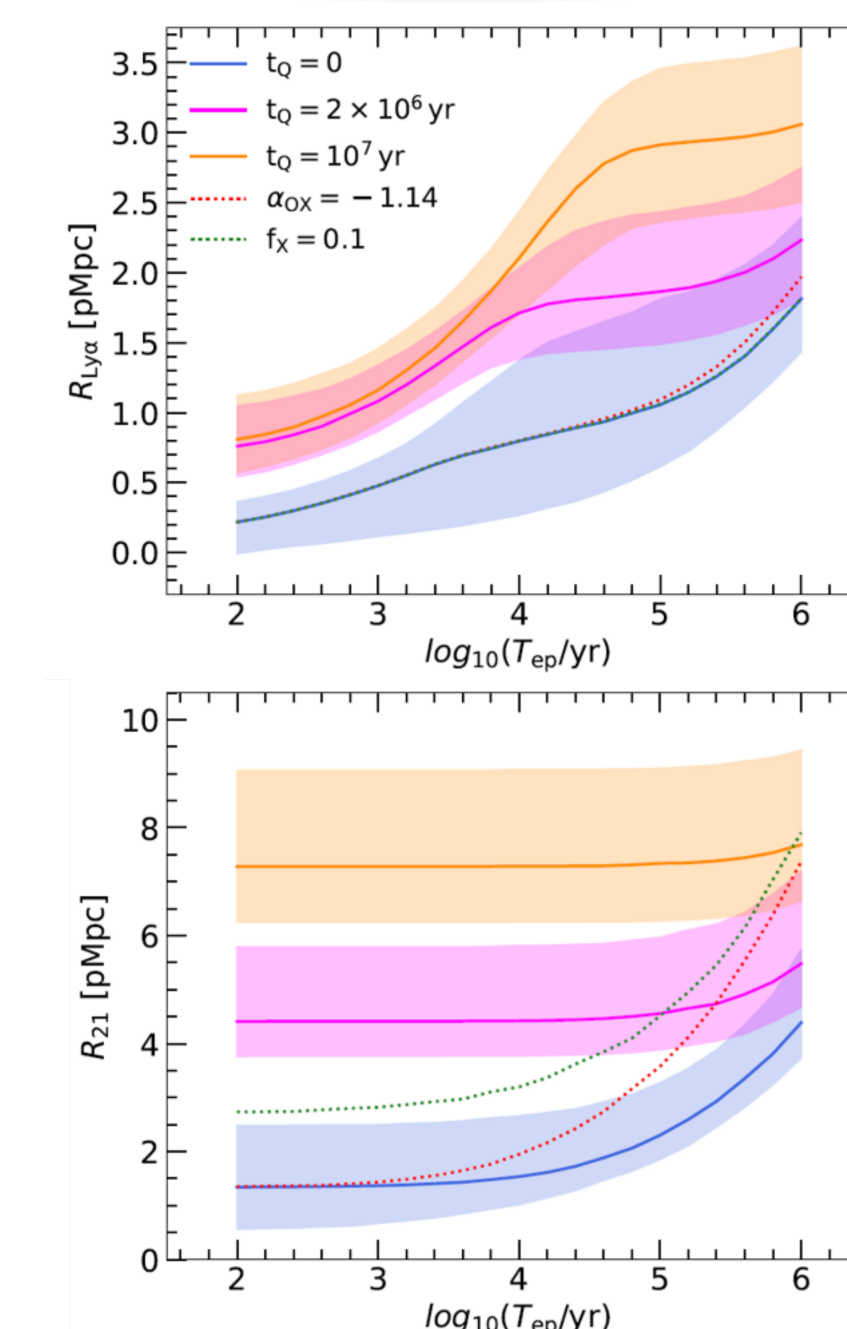


Figure: Ly α (left) and 21-cm (right) forest proximity zone sizes evolution over a single ON/accretion period for a 0 Myr (blue), 2 Myr (fuchsia) and 10 Myr (orange) old quasar in inhomogeneous IGM.

Conclusions

- Recently, small Ly α proximity zones have been measured (Eilers et al. 2017, ApJ, 840, 1, 24)
- This can be achieved if the quasar is still young or old but flickering (Davies et al. 2020, MNRAS, 493, 1, 1330)
- However, the R_{21} will be small only when the quasar is young
- Therefore, measurements of the 21-cm forest proximity zones might discern between these two cases, and hence provide additional information on the supermassive black hole growth models