Lyman continuum escape fraction during cosmic reionization

Ivan Kostyuk
with Benedetta Ciardi, Andrea Ferrara, Martin Glatzle, Dylan Nelson and Annalisa Pillepich

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MAX PLANCK INSTITUTE
FOR ASTROPHYSICS

Motivation

- Abundance of high z quasars too low $\Rightarrow$ galaxies drive reionization.
- Two main questions remain:
  1. Photon production in high z galaxies
  2. Photon escape from galaxies
- f_{esc}: connection between ionizing photon production and reionization of the IGM

Analyzing $f_{\rm esc}$ of TNG50 galaxies

Simulating radiation transfer:

- Radiation transfer not self consistently included $\Rightarrow$ halos need to be post-processed.
- RT code CRASH (*Ciardi et al. 2001, Graziani et al. 2013, Glatzle et al. 2019*)
- Select $\approx 10^4$ halos ($z = 6 - 10$, $M_\star = 10^6 - 10^8 \mathrm{M}_\odot$)

(Published in Kostyuk et al. 2023)

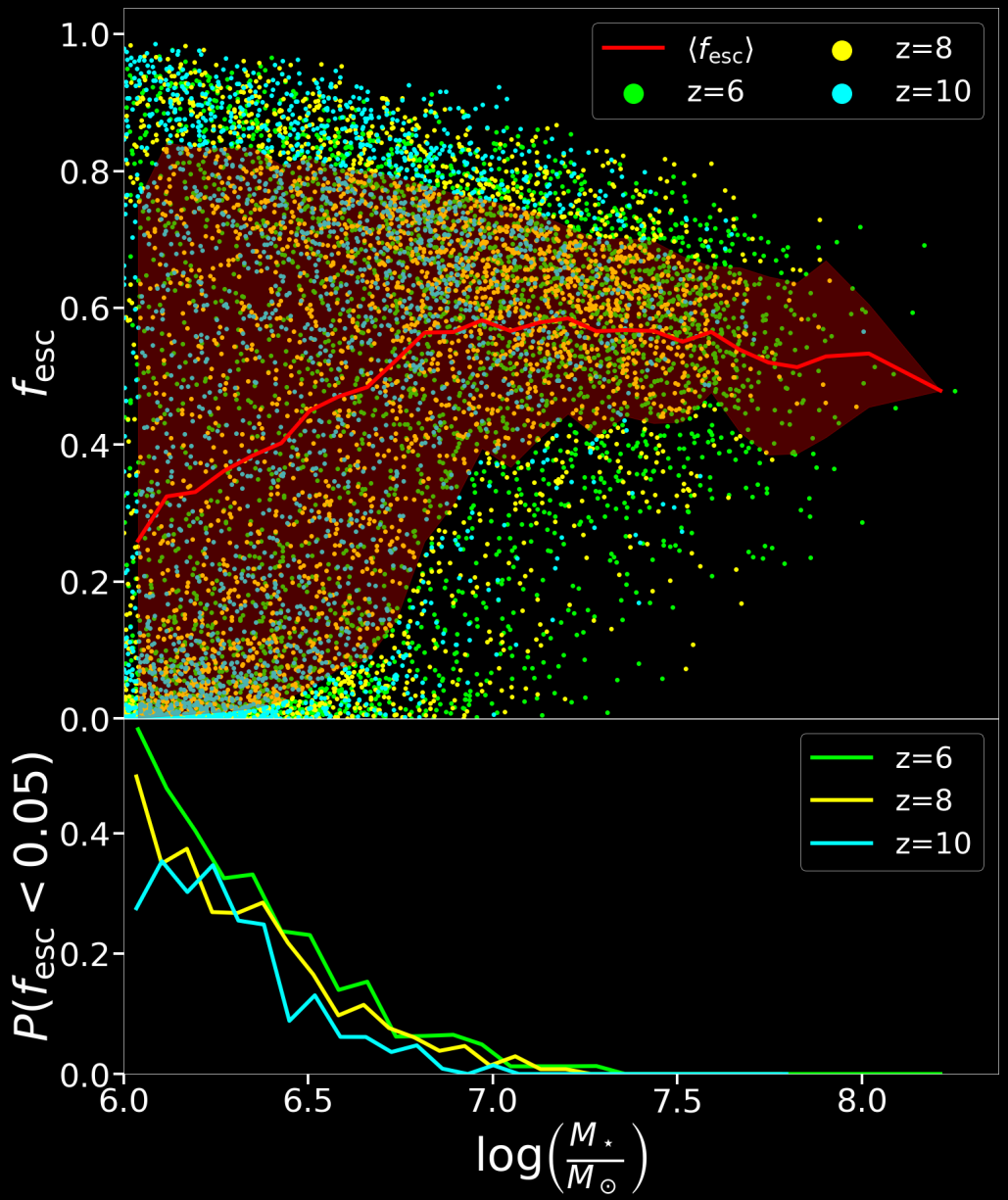
Semianalytic modelling of $f_{\rm esc}$:

- Galaxy modelled as a thin slate based on Ferrara et al. (2023 in prep.)
- Ionizing flux derived from SFR
- Process all galaxies with $z > 5.2$ ($\approx 6 \times 10^5$)

(Kostyuk, Ferrara & Ciardi in prep.)

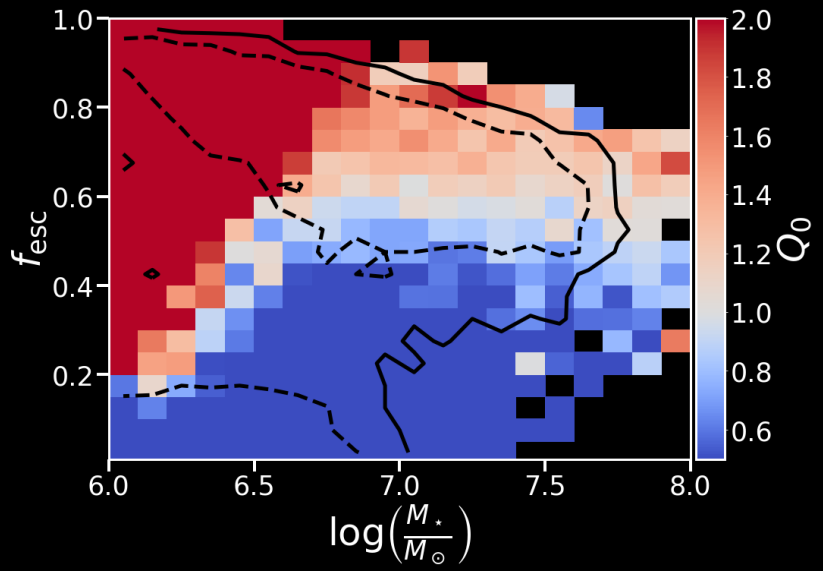
Dependence on stellar mass

- $f_{\rm esc}$ bimodal for low $M_\star$
- Small galaxies with recent starbursts have high $f_{\rm esc}$
- In larger halos this effect averages out

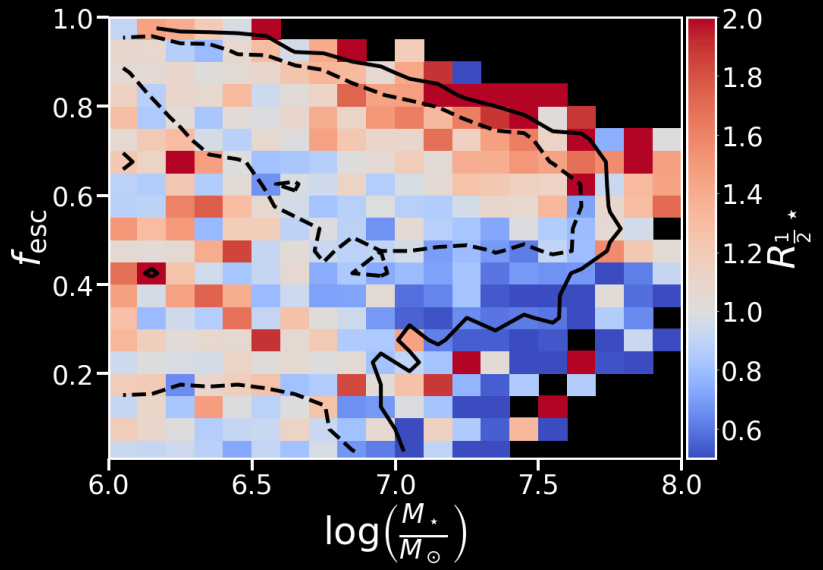


Correlation with halo properties

- For small $M_\star$: $f_{\rm esc}$ correlated with ionizing emissivity

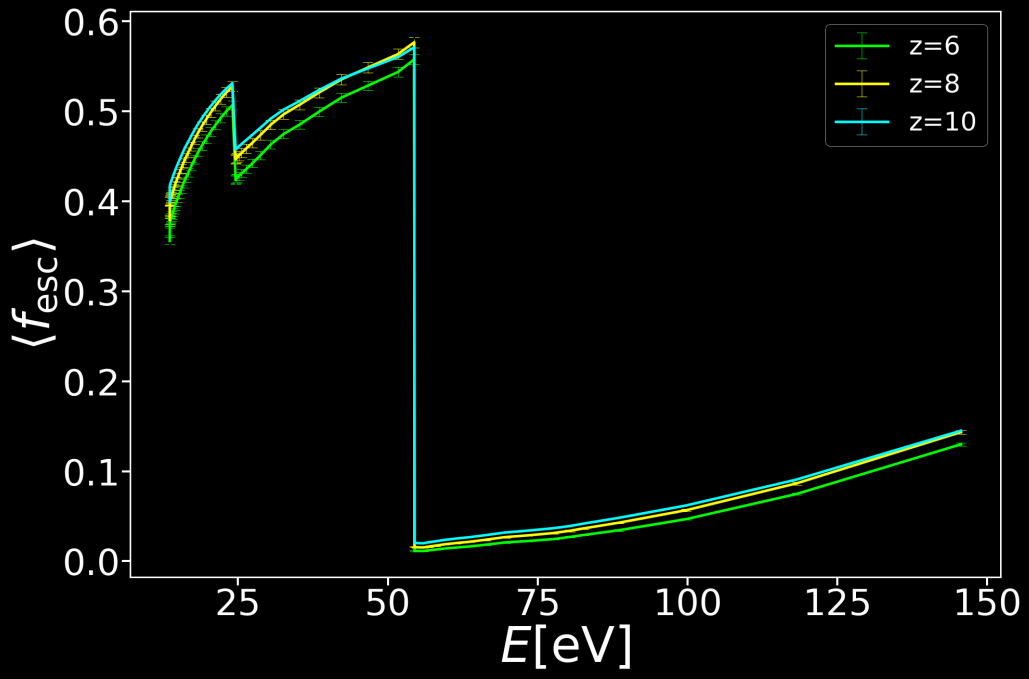


- For large $M_\star$: $f_{\rm esc}$ correlated with spread of stellar populations



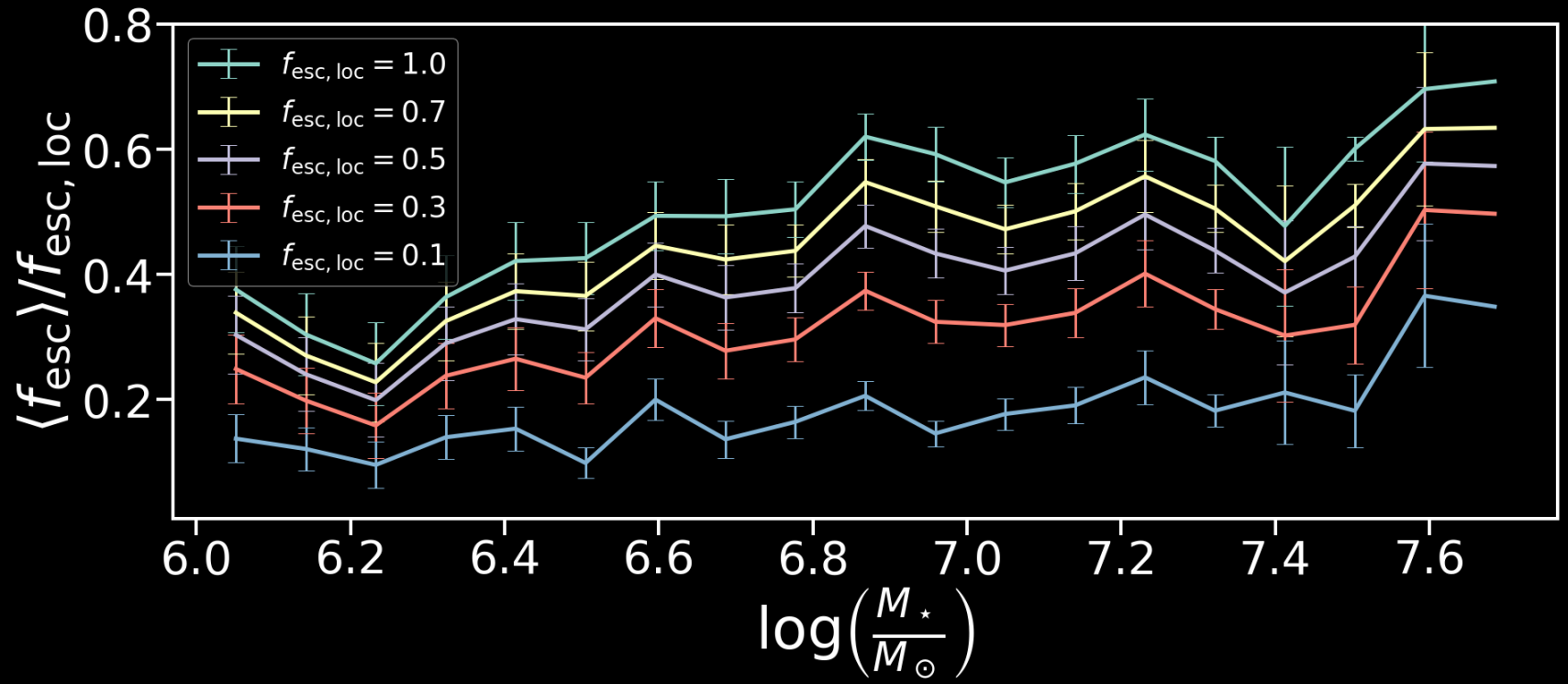
$f_{\rm esc}$ dependence on photon energy

- $f_{\rm esc}$ decreases near exact ionization energies due to larger cross sections
- $f_{\rm esc}$ of HeII ionizing photons strongly suppressed



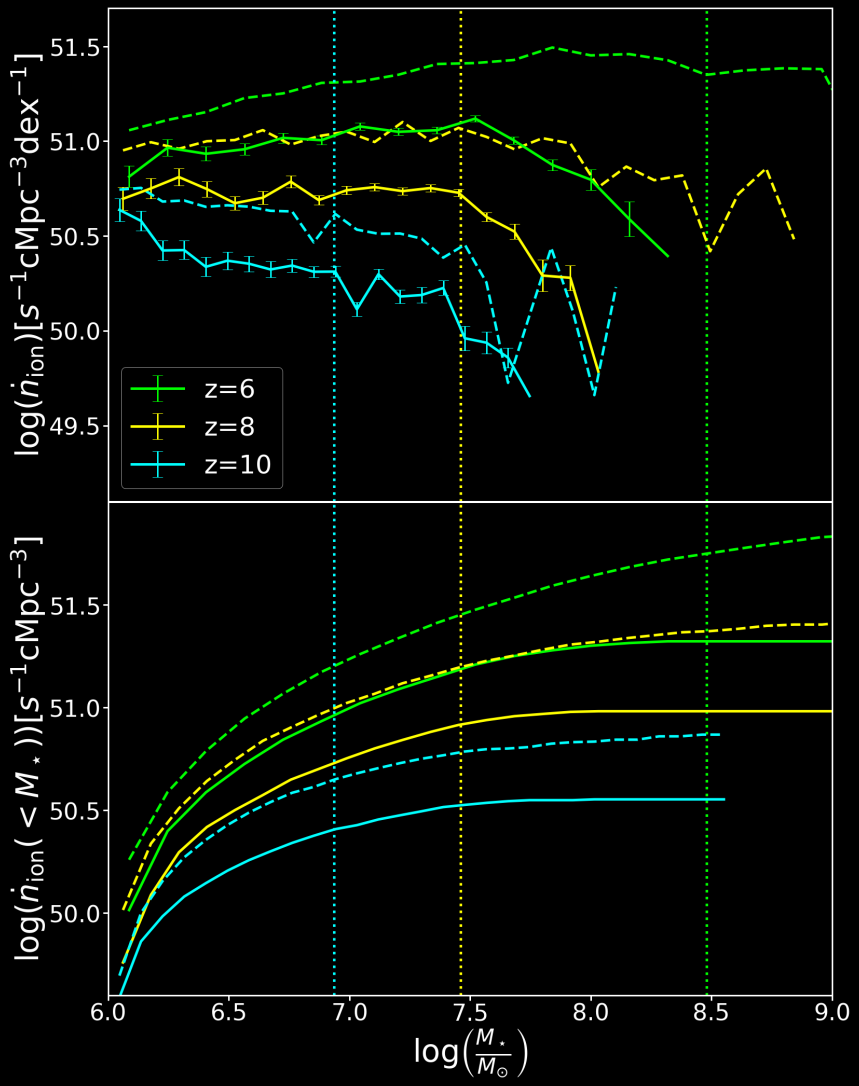
Dependence on the unresolved escape fraction

- No strong dependence on stellar mass.
- For $f_{\mathrm{esc,loc}} \geq 0.3$, changes in $f_{\mathrm{esc,loc}}$ have a proportional effect on the global f_{esc}



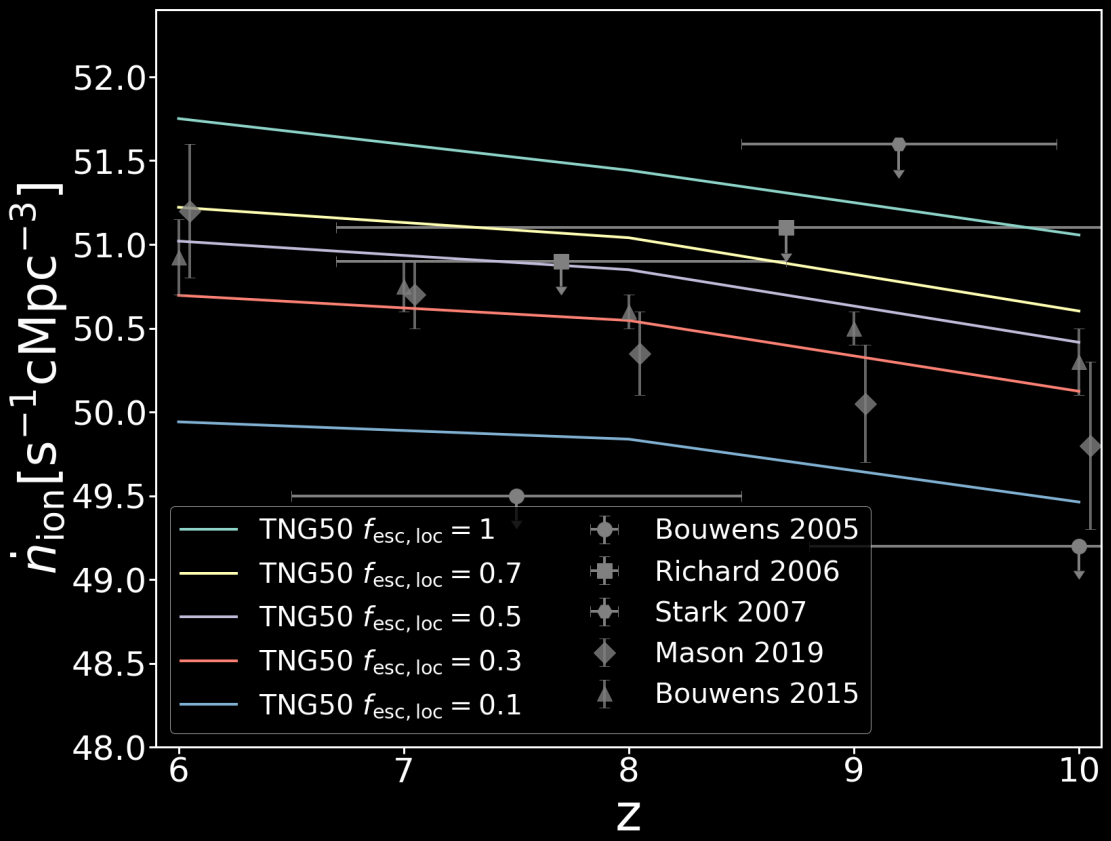
Density of ionizing photons escaping into the IGM

- $\dot{n}_{\rm ion}$ increases with z.
- At $z = 6$ and 8 most photons escape from halos with $M_\star = 10^{6-7} M_\odot$
- At $z = 10$ halos with $M_\star < 10^6 M_\odot$ contribute significantly



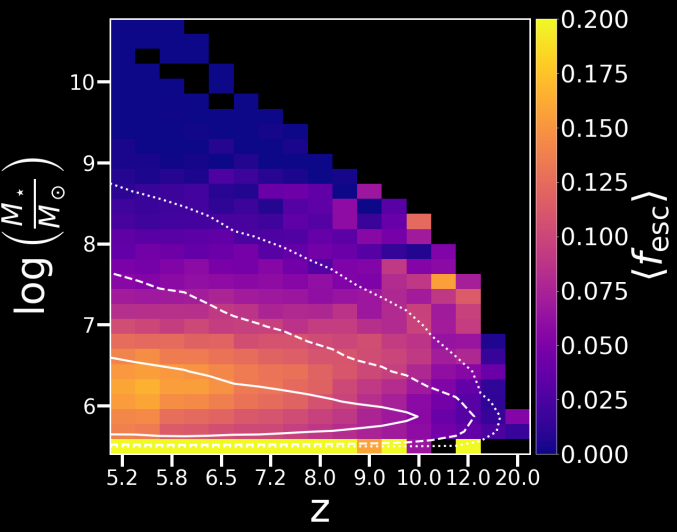
Ionizing photon emissivity density: Comparison to observations

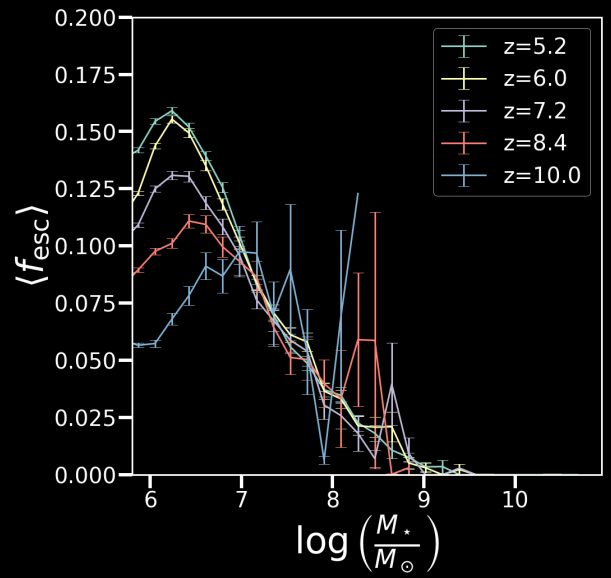
- Emissivities with $f_{\mathrm{esc,loc}} = 0.3 - 0.5$ consistent with observational constraints



Semianalytic modelling of LyC escape

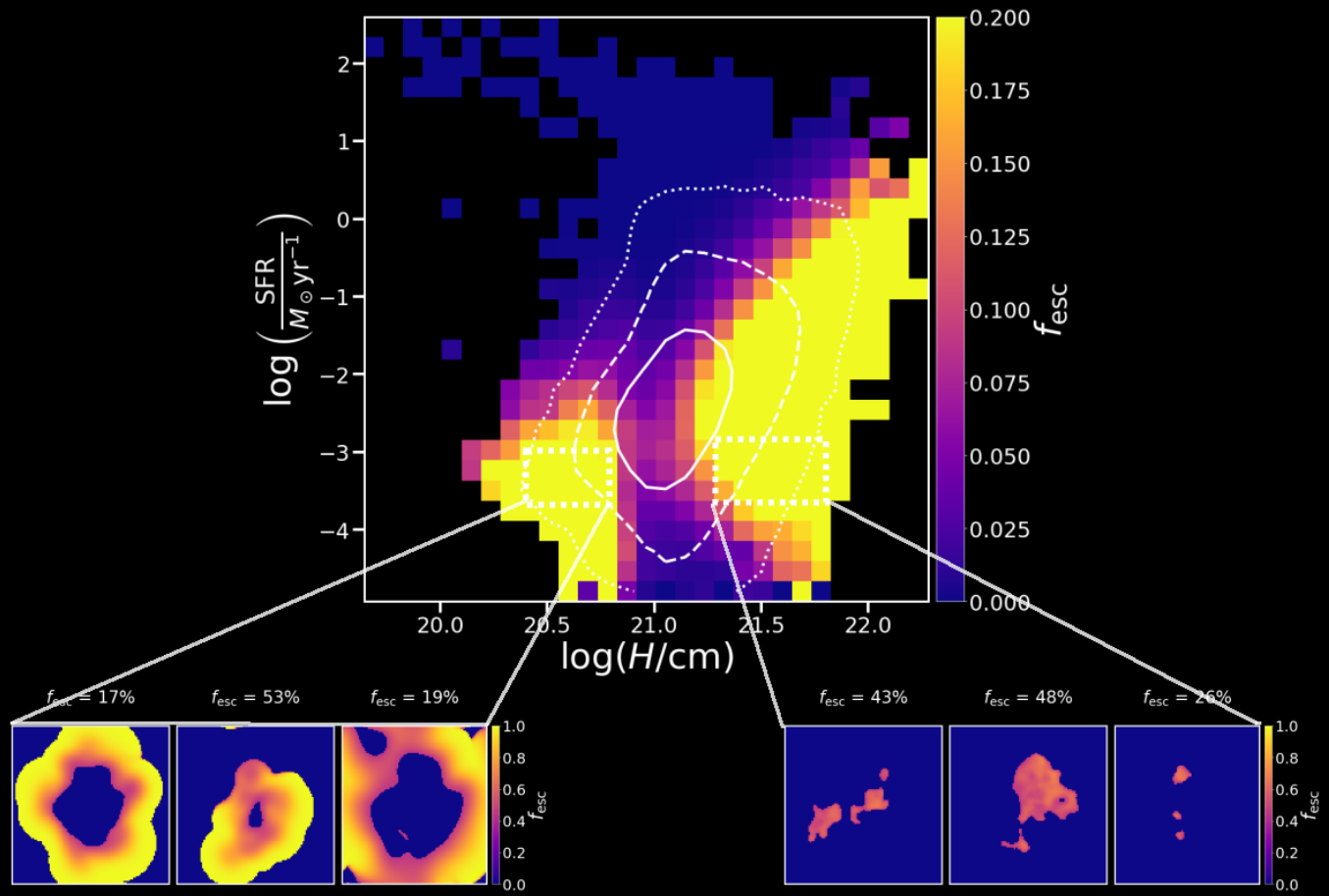
- $\langle f_{\rm esc} \rangle$ decreases with redshift for low $M_\star$ and increases for high $M_\star$
- Low abundance of high $M_\star$ galaxies at high $z \Rightarrow$ overall decrease in $f_{\rm esc}$ with redshift.
- LyC escape into the IGM dominated by light galaxies ($M_\star < 10^8 \mathrm{M}_\odot$)





Semianalytic modelling of LyC escape

- LyC photons have two modes of escape



Extensive SF, high Z

Localized SF, low Z

Conclusions

- RT modelling of $f_{\rm esc}$:
  - For $M_\star < 10^7 \mathrm{M}_\odot$ the distribution of $f_{\rm esc}$ is bimodal.
  - $\langle f_{\rm esc} \rangle$ is strongly dependent on the photon energy. With few photons with $E_\gamma > 54$eV escaping.
  - Non-linear dependence of $f_{\rm esc}$ on the value adopted for $f_{\rm esc,loc}$.
  - Halos with a $M_\star \lesssim 10^{7.5} M_\odot$ contribute most of the ionizing photons.
- Physical modelling of $f_{\rm esc}$:
  - LyC escape dominated by small galaxies $M < 10^8 \mathrm{M}_\odot$
  - Extensive leakage from the outer regions in small high metallicity galaxies
  - Localized leakage through small channels with high SF in younger metal poor galaxies.