Constraining models of escape fraction evolution
Constraining models of escape fraction evolution
\[ N_{b*}(r)N_{\gamma} f_{\text{esc}} \geq (1 + \bar{N}_{\text{rec}})N_{\text{atom}}(r) \]
A key goal of DRAGONS is to connect the evolution of the 21 cm signal from reionization to the large-scale structure of the universe, particularly the growth of dark matter haloes and the formation of galaxies. The structure of reionization is sensitive to galaxy formation processes, such as the cooling of gas and the triggering of star formation. This is manifested in the inequality:

$$N_{b^*}(r)N_\gamma f_{\text{esc}} \geq (1 + \bar{N}_{\text{rec}})N_{\text{atom}}(r)$$

where $N_{b^*}(r)$ is the number of ionizing photons, $N_\gamma$ is the mean number of ionizing photons per baryon, $f_{\text{esc}}$ is the fraction of ionizing photons that escape, $\bar{N}_{\text{rec}}$ is the mean number of recombinations per baryon, and $N_{\text{atom}}(r)$ is the number of stellar baryons in the halo at radius $r$. This inequality reflects the balance between ionizing and absorbing processes in the intergalactic medium.
\[ N_{b^*}(r) N_\gamma f_{\text{esc}} \geq (1 + \bar{N}_{\text{rec}}) N_{\text{atom}}(r) \]

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**Galaxy growth**

**Cosmology**
See upcoming talks by Fuyan Bian & Naveen Reddy for an observational perspective.

See also talk by Mike Norman.
See upcoming talks by Fuyan Bian & Naveen Reddy for an observational perspective.

See also talks by Brad Greig & Catherine Watkinson.
1. WHAT STATISTICAL CONSTRAINTS CAN WE PLACE ON $F_{\text{esc}}$?

2. HOW DOES $F_{\text{esc}}$ VARY AS A FUNCTION OF DIFFERENT GALAXY PROPERTIES?
100 Mpc

MERAXES
[məˈræksɪz] mər-ahk-seez

DRAGONS

ASTRO 3D
100 Mpc

Meraxes

[ˈmɛrəksɪz]  mər-əhks-iz

DRAGONS

ASTRO 3D
100 Mpc

MERAXES
[məˈræksɪz] mər-ahk-seez

DRAGONS
REPRODUCING KEY OBSERVABLES

- SMF (z=0.6—8) [SM+ (2016), Qin+ (2017)]
- BH—M★ relation (z=0.6) [Qin+ (2017), Marshall+ (2019)]
- QSO UV LFs (z>1) [Qin+ (2017)]
- Ionizing emissivity (z>2) [SM+ (2016), Davies+ (in prep)]
- Galaxy UV LF (z>5) [Liu+ (2016), Park+ (2017), Qiu+ (2019)]
- Thompson scattering optical depth (z>6) [SM+ (2016), Geil+ (2016)]
- Galaxy size evolution (z>5) [Liu+ (2017), Marshall+ (2019)]
- LBG correlation functions (z>4) [Park+ (2017), Qiu+ (2018)]
Full hydrodynamic simulations + RT

Meraxes

Semi-numerical models (e.g. 21cmFAST)

Computationally expensive

No direct modelling of galaxies.
Full hydrodynamic simulations + RT

Computationally expensive

PARAMETER EXPLORATION

(E.G. MCMC, BAYESIAN EMULATION, NESTED SAMPLING)

Semi-numerical models (e.g. 21cmFAST)

No direct modelling of galaxies.
Full hydrodynamic simulations + RT

Computationally expensive

PARAMETER EXPLORATION

(E.G. MCMC, BAYESIAN EMULATION, NESTED SAMPLING)

Semi-numerical models (e.g. 21cmFAST)

No direct modelling of galaxies.
The evolution of the galaxy stellar mass function from $z=4-7$
\[ f_{\text{esc}} N_{b^*}(r) N_{\gamma} \]

- **Thompson scattering optical depth**
  - *Constraints:* Approximate timing and duration of reionisation

- **Ionising emissivity evolution (z<6)**
  - *Constraints:* Ionising flux in the IGM post reionisation

- **Dark pixel fraction**
  - *Constraints:* Neutral fraction during latter stages of reionisation
A redshift dependent $f_{\text{esc}}$

$$f_{\text{esc}}(z) = \theta_n \left( \frac{1 + z}{6} \right)^{\theta_z}$$
A redshift dependent $f_{\text{esc}}$

Fixed stellar mass growth history

\[ f_{\text{esc}}(z) = \theta_n \left( \frac{1 + z}{6} \right)^{\theta_z} \]

\[ \dot{N} \]
\[ \tau_e \]
\[ \chi_{\text{HI}} \]
combined

(a) $N$ [Y$_{\text{H}_1}$, Gyr$^{-1}$]
(b) $\dot{N}$ [Y$_{\text{H}_1}$, Gyr$^{-1}$]
(c) $\chi_{\text{HI}}$ [Y$_{\text{H}_1}$, Gyr$^{-1}$]
A redshift dependent $f_{\text{esc}}$

Fixed stellar mass growth history

$$f_{\text{esc}}(z) = \theta_n \left( \frac{1 + z}{6} \right)^{\theta_z}$$
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Fixed stellar mass growth history
A redshift dependent $f_{\text{esc}}$

Fixed stellar mass growth history

$$f_{\text{esc}}(z) = \theta_n \left( \frac{1 + z}{6} \right)^{\theta_z}$$

- $\dot{N}$
- $\tau_e$
- $\chi_{\text{HI}}$
- combined

(a) 
(b) 
(c) 
D’Aloisio et al. (2018)
McGreer et al. (2015)
Planck collaboration (2017)
A redshift dependent $f_{\text{esc}}$

$$f_{\text{esc}}(z) = \theta_n \left( \frac{1 + z}{6} \right)^{\theta_z}$$

**Fixed stellar mass growth history**

![Graphs showing redshift dependent $f_{\text{esc}}$]
A redshift dependent $f_{\text{esc}}$

Fixed stellar mass growth history

$$f_{\text{esc}}(z) = \theta_n \left( \frac{1 + z}{6} \right)^{\theta_z}$$

$$f_{\text{esc}} = 0.08^{+0.02}_{-0.02} \left( \frac{1 + z}{6} \right)^{1.9^{+0.9}_{-1.0}}$$
Degeneracies emerge between star formation, supernova feedback, and escape fraction evolution.

\[ f_{\text{esc}} = 0.09^{+0.02}_{-0.02} \left( \frac{1 + z}{6} \right)^{1.66^{+1.19}_{-0.79}} \]
\[ f_{\text{esc}}(z) = \theta_n \left( \frac{1 + z}{6} \right)^{\theta_z} \]
\( f_{\text{esc}}(z) = \theta_n \left( \frac{1 + z}{6} \right)^{\theta_z} \)
$$f_{\text{esc}}(x, z) = \theta_n \left( \frac{1 + z}{6} \right)^{\theta_z} \left( \frac{x}{\eta} \right)^{\theta_x}$$
UNFINALISED RESULTS!
SSFR dependant $f_{\text{esc}}$

$$f_{\text{esc}} = \theta_n \left( \frac{1 + z}{6} \right) \theta_z \left( \frac{\text{SSFR}}{\text{yr}^{-1}} \right) \theta_x$$
SSFR dependant $f_{\text{esc}}$

$$f_{\text{esc}} = \theta_n \left( \frac{1+z}{6} \right) \theta_z \left( \frac{\text{SSFR}}{\text{yr}^{-1}} \right) \theta_x$$

SSFR is stochastic...
\[ f_{\text{esc}} = \theta_n \left( \frac{1 + z}{6} \right) \theta_z \left( \frac{M_{\text{vir}}}{10^{10} M_\odot} \right) \theta_x \]
$f_{\text{esc}} = \theta_n \left( \frac{1 + z}{6} \right) \theta_z \left( \frac{M_{\text{vir}}}{10^{10} M_\odot} \right) \theta_x$
The escape fraction is a key property to understand if we want to maximise what we learn about galaxy formation from future 21cm observations.

Semi-analytic modelling of galaxy growth & the EoR is a valuable tool for investigating this poorly constrained regime.
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Semi-analytic modelling of galaxy growth & the EoR is a valuable tool for investigating this poorly constrained regime.