Constraining the escape fraction of Lyman continuum photons from reionization epoch galaxies using the James Webb Space Telescope

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What is the point?

The punchline!

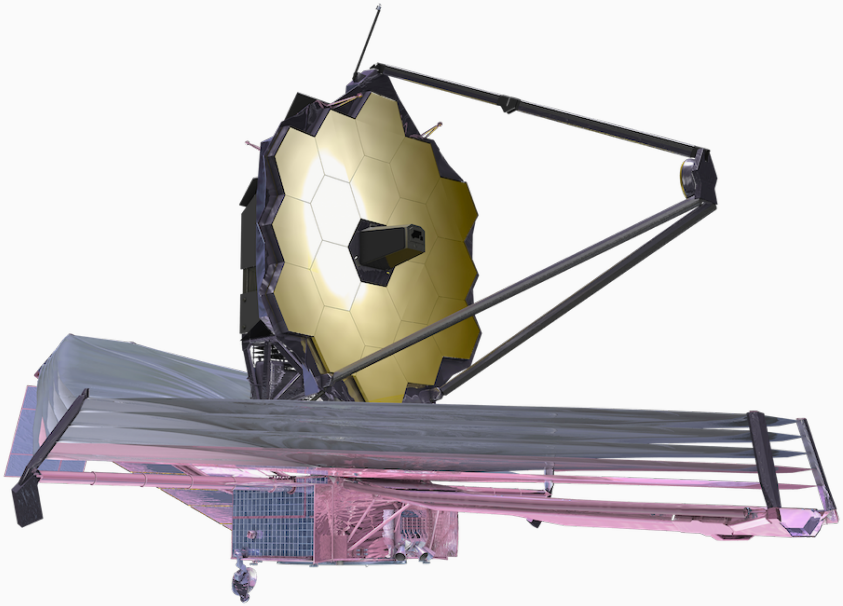


Image from https://jwst-docs.stsci.edu/display/JS/jwst+SEO+Home

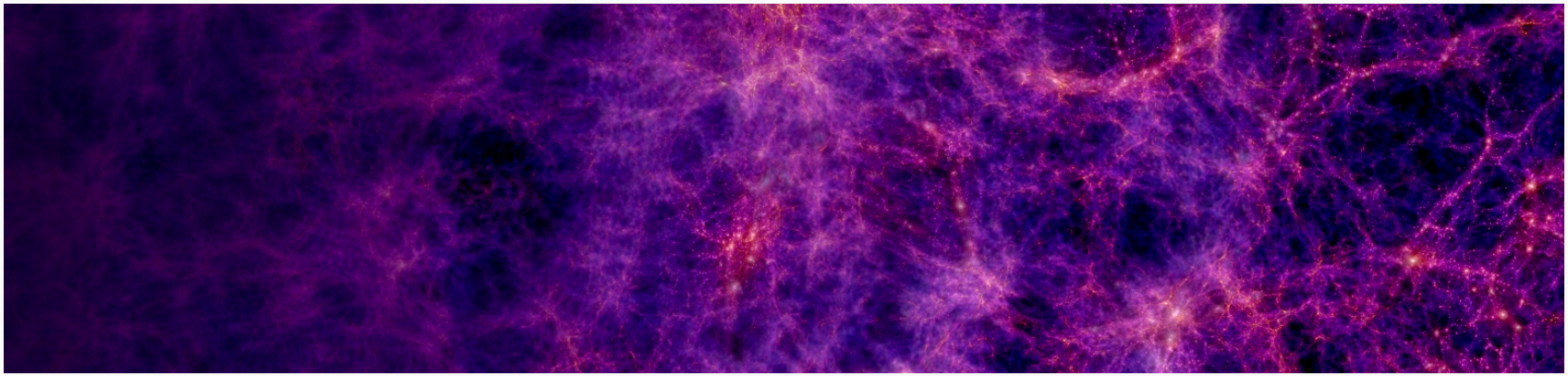
Our method can estimate the escape fraction of ionizing photons from reionization epoch galaxies

We want to know if galaxies could be the driving mechanism of the cosmic reionization

We could do so without a need for dedicated observations (Use JWST Early Release Science Program)

In short: We can squeeze more science out of the JWST!

Reionization & JWST

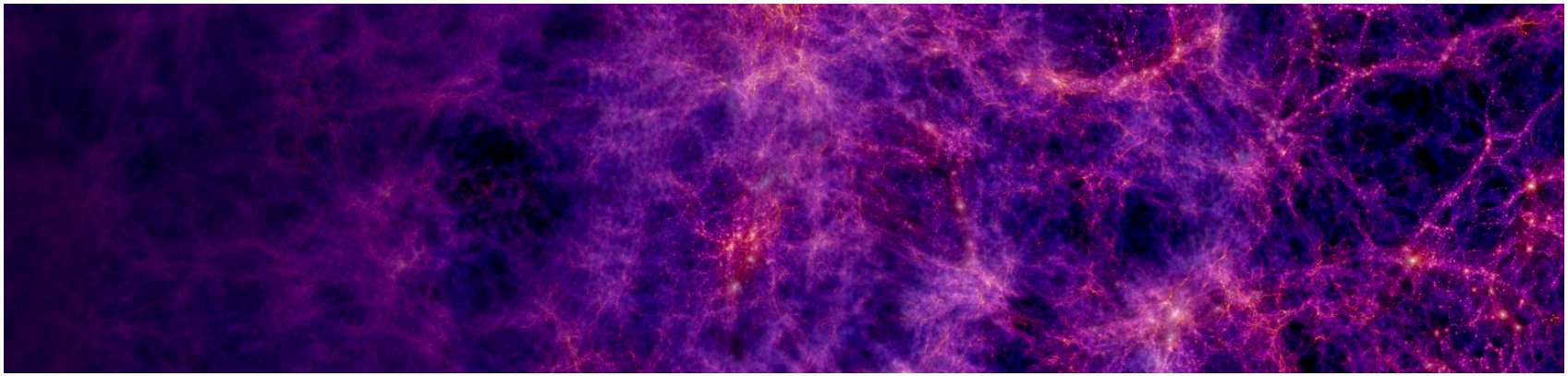


Remixed image from Millenium simulation

$z \sim 10$

$z \sim 6$

Reionization & JWST



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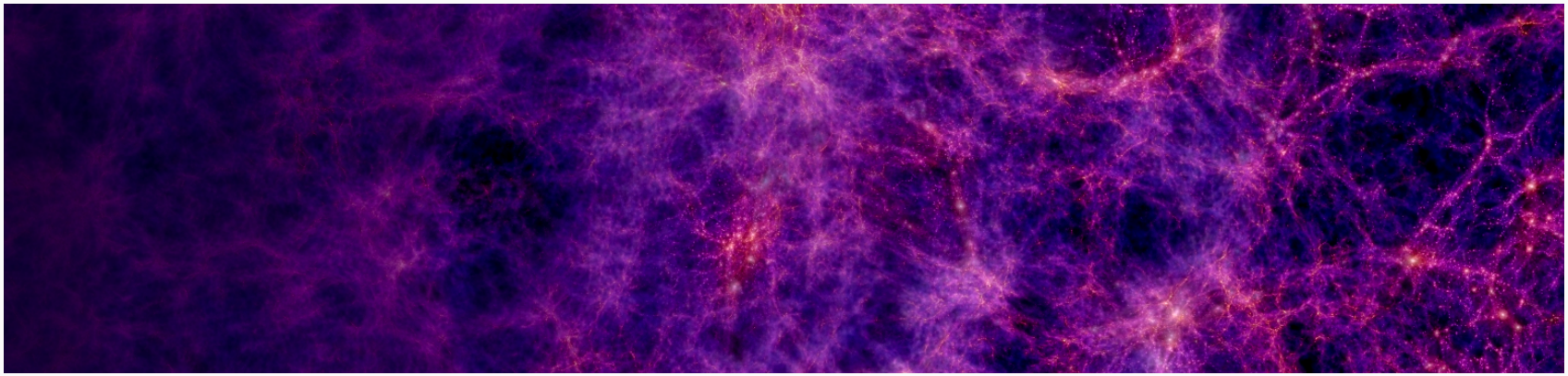
$z \sim 10$ $z \sim 6$

- To reionize the universe, we have to have sources of ionizing radiation

Reionization & JWST



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$z \sim 10$ $z \sim 6$

- To reionize the universe, we have to have sources of ionizing radiation
- Constraints are consistent with galaxy driven reionization **IF** the typical escape fraction is large enough ($\sim 20\%$).

Reionization: Problems & Solutions

Reionization photon budget: $\dot{N}_{\rm ion}(z) = f_{\rm esc}(z)\xi_{\rm ion}(z)\rho_{\rm UV}(z)$

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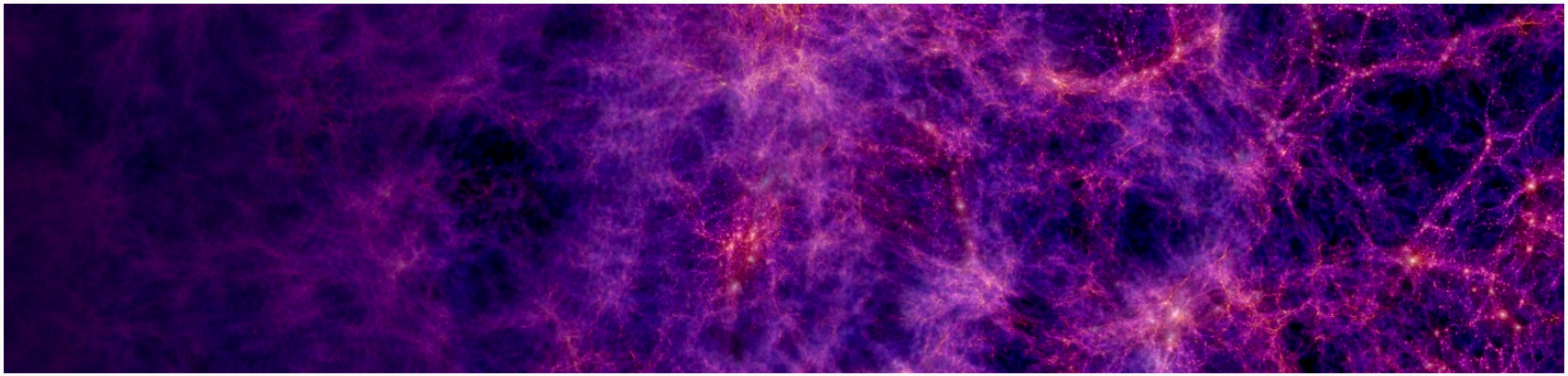
- $\rho_{\rm UV}(z)$ - Number of star forming galaxies during reionization
- $\xi_{\rm ion}$ - How efficiently galaxies produce ionizing radiation
- f_{esc} - How much ionizing radiation is escaping the galaxy (hard to determine)

Reionization: Problems & Solutions



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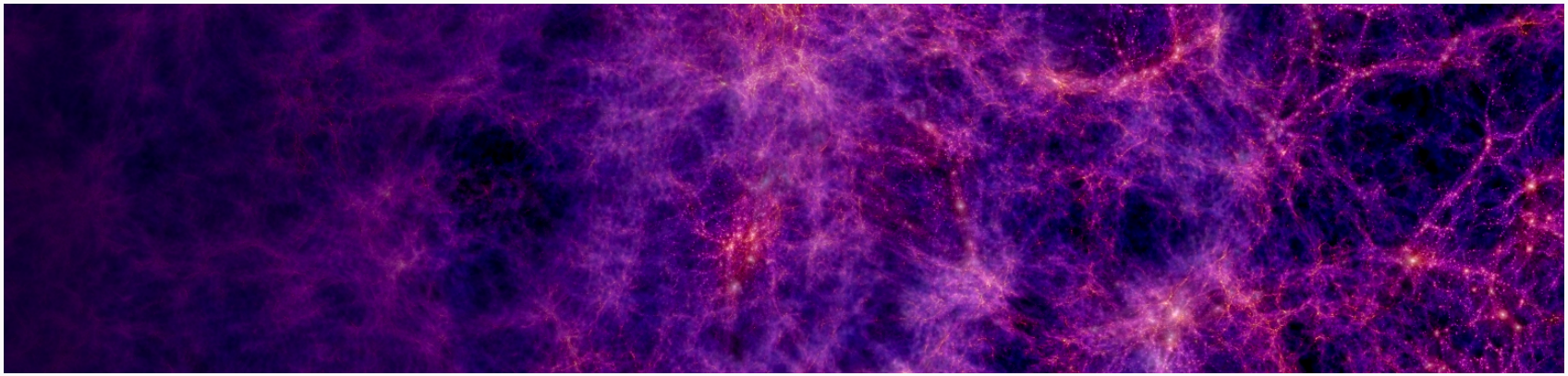
Neutral IGM at $z > 5$ makes it impossible to directly detect escaping LyC.

Reionization: Problems & Solutions



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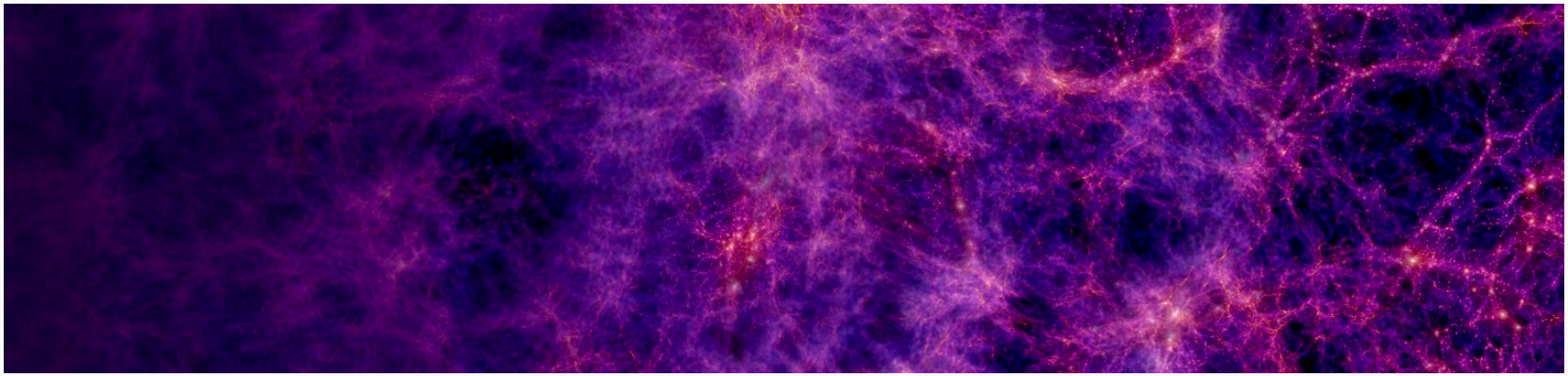

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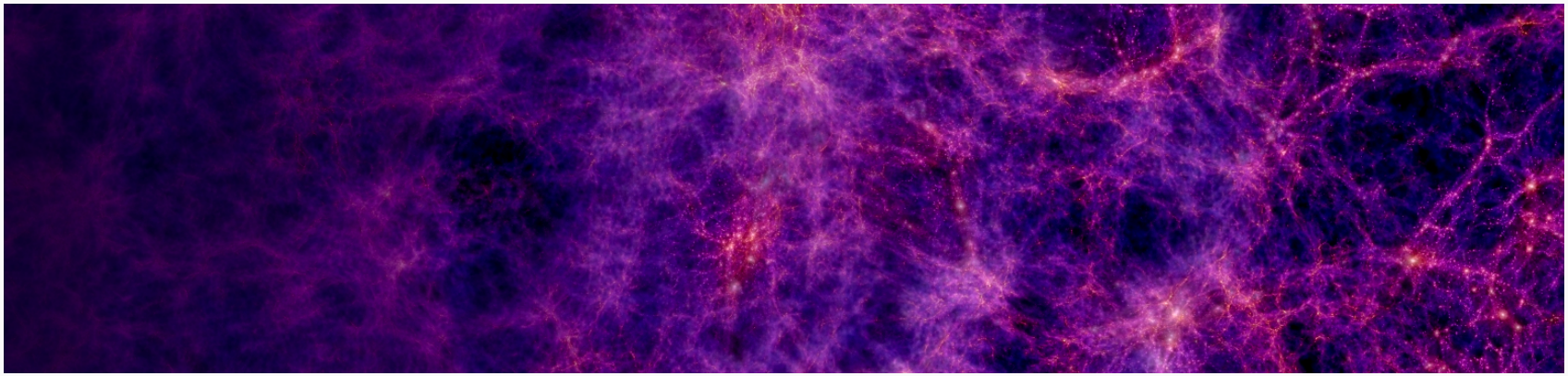

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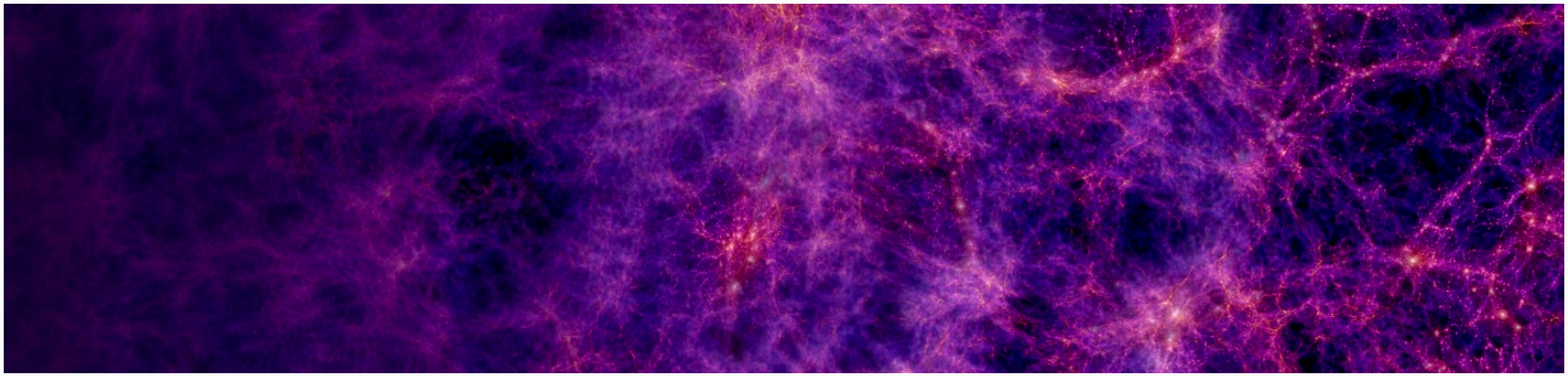

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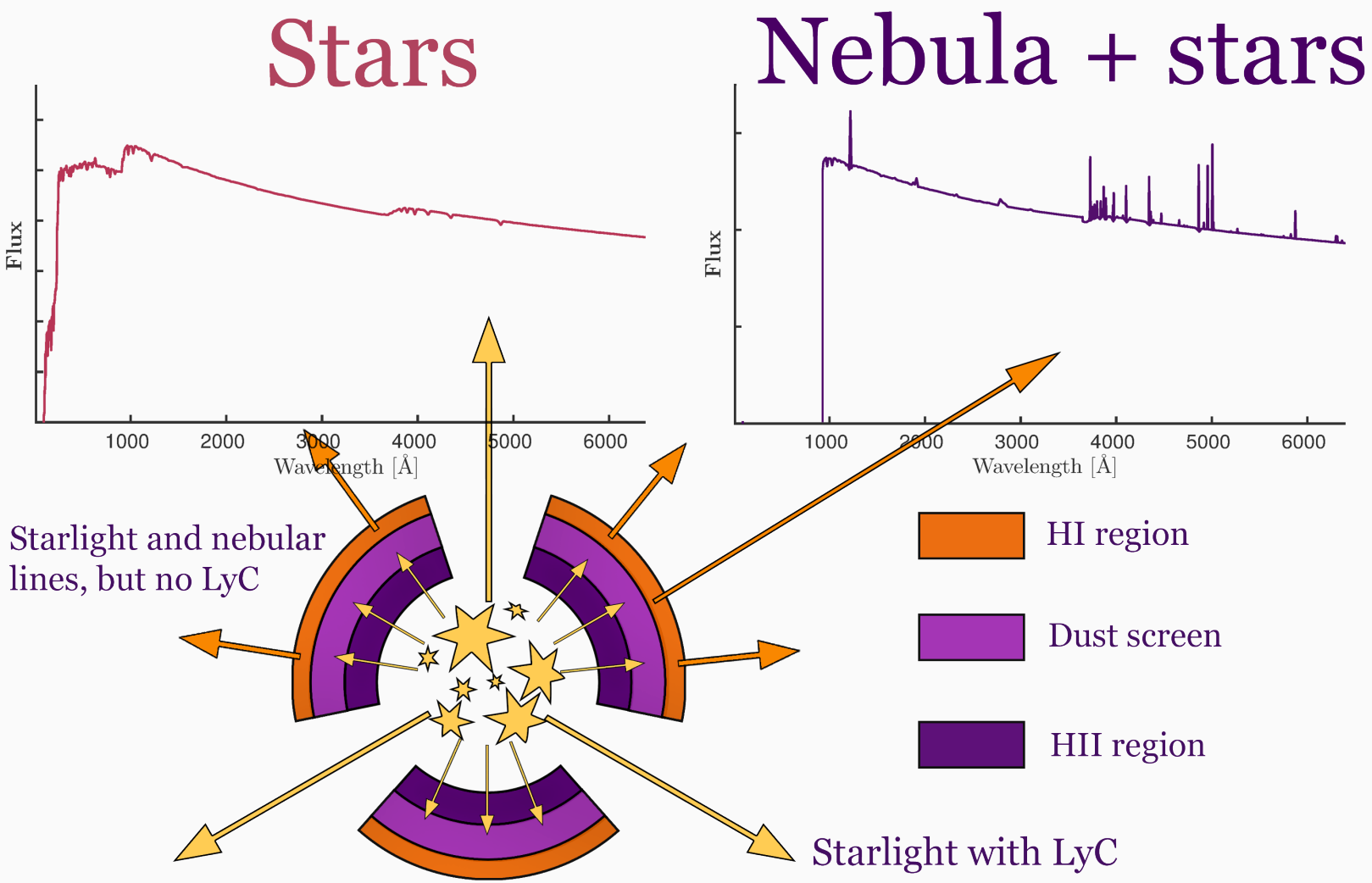
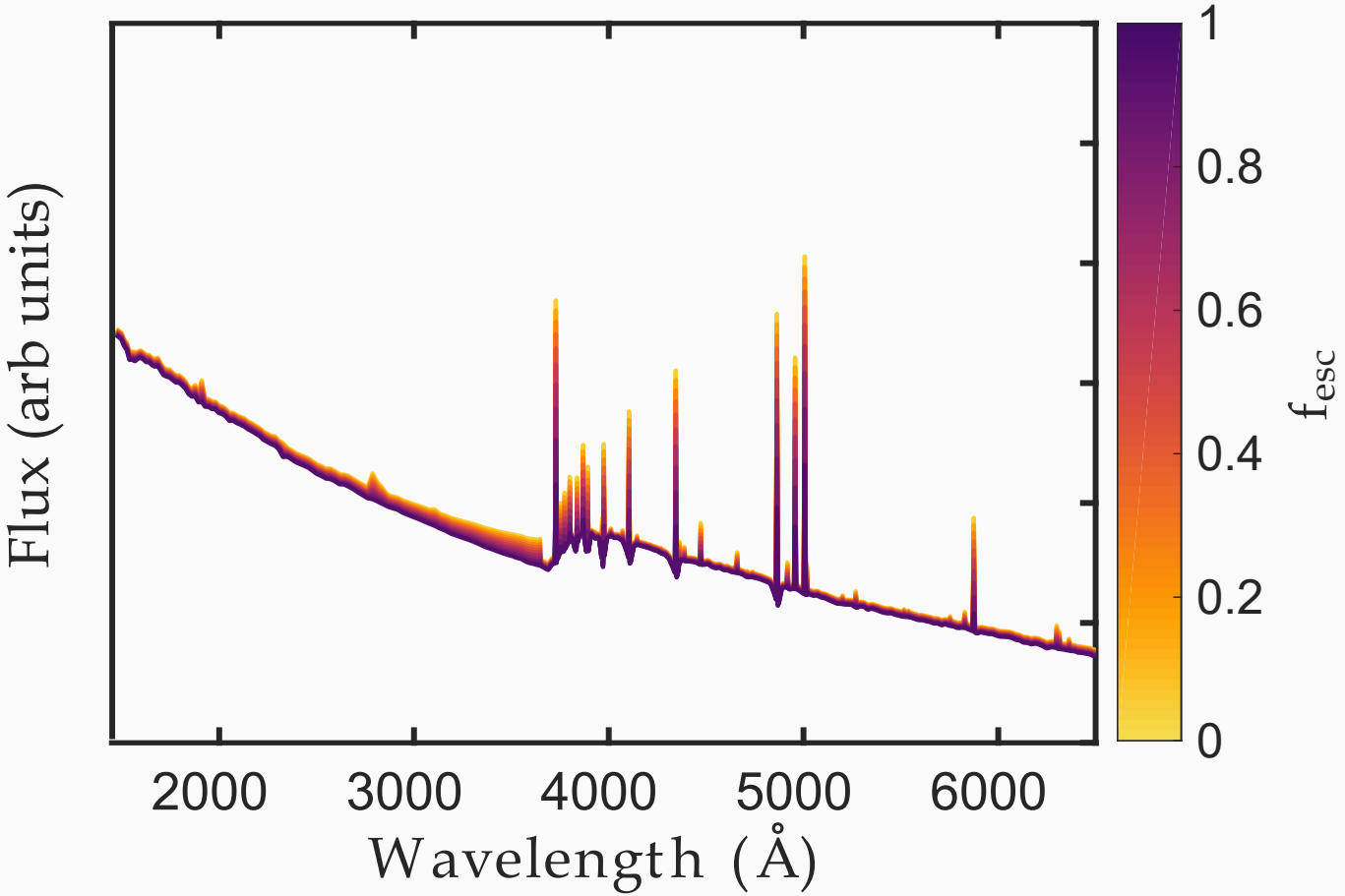
JWST NIRSpec could be used to indirectly determine the escape fraction

Reionization: Problems & Solutions



Estimating the escape fraction

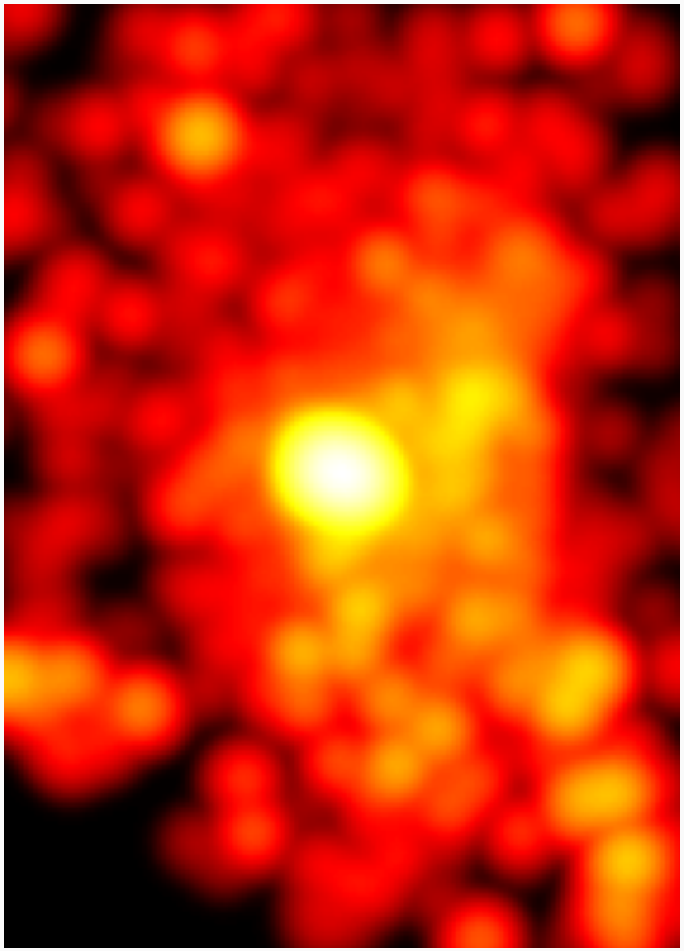


The escape fraction will determine the strength of certain spectral features like emission lines and UV slope

But does this work on realistic galaxies?

Estimating the escape fraction

We test the method on simulated galaxies!



Shimizu et al. 2014

4 different simulation suites:

- **Shimizu et al.**
- **CROC** (Gnedin et al.)
- **Finlator et al.**
- **FiBY** (Paardekooper et al.)

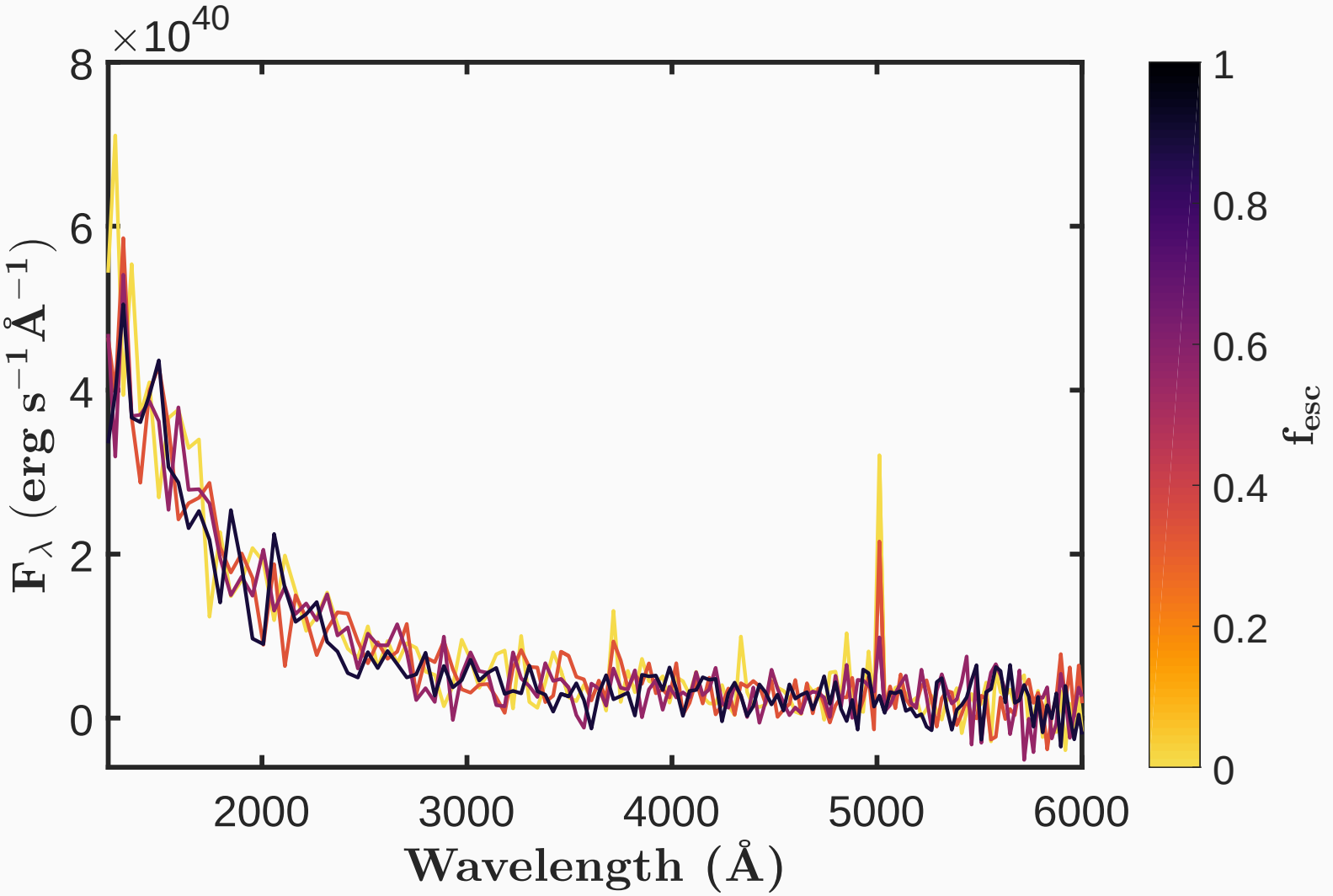
LYCAN + NIRSpec Noise = SEDs with varying f_{esc}[1].

[1] Available at http://www.astro.uu.se/~ez/lycan/lycan.html

There are a lot of combinations, so I will focus on results from one.

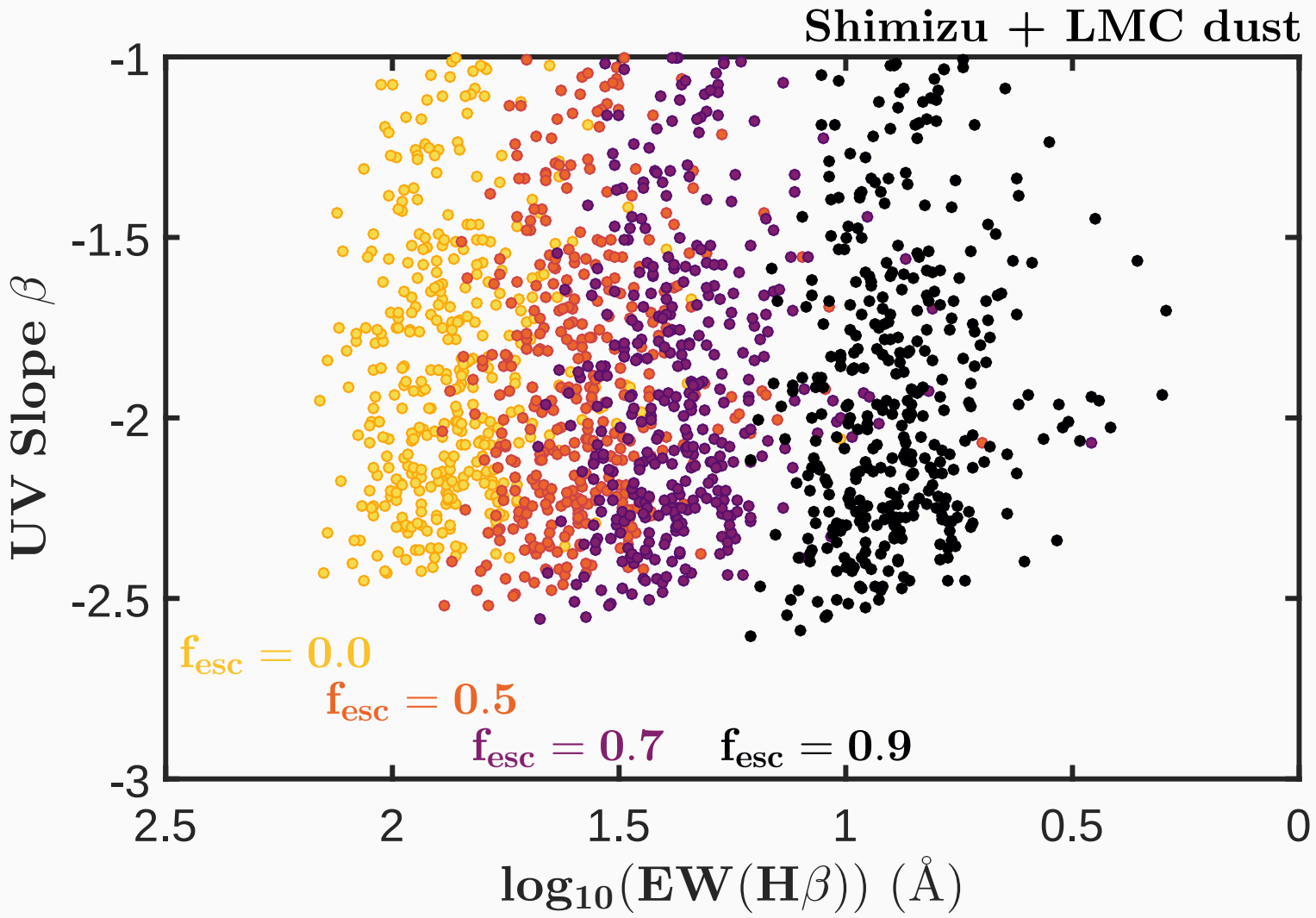
Estimating the escape fraction: Results

Mock spectrum of reionization epoch galaxies



3 hour NIRSpec spectrum with R=100 of $m_{AB} \approx 27$ galaxy.

Estimating the escape fraction: Results



Can we improve the method by including more features than UV slope and EW(Hβ)?

Machine learning

Paper on Arxiv: http://arxiv.org/abs/1603.09610

A MACHINE-LEARNING APPROACH TO MEASURING THE ESCAPE OF IONIZING RADIATION FROM GALAXIES IN THE REIONIZATION EPOCH

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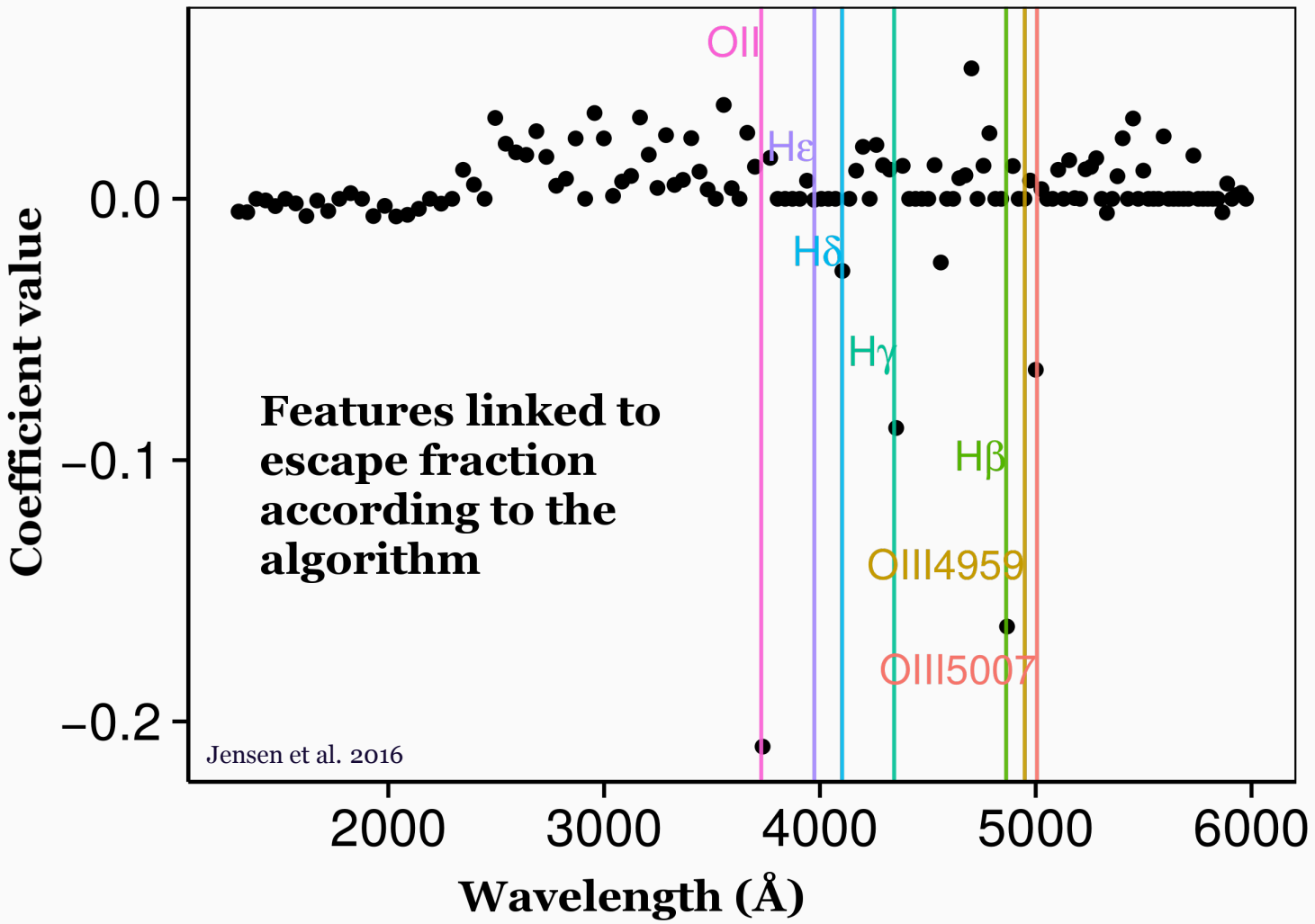
Draft version March 31, 2016

ABSTRACT

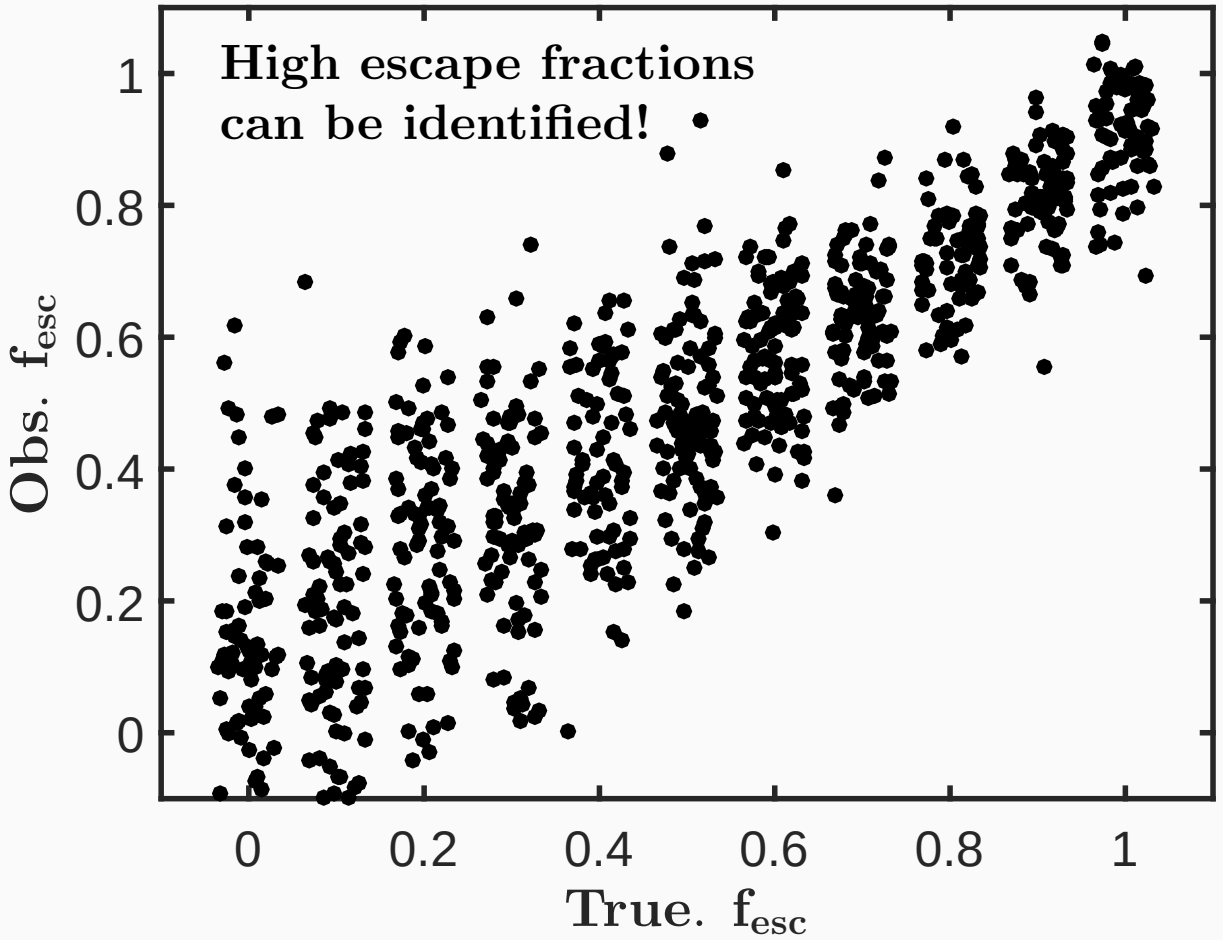
Recent observations of galaxies at $z \gtrsim 7$, along with the low value of the electron scattering optical depth measured by the Planck mission, make galaxies plausible as dominant sources of ionizing photons during the epoch of reionization. However, scenarios of galaxy-driven reionization hinge on the assumption that the average escape fraction of ionizing photons is significantly higher for galaxies in the reionization epoch than in the local Universe. The NIRSpec instrument on the James Webb Space Telescope (JWST) will enable spectroscopic observations of large samples of reionization-epoch galaxies. While the leakage of ionizing photons will not be directly measurable from these spectra, the leakage is predicted to have an indirect effect on the spectral slope and the strength of nebular emission lines in the rest-frame ultraviolet and optical. Here, we apply a machine learning technique known as lasso regression on mock JWST/NIRSpec observations of simulated $z = 7$ galaxies in order to obtain a model that can predict the escape fraction from JWST/NIRSpec data. Barring systematic biases in the simulated spectra, our method is able to retrieve the escape fraction with a mean absolute error of $\Delta f_{\rm esc} \approx 0.12$ for spectra with $S/N \approx 5$ at a rest-frame wavelength of 1500 Å for our fiducial simulation. This prediction accuracy represents a significant improvement over previous similar approaches.

Keywords: galaxies: high-redshift – dark ages, reionization, first stars – methods: statistical

Machine learning



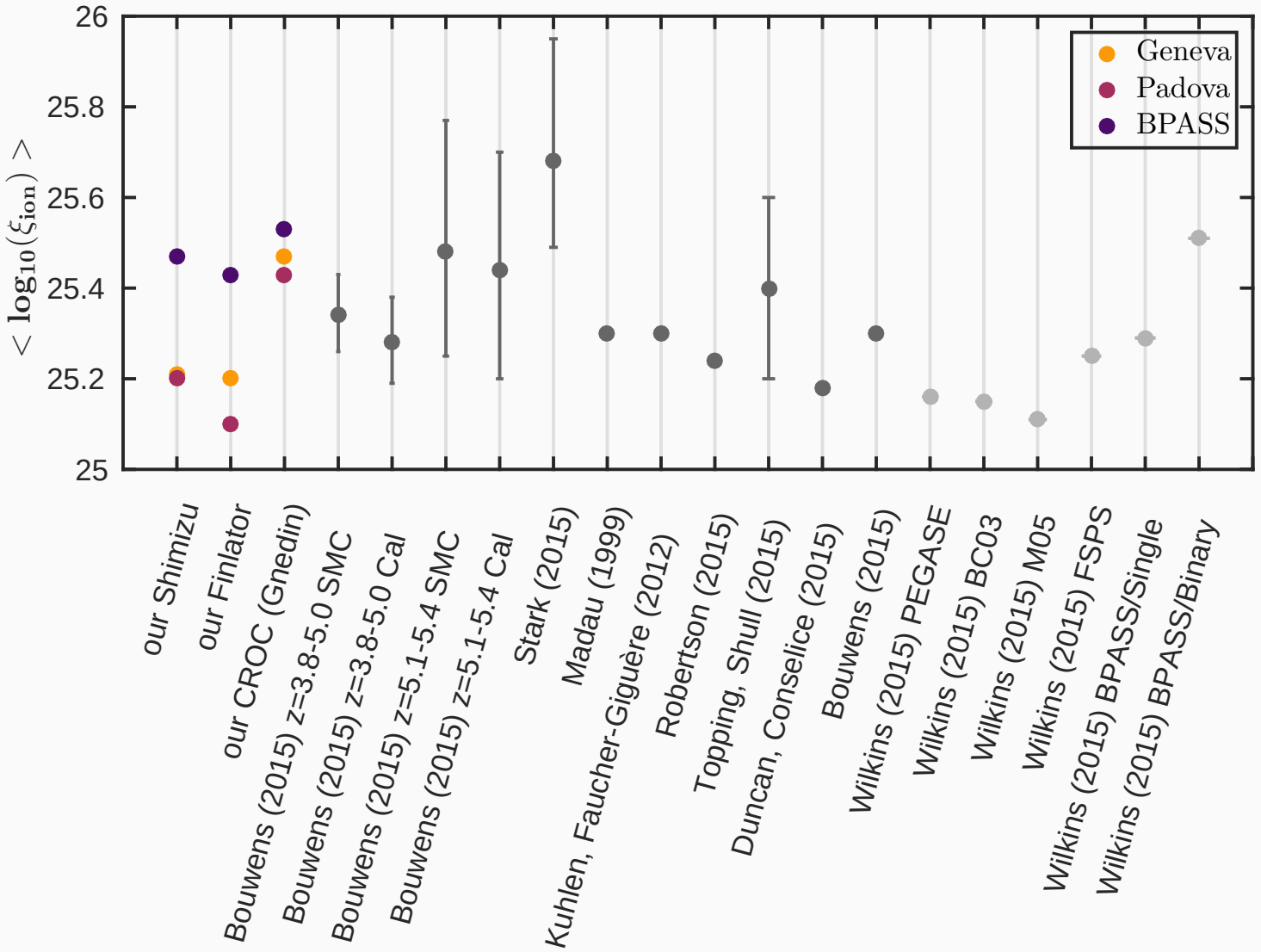
Machine learning



NIRSpec spectra with R=100 with $S/N = 5$ (in bin centered at 1500 Å).

How does the LyC production efficiency look? Are these galaxies typical?

Results: Simulations



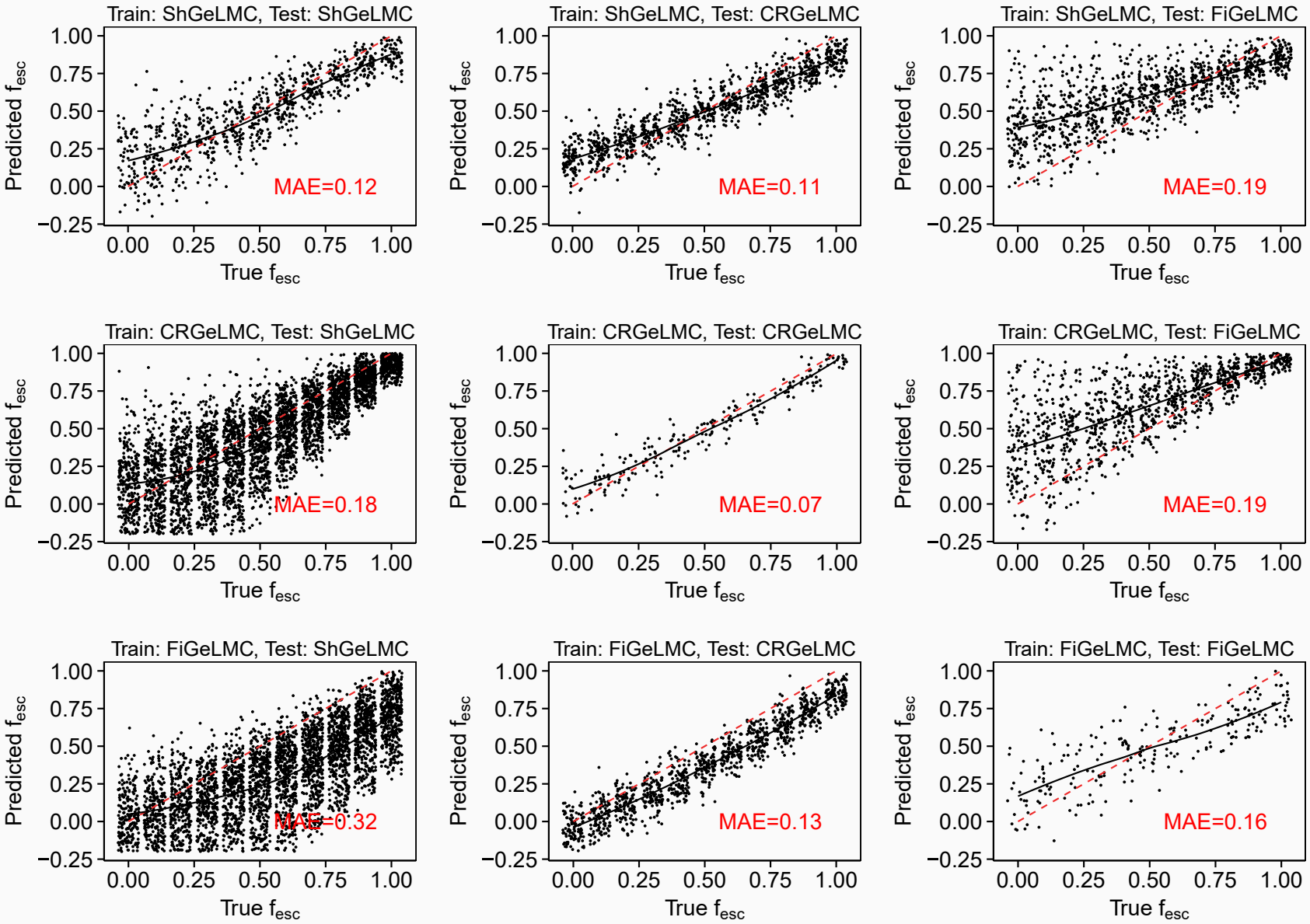
The point: Again (Summary)

- Determining the escape fraction of ionizing photons for reionization epoch galaxies is crucial for determining if galaxies drove reionization.

- JWST/NIRSpec can allow us to determine the escape fraction of ionizing photons emitted from reionization epoch galaxies

- The project could use observations from JWST ERS (planned April 2019)

- The SEDs that were produced in order to test the method are available to the public at http://www.astro.uu.se/~ez/lycan/lycan.html.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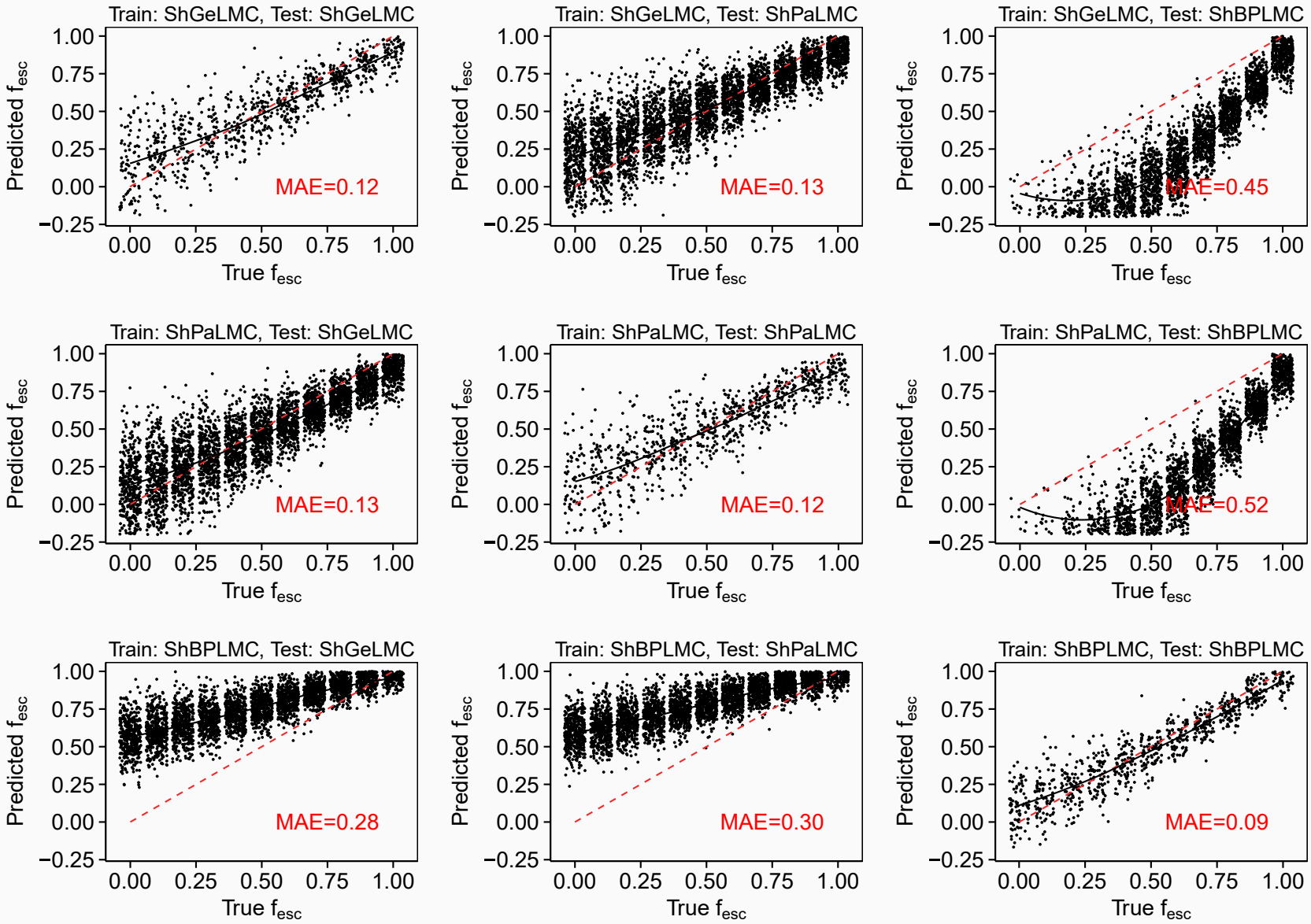
MAE=0.12
Train: ShGeLMC, Test: CRGeLMC
MAE=0.11
Train: ShGeLMC, Test: FiGeLMC
MAE=0.19
Train: CRGeLMC, Test: ShGeLMC
MAE=0.18
Train: CRGeLMC, Test: CRGeLMC
MAE=0.07
Train: CRGeLMC, Test: FiGeLMC
MAE=0.19
Train: FiGeLMC, Test: ShGeLMC
MAE=0.32
Train: FiGeLMC, Test: CRGeLMC
MAE=0.13
Train: FiGeLMC, Test: FiGeLMC
MAE=0.16
Predicted f_{esc}
True f_{esc}
1.00
0.75
0.50
0.25
0.00
−0.25
0.00
0.25
0.50
0.75
1.00

Jensen et al.


Train: ShGeLMC, Test: ShGeLMC
MAE=0.12
Train: ShGeLMC, Test: ShPaLMC
MAE=0.13
Train: ShGeLMC, Test: ShBPLMC
MAE=0.45
Train: ShPaLMC, Test: ShGeLMC
MAE=0.13
Train: ShPaLMC, Test: ShPaLMC
MAE=0.12
Train: ShPaLMC, Test: ShBPLMC
MAE=0.52
Train: ShBPLMC, Test: ShGeLMC
MAE=0.28
Train: ShBPLMC, Test: ShPaLMC
MAE=0.30
Train: ShBPLMC, Test: ShBPLMC
MAE=0.09
Predicted f_{esc}
True f_{esc}
1.00
0.75
0.50
0.25
0.00
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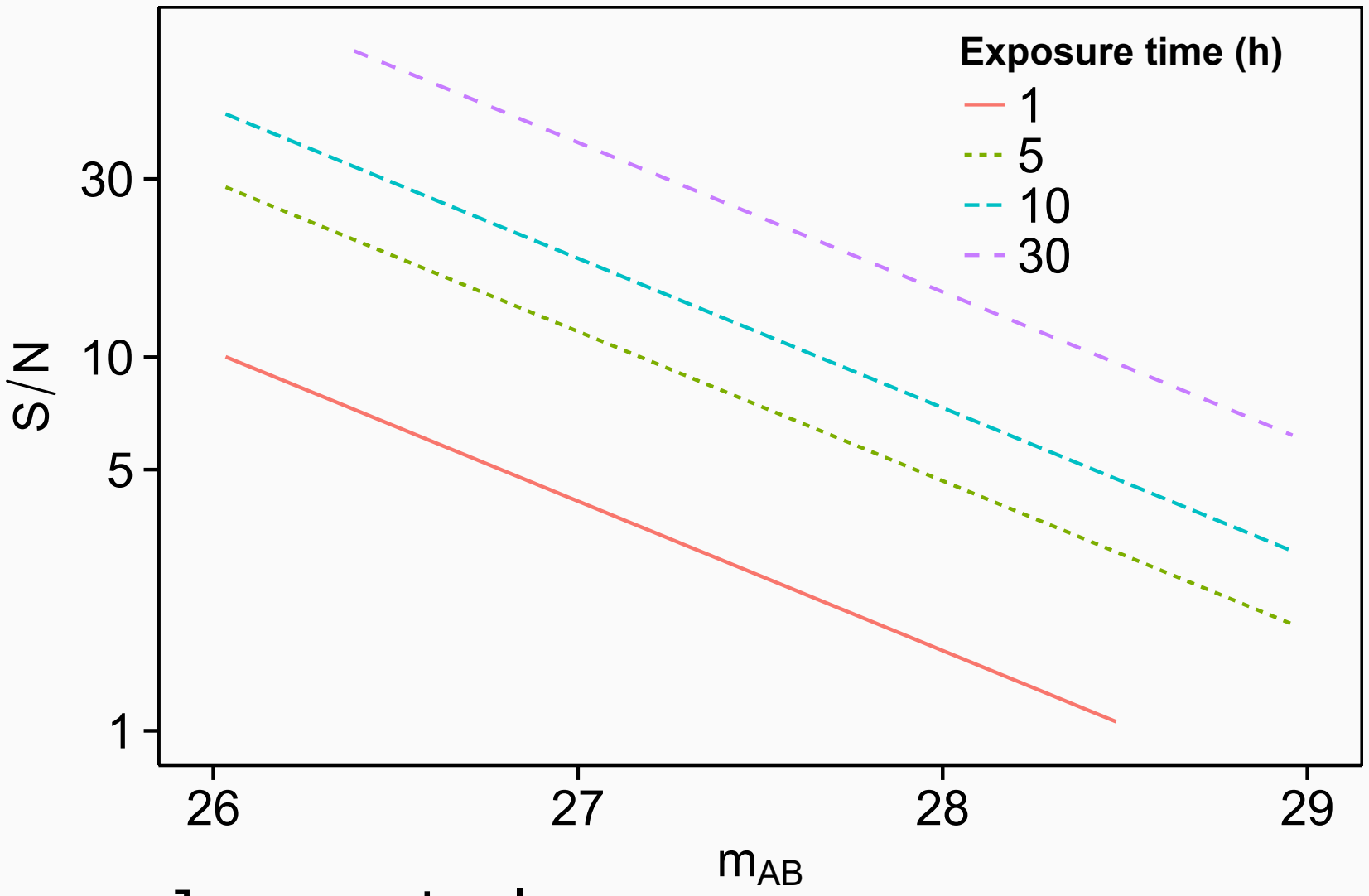
0.25
0.50
0.75
1.00



Jensen et al.