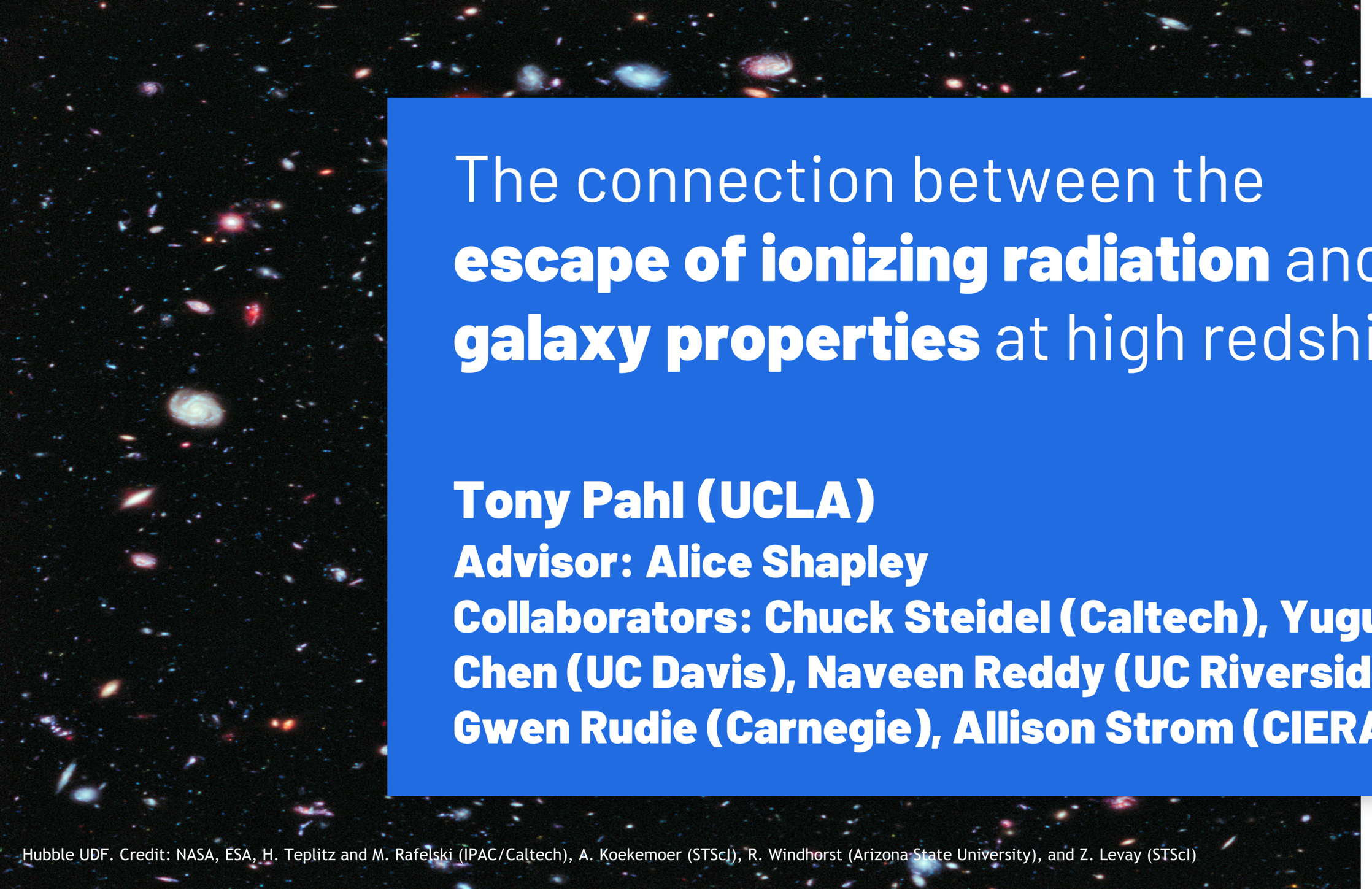


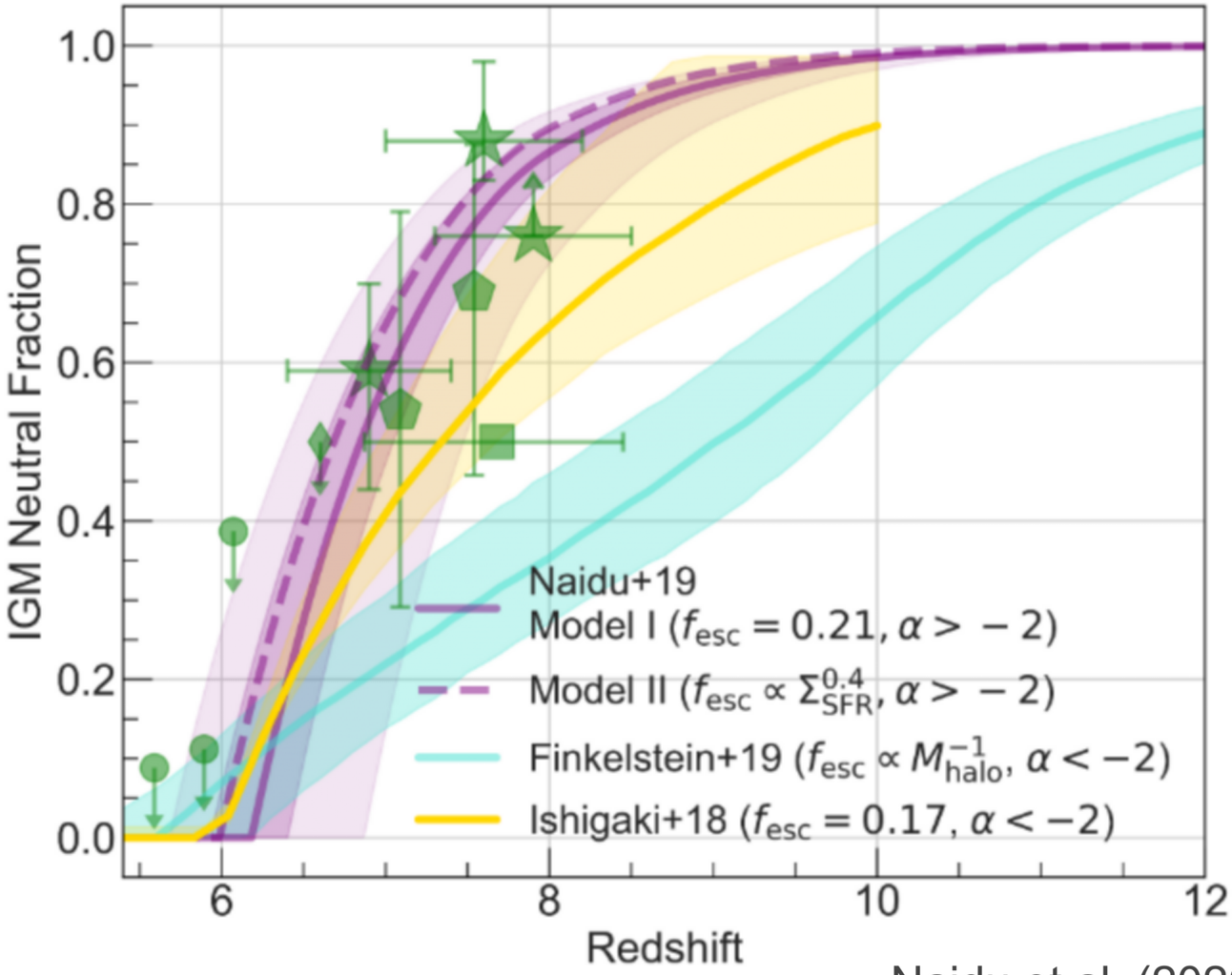
The connection between the **escape of ionizing radiation** and **galaxy properties** at high redshift

Tony Pahl (UCLA)
Advisor: Alice Shapley
Collaborators: Chuck Steidel (Caltech), Yuguang Chen (UC Davis), Naveen Reddy (UC Riverside), Gwen Rudie (Carnegie), Allison Strom (CIERA)

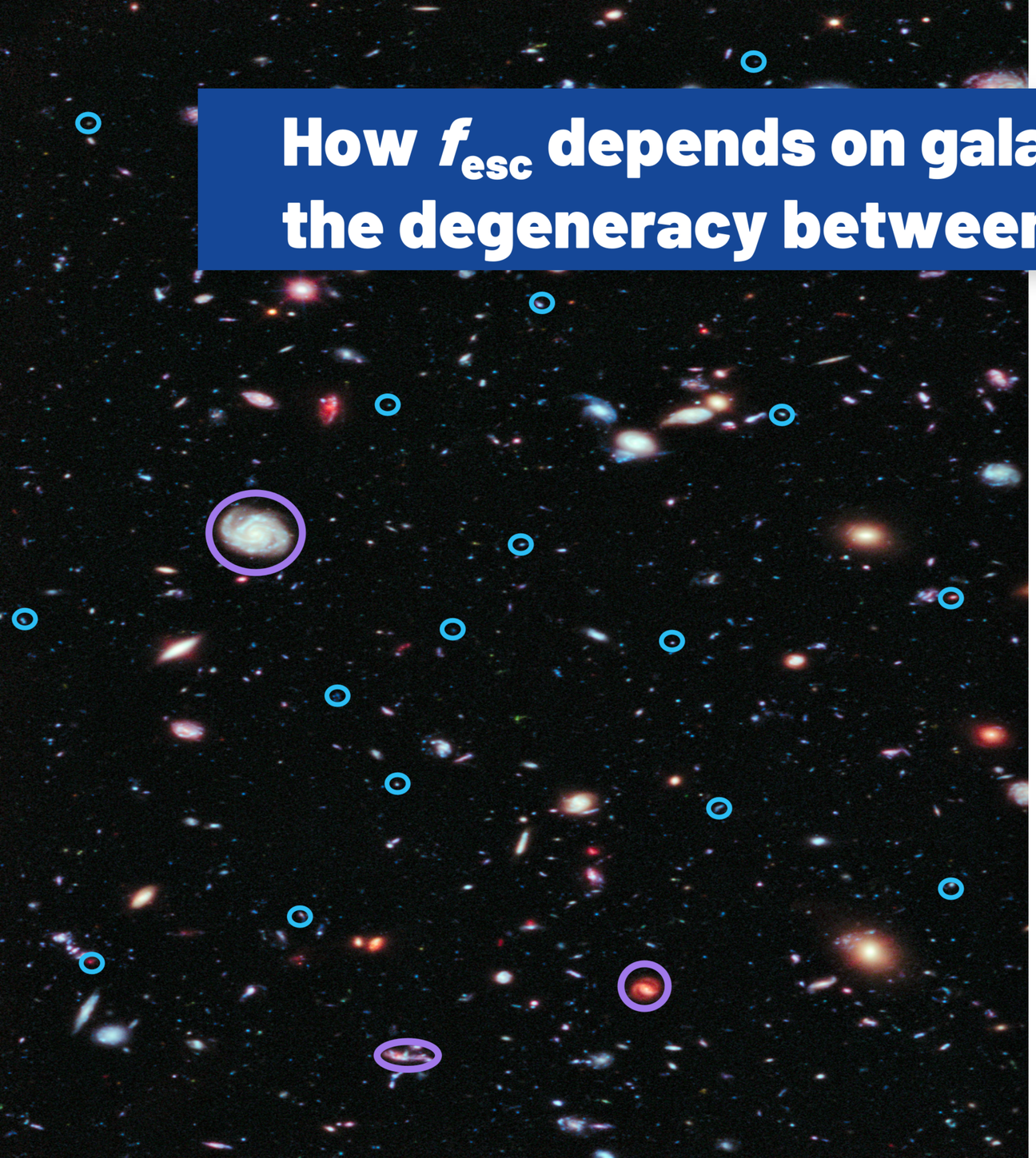
Hubble UDF. Credit: NASA, ESA, H. Teplitz and M. Rafelski (IPAC/Caltech), A. Koekemoer (STScI), R. Windhorst (Arizona State University), and Z. Levay (STScI)

The timeline of reionization is under debate

- Rapid vs. slow reionization



Naidu et al. (2020)



How f_{esc} depends on galaxy property can break the degeneracy between reionization models

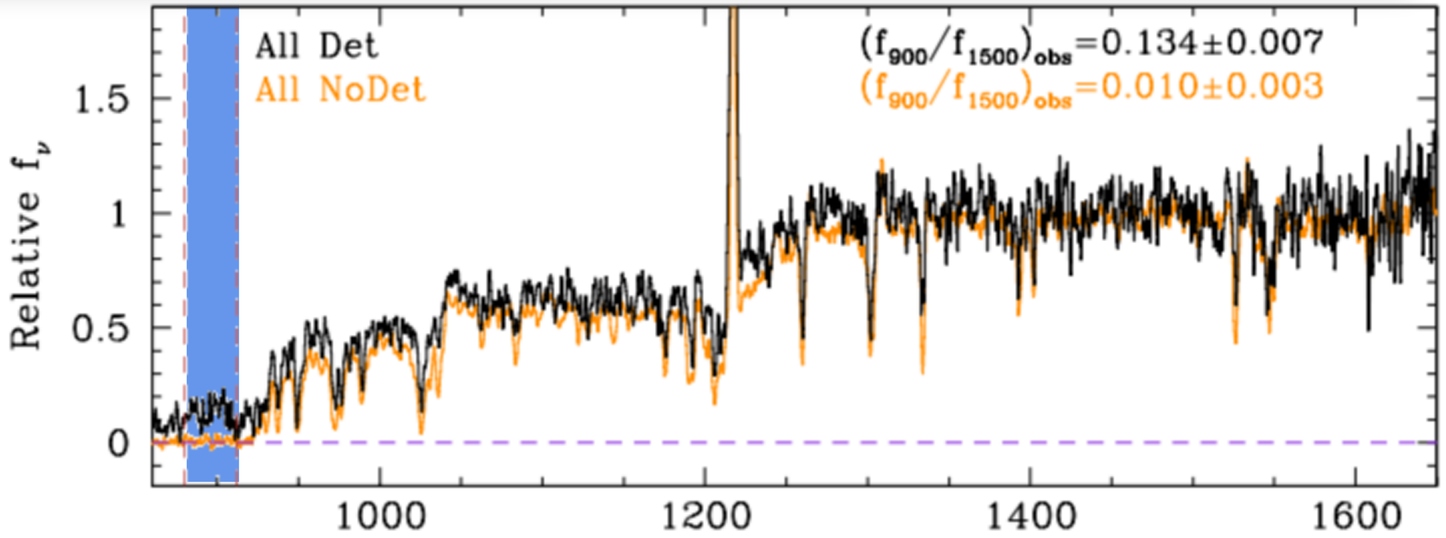
- "Democratic":
  driven by numerous faint sources with high f_{esc}

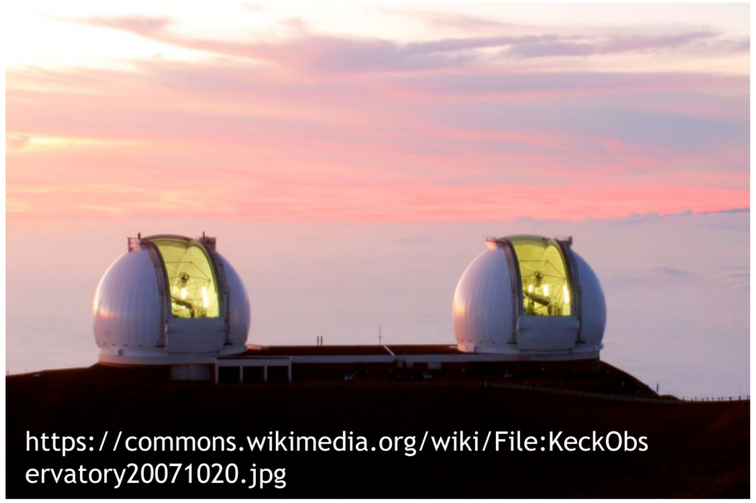
- "Oligarchical":
  <5% of galaxies contribute >80% of reionization budget

Naidu et al. (2020)

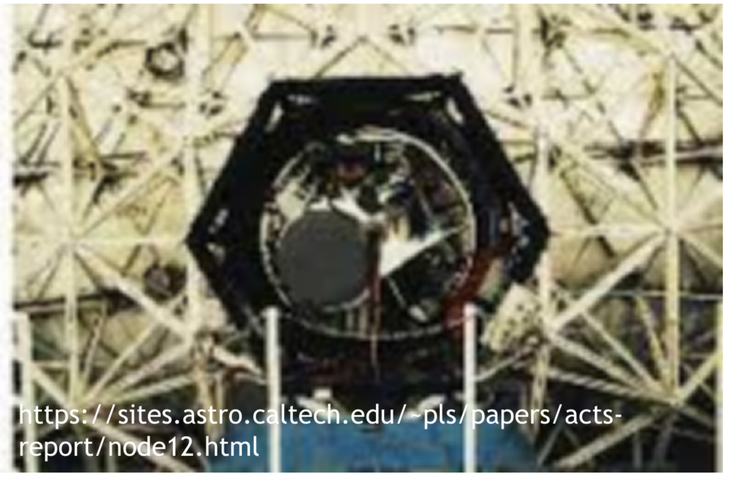
What galaxy properties correlate with f_{esc}?

Keck Lyman Continuum Spectroscopic Survey: A deep LRIS survey of star-forming galaxies at z~3





https://commons.wikimedia.org/wiki/File:KeckObservatory20071020.jpg

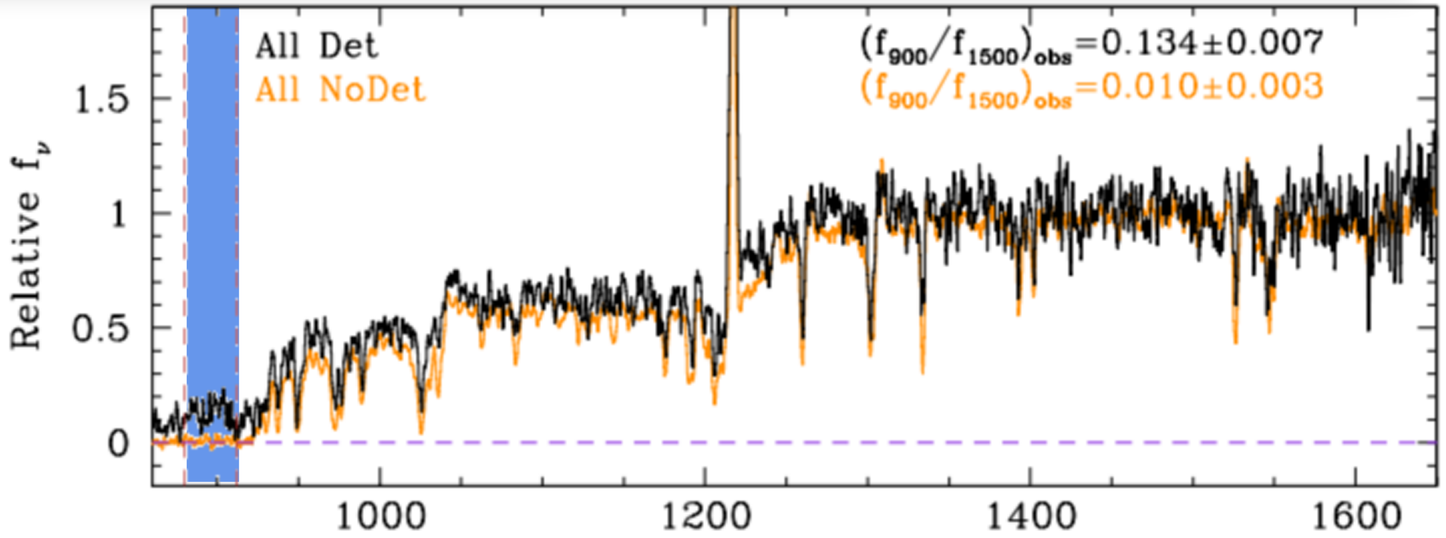


https://sites.astro.caltech.edu/~pls/papers/acts-report/node12.html

Steidel et al. (2018)

What galaxy properties correlate with f_{esc}?

Keck Lyman Continuum Spectroscopic Survey: A deep LRIS survey of star-forming galaxies at z~3



- After contamination removal, 13 / 120 galaxies had significant LyC detections
- $\langle f_{esc} \rangle = 0.06 \pm 0.01$
- $\varepsilon_{LyC} \simeq 5.5 \times 10^{24}$ erg s^{-1} Hz^{-1} Mpc^{-3}
- Higher f_{esc} found with greater Lyα equivalent width, lower UV luminosity

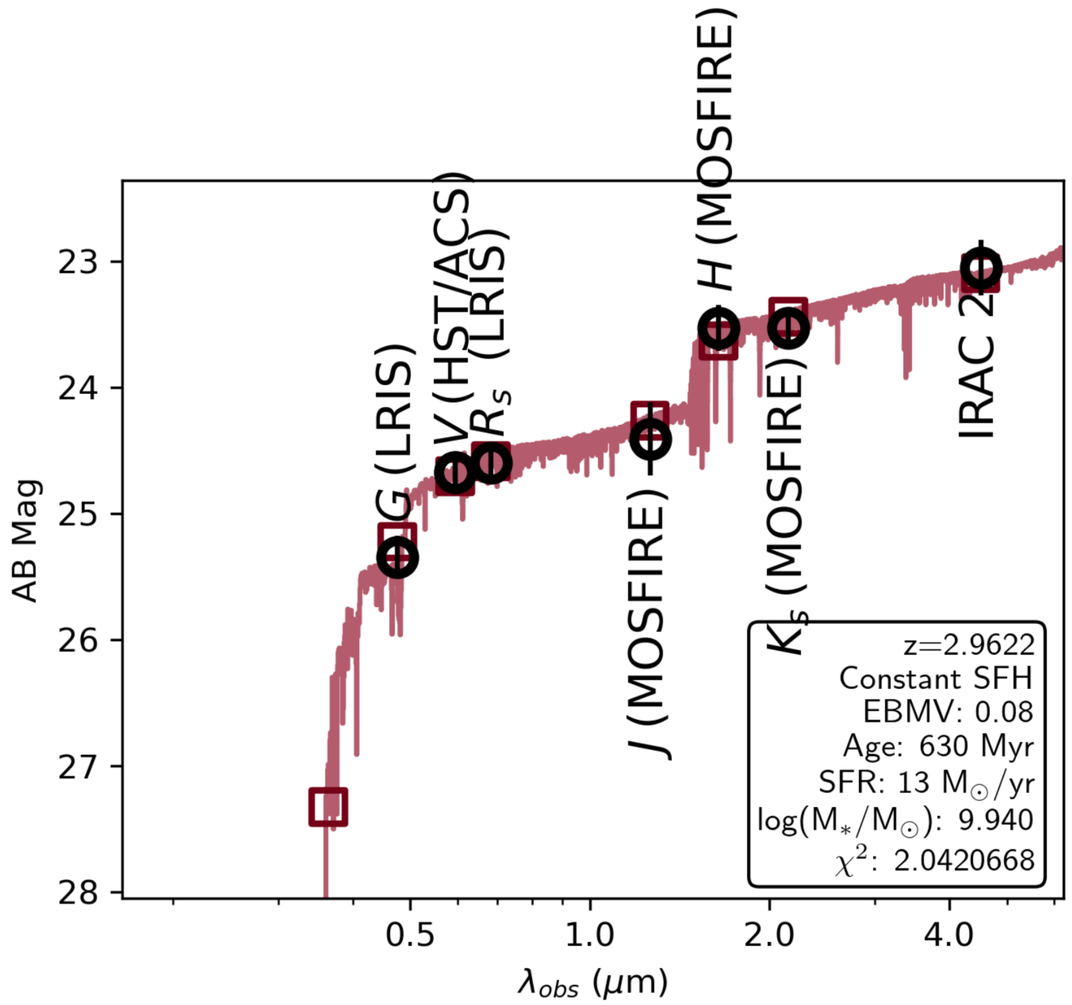
Pahl et. al (2021)

A wealth of photometric data is available for the objects in KLCS

Filter	Instrument
U_n, G, R_s, I	COSMIC (Palomar), Prime Focus Imager (WHT), Keck/LRIS
u^*, g', r', i', z'	CFHT Legacy Survey
J_{125}, H_{160}, V_{606}	HST/WFC3, HST/ACS
J, H, K_s	Keck/MOSFIRE, Fourstar (Magellan Baade), CFHT/WIRCam
IRAC1, IRAC2, IRAC3	Spitzer/IRAC

Pahl et al. (2023)

A wide range of galaxy properties can be determined from fits to Spectral Energy Distributions (SED)



E(B-V)
stellar mass (M*)
star-formation rate (SFR)
age

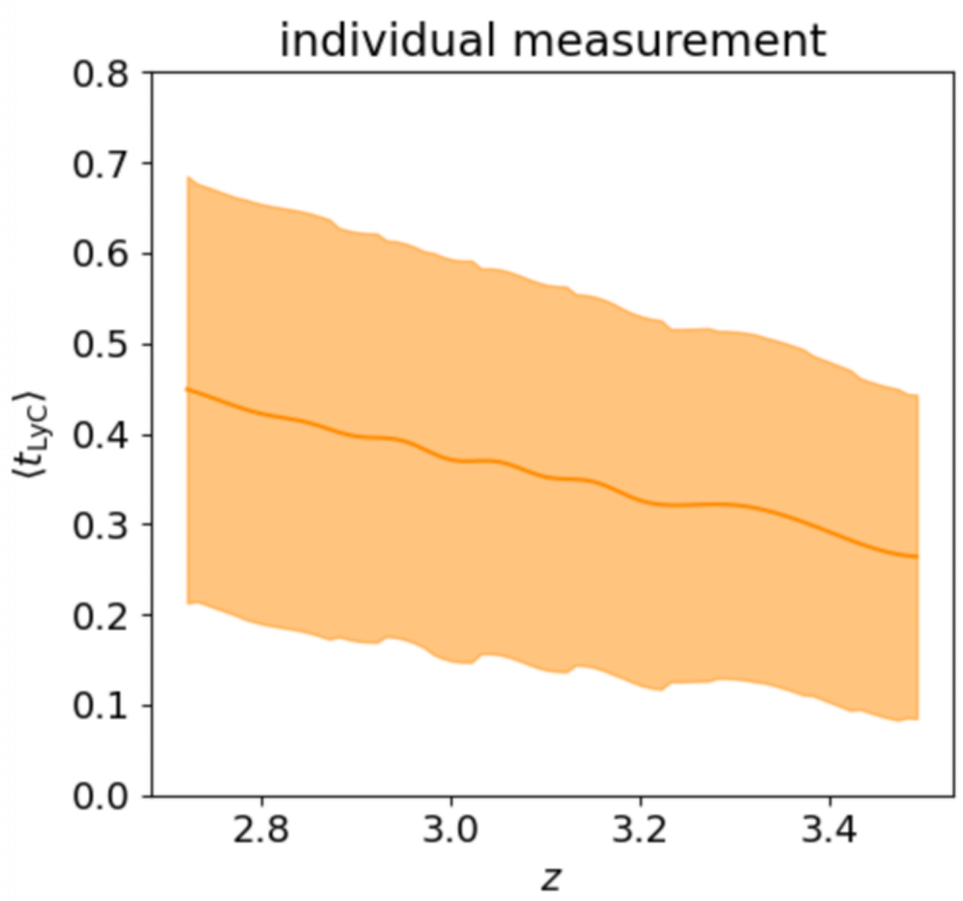
Pahl et al. (2023)

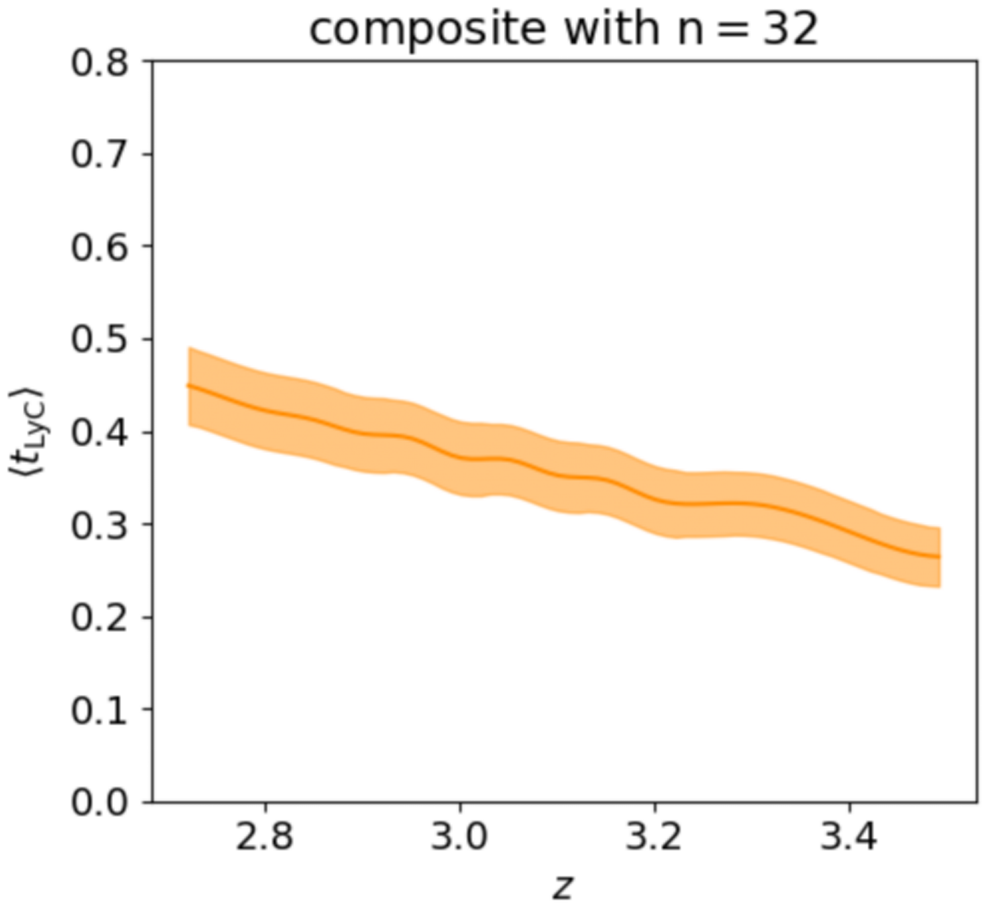
A subset of the KLCS survey can be used to measure the correlation between f_{esc} and SED-derived properties

96 galaxies with well-described multi-band photometry
binned as a function of..
M_*, E(B-V), age, sSFR

Pahl et al. (2023)

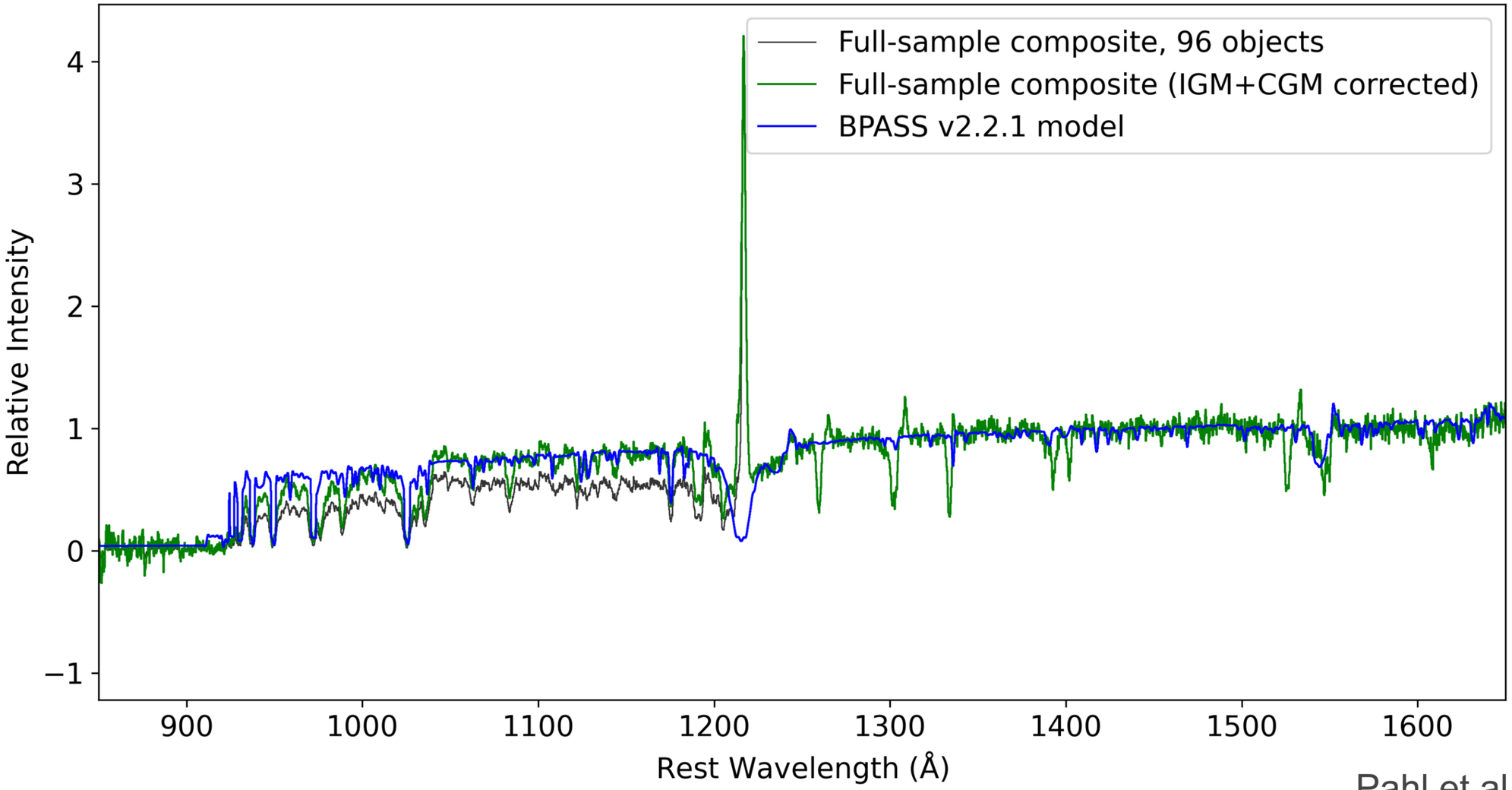
Stacked spectra are required to reduce uncertainty of LyC transmission





Pahl et al. (2023)

We can model f_{esc} from stacked spectra



Pahl et al. (2023)

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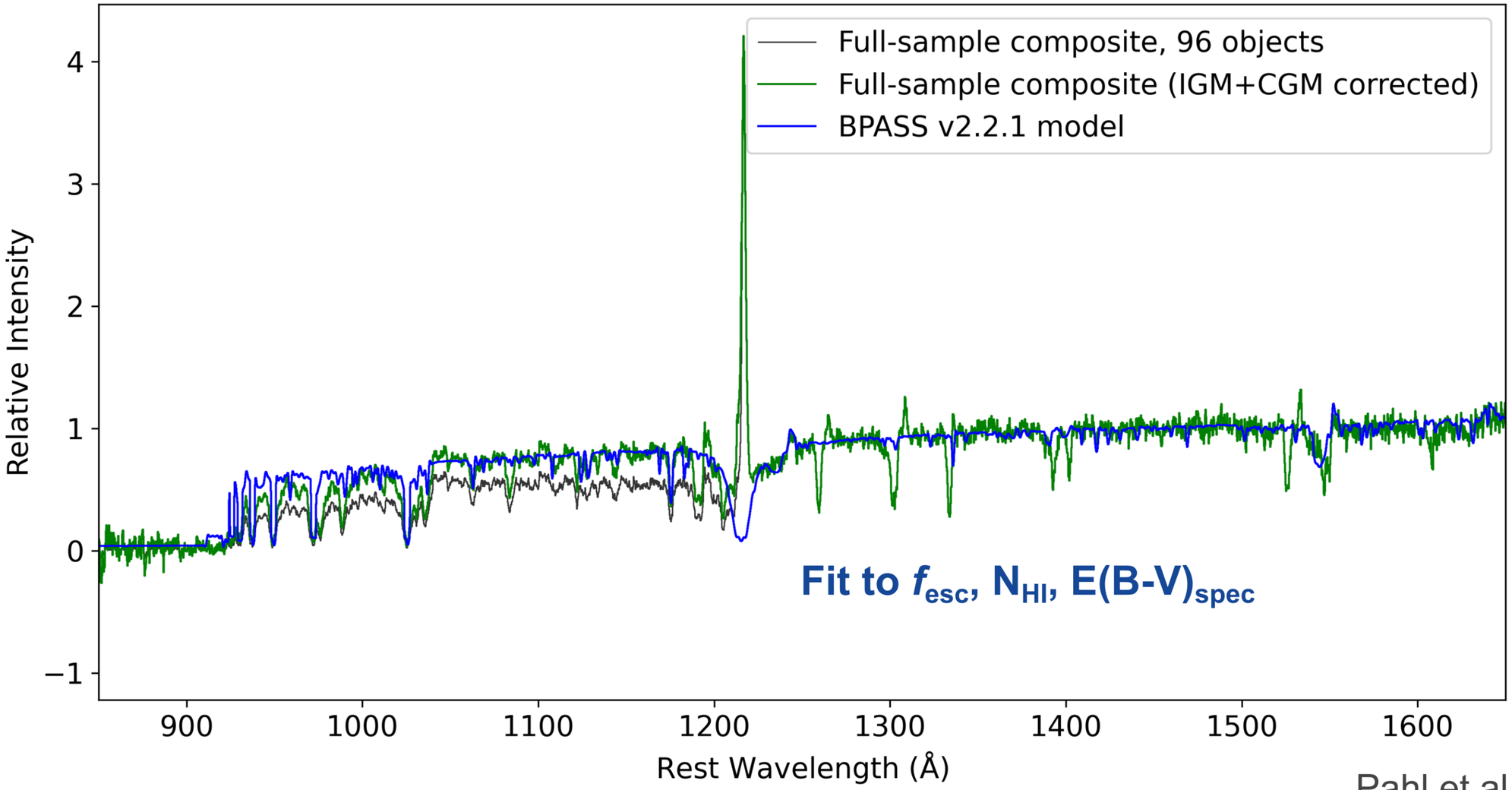

Pahl et al. (2023)

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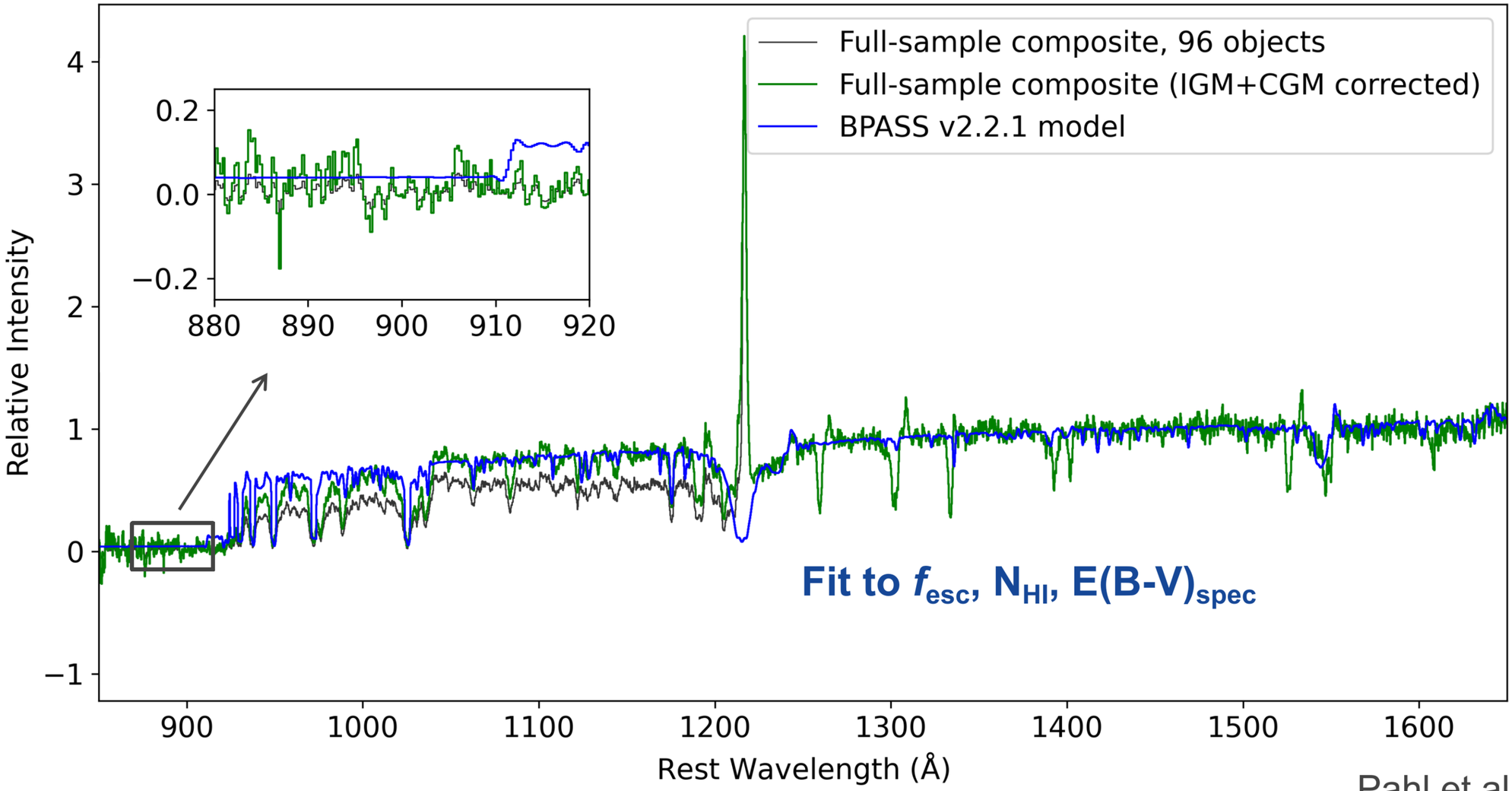
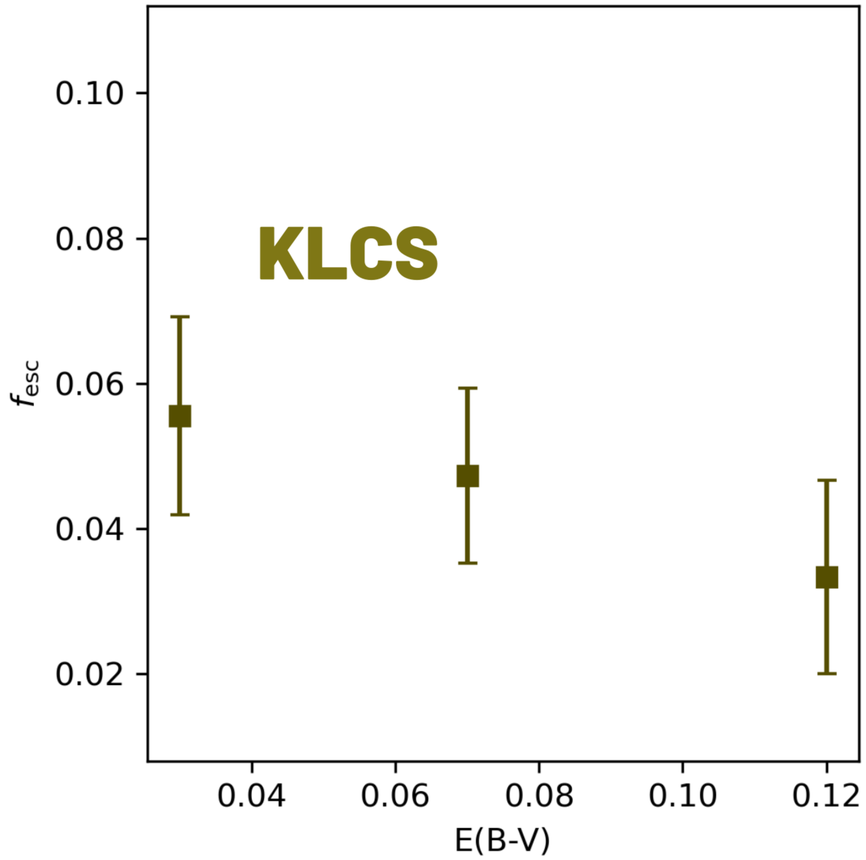
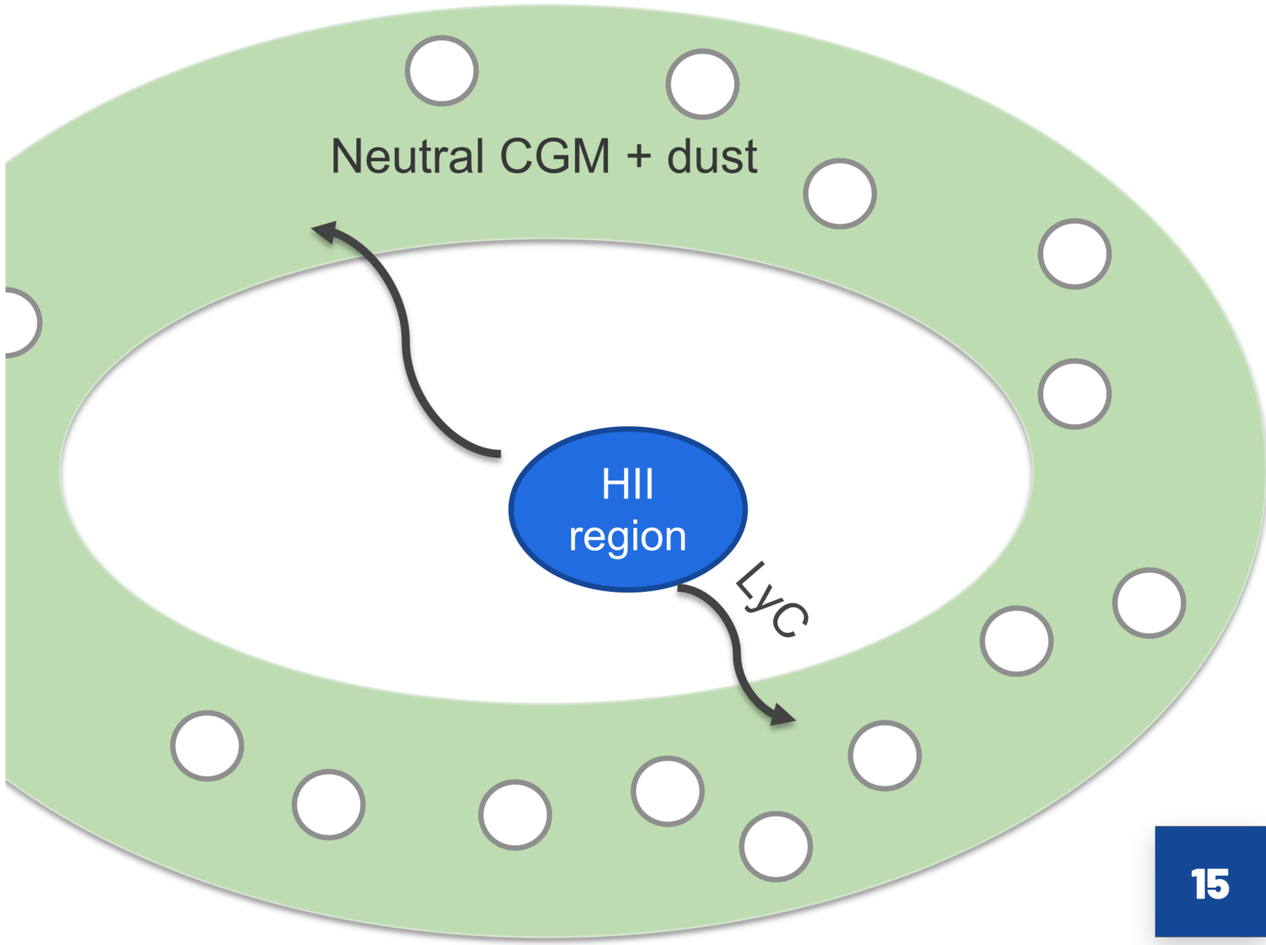


Pahl et al. (2023)

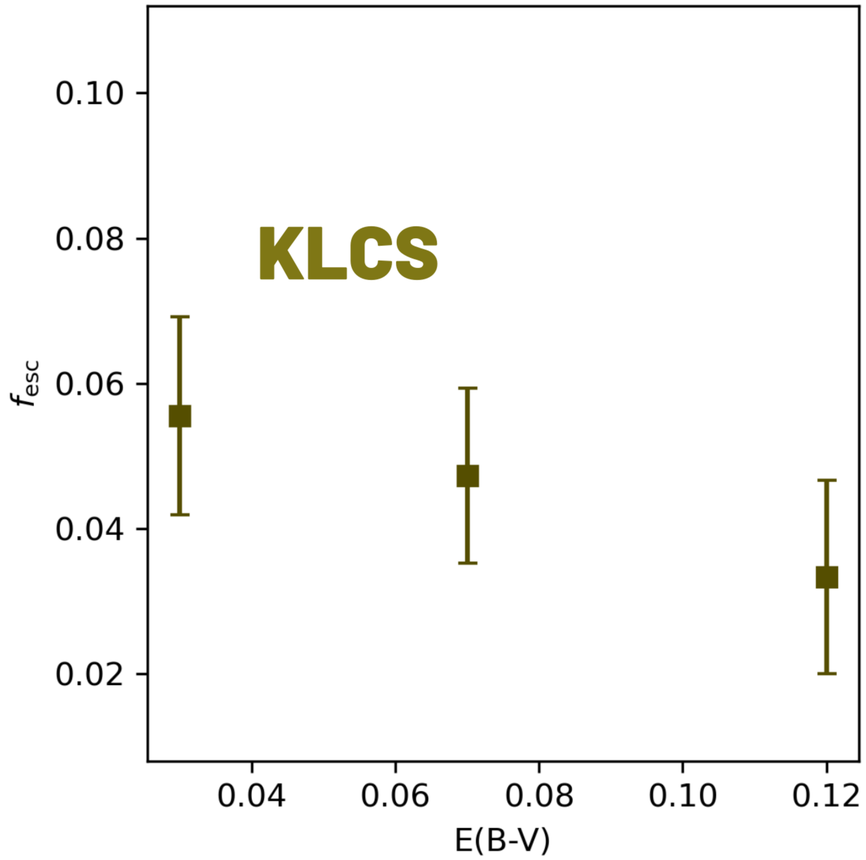
f_{esc} is inversely correlated with E(B-V), supporting physical picture of LyC escape

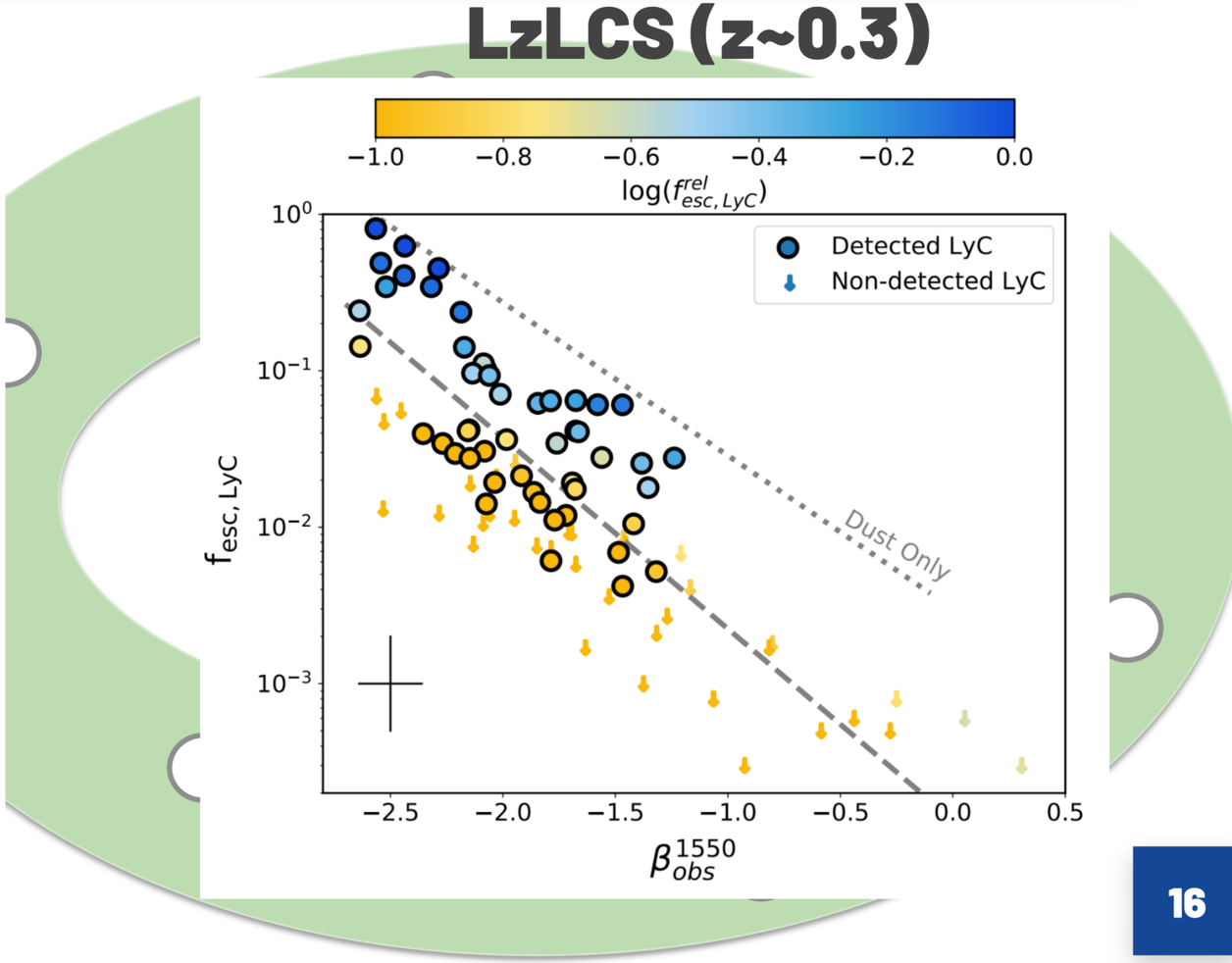




Pahl et al. (2023)

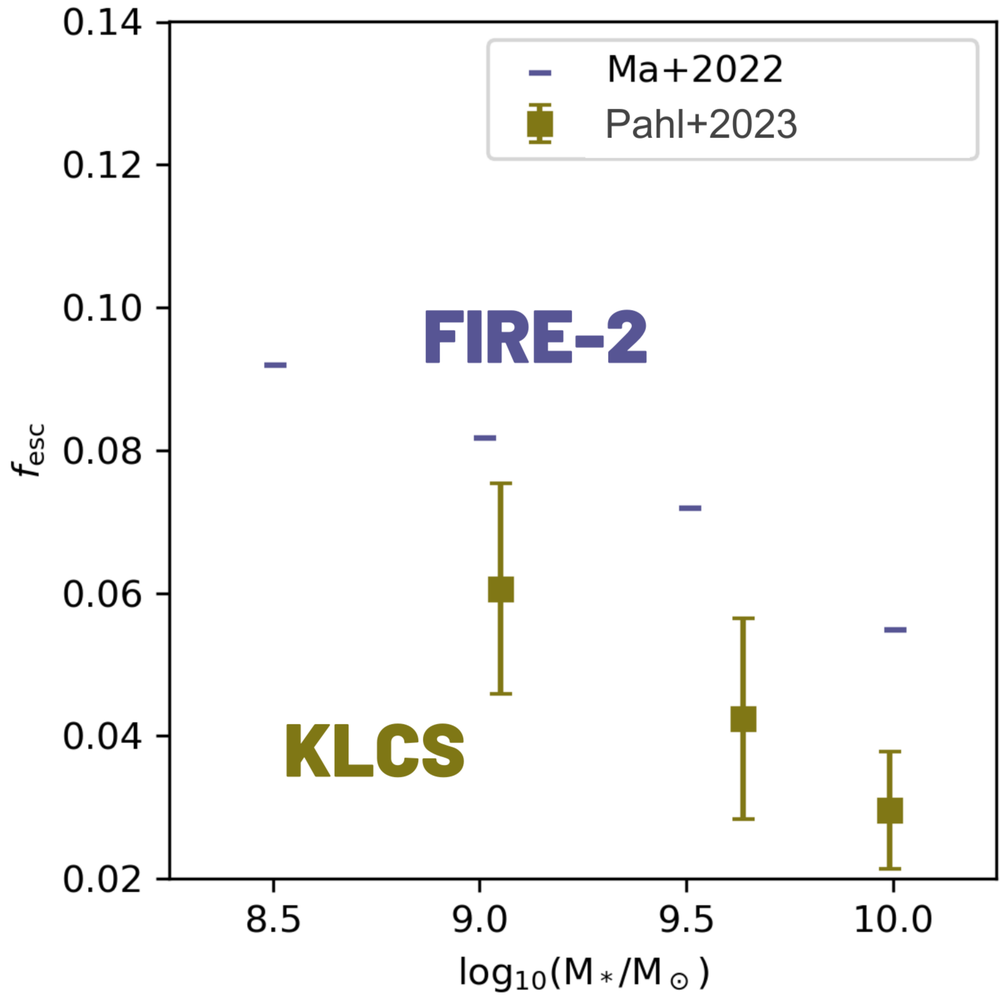
f_{esc} is inversely correlated with E(B-V), supporting physical picture of LyC escape





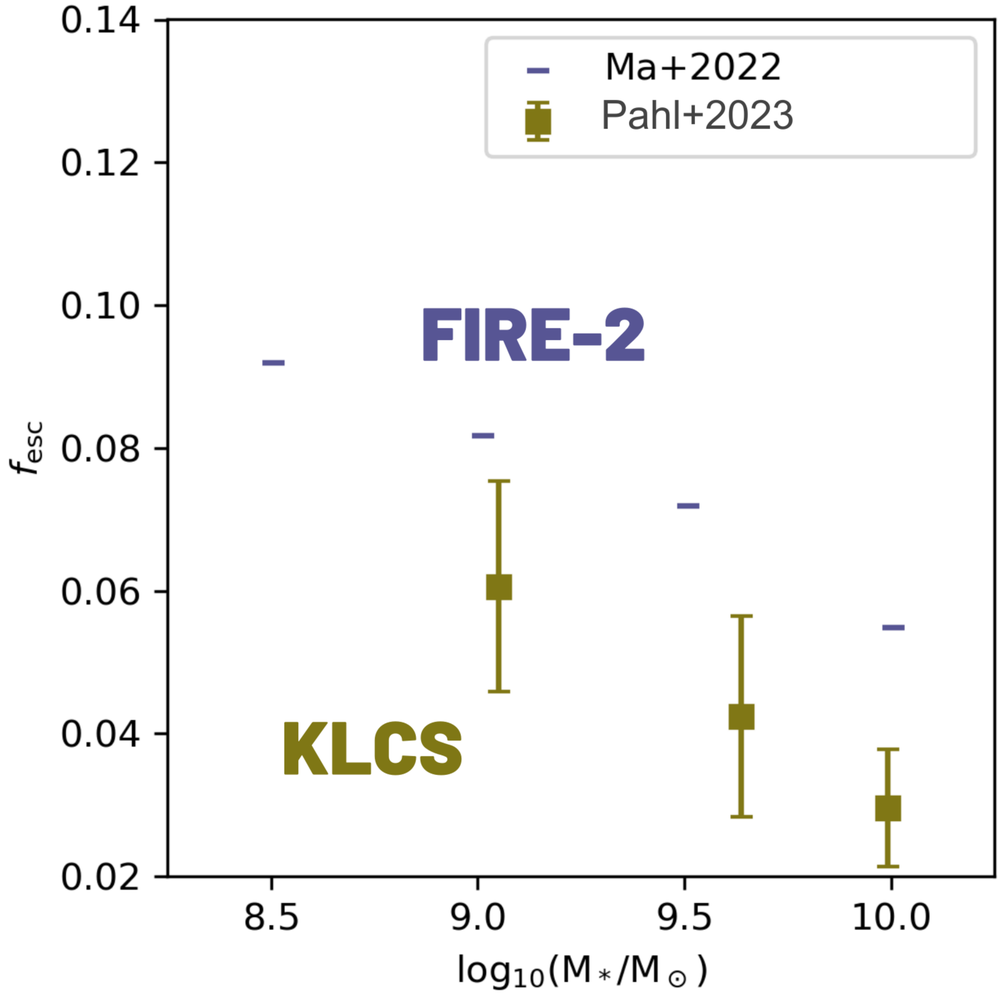
Chisholm et al. (2022)

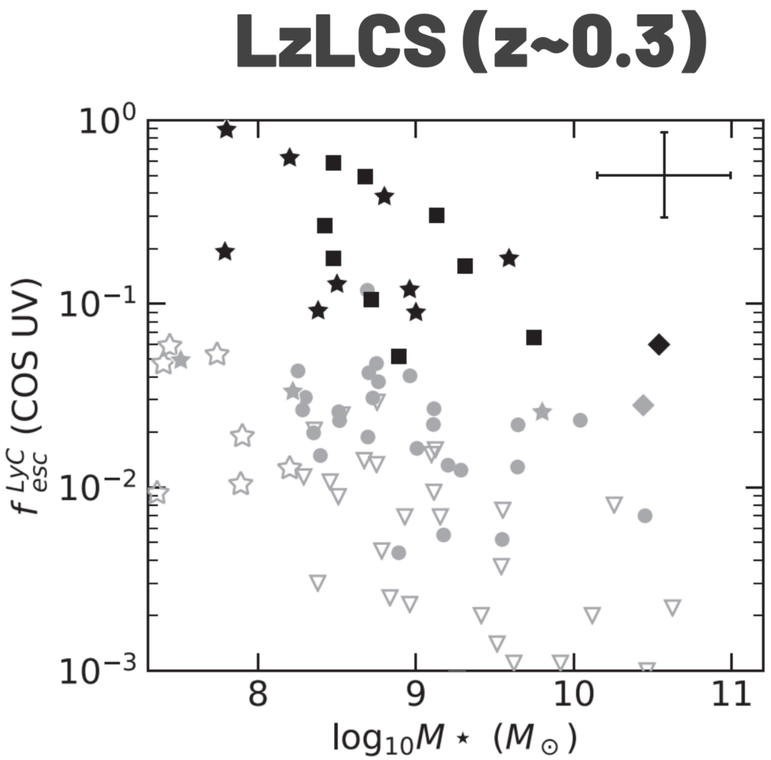
f_{esc} is inversely correlated with stellar mass, consistent with predictions from FIRE-2



Pahl et al. (2023)

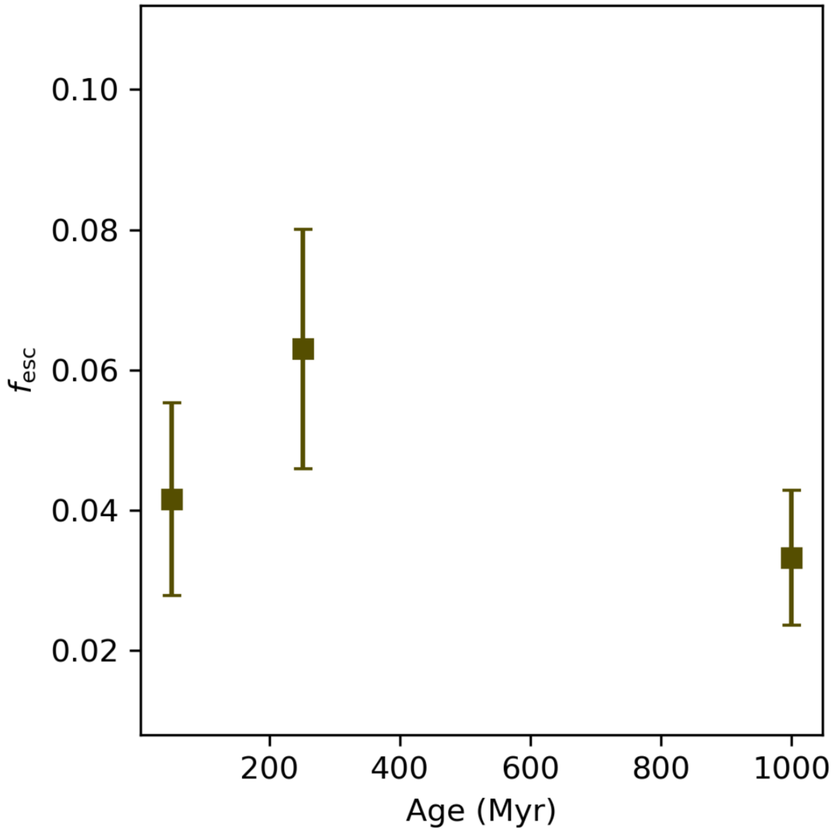
f_{esc} is inversely correlated with stellar mass, consistent with predictions from FIRE-2

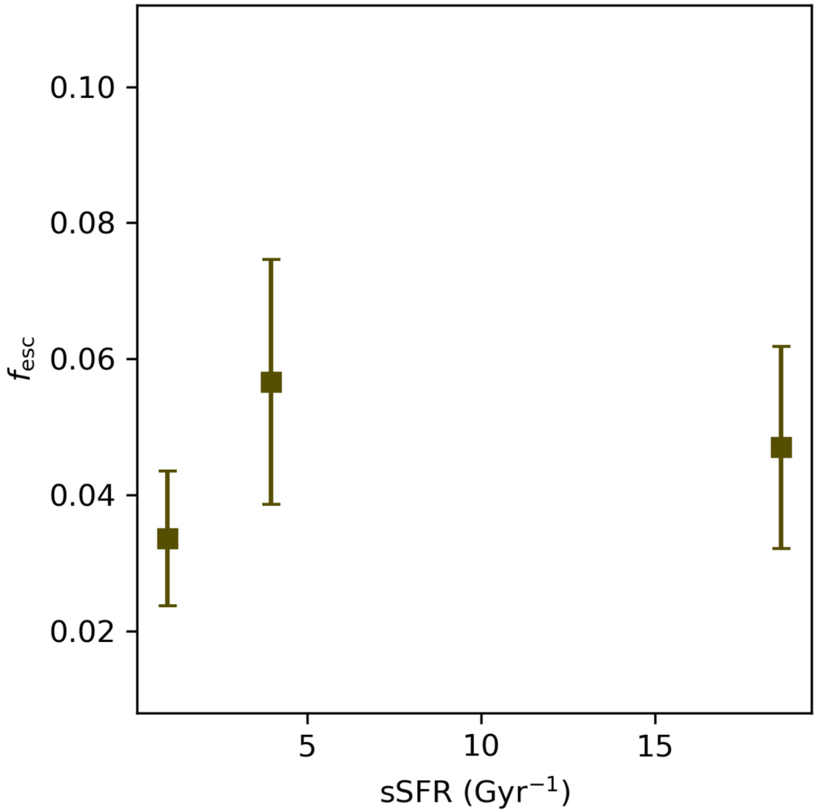




Flury et al. 2022b

No correlation found between f_{esc} and age, sSFR





- No observational support for synchronization of onset of star formation and LyC escape

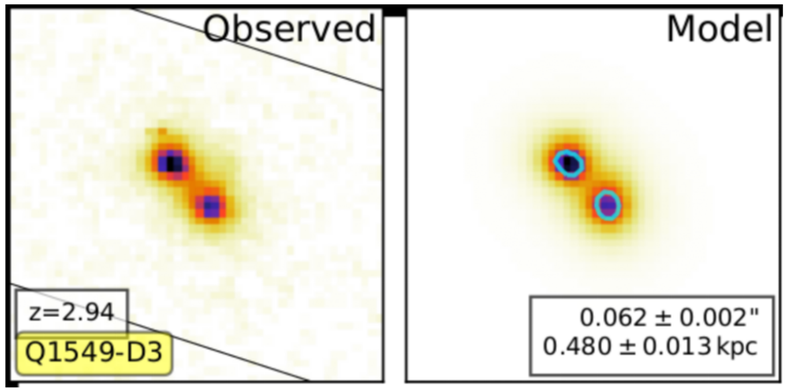
Pahl et al. (2023)

A subset of the KLCS survey can be used to measure the correlation between f_{esc} and Σ_{SFR}

35 galaxies with ***HST*** V_{606} **images** and multi-band photometry

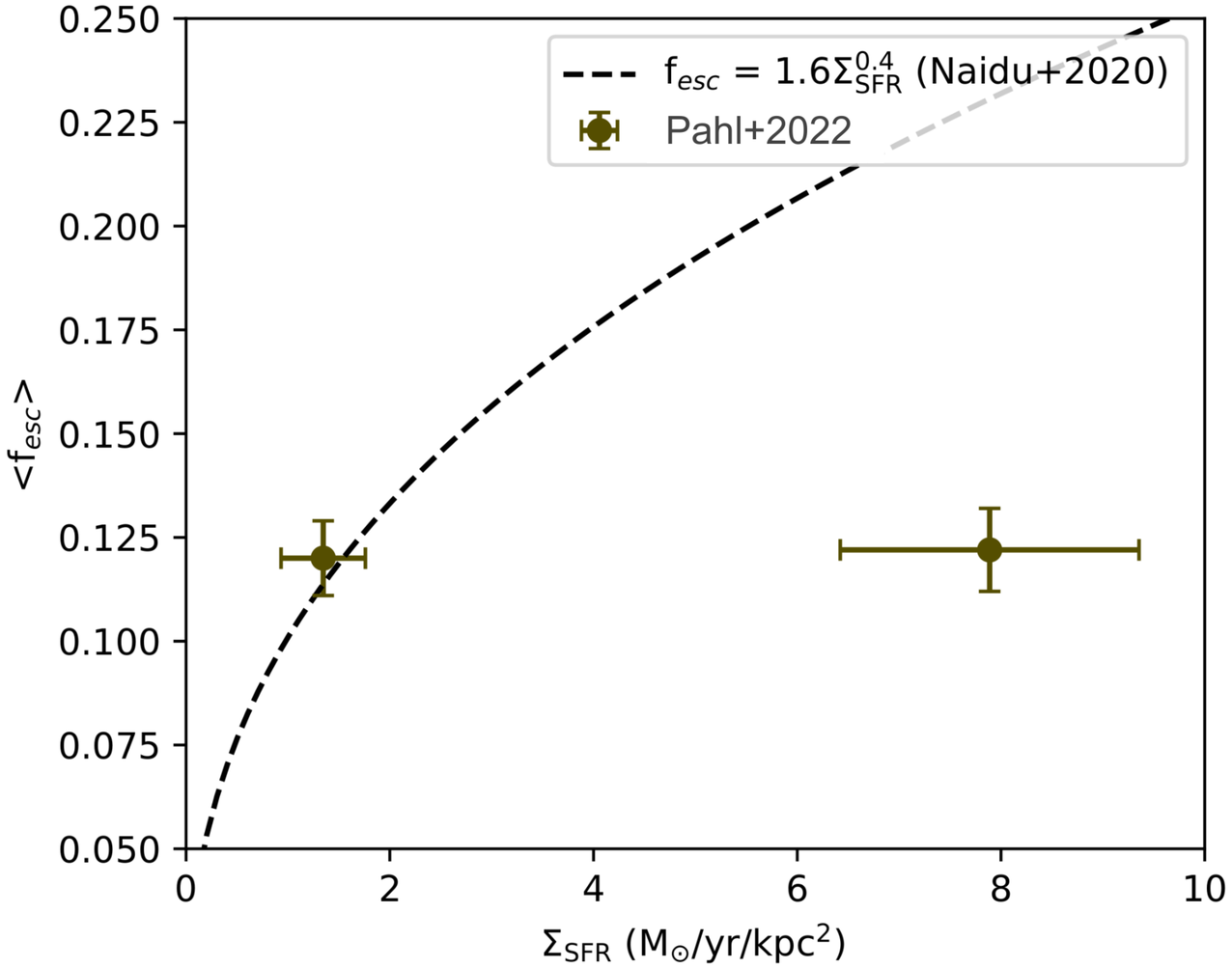
binned as a function of..

Σ_{SFR}



Pahl et al. (2022)

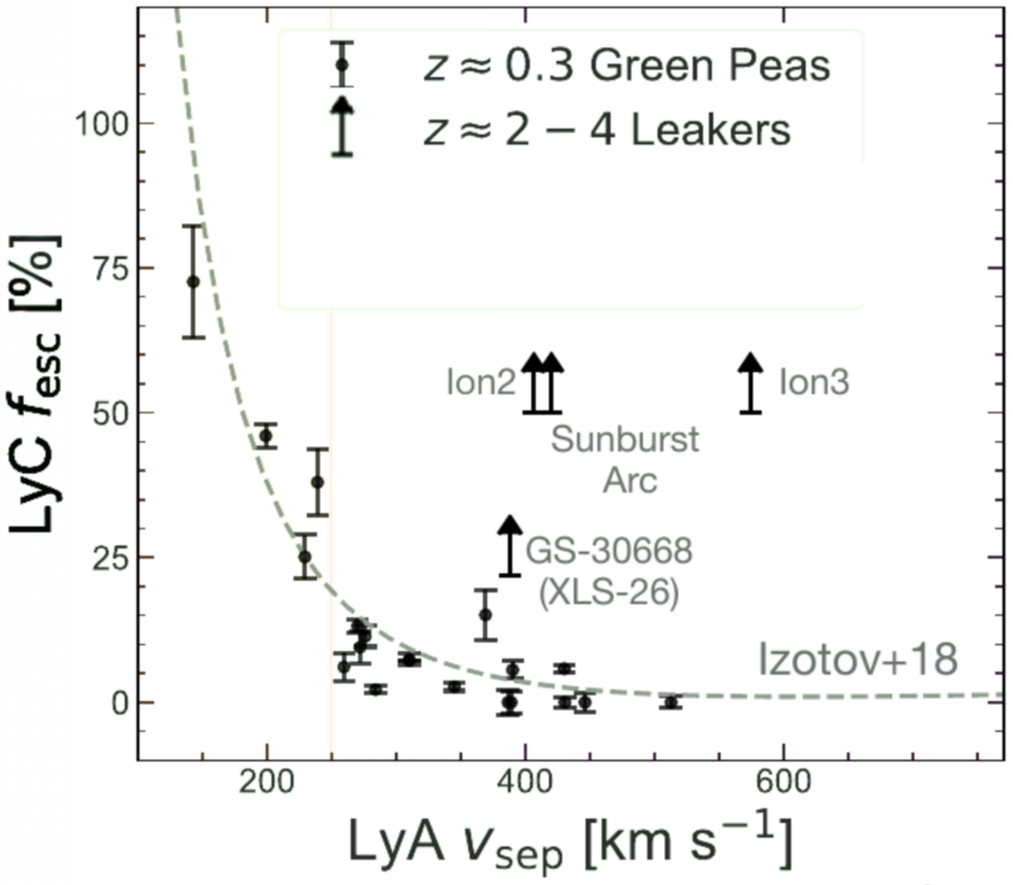
Galaxies with elevated Σ_{SFR} do not *appear* to have higher f_{esc} …



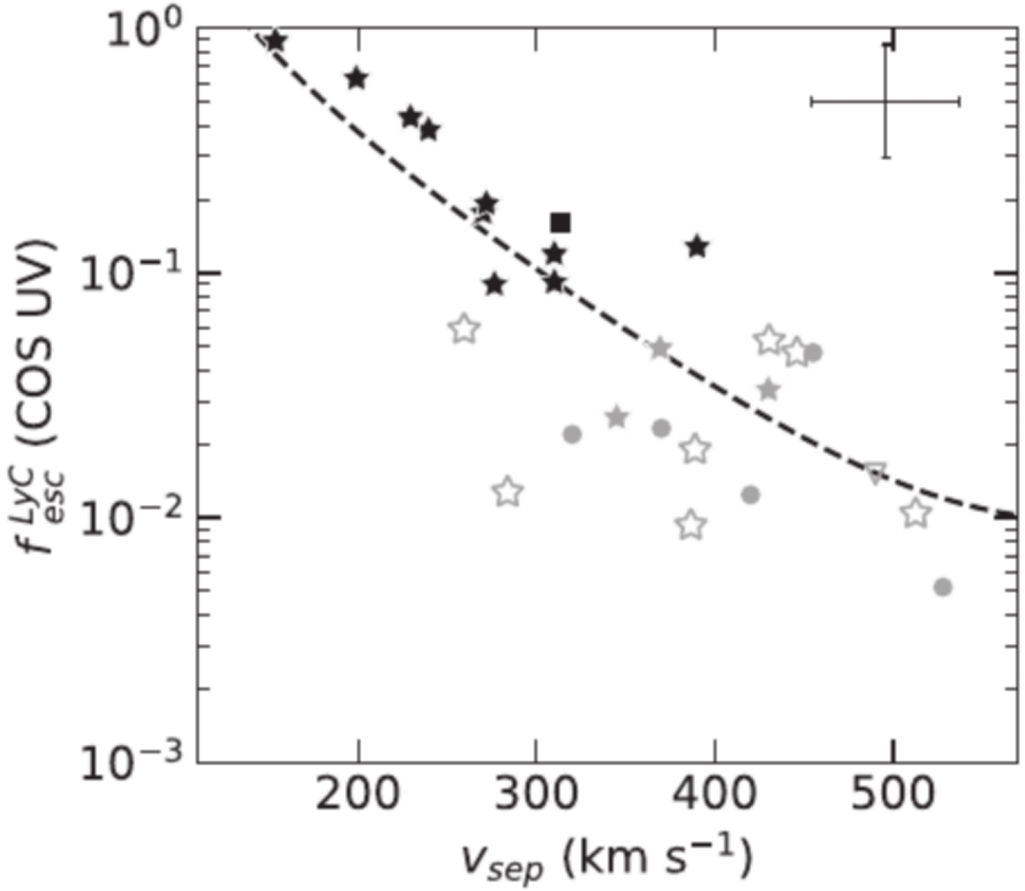
… but more data is needed

Pahl et al. (2022)

f_{esc} is correlated with Lyα peak seperation at low redshift; unconfirmed at z~3

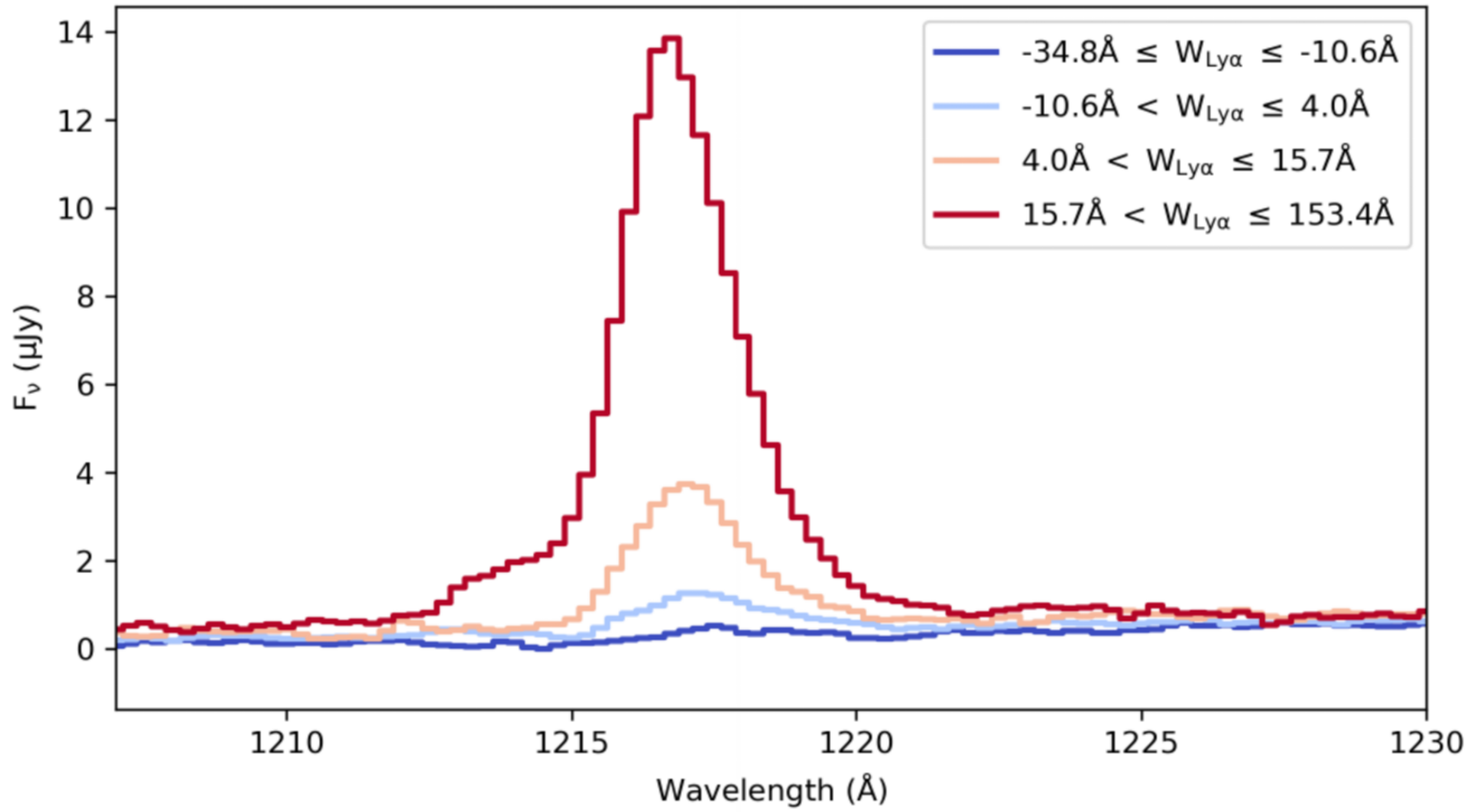


adapted from Naidu et al. (2021)



Flury et al. (2022)

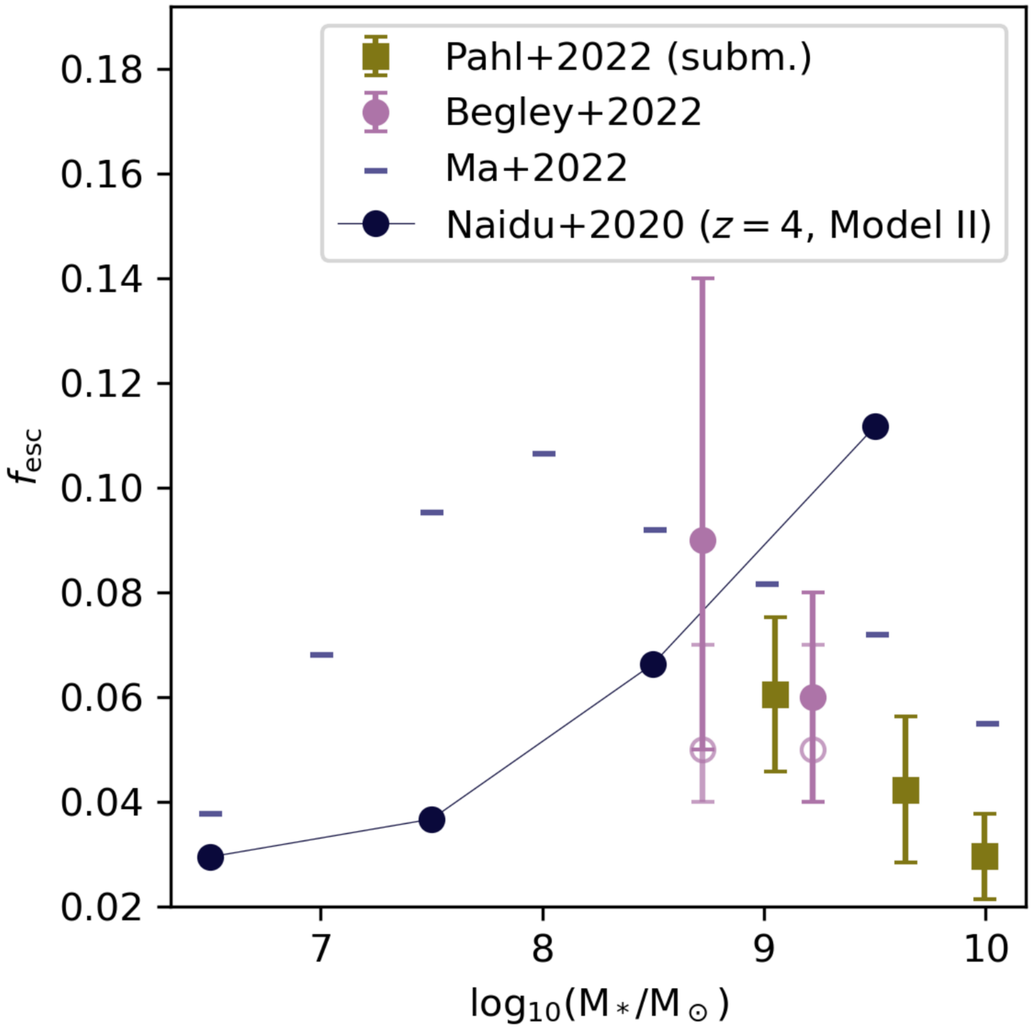
Using a higher-resolution LRIS grating, we can constrain Lyα peak seperation for the KLCS



Keck U043, *The Connection between Lyα Profile and Lyman Continuum Escape at z~3* (2022A/B, PI Shapley)

Pahl et al. in prep

Positive trends between f_{esc} and Σ_{SFR}, M* are directly tied to the oligarchical model, and are unconfirmed by our analysis



KLCS

VANDELS

FIRE-2

Naidu+2020 ($f_{esc} \propto (\Sigma_{SFR})^{0.4}$)

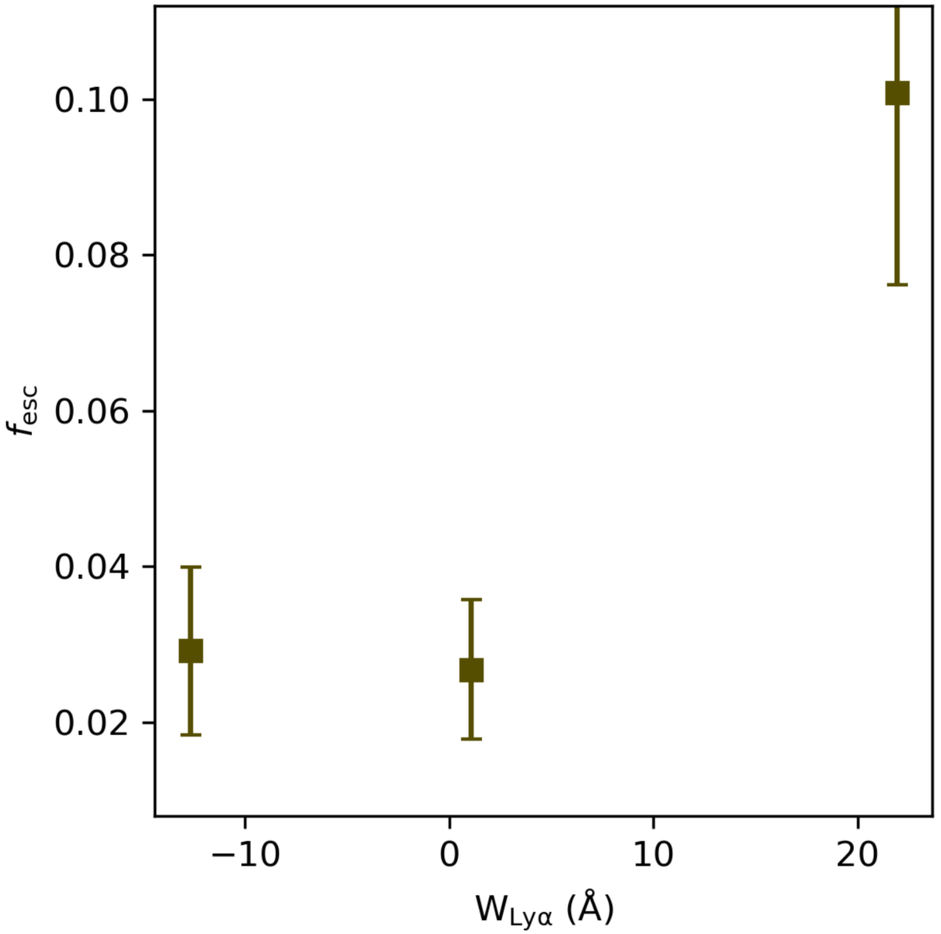
Pahl et al. (2023)

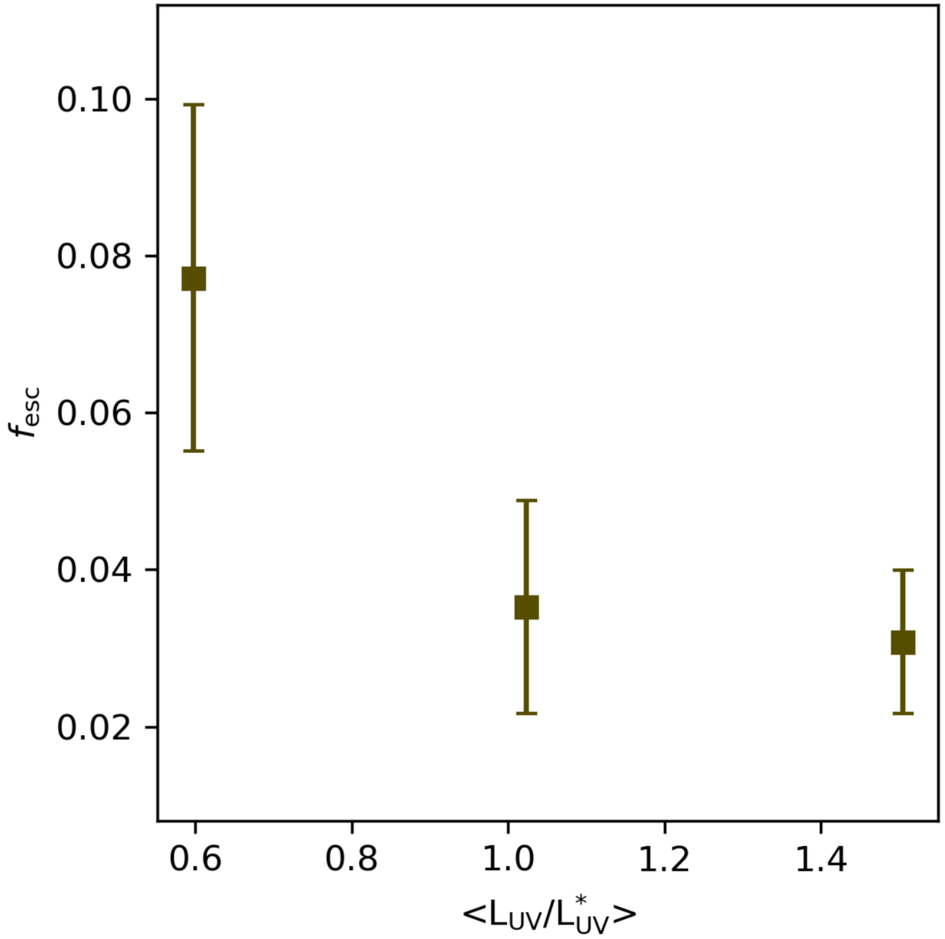
Summary

- **f_{esc} is a key unknown to reionization modeling** and requires direct LyC detections and statistical samples.
- Understanding the **correlation between f_{esc} and galaxy property** can distinguish between competing models.
- We use **96 galaxies with multi-band photometry and LRIS spectra** to explore connections between f_{esc} and median galaxy properties.
- We find **a negative correlation** between f_{esc} and M*, E(B-V), and **no correlation** between f_{esc} and sSFR, age.
- Potential tracers of f_{esc} of **Σ_{SFR}, v_{sep}** can be tested using KLCS

Pahl et al. (2023)

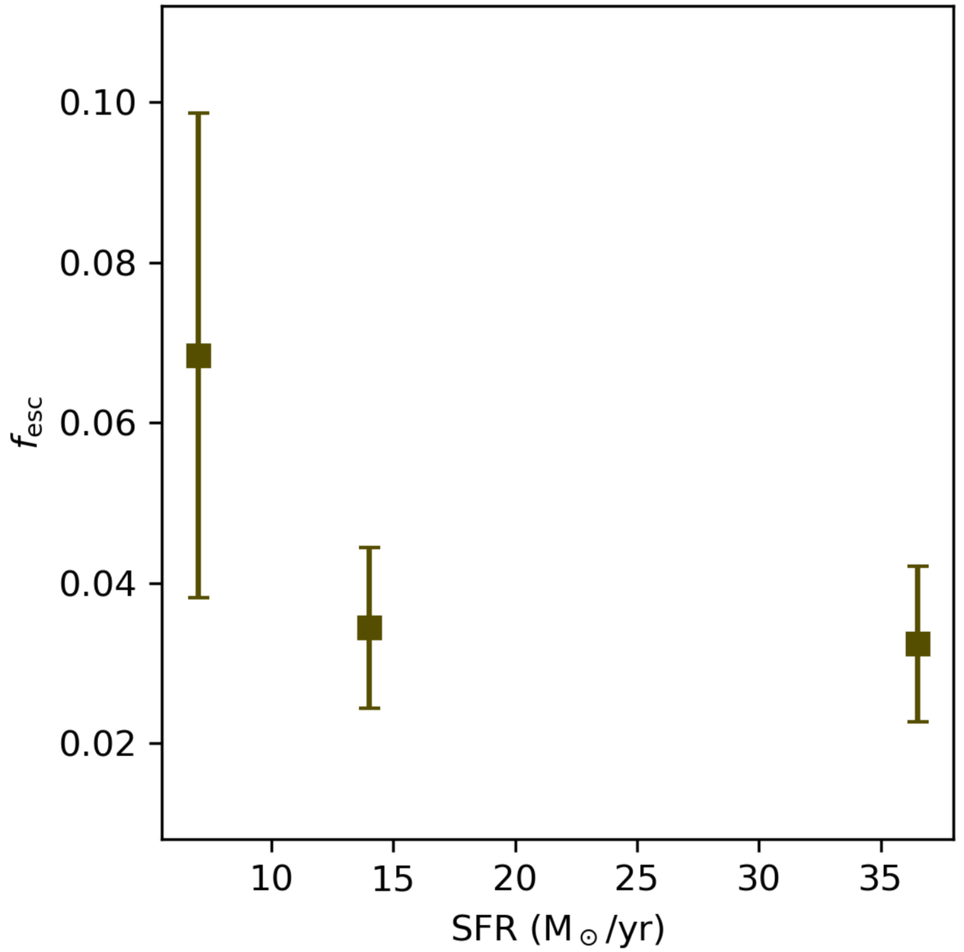
KLCS SED sample reproduces trends with f_{esc} and $W_{Ly\alpha}$, L_{UV}





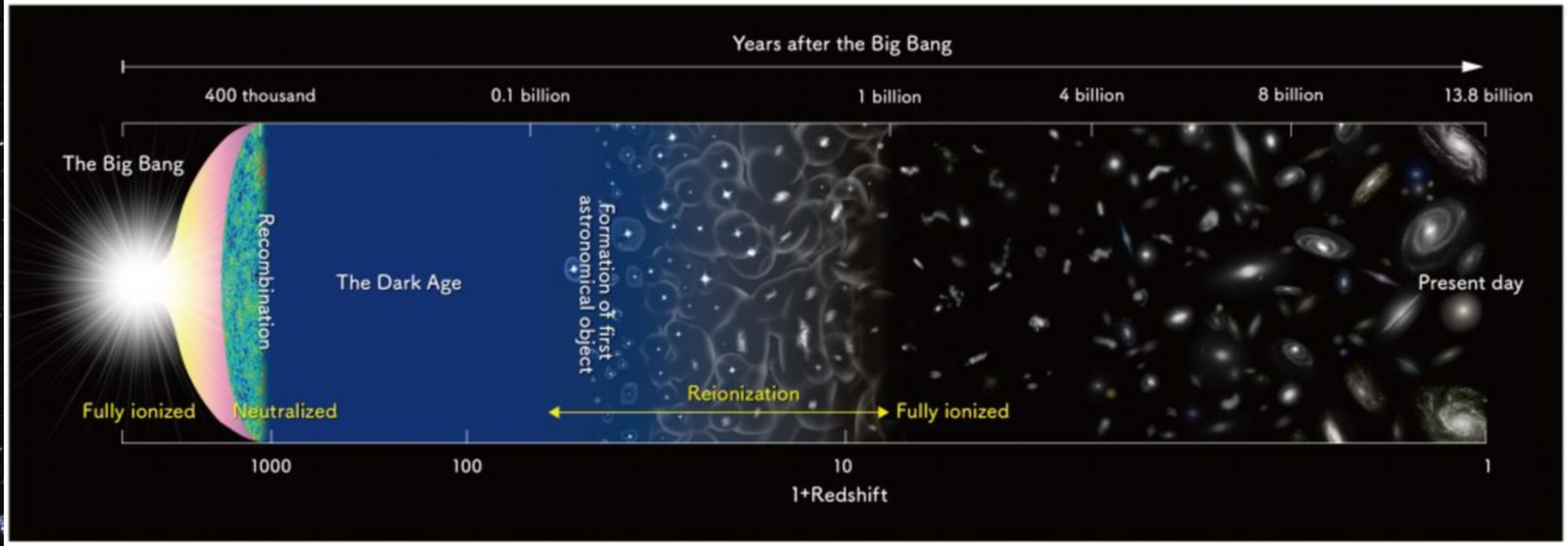
Pahl et al. in prep.

f_{esc} is inversely correlated with SFR



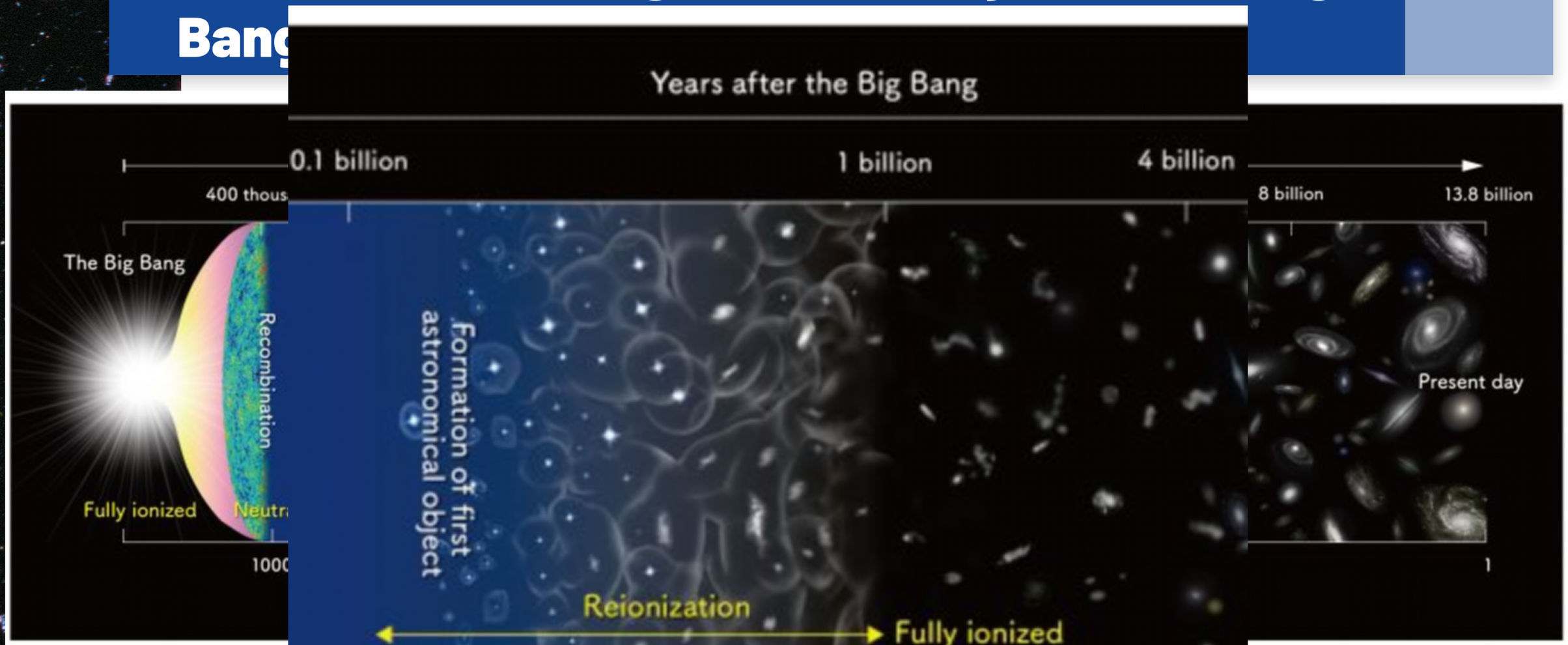
Pahl et al. in prep.

The Universe changes drastically from the Big Bang to today



Credit: NAOJ

The Universe changes drastically from the Big Bang



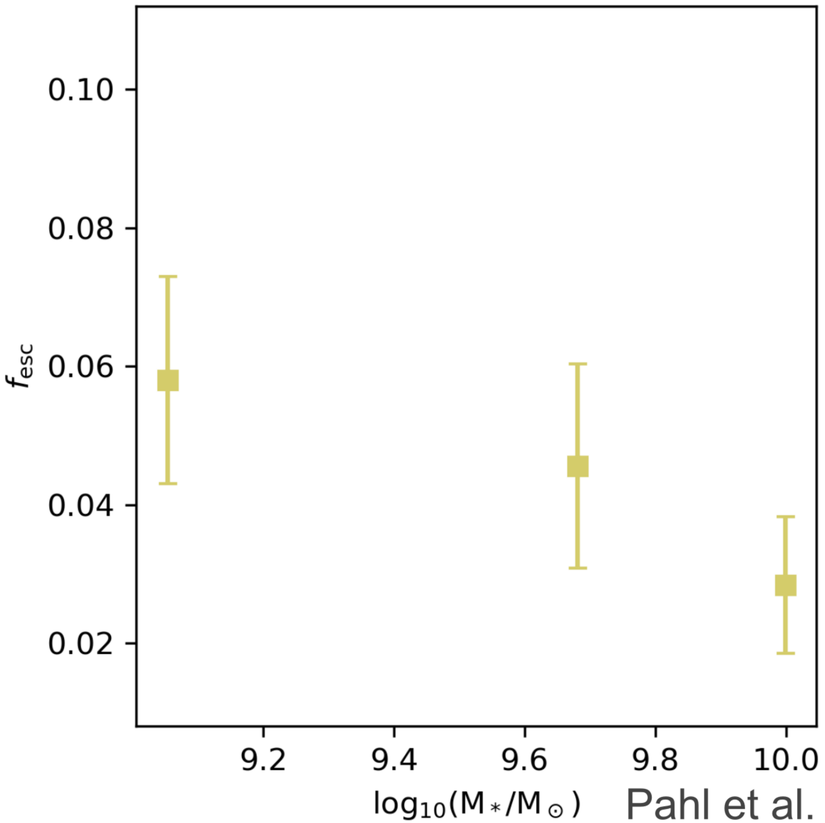
Credit: NAOJ

The Universe changes drastically from the Big Bang

Credit: NAOJ

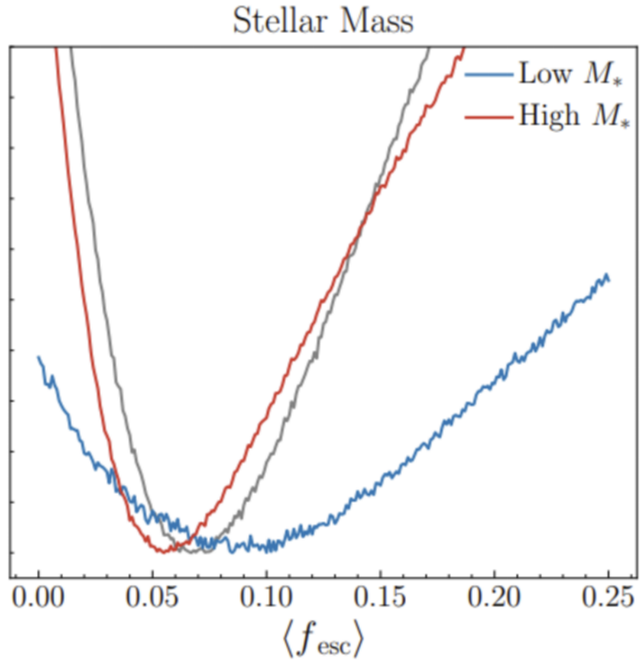
f_{esc} is inversely correlated with stellar mass, mirroring previous results

KLCS



Pahl et al. in prep.

148 galaxies from VANDELS at 3.34<z<3.95 with ultra-deep *U*-band *imaging*



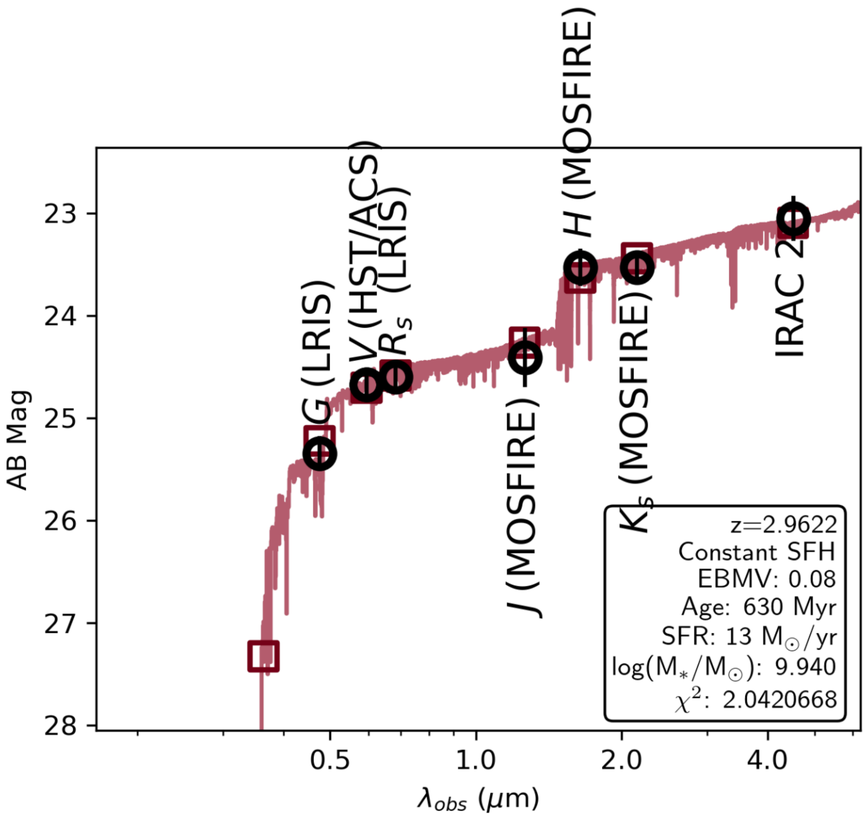
Begley et al. (2022)

A subset of the KLCS survey can be used to measure the correlation between f_{esc} and SED-derived properties

96 galaxies with well-described multi-band photometry

binned as a function of..

M_*, sSFR, E(B-V), age



Pahl et al. 2022b (subm)