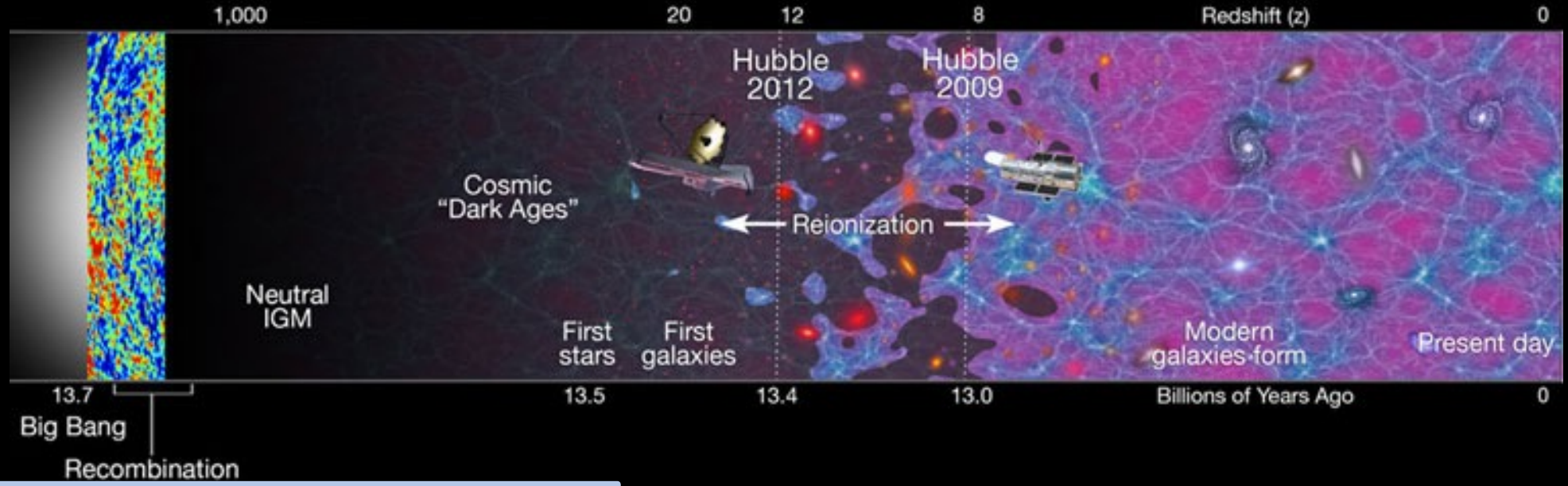
Understanding reionization through Lyman Continuum Emitters at z > 3

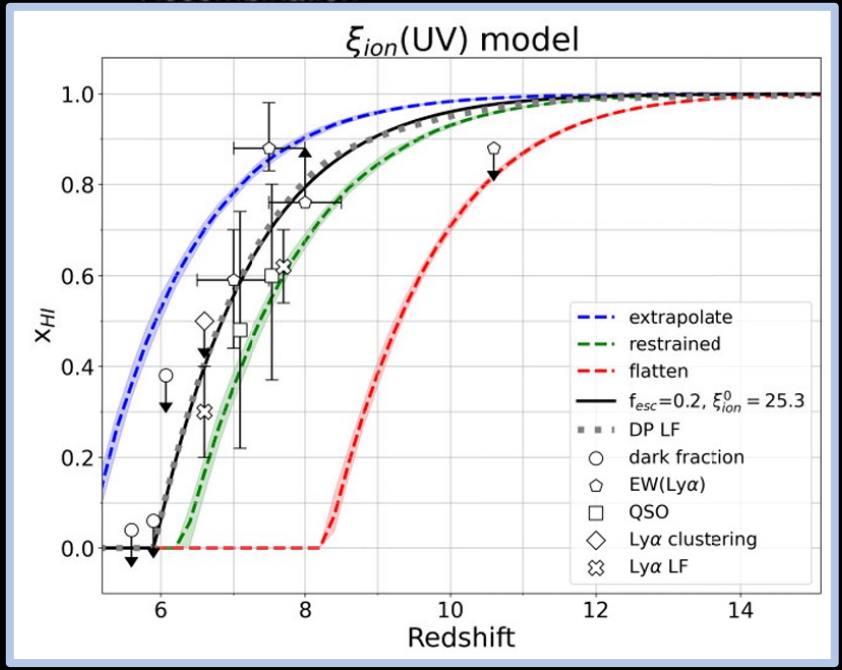
Alex Beckett

Lyman 2025 Conference, 11th April 2025

Marc Rafelski, Claudia Scarlata, Wanjia Hu, Keunho Kim, Harry Teplitz, Uros Mestric, Eros Vanzella, Mauro Giavalisco, Matt Malkan, Wayne Webb, Vihang Mehta and the PIE collaboration

Reionization



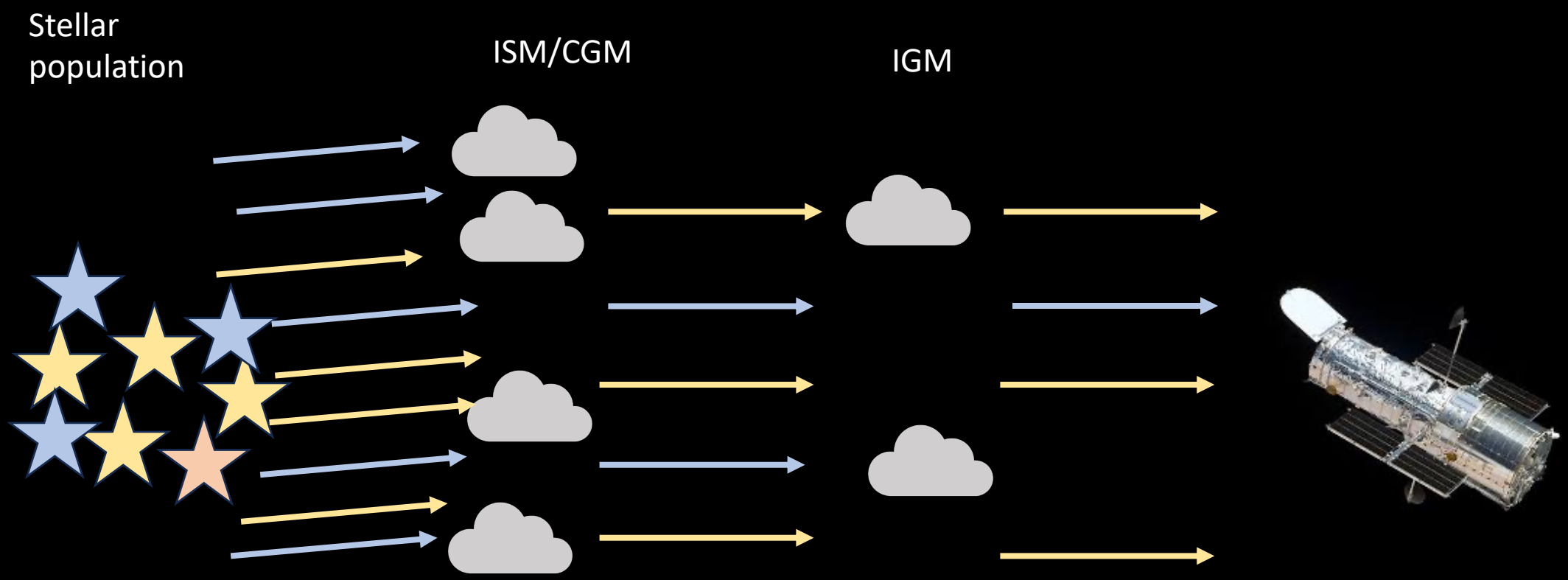


Reionization (z~ 5-10) - not yet clear which sources contributed the most ionizing photons

Left: Lin et al. (2024), Top: NASA public image

LyC emission

$$F(LyC)/F(UV) = L(LyC)/L(UV) \times fesc \times T(IGM)$$



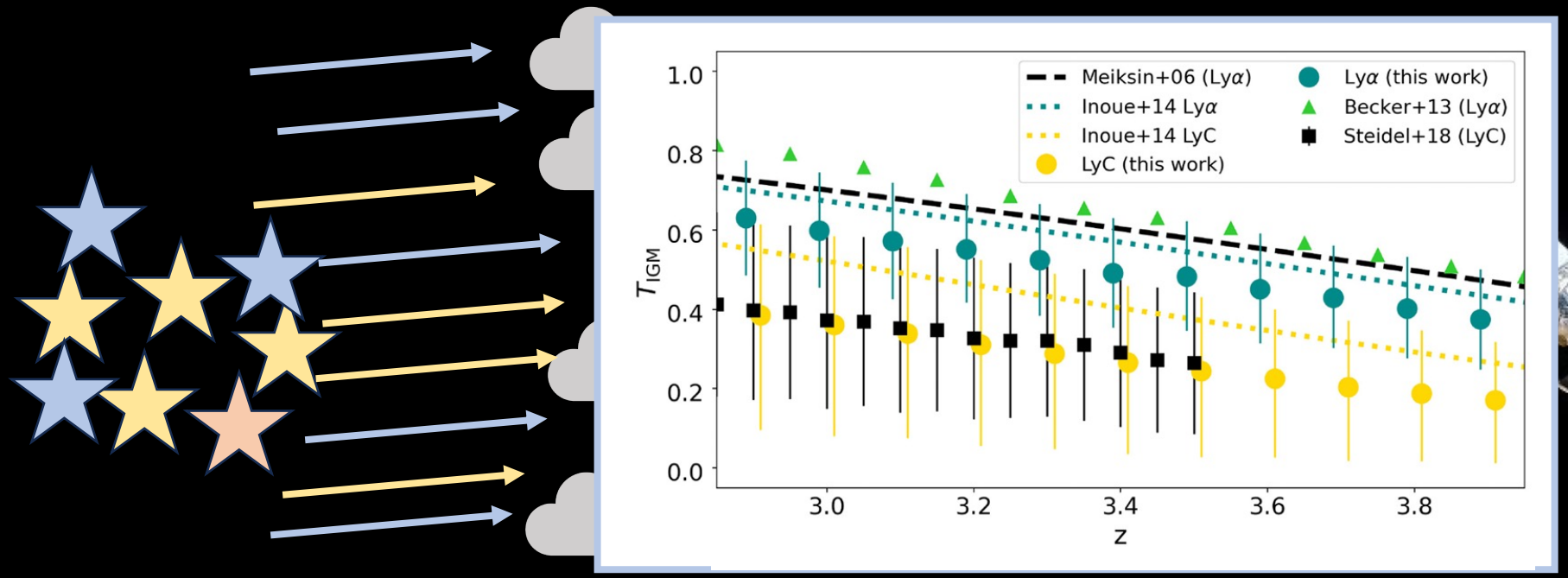
LyC emission

F(LyC)/F(UV) = L(LyC)/L(UV) x fesc x T(IGM)

Stellar population

ISM

IGM



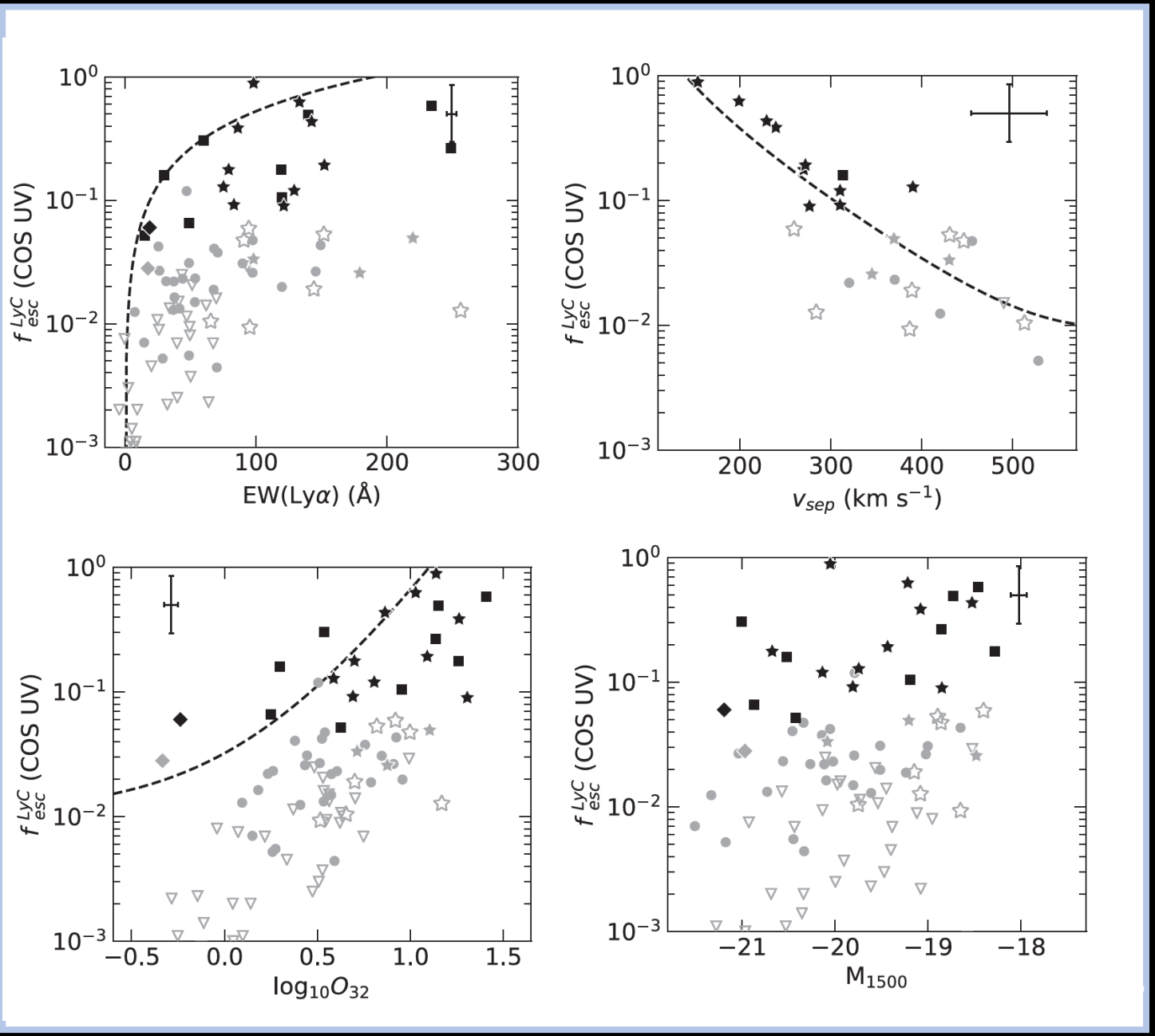
Bassett+21

Low-z LyC emitters

Indirect indcators of LyC emission are needed

These can be detected at z>5 and used to infer levels of ionizing flux from galaxies during reionization

LzLCS (Flury+22) has tested the reliability of some possible indicators at z ~ 0.3



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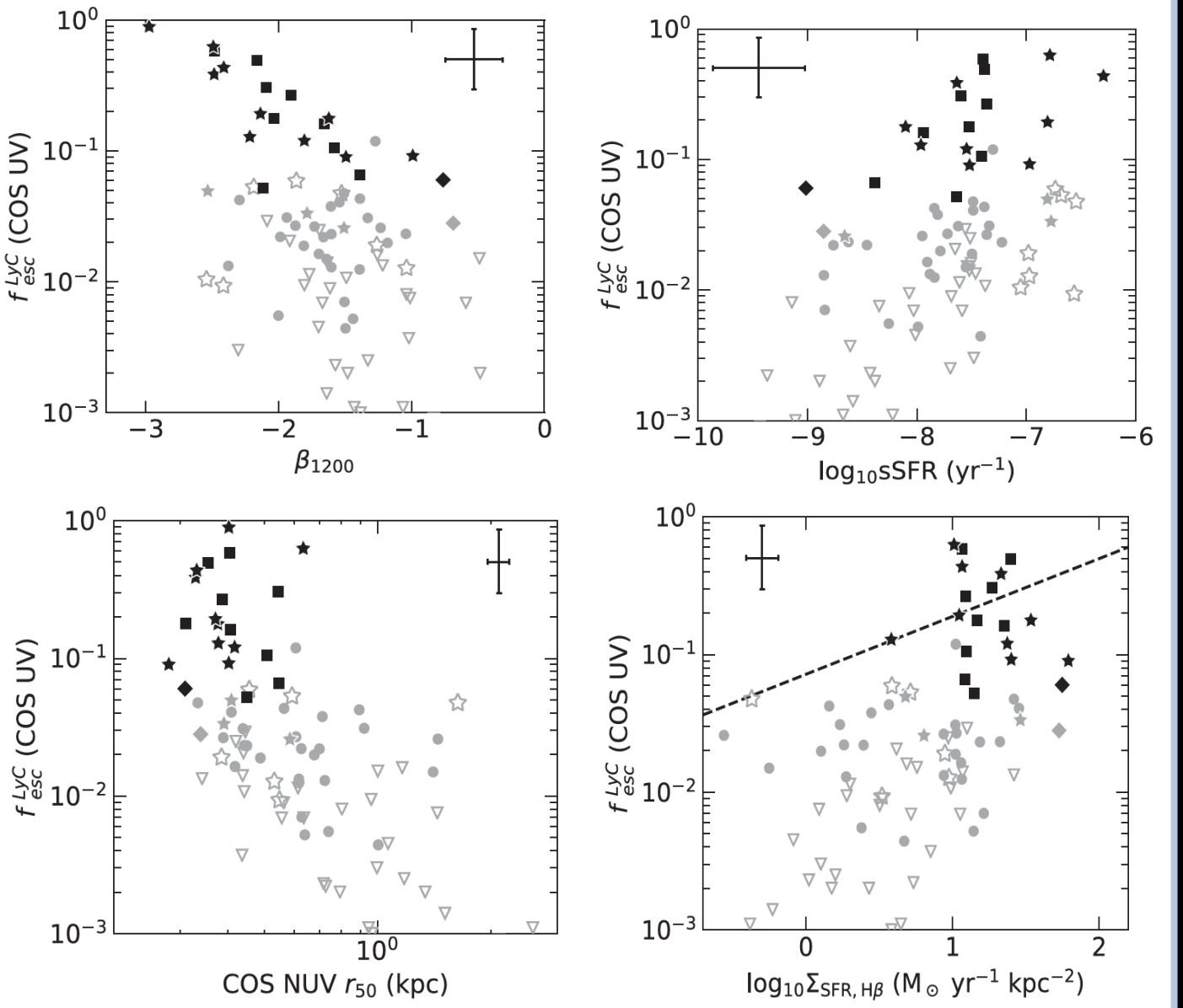
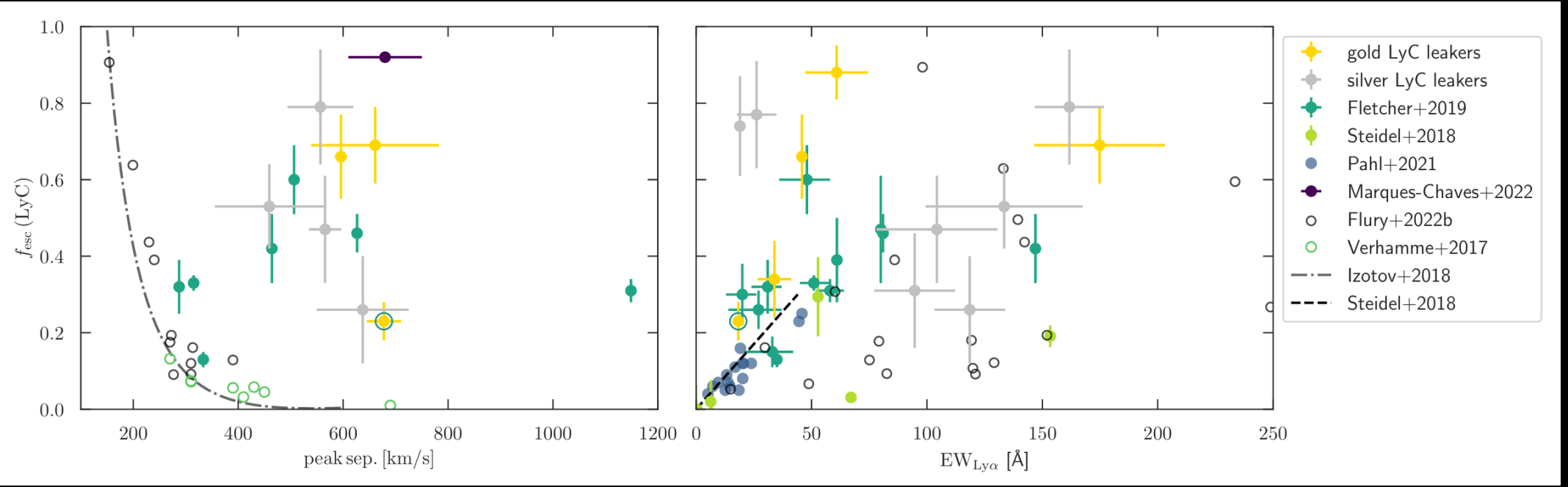


Low-z LyC emitters

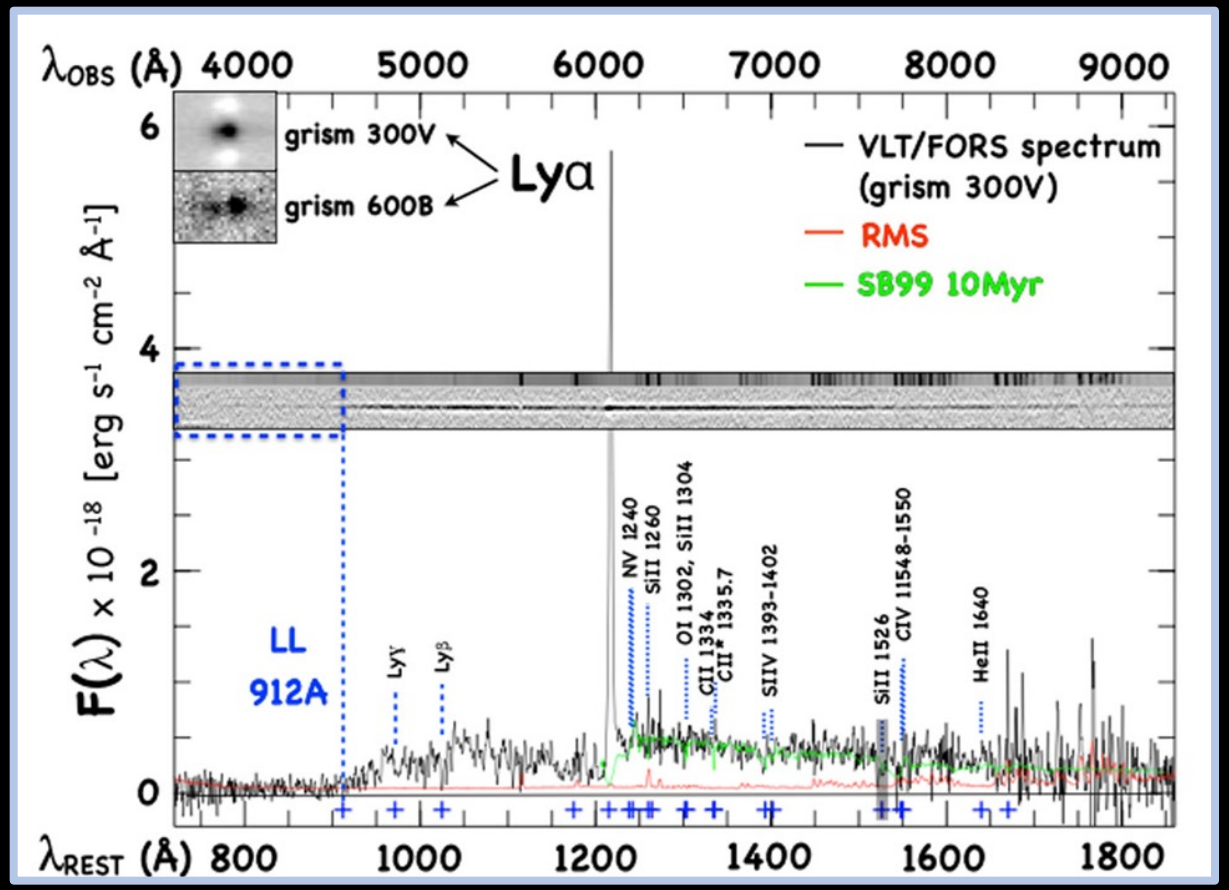


Kerutt+24

Multi-variate analysis can help reduce scatter

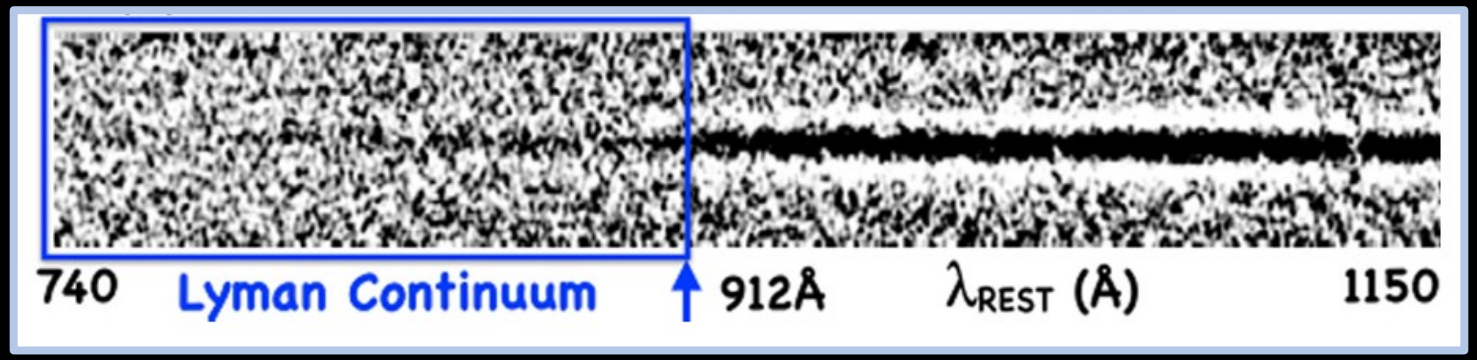
Do these relationships hold at higher redshifts?

Ion3



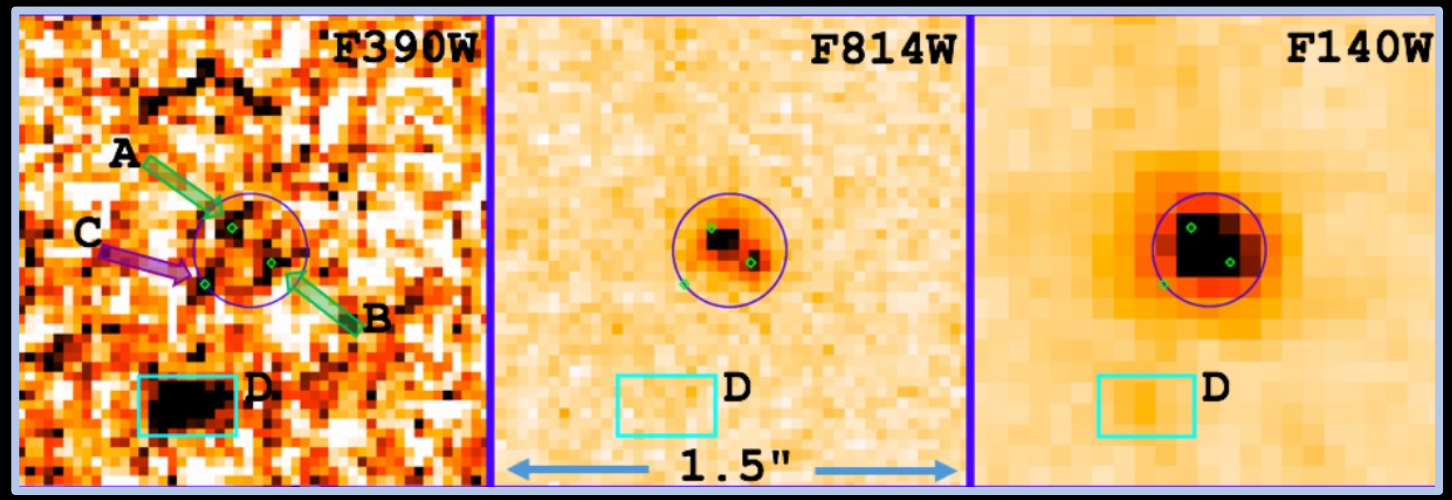
Among most distant confirmed LyC leakers (z=3.999)

FORS spectrum confirms redshift and shows clear emission blueward of Lyman limit



Vanzella et al. (2018)

Ion3



Rest frame: 650—900 Å 1400—1950 Å 2350—3200 Å

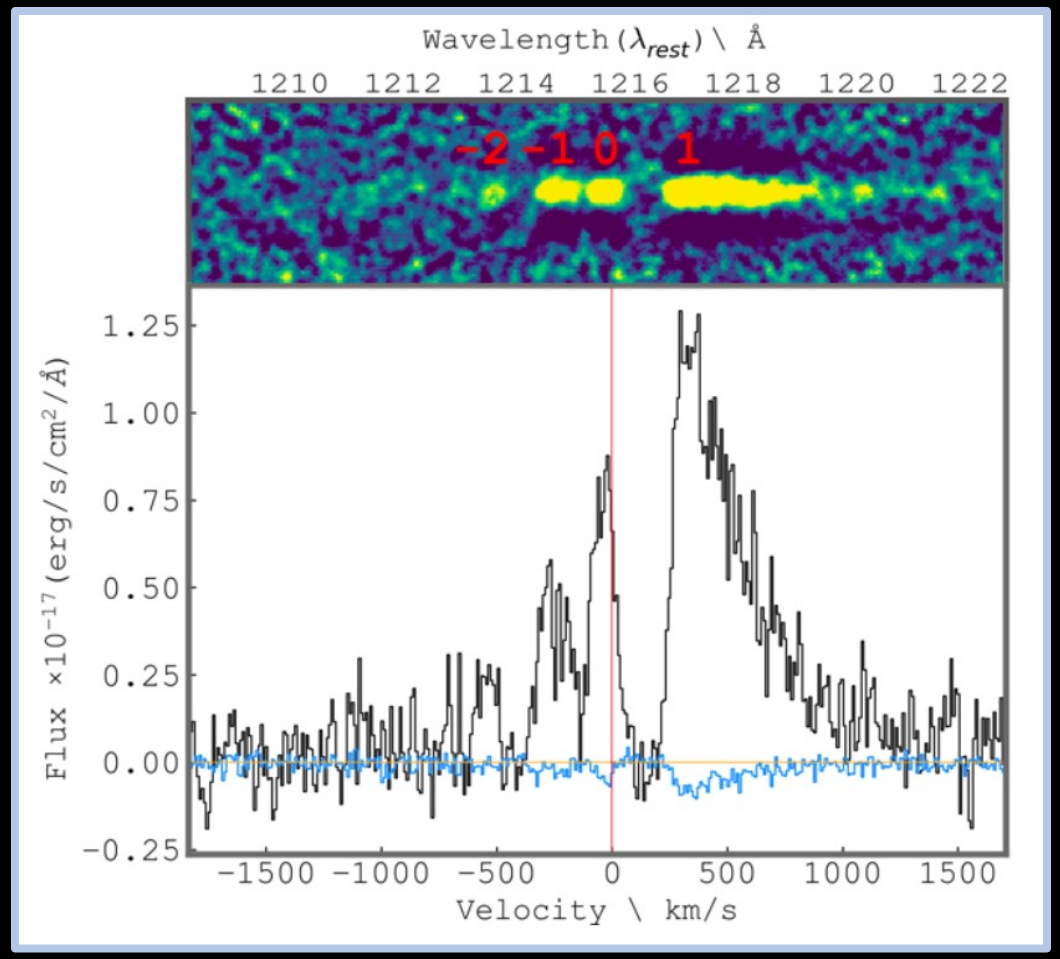
Mestric et al. (submitted)

Among most distant confirmed LyC leakers (z=3.999)

HST imaging shows multiple LyC-emitting clumps (Reff < 200pc for each clump) and low-z interloper

Likely f_{esc} ~ 10%, but depends on unknown IGM opacity (previous estimate ~60%)

Ion3

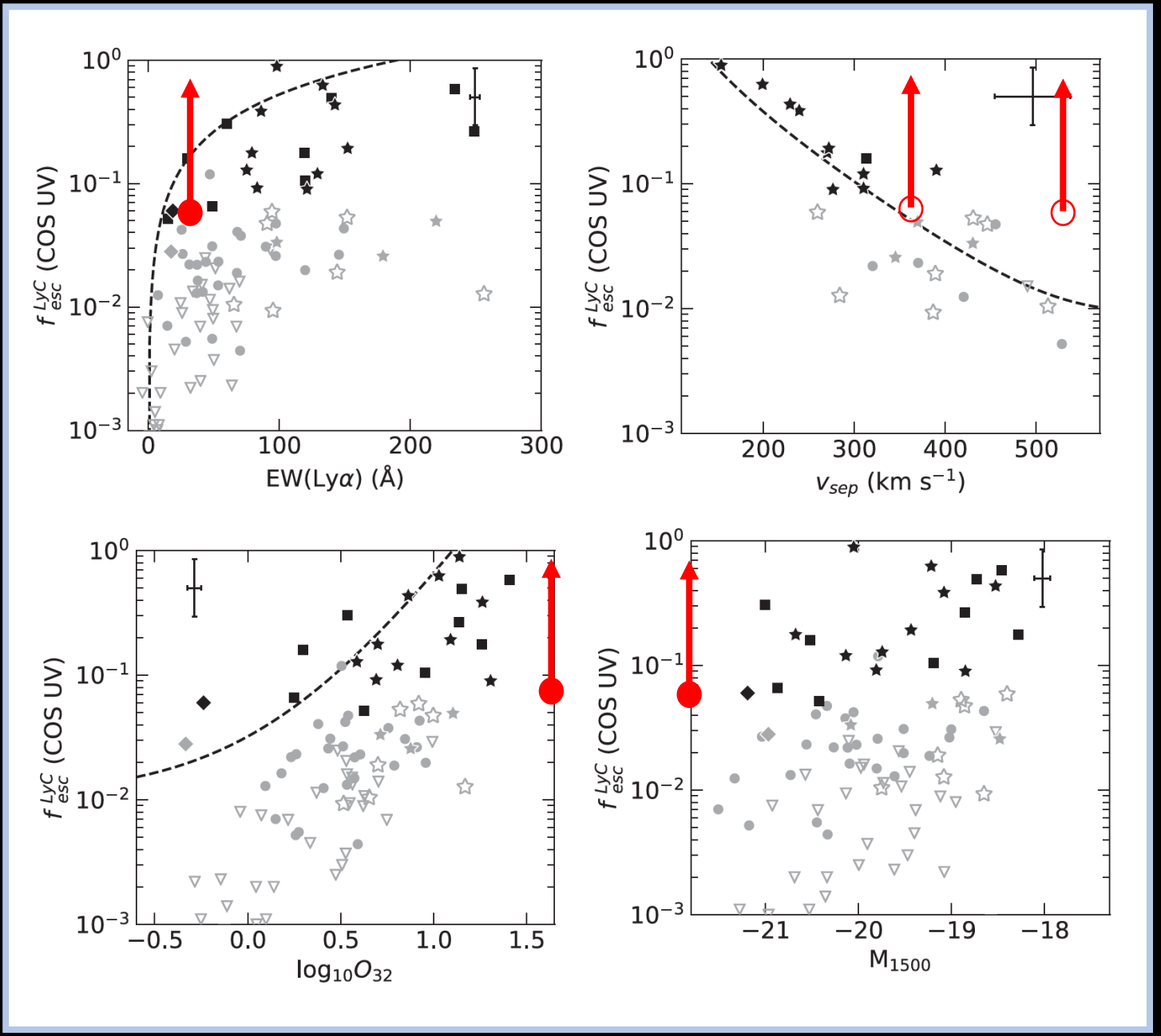


Mestric et al. (submitted)

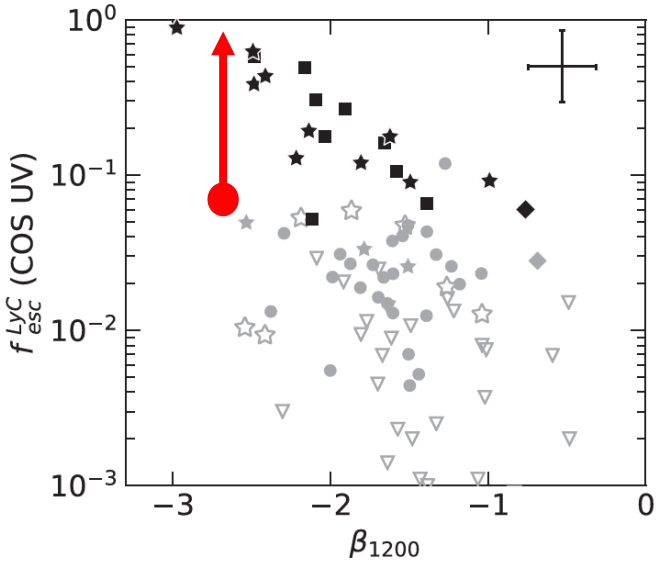
Strong Ly-alpha peak at systemic redshift

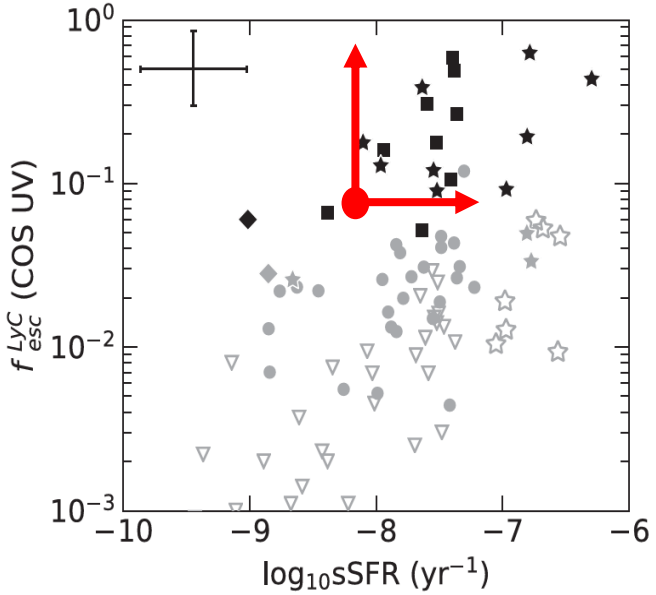
Low-mass, low-metallicity, high-SFR, high-ionization ISM, similar to many low-z LyC emitters

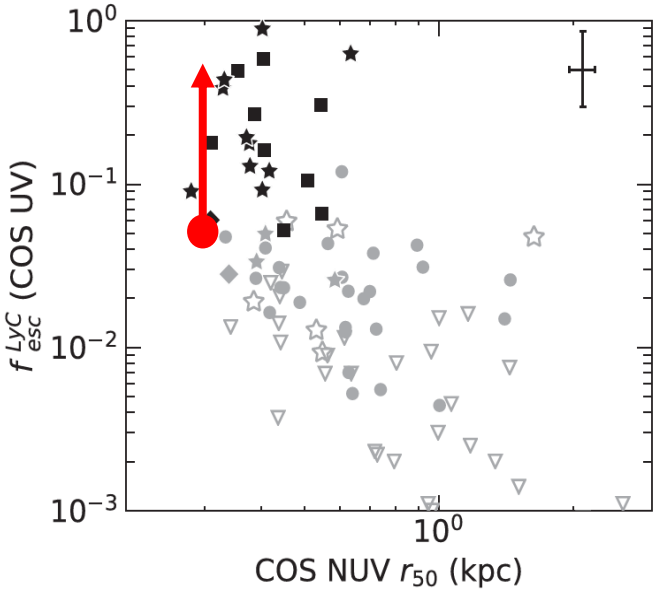
Ion3

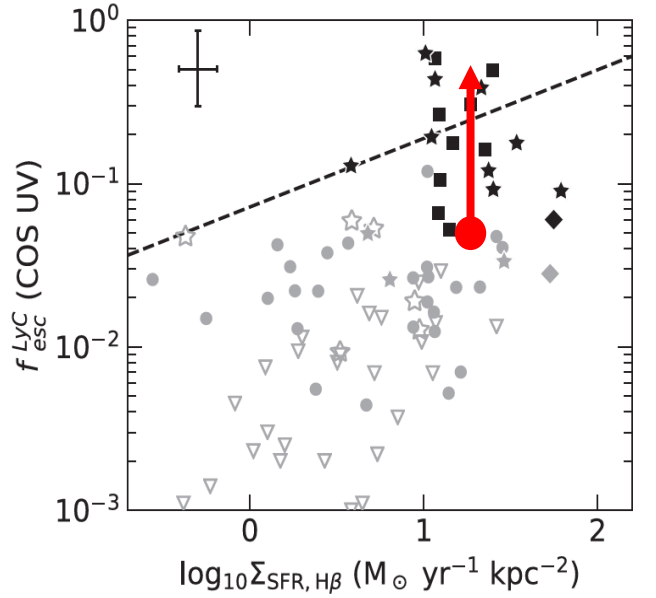


Ion3

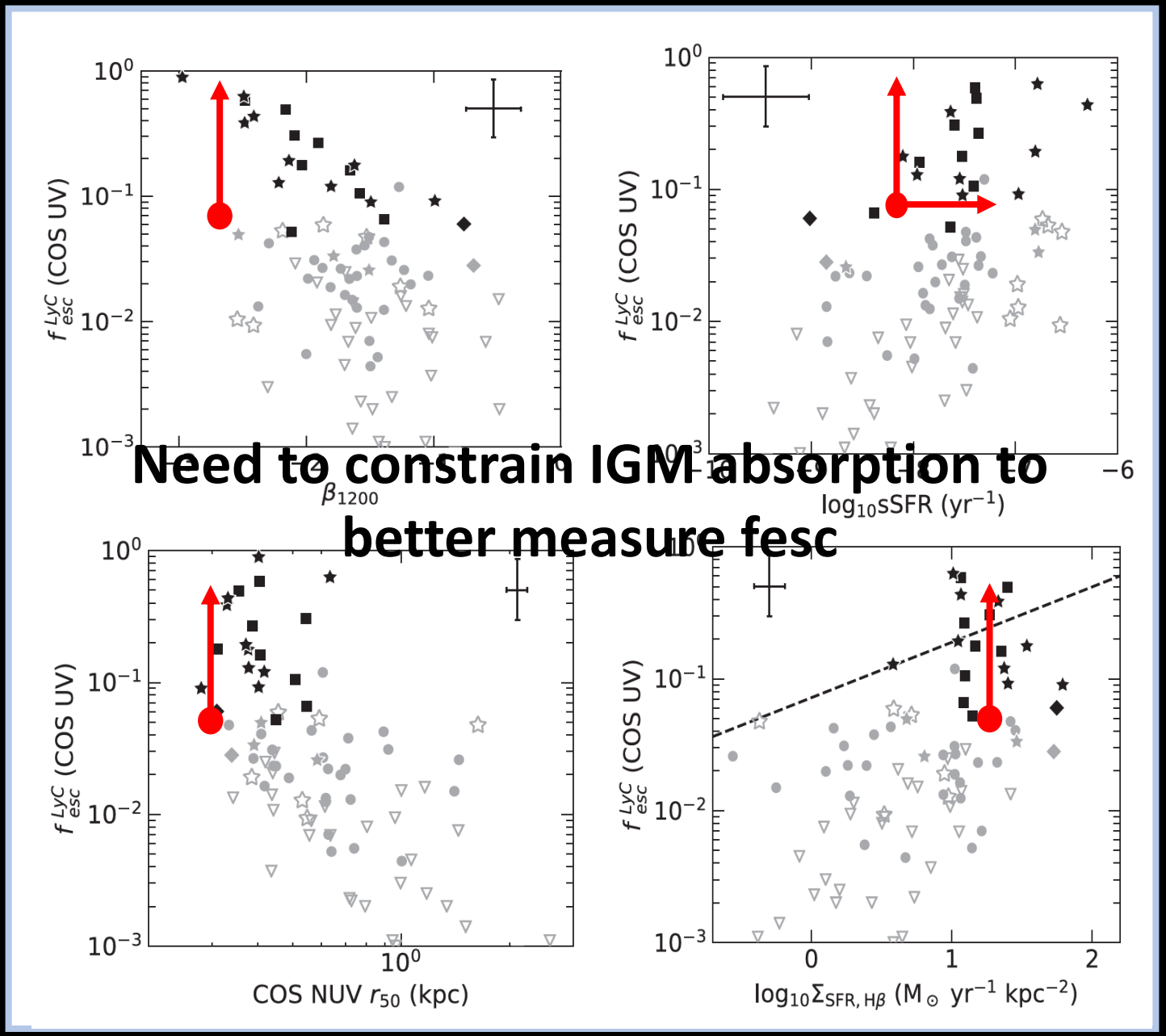

10^0
10^{-1}
10^{-2}
10^{-3}
f_{esc}^{LyC} (COS UV)
−3
−2
−1
0
β_{1200}


10^0
10^{-1}
10^{-2}
10^{-3}
f_{esc}^{LyC} (COS UV)
−10
−9
−8
−7
−6
$\log_{10}$sSFR (yr^{-1})


10^0
10^{-1}
10^{-2}
10^{-3}
f_{esc}^{LyC} (COS UV)
10^0
COS NUV r_{50} (kpc)


10^0
10^{-1}
10^{-2}
10^{-3}
f_{esc}^{LyC} (COS UV)
0
1
2
$\log_{10}\Sigma_{SFR,H\beta}$ ($M_\odot$ yr^{-1} kpc^{-2})

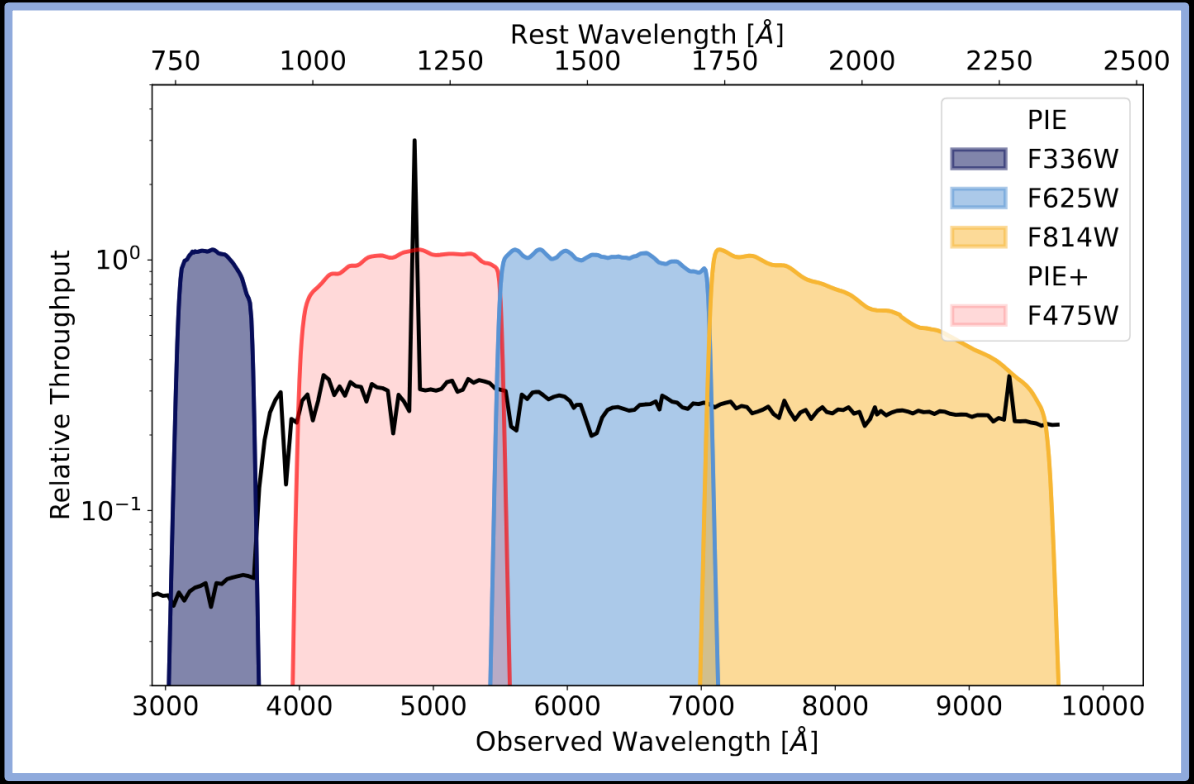
Ion3



Need to constrain IGM absorption to better measure fesc

PIE

Parallel Ionizing Emissivity survey (Cycle 30), PI Scarlata
PIE+ (Cycle 31), PI Beckett



Beckett et al. (submitted)

- **Step 1: HST imaging**
  - **37 fields observed using 3 or 4 bands**
  - **F336W probes LyC at z > 3.1**
  - **F475W/F625W/F814W probe rest-frame UV continuum**

PIE

Parallel Ionizing Emissivity survey (Cycle 30), PI Scarlata
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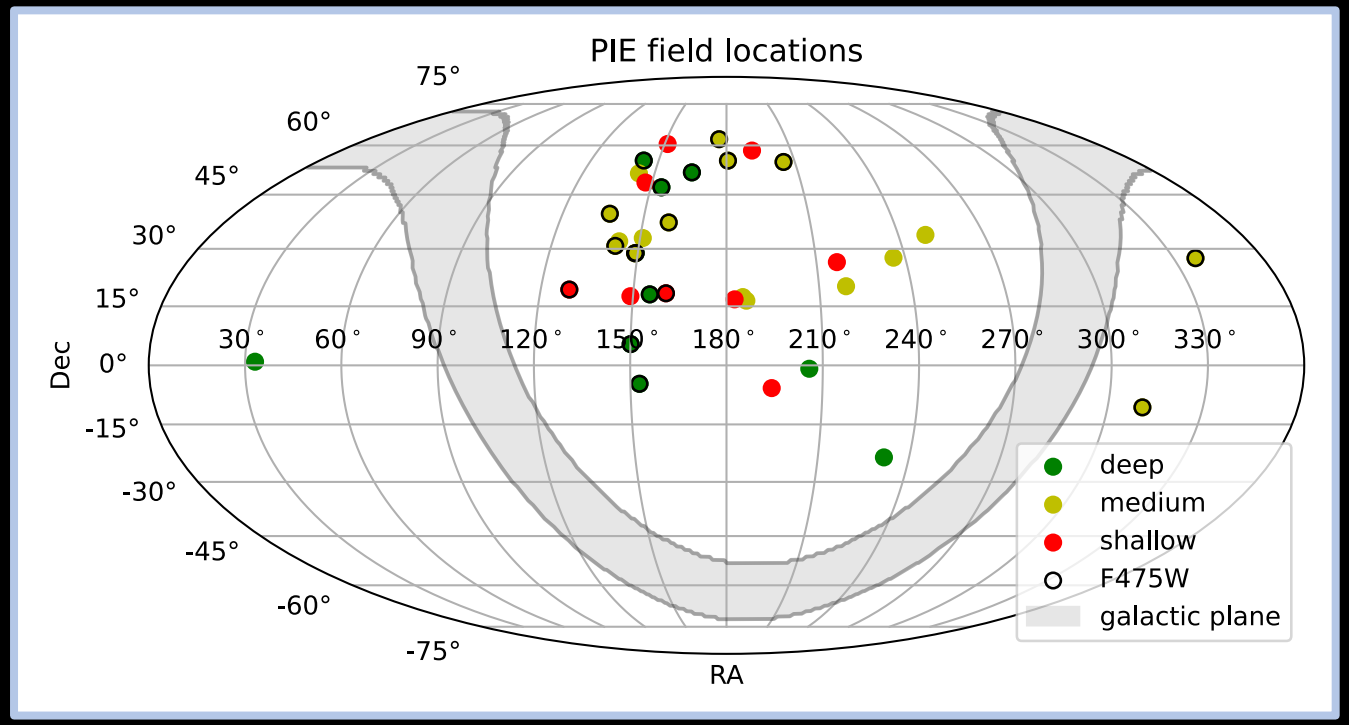
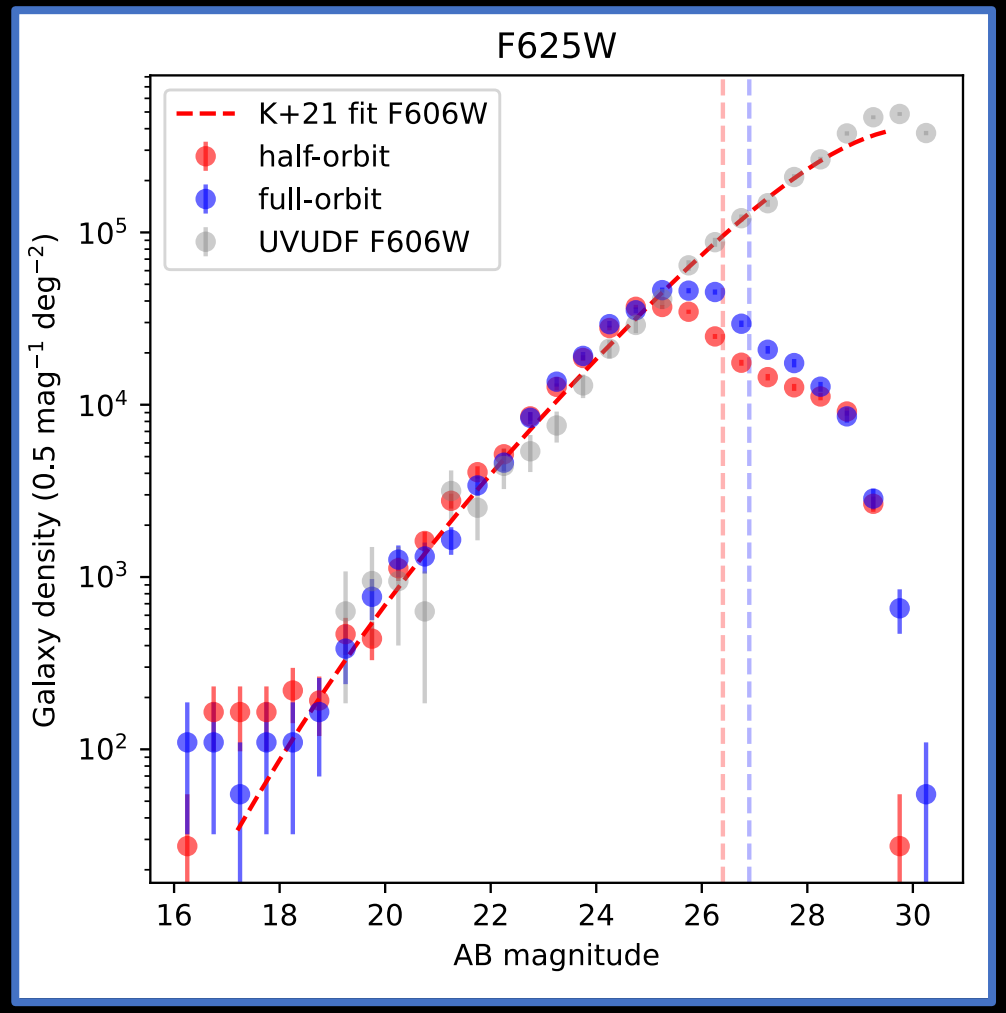


Beckett et al. (submitted)

- **Step 1: HST imaging**
  - **37 fields observed using 3 or 4 bands**
  - **F336W probes LyC at z > 3.1, F475W/F625W/F814W probe rest-frame UV continuum**
  - **Fields are spread across the sky to avoid correlations in the IGM due to large-scale structure**
  - **Observations now complete**

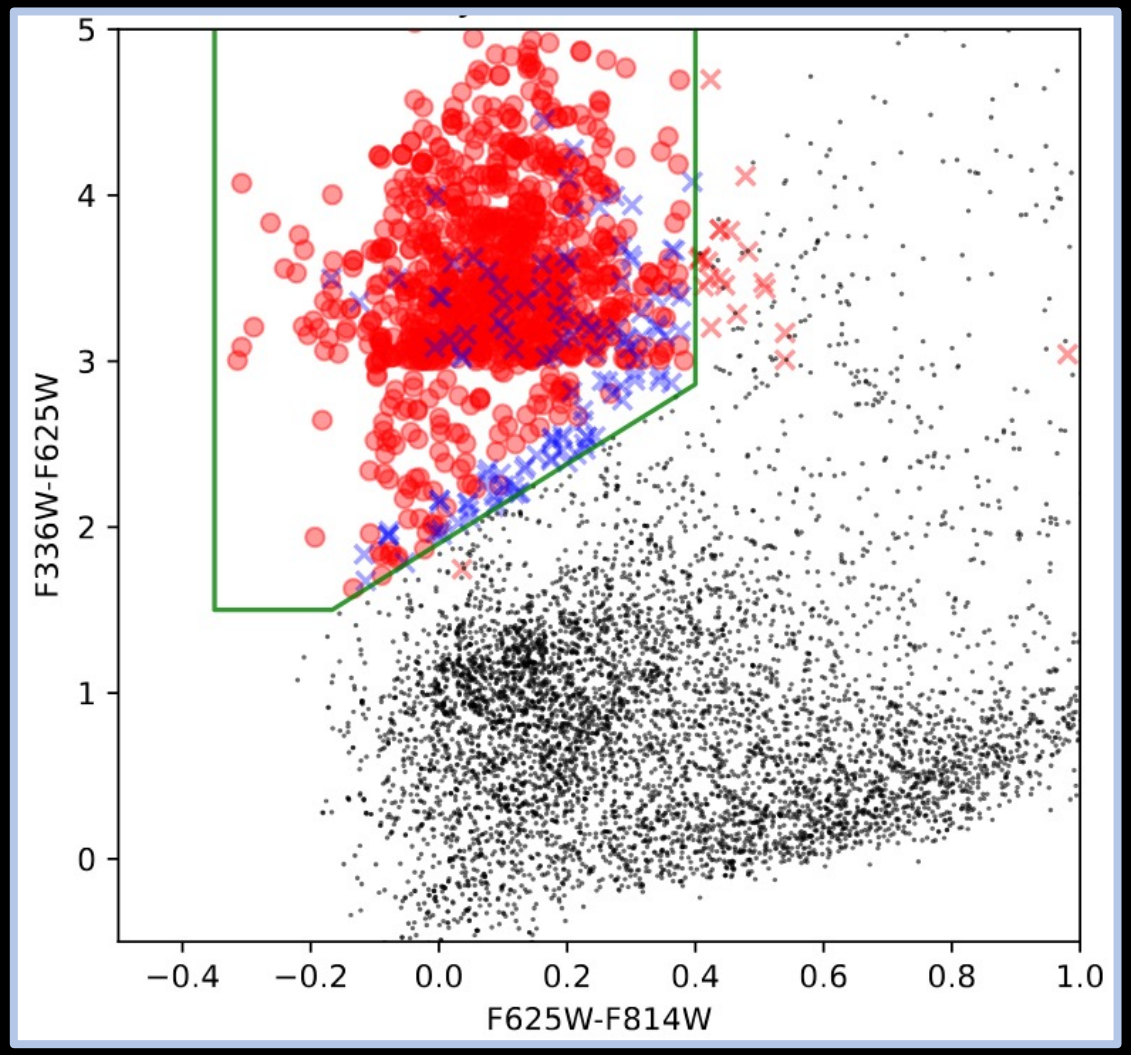
PIE



Beckett et al. (submitted)

- **Step 1: HST imaging**
  - **37 fields observed using 3 or 4 bands, spread across the sky to avoid IGM correlations**
  - **F336W probes LyC at z > 3.1, F475W/F625W/F814W probe rest-frame UV continuum**
  - **Photometric apertures based on F625W+F814W image**
  - **~50% complete to AB=26 in F625W**

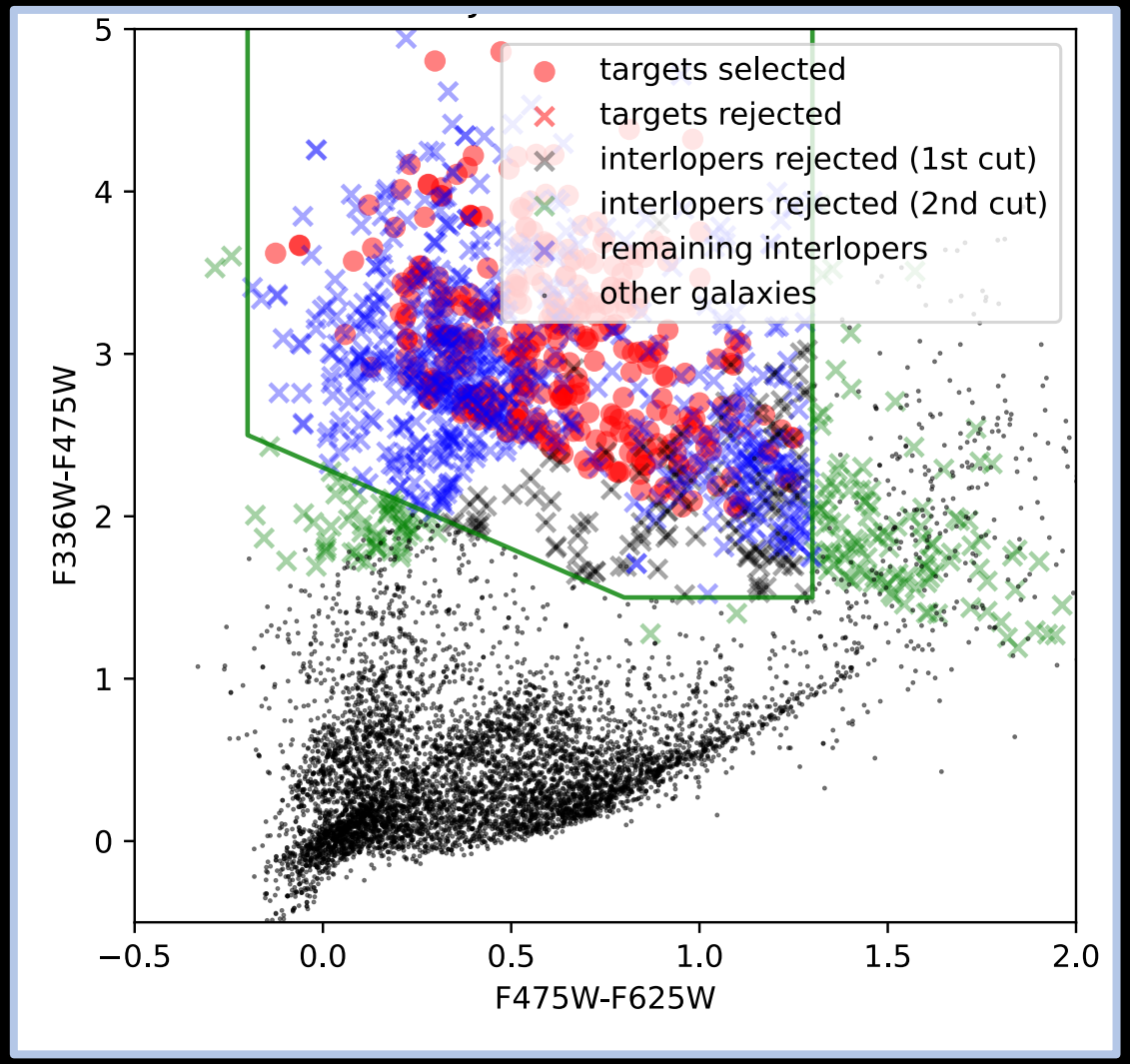
PIE



Beckett et al. (submitted)

- Step 1: HST imaging (complete)
- Step 2: Color selection
  - Mocks show we can reliably select targets at 2.7<z<4.0 for follow-up spectroscopy
  - 98% completeness, ~90% purity
  - Only 30% lie at 3.1 < z < 3.5, where F336W probes pure LyC

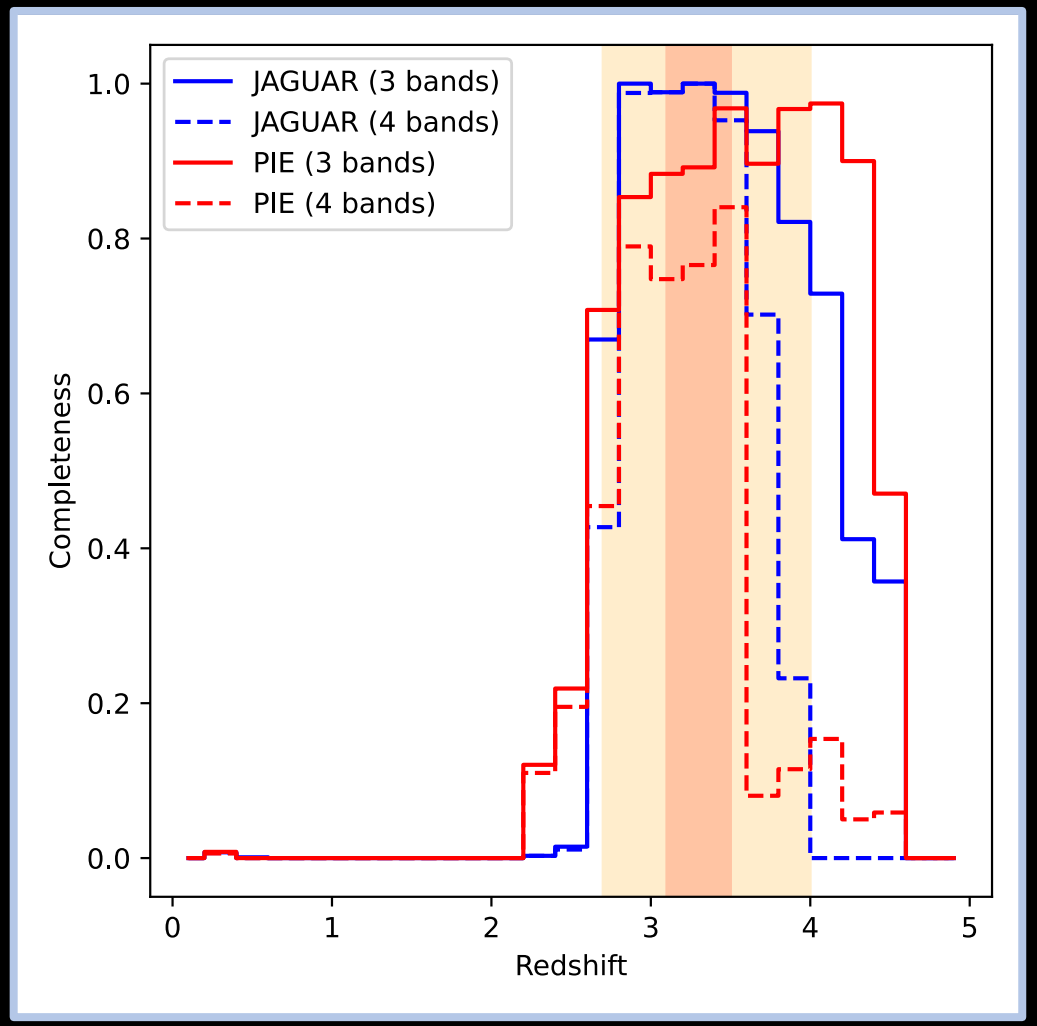
PIE



Beckett et al. (submitted)

- **Step 1: HST imaging (complete)**
- **Step 2: Color selection**
  - **98% completeness, ~30% purity in selecting 3.1<z<3.5 galaxies**
  - **18 fields also have F475W, allowing additional color cuts**
  - **Purity increases to ~45% with these cuts**

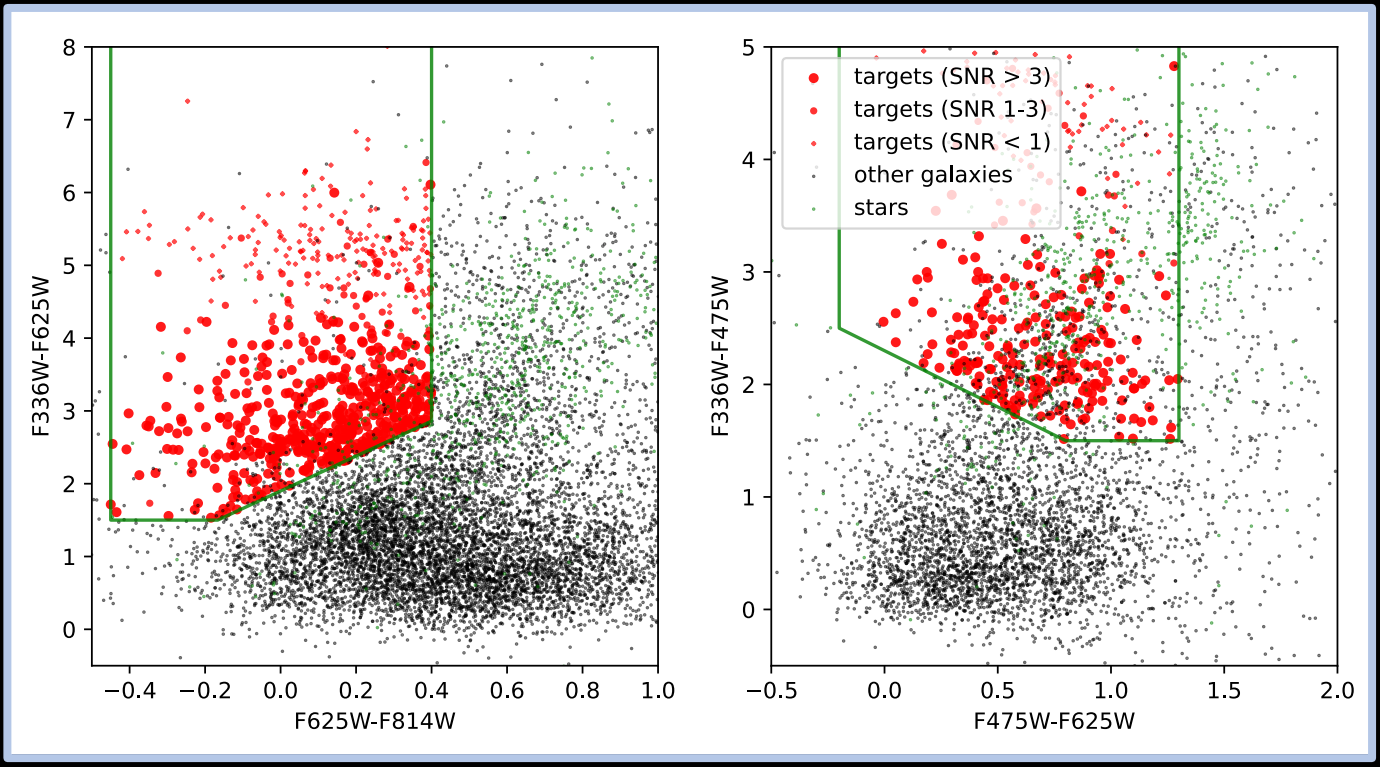
PIE



Beckett et al. (submitted)

- Step 1: HST imaging (complete)
- Step 2: Color selection
  - 98% completeness, ~30% purity in selecting 3.1<z<3.5 galaxies (with 3-bands), increasing to 45% purity with 4-bands
  - Very few low-redshift interlopers

PIE

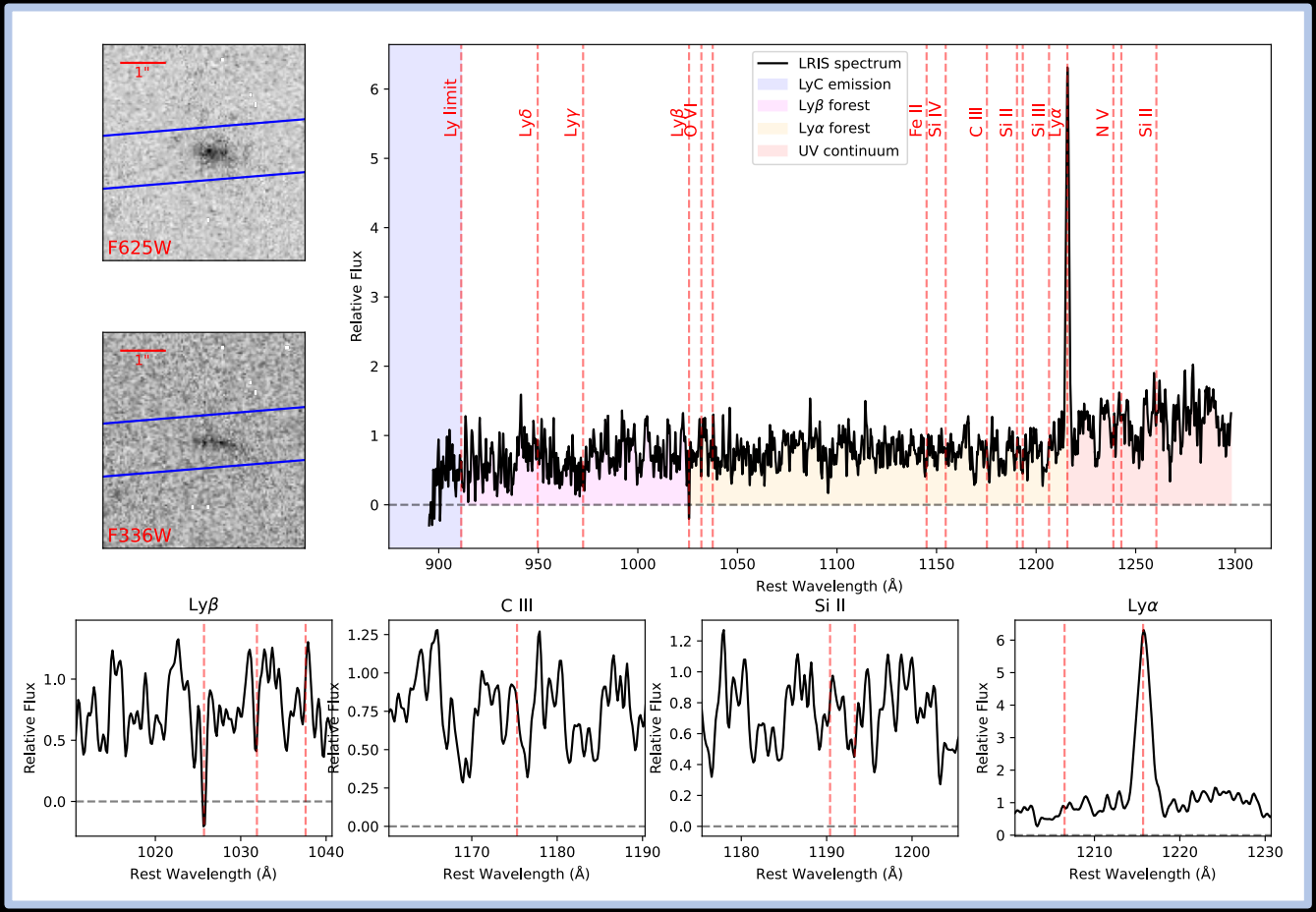


Beckett et al. (submitted)

- Step 1: HST imaging (complete)
- Step 2: Color selection
  - 98% completeness, ~30% purity in selecting 3.1<z<3.5 galaxies (with 3-bands), increasing to 45% purity with 4-bands

- In total:
- ~1300 targets selected
- ~1100 LBGs
- ~450 galaxies at 3.1<z<3.5
- ~40 confirmed LyC emitters

PIE

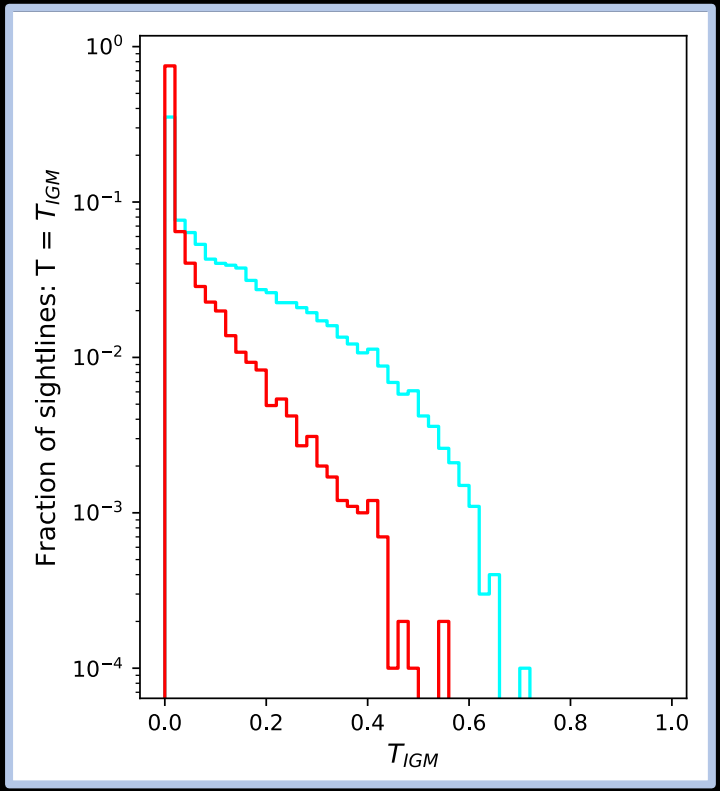


Beckett et al. (submitted)

- Step 1: HST imaging (complete)
- Step 2: Color selection (complete)
- Step 3: Spectroscopic confirmation
  - First spectroscopic observations complete
  - Include plausible LyC emitter at 3.067 confirmed with Keck/LRIS
  - Further observations ongoing

PIE

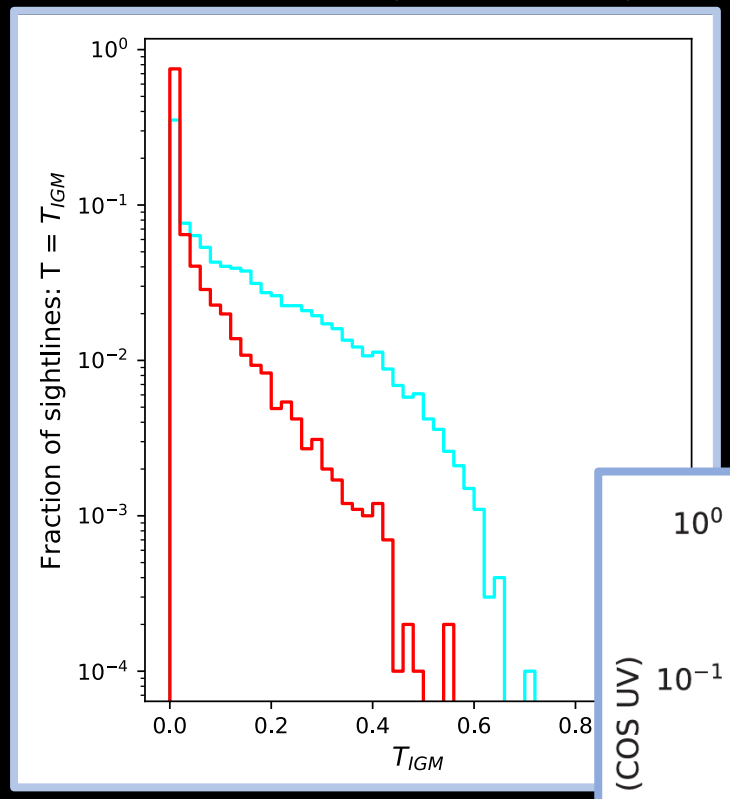
Beckett et al. (submitted)

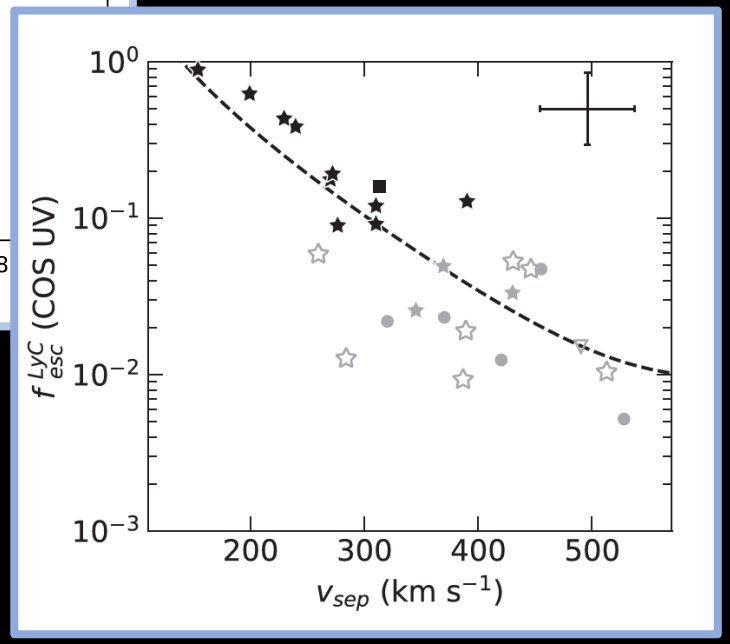


- **Step 1: HST imaging (complete)**
- **Step 2: Color selection (complete)**
- **Step 3: Spectroscopic confirmation (ongoing)**
- **Step 4: Stack galaxies to measure LyC flux (future work)**
  - **We can average over the IGM distribution to measure more accurate escape fractions**

PIE

Beckett et al. (submitted)





Flury et al. (2022)

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  - **We can average over the IGM distribution to measure more accurate escape fractions**

Thanks for listening!

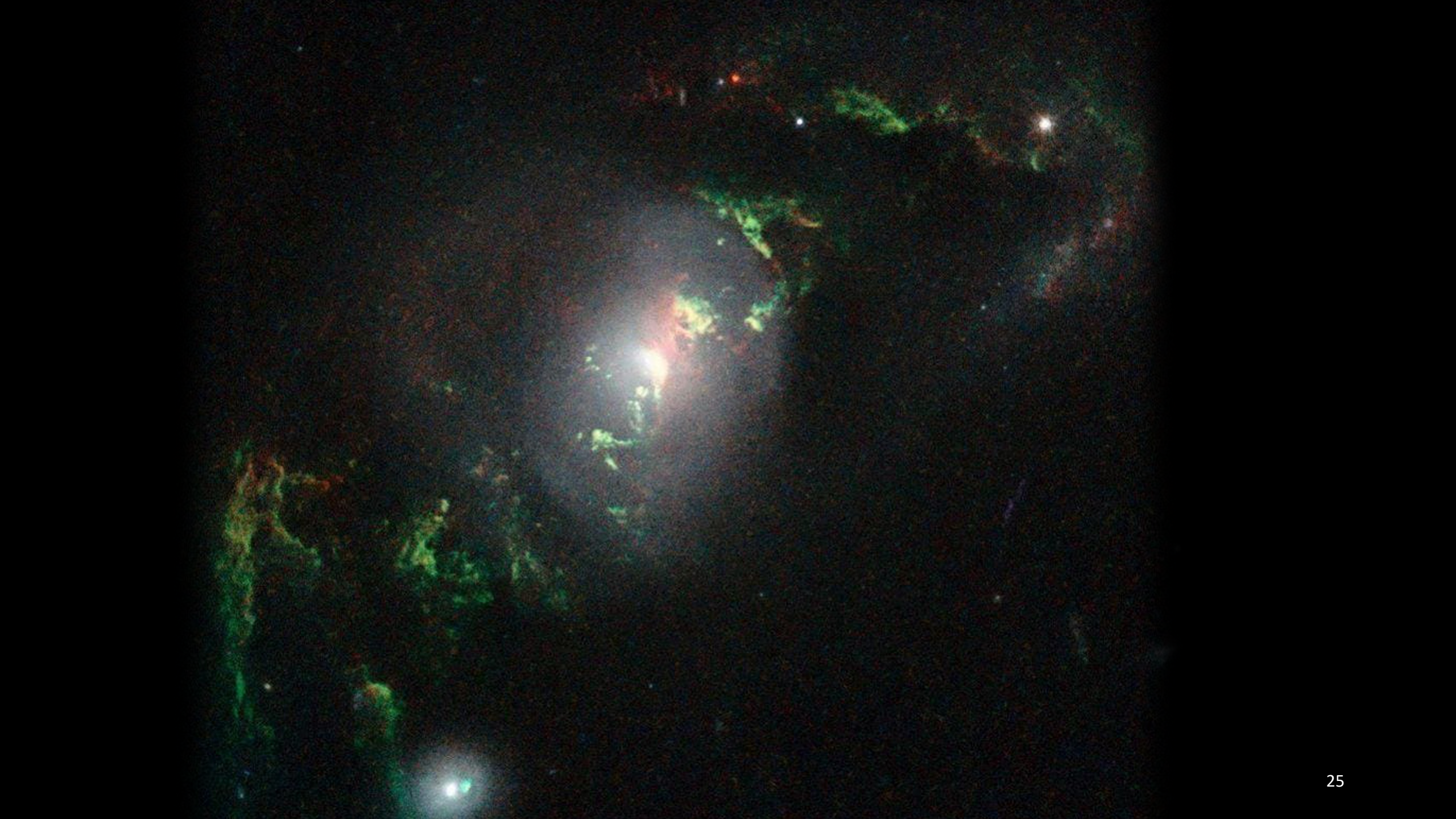
Detailed studies of high-redshift galaxies reveal how LyC radiation escapes from galaxies

Large surveys needed to reduce uncertainties on fesc and hence calibrate LyC indicators that can be observed in the EoR

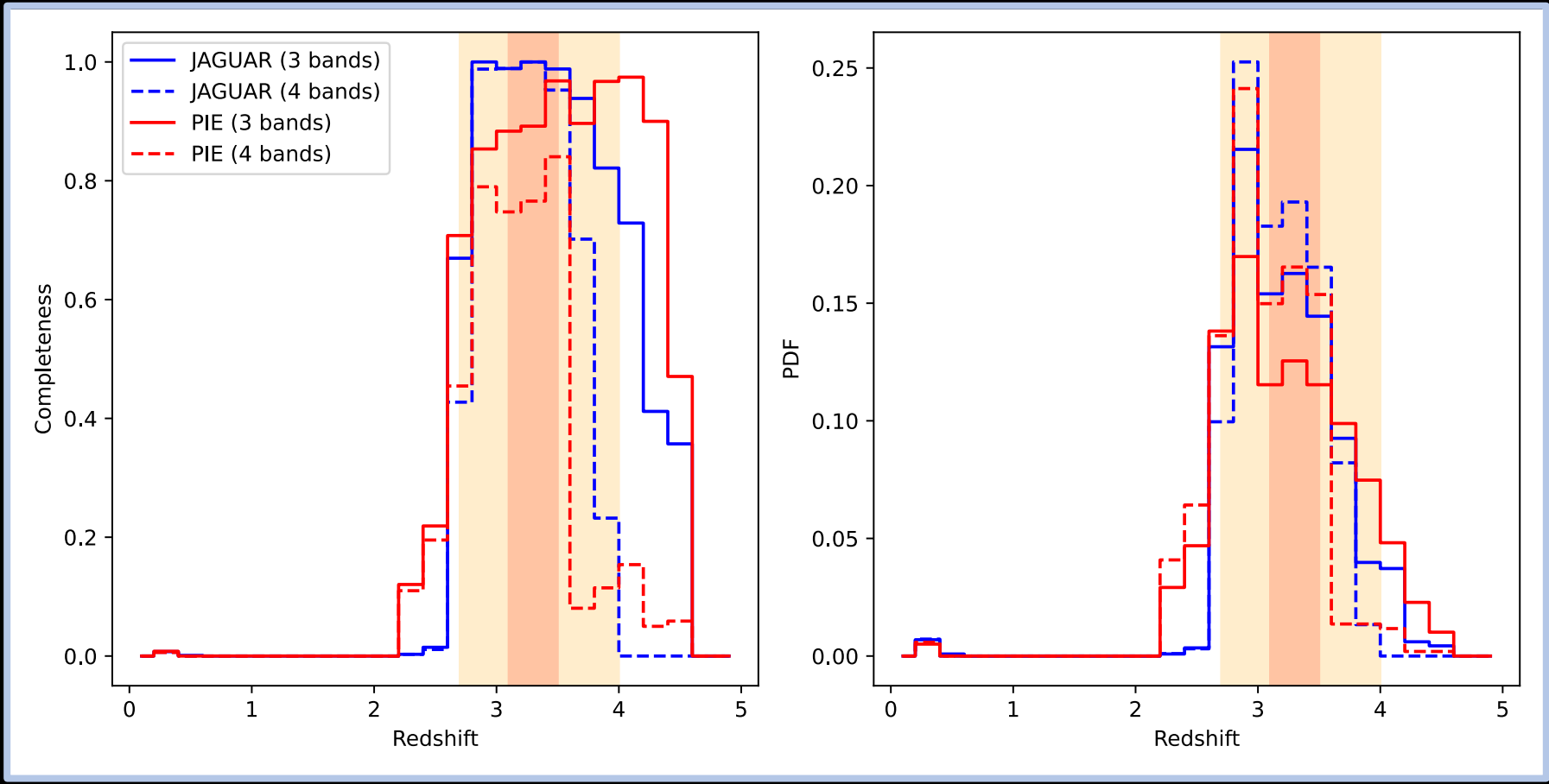
abeckett@stsci.edu

Mestric et al. 2025 (submitted)

Beckett et al. 2025 (submitted, arxiv:2503.20878)

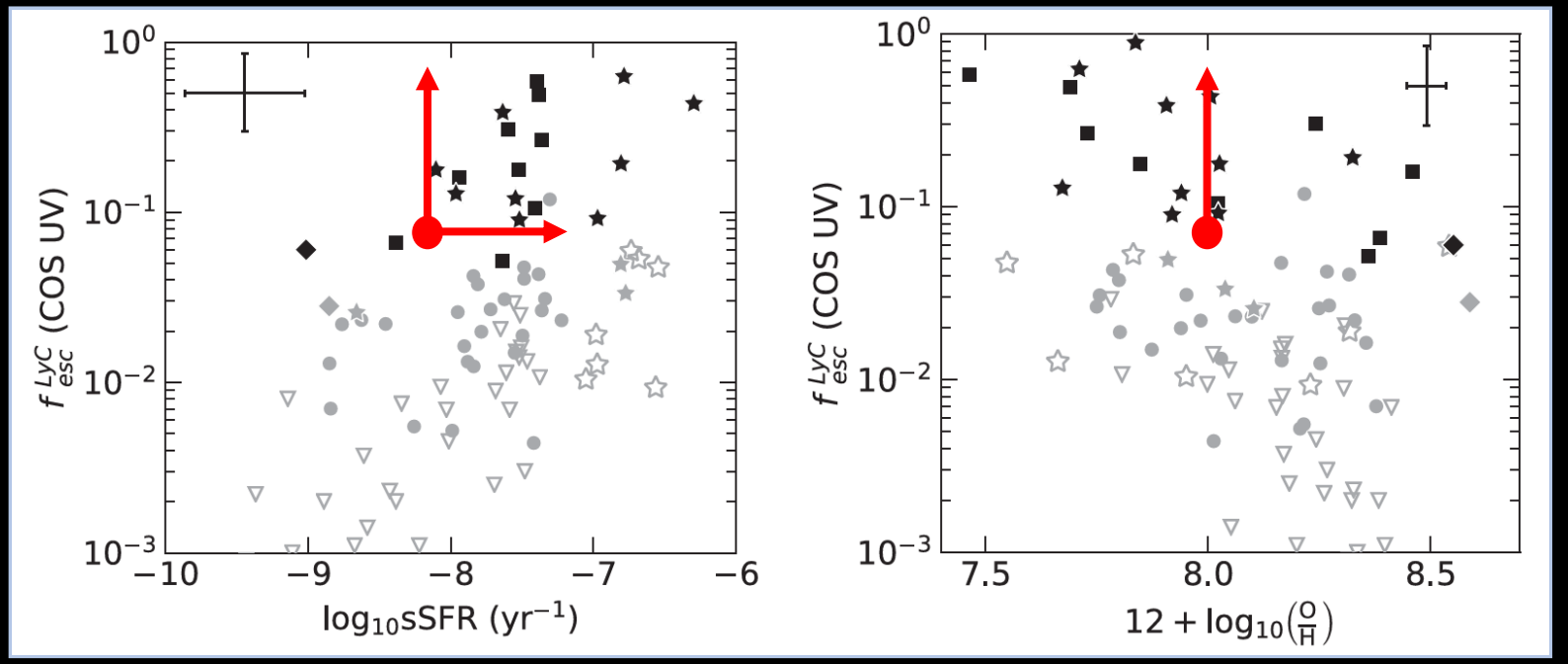


PIE



Beckett et al. (submitted)

Ion3

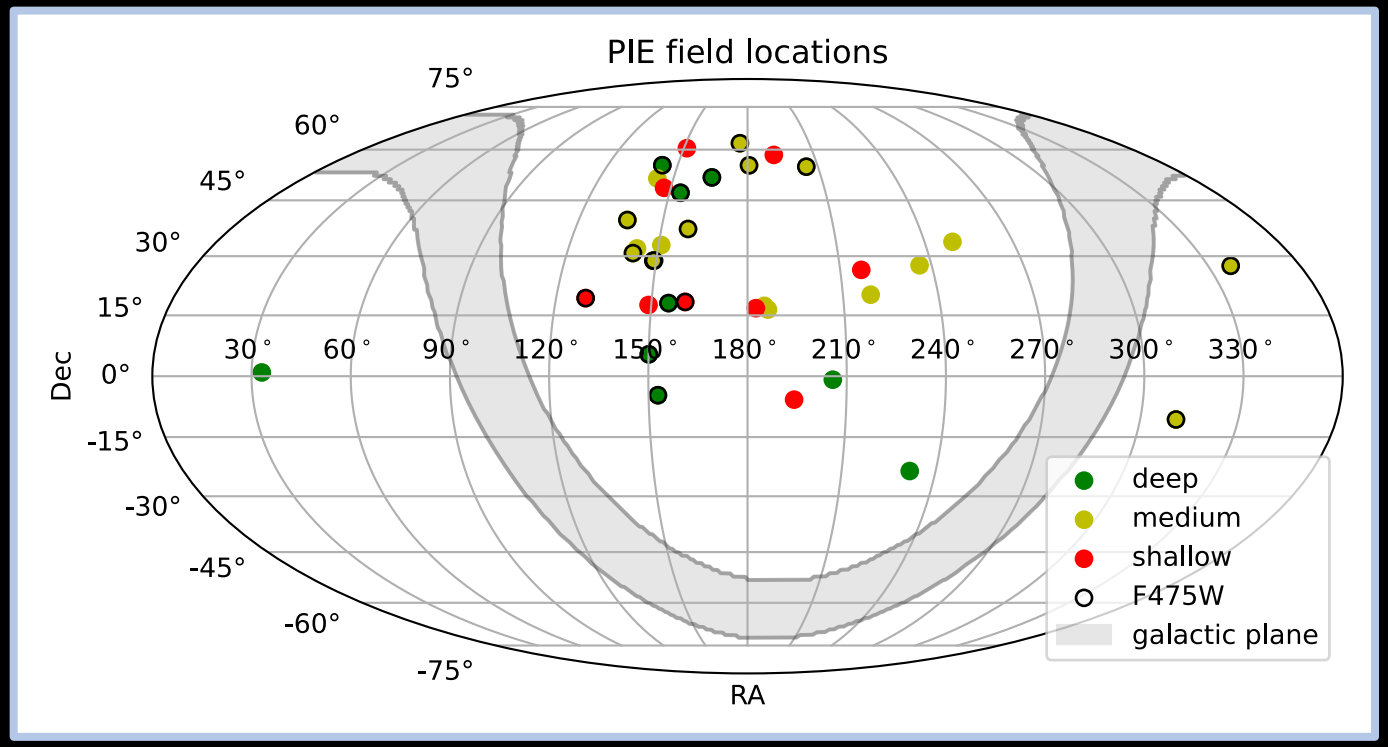


Need large samples of galaxies in independent fields to reduce the uncertainties on f_{esc} due to IGM transmission

PIE

Parallel Ionizing Emissivity survey (Cycle 30), PI Scarlata

PIE+ (Cycle 31), PI Beckett



Beckett et al. (submitted)

Survey of 54 independent fields

3 bands allow LyC detection and color selection of z~3 galaxies

Independent fields reduce the uncertainties on f_{esc} due to IGM transmission

PIE

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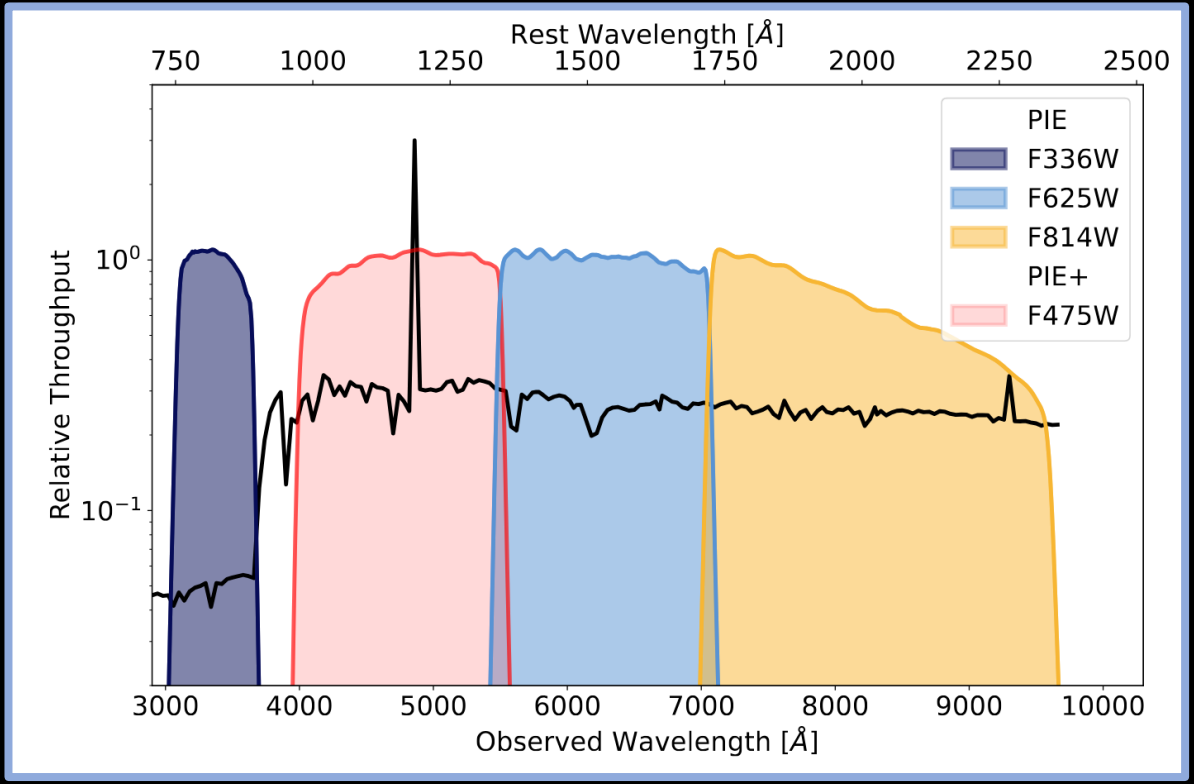
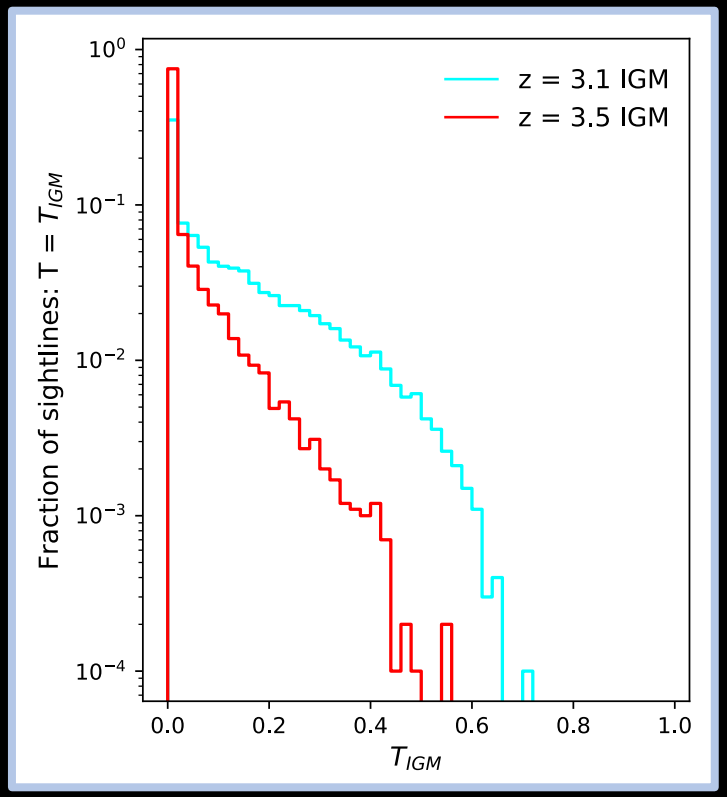
PIE+ (Cycle 31), PI Beckett



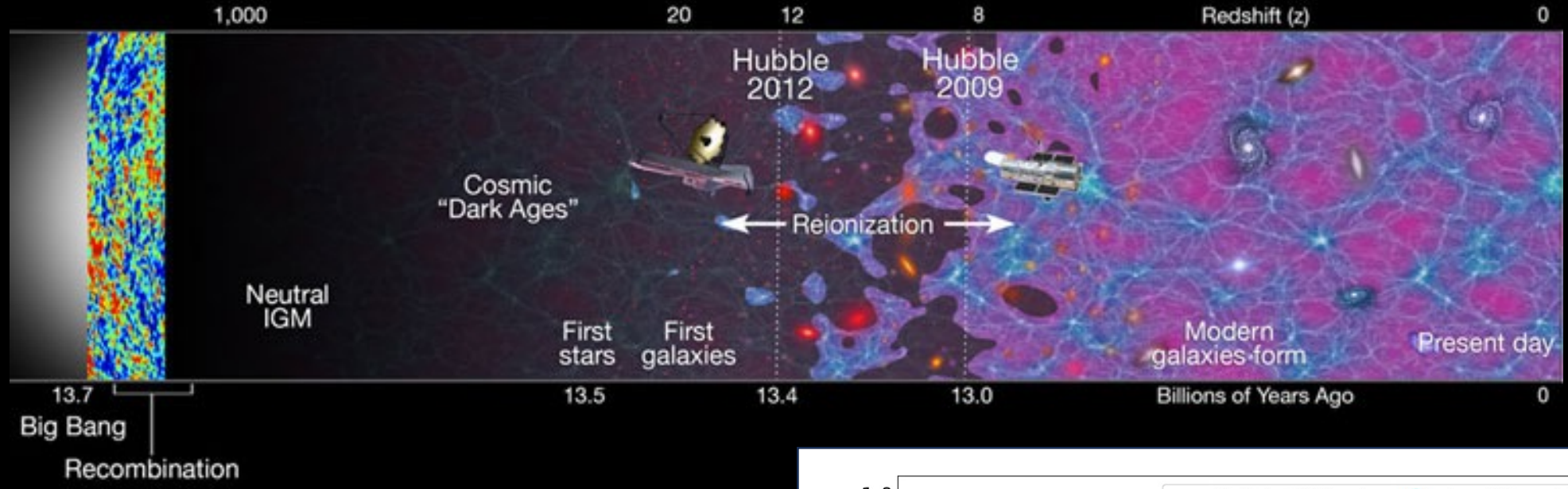
Beckett et al. (submitted)



Beckett et al. (submitted)

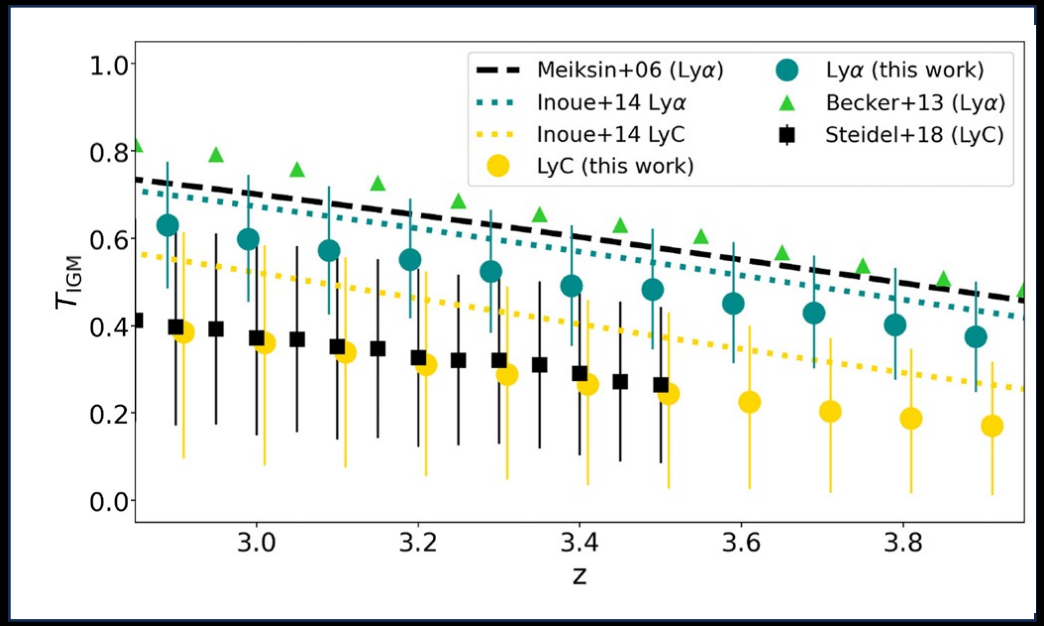
Survey of 54 independent fields to reduce the uncertainties on f_{esc} due to IGM transmission

Reionization



LyC emission from the sources that reionized the Universe can not be observed directly due to the opacity of the IGM

It is not yet clear which sources reionized the IGM at z~12-5



Top: NASA public image, Right: Bassett+21

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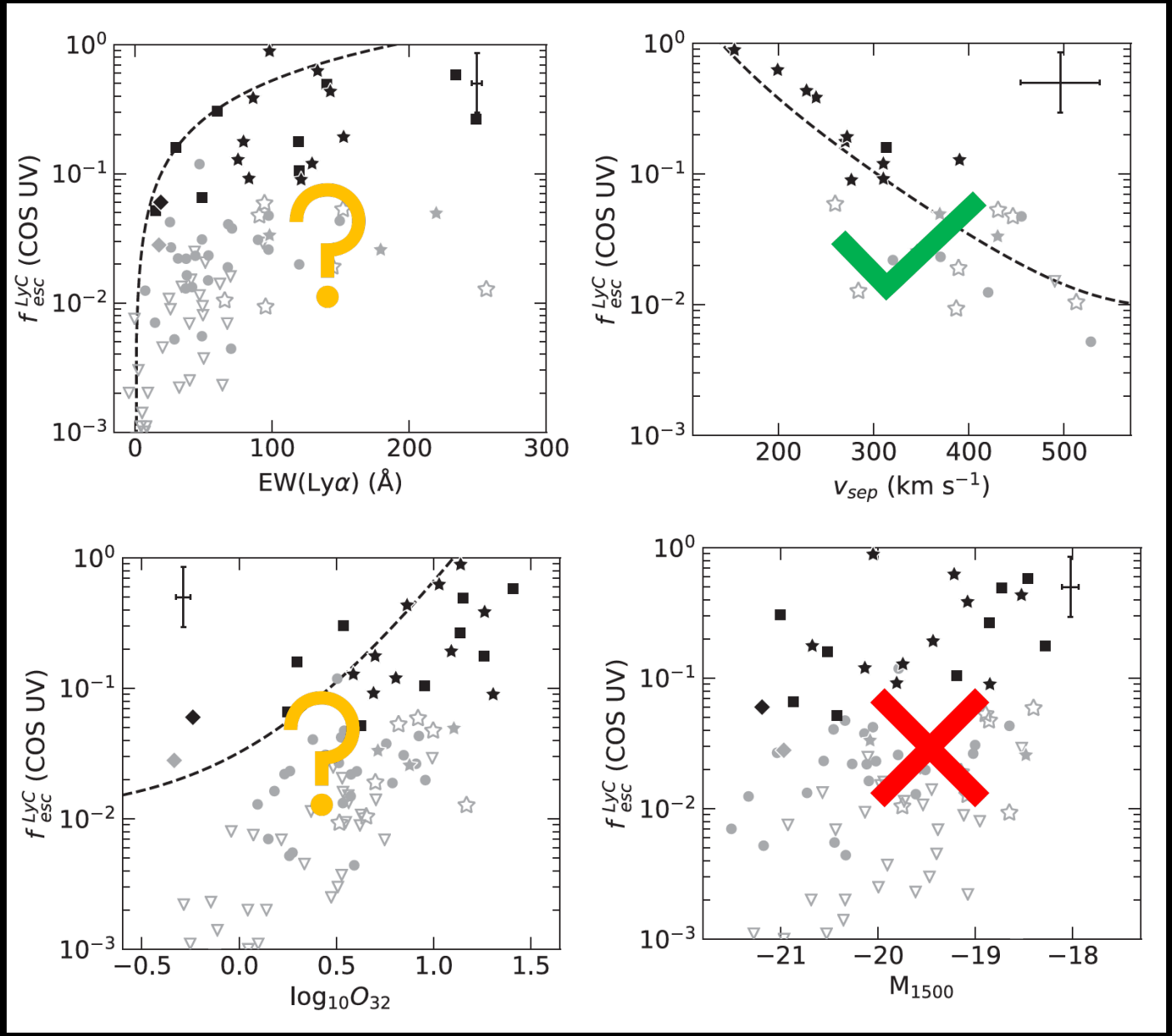
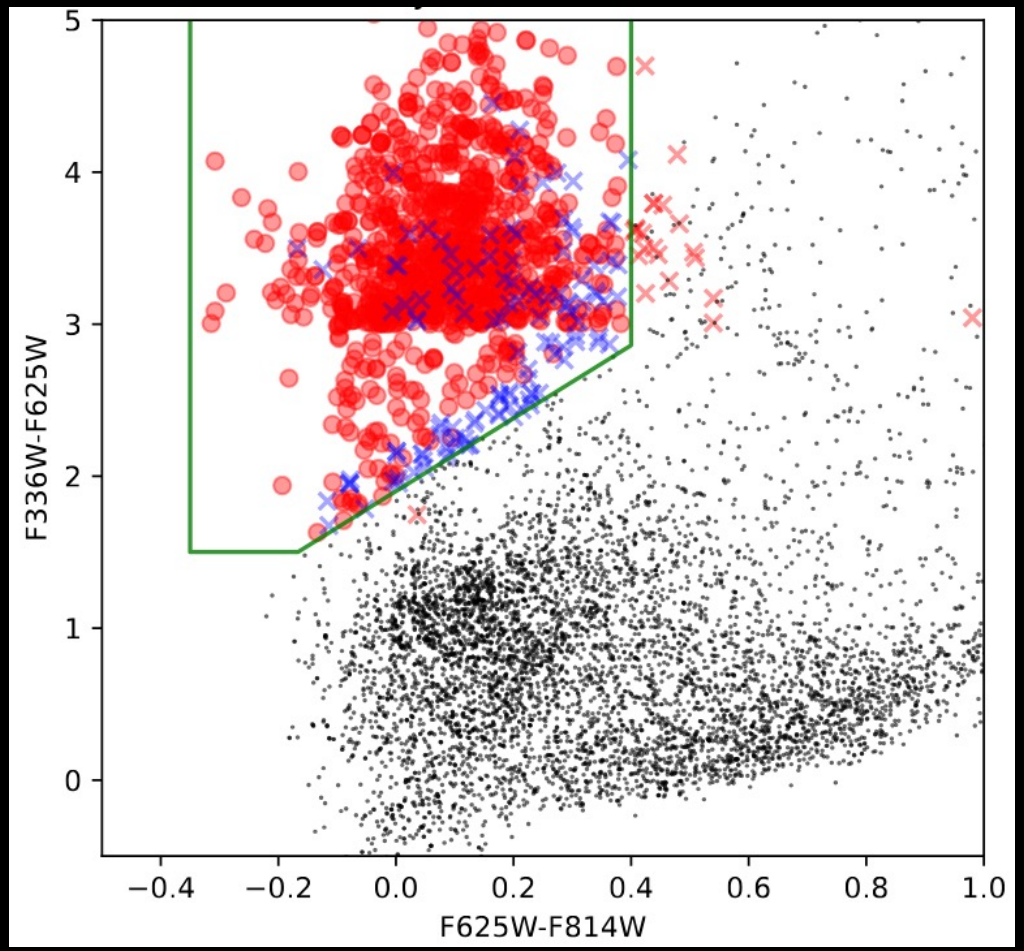
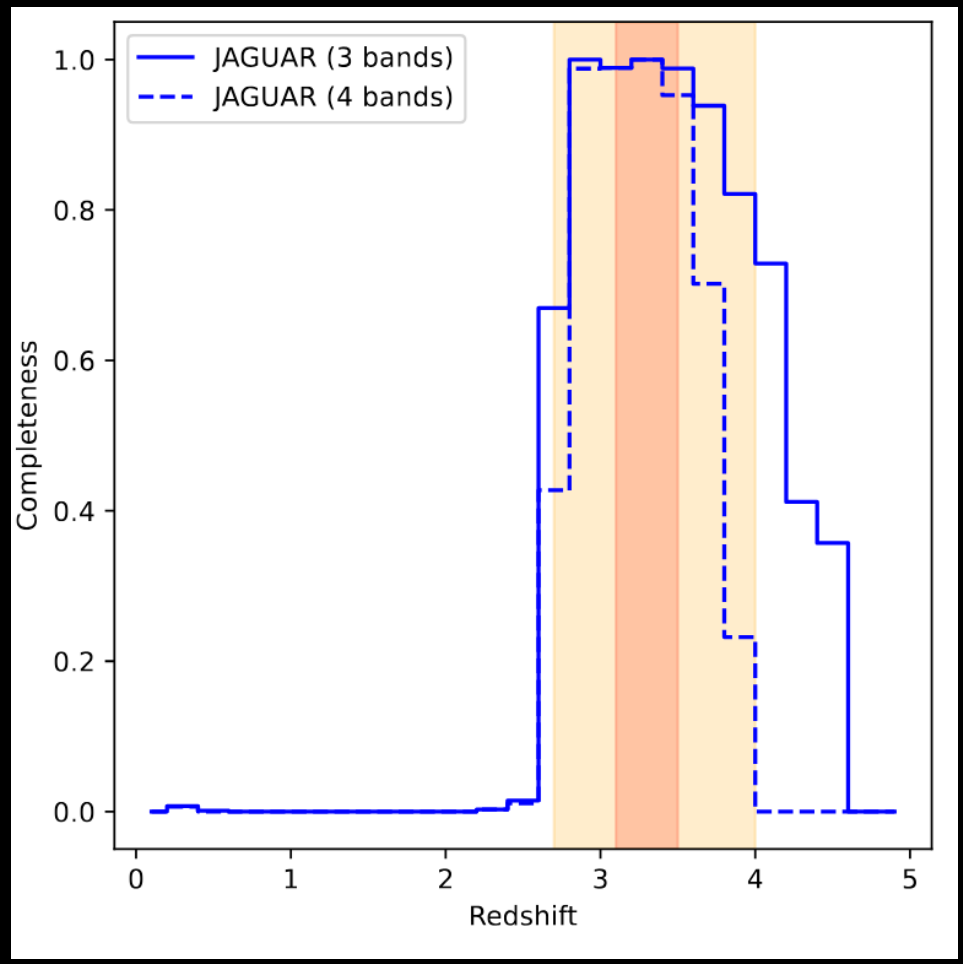


PIE



Beckett et al. (in prep)



Beckett et al. (in prep)