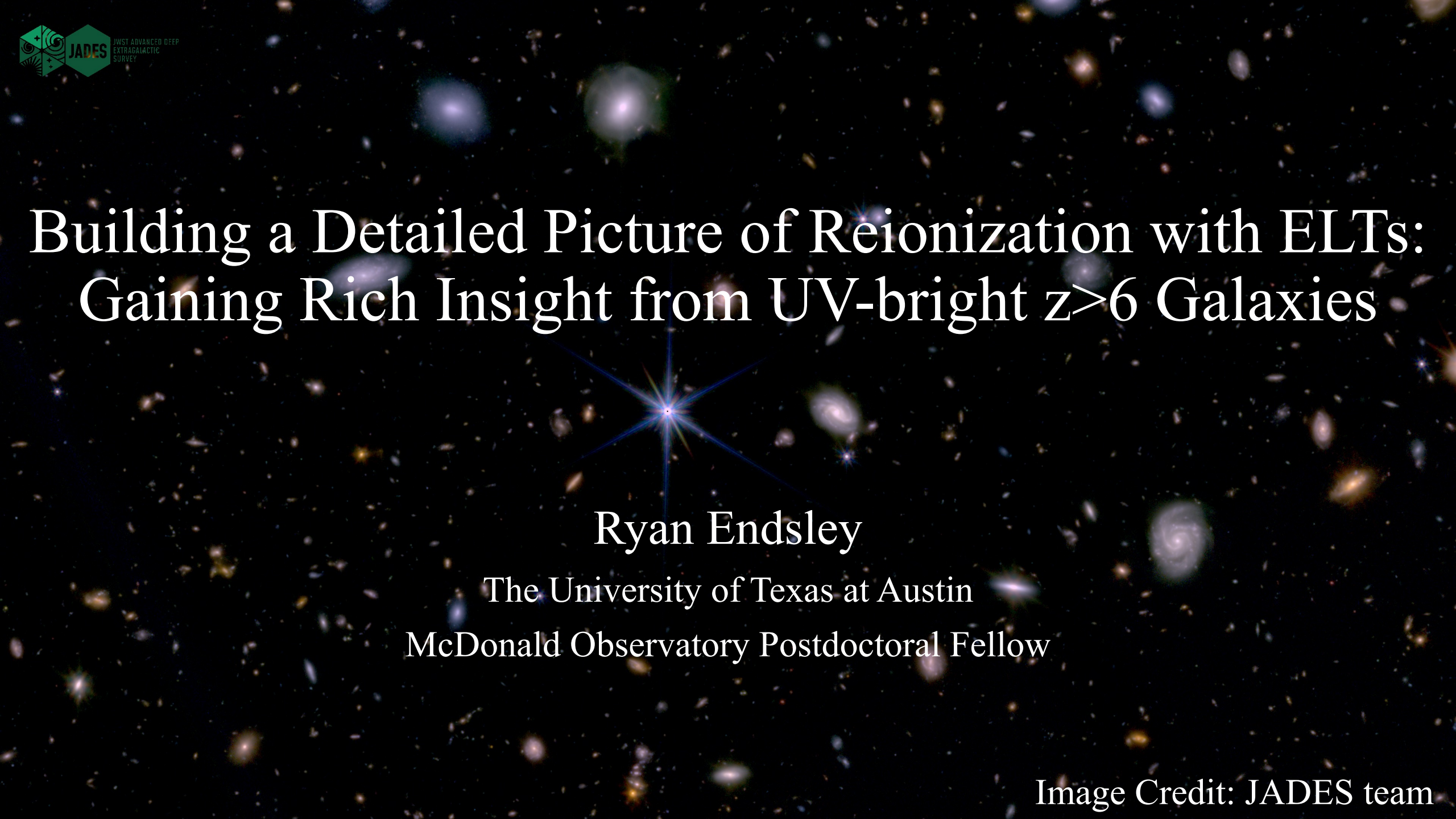


Building a Detailed Picture of Reionization with ELTs: Gaining Rich Insight from UV-bright z>6 Galaxies

Ryan Endsley

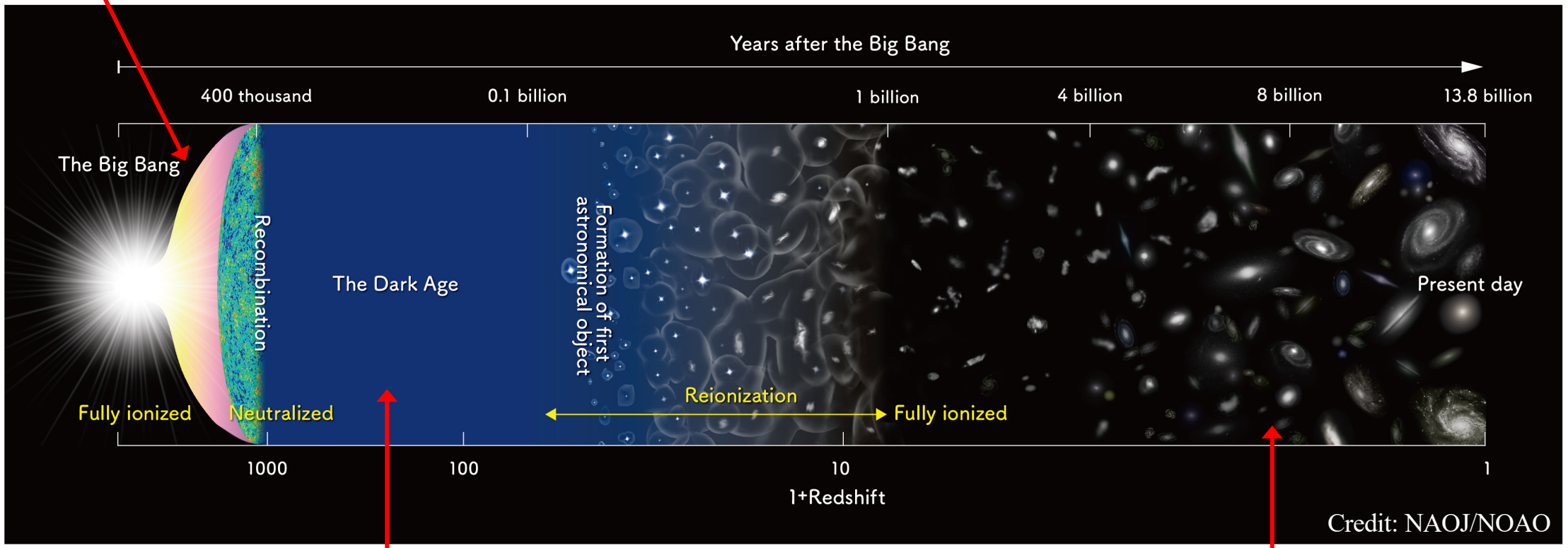
The University of Texas at Austin

McDonald Observatory Postdoctoral Fellow

Image Credit: JADES team

The Epoch of Hydrogen Reionization

Universe is very hot and ionized.



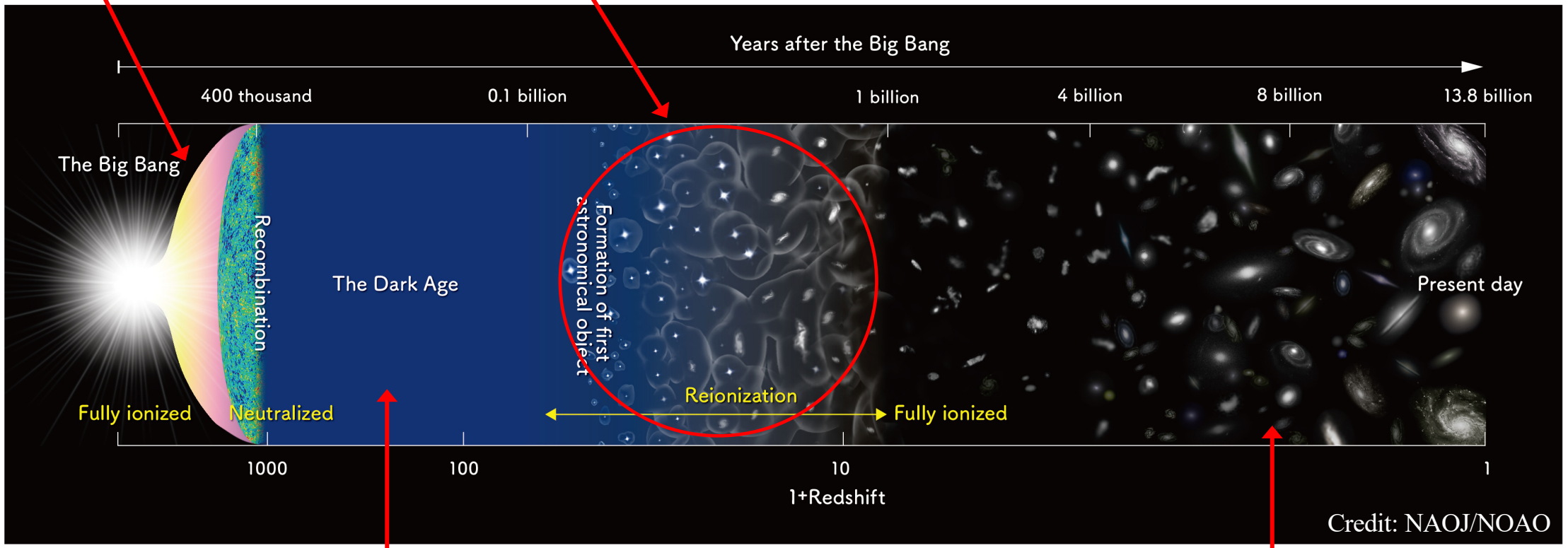
Cooled down due to expansion. Hydrogen atoms are neutral.

We see the Universe reionized at present day.

The Epoch of Hydrogen Reionization

Universe is very hot and ionized.

Galaxies begin forming and producing high-energy light.

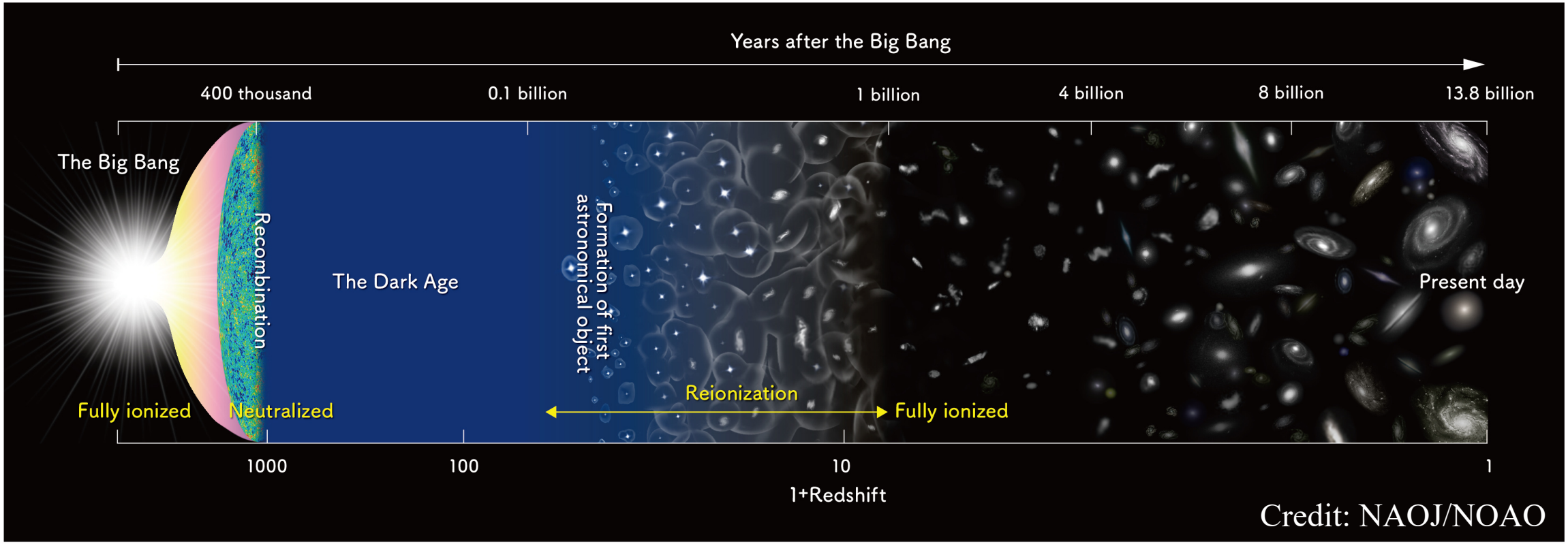


Cooled down due to expansion. Hydrogen atoms are neutral.

We see the Universe reionized at present day.

Key Outstanding Questions on Reionization

1. What were the ionizing properties of z>6 galaxies?
2. What was the relative role of bright versus faint galaxies?
3. How and where did ionized bubbles grow?



A First Look at Ionizing Properties with JWST

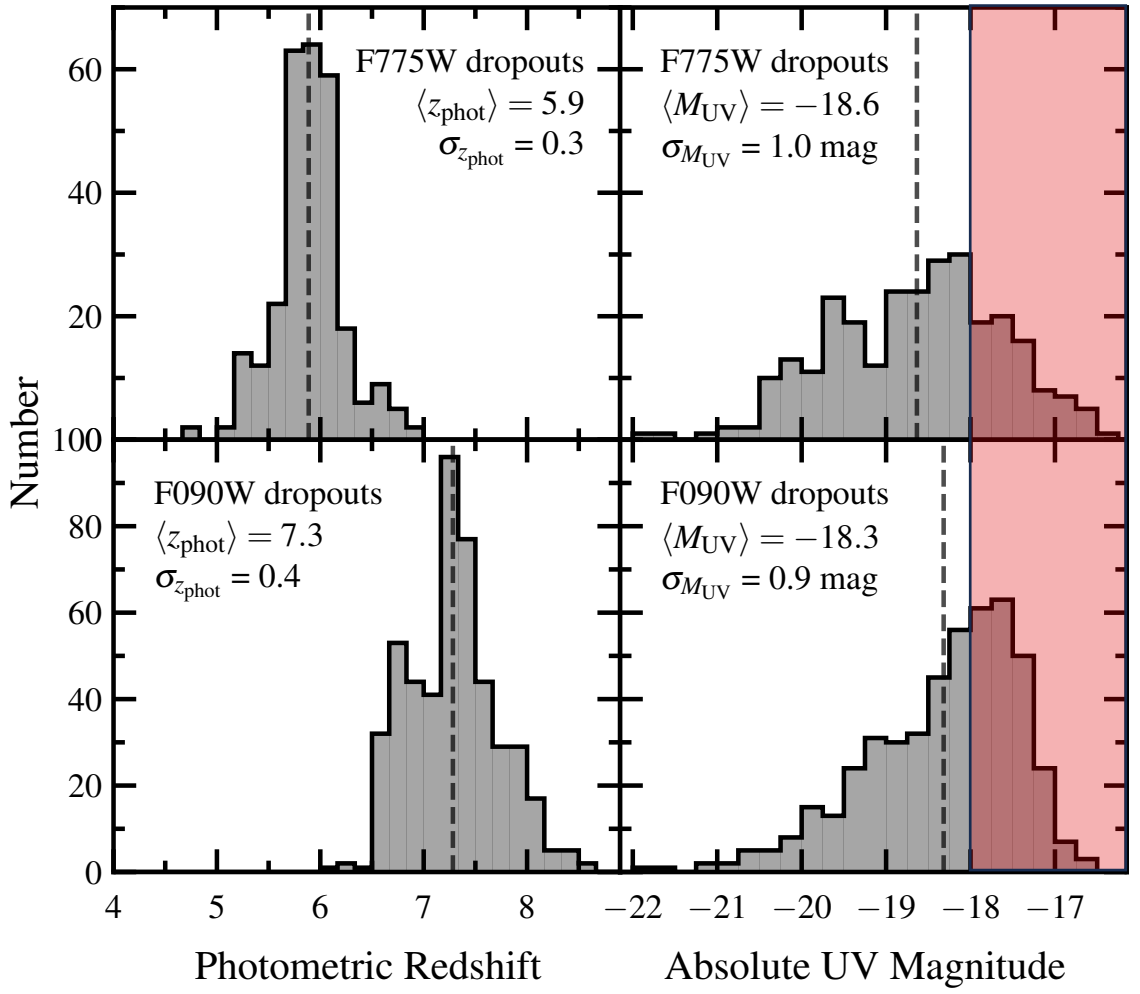
GTO JADES survey provides exceptionally deep (m_{AB} ~ 30-31 5σ) imaging in nine NIRCam bands.

- Enables greatly improved constraints on rest-optical line emission for reionization-era galaxies.
- In turn yields unprecedented insight into ionizing photon production efficiency of early galaxies.

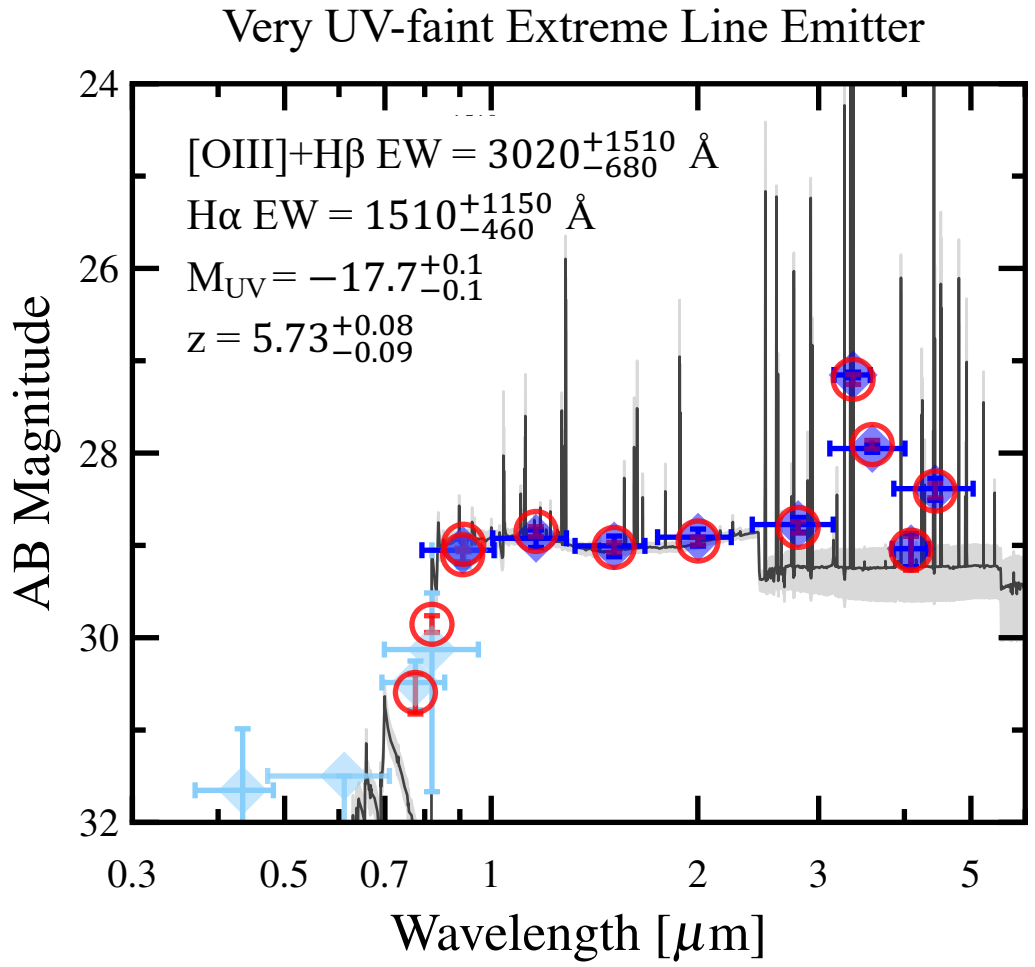
Assembled a very large sample of Lyman-break z~6-9 galaxies (N=756) spanning a factor of ~200 in UV luminosity.

- Now able to explore UV luminosity dependence on ionizing properties for the first time at z>6.

Endsley+23c: arXiv:2306.05295



Example Constraints from JADES



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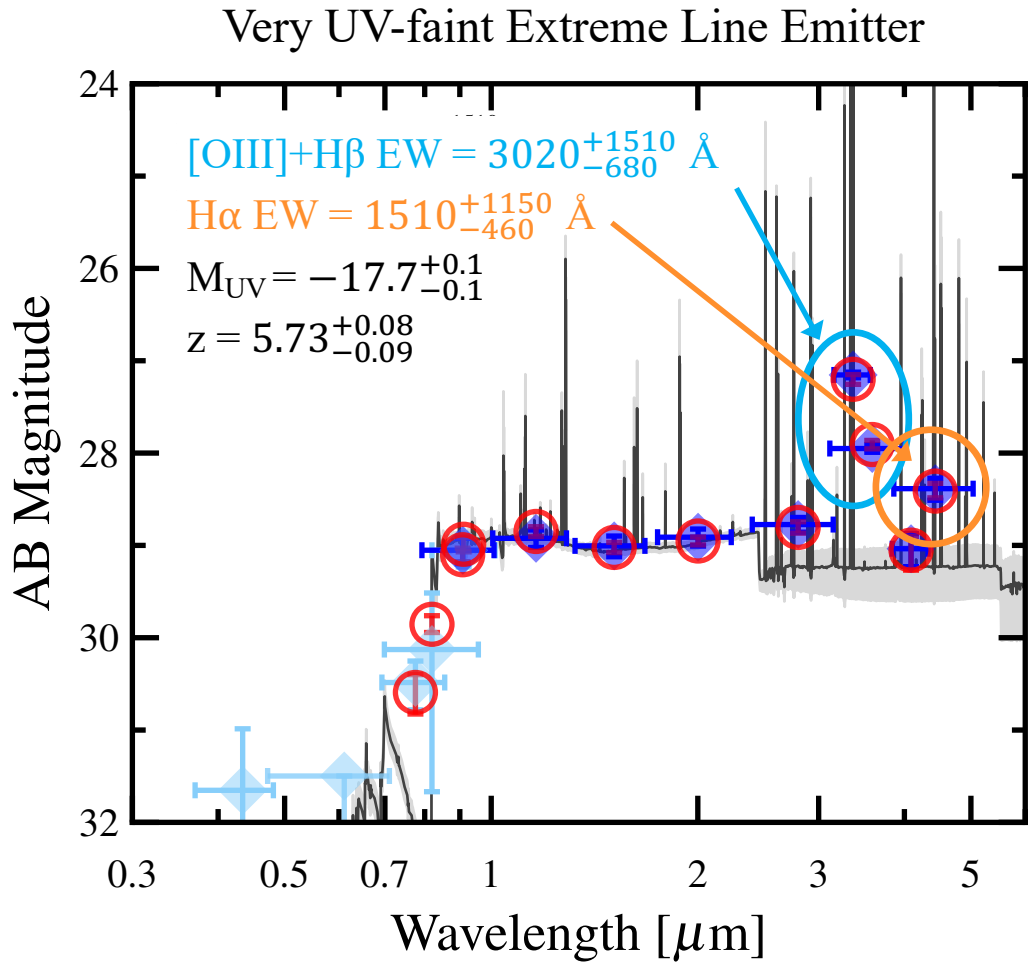
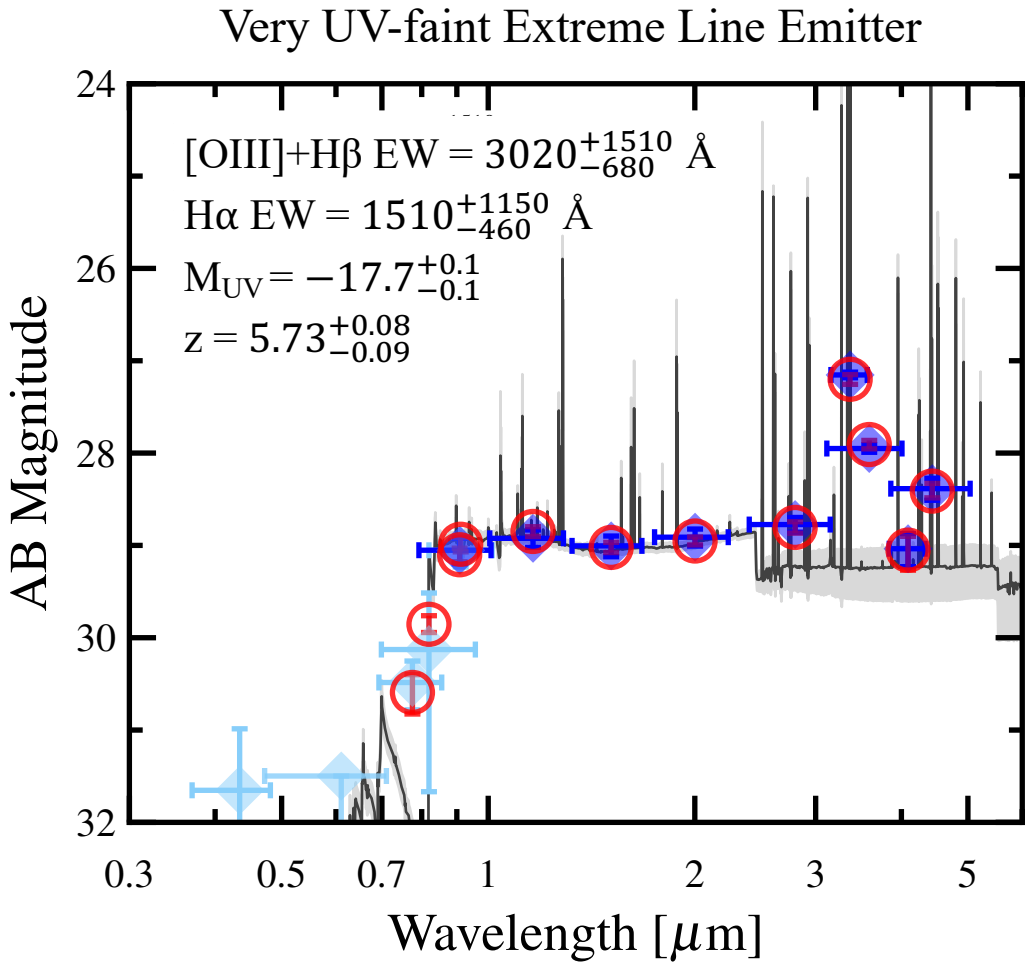


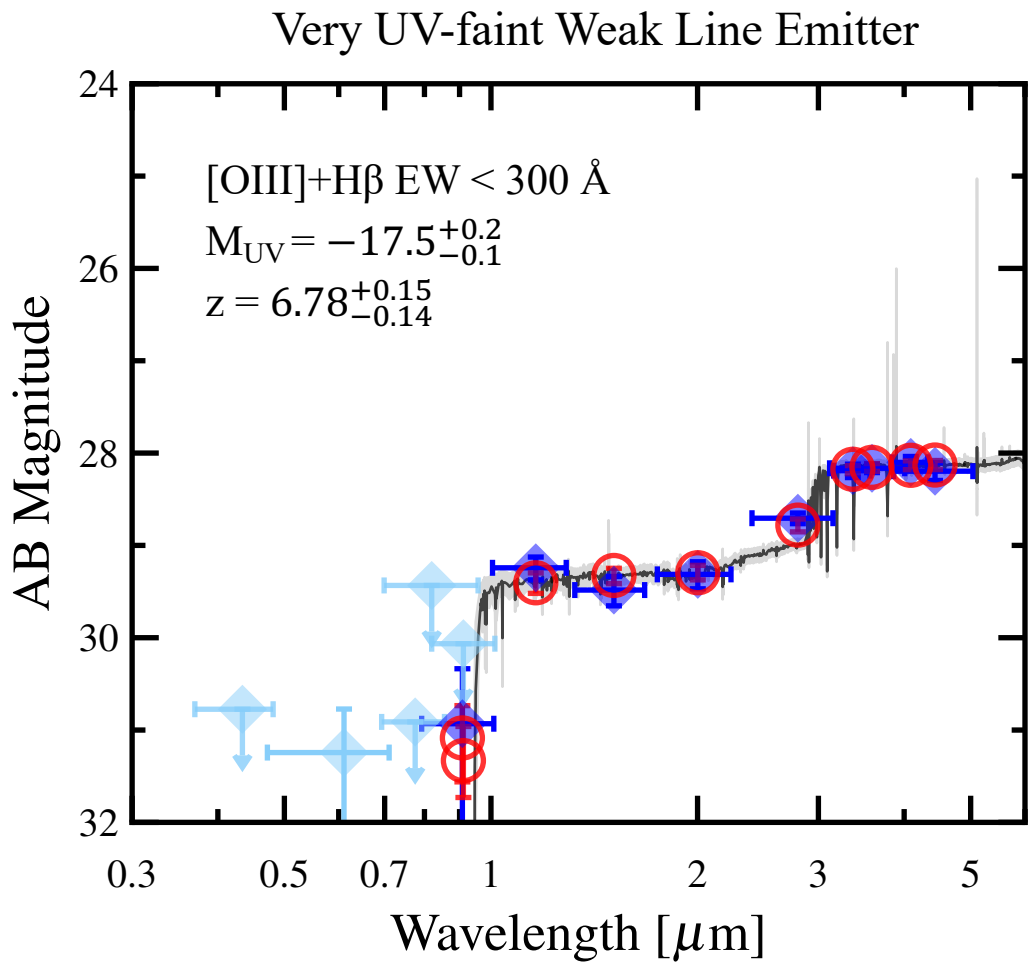
Extremely high equivalent widths indicate that the emergent light is completely dominated by recently-formed O stars.

- This galaxy is producing ionizing photons at an incredibly rapid rate due to a rapid upturn in SFR.

Endsley+23c: arXiv:2306.05295

Example Constraints from JADES



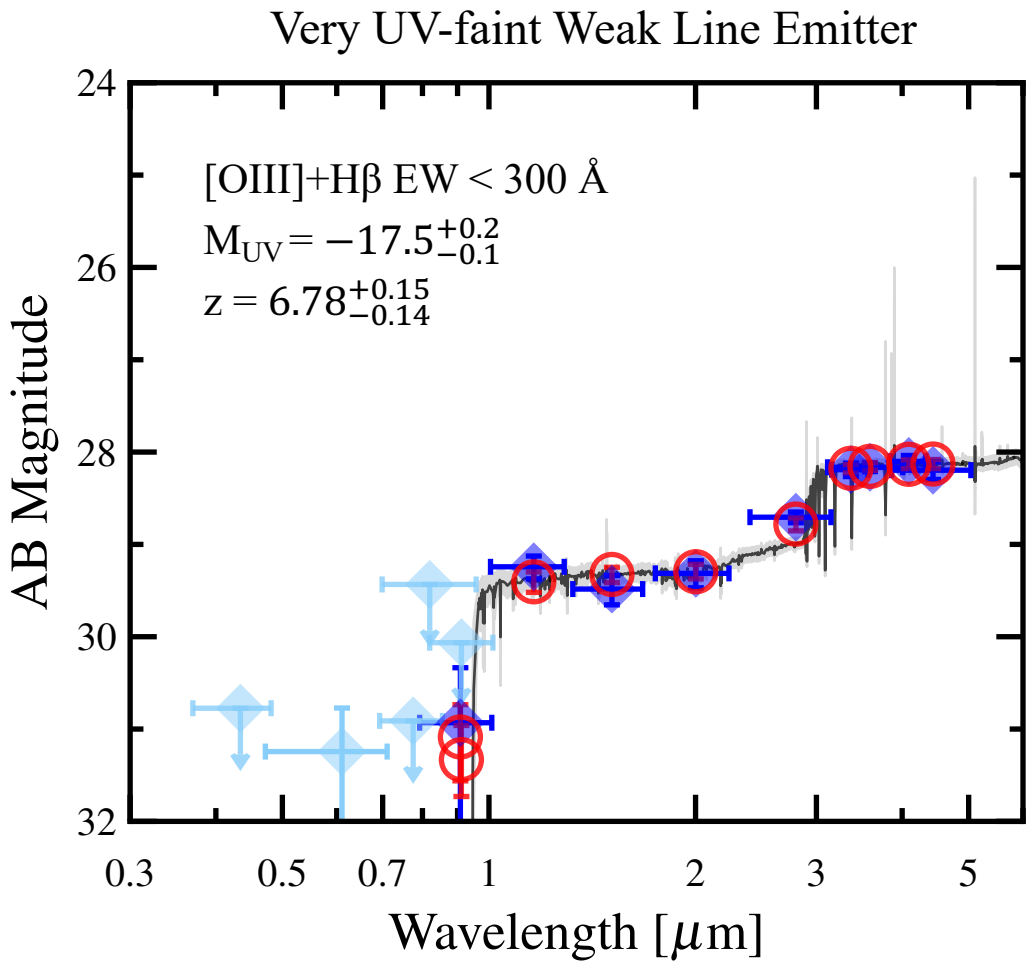


Endsley+23c: arXiv:2306.05295

Example Constraints from JADES

No sign of any significant nebular line emission. Spectrum dominated by A stars formed ~100 Myr ago.

- This galaxy is producing far fewer ionizing photons due to dearth of recently-formed O stars.

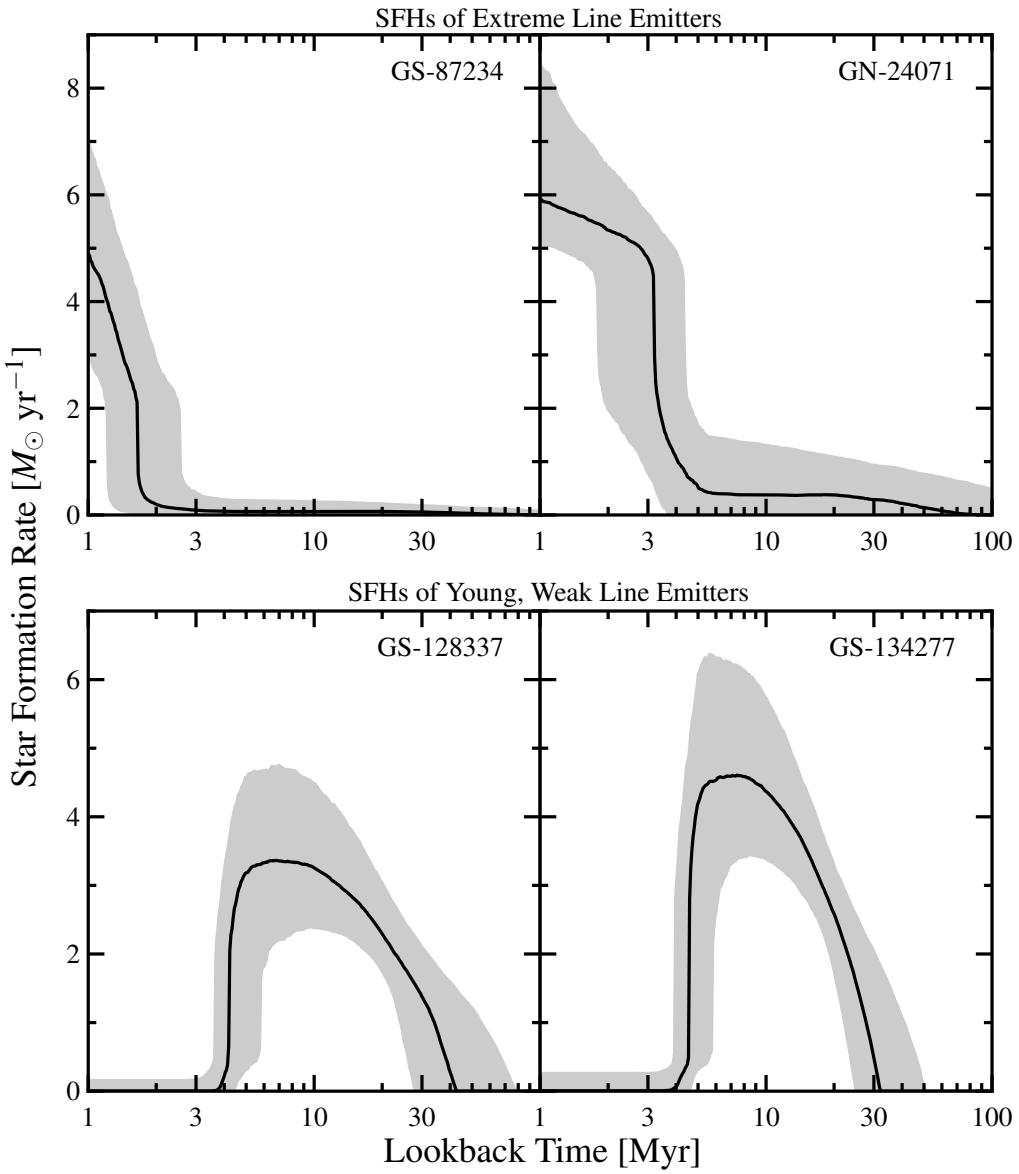


Endsley+23c: arXiv:2306.05295

Empirical Evidence for Bursty Star Formation

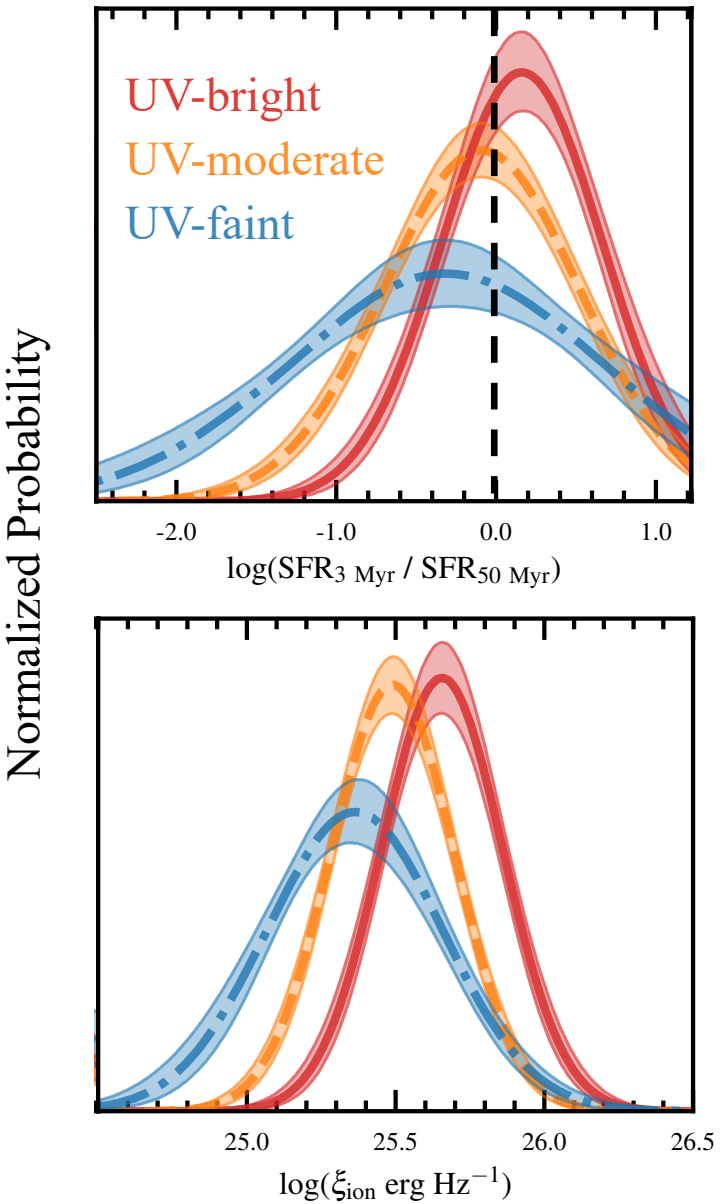
Across the full sample, find z~6-9 galaxies with a very wide range of inferred star formation histories.

- Extreme line emitters have had very strong upturns in SFR over the past ~3 Myr.
- Subset of weak line emitters have had negligible star formation over the past 5 Myr, but underwent relatively intense star formation ~10-30 Myr ago.



Endsley+23c: arXiv:2306.05295

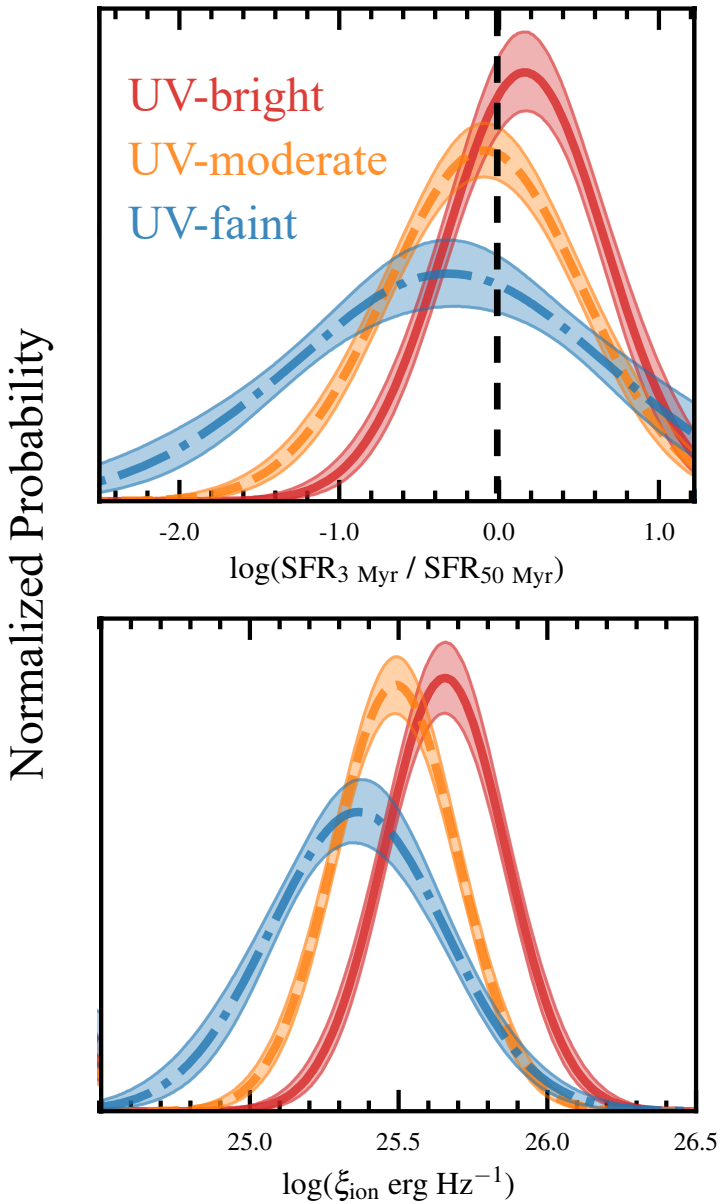
The Nature of UV-bright z>6 Galaxies



Strong statistical evidence that UV-bright z>6 galaxies are frequently in 'burst-mode' of star formation with emergent light completely dominated by hot O stars.

Endsley+23c: arXiv:2306.05295

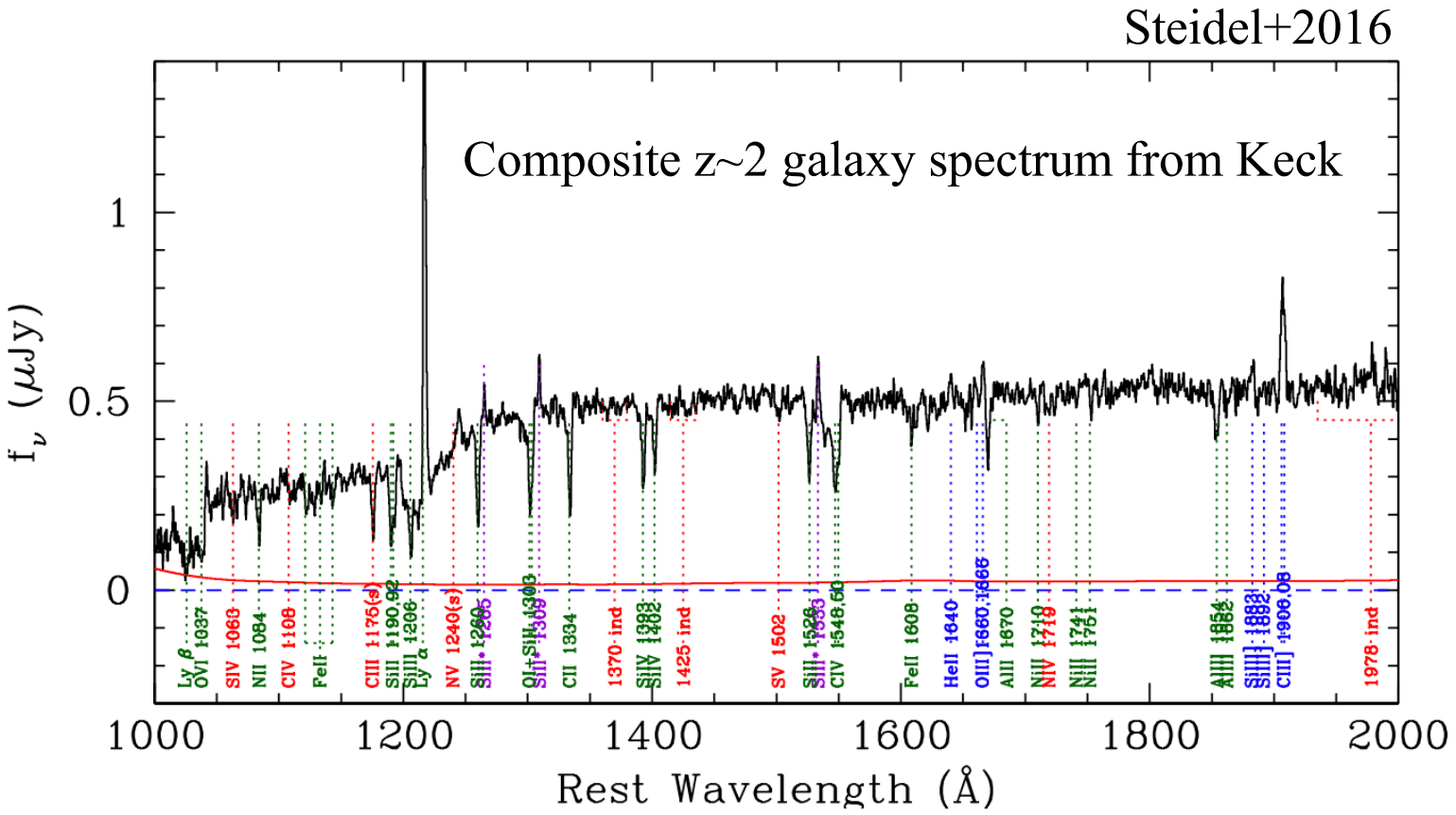
Advancing Reionization Science with ELTs



Strong statistical evidence that UV-bright z>6 galaxies are frequently in 'burst-mode' of star formation with emergent light completely dominated by hot O stars.

- UV-bright z>6 galaxies will be fantastic targets to characterize the ionizing spectra of early O stars which powered reionization.

Revealing The Ionizing Spectra of Early Galaxies

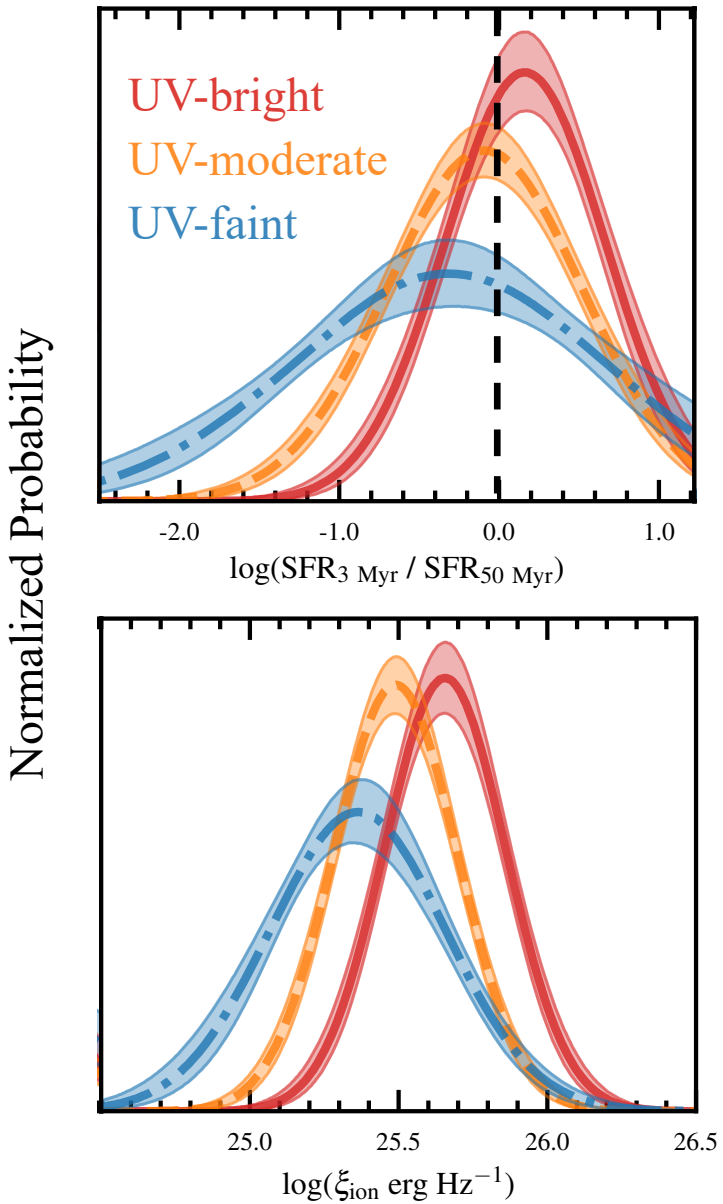


ELTs will easily enable very high S/N composite spectra of UV-bright z~6-8 galaxies, building on past work at lower redshifts.

- Probe several nebular emission lines spanning low (~10 eV) to very high (~75 eV) ionization potentials.
- Reveal shape of the ionizing spectra from metal-poor massive stars that are commonly thought to be the agents of reionization.

See also, e.g., Shapley+03, Topping+20

Advancing Reionization Science with ELTs

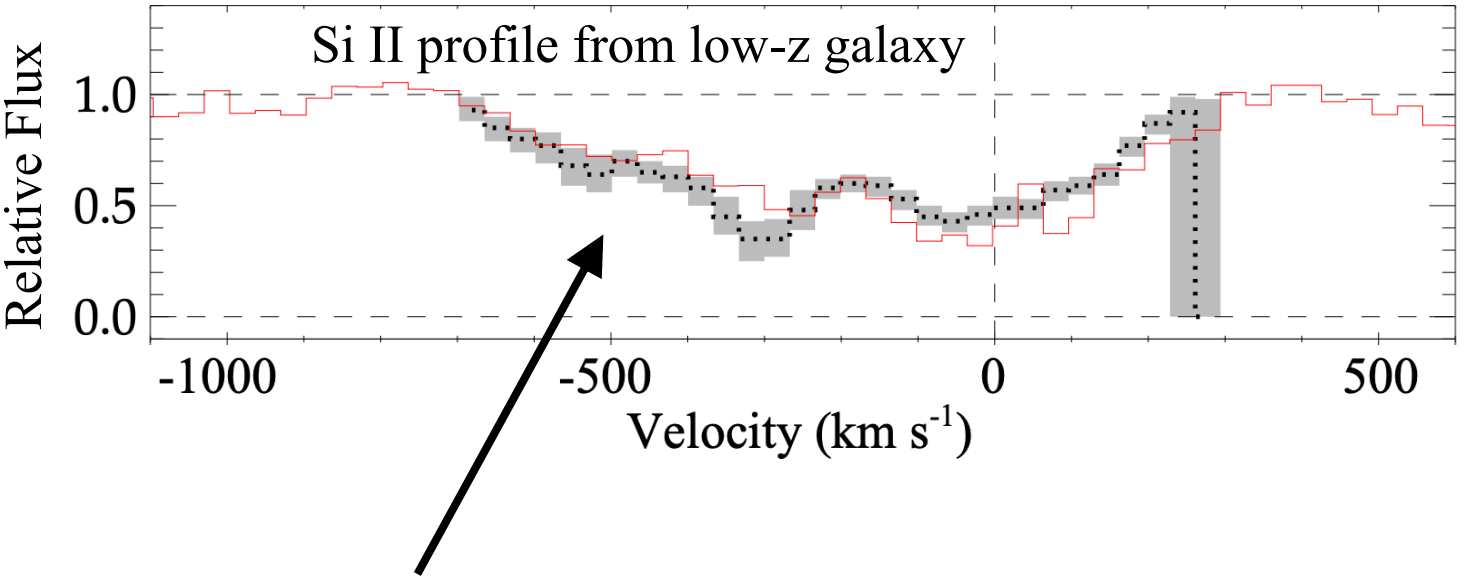


Strong statistical evidence that UV-bright z>6 galaxies are frequently in 'burst-mode' of star formation with emergent light completely dominated by hot O stars.

- UV-bright z>6 galaxies will be fantastic targets to characterize the ionizing spectra of early O stars which powered reionization.
- Use ELTs to constrain ionizing photon escape and hence role of UV-bright galaxies to reionization.

f_{esc} Constraints on UV-bright z>6 Galaxies

Jones+2013



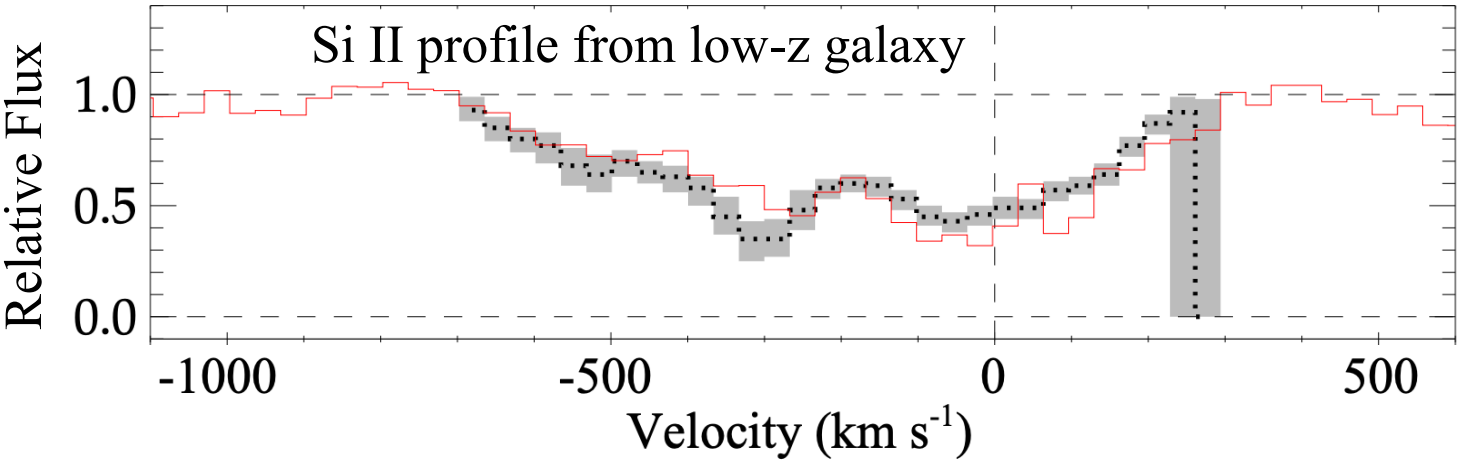
Absorption depth places firm upper limit on escape fraction of hydrogen ionizing photons.

Use low-ionization UV absorption features to constrain f_{esc} from individual bright z>6 galaxies.

See also, e.g., Reddy+16

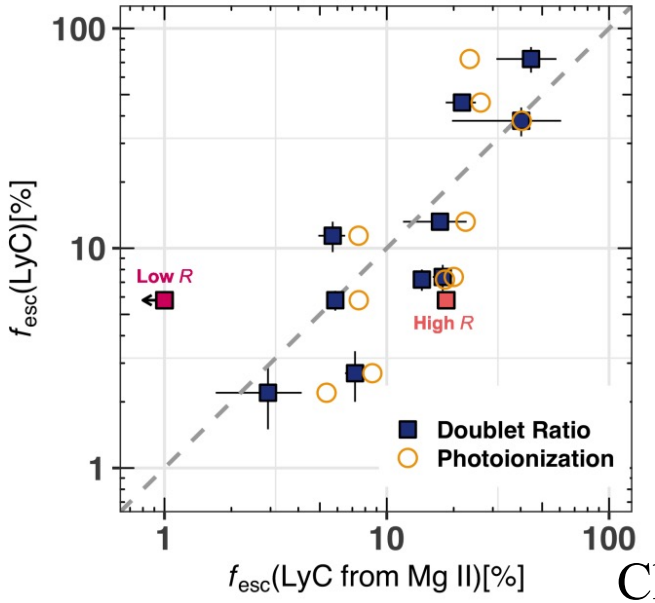
f_{esc} Constraints on UV-bright z>6 Galaxies

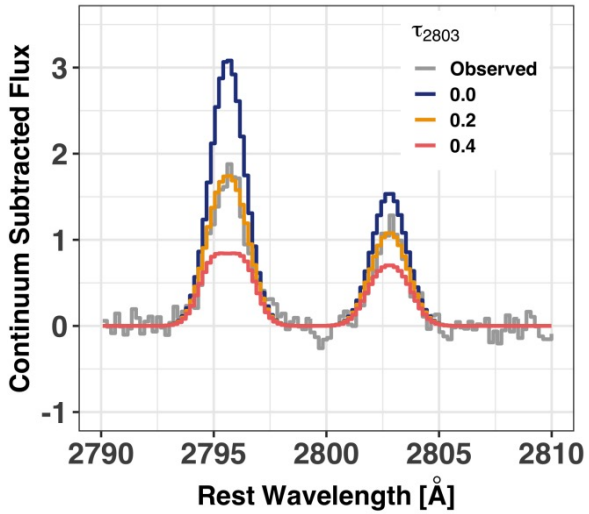
Jones+2013



Use low-ionization UV absorption features to constrain f_{esc} from individual bright z>6 galaxies.

…or other powerful UV diagnostics of f_{esc} such as Mg II emission.

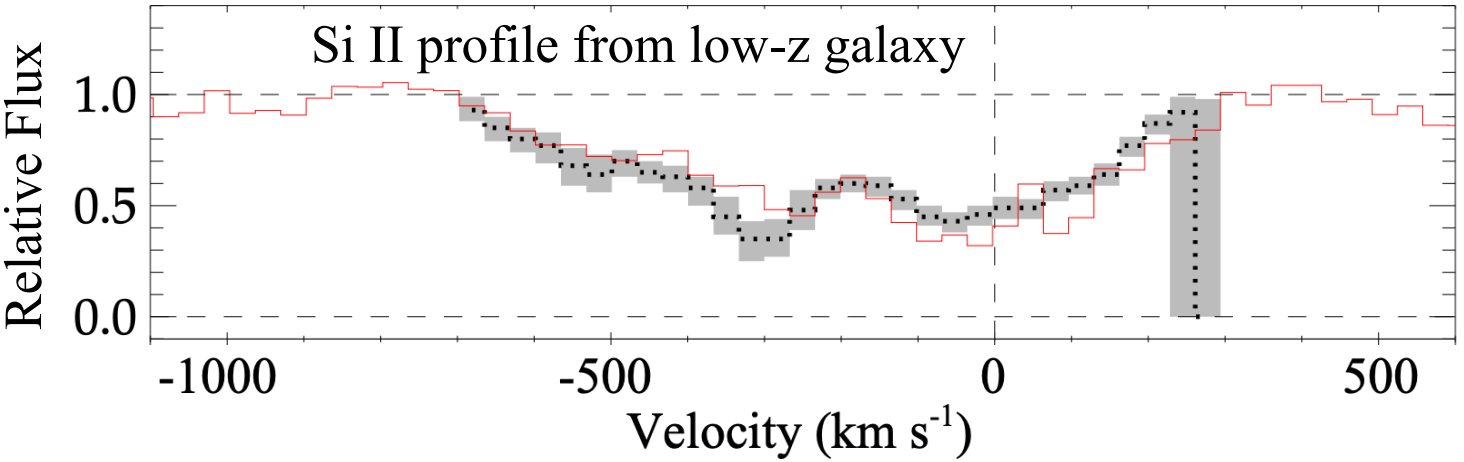




Chisholm+2020

f_{esc} Constraints on UV-bright z>6 Galaxies

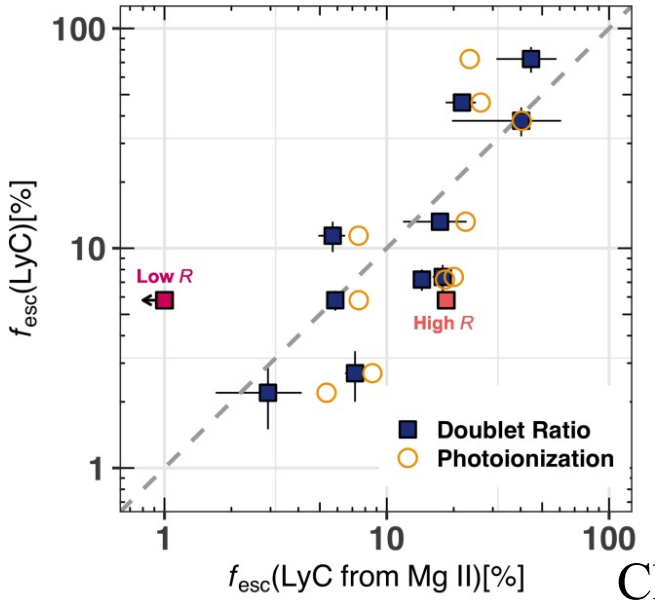
Jones+2013

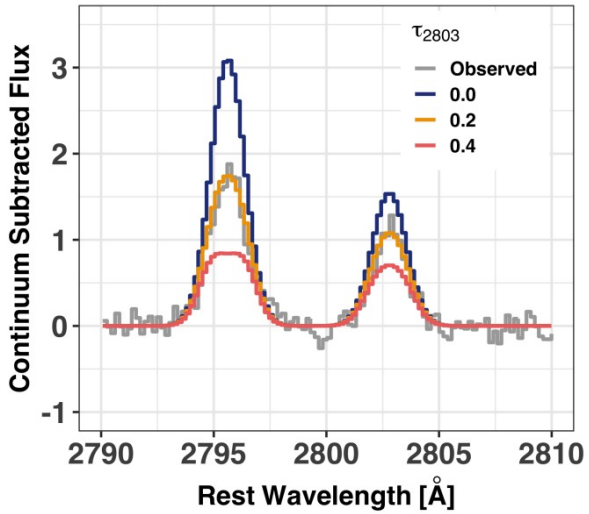


Use low-ionization UV absorption features to constrain f_{esc} from individual bright z>6 galaxies.

…or other powerful UV diagnostics of f_{esc} such as Mg II emission.

ELTs will enable f_{esc} constraints on individual star-forming regions within UV-bright z>6 galaxies!

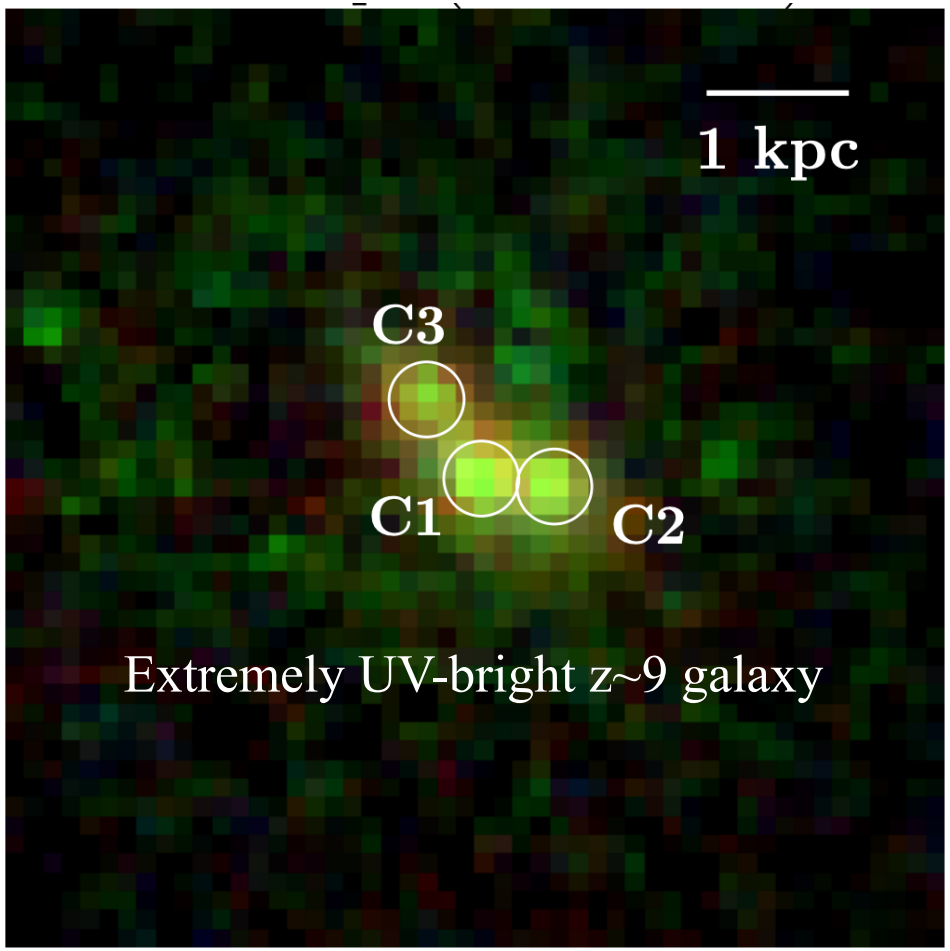




Chisholm+2020

f_{esc} Constraints on UV-bright z>6 Galaxies

Whitler+23



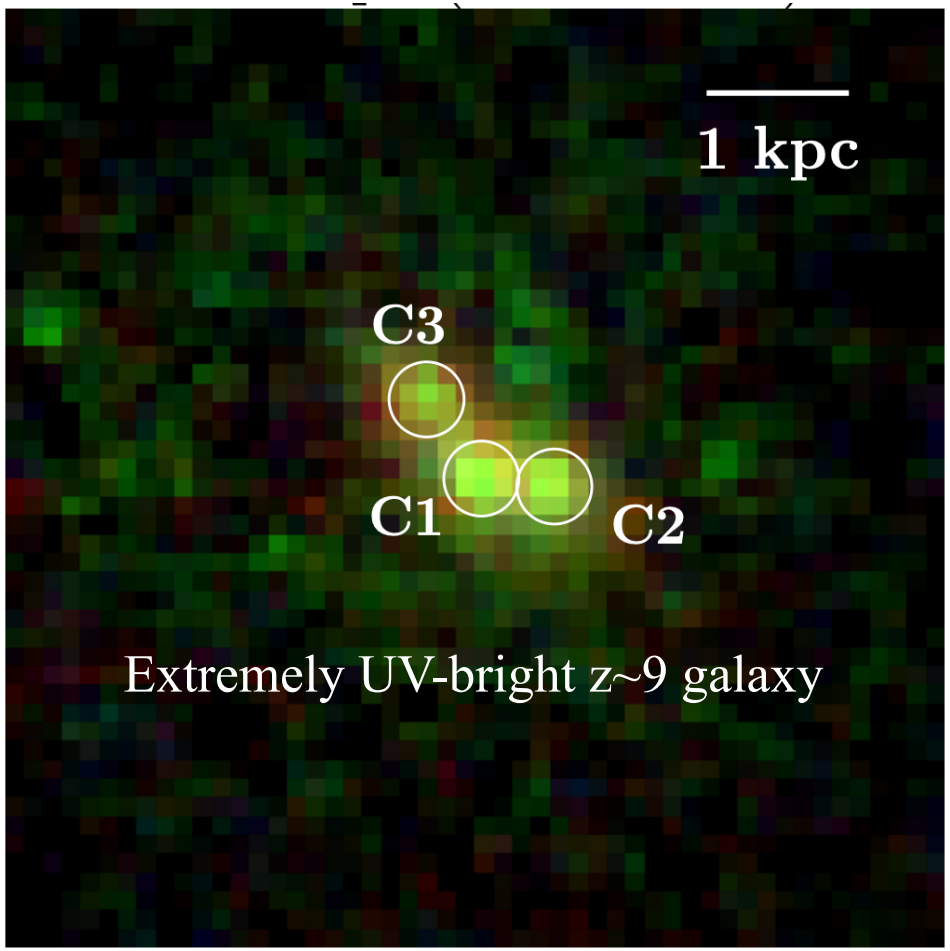
Early JWST observations are showing that the brightest z>6 galaxies are often composed of multiple extremely compact star-forming clumps.

- Half-light radii <~100 pc.
- Stellar masses of ~10^7–10^8 $M_\odot$ per clump.
- Light-weighted ages <5 Myr.

See also, e.g., Chen+23, Larson+23

f_{esc} Constraints on UV-bright z>6 Galaxies

Whitler+23



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Near-IR IFUs on ELTs will detect UV continua of individual clumps with S/N≈10 in one hour*.

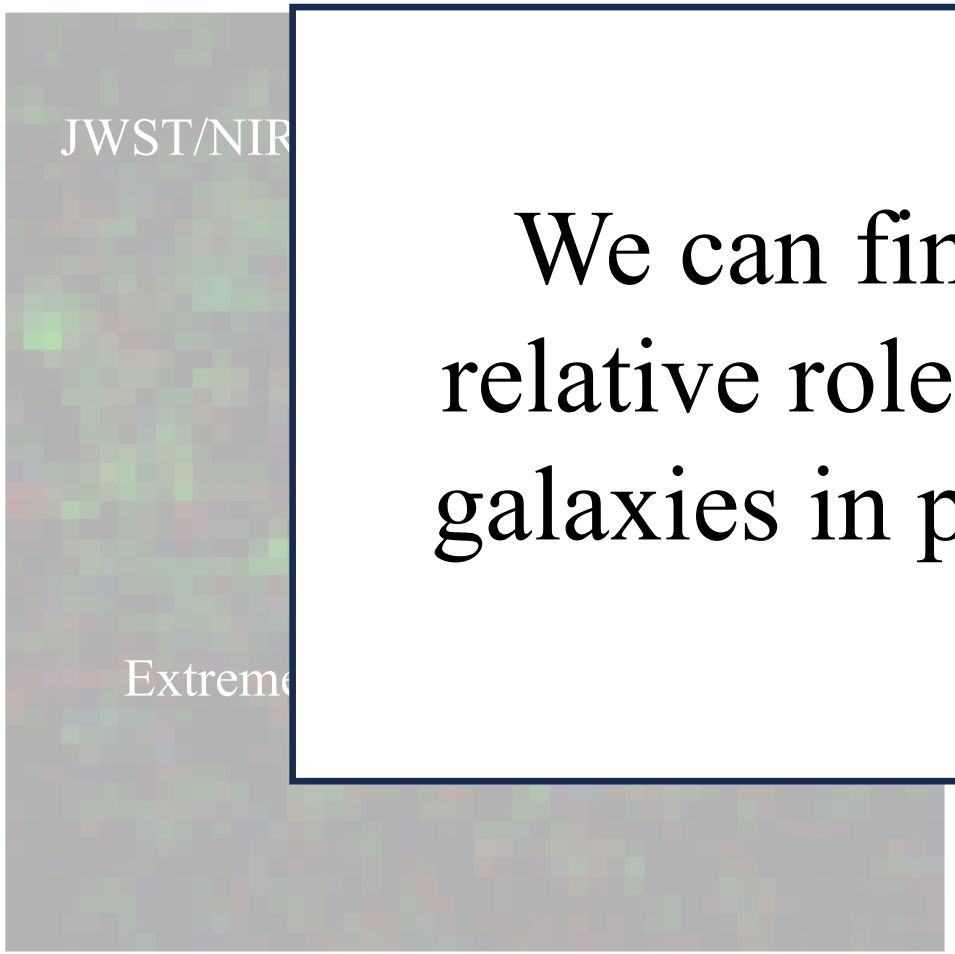
➢ Readily deliver spatially-resolved constraints on f_{esc} within individual z>6 galaxies via absorption line analyses.

See also, e.g., Chen+23, Larson+23

*Using GMTIFS ETC

f_{esc} Constraints on UV-bright z>6 Galaxies

Whitler+23



We can finally disentangle the relative role of bright versus faint galaxies in powering reionization.

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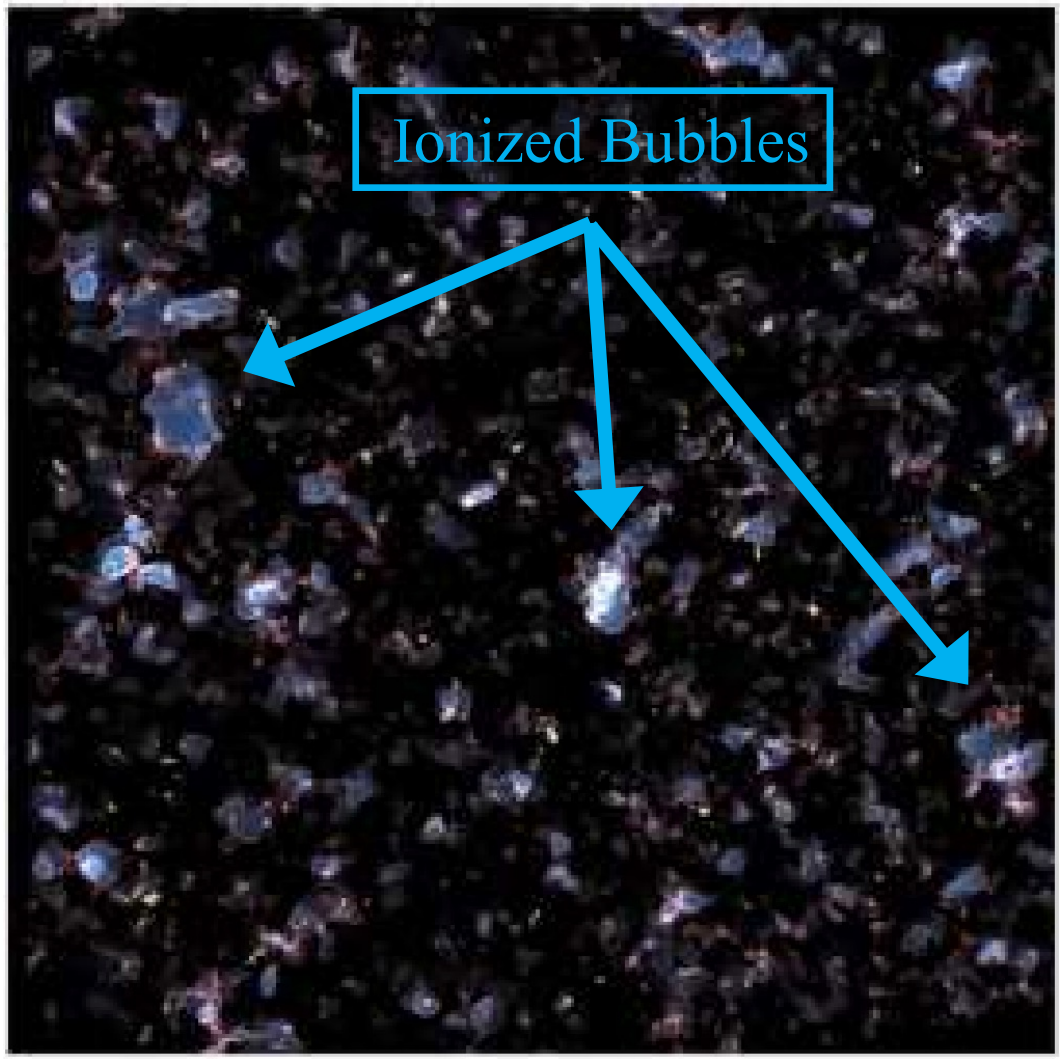
Understanding the Growth of Ionized Bubbles

Simulated View of Reionization



Alvarez+2009

Understanding the Growth of Ionized Bubbles

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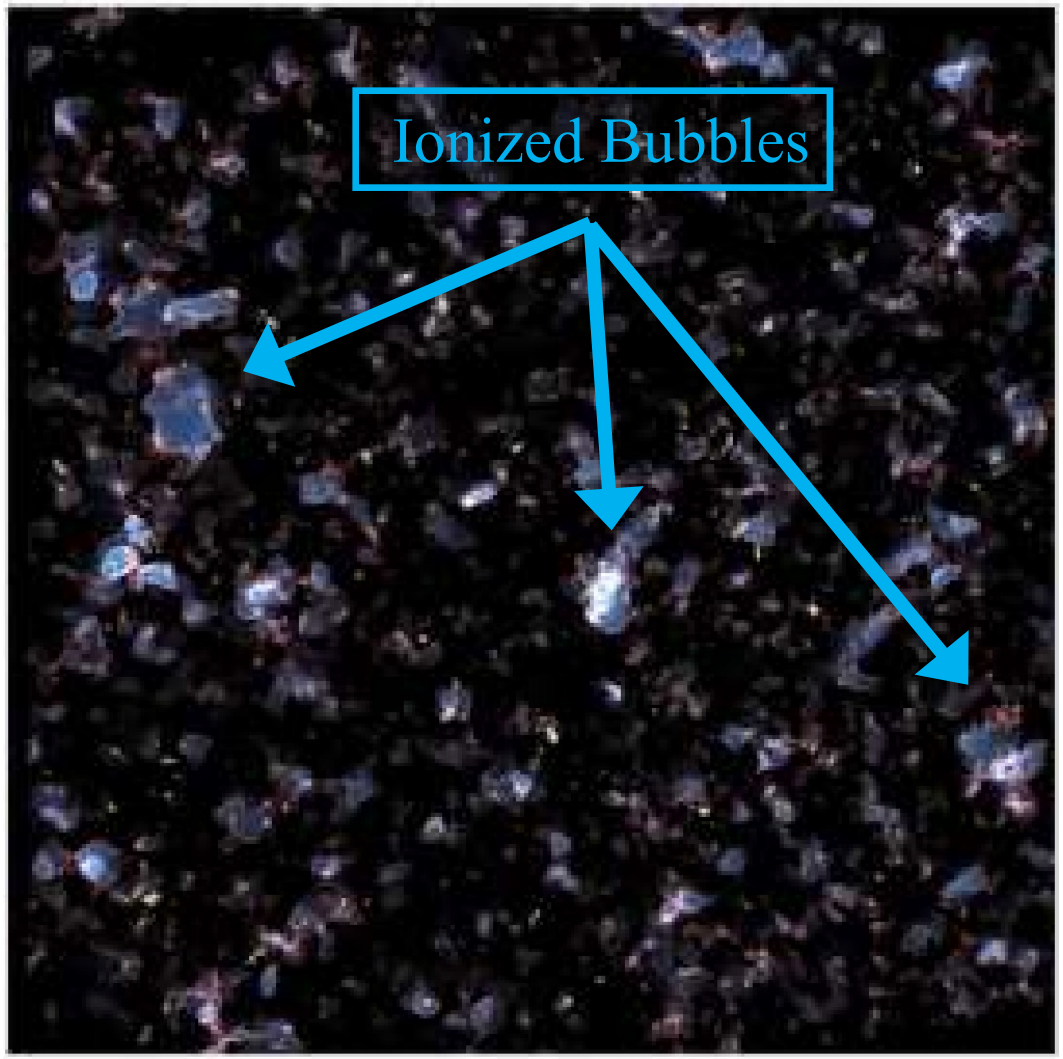
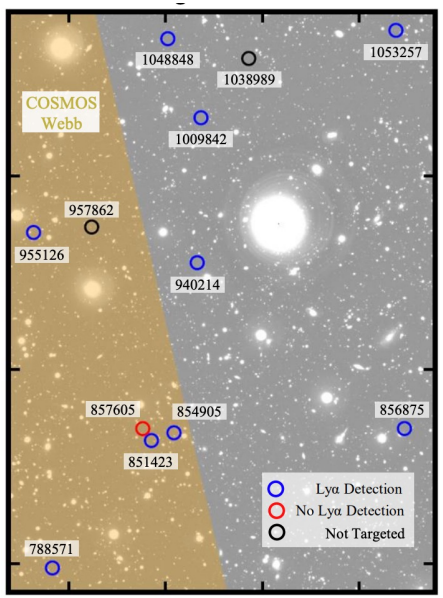
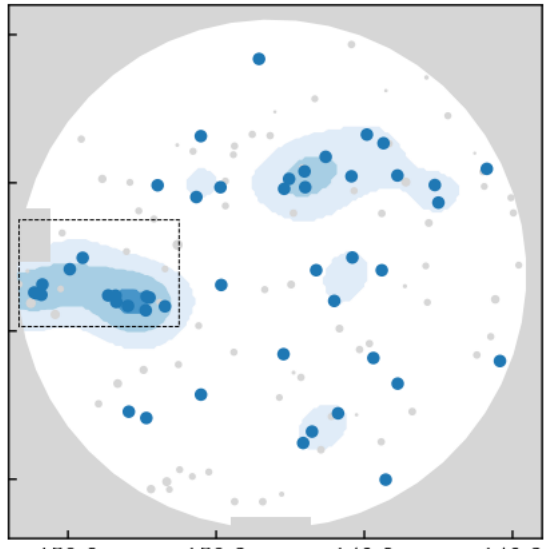


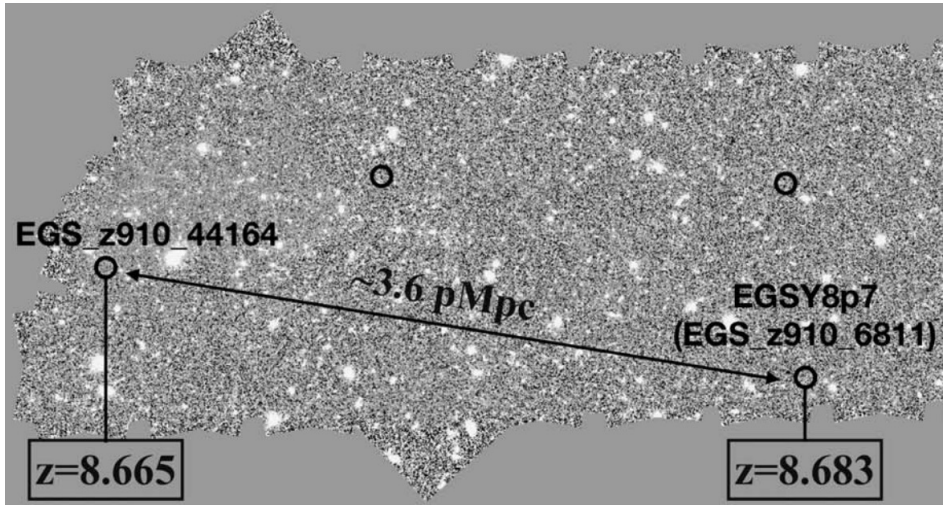
Alvarez+2009

Endsley+2022



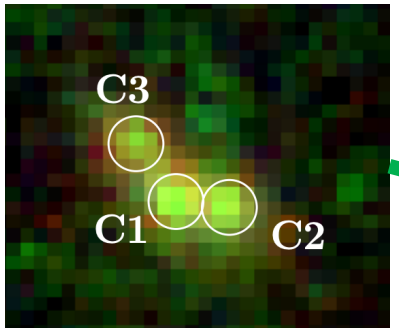
Hu+2021



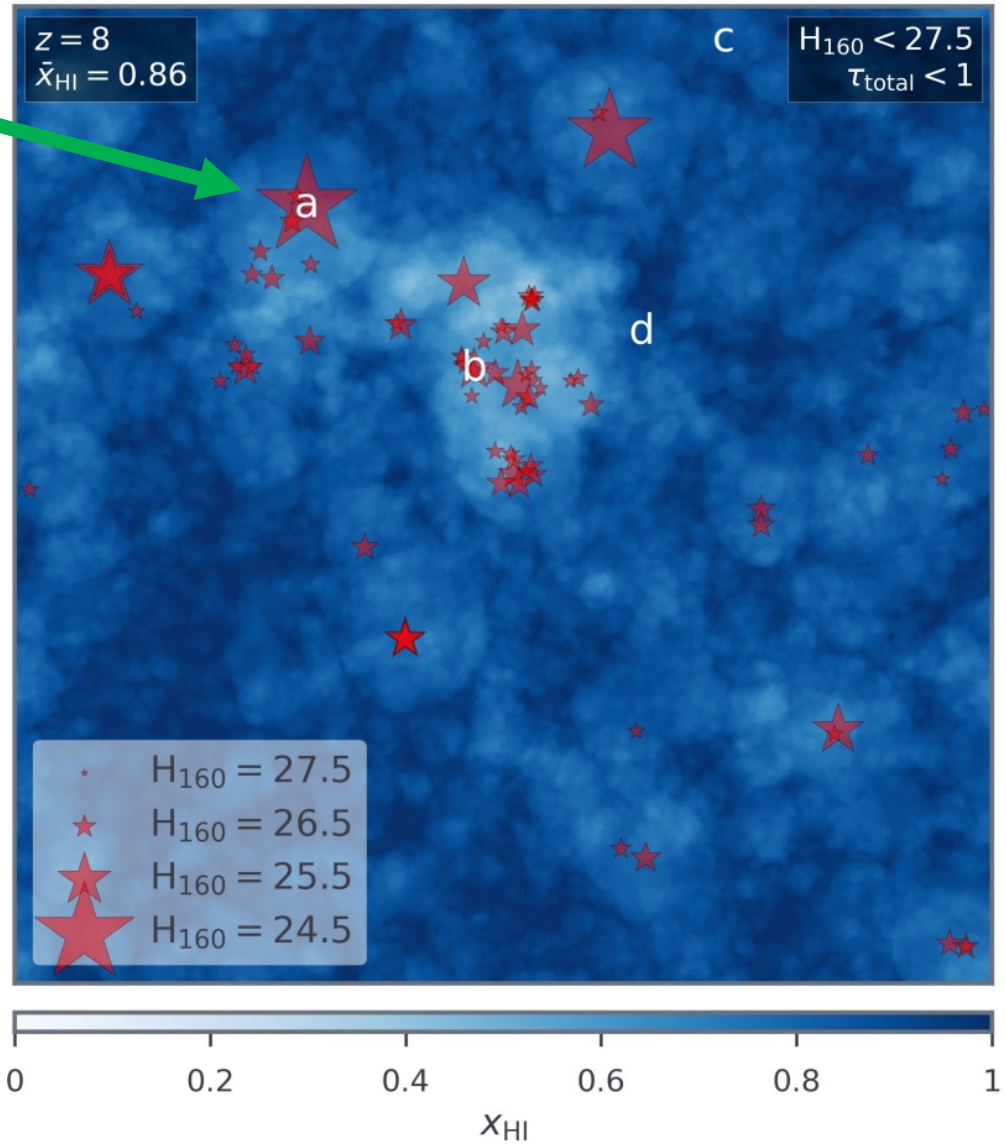


Larson+2022

Understanding the Growth of Ionized Bubbles



Qin+2022



Combine the power of ELTs and JWST to assess the role of UV-bright galaxies in powering the formation of large ionized bubbles.

- Answer how UV-bright galaxies are driving the morphology and residual HI content within ionized bubbles.
- Strong synergy with 21cm and Lyα surveys over the coming decades to build a detailed picture of how reionization happened.

A Bright Future on Understanding Reionization

Programs targeting UV-bright z>6 galaxies with ELTs will deliver revolutionary insight on how galaxies powered reionization, as well as how reionization progressed through ionized bubble growth.