Implications for the Epoch of Reionization in the Local Universe

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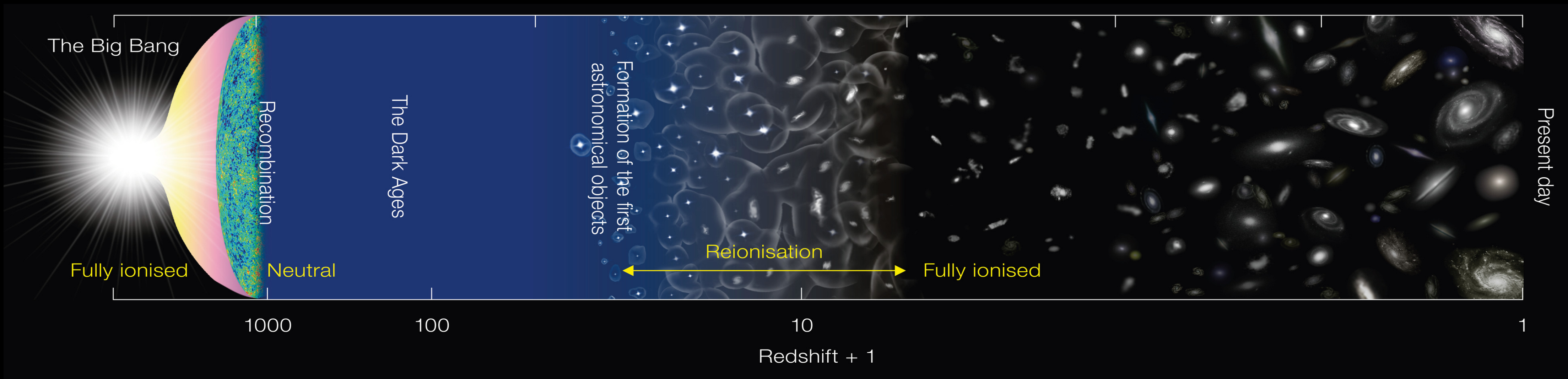


Reionization started when the universe saw its first light—the radiation from the very early astronomical objects ionized the neutral hydrogen that once filled the entire universe.
Direct observations of those ionizing Lyman-continuum (LyC) photons is naturally precluded by the neutral intergalactic medium (IGM) at these redshifts.

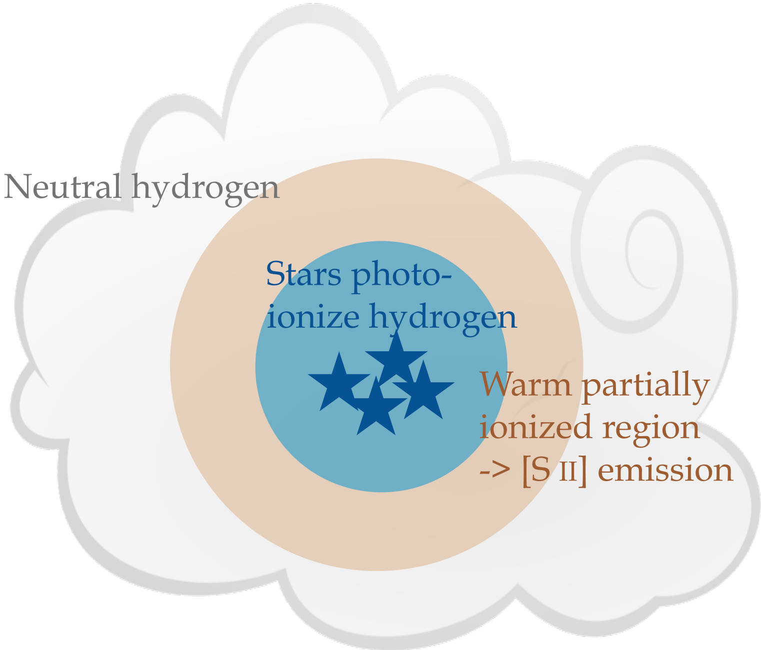
We aim to understand how reionization happened through local galaxies that are LyC emitters (LCEs).

Questions to be answered:

- How to find LCEs?
- What is the escape fraction of LyC?
- How do LyC photons escape into IGM?

Refs: BW, Heckman+ ApJ 2019 & ApJ 2020 **Contact: bwang@jhu.edu; pages.jh.edu/~bwang50/** **(Image: NAOJ)**

{ A new technique for finding galaxies leaking LyC radiation: [S II]-deficiency }



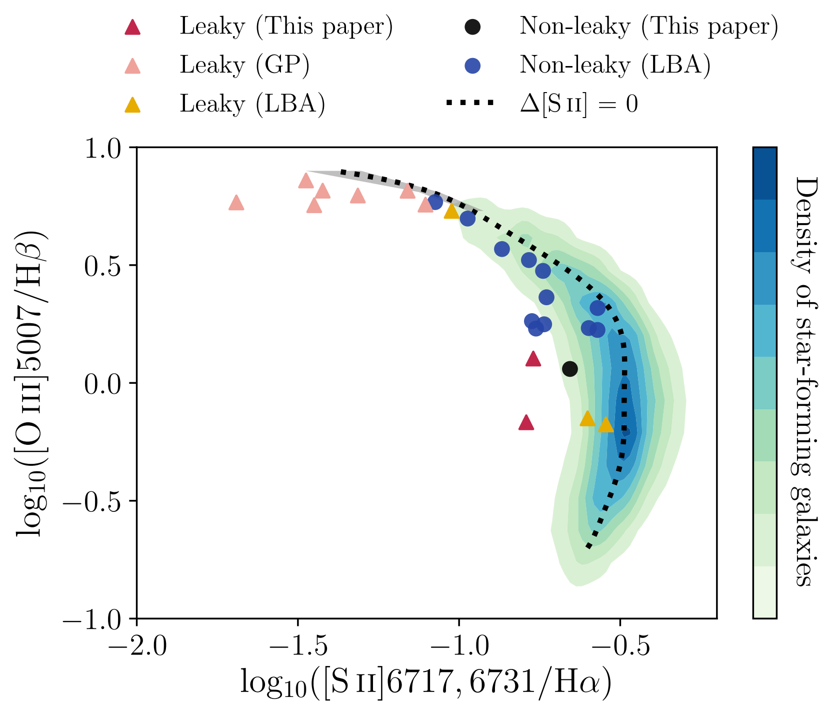
I. Tracing optically thin conditions

The ionization potential for producing [S II] (10.4 eV) is less than that is needed for ionizing neutral hydrogen (13.6 eV). Much of the [S II] emission therefore arises in the warm partially ionized region near and just beyond the outer edge of the Stromgren sphere.

In an HII region that is optically thin to ionizing radiation, this partially ionized [S II] zone is weak or even absent, and so the relative intensity of the [S II] emission lines drop significantly.

II. Defining [S II]-Deficiency

We define [S II]-deficiency with respect to typical SDSS star-forming galaxies, as shown in the following BPT diagram. The black dotted line is fitted to the locus of the peak density of this sample. The [SII]-deficiency, denoted as Δ[SII], is a galaxy's displacement in log([SII]/Hα) from this ridge-line.



III. Results from a pilot study (BW+ 2019)

(HST-GO-15341; PI T. Heckman)

- Significant fluxes below the Lyman limit are detected in two of the three [S II]-weak-selected starburst galaxies at z ~ 0.3.
- High relative escape fractions: 93.3% & 79.8% (photo-electric absorption of LyC due to hydrogen only).
- Low absolute escape fractions: 3.5% & 4.1% (high dust extinction).

{ Towards an understanding on gas geometry }

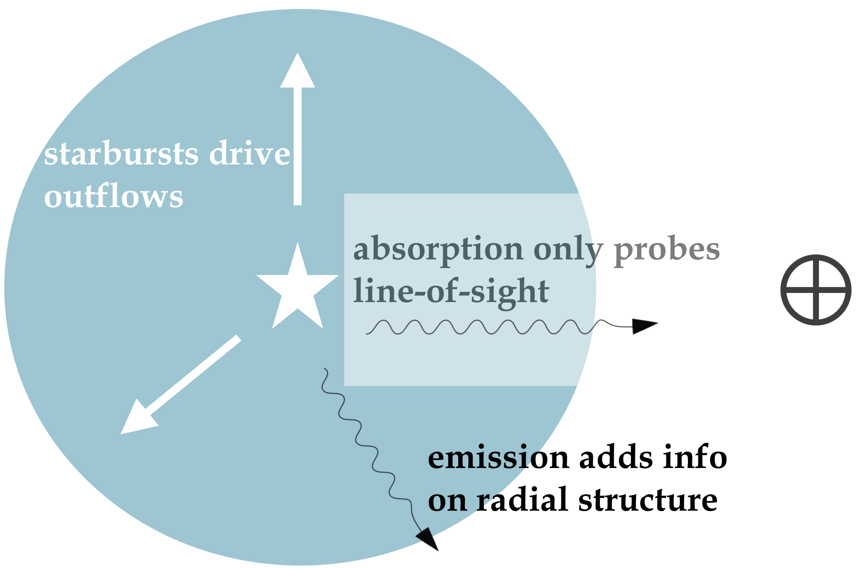
Following up with the HST low-z LyC survey (BW+ 2020, in prep.)

With a larger sample from LzLCS (HST-GO-15626; PI A. Jaskot), we confirm the robustness of the [SII]-deficiency diagnostic. Preliminary results also reveal a complex relation between optical emission line properties and the escape fraction of LyC. Therefore, theories on what promotes LyC leakage remains to be tested.

I. Geometry of ISM/CGM

Understanding LyC radiative transfer requires knowledge of ISM/CGM conditions. Little is known, however, of the spacial distribution of gas.

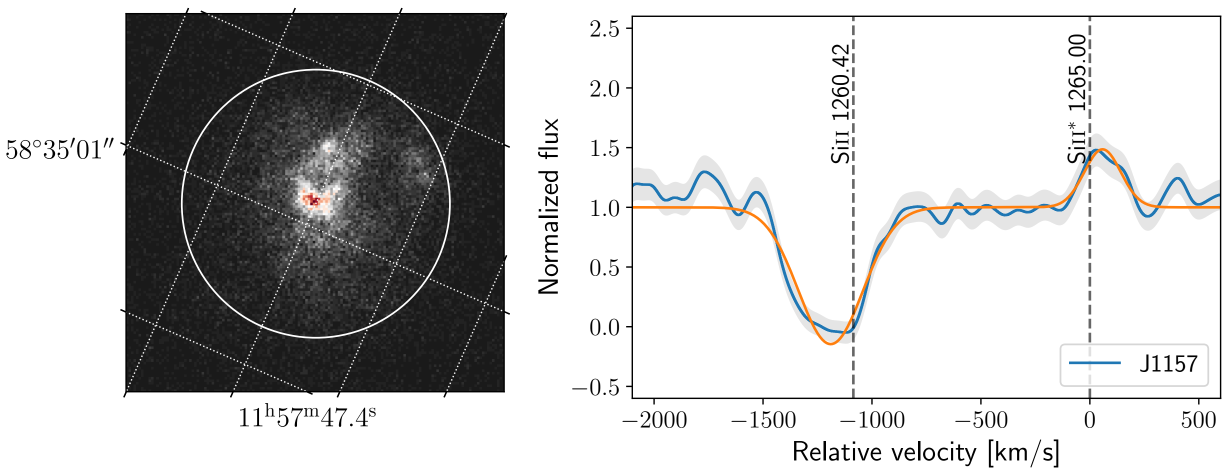
We will use absorption and emission lines to probe the geometry, building on our previous work (BW+ 2020).



II.A. Insights from emission-line studies on local starbursts (BW+ 2020)

We observe a sample of starbursts (HST-GO-15340; PI T. Heckman), and find that their fluorescence emission lines are systematically weaker than the resonance absorption lines. An example is shown below.

We argue that the observed weakness is due to the missing emission arising on scales larger than those encompassed by the aperture of the Cosmic Origins Spectrograph on board the HST (cf. Prochaska+ 2011; Scarlata & Panagia 2015; Zhu+ 2015).



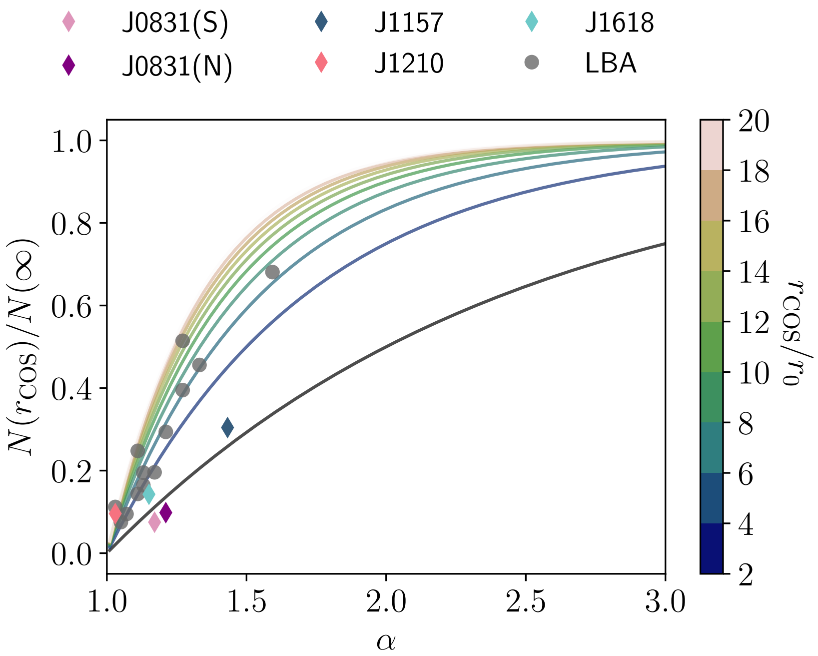
(left) The COS NUV ACQ image of one of the galaxies in BW+ 2020. The white circle indicates the COS aperture of radius 1″25.
(right) The COS spectrum of the same galaxies showing a pair of resonance absorption and fluorescence emission lines.

{ Modeling the circum-galactic medium }

II.B. Simple models suggest large-scale galactic outflows (BW+ 2020)

We assume power-law models for the radial velocity and density distributions of gas. Analytical arguments then suggest

i. shallow radial density profiles in these outflows;
ii. most of the observed absorbing material are created/injected at radii much larger than that of the starbursts.



Ratios between the column density of absorbing material inside the radius probed by HST/COS and the total column density are plotted as functions of the power-law index α of the radial density profile for the absorbing gas. Shades of color denote the ratio of the radius of the COS aperture relative to the starburst radius. We show the locations of the individual galaxies in our sample, and find that a shallow density profile (α < 1.5) is required in nearly all cases.

III. Ongoing work:

Constraining gas geometry with advanced models

Taking a step further, we are using a modified version of RASCAS (Michel-Dansac+ 2020) to constrain the gas geometry in greater details.

Collaborators: T. Heckman (JHU), T. Garel (Univ Lyon, Observatoire de Genève), & A. Henry (STScI)

IV. Future work:

Shedding light on LyC radiative transfer

Emission and absorption-line profiles have been measured in some of the LCEs (e.g., Jaskot+ 2019);
Additional data will be readily available from the HST low-z LyC survey.

We will compare our models with observations to

i. identify which diagnostics are the most reliable LyC predictors;
ii. investigate the role of ISM/CGM geometry in LyC escape.

Thank you!