Radiative Transfer in the Circumgalactic Medium: Lyα and He II

By: James Wiley


The Cosmic Web

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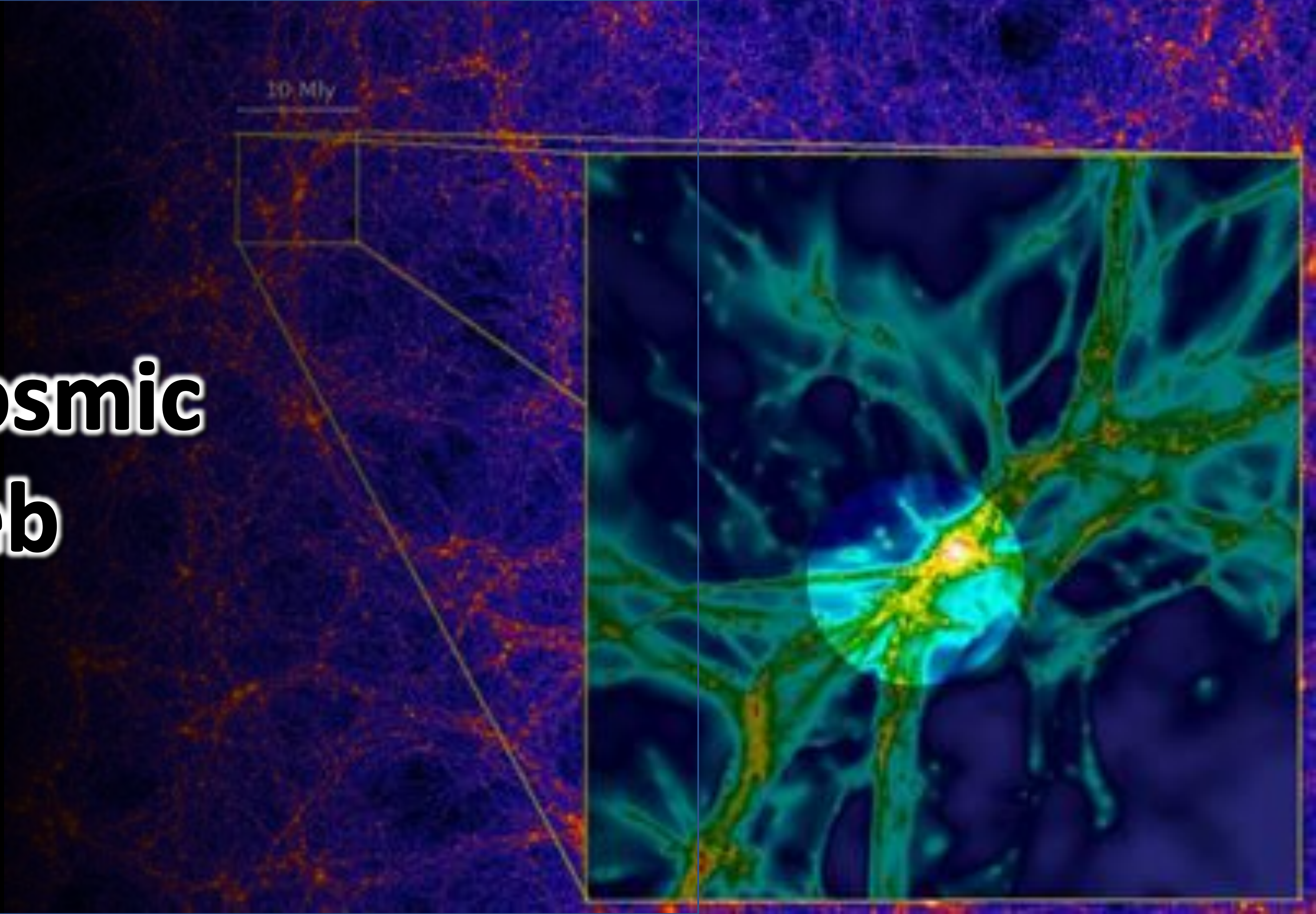


The Slug Lyα Nebula

- Quasar fluorescence illuminating part of a hydrogen filament. The quasar acts as a flashlight lighting up the filamentary part of the cosmic web around it.

- Discovered by a team at UCSC in 2013 using KCWI on Keck

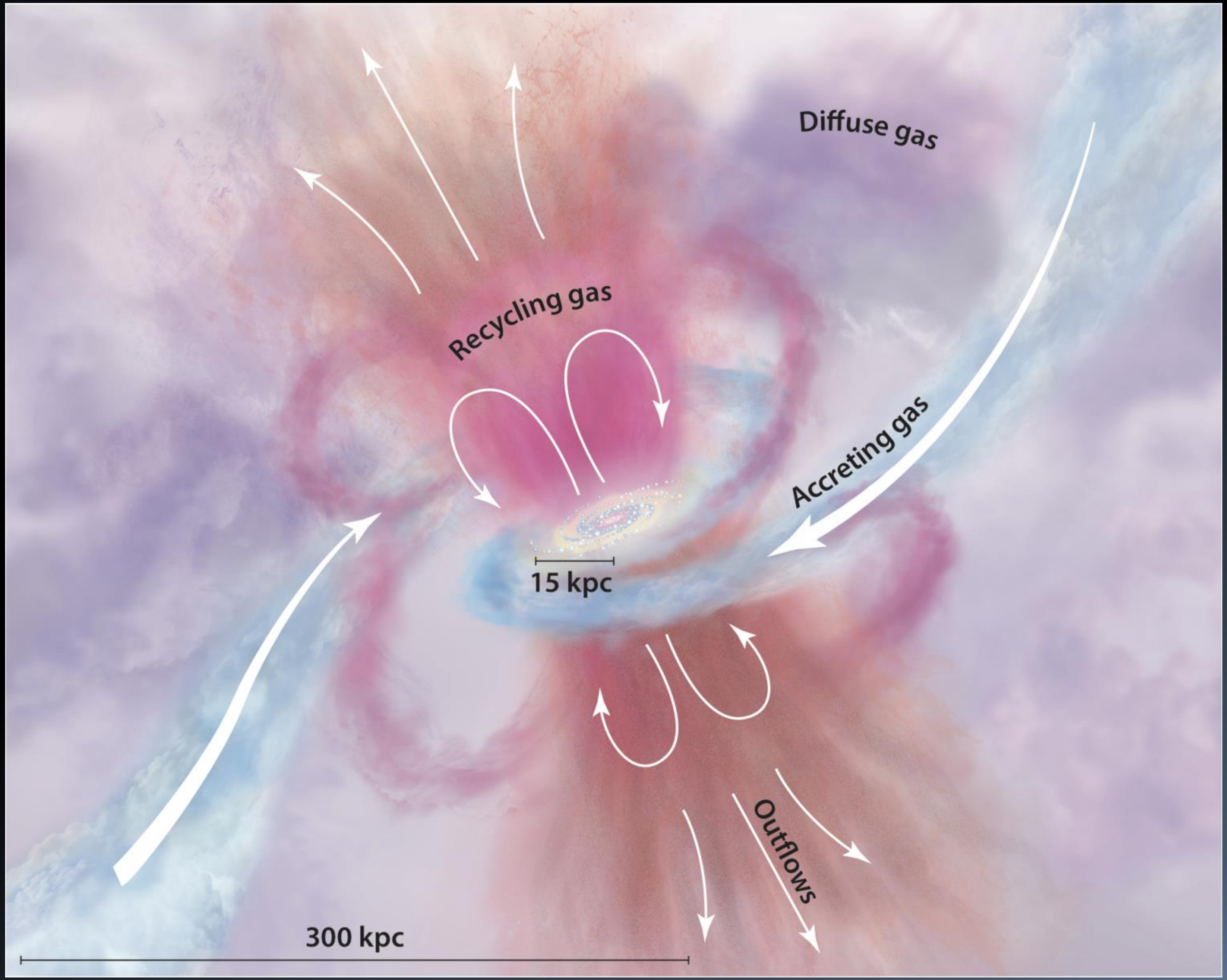
- Extends over 1’ on the sky or 2 Mly.

What is the Circumgalactic Medium (CGM)?

- Galaxies evolve under the influence of gas flows between their interstellar medium (ISM) and their surrounding gaseous halos known as the circumgalactic medium (CGM).

- The CGM is a major reservoir of galactic baryons and metals, and plays a key role in accretion, feedback, and the recycling of gas that drives star formation.

- In order to fully understand the physical processes at work within galaxies, it is essential to have a firm understanding of the composition, structure, kinematics, thermodynamics, and evolution of the CGM.

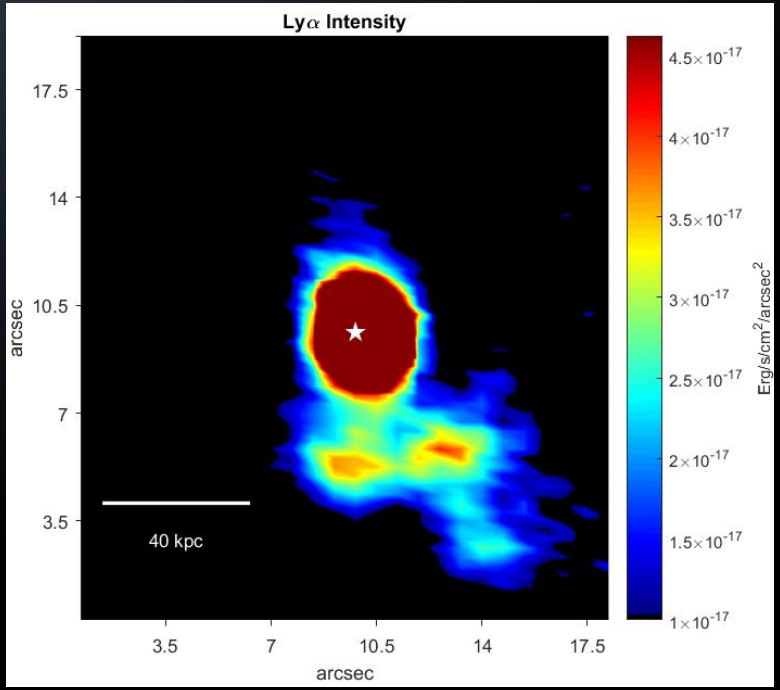


Tumlinson, Peeples, & Werk 2017

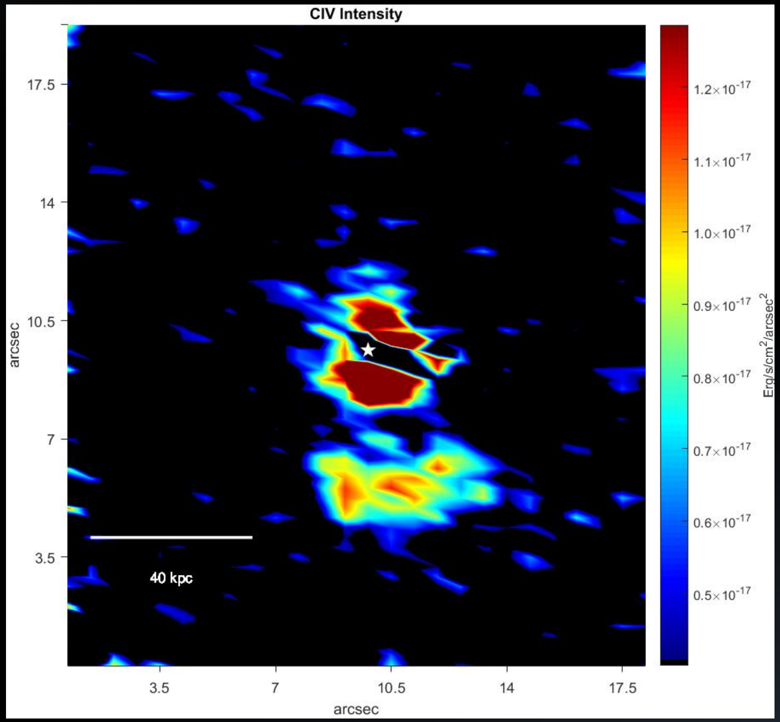
My Research: Observations of Z ~ 2 Galaxies with KCWI

- The CGM around high redshift quasars is illuminated through quasar fluorescence, creating a unique laboratory for studying gas kinematics and ionization mechanisms.
- KCWI in the BLM configuration covers Lyα and He II λ1640 at R~1800 and spatial scale of 0.7”
- 9 hours of integration time on the QSO 4C05.84 (z~2.32)
- Complicated data reduction: scaled sky subtraction and PSF subtraction
- Modeling in CLOUDY

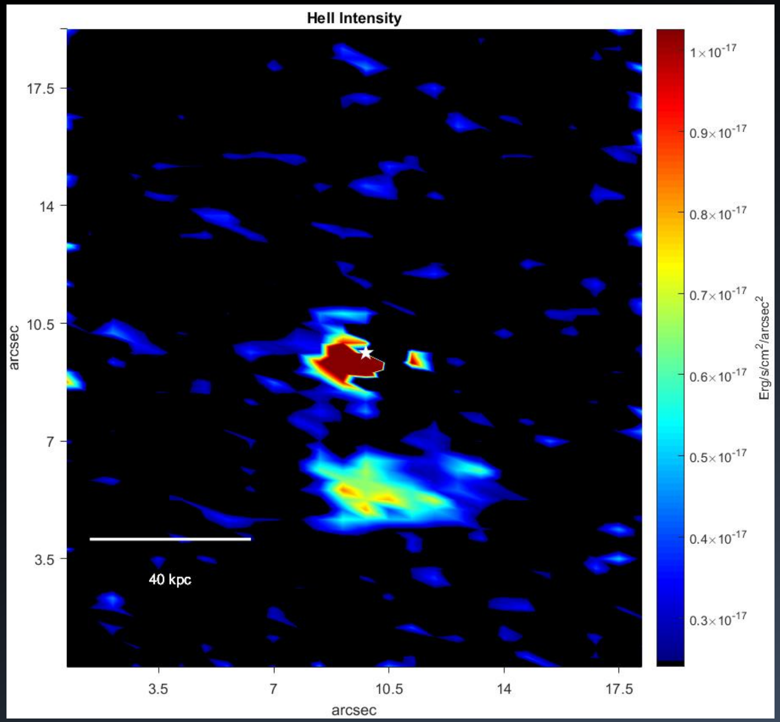
My Research: The CGM around 4C05.84



Lyα integrated line intensity



C IV λ1548 integrated line intensity



He II λ1640 integrated line intensity

My Research: Radiative Transfer

1. Quasar Fluorescence
2. Lyα Radiative Transfer
3. He II Radiative Transfer

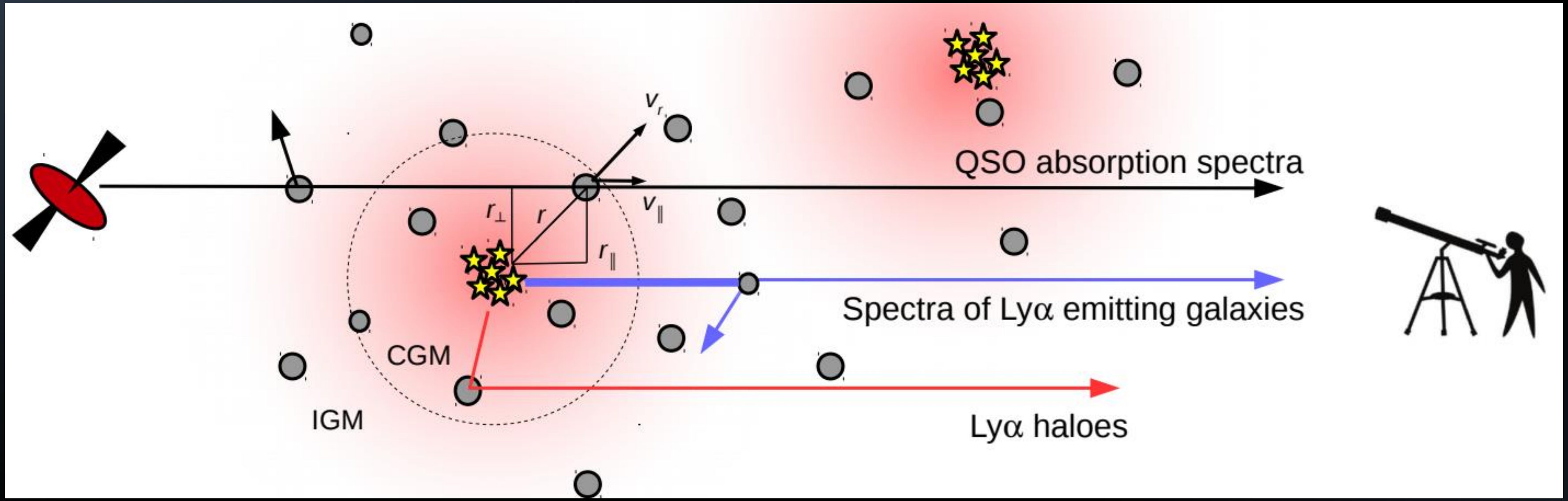
1. Quasar Fluorescence

If we assume that all the ionizing photons from an AGN are absorbed by the surrounding medium and re-emitted as recombination lines. The line (Lyα or He II) luminosity of the surrounding blob is given by:

$$L_{line} = c_{line} Q = c_{line} \int_{\nu_{LL}}^{\infty} \frac{L_0}{h\nu} (\frac{\nu}{\nu_0})$$

where Q is the number of ionizing photons emitted per unit time, ν_{LL} is the frequency of the Lyman limits for the hydrogen and He II ($h\nu_{LL}$ = 13.6 eV and 54.4 eV, respectively), and the line emission coefficient c_{line} in ergs is the energy of the line photon emitted for each H I or He II ionizing photon.

2. Lyα Radiative Transfer, Absorption



"A new model framework for circumgalactic Lyα radiative transfer constrained by galaxy-Lyα forest clustering" K. Kakiichi 2018

for the photons emitted at frequency ν_e from a galaxy or background QSO, the Lyα optical depth of an absorber is given by

$$\tau_a(\nu_e|\mu_{||}, N_{HI}) = \sigma_\alpha N_{HI} \varphi_\nu \left[T, \nu_e\left(1 - \frac{\mu_{||}}{c}\right)\right]$$

where σ_α= $(\pi e^2/m_e c) f_{12}$ = 0.011 cm2 Hz is the Lyα cross section and φ_ν(T, ν) is the Voigt profile at gas temperature T and frequency ν, e is the electron charge, m_e is the mass of electron, and c is the speed of light, and f_{12} = 0.4164 is the oscillator strength of 2P → 1S transition

2. Lyα Radiative Transfer, Scattering

Apparent specific Lyα luminosity as seen by an observer is given by:

$$< L_\nu(\nu_e) > = e^{-\tau_{eff}^{Ly\alpha}(\nu_e)} < f_{esc,ISM}^{Ly\alpha} >< L_\alpha^{intr} >< \phi_\alpha^{ISM}(\nu_e) >$$

Where $< L_\alpha^{intr} >$ is the average Lyα luminosity due to nebular recombination in star-forming regions, $< \phi_\alpha^{ISM}(\nu_e) >$ is the intrinsic average Lyα profile, $< f_{esc,ISM}^{Ly\alpha} >$ is the ISM Lyα escape fraction, and $\tau_{eff}^{Ly\alpha}(\nu_e)$ is the effective optical depth.

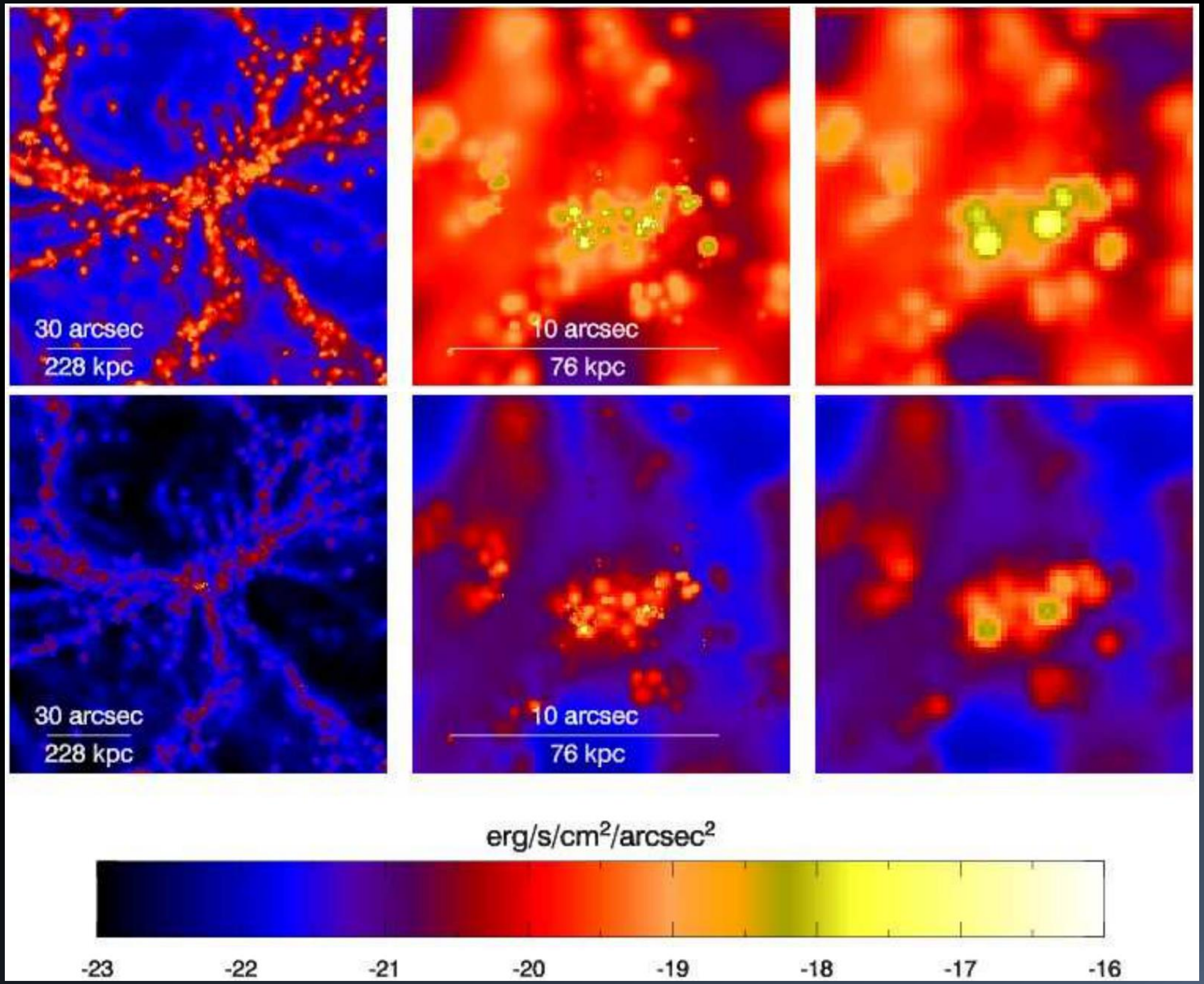
For scattered Lyα halos around galaxies in the single scattering approximation, the luminosity is given by:

$$L_\alpha(r, \nu_r, N_{HI}) = \int \left[1 - e^{-\tau_a(\nu_{inj}, N_{HI})}\right] L_\nu(\nu_e) d\nu_e$$

3. Lyα and He II, Cooling Radiation

This images shows H I and He II cooling radiation at a redshift of Z = 3. The middle panel is a zoom in of the left, and the right panel is a predicted observation with current facilities.

Gravitational cooling simulations show He II always over an order of magnitude dimmer than Lyα.



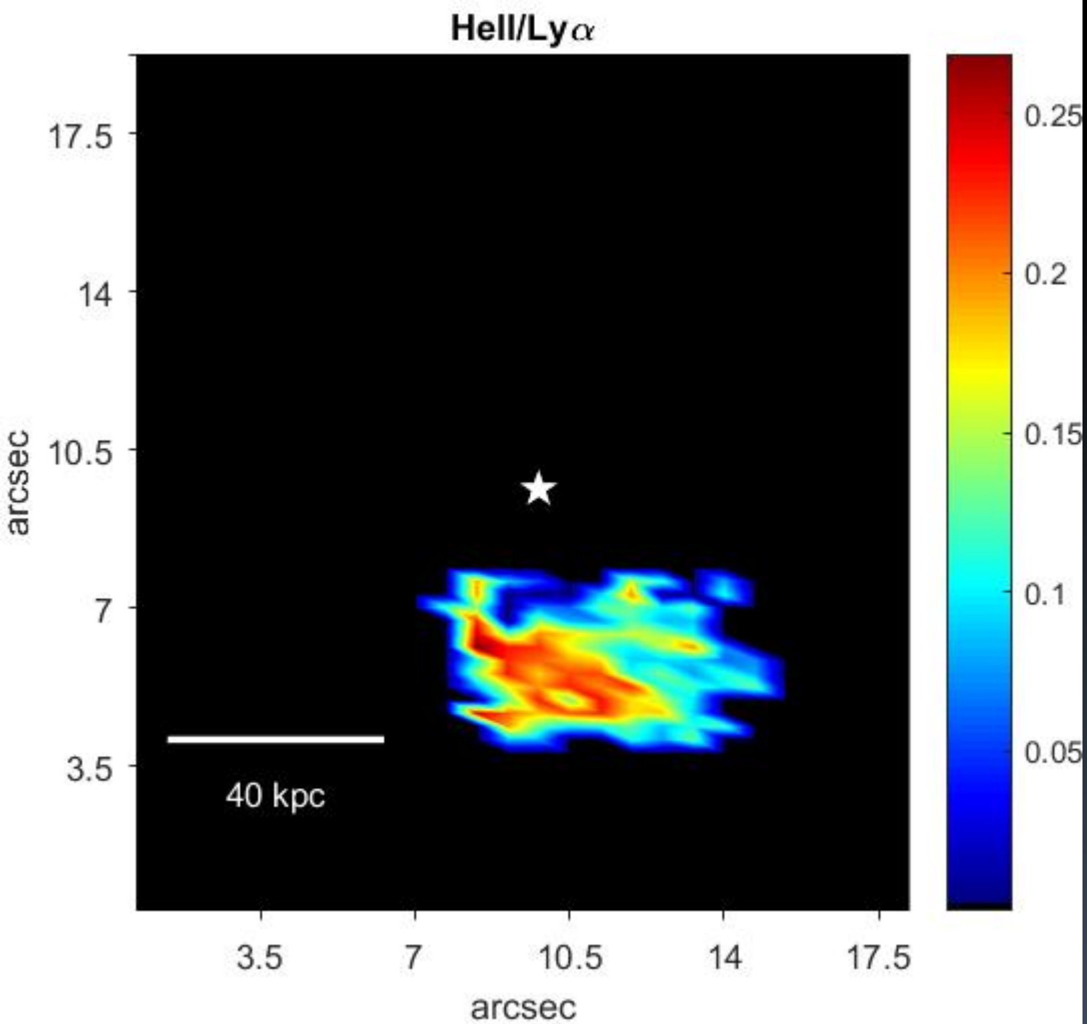
Yang 2005

3. Lyα and He II Line Ratio

The measured HeII/Lyα line ratio produced by recombination processes (in absence of dust and radiative transfer effects) is defined, from an observational point of view, as:

$$\frac{< F_{He\ II} >}{< F_{Ly\alpha} >} = \frac{h\nu_{HeII}}{h\nu_{Ly\alpha}} \frac{\alpha_{HeII}^{eff}(T)}{\alpha_{Ly\alpha}^{eff}(T)} \frac{< n_e n_{HeIII} >}{< n_e n_p >}$$

Where α is the temperature-dependent effective recombination coefficient



He II λ1640 divided by Lyα line ratio.

Summary

- The cosmic web is composed of filaments of pristine gas that are accreted and drive galaxy formation. To understand the relationship between galaxies and the surrounding IGM, it is important to look at the CGM.
- Due to complicated radiative transfer and the difficulty of separating it from kinematics in Lyα, He II provides a unique look at gas kinematics and ionization mechanisms in the CGM.
- 9 hours observation time of the CGM around the QSO 4C05.84 through quasar fluorescence with KCWI on Keck. Photoionization modelling in CLOUDY.
- Radiative Mechanisms:
    1. Quasar fluorescence
    2. Lyα absorption and scattering
    3. Gravitational cooling