V. Langen et al. (in prep.)

Characterizing the Circumgalactic Medium of Quasars at z~2.2 through Hα and Lyα Emission

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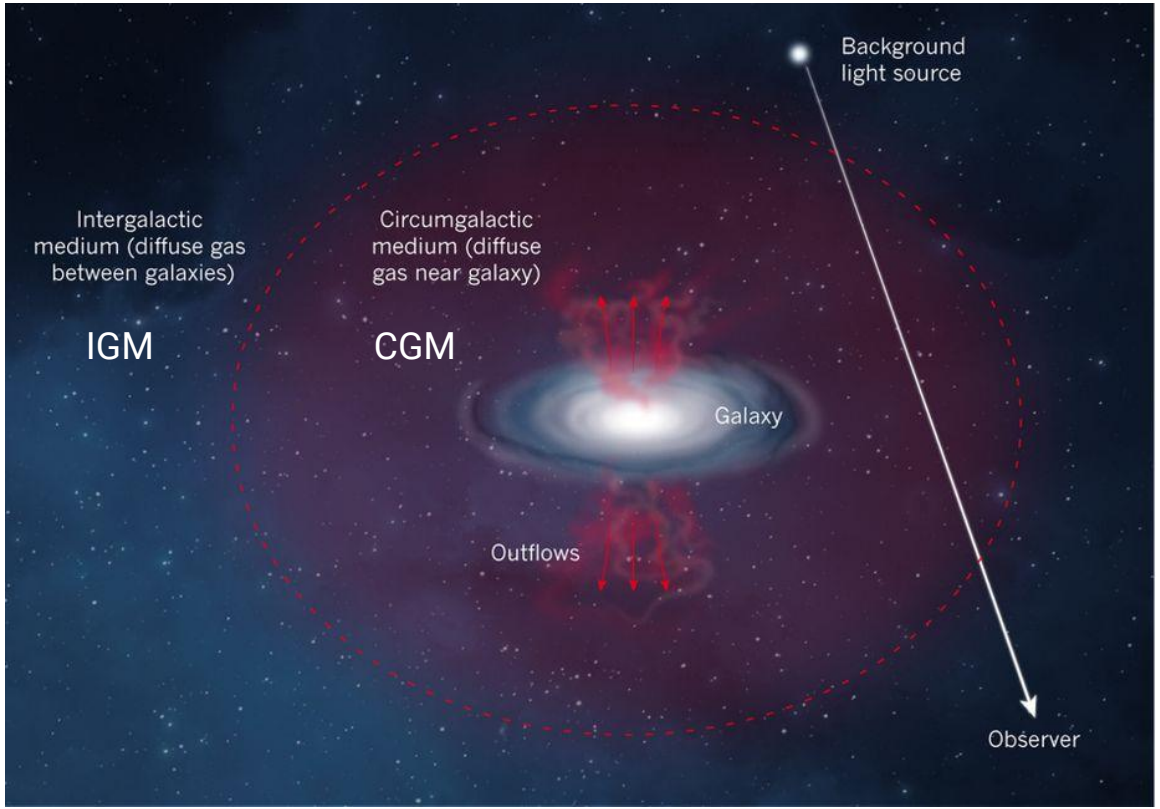
Outline

1. Motivation and Preliminaries
   - *Why* do we care about the CGM?
   - *How* can we study it?
2. Lyman-α observations
3. Hydrogen Hα follow-up
4. Comparison between Lyα and Hα
   - Emission mechanism
   - Physical properties of the gas
5. Conclusion and future prospects

1. Motivation and Preliminaries

1. Motivation

- Galaxies fueled by gas from IGM/CGM
- How does it accret onto galaxies?
- The detailed physical properties are still matter of active research



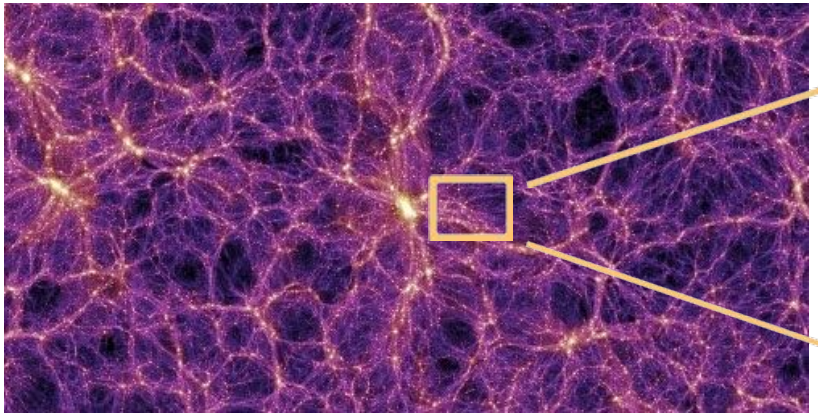
1. Preliminaries

- Snap-shot of illustris simulation
- Most material relatively cold, $\mathrm{T} \sim 10^4\,\mathrm{K}$ and confined to filaments

- Environment around galaxies
  → CGM
- ***How can we study the CGM?***

➔ Gas around active nuclei ***'illuminated'***

➔ **'Fluorescent'** emission



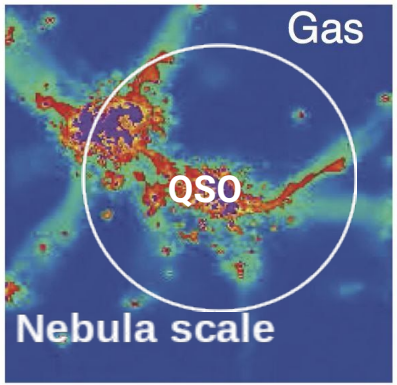


Image credit: simulation by B. Oppenheimer, Leiden University

The cosmic web in emission

- Most abundant element: **Hydrogene**

➔ Hydrogen emission lines

➔ Most prominent: **Lyα**

<u>Studied extensively</u>:
Borisova E., et al., 2016,
Cai Z., et al., 2017,
O'Sullivan D., et al 2019, Etc, …

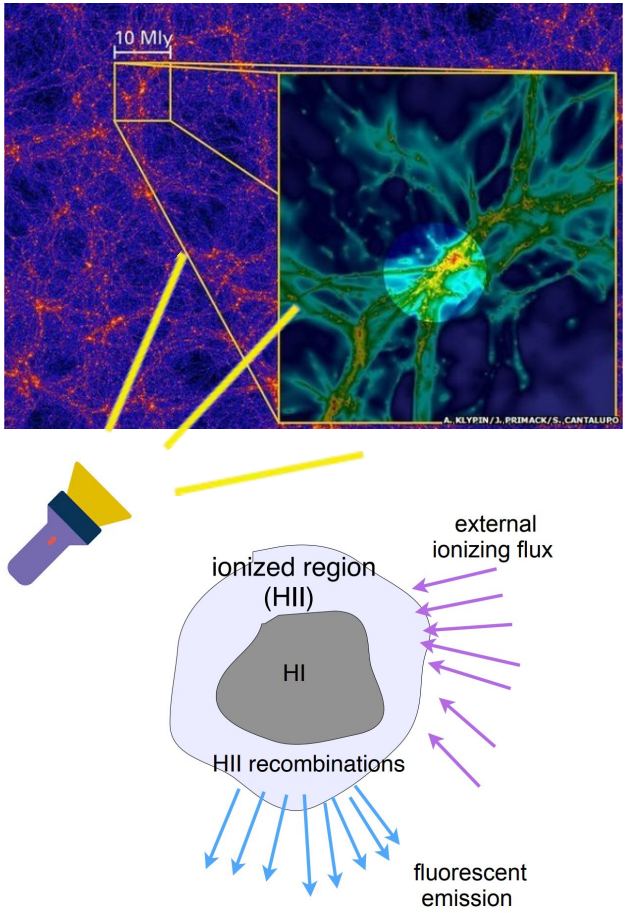
- Lyα emission mechanism is very complex

➔ Resonant line

➔ **No** direct tracer of kinematics

- How can we understand its emission?

➔ Non-resonant line: Hydrogen **Hα**



Emission mechanism

Recombination
(*Intrinsic* Lya emission)

$$\frac{F_{Ly\alpha}}{F_{H\alpha}} = 8.3$$

for $T = 5 \times 10^3$ - 4×10^4K
$n_e = 10^2 - 10^4\,cm^3$

Scattering from QSO
BL region

No Hα

Collisional excitation
(*Cooling radiation)*

$$\frac{F_{Ly\alpha}}{F_{H\alpha}} \approx 100 - 120$$

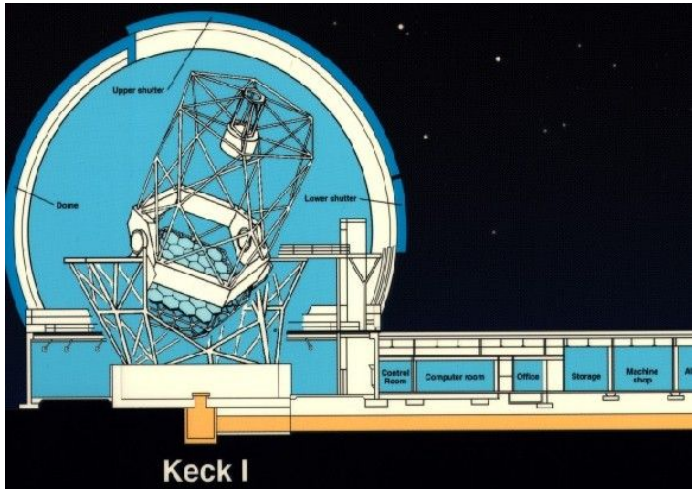
for $n_e = 10^2\,cm^3$
$T = (1.5 - 4) \times 10^4\,K$

GOALS

- Pilot study: detect Hα
- Constrain the emission mechanisms
- Infer properties of the gas, e.g. density, temperature, morphology
- Investigate the gas kinematics

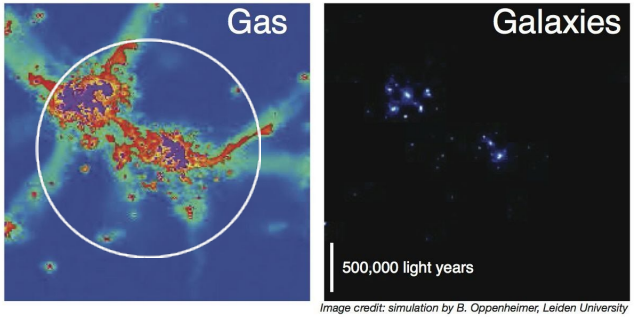
2. Lyα observations

The Keck Cosmic Web Imager



➔ Extended Lyα emission: brightest and most extended for Hα follow-up

Preliminary Lyα results



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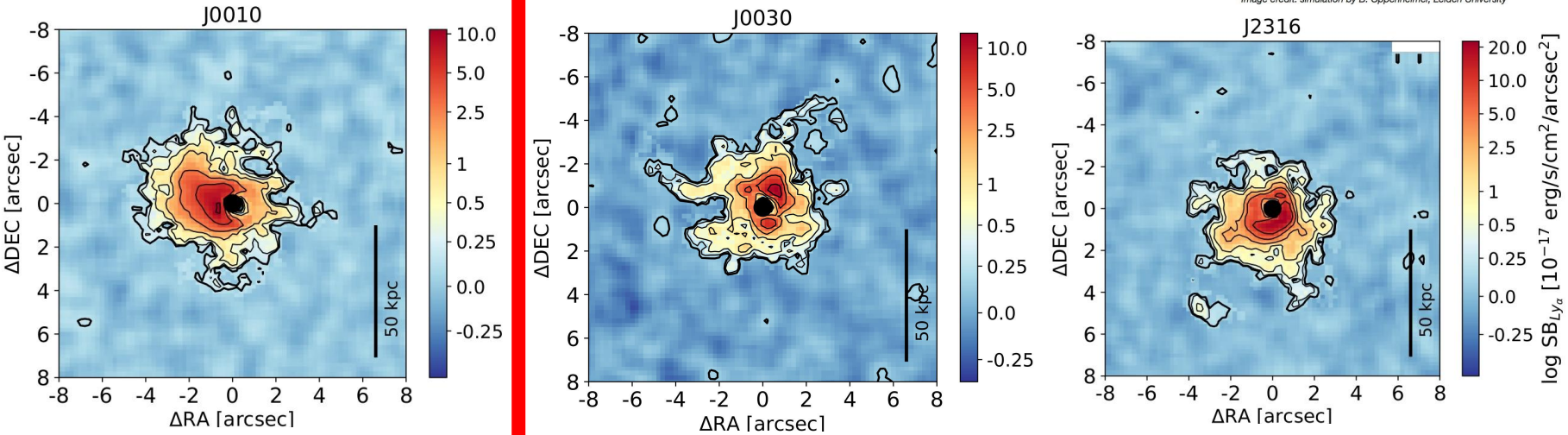
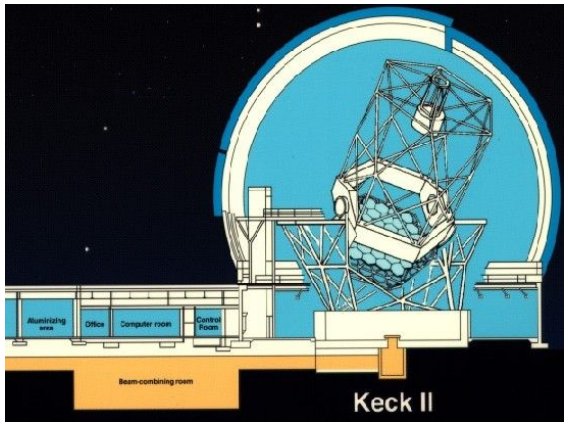
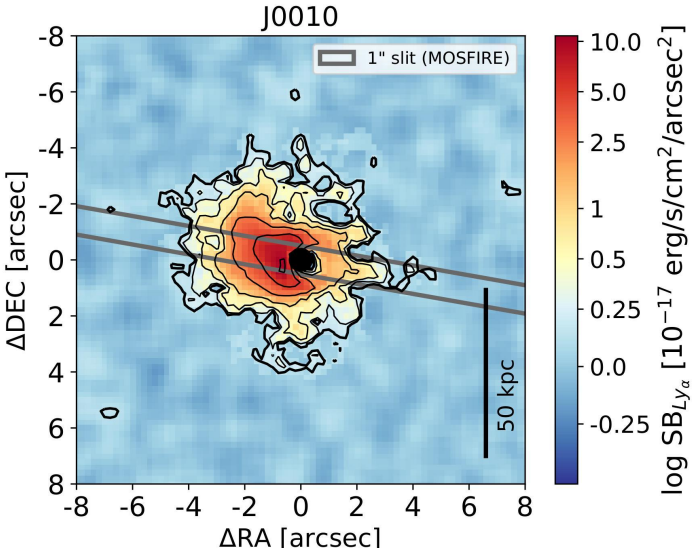


3. Hα follow-up

The Multi-Object Spectrograph for Infrared Emission

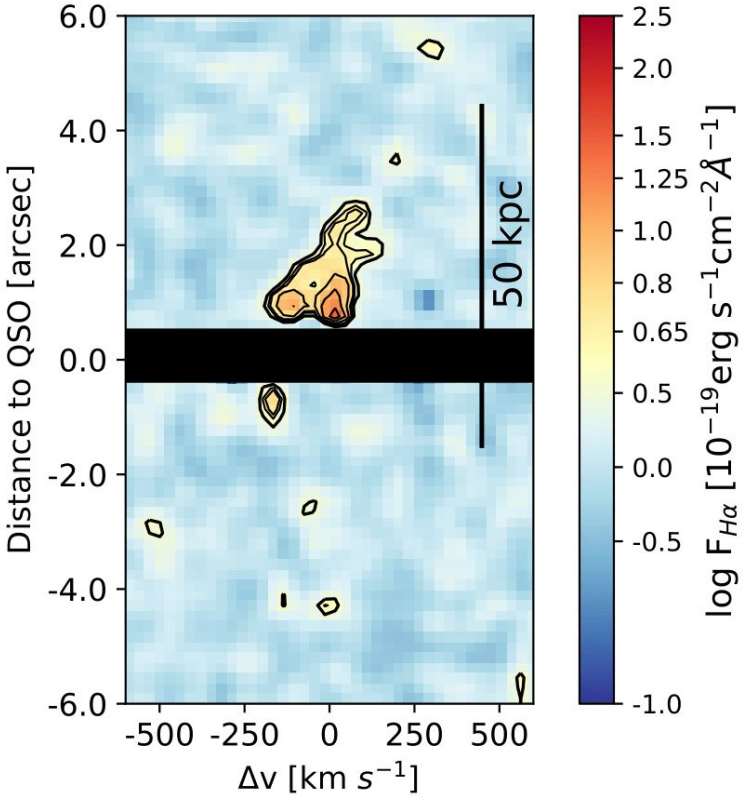


Slit configuration



➔ Cover maximum flux

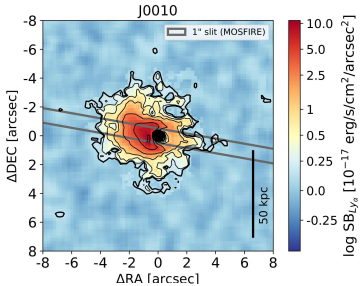
Hα results

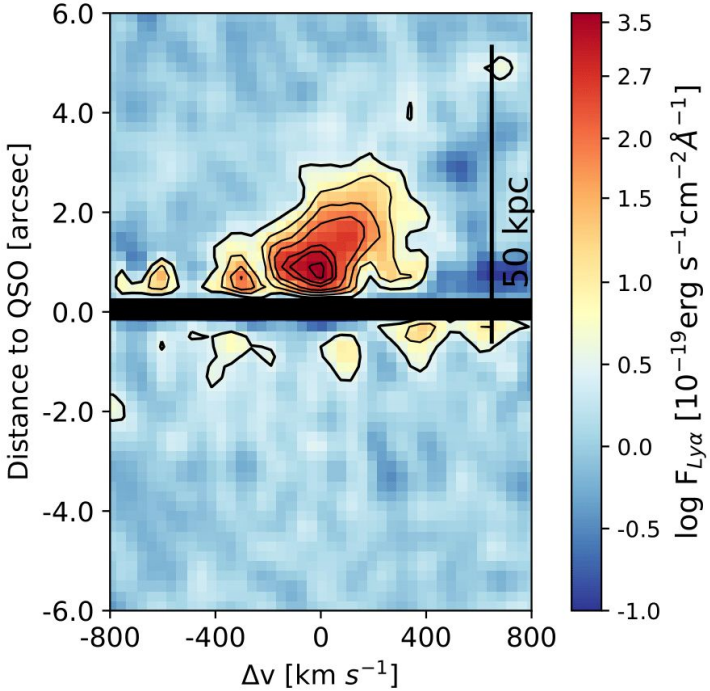


- SNR > 2
- Spatial extend >2 arcsec (20 kpc)
- Zero velocity corresponds to peak of the integrated Lya emission line of the entire nebula
- Spectral width ~400 km/s
  -> relatively narrow
- Double peak structure
  -> complex origine

4. Comparison between Lyα and Hα

Lyα slit

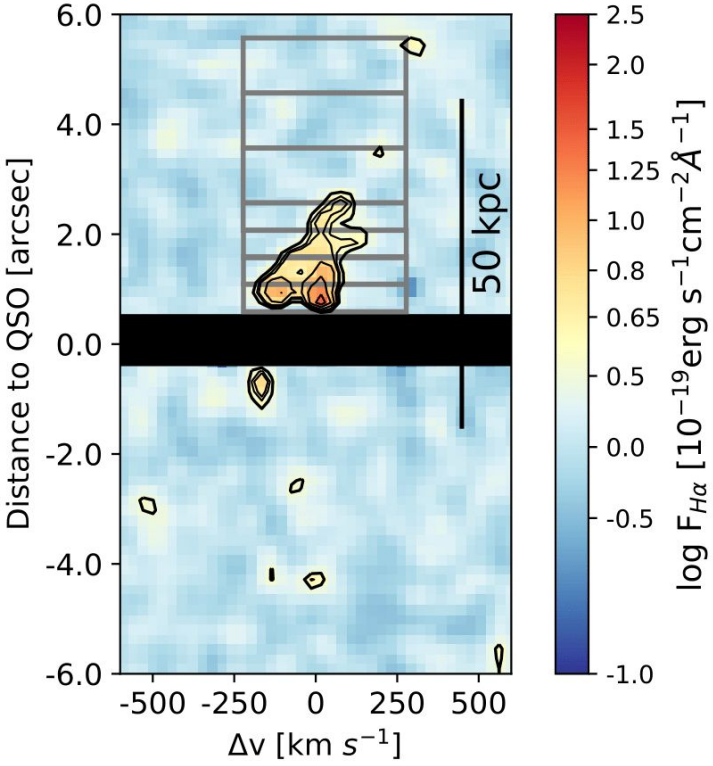


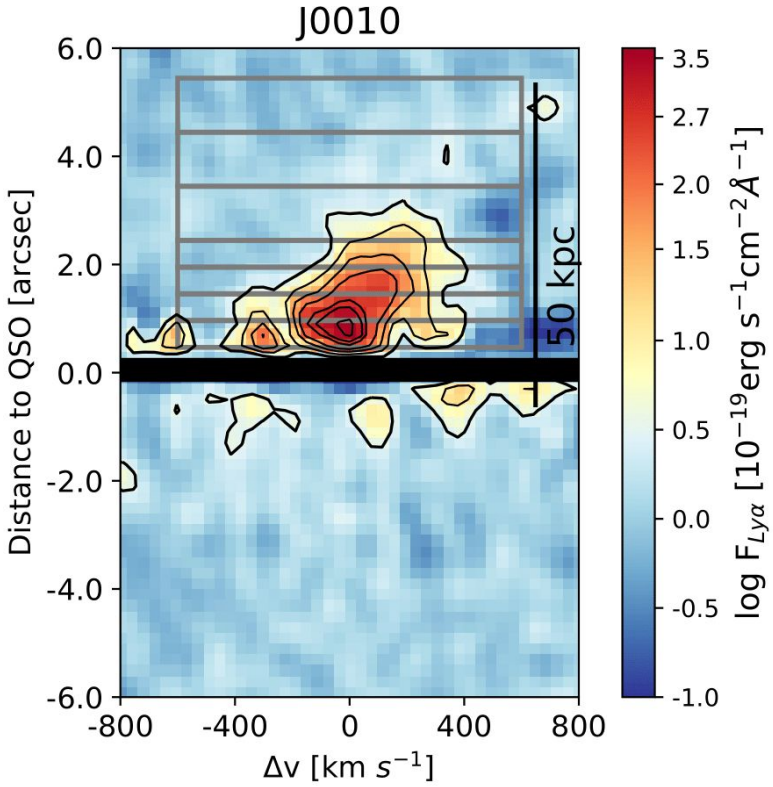


- Create pseudo-slit with equal parameters and units
- Emission extends >3 arcsec (40 kpc)
- Spectral width >800 km/s

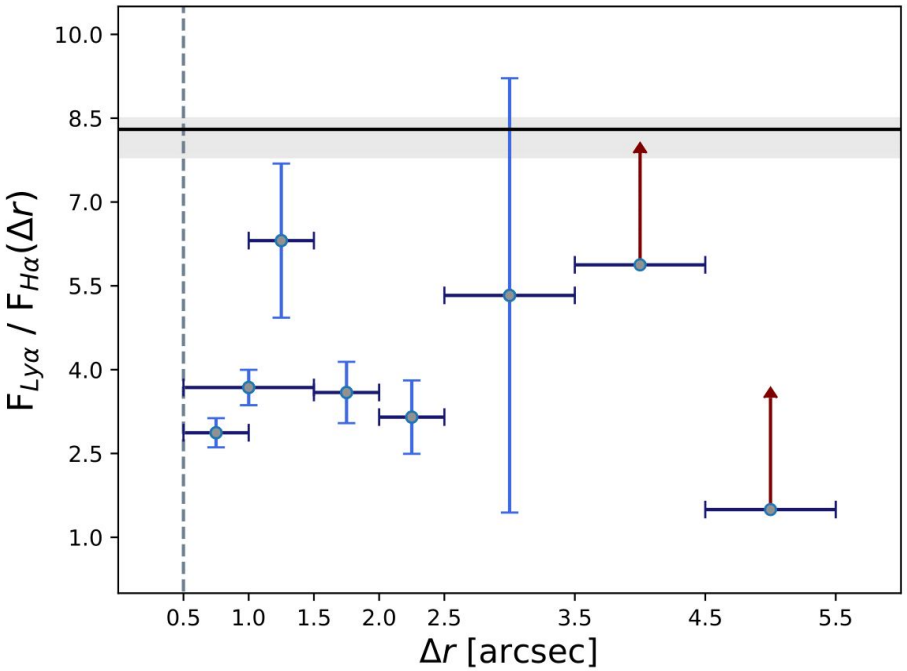
➔ Directly compare the emission
➔ Flux ratios in function of distance to QSO
➔ Spectral projection in function of distance to QSO

Flux apertures





Flux ratio in function of distance from the QSO



- Total flux ratio :

$$\frac{\mathrm{F}_{\mathrm{Ly}\alpha}}{\mathrm{F}_{\mathrm{H}\alpha}} = 3.6 \pm 0.3$$

- Consistent with recombination radiation
- In virginity of the QSO: ratio < 8.3

➔ *What could reduce this ratio?*
➔ *Look at the spectral shapes*

5. Discussion

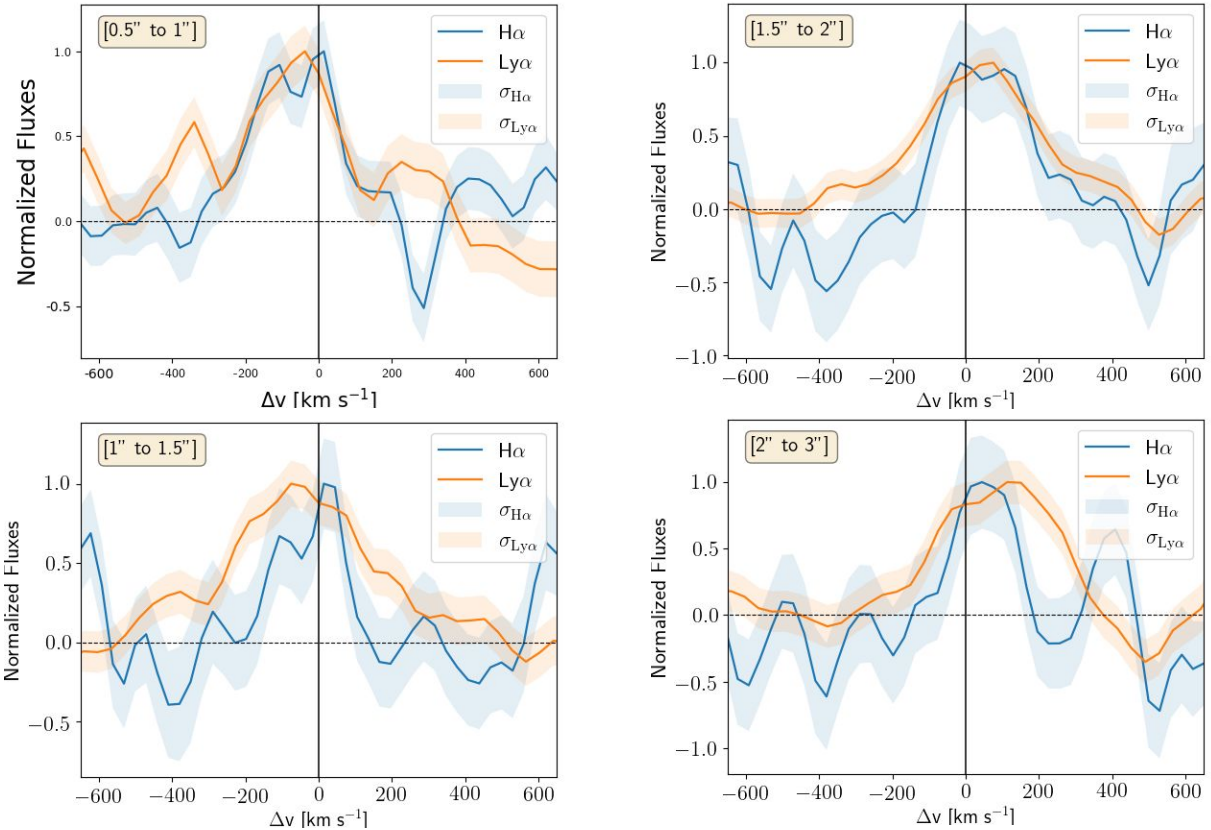
➔ Emission dominated by recombination

➔ Why ratio < 8.3 ?

- Literature value originally derived for ISM around galaxies: higher densities lead to higher ratios
- Lya suffers more from dust absorption (longer wavelength)
- radiative transfer effects: diffusion in space and frequency

➢ Look at projected line shapes

Spectral shapes in function of distance from the QSO



- Similar line profiles
- Lya boradens more outwards

- Little peak movement -> quiescent kinematics
- Complex origin of gas cloud

GOALS

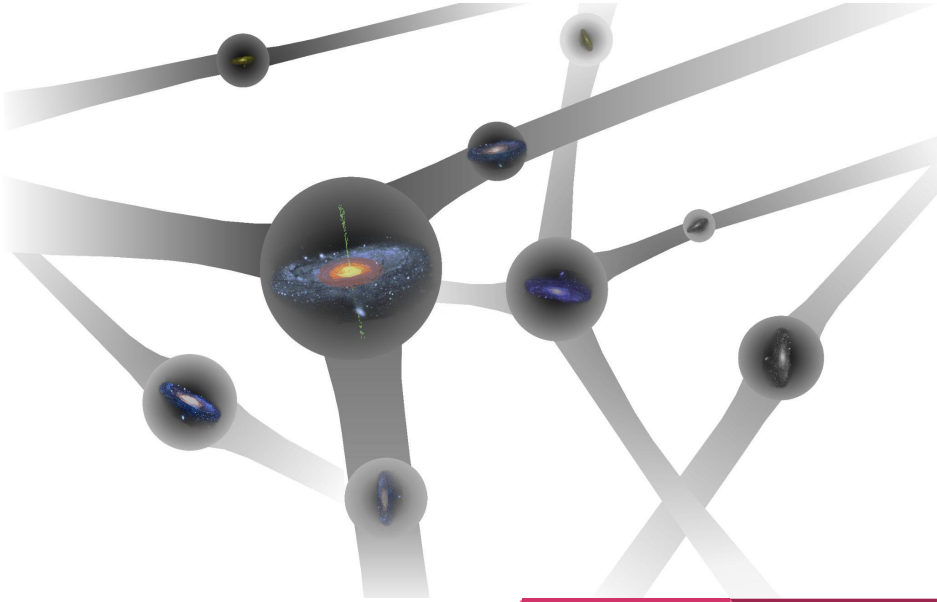
- Extended Hα emission
- Constrain the emission mechanisms
- Infer properties of the gas, e.g. density, temperature, morphology
- Investigate the gas kinematics

5. Conclusion and future prospects

5. Conclusion and outlook

- ➢ Quiescent kinematics
- ➢ Complex origin of gas cloud
  E.g. multiple structures in projection
- ➢ Less neutral gas then around galaxies
- ➢ Clumpy, dense medium
  - higher clumpyness than currently resolved in simulations

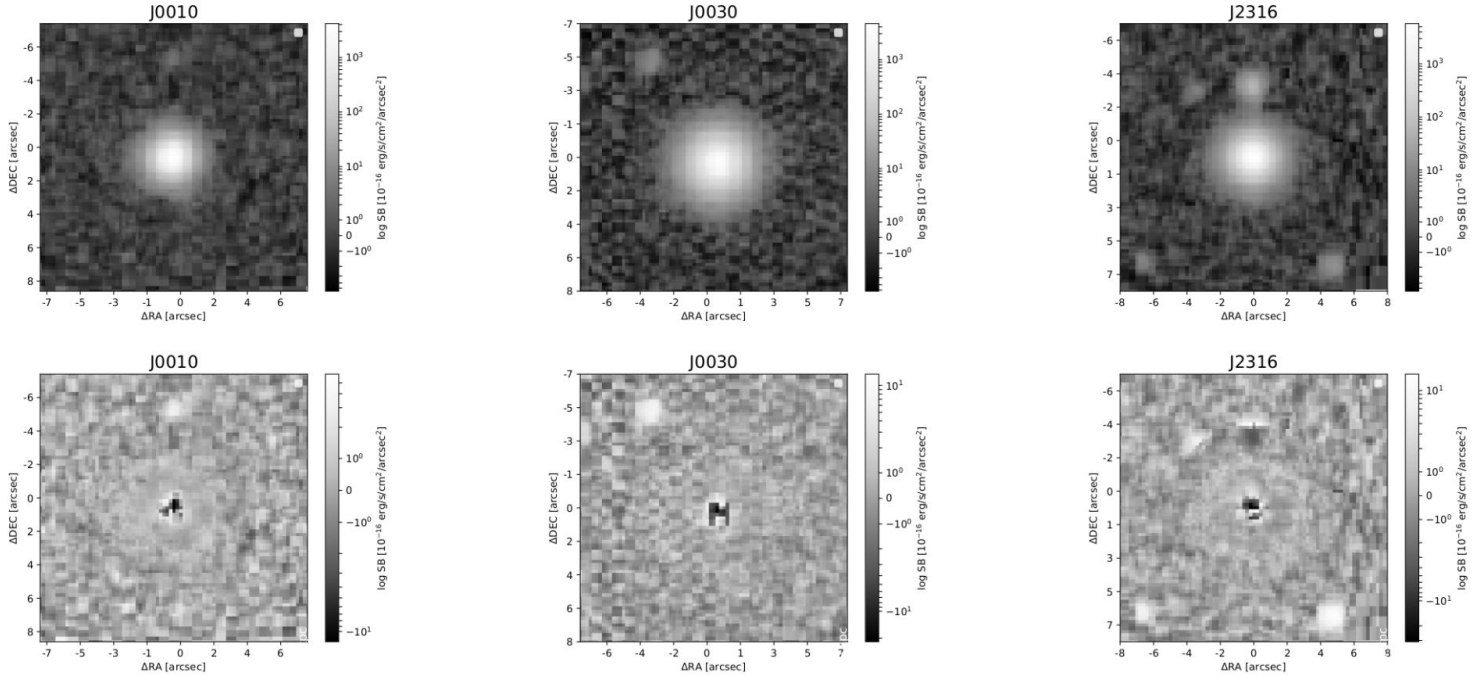
- ➔ Integral Field studies with Hα
- ➔ Higher sample of nebula
- ➔ JWST
- ➔ Numerical models of Lyα/Hα emission



Thank you very much for your attention !

I am happy to answer further questions?

White Light Images

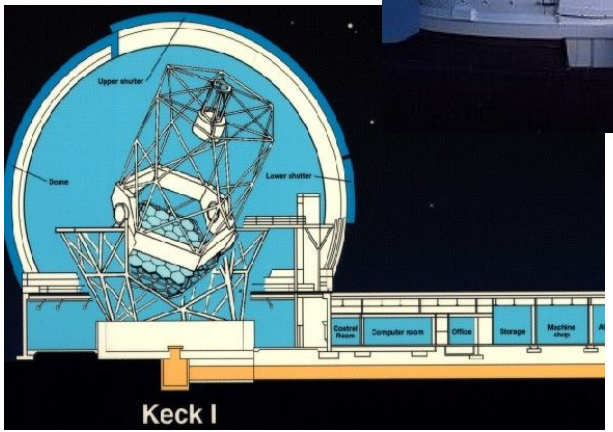


Some relations

- Size of BH and size (i.e. stellar mass) of host galaxies seem to correlate
  Why (?):
  - AGN feedback (strong outflow, jets, winds) enhance SFR as well as their heavier accretion gets more gas into the galaxy
  (-> study by Ding et al (U. of California): hydrodynamic simulations)
  And outflows we see here are indicators for AGN feedback!
- More about host galaxy?
  No, because after PSF subtraction there is nothing left of galaxy emisison

The Keck Cosmic Web Imager

- Wide-field integral field spectrograph
- Optimized for low surface brightness phenomena



Target selection

- 3 targets from SDSS catalog:
  - QSO magnitude m > 18.5
  - redshift 2.25 < z < 2.27

- Extended Ly a emission
  -> brightest and most extended for Hα follow-up

The Multi-Object Spectrograph for Infrared Emission

- Slit spectrograph optimal for faint emission
- K-band range to detect H α

Slit configuration

- Longslit: 120 arcsec
  -> exceeds KCWI FoV
- Wide slit: 1 arcsec
  -> encompass maximum flux
- Sky position angle: 80 deg