Understanding Reionization with 21cm observations of high-redshift analog galaxies

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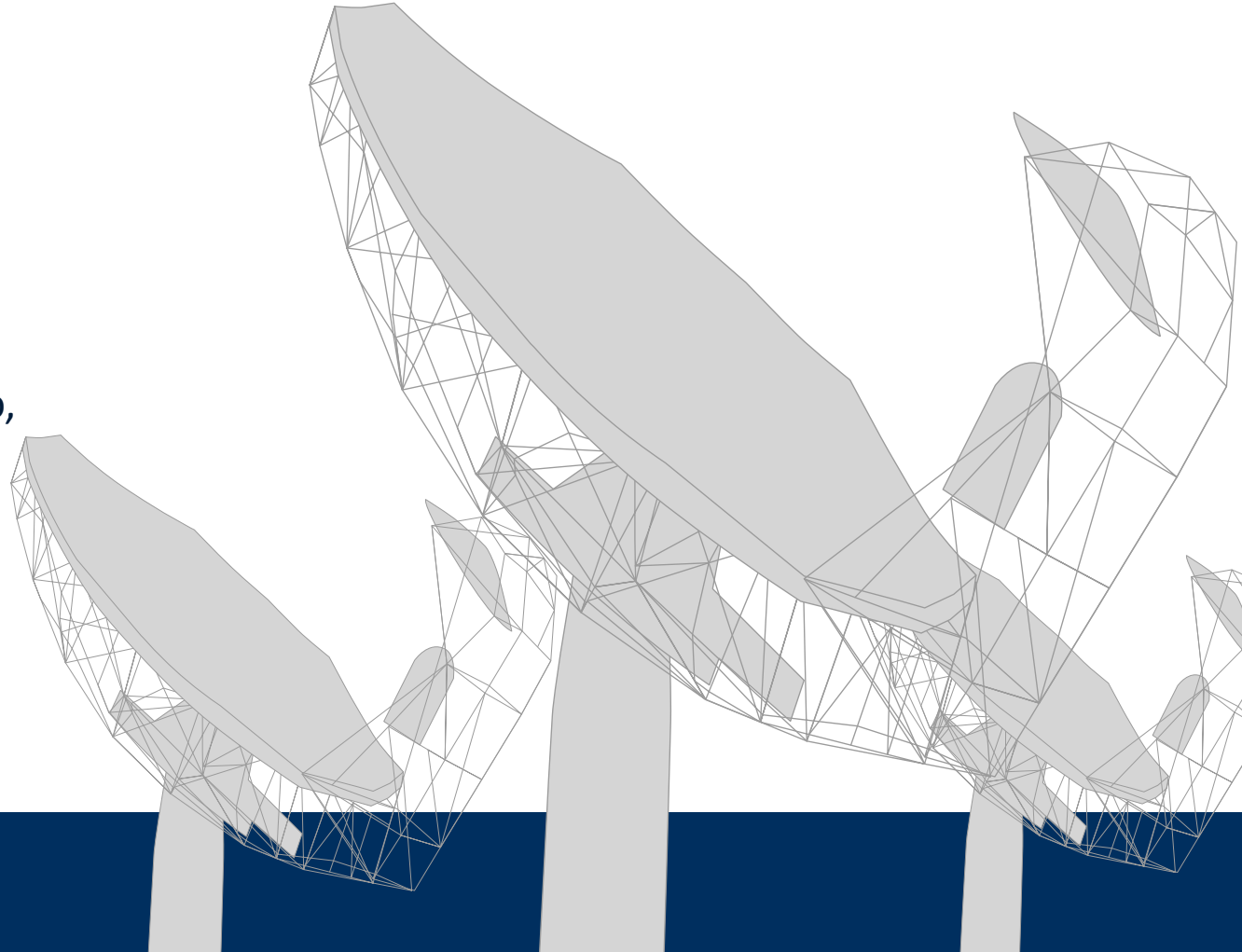
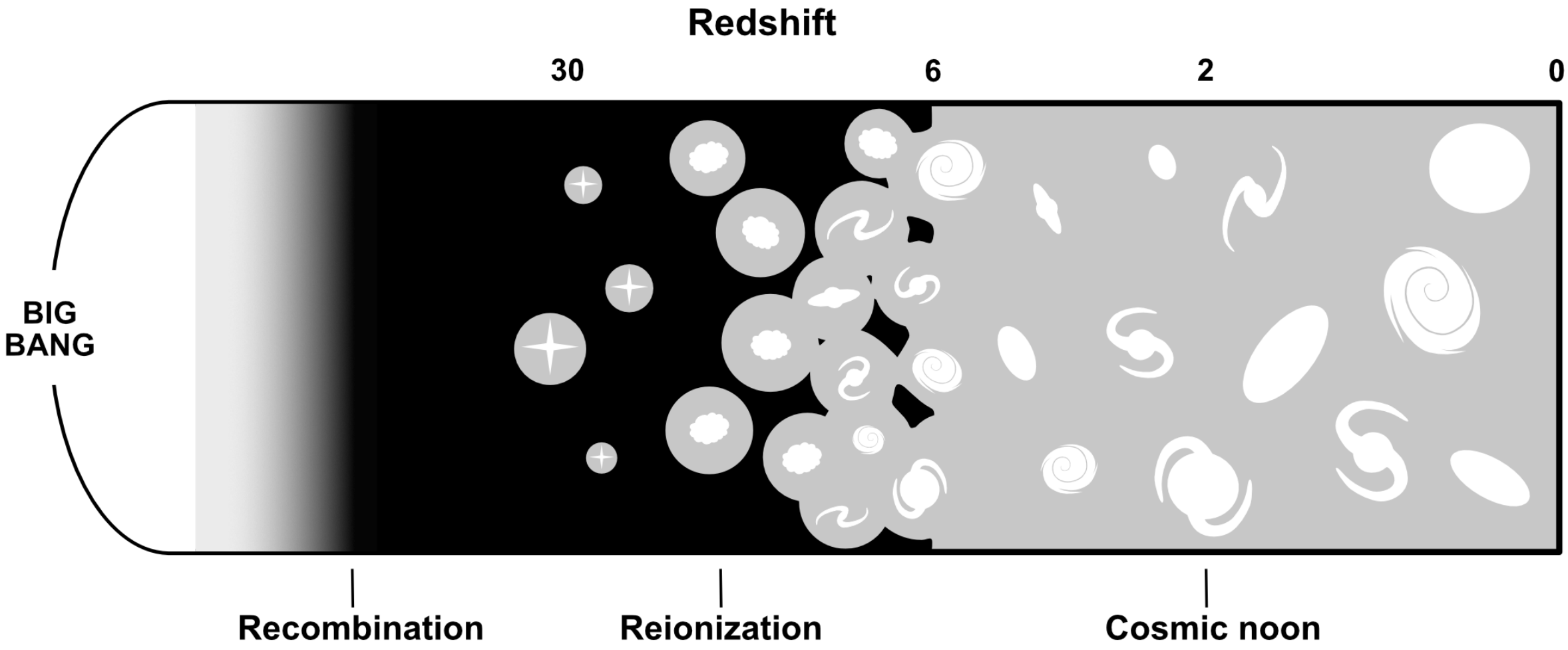
January 12, 2023
Uppsala



History of the Universe



Cosmic reionization

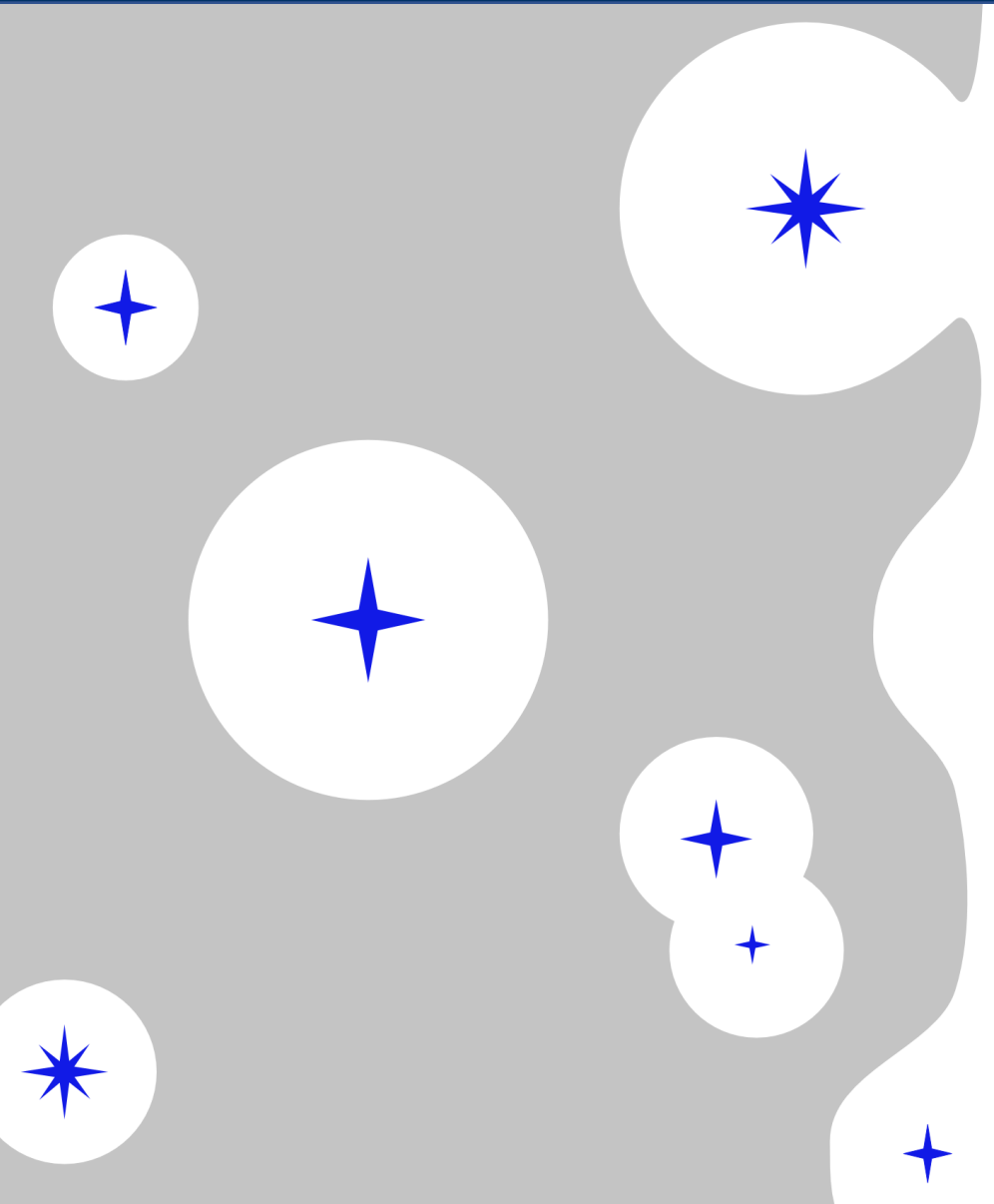
Reionization:

- Period during which the bulk of neutral gas (HI) in the Universe is ionized by primordial sources.

- Last phase transition of the Universe.

→ How does it happen?

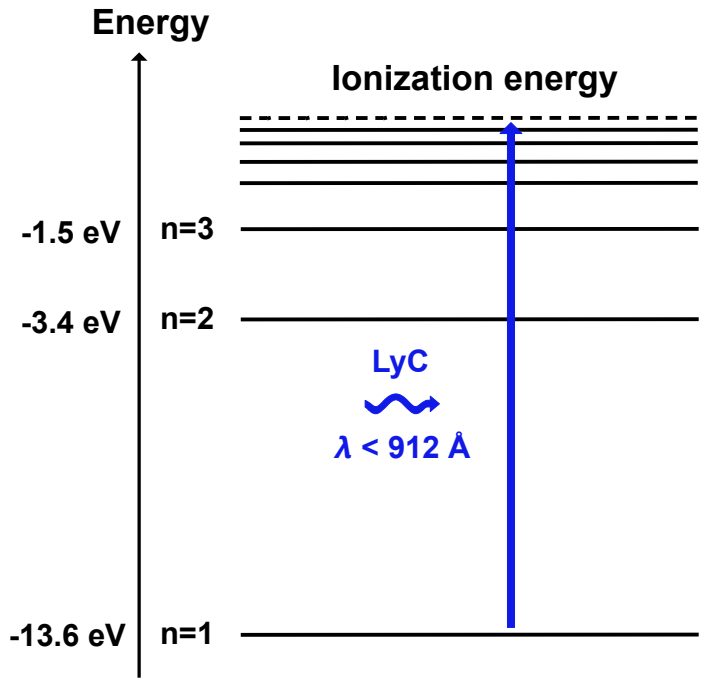
How was the Universe reionized ?



To Ionize Hydrogen: photons with E > 13.6 eV

$$\lambda < 912\ \text{Å}$$

→ **Lyman Continuum (LyC)**

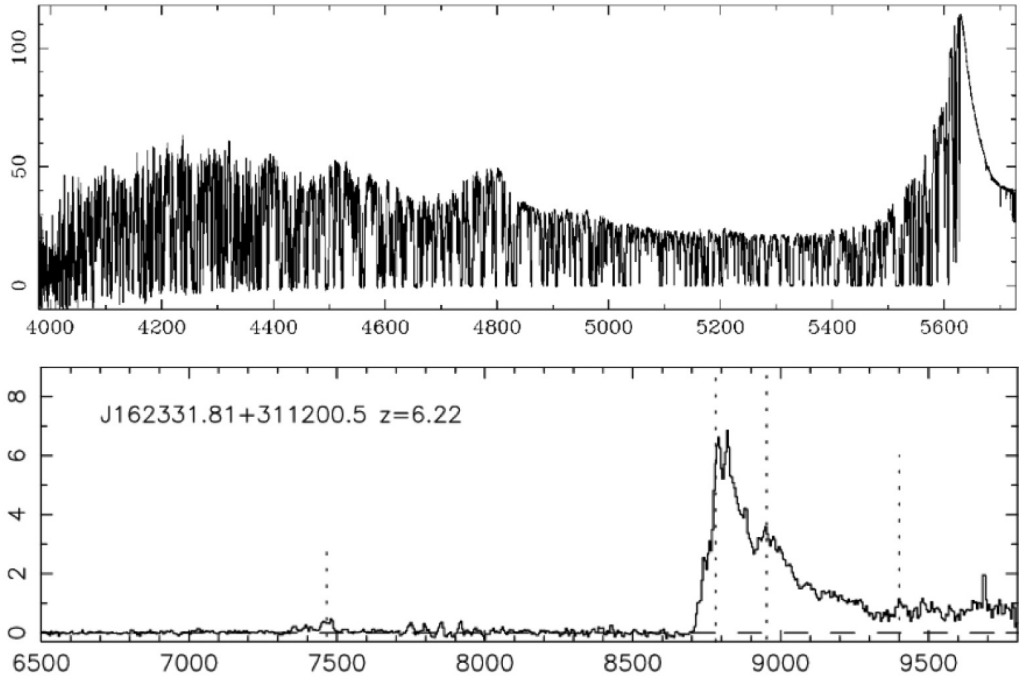


→ Need objects producing UV radiation

How long does reionization take?

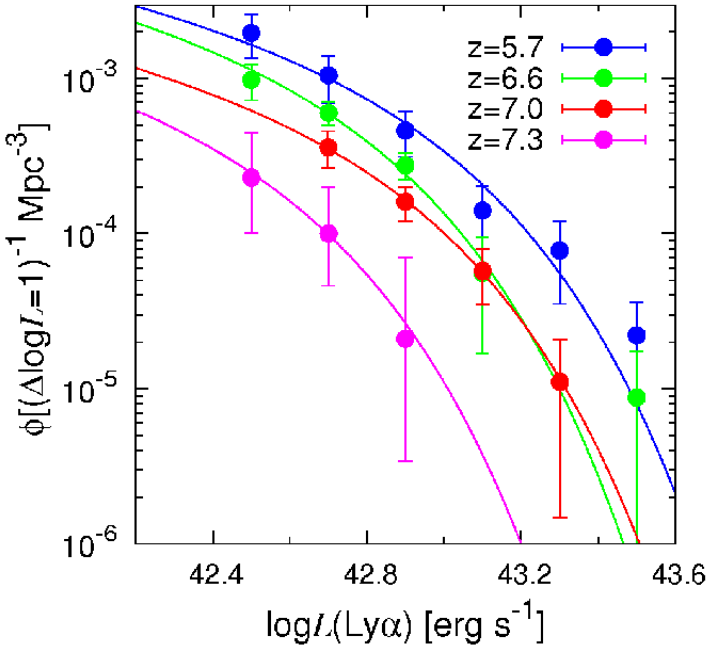
Observations

Lyα forest and Gunn-Peterson trough



Rauch 1998, Fan et al. 2004

Lyα luminosity function



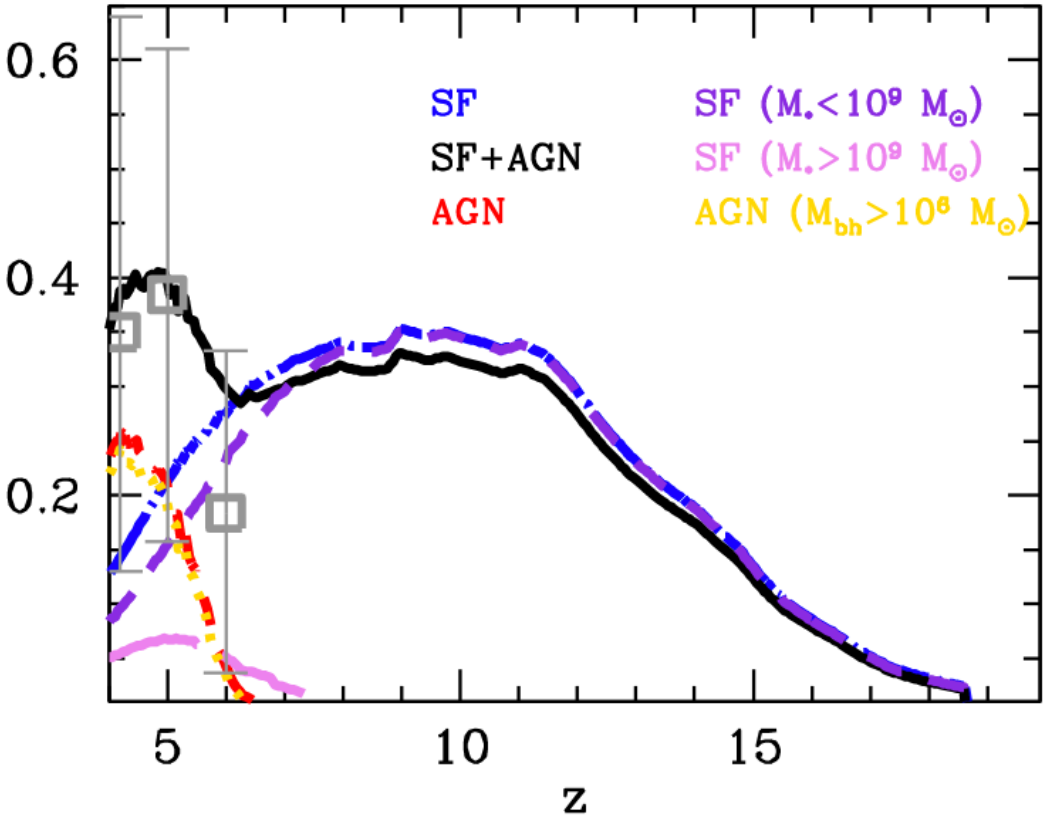
Ota et al 2017

Observations suggest **reionization is over by redshift 6**

What objects are responsible for reionization?

Simulations

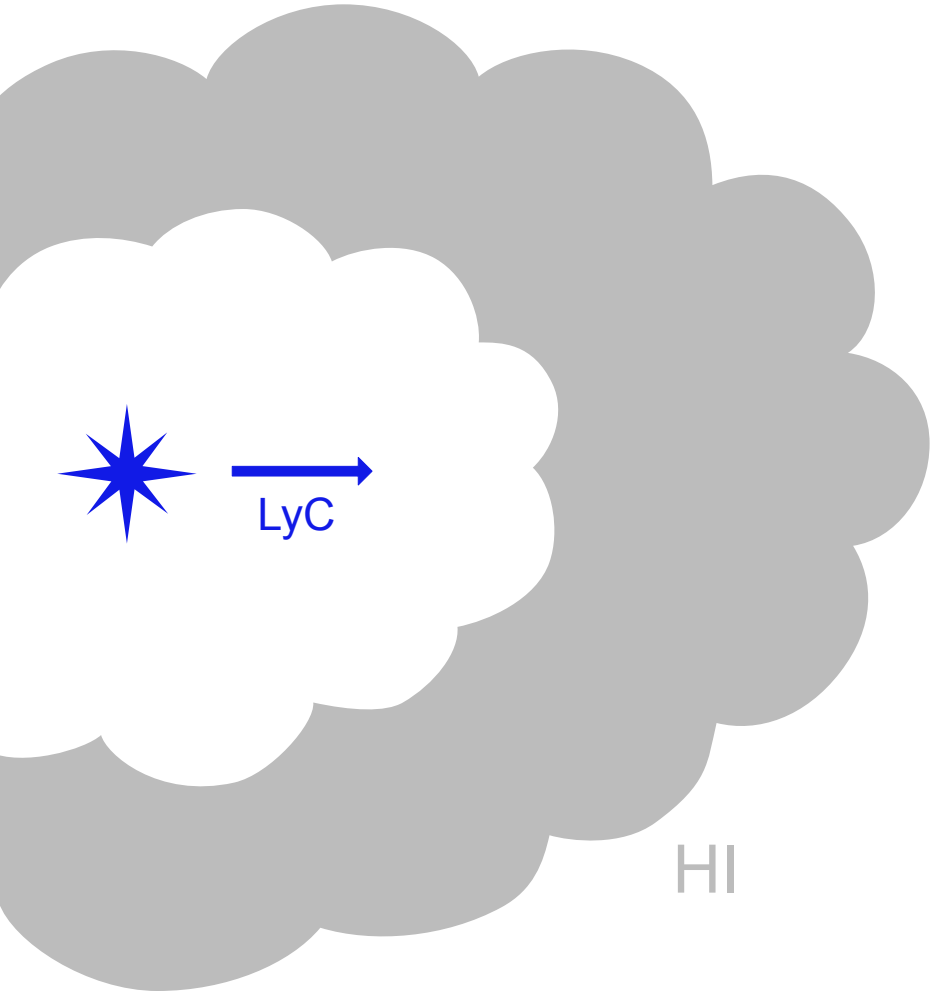
Ionizing photon emissivity evolution



Dayal et al. 2020

Simulations indicate **dwarf galaxies** are the main source of ionizing photons during reionization.

How did galaxies reionize the Universe?



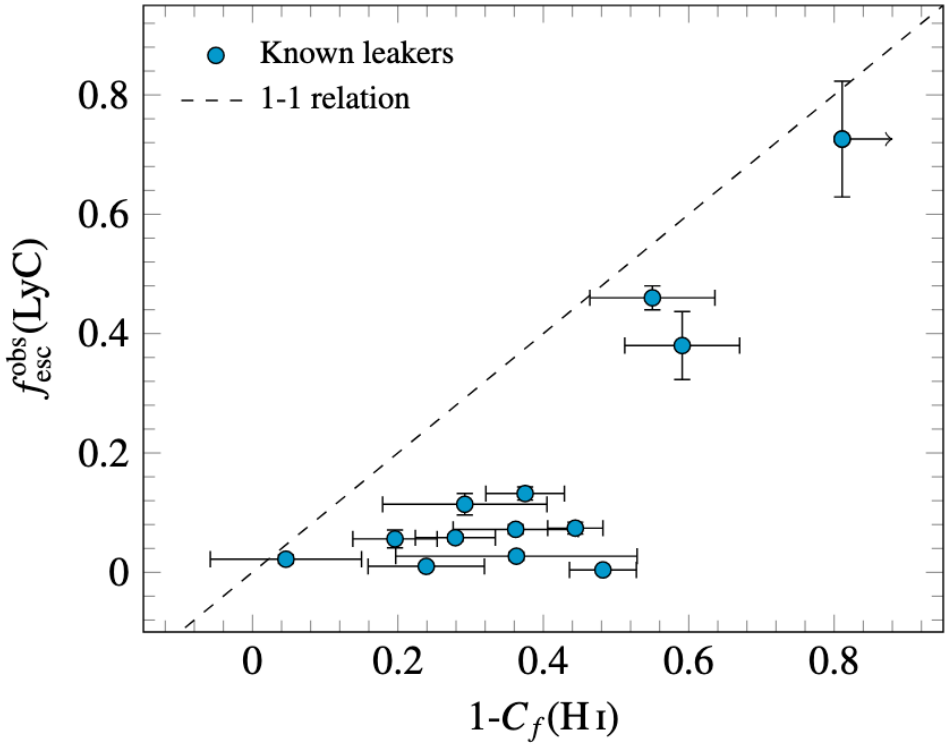
Neutral gas in the Interstellar medium absorbs LyC

$$\tau = 1 \text{ at } \quad N_{HI} \sim 10^{17} cm^{-2}$$

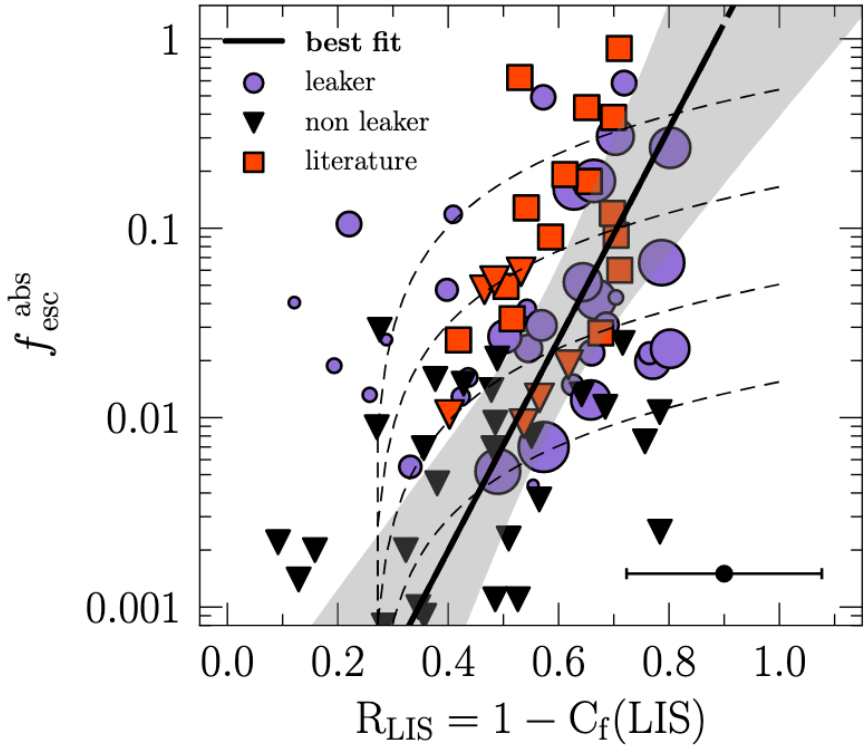
In galaxies, $N_{HI} \approx 10^{19} - 10^{22} cm^{-2}$
→ **Need low column density ISM**

Need **5-20%** LyC escape fraction to reionize the Universe.

Absorption line studies in local emitters



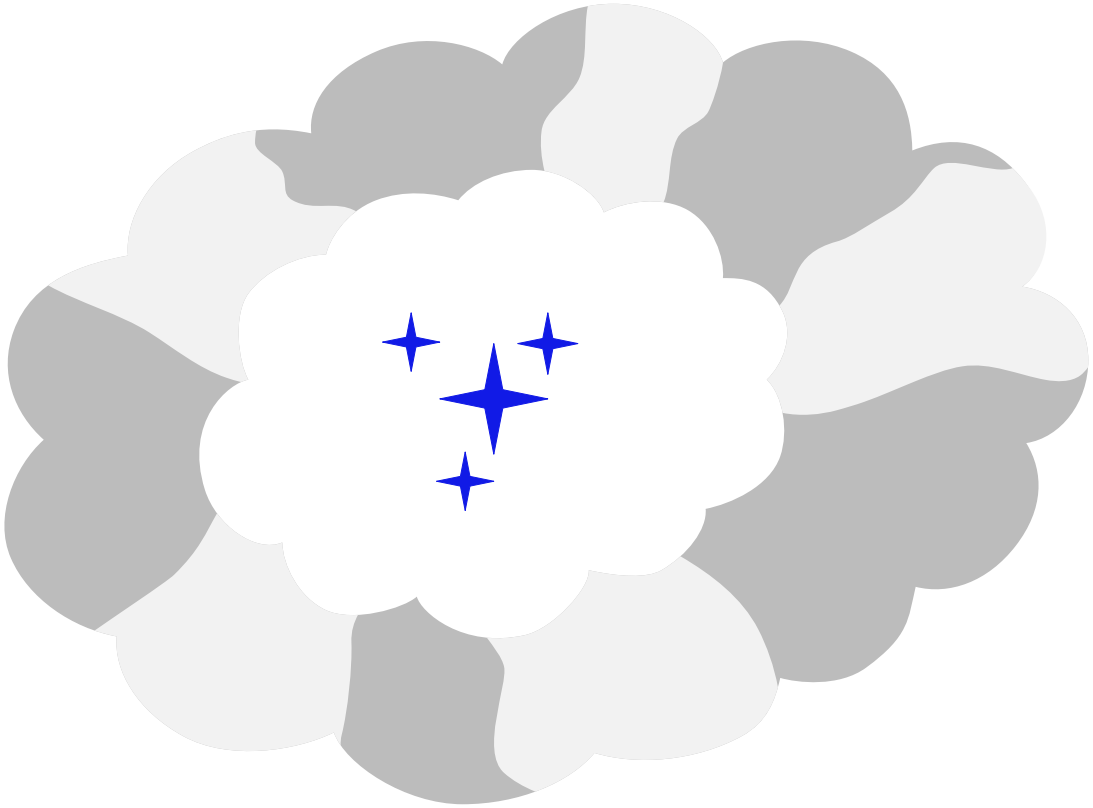
Gazagnes 2020



Saldana-Lopez 2022

Covering fraction of neutral gas : main parameter (unresolved absorption studies).

Absorption line studies in local emitters



Covering fraction of neutral gas : main parameter (unresolved absorption studies).

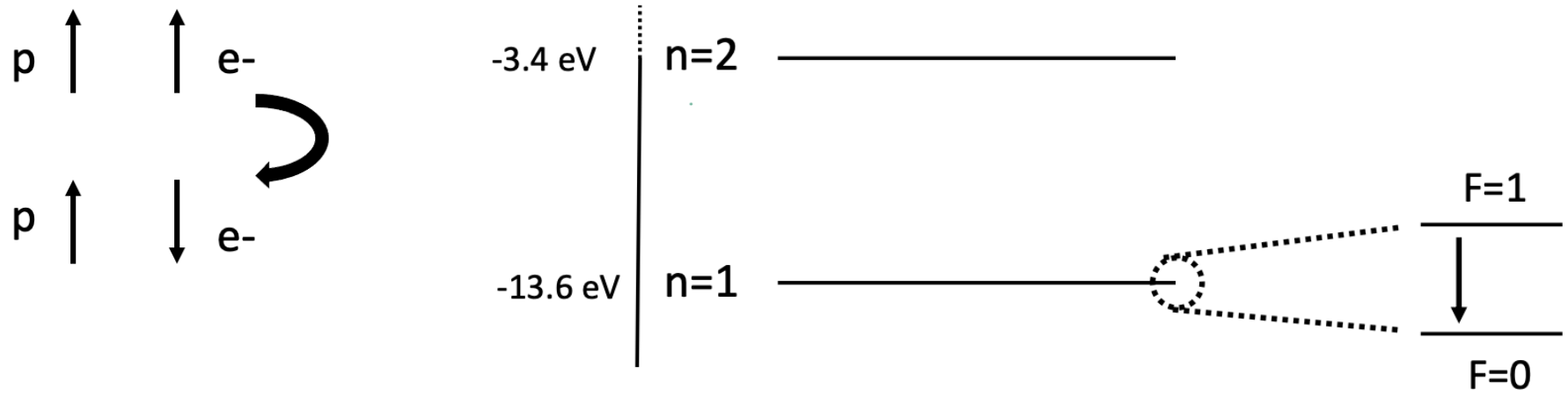
How did galaxies reionize the Universe?

To understand LyC escape and reionization, we need **resolved observations of the neutral gas** distribution

→ 21cm line of Hydrogen

Neutral gas observations: the 21cm line

21cm line of Hydrogen: hyperfine transition due to the spin flip of the electron



Emitted spontaneously by Hydrogen atoms in the ground state

→ **direct tracer of neutral Hydrogen**

Neutral gas observations: the 21cm line

$$\theta \sim \frac{\lambda}{D}$$

Diffraction limit: need **large** telescopes

Single dish telescope

Interferometer

Neutral gas observations: the 21cm line

$\theta \sim \frac{\lambda}{D}$ Diffraction limit: need **large** telescopes

Single dish telescope

+ very sensitive

- limited in size

Interferometer

+ larger: better resolution

- less sensitive

- computationally expensive

Neutral gas observations: the 21cm line

$$\theta \sim \frac{\lambda}{D}$$

Diffraction limit: need **large** telescopes

Single dish telescope

Interferometer

Current 21cm observational limit for an individual source: $z_{max} = 0.376$

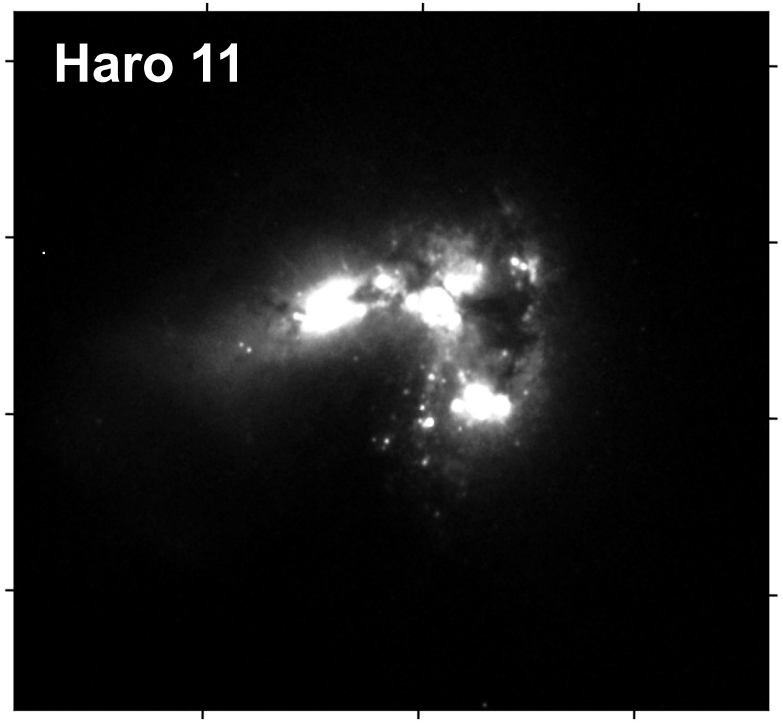
21cm observations of LyC-emitting galaxies

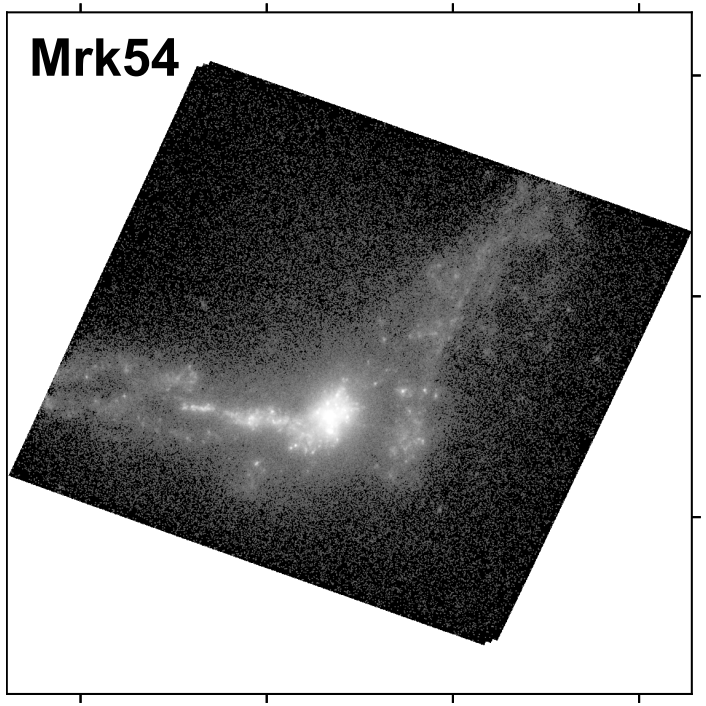
Problem: we cannot observe neutral gas of individual galaxies at the Epoch of Reionization.

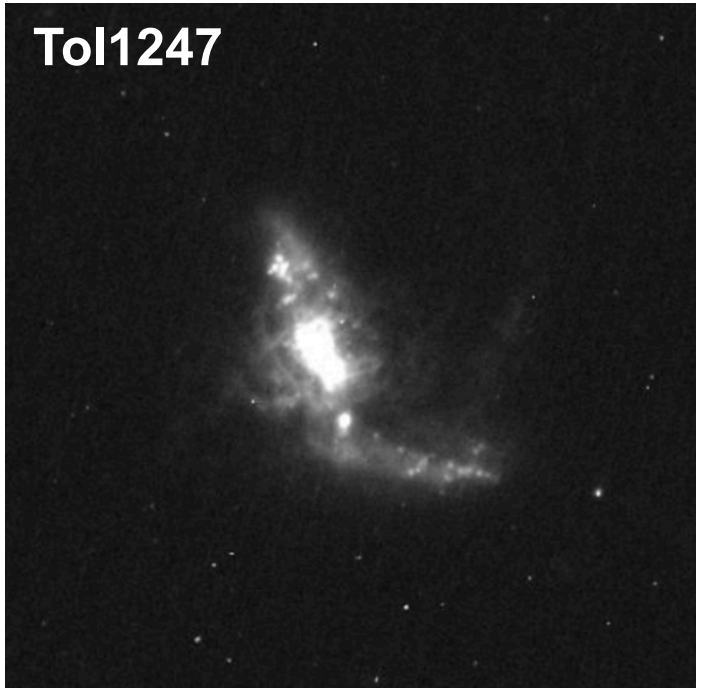
Solution: Observe nearby analog galaxies instead.

Local analogs to reionization-era objects

There are 3 galaxies with confirmed LyC detections within 1000 Mpc.

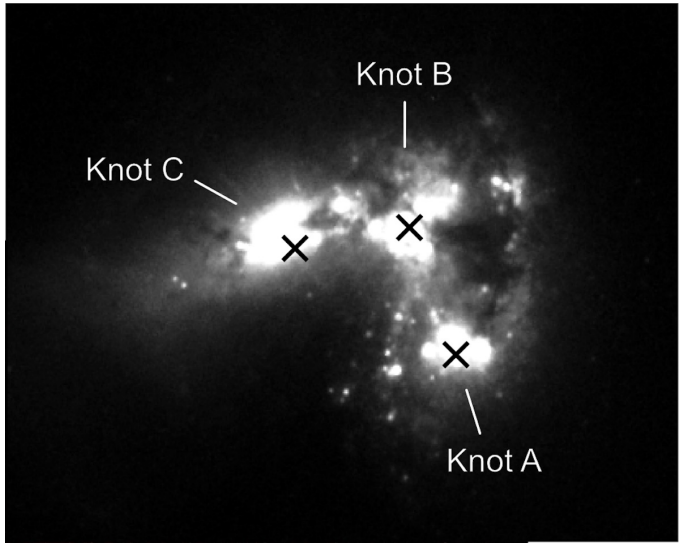


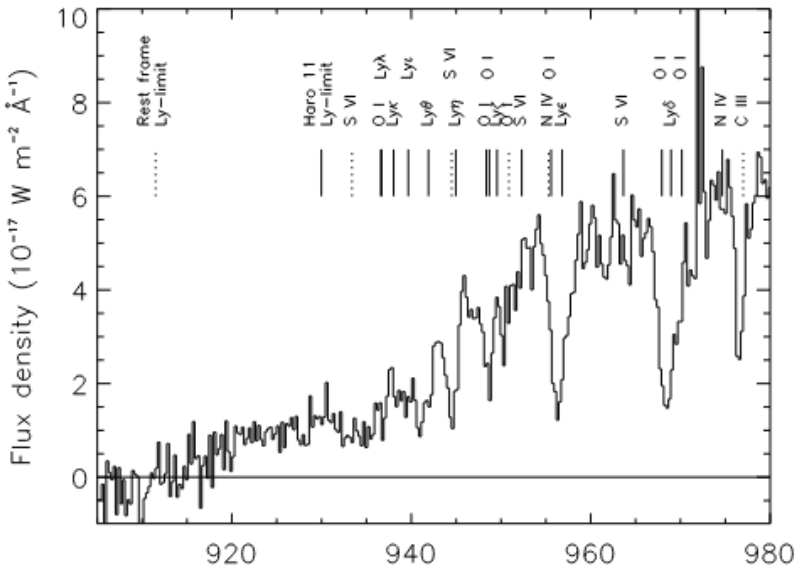




→ Potentially detectable in 21cm HI with interferometers.

Haro 11 : a special laboratory





- First and closest (z~0.02) LyC emitter to be detected (in Uppsala!)
- Blue compact galaxy
- SFR = 20-30 $M_\odot$/yr
- Escape fraction: 4-10%
- 12+ log O/H = 7.9
- $M_* = 1.6\times10^{10}\ M_\odot$

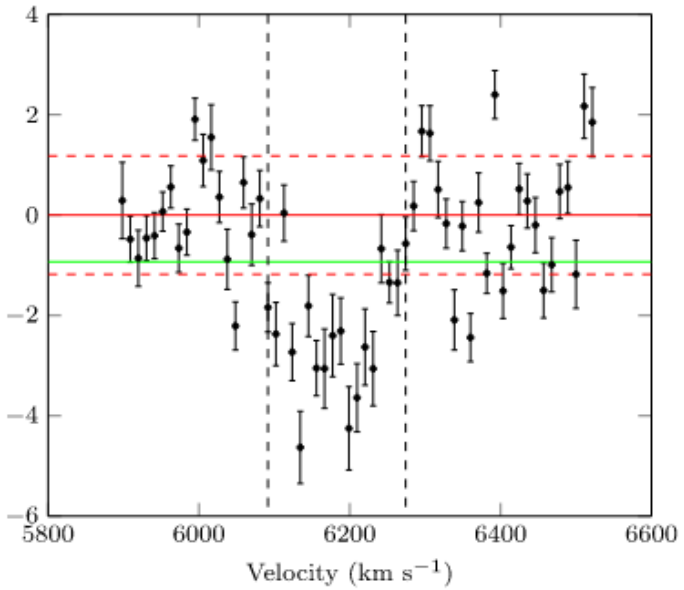
Bergvall et al. 2006

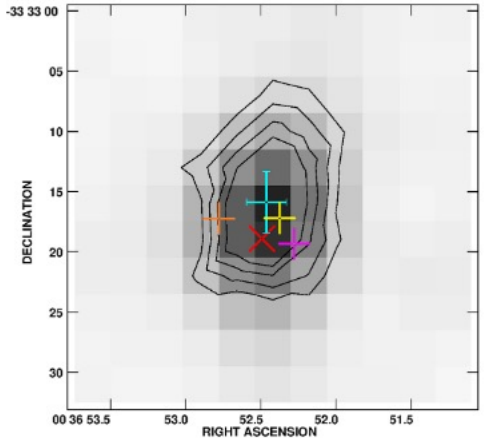
The Haro11 HI puzzle

2014MNRAS.438L..66M 2014/02 cited: 10

Detection of H I absorption in the dwarf galaxy Haro 11

MacHattie, Jeremy A.; Irwin, Judith A.; Madden, Suzanne C. *and*





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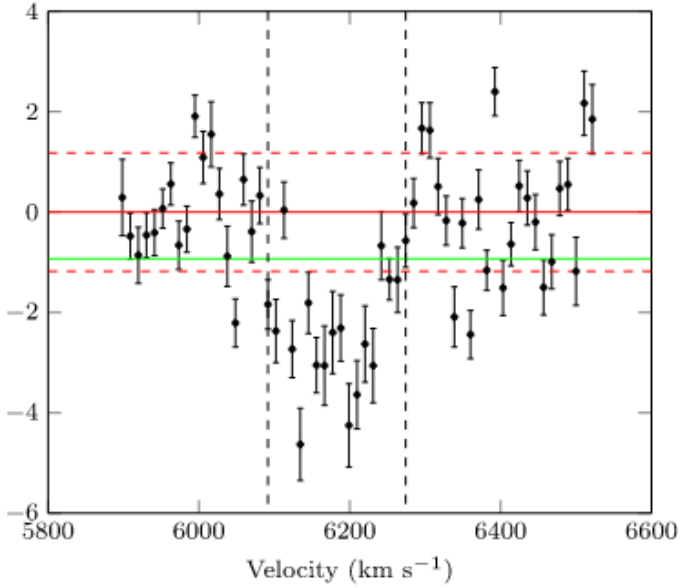
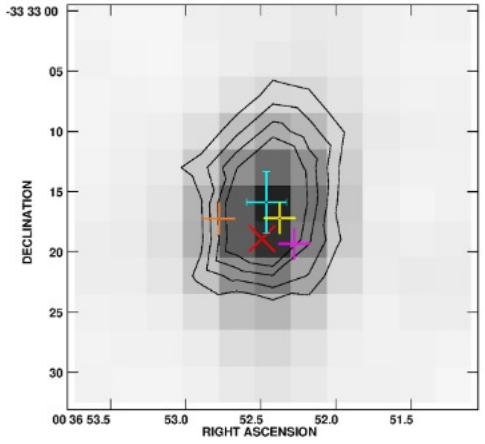
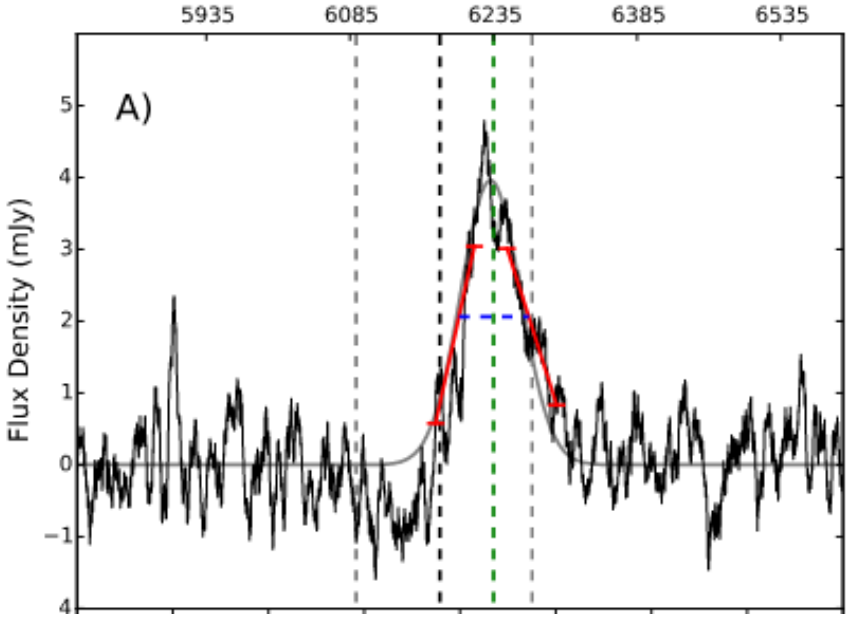




2016AJ....152..178P 2016/12 cited: 10

Detection of H I in Emission in the LYα Emitting Galaxy Haro 11

Pardy, Stephen A.; Cannon, John M.; Östlin, Göran *and 2 more*



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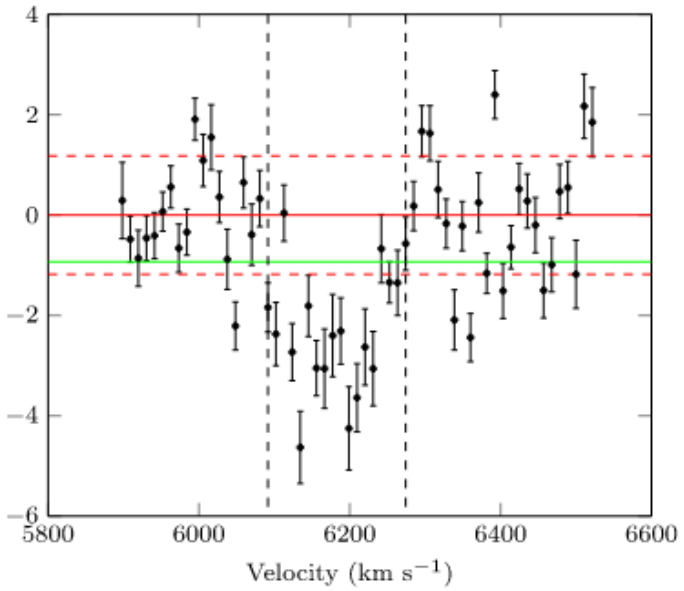

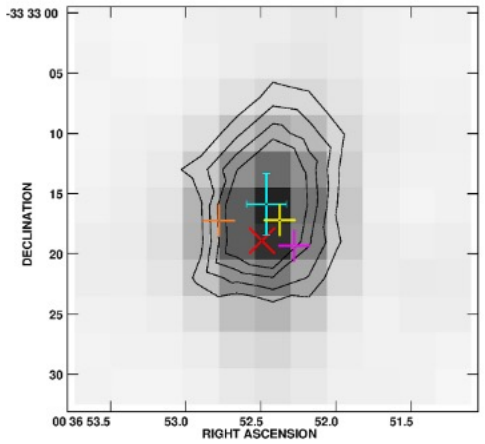

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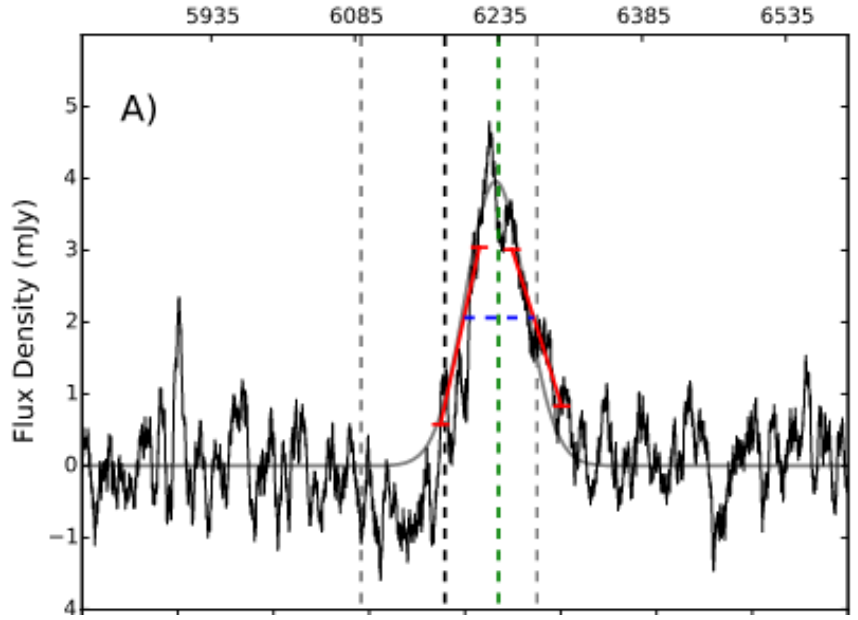
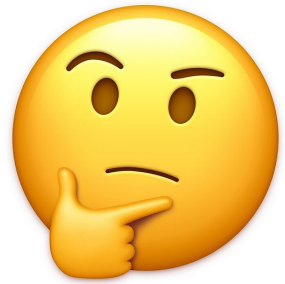
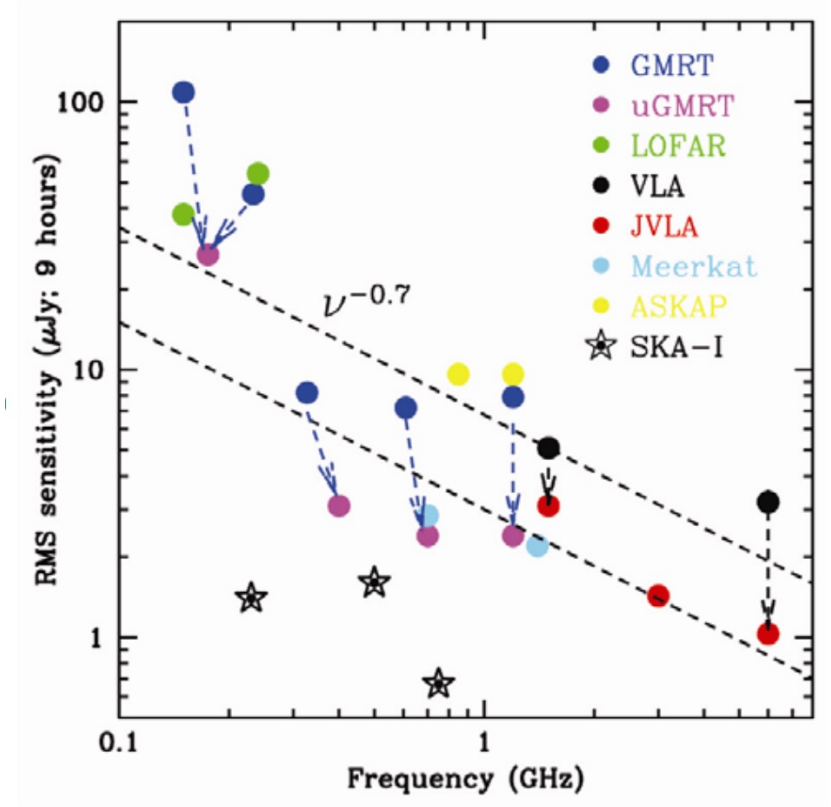




→ How can the 21cm output be so different?

21cm with the MeerKAT telescope



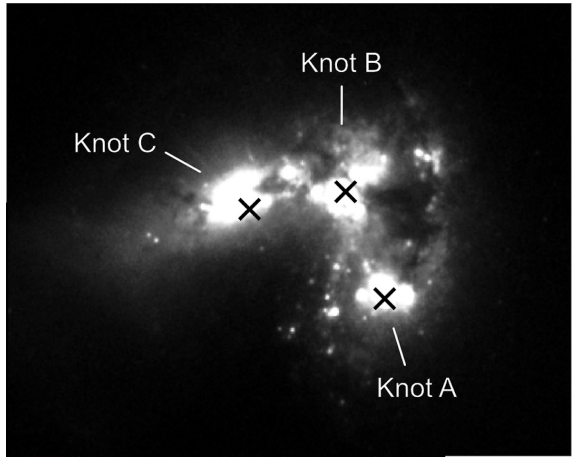
- ✓ The most sensitive telescope for HI studies
- ✓ In the south
- ? First international open call in 2020

21cm with the MeerKAT telescope

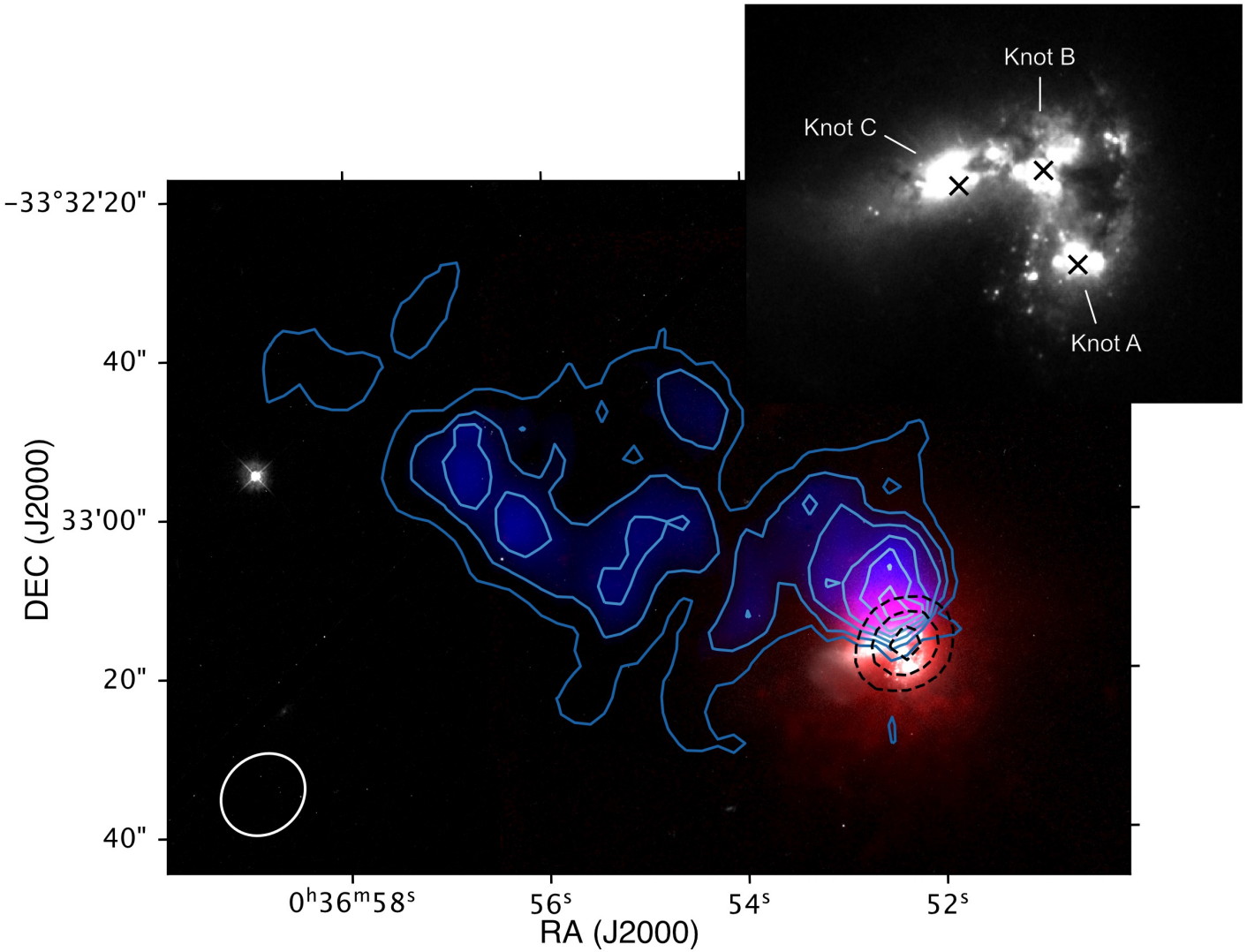
2020 Open Time Call accepted proposals

Proposal Title	Principal Investigator	Priority Group
Observing HI in the Reionization Epoch Analog Galaxy Haro11	Alexandra Le Reste	A

What is happening in Haro11 ?

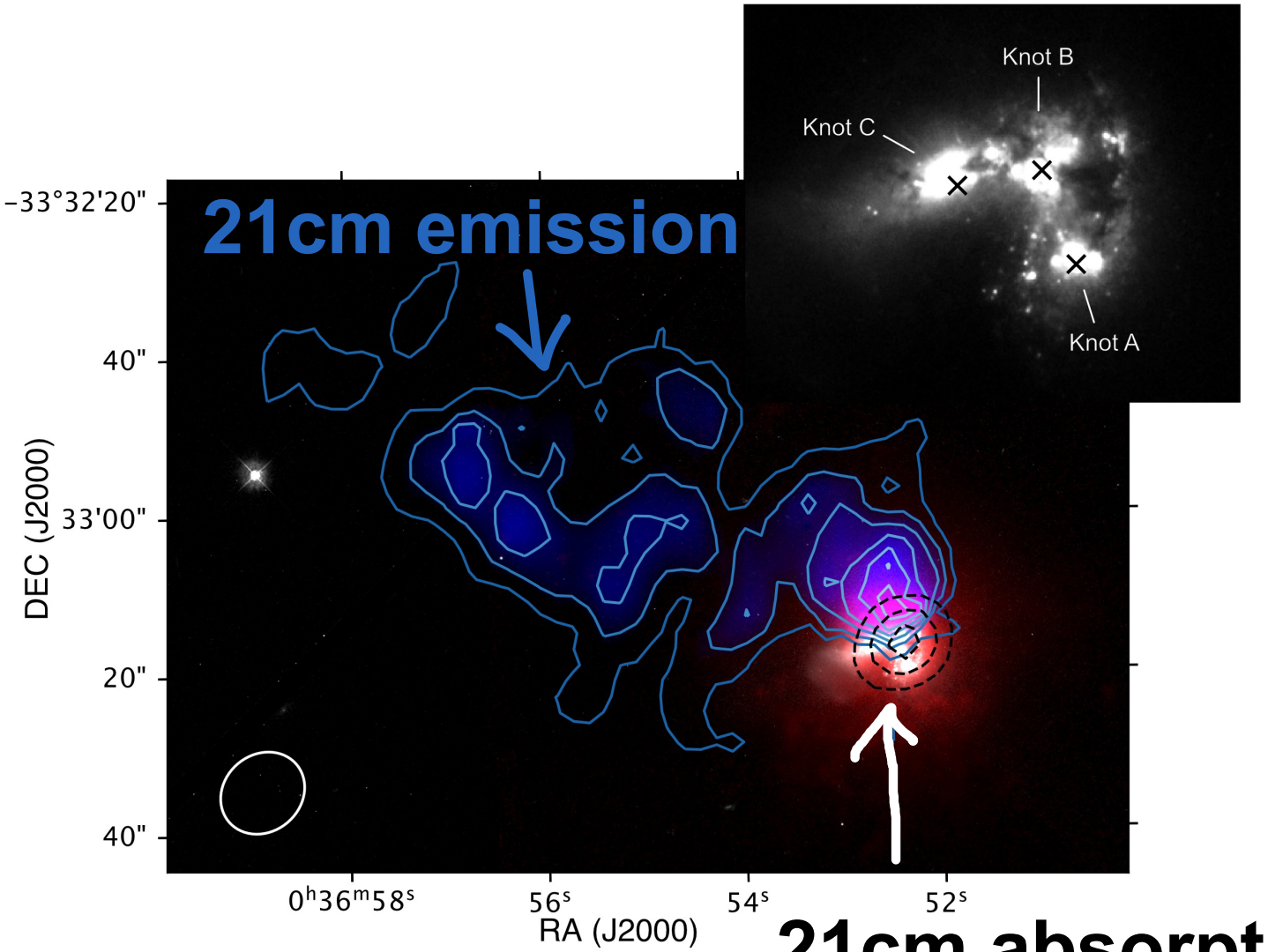


What is happening in Haro11 ?

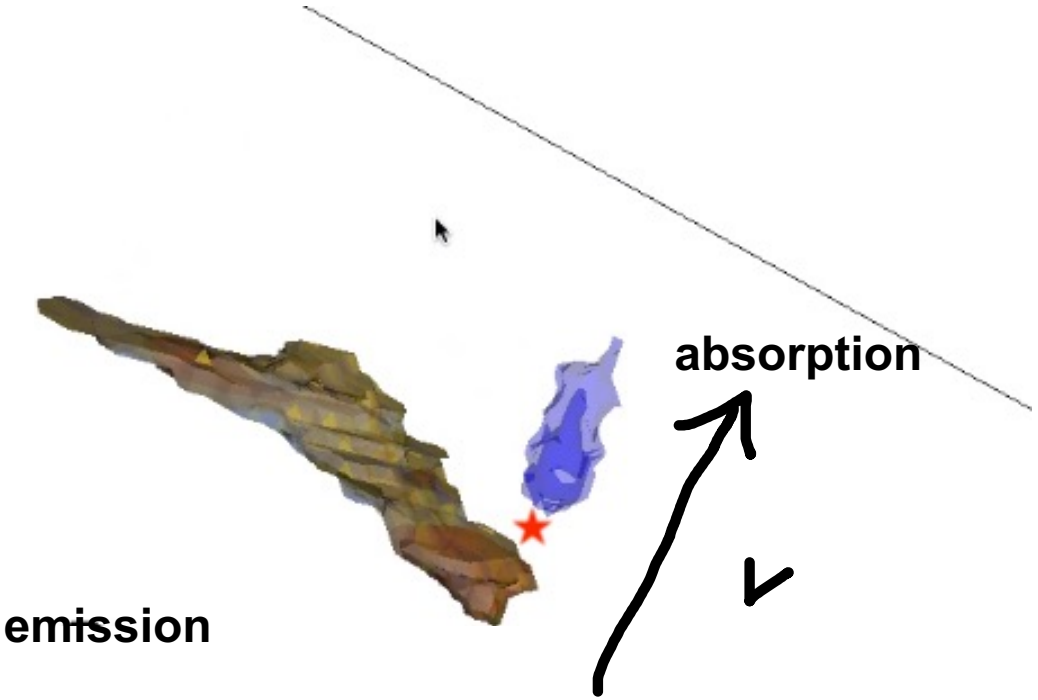


Le Reste et al. 2023, subm. to Nature Astronomy arXiV: 2301.02676

What is happening in Haro11 ?

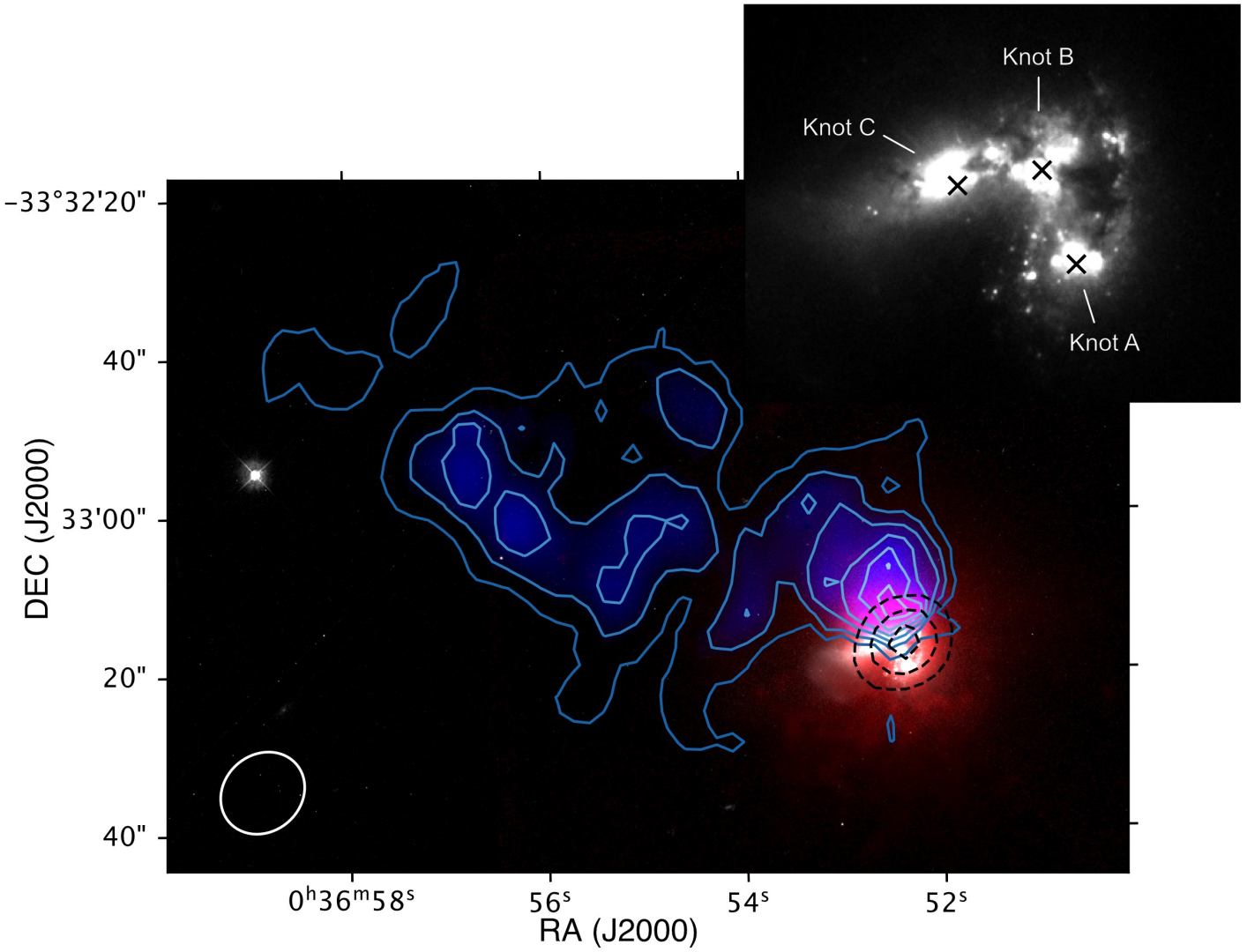


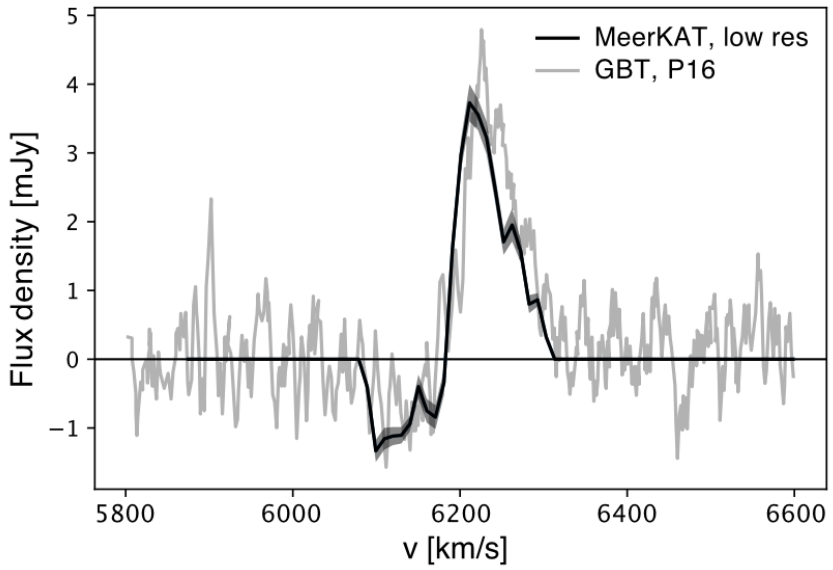
3D rendering tool:

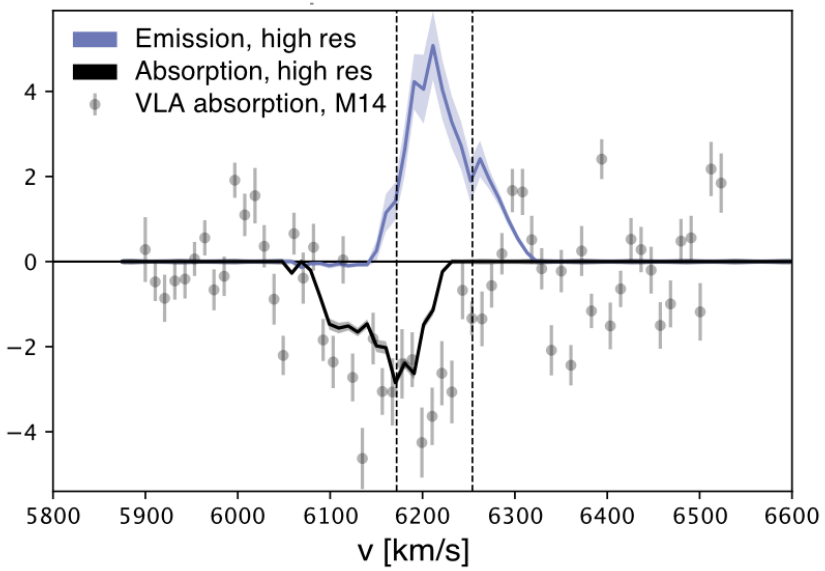


21cm absorption

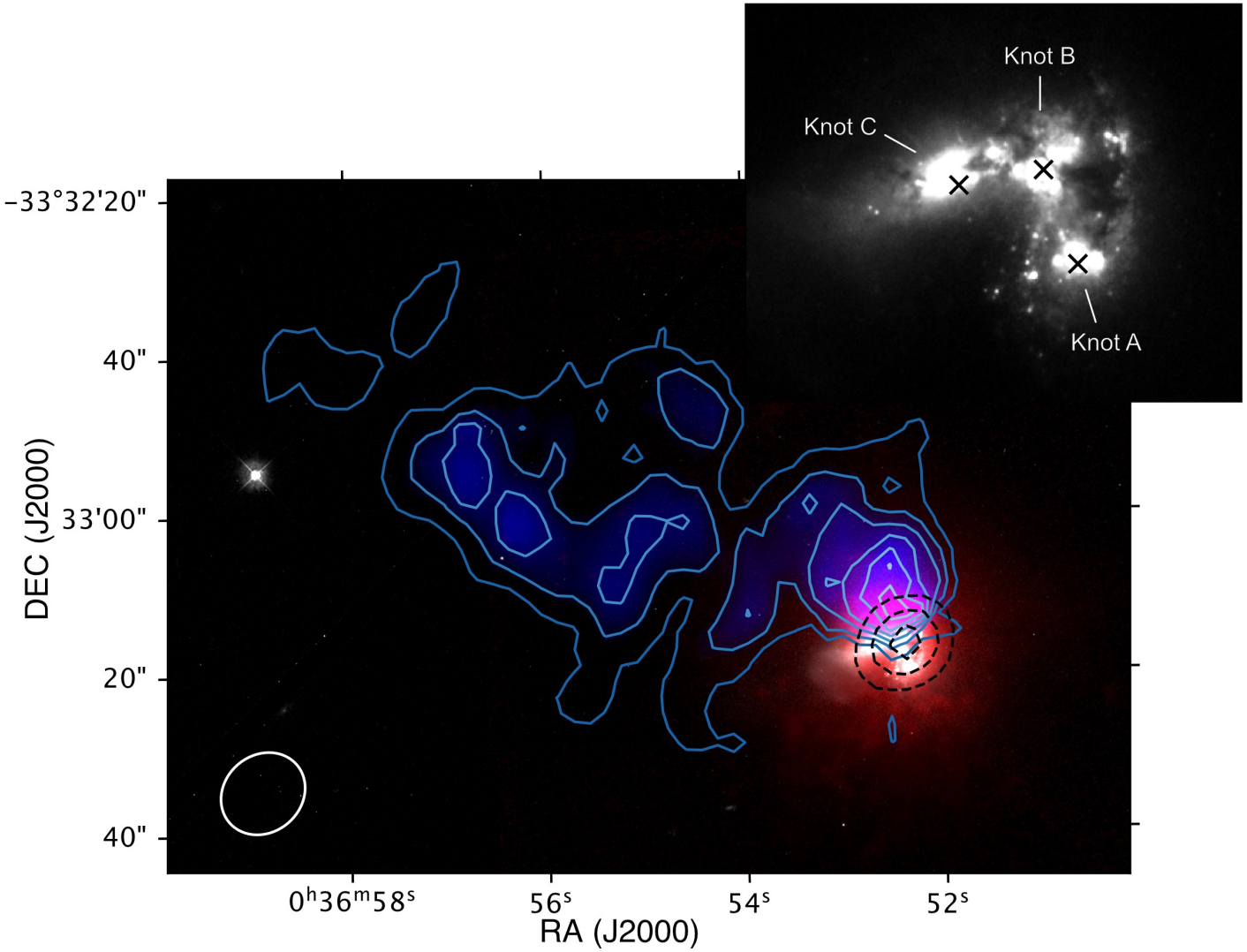
What is happening in Haro11 ?







Neutral gas content of the galaxy



Neutral gas mass:

$$M_{HI,em} = 7.99 \pm 0.85 \times 10^8 M_\odot$$
$$M_{HI,abs} = 3.30 \pm 2.41 \times 10^8 M_\odot$$

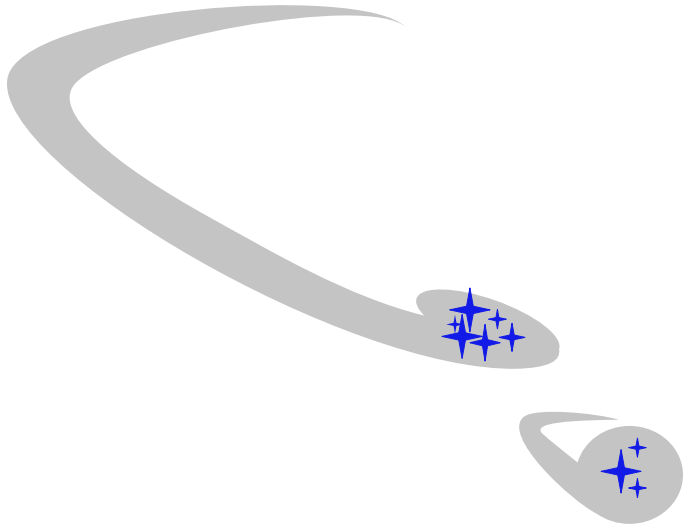
Total mass of $1.1 \pm 0.3 \times 10^9$ $M_\odot$

Up to 82% of the total gas mass is offset from the locations where LyC is produced

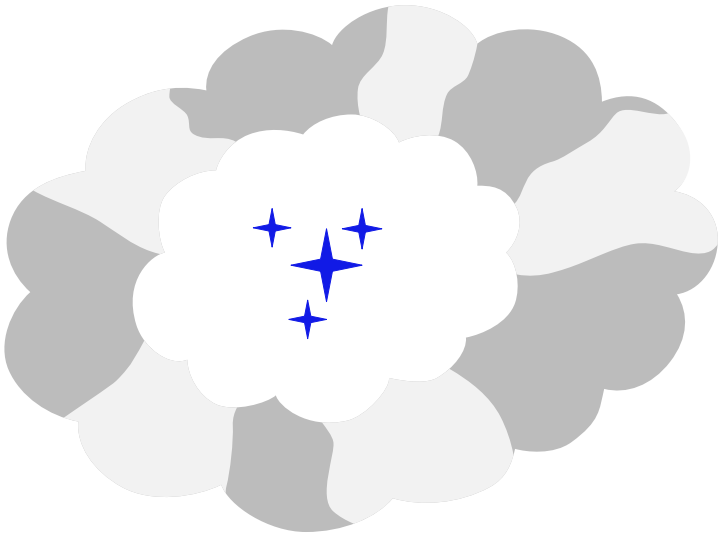
Geometry results from **merger interactions**

The role of the merger

The merger plays several roles in enabling LyC escape in Haro11:



1) Cause several starburst episodes:
Creates massive stars
→ LyC production



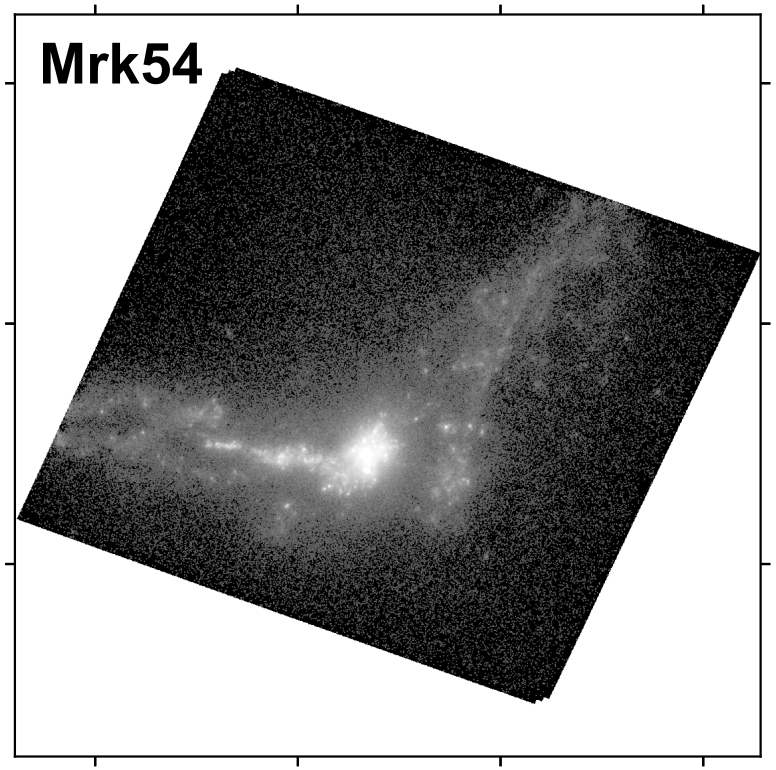
2) Starburst generates large-scale ionized channels

3) Large scale displacement of HI
→ anisotropic escape to IGM

Mergers and LyC escape

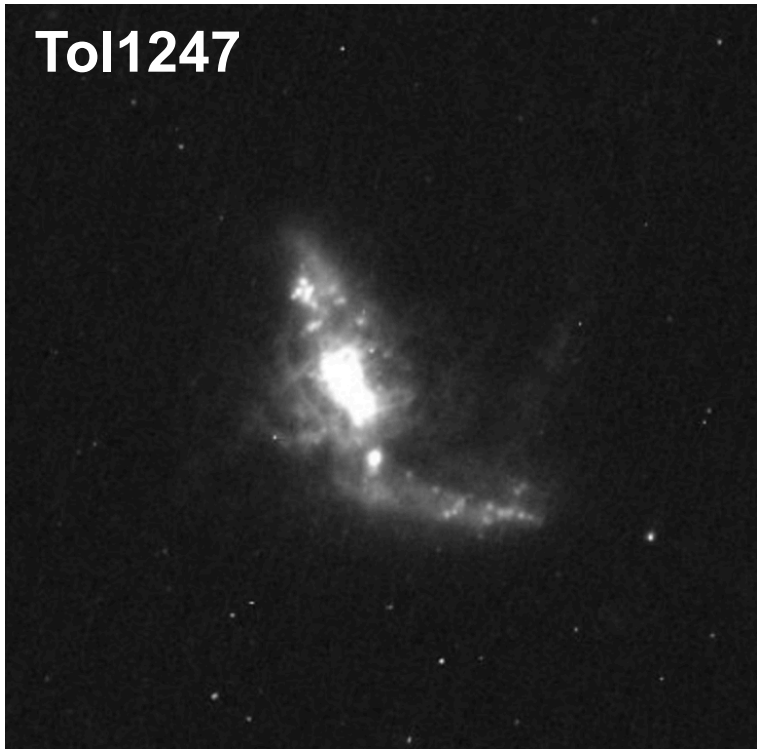
Are mergers a characteristic process for ionizing radiation to escape the interstellar medium of galaxies?

Local LyC emitters



$M_{HI} = 1.58{\times}10^{10}\ M_{\odot}$

Haynes et al. 2018

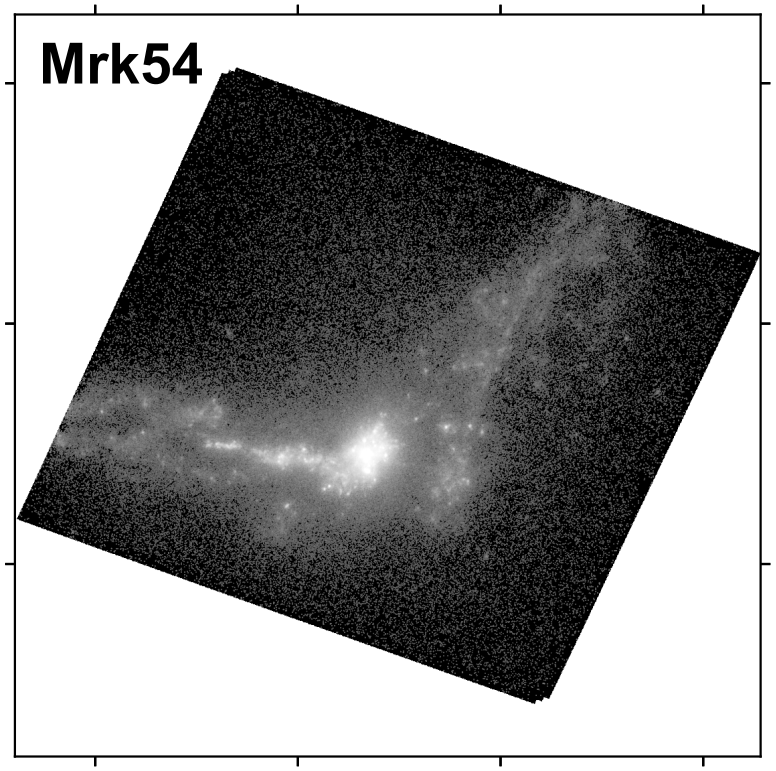


Undetected, $M_{HI} < 10^{9}\ M_{\odot}$

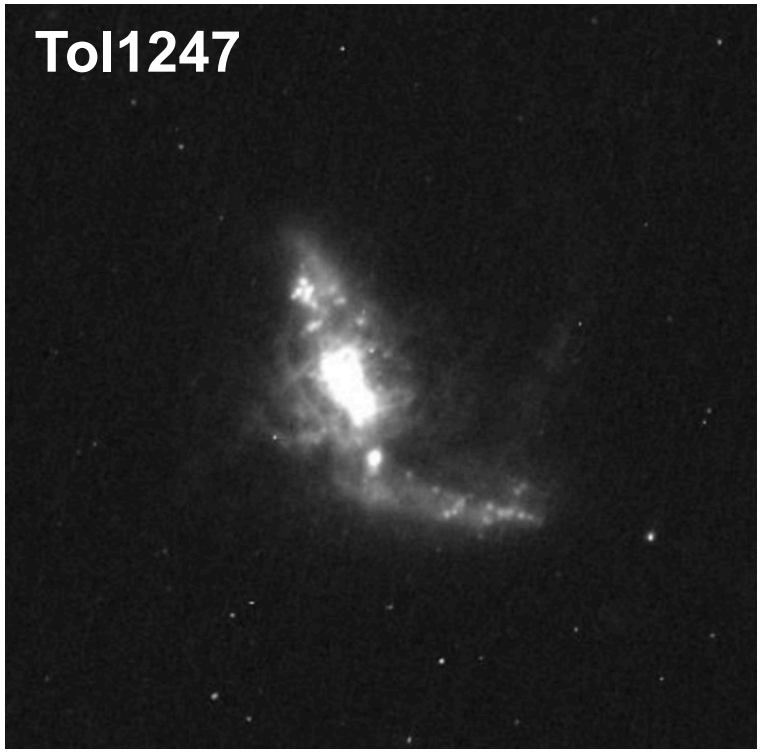
Puschnig et al. 2017

Clear merger morphology → neutral gas distribution?

Local LyC emitter



observed with the VLA in C configuration in 2022
will be observed with B configuration in 2023



MeerKAT proposal to be submitted soon

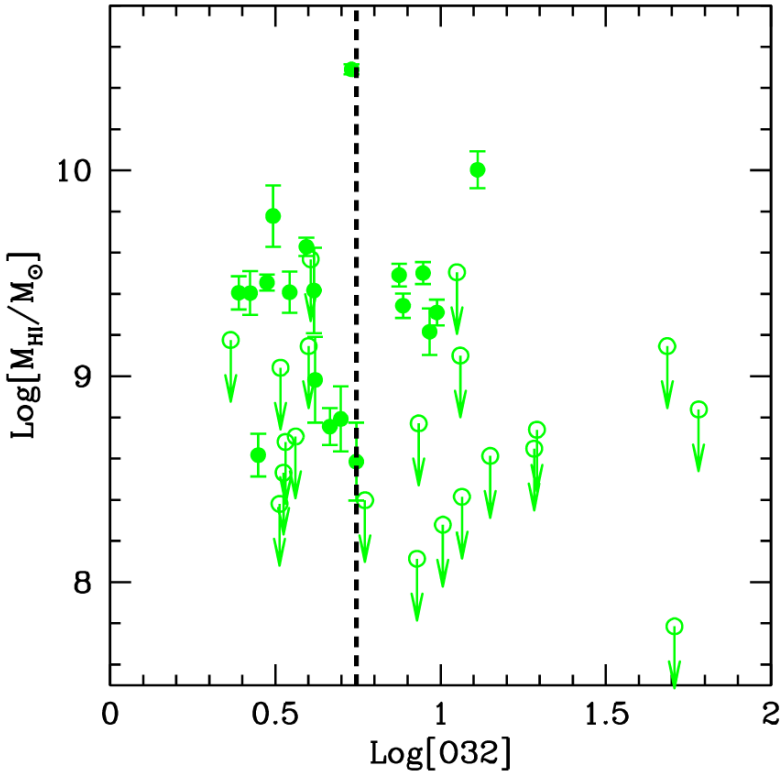
Mergers and LyC escape

Green pea galaxies

Cardamone 2009

Analogs to high-redshift galaxies

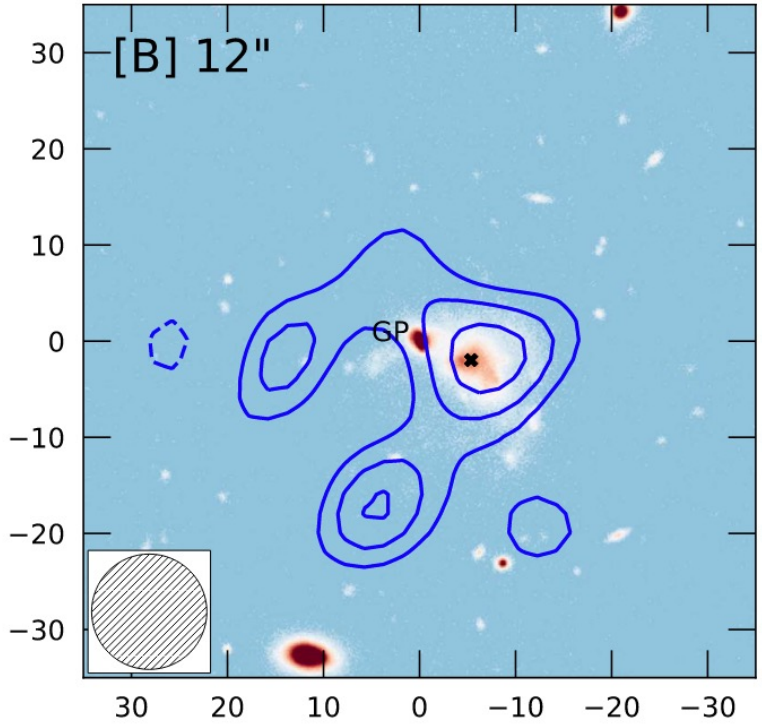
Unresolved HI observations:



Kanekar 2021

Detect 19/44 galaxies
22% have HI properties indicating merger

One resolved HI observation:



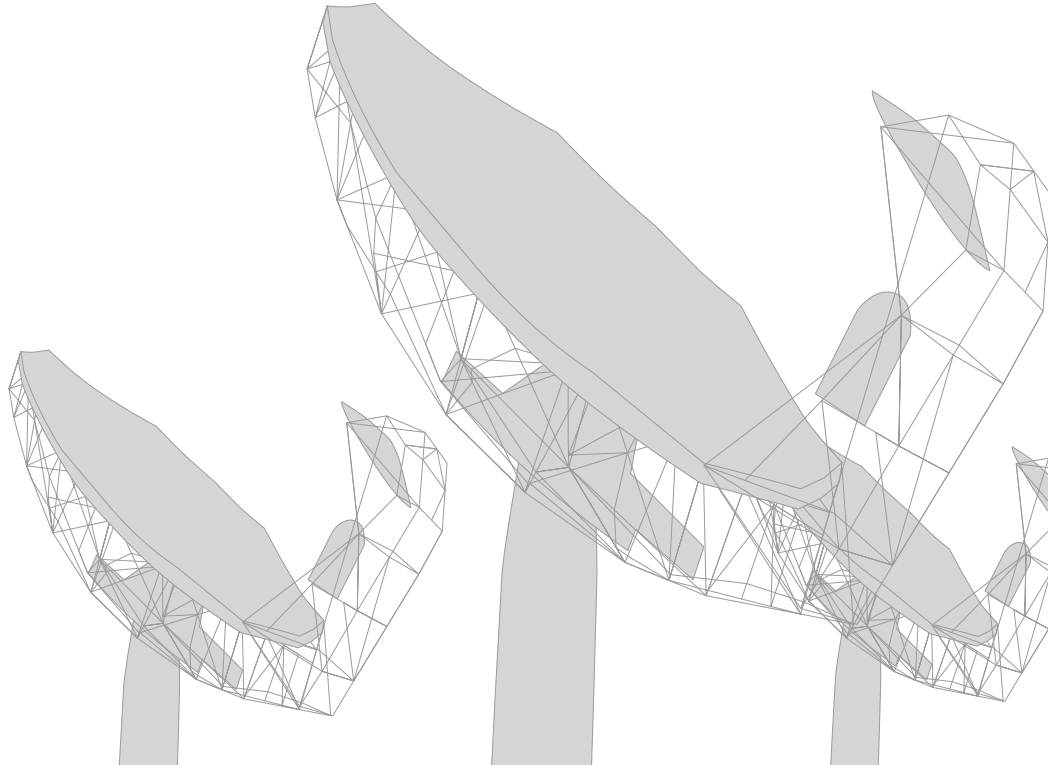
Purkayastha et al. 2022

Merger facilitates Lyα escape.

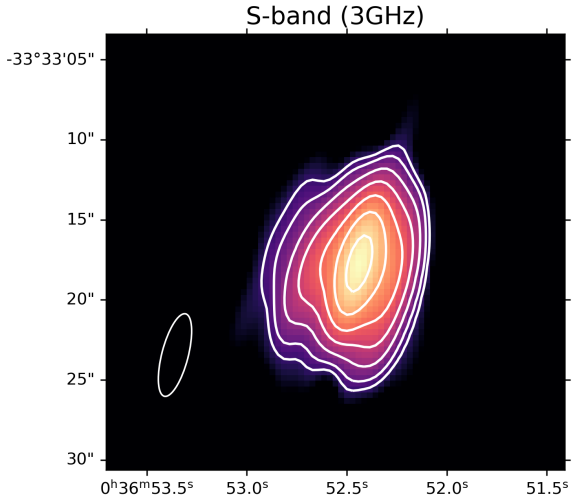
Conclusions

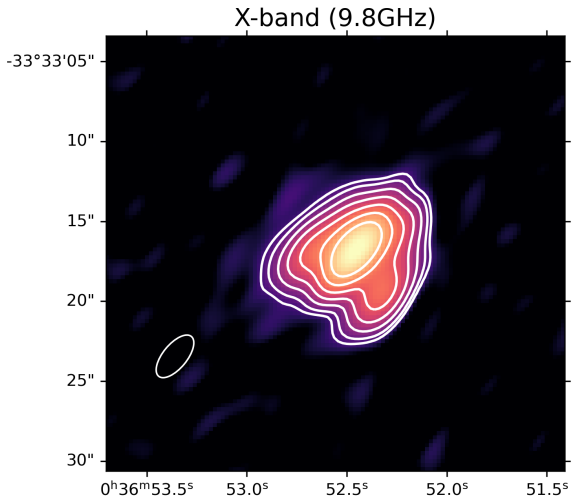
- High-redshift analogs: detailed observations of physical and radiative processes
- First direct HI imaging in a confirmed LyC emitting galaxy, Haro11
- The neutral gas is offset due to merger interactions
- Mergers of galaxies/environment could contribute to reionization:
  → **Need systematic assessment of the impact of environment.**

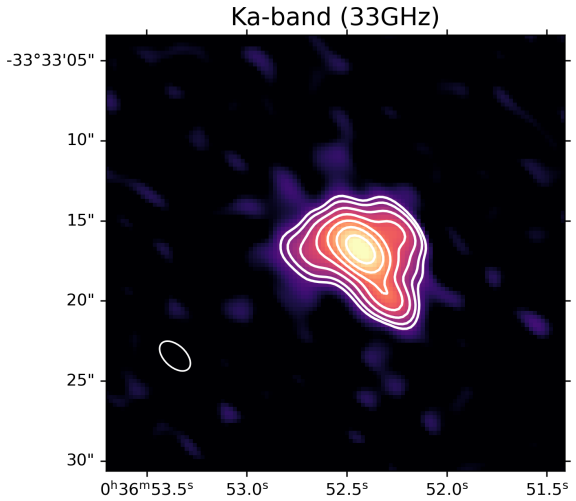
Thank you for your attention !

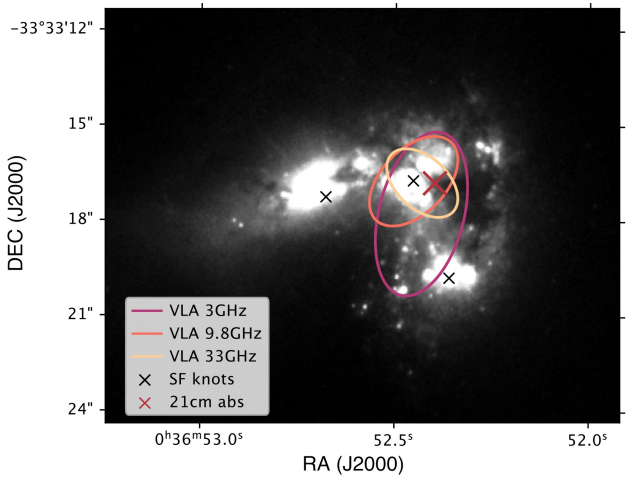


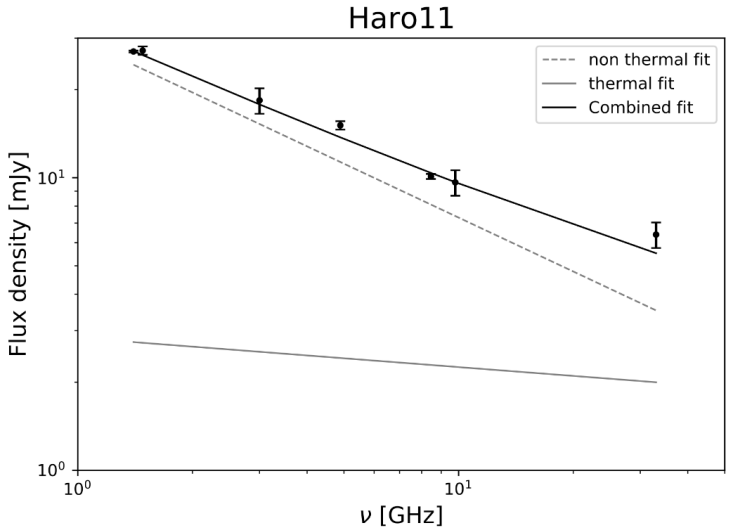
Radio continuum source

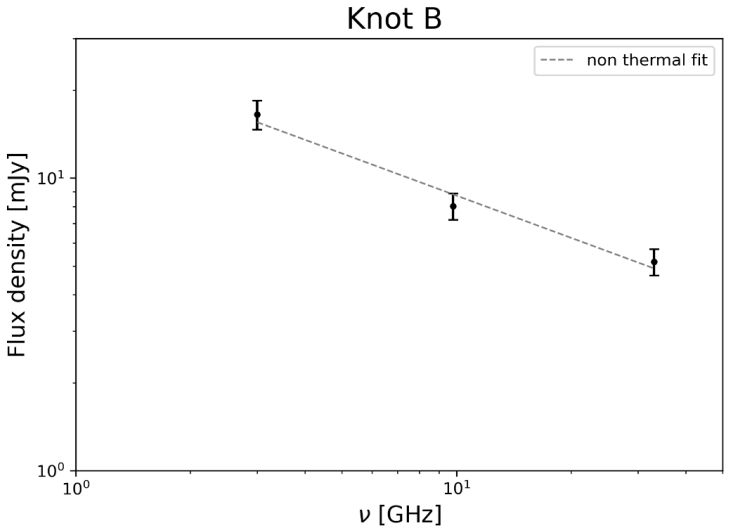


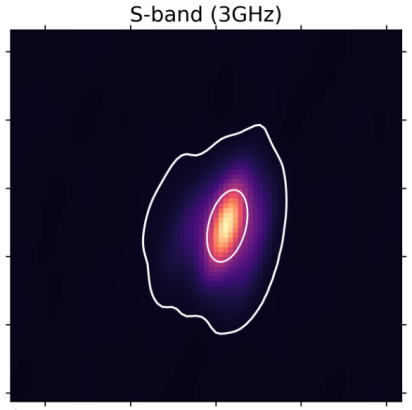


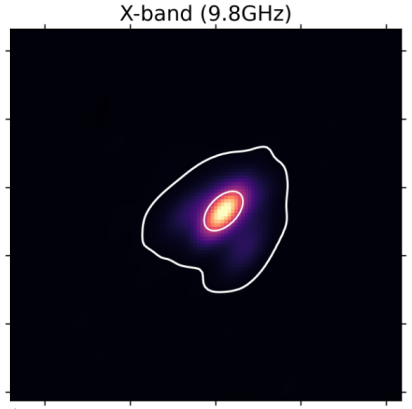


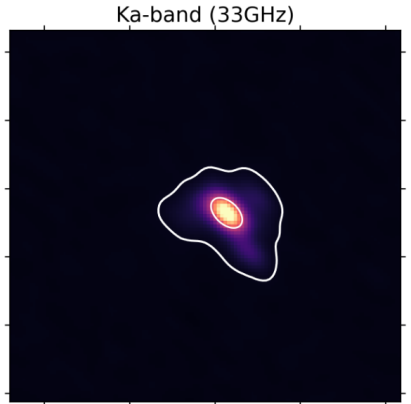




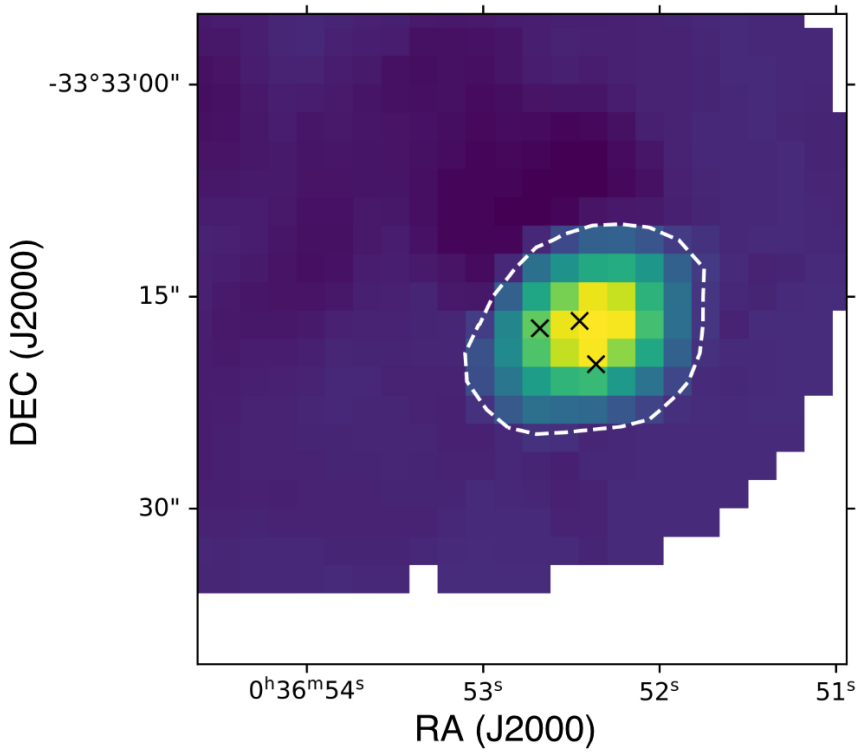


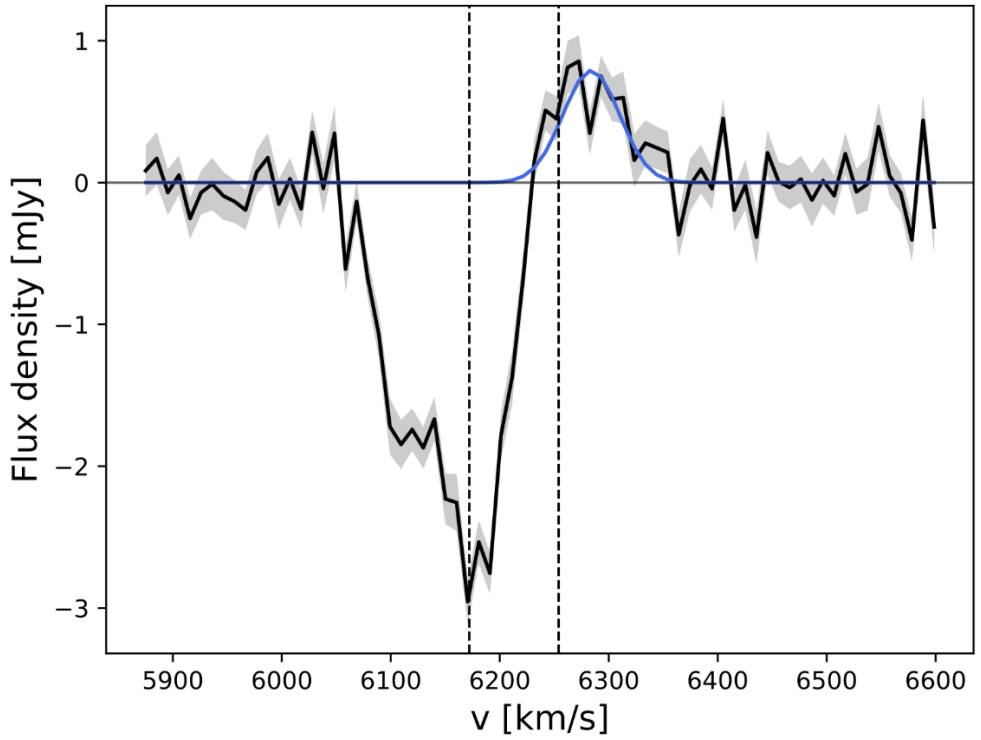




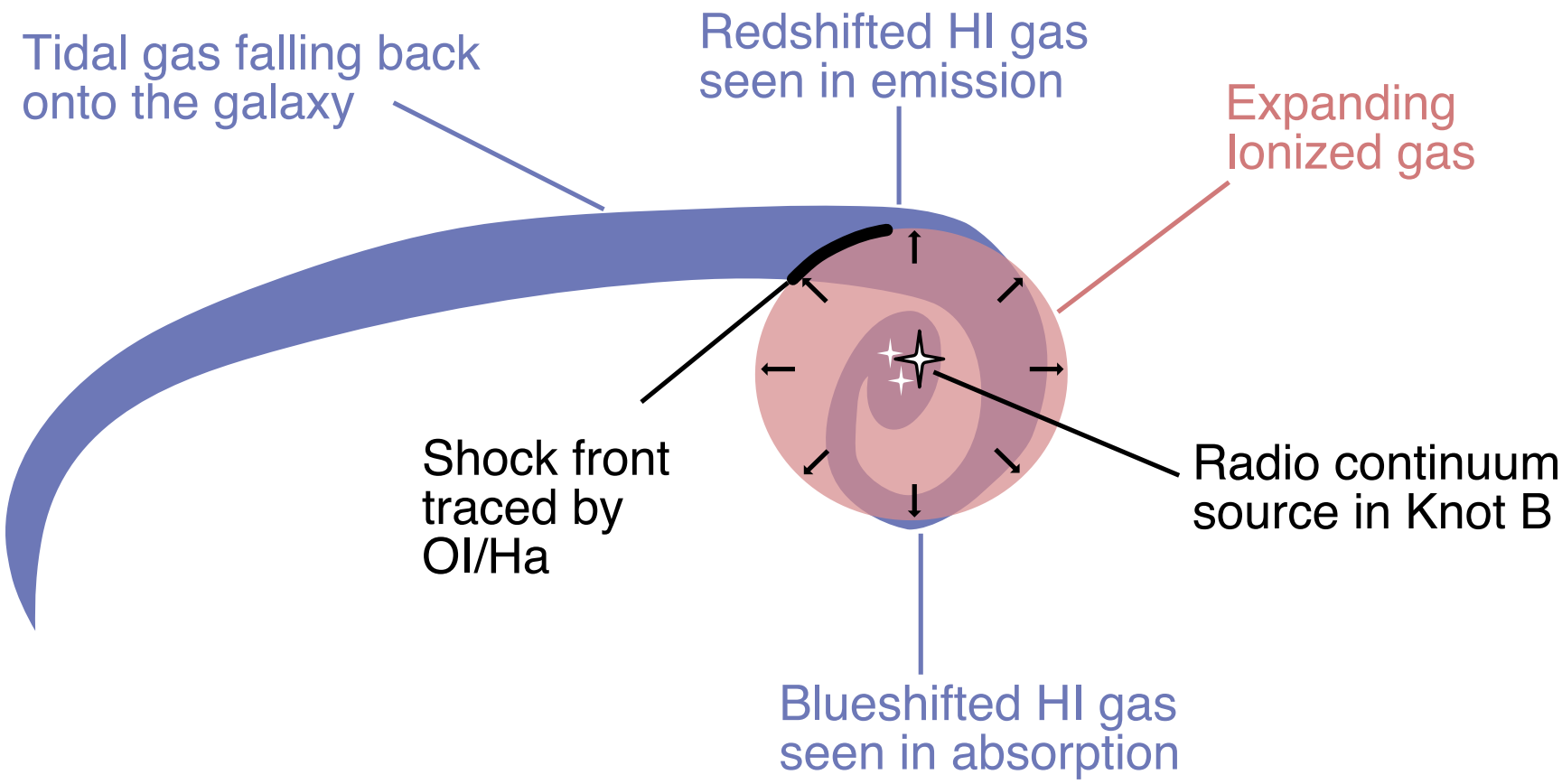


Neutral gas at absorption location





Interstellar medium of Haro11 - a model



Ionized gas structure