# ALMA and MUSE Reveal Gas-rich Galaxy Group Connected to a Lyman Alpha Absorber

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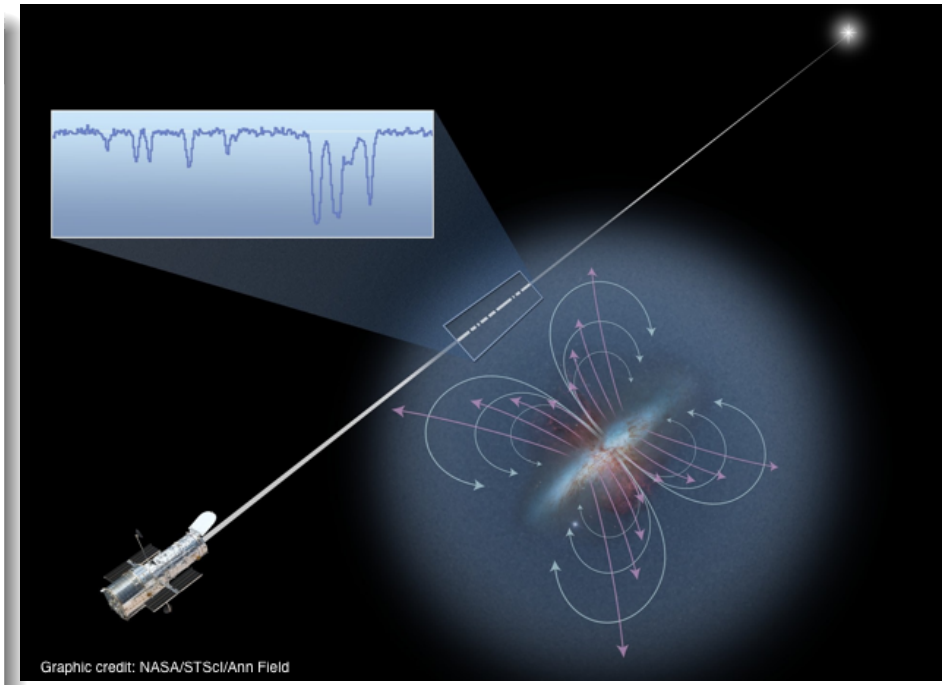
# Introduction

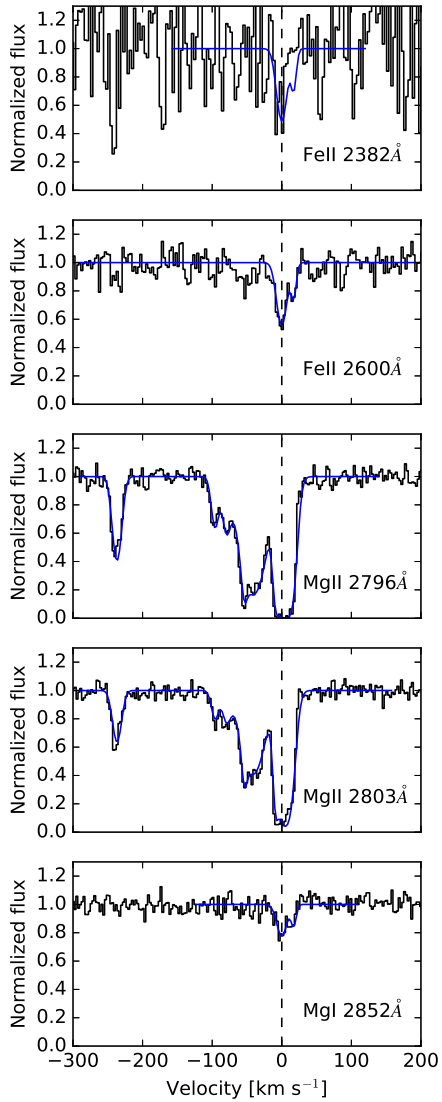
## Our Tools and Aims

- Use intervening absorbers to study the CGM.
- Study the multiphase ISM and CGM of the connected galaxies (neutral, ionized and molecular gas)
- Understand the flow of bayons into and out of galaxies



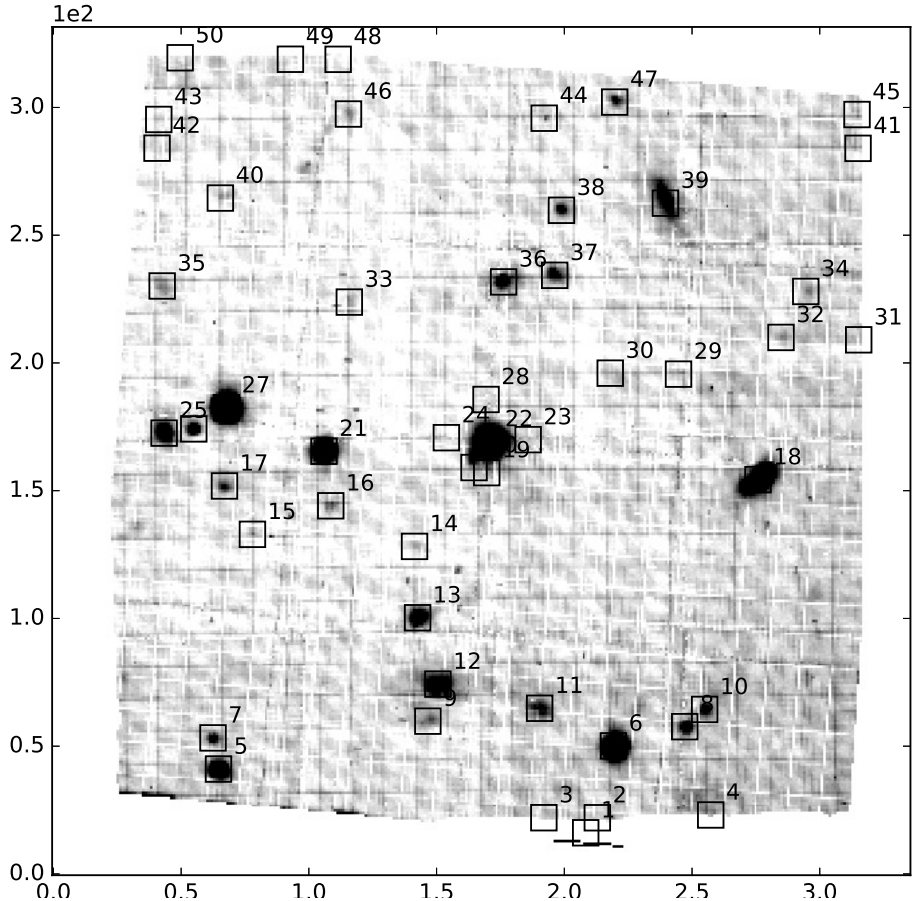
# The Neutral Gas Probed in Absorption

- LLS at $z = 0.633$, [Fe/H] = -1.16
- Complex structure, multiple absorbing clouds in MgII
- Studied by several groups before (Yanny et al. 1990, Yanny & York 1992, Rao et al. 2006, 2010) **BUT** no consensus on the origin of the absorption



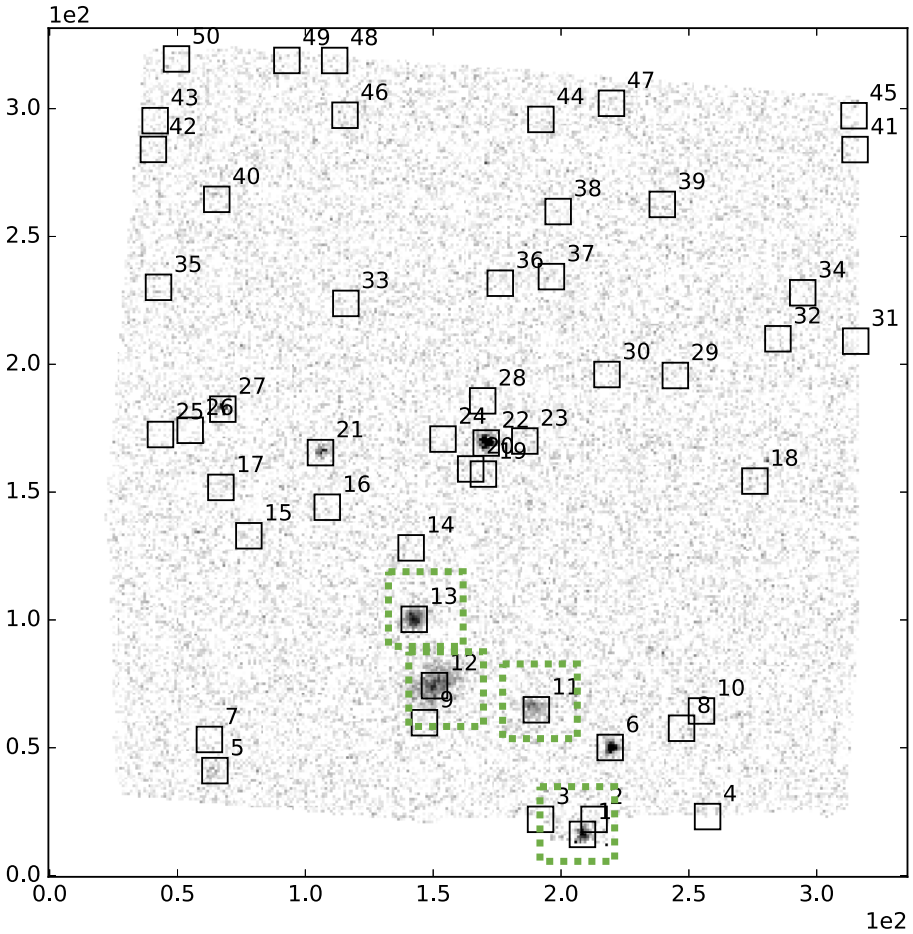
# The Ionized Gas Probed With MUSE

- 2h MUSE DDT observation time (observed Dec. 2016)
- Source finding with MUSELET



# The Ionized Gas Probed With MUSE

- Identify 4 galaxies at the absorber redshift
- Gal 13, 11, 1: $M_\star \sim 10^{10.3} M_\odot$, SFR $\sim 1\ M_\odot/yr$
- Gal 12: $M_\star \sim 10^{11.2} M_\odot$, SFR $\sim 3\ M_\odot/yr$
- Super solar metallicity



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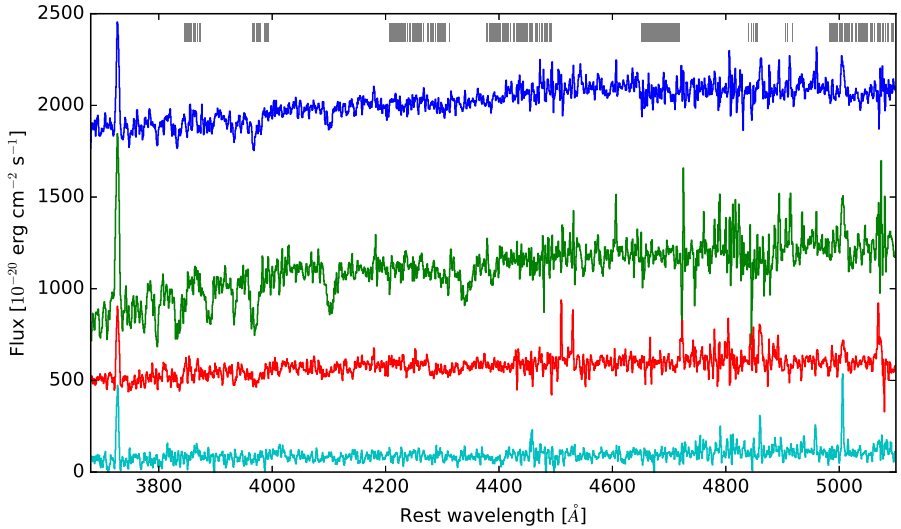
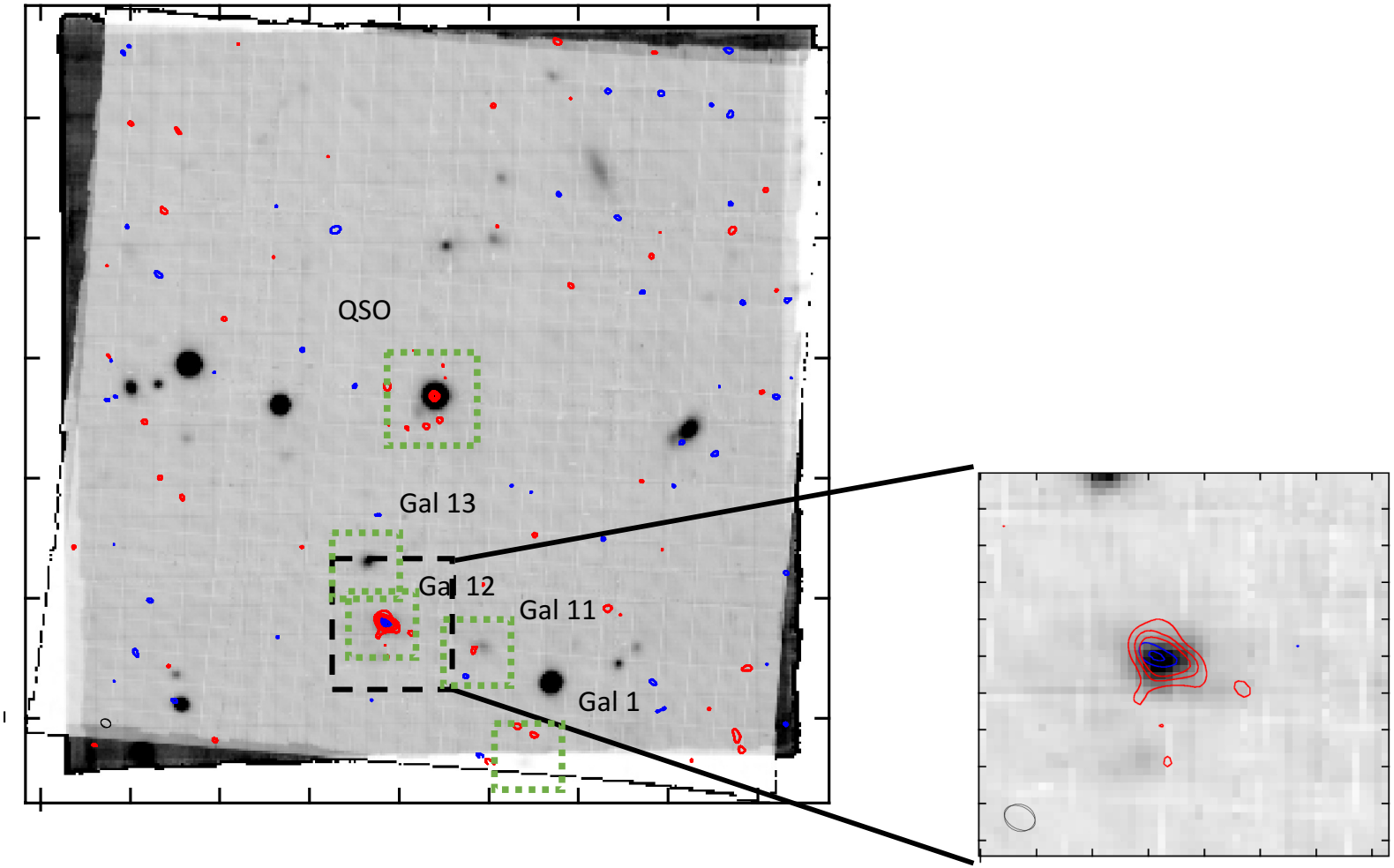


# The Molecular Gas Probed With ALMA

## Detection of CO(2-1) and CO(3-2)



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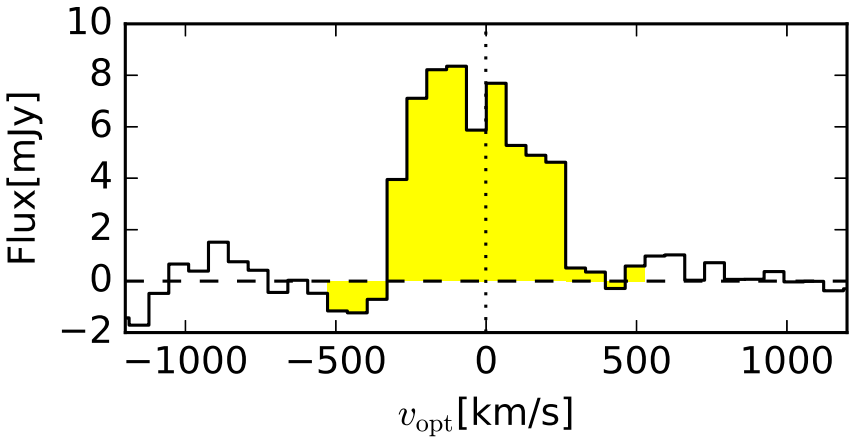
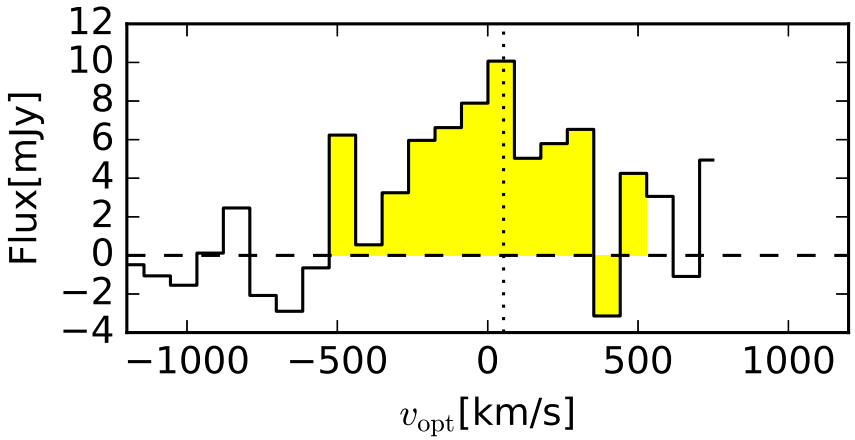
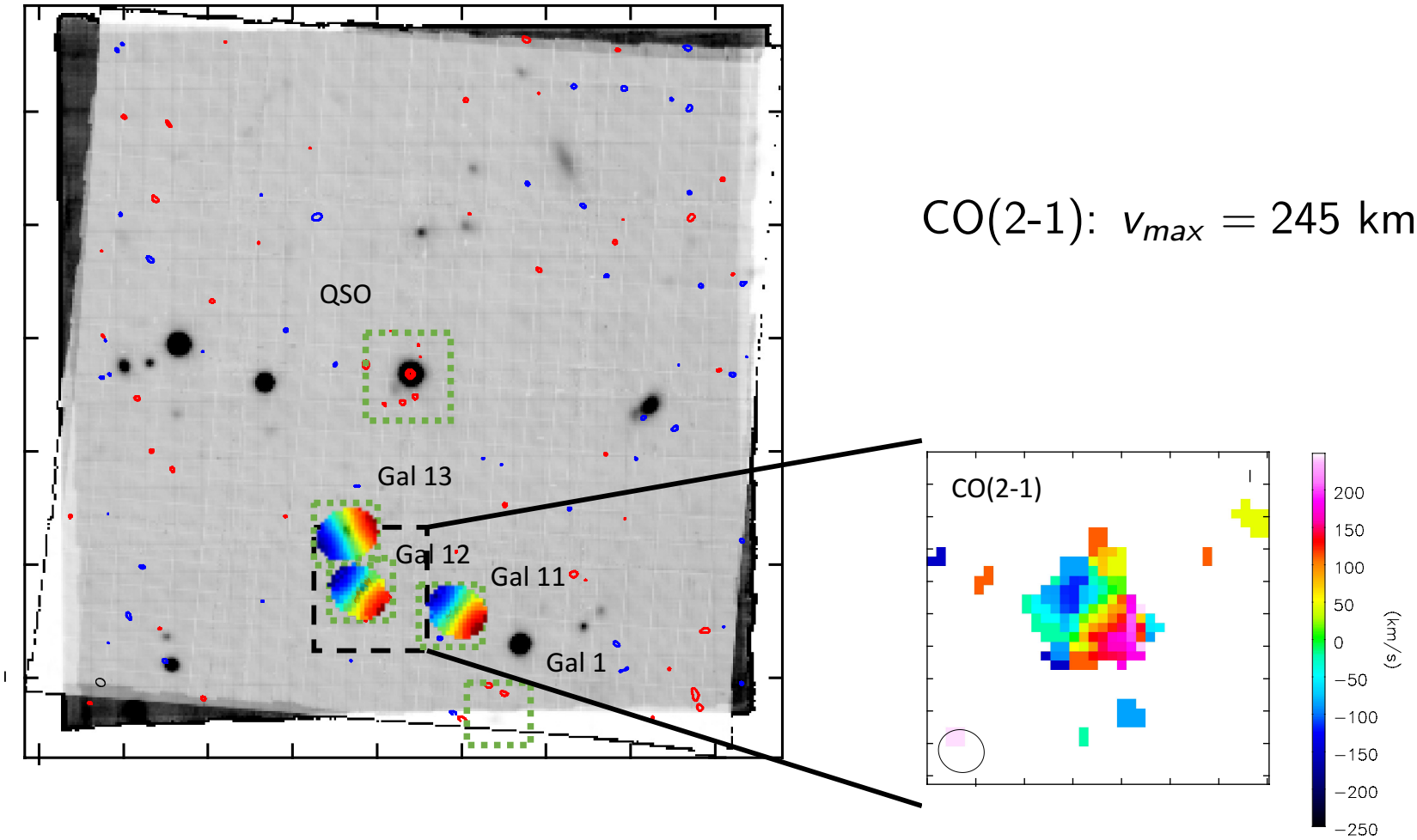



- Line width: $w_{50} \sim 600$ km/s
- Emission line ratio suggest LIRG-type ISM conditions.
- Molecular gas mass: $M_{H2} = 1.3 \times 10^{10}$ $M_\odot$

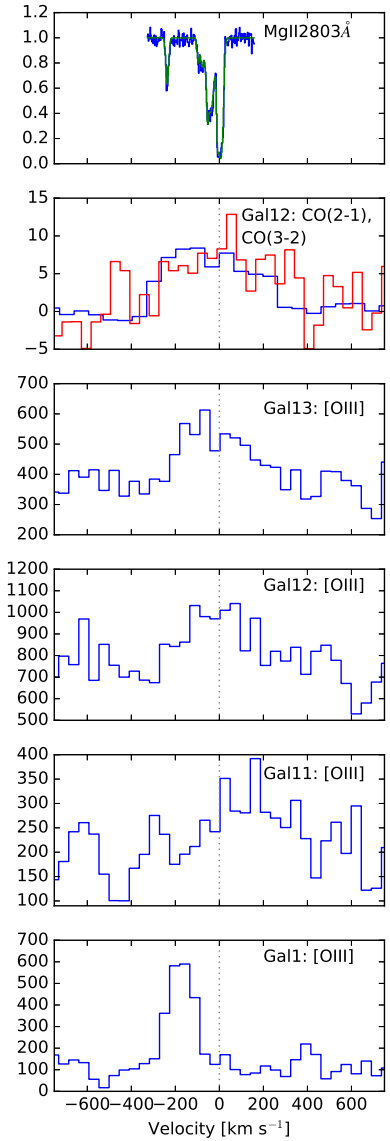
# Kinematics of the Ionized and Molecular Gas




CO(2-1): $v_{max} = 245$ km/s

# What is the Nature of the Gas?

All components of the group are aligned in velocity space!



# What is the Nature of the Gas?

## Are we missing something?

- Large impact parameter of >100 kpc
- Limiting SFR: 0.2 $M_\odot$/yr

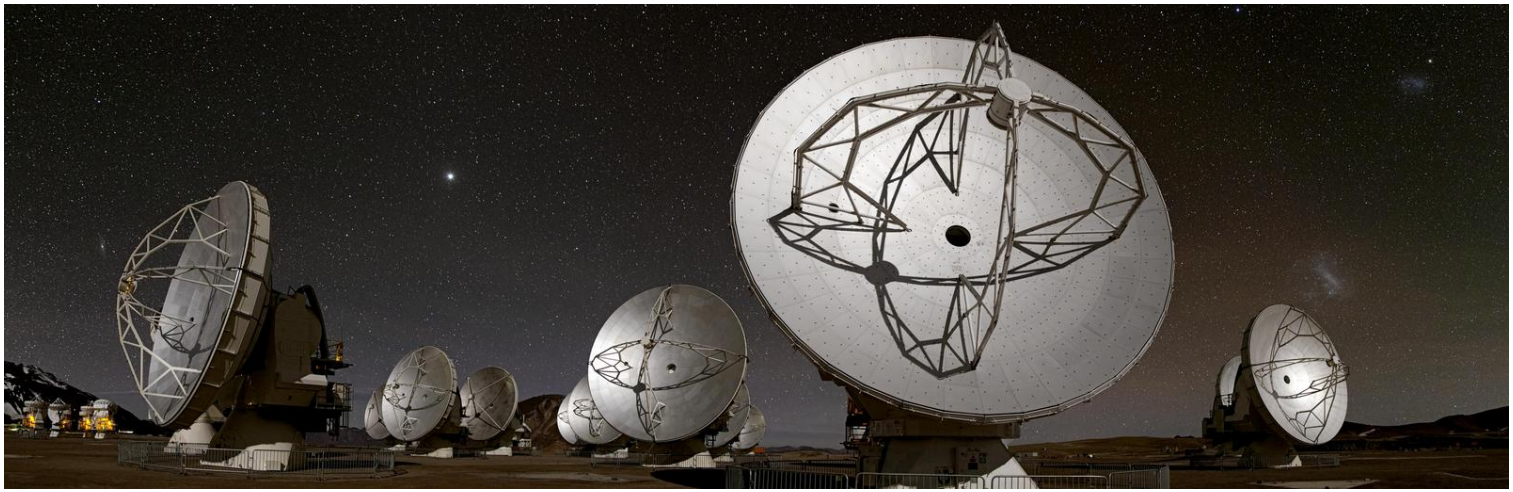
## Could it be outflow?

- Assuming an outflow speed of **300km/s** it takes $\sim$ **440 Myr** to get there.
- Aligned with the minor axis.
- How can the gas be kept cool? Is it cooling at larger distances?

## Is it intra-group gas?

- 130 kpc is within the quoted range of the CGM extent in groups.
- Whiting et al. 2006, Péroux et al. 2017, Bielby et al. 2017 and others find quasar absorbers associated with intra-group gas.

# ALMACAL



- Unique (sub)mm archival survey carried out by utilizing ALMA calibrator observations.
- Up until today $\sim$ 600 quasar fields observed.
- Frequency setup depends on the science observations.
- Cross match with known absorbers to search for CO emission from connected galaxies.
- Up until now seven detections for six known absorbers.

# Conclusions

- Combining observations of the ionized gas with MUSE and the molecular gas with ALMA in **galaxies connected to Ly$\alpha$ absorbers** offers a powerful tool to probe the **conditions of star formation** within these galaxies.
- In this system we find **four massive galaxies** at the absorber redshift offering further evidence that the classical picture of one galaxy being responsible for the absorption needs to be revised.
- We find one galaxy with a **large reservoir of molecular gas** and the line ratio indicates **LIRG-type ISM conditions**.
- The gas seen in absorption could either be tracing an **outflow** or **intra-group gas**.
- With the new ALMACAL survey, there is more to come!