

Does gas in the IGM care about galaxies?

Tracing the Circumgalactic Medium in Ly α with COS

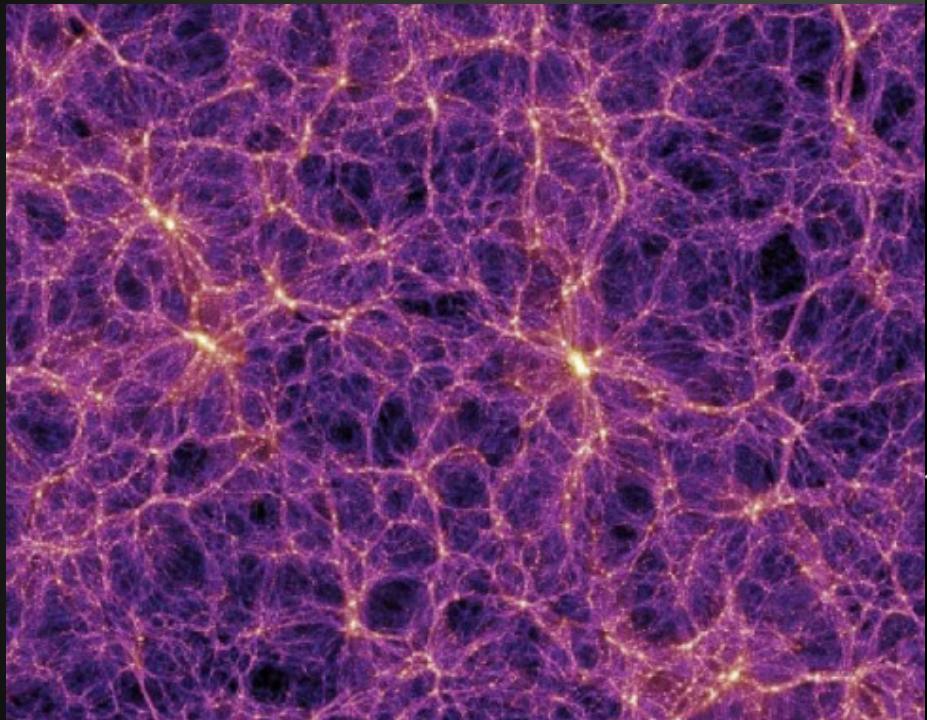
David M. French

University of Wisconsin - Madison

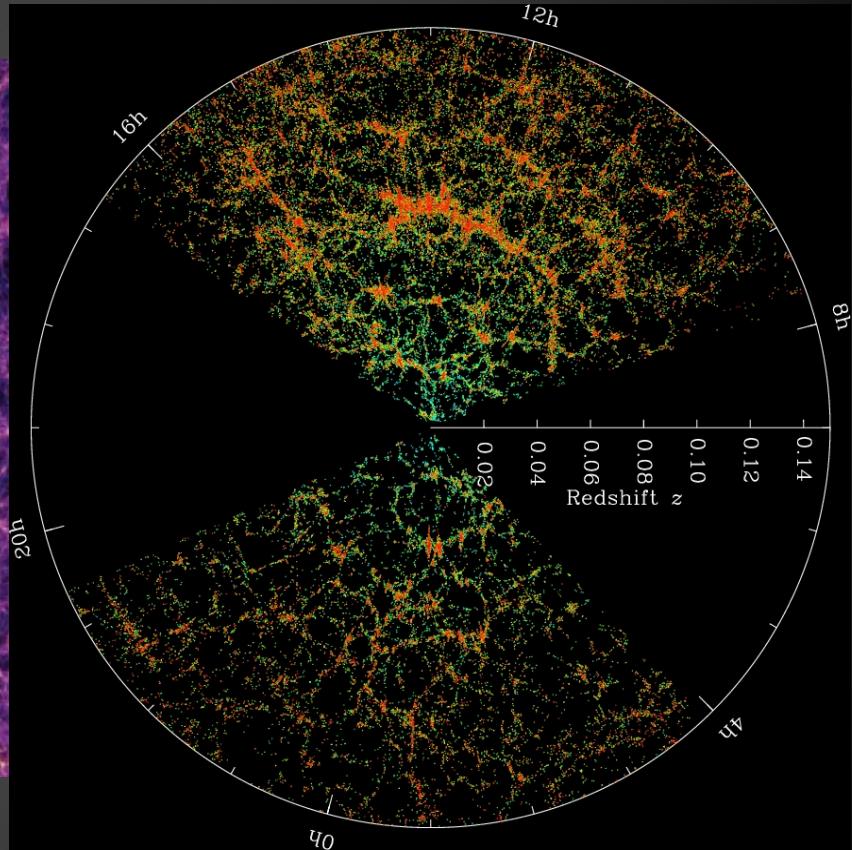
Advisor: Bart Wakker

June 19, 2018

Gas + galaxies trace the same potential



The Millenium Simulation



SDSS Collaboration

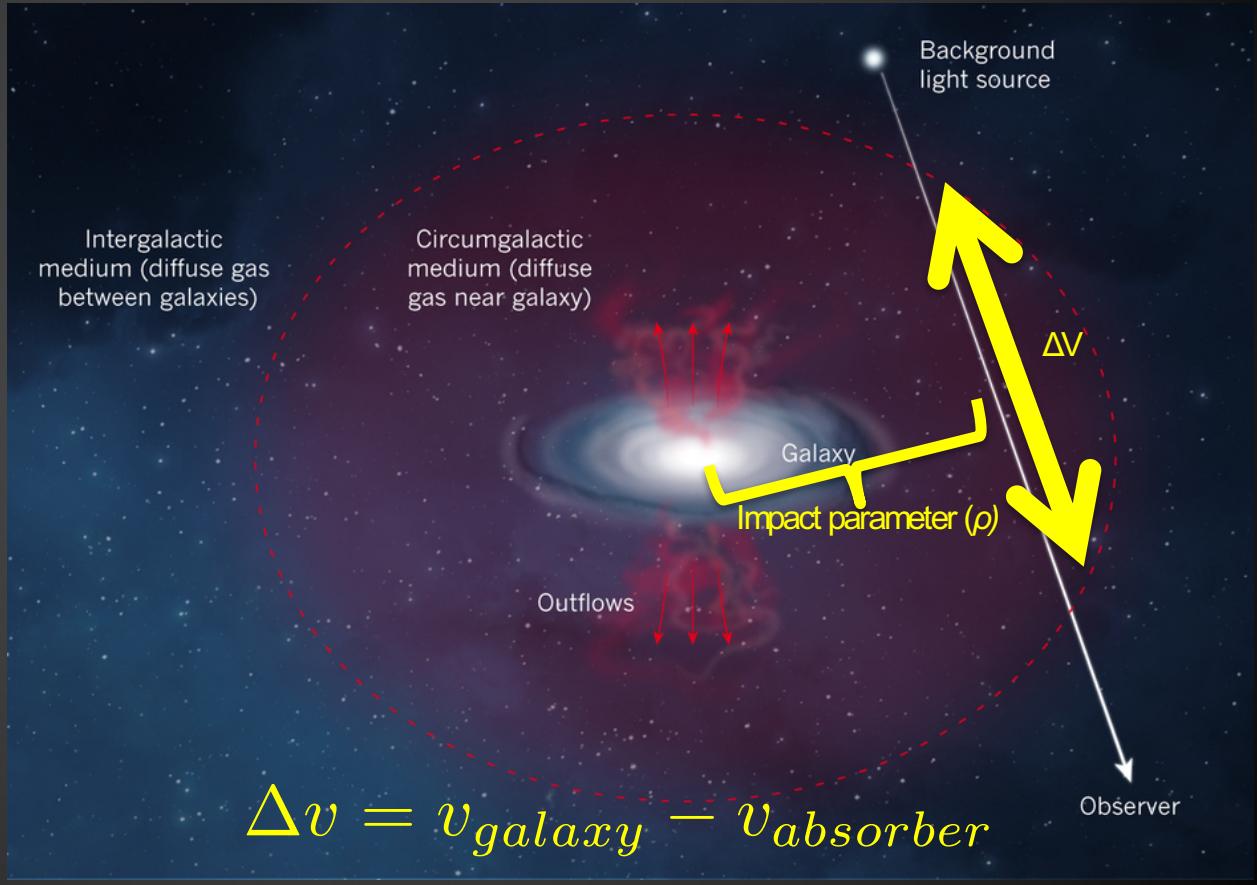
Does the gas care about the galaxies?

- Gas and galaxies should follow the same DM potential
 - Galaxies need to continue accreting gas over cosmic time to match observations
- ↔
- Feedback kicks gas out of galaxies

★ How do the properties of halo gas correlate with nearby galaxy properties?

Probing the CGM with QSO absorption

- Can't uniformly sample a single halo
- Must rely on serendipitous QSO locations
- Build a sample of single galaxy-QSO pairs
- Impact parameter and ΔV give absorber position



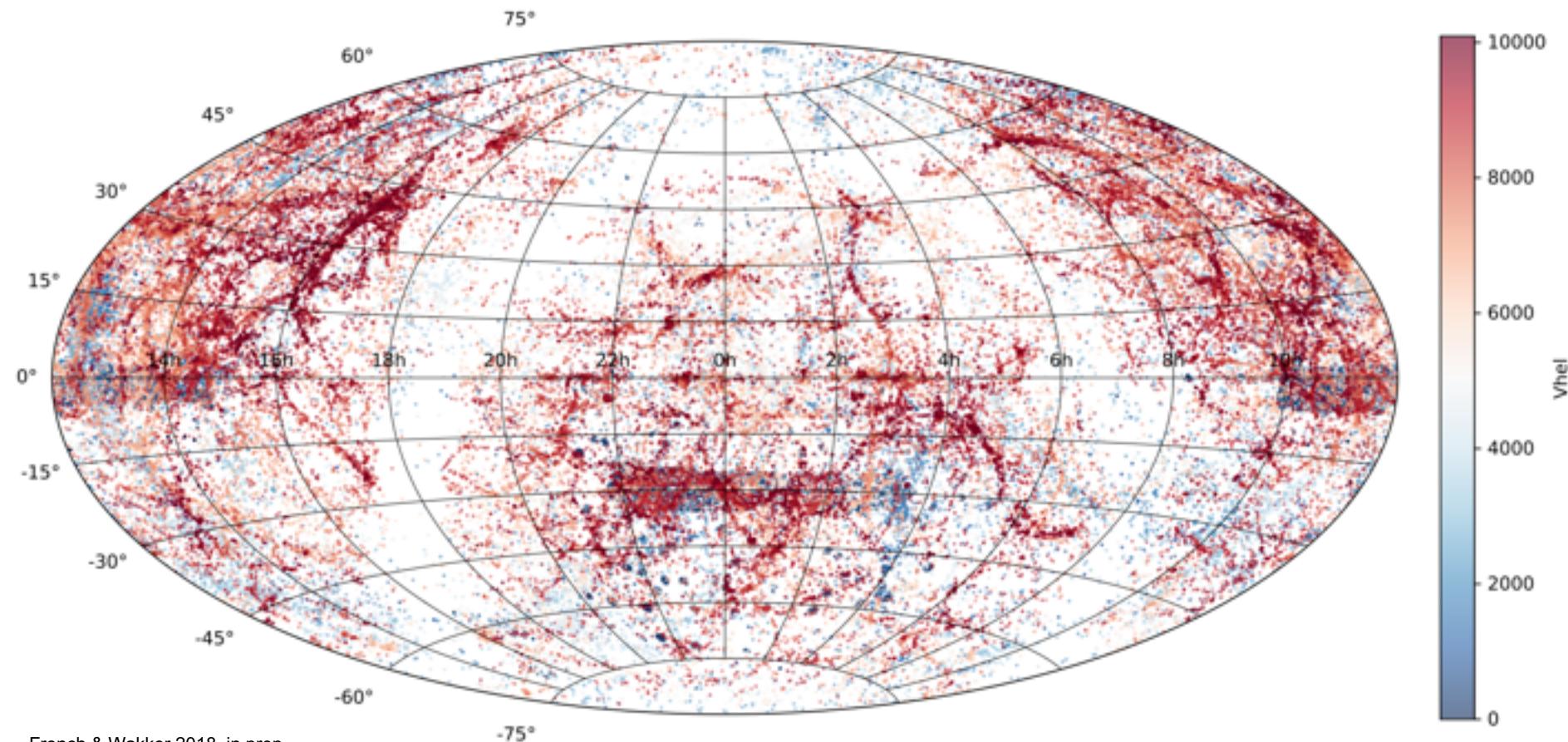
Science Outline

- Use archival COS sightlines (~700 total)
 - Catalog Ly-alpha lines
- Correlate with galaxy environment
 - IMPORTANT! Have to know where the galaxies are!
 - Limit search to $cz < 10,000 \text{ km/s}$
- Ask:
 - 1. Ly-alpha EW – vs – galaxy proximity, size, orientation
 - 2. Ly-alpha velocity – vs – galaxy rotation (co-rotation?)

New Nearby Galaxy Catalog

Gather existing galaxy data

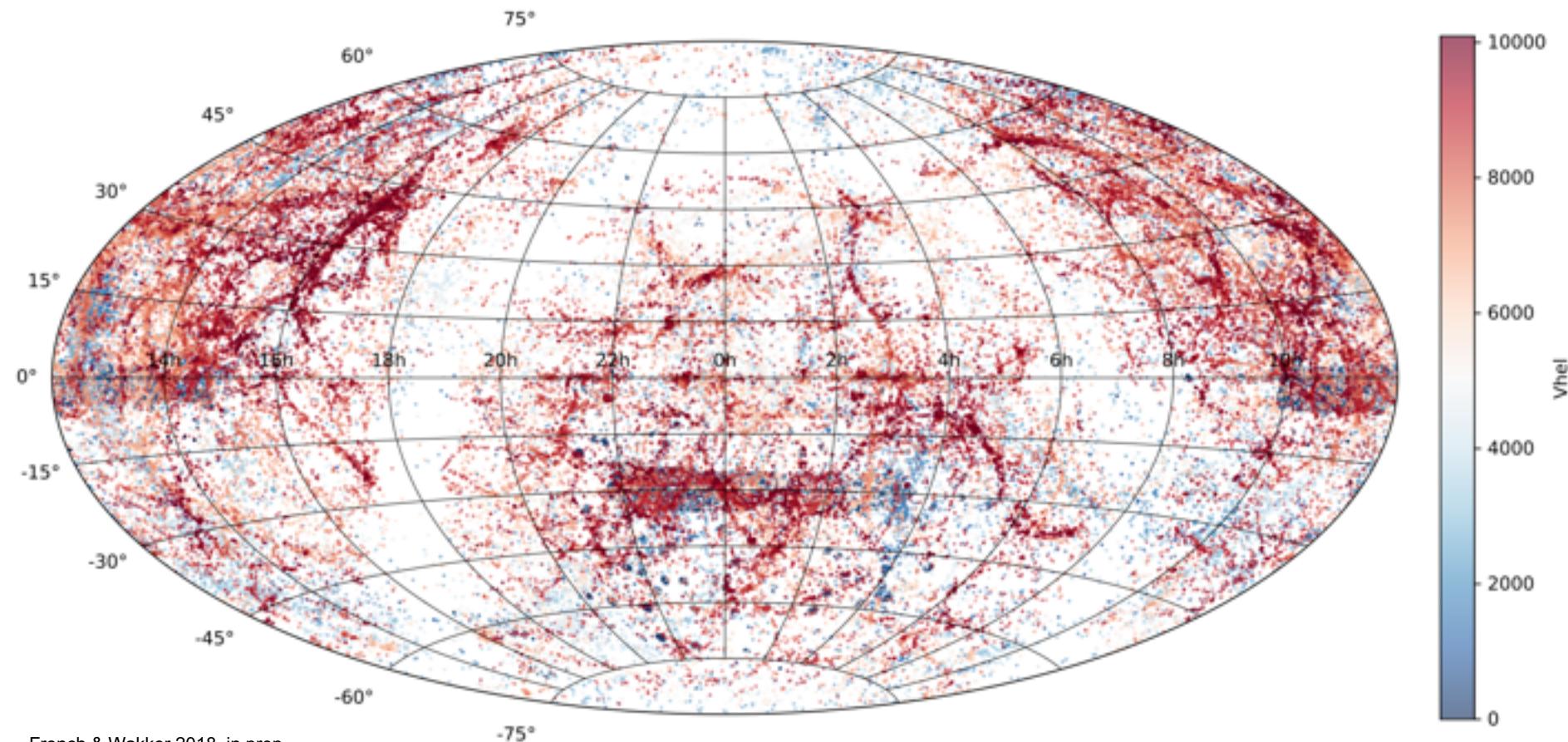
- NED + IRSA
- 130,000+ galaxies with $cz < 10,000$ km/s



New Nearby Galaxy Catalog

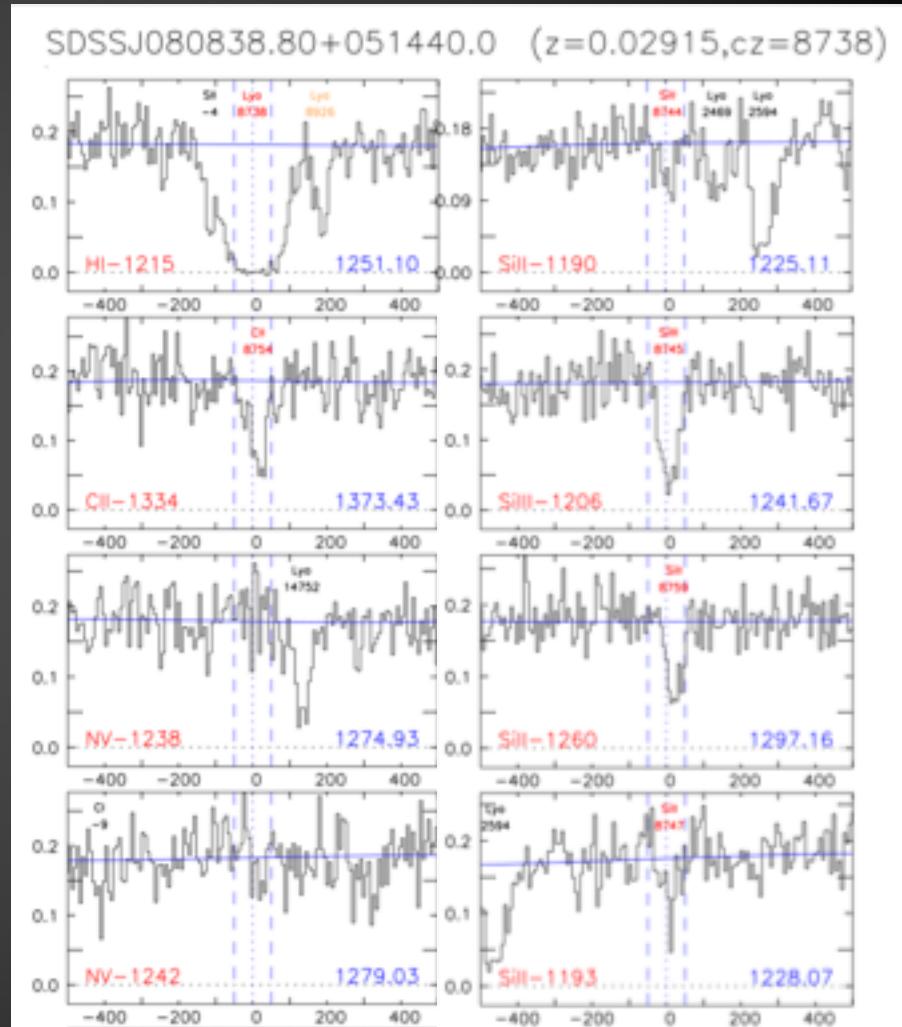
Homogenize existing data

- Normalize diameters, inclinations, PAs to 2MASS values
- Choose representative magnitudes, calculate (L^* , R_{vir})



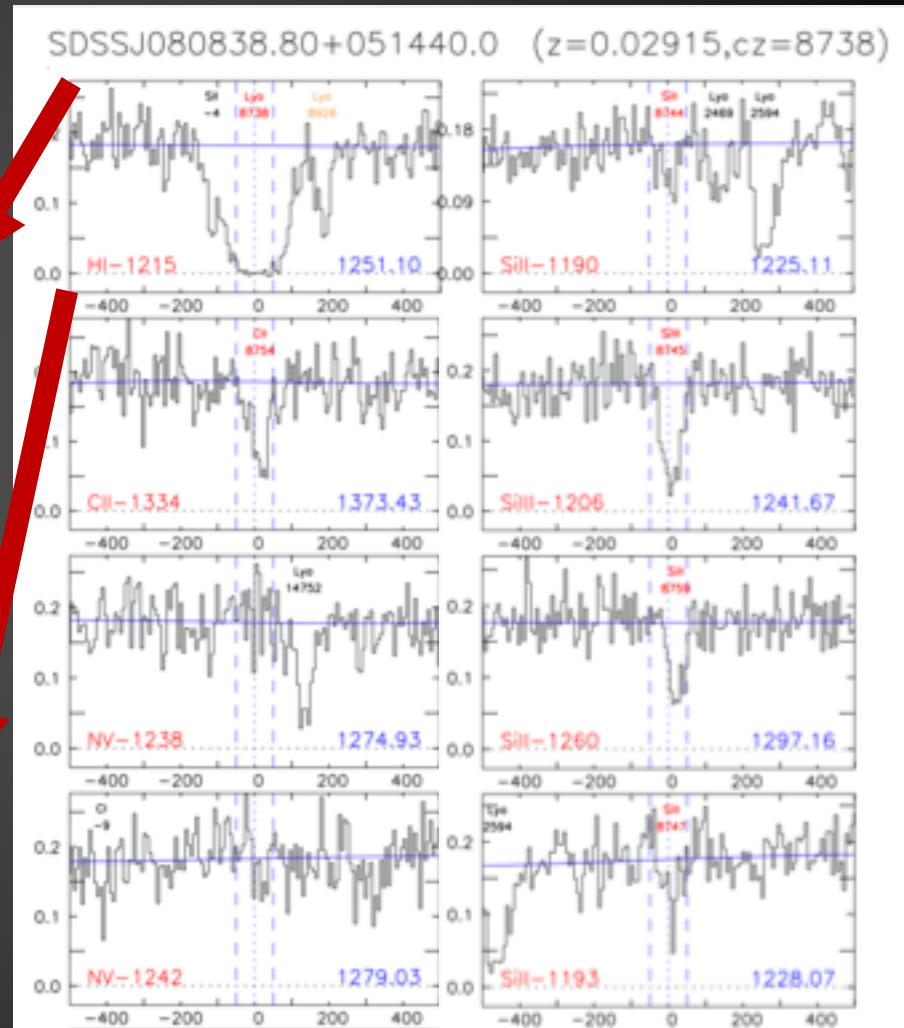
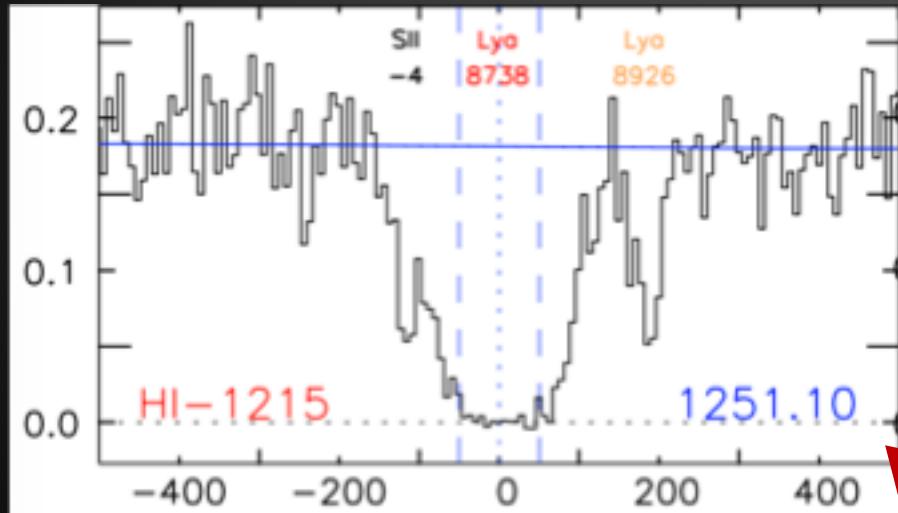
Catalog the absorbers

- 700+ G130M COS targets
 - Reduce, identify and measure all lines
 - Produce a catalog of fit parameters



Catalog the absorbers

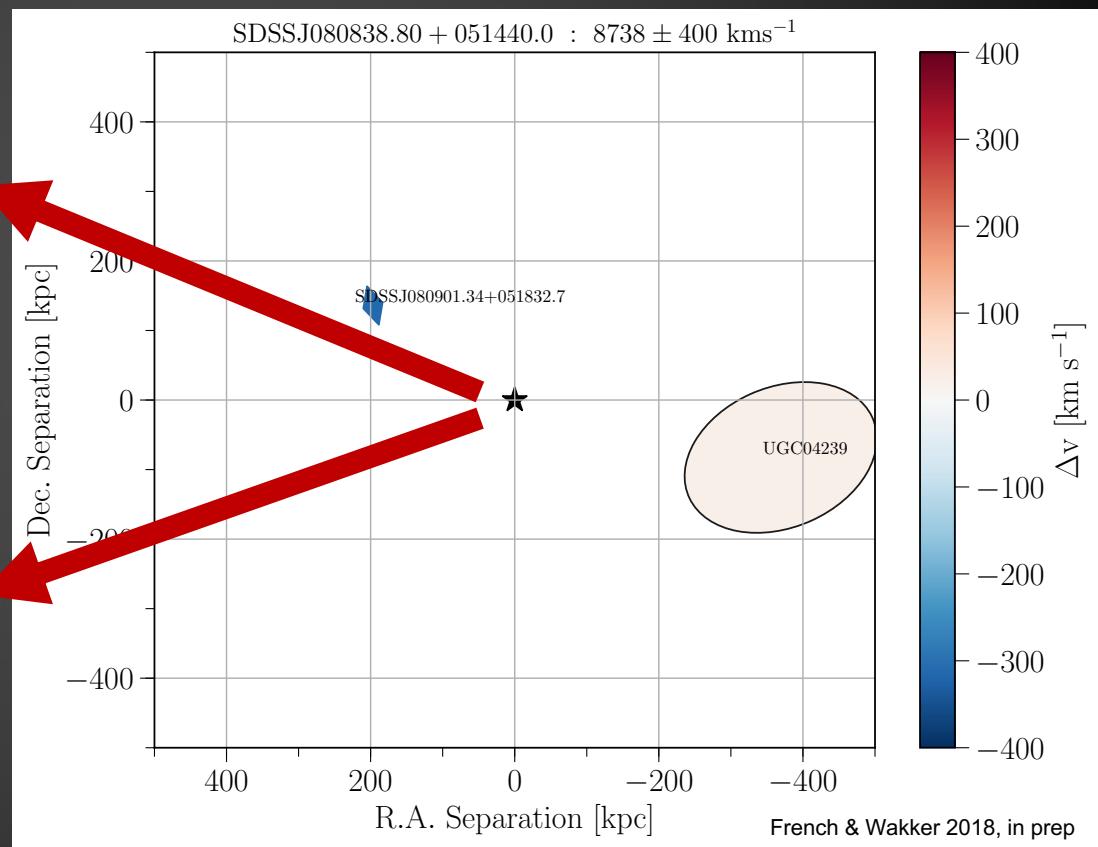
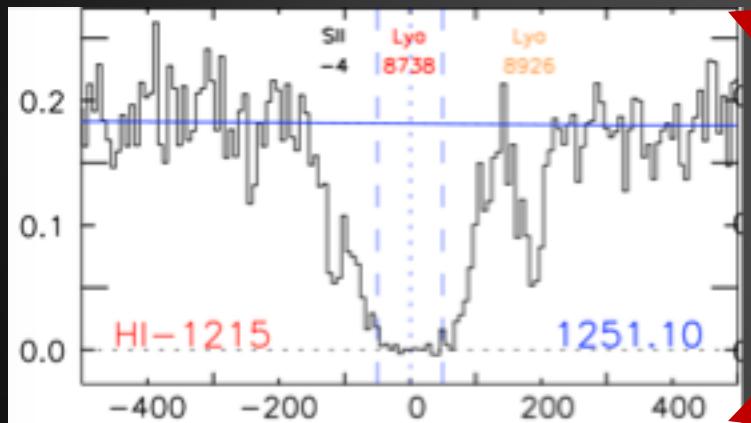
- Concentrate on Ly-alpha
 - Correlate with galaxy environment



Catalog the absorbers

Connecting with galaxies – using our galaxy catalog

- Which one?



French & Wakker 2018, in prep

Matching absorbers with galaxies

Define an objective “likelihood” parameter:

- Define a likelihood:

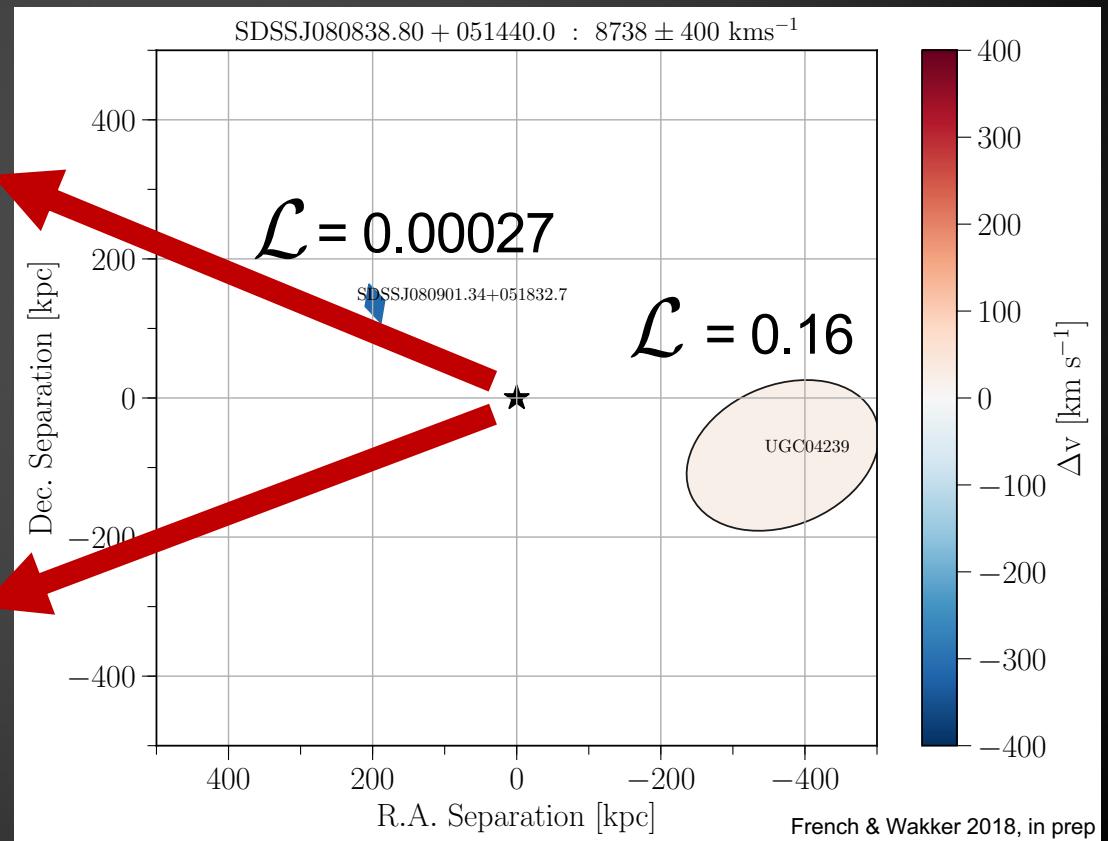
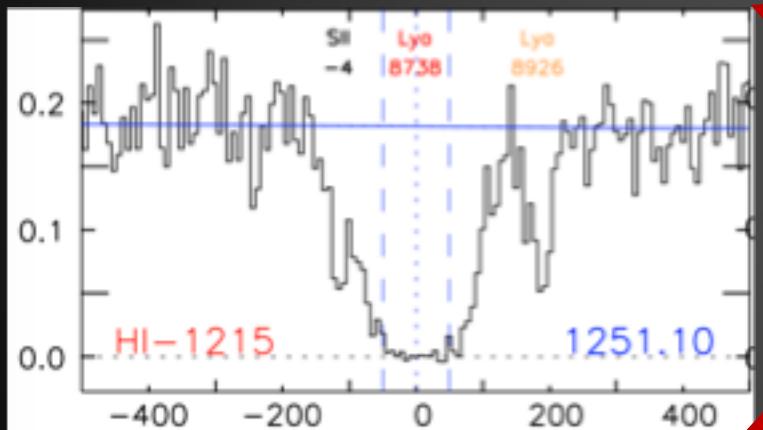
$$\mathcal{L} = e^{-(\frac{\rho}{R_{vir}})^2} e^{-(\frac{\Delta v}{200})^2}$$

- ρ = impact parameter
- $\Delta v = v_{galaxy} - v_{absorber}$
- R_{vir} = viral radius of the galaxy

Matching absorbers with galaxies

Applying the likelihood method

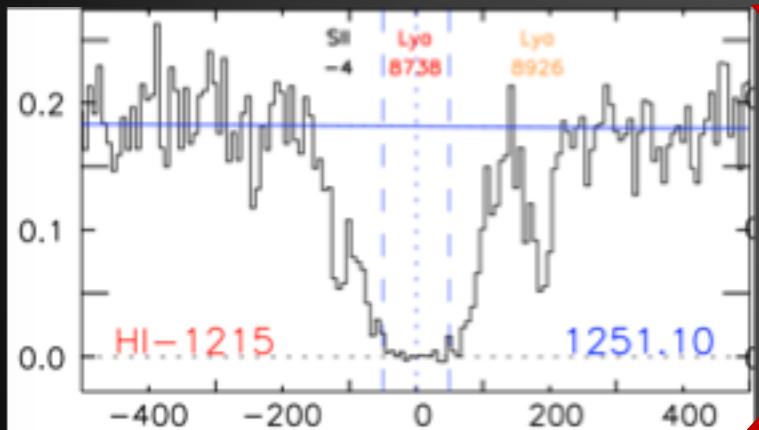
- 3D proximity indicator
- Set criteria for "association"



Matching absorbers with galaxies

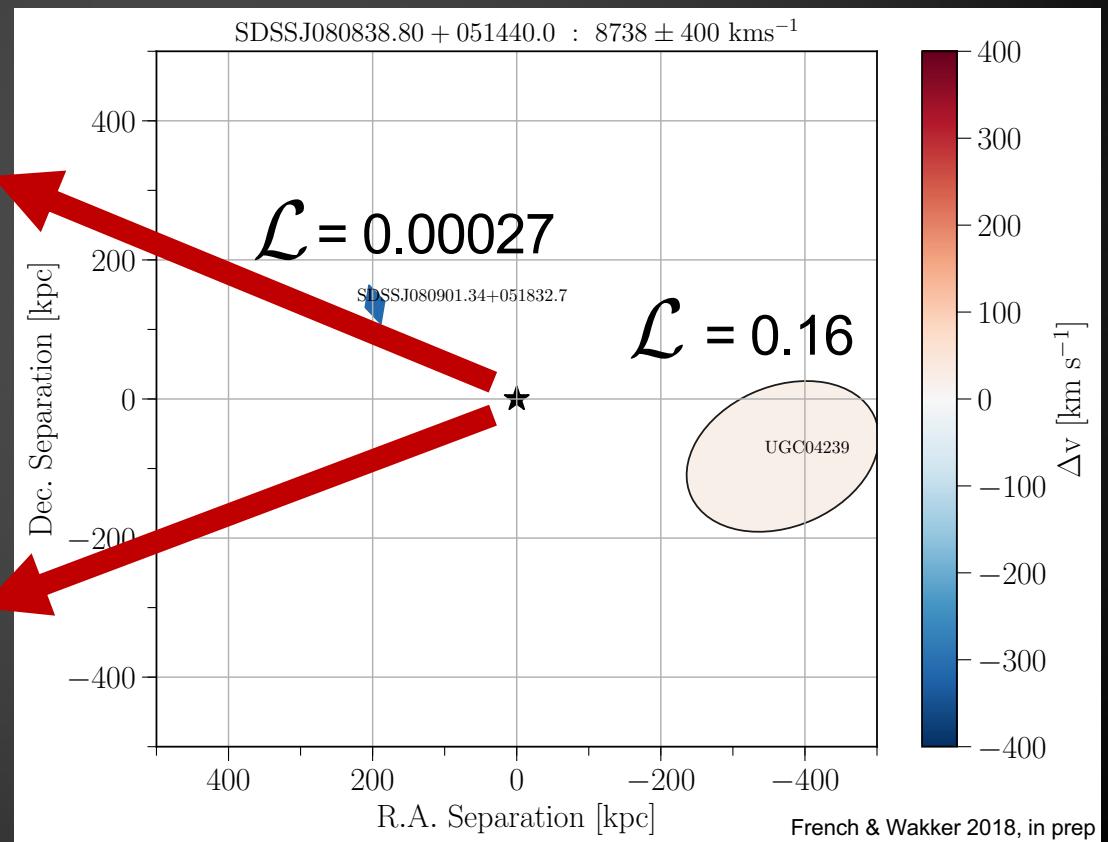
Applying the likelihood method

- 3D proximity indicator
- Set criteria for "association"



$$\mathcal{L}_1 \geq 0.01$$

$$\mathcal{L}_1 > 5\mathcal{L}_2$$

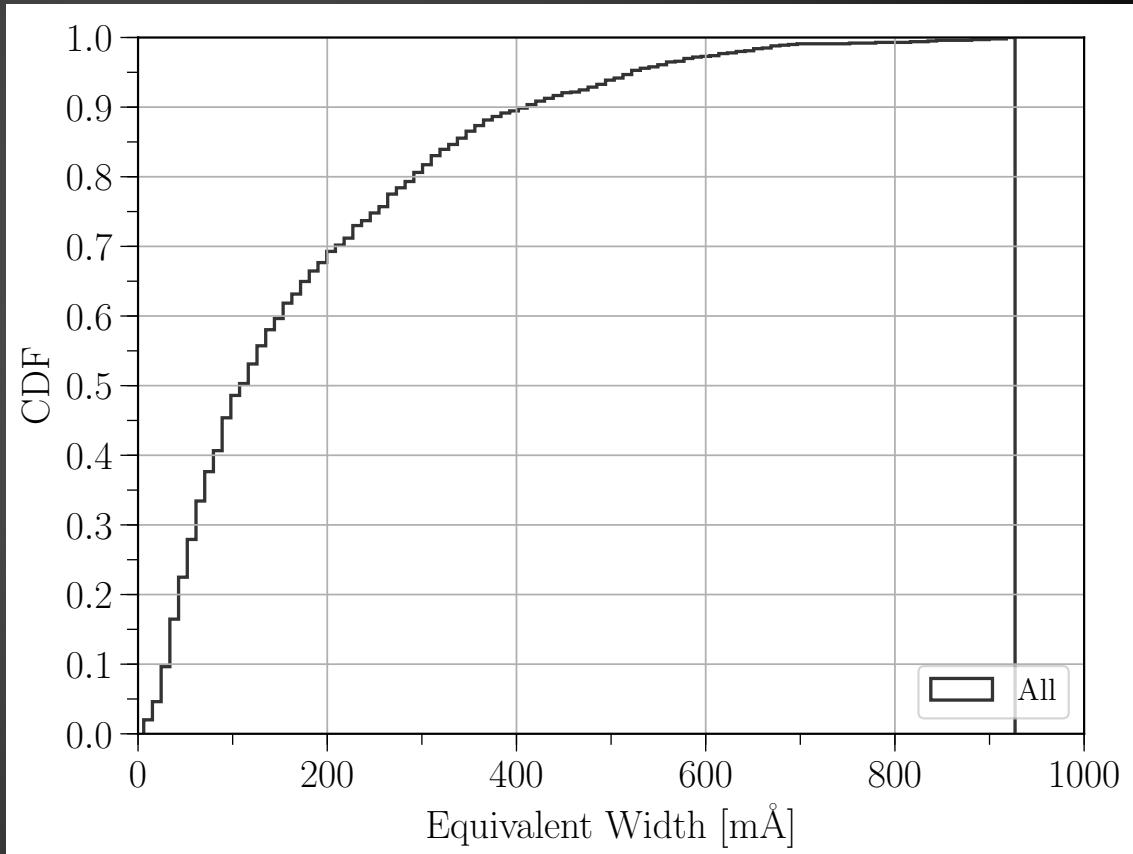


French & Wakker 2018, in prep

Results!

Status:

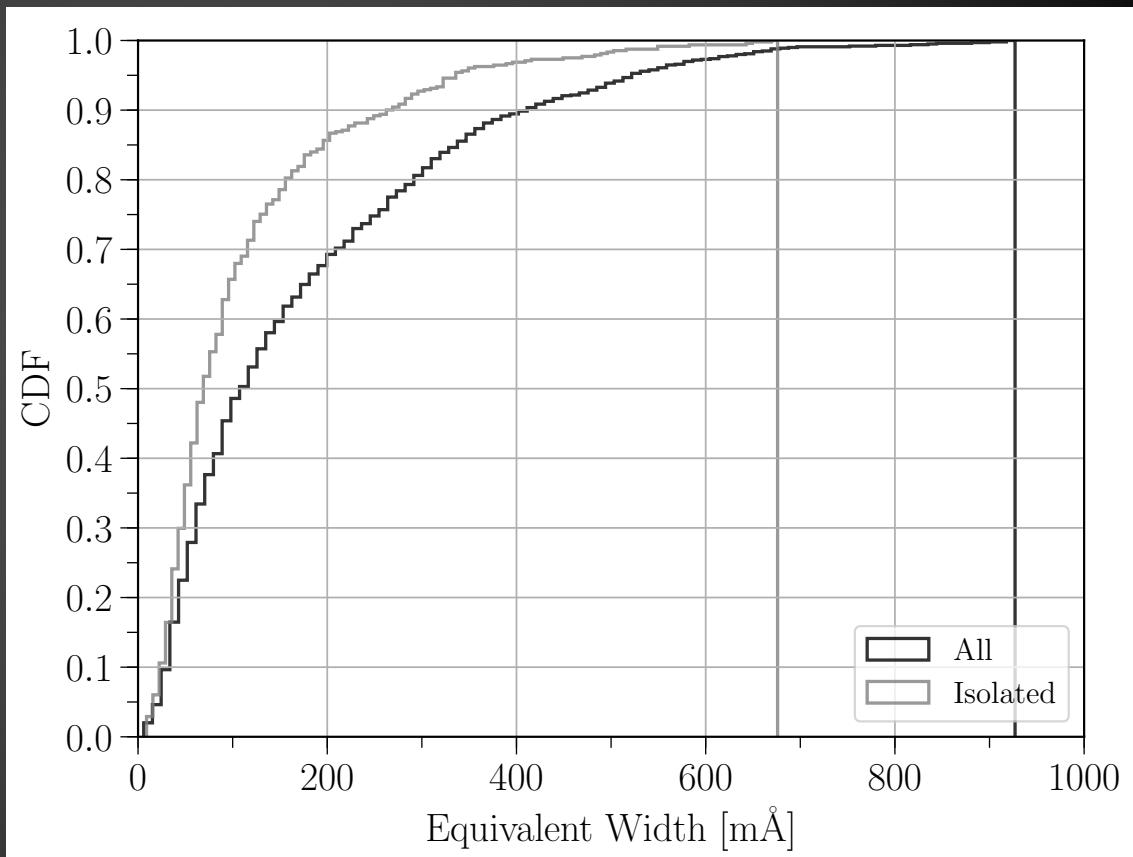
- **224 spectra reduced,
identified AND
measured:**
 - 1004 Ly-alpha absorbers



EW Distributions

Status:

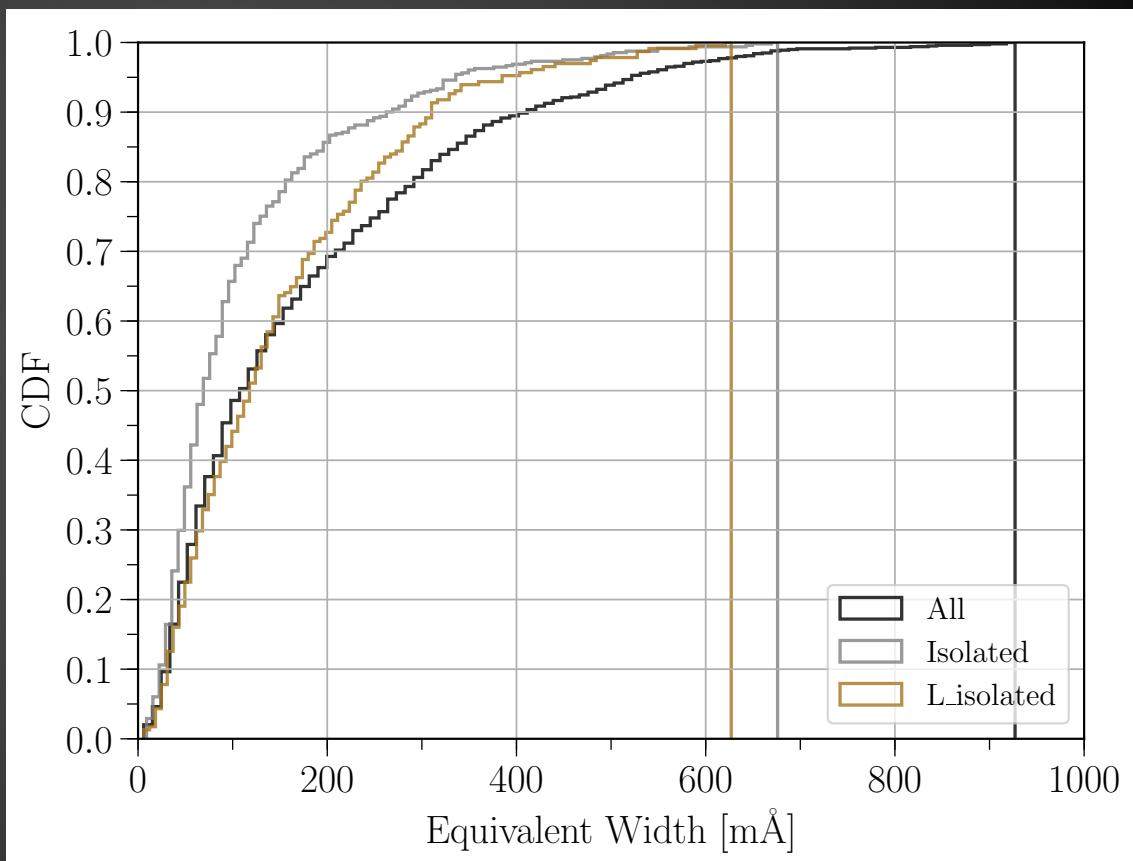
- **224 spectra measured:**
 - 1004 Ly-alpha absorbers
 - 481 isolated (>500 kpc)



EW Distributions

Status:

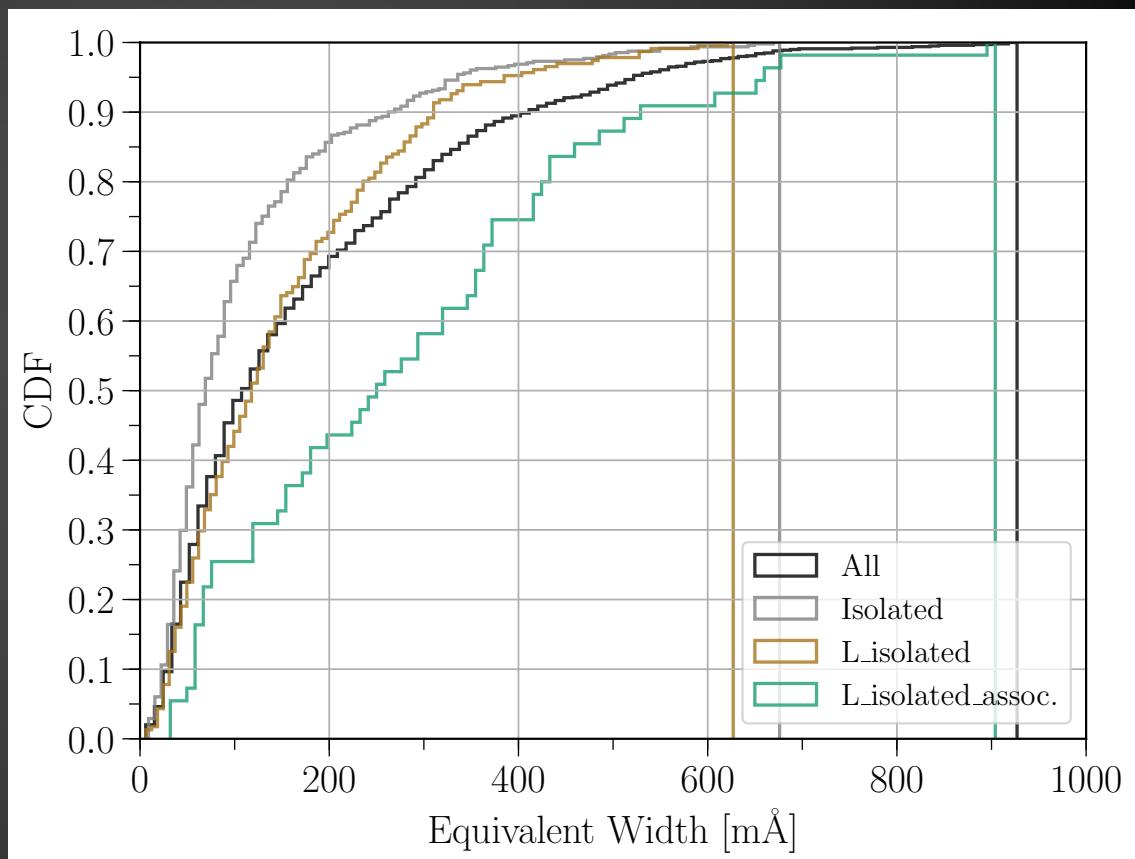
- **224 spectra measured:**
 - 1004 Ly-alpha absorbers
 - 481 isolated (>500 kpc)
 - 232 isolated (but within 500 kpc)



EW Distributions

Status:

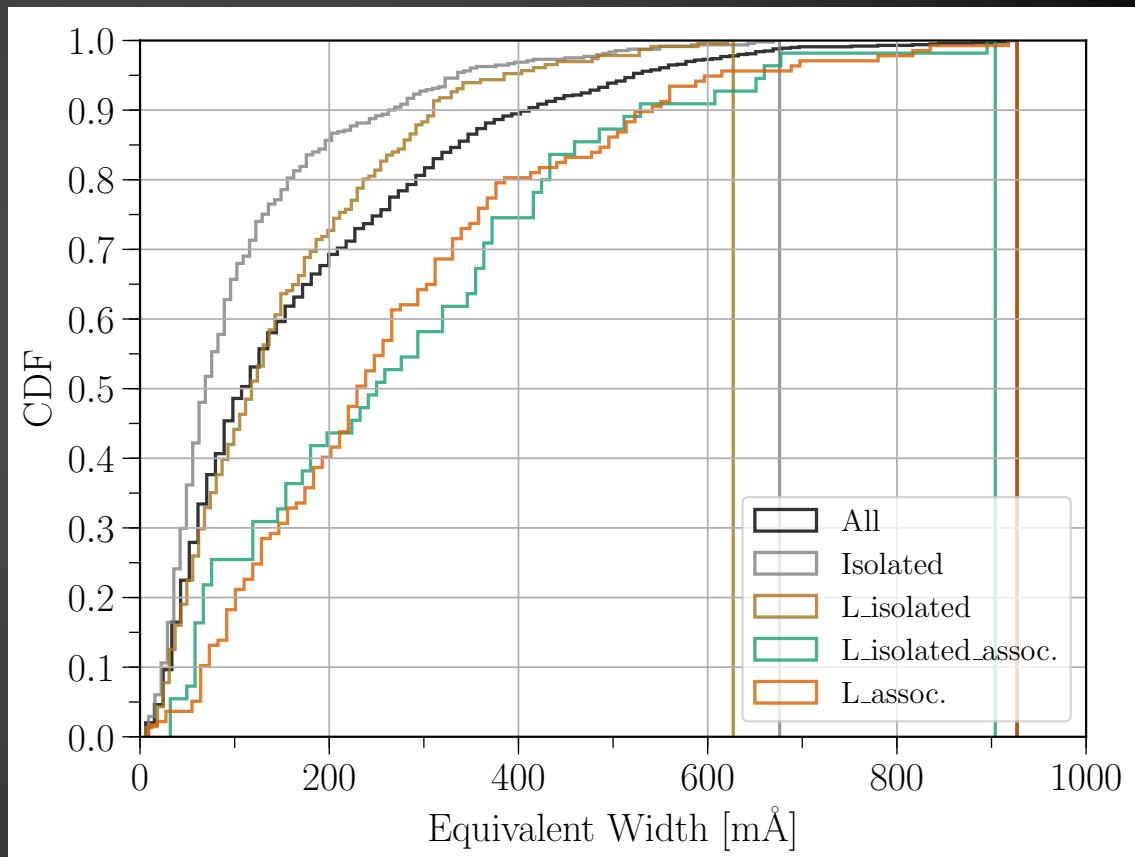
- **224 spectra measured:**
 - 1004 Ly-alpha absorbers
 - 481 isolated (>500 kpc)
 - 232 isolated (but within 500 kpc)
 - 55 associated with 1 isolated galaxy



EW Distributions

Status:

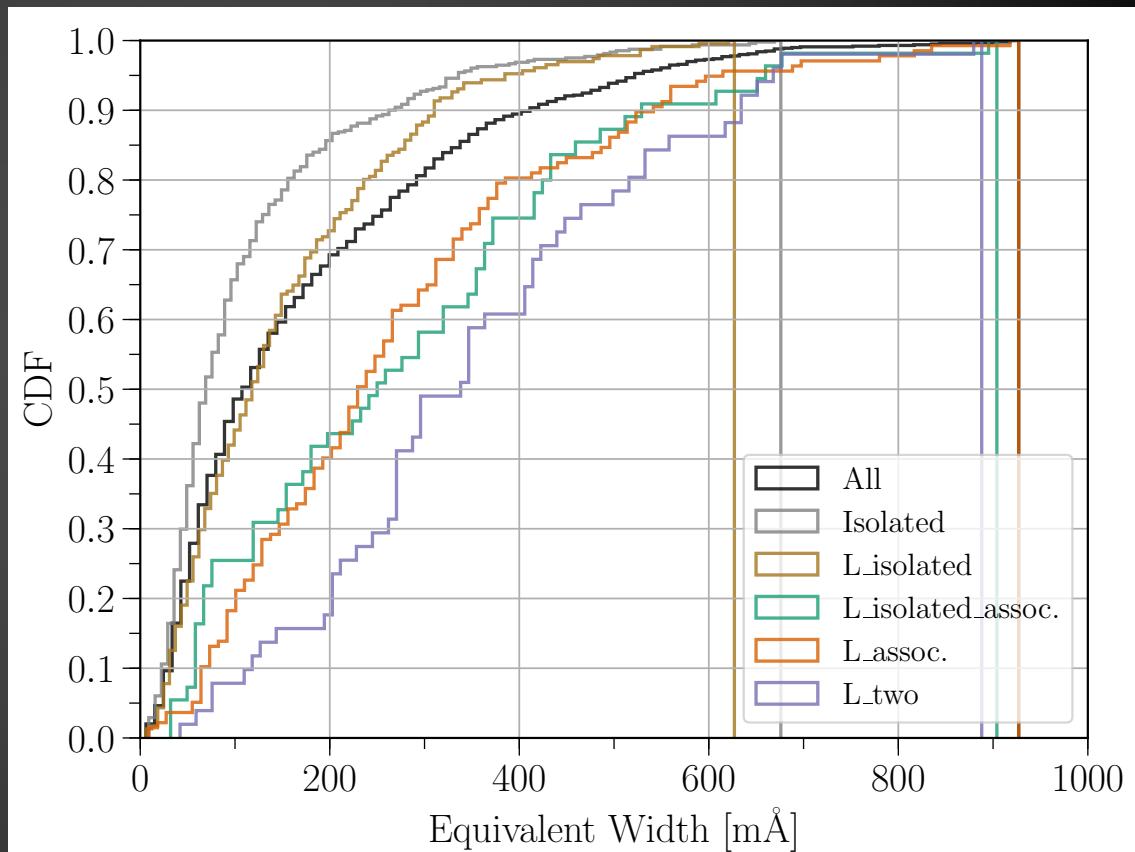
- **224 spectra measured:**
 - 1004 Ly-alpha absorbers
 - 481 isolated (>500 kpc)
 - 232 isolated (but within 500 kpc)
 - 55 associated with 1 isolated galaxy
 - 141 associated with 1 galaxy, others around



EW Distributions

Status:

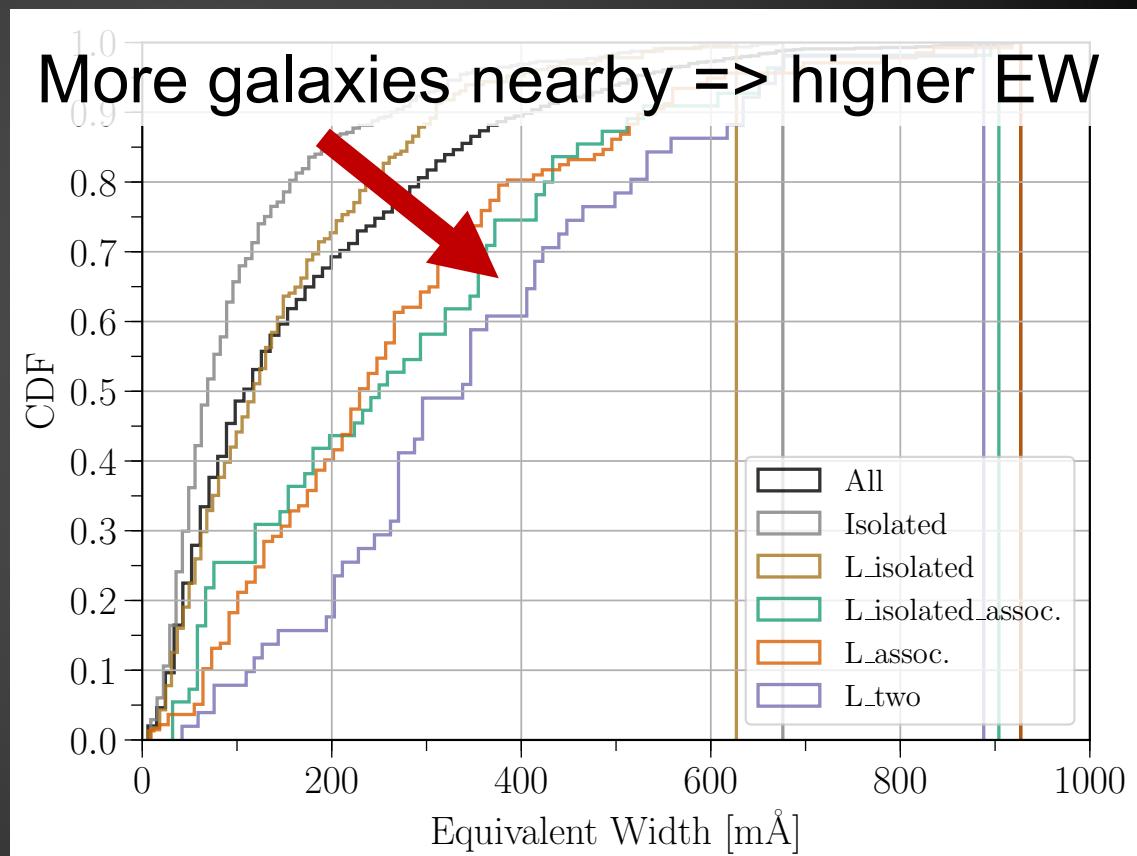
- **224 spectra measured:**
 - 1004 Ly-alpha absorbers
 - 481 isolated (>500 kpc)
 - 232 isolated (but within 500 kpc)
 - 55 associated with 1 isolated galaxy
 - 141 associated with 1 galaxy, others around
 - 51 associated with 2 galaxies



EW Distributions

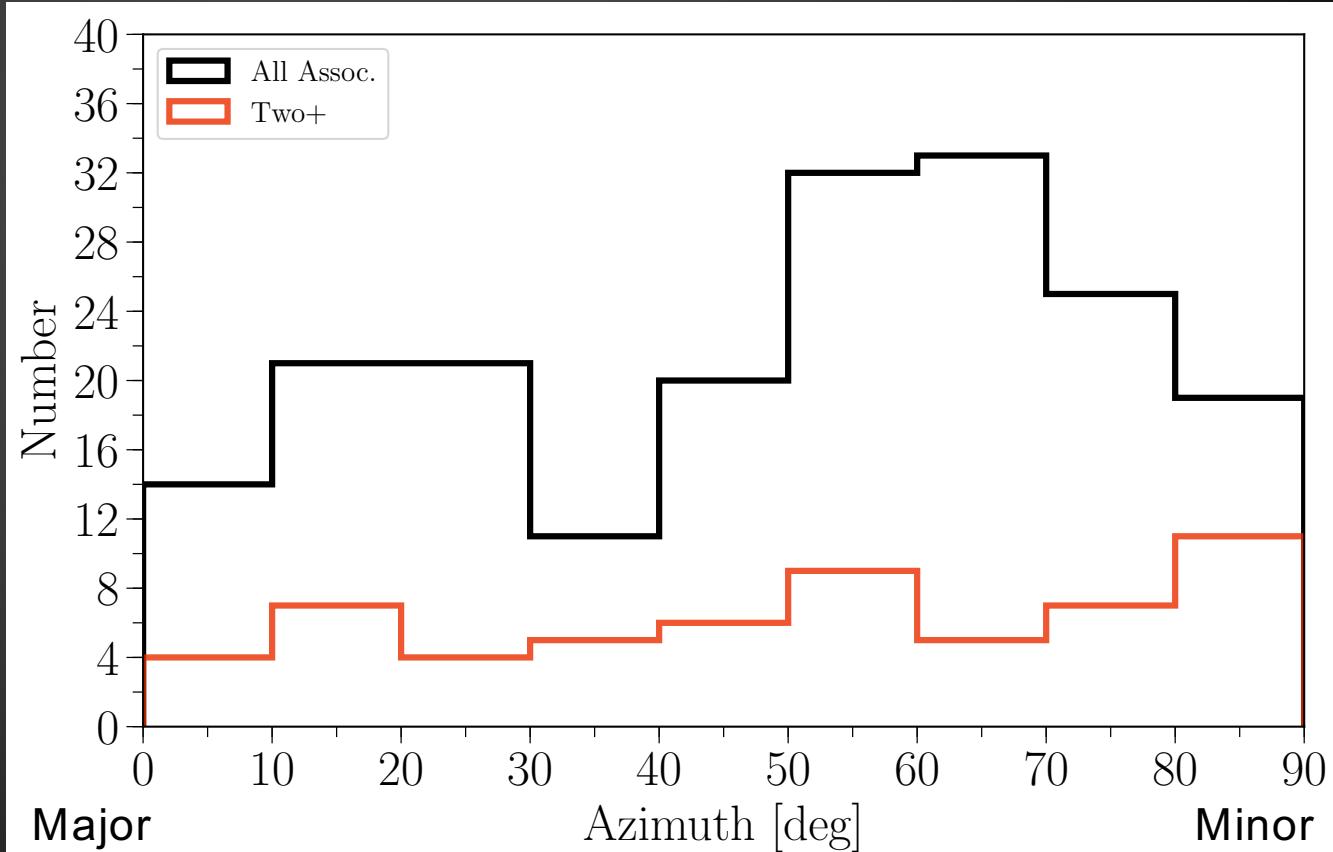
Status:

- **224 spectra measured:**
 - 1004 Ly-alpha absorbers
 - 481 isolated (>500 kpc)
 - 232 isolated (but within 500 kpc)
 - 55 associated with 1 isolated galaxy
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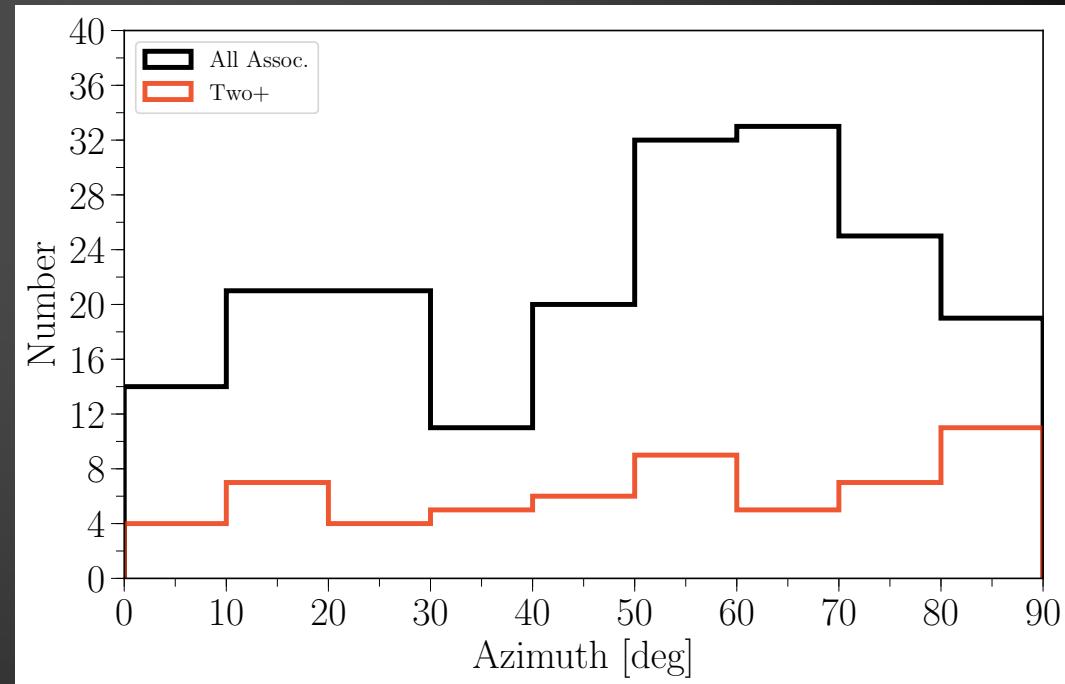
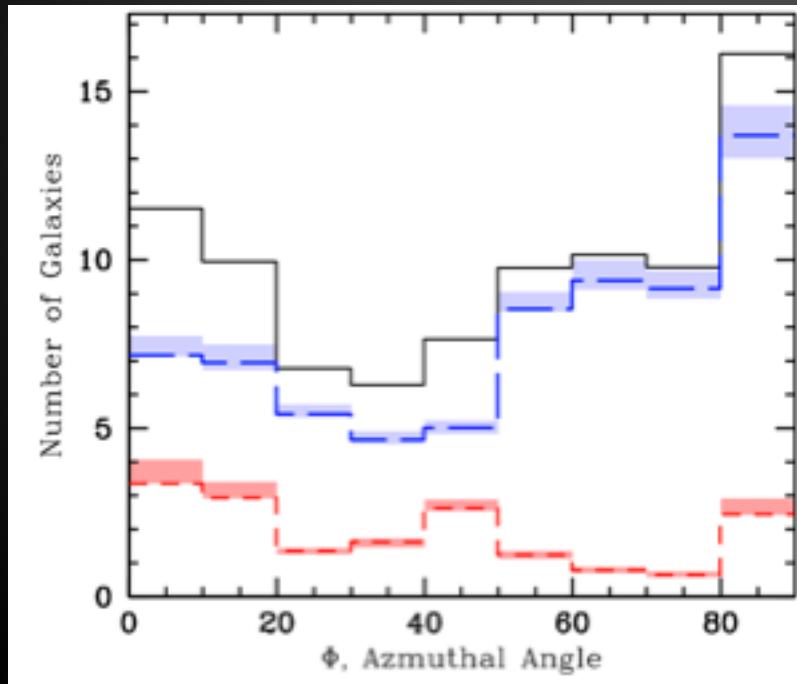
Azimuth Dependence

- Associated absorbers are bimodally distributed
- Absorbers near 2+ galaxies are NOT



Azimuth Dependence

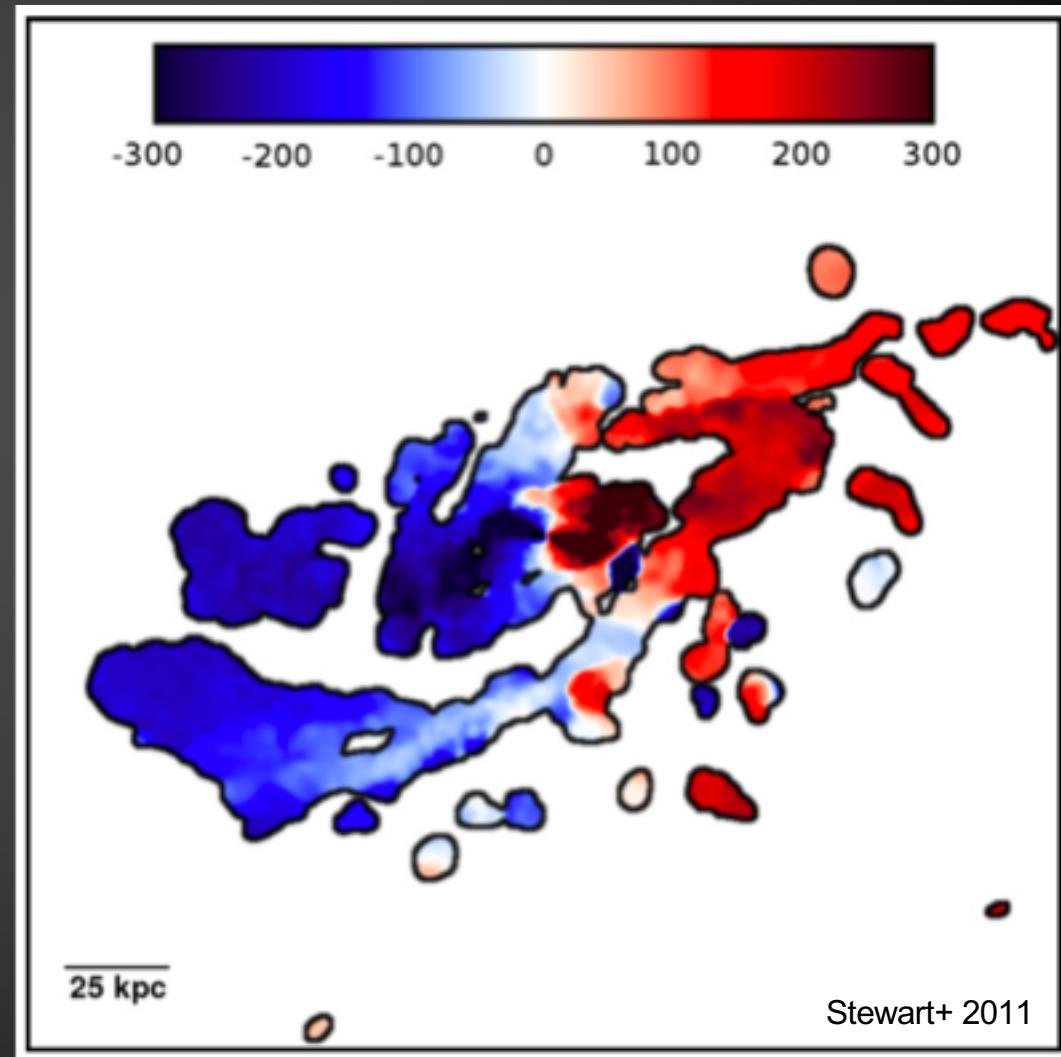
- Similar to MgII azimuth dependence (Kacprzak+ 2012)
 - Shifted away from major/minor axis slightly?



Do Ly-alpha absorbers care about galaxy rotation?

Simulations suggest yes

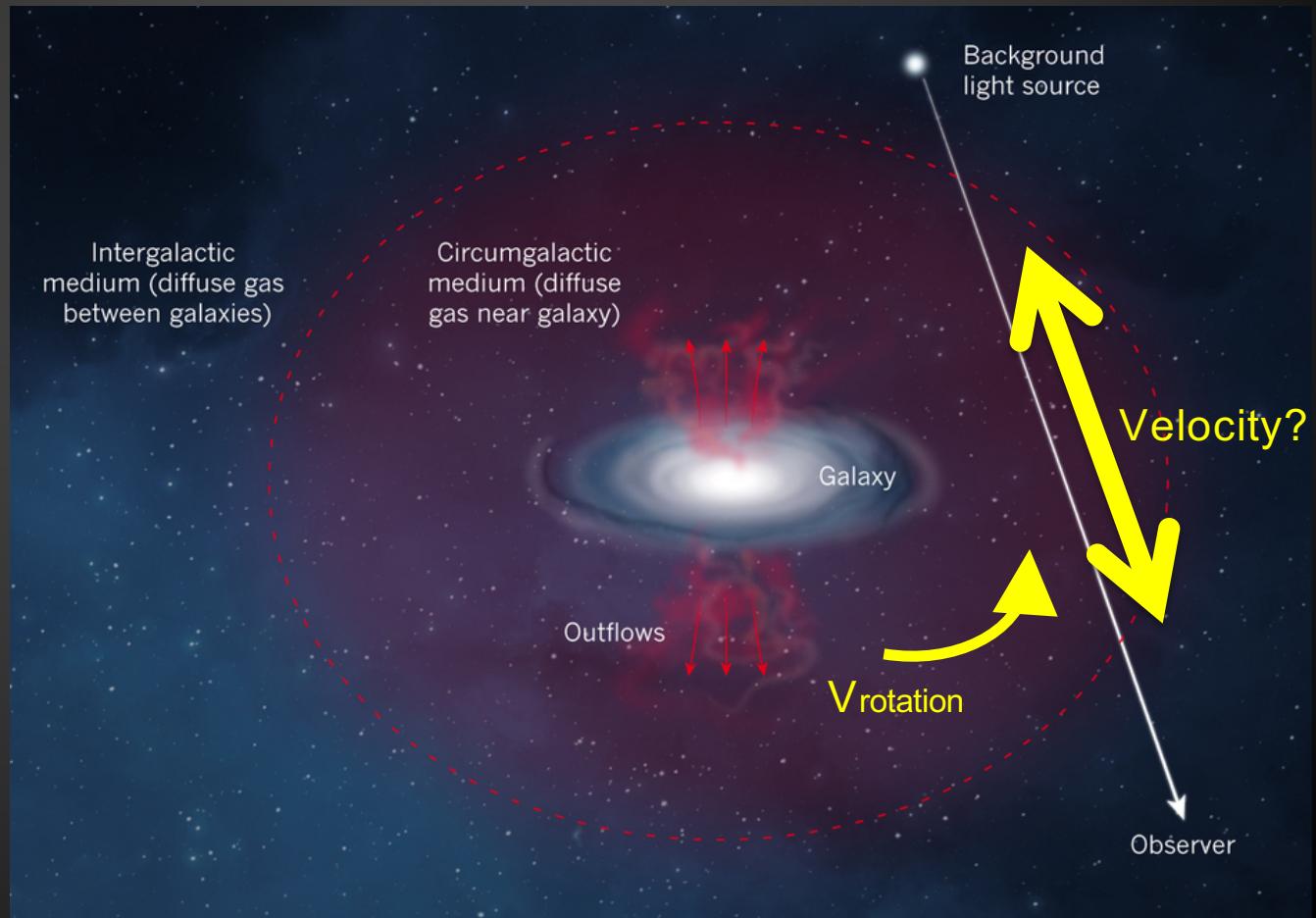
(e.g., Stewart+ 2011)



Sightline velocity structure

Can we detect co-rotation with a sightline?

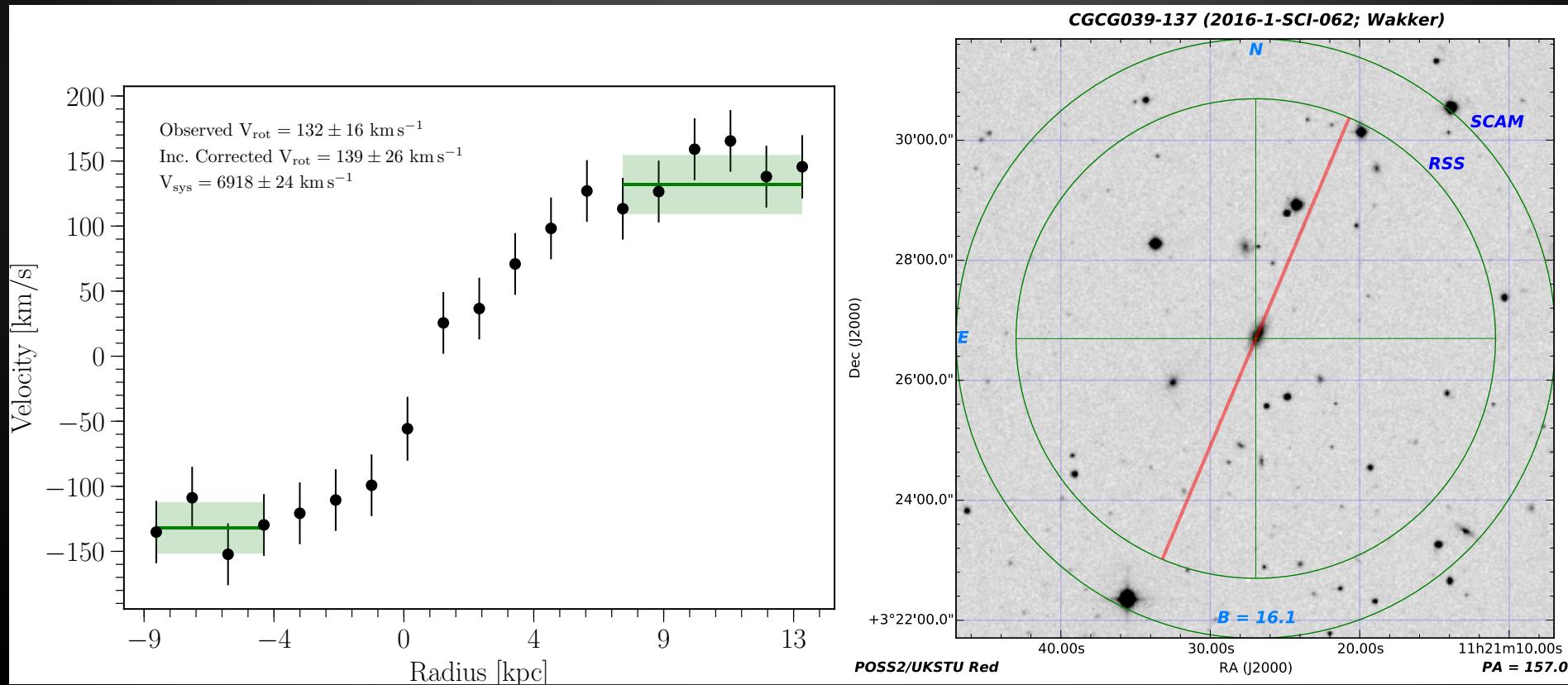
- What does the sightline actually “see”?



Model sightline velocity structure

What does the sightline “see”?

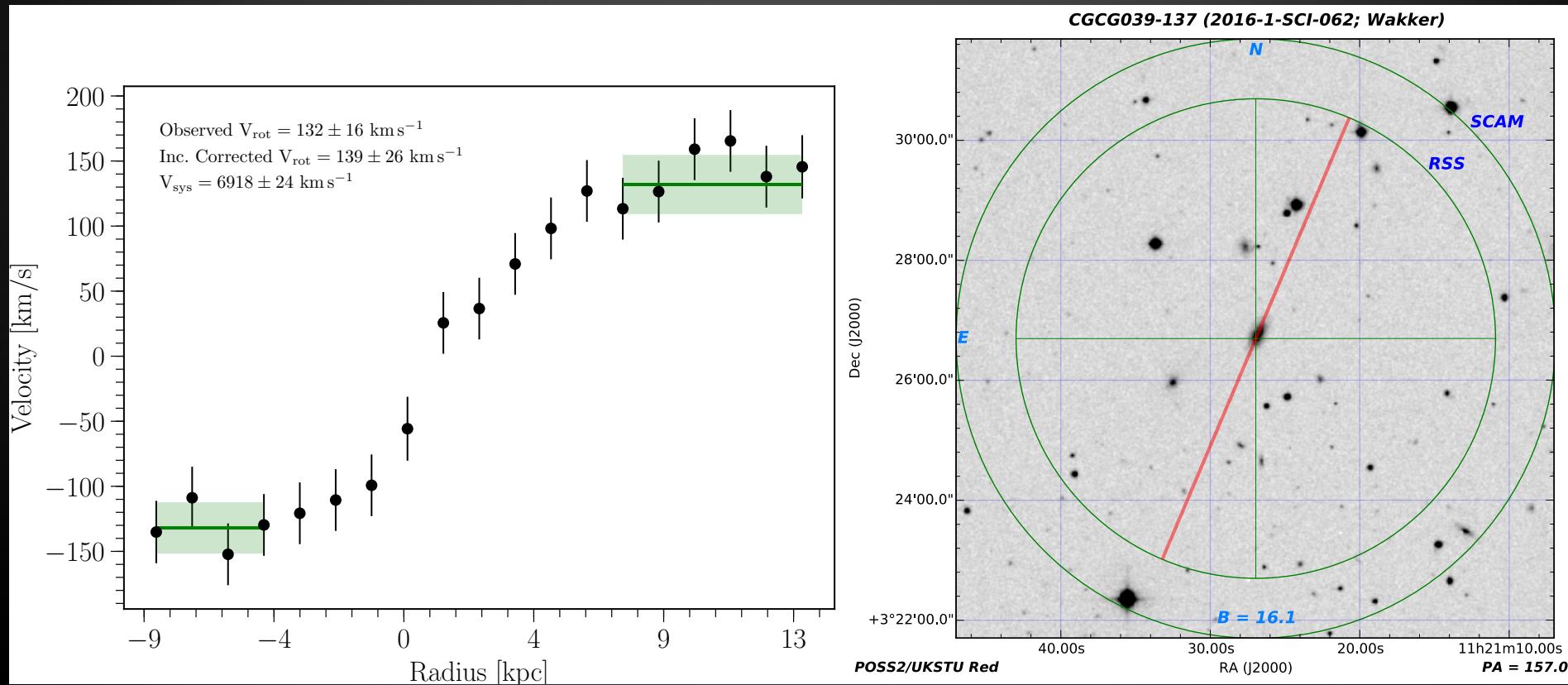
- Step 1: Galaxy rotation curves (H-alpha from SALT + additional from literature)



Model sightline velocity structure

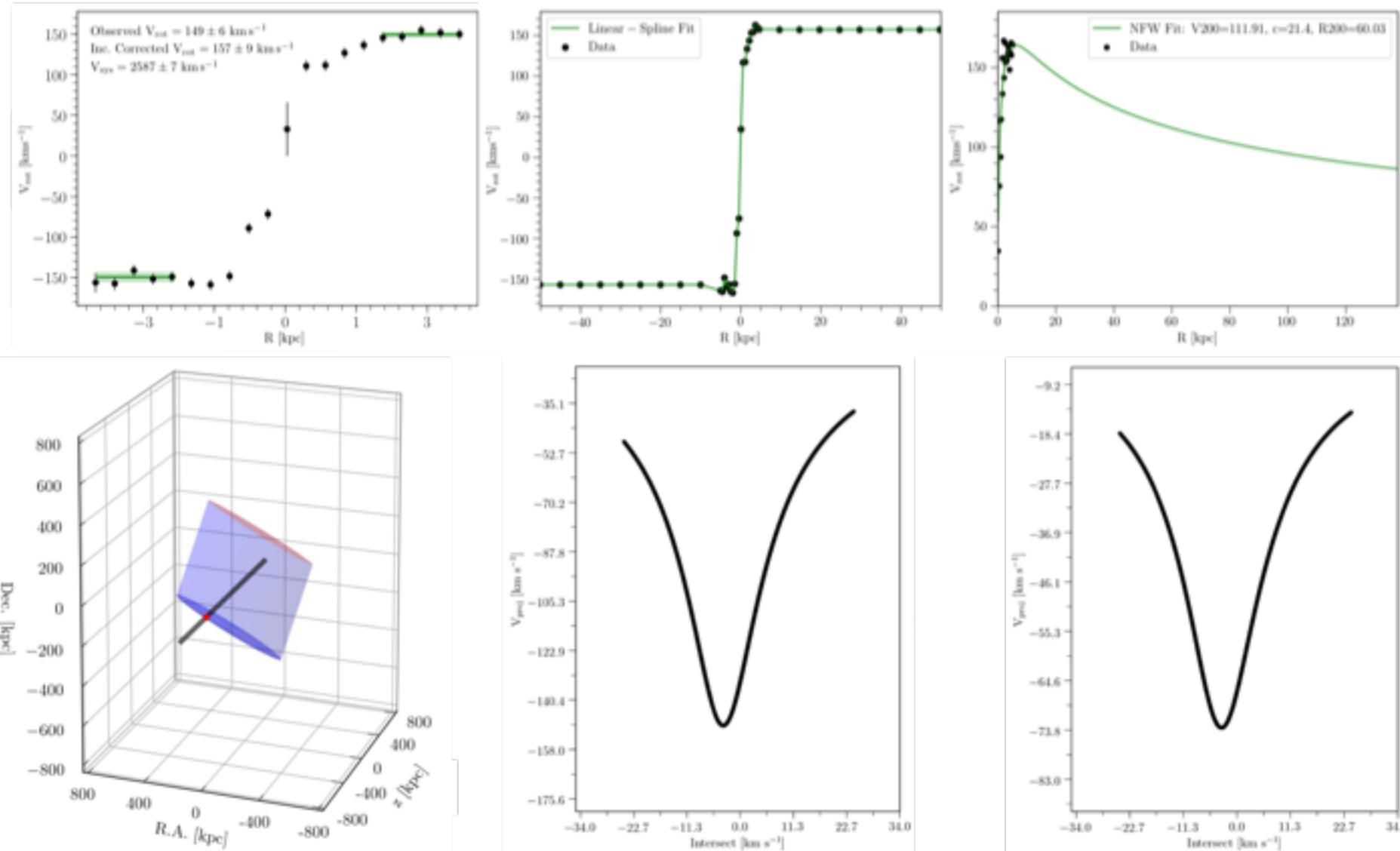
What does the sightline “see”?

- Step 1: Galaxy rotation curves (H-alpha from SALT + additional from literature)
- Step 2: Model rotating halo based on rotation curve – project onto sightline



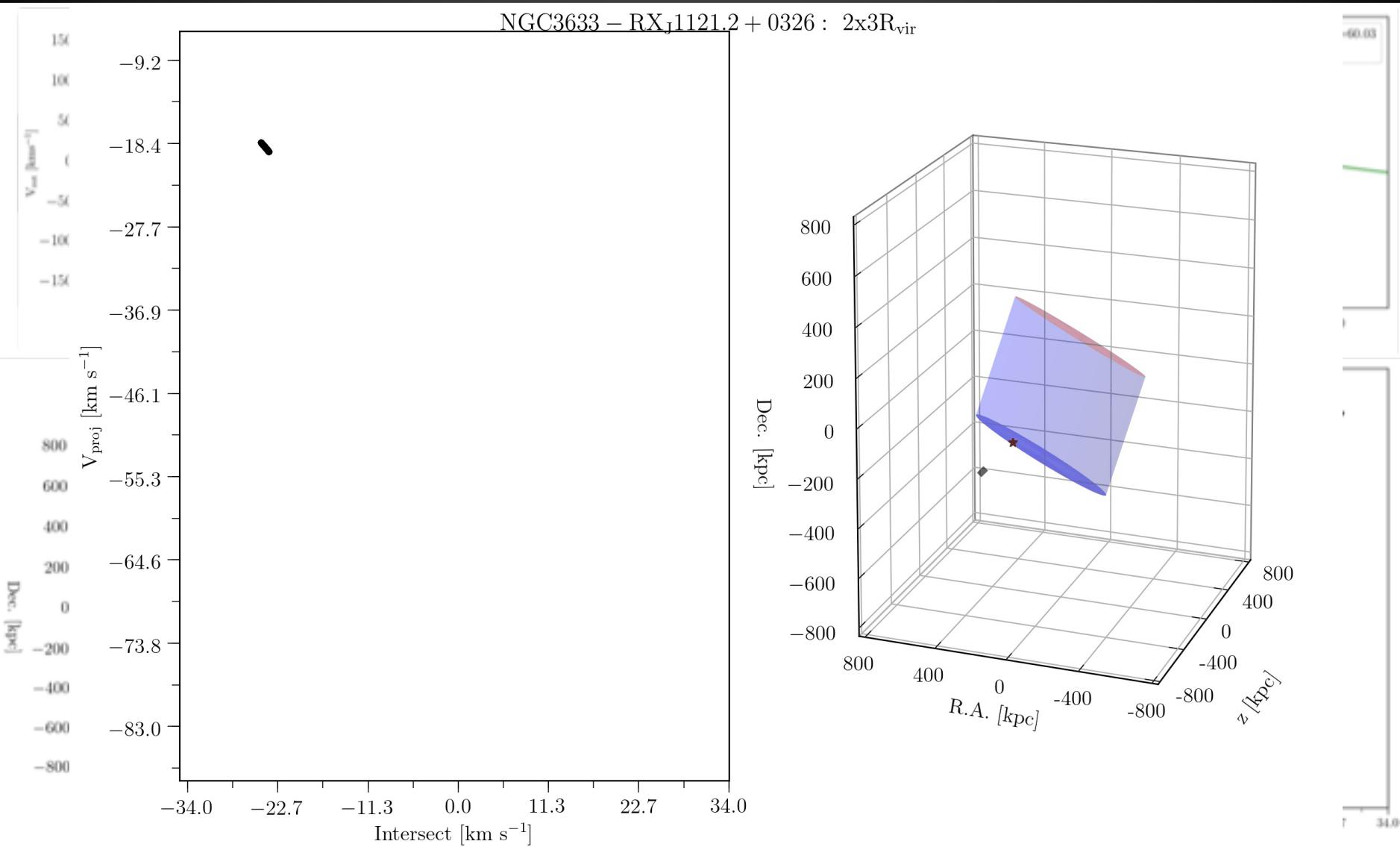
Model sightline velocity structure

What does the sightline “see”?



Model sightline velocity structure

What does the sightline “see”?

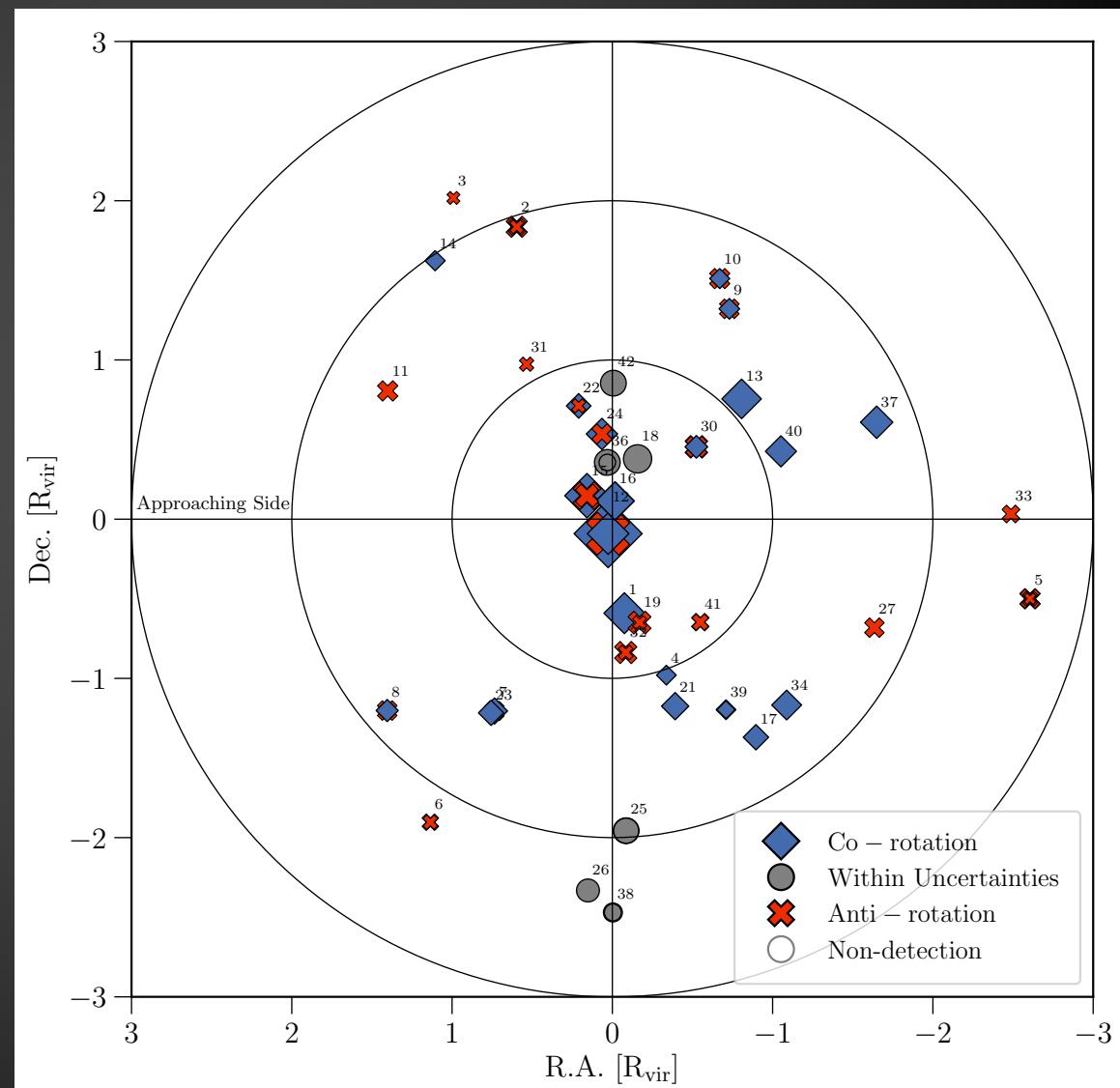


Ly-alpha co-rotation fraction

- **29 galaxies:**
 - 12 new rotation curves taken with SALT
 - 17 additional from literature
- **41 nearby QSOs:**
 - 65 individual Ly-alpha component-galaxy matchups

Ly-alpha co-rotation fraction

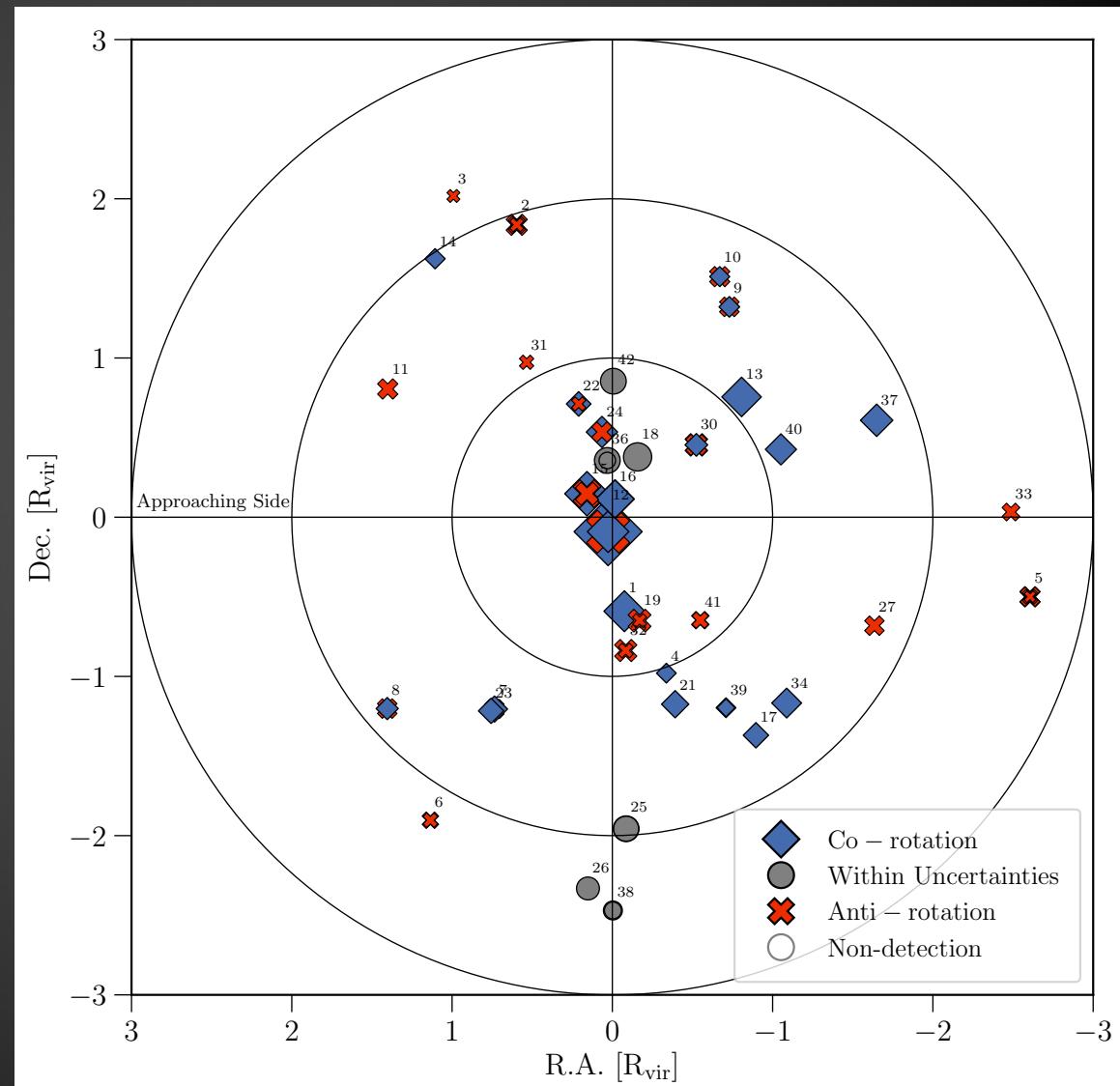
NFW halo model:



Ly-alpha co-rotation fraction

NFW halo model:

43% co-rotating

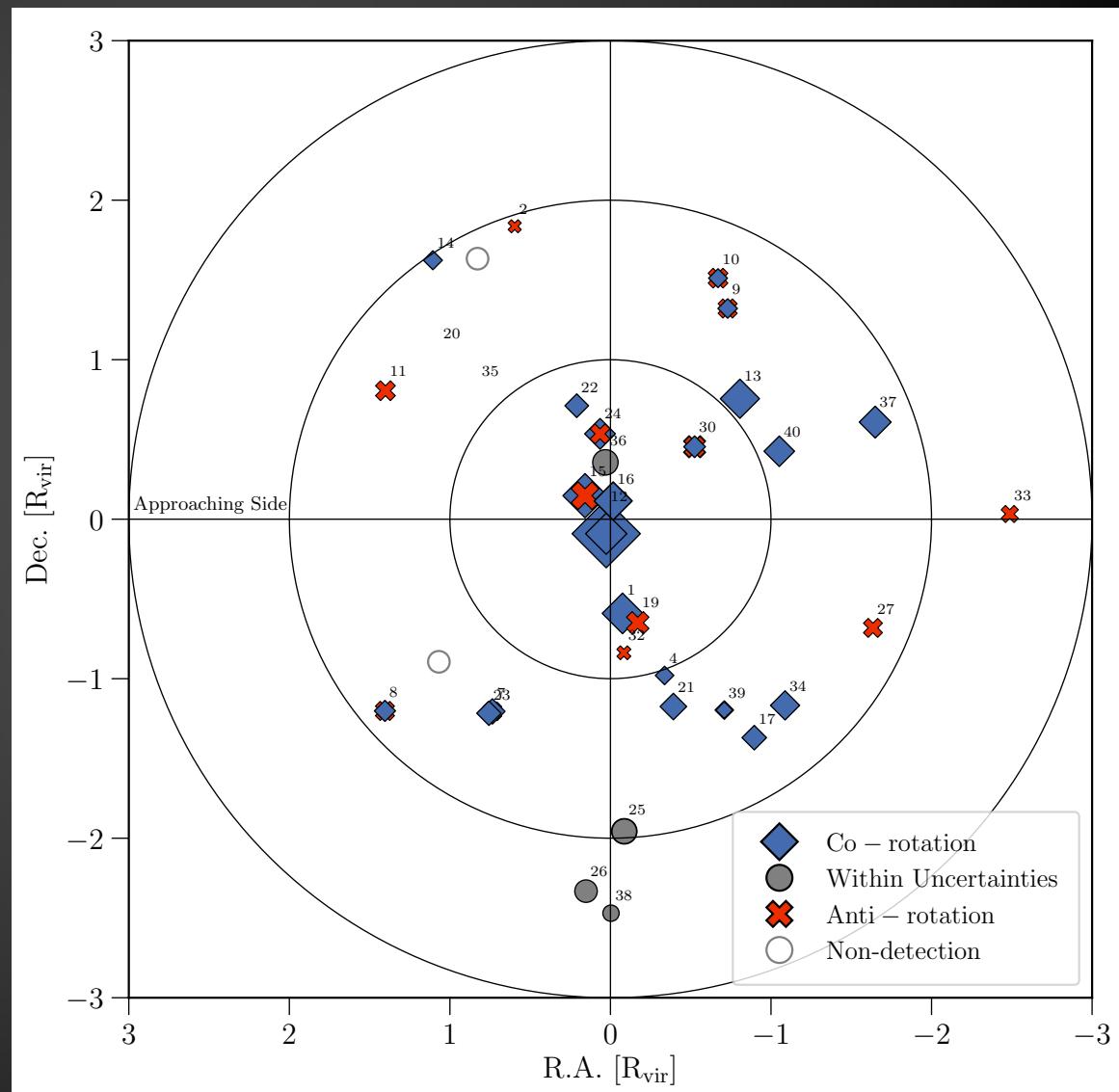


Ly-alpha co-rotation fraction

NFW halo model:

Only include Ly-alpha with
 $\Delta v = +/- v_{\text{rot}}$

63% co-rotating



Ly-alpha co-rotation fraction

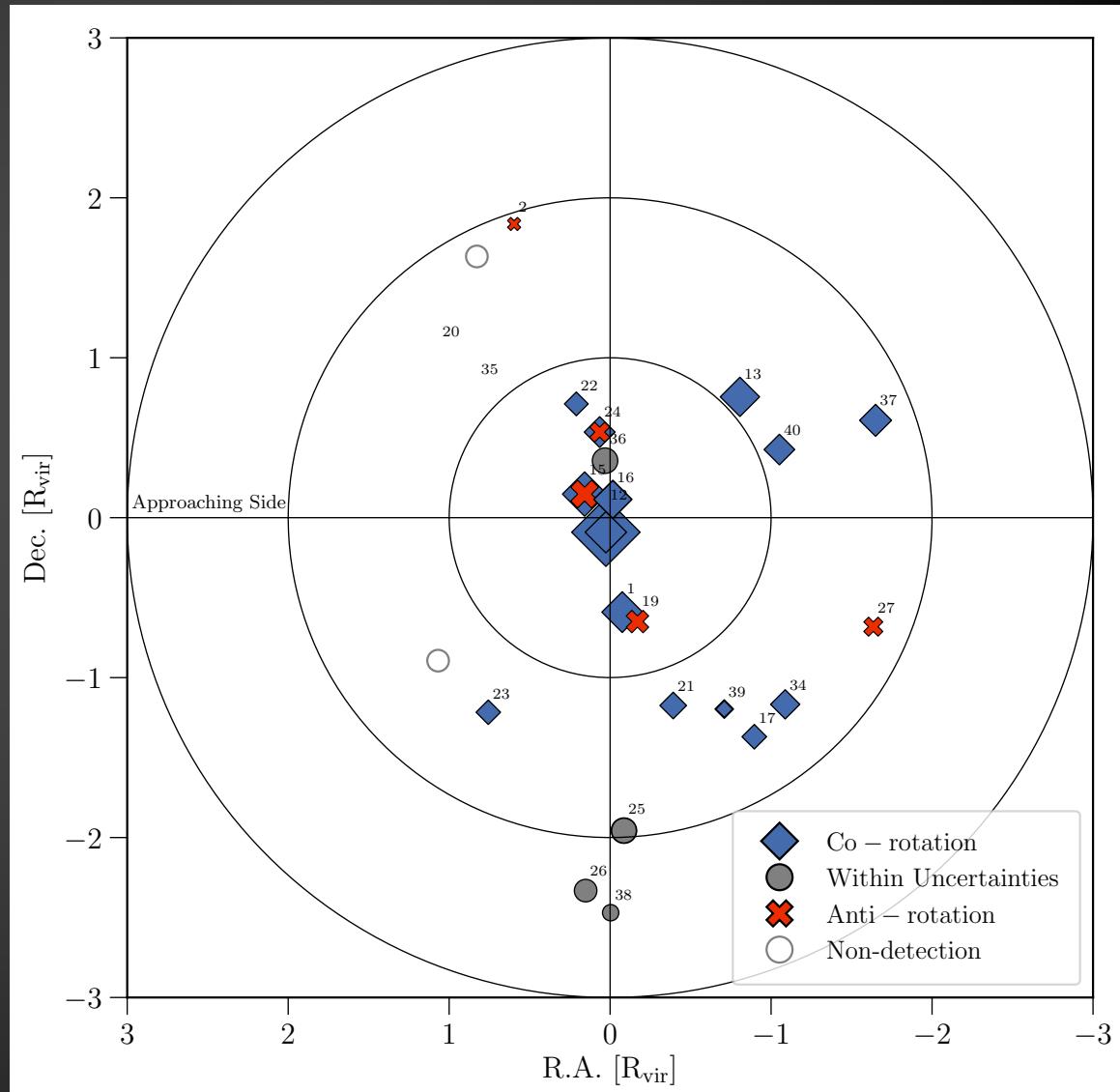
NFW halo model:

Only include Ly-alpha with
 $\Delta v = +/- v_{\text{rot}}$

Split around L^*

1.5 L^* and lower:

77% co-rotating



Ly-alpha co-rotation fraction

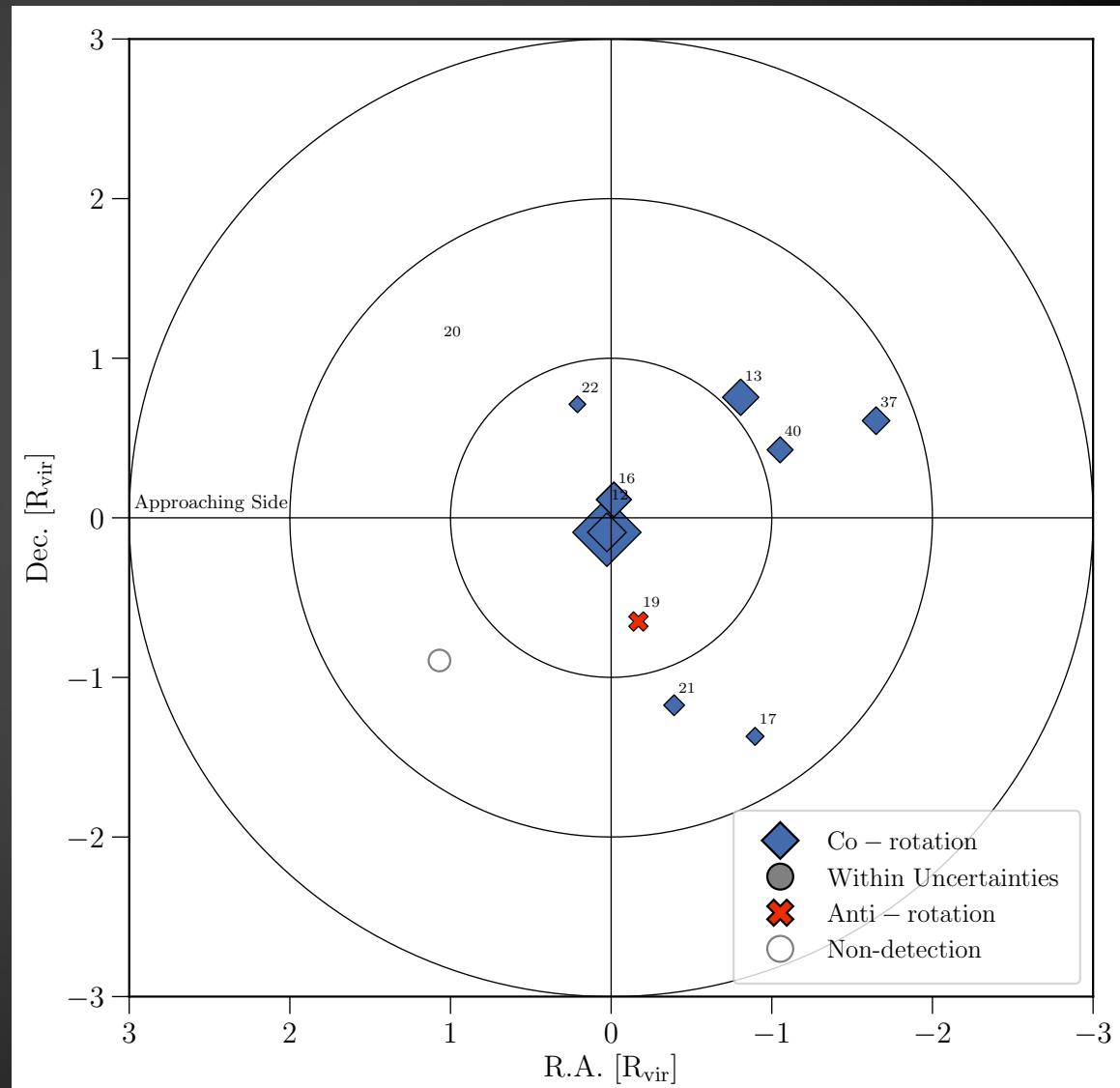
NFW halo model:

Only include Ly-alpha with
 $\Delta v = +/- v_{\text{rot}}$

Split around L^*

0.5 L^* and lower:

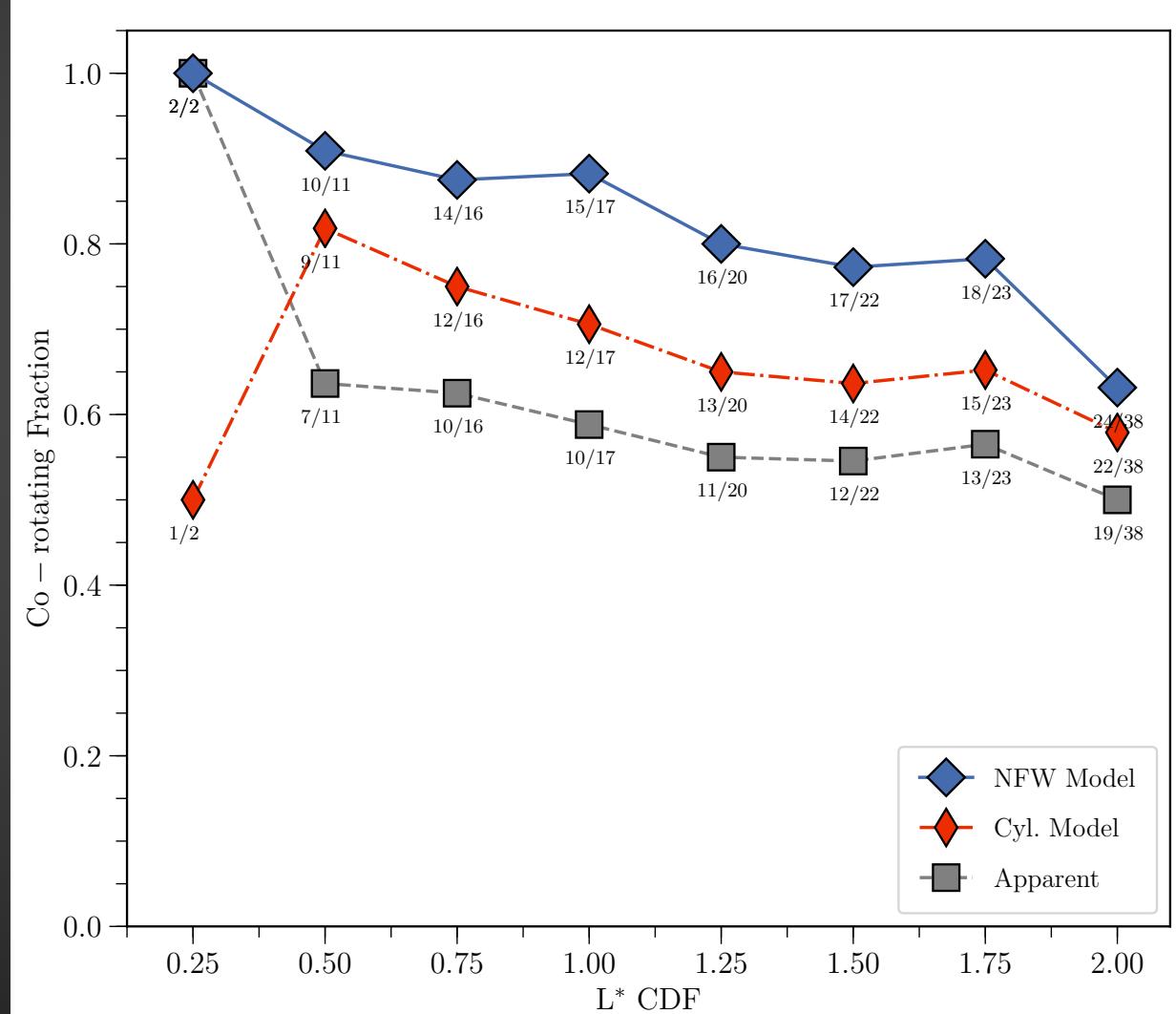
90% co-rotating



Ly-alpha co-rotation fraction

Co-rotation
fraction smoothly
decreases with
increasing L^*

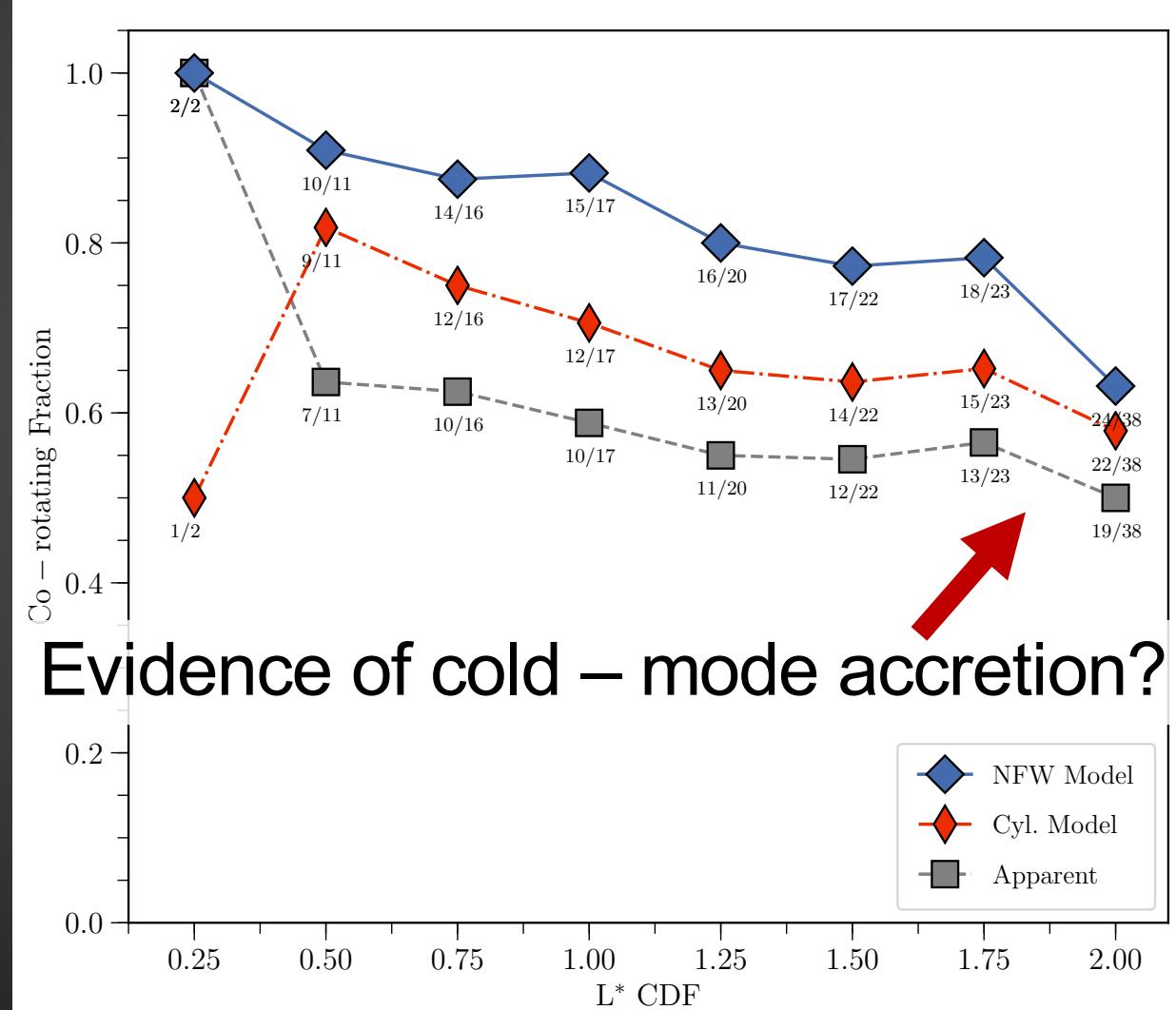
Model
independent



Ly-alpha co-rotation fraction

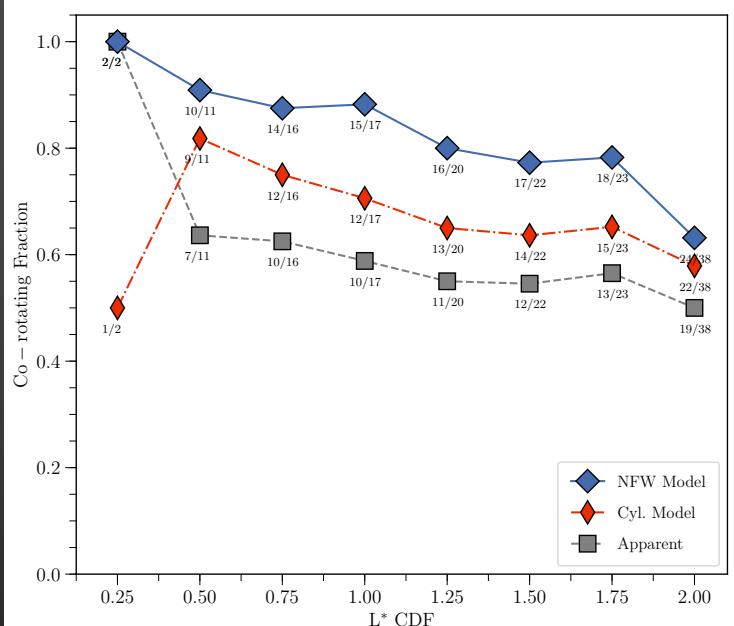
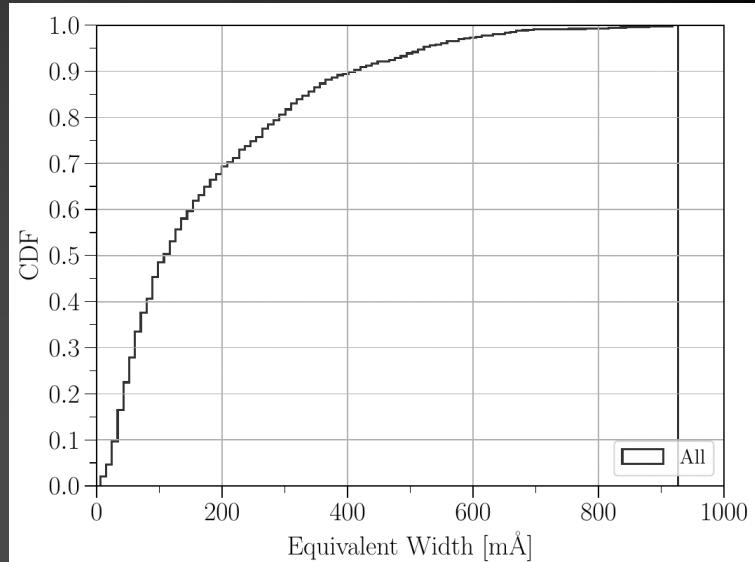
Co-rotation
fraction smoothly
decreases with
increasing L^*

Model
independent



Summary:

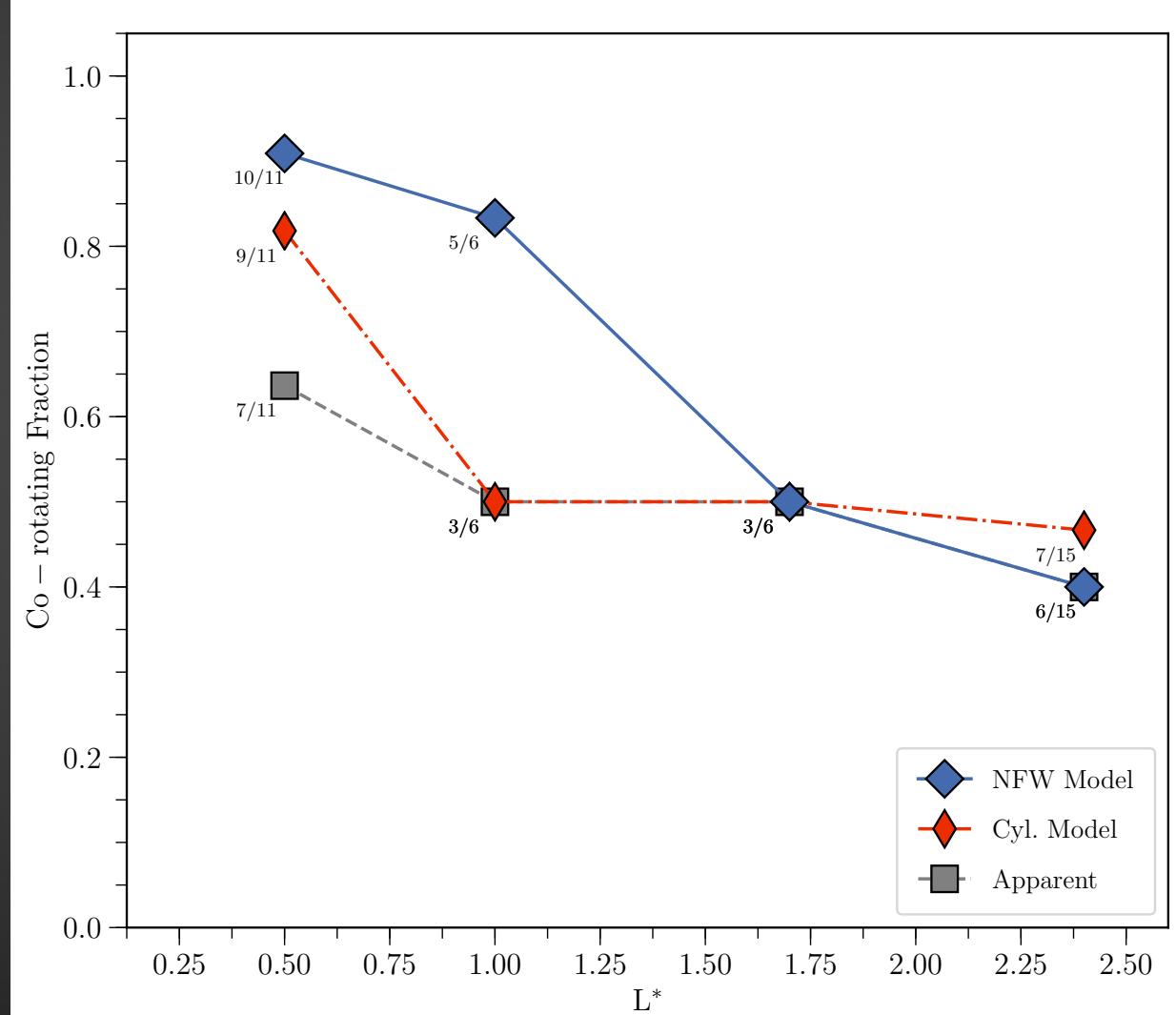
- **Correlating Ly-alpha from COS spectra with nearby galaxies**
 - 1004 absorbers - using likelihood method to pair with the galaxy environment
 - Denser environment leads to higher EW Ly-alpha
 - Bimodal distribution around major and minor axes
- **Galaxy halo kinematics**
 - Ly-alpha co-rotation fraction anti-correlates with galaxy L^* and relative distance
 - Evidence for halo-disk kinematic connection?
 - Cold – mode accretion?
- **Does CGM gas care about galaxies?**
 - Yes!



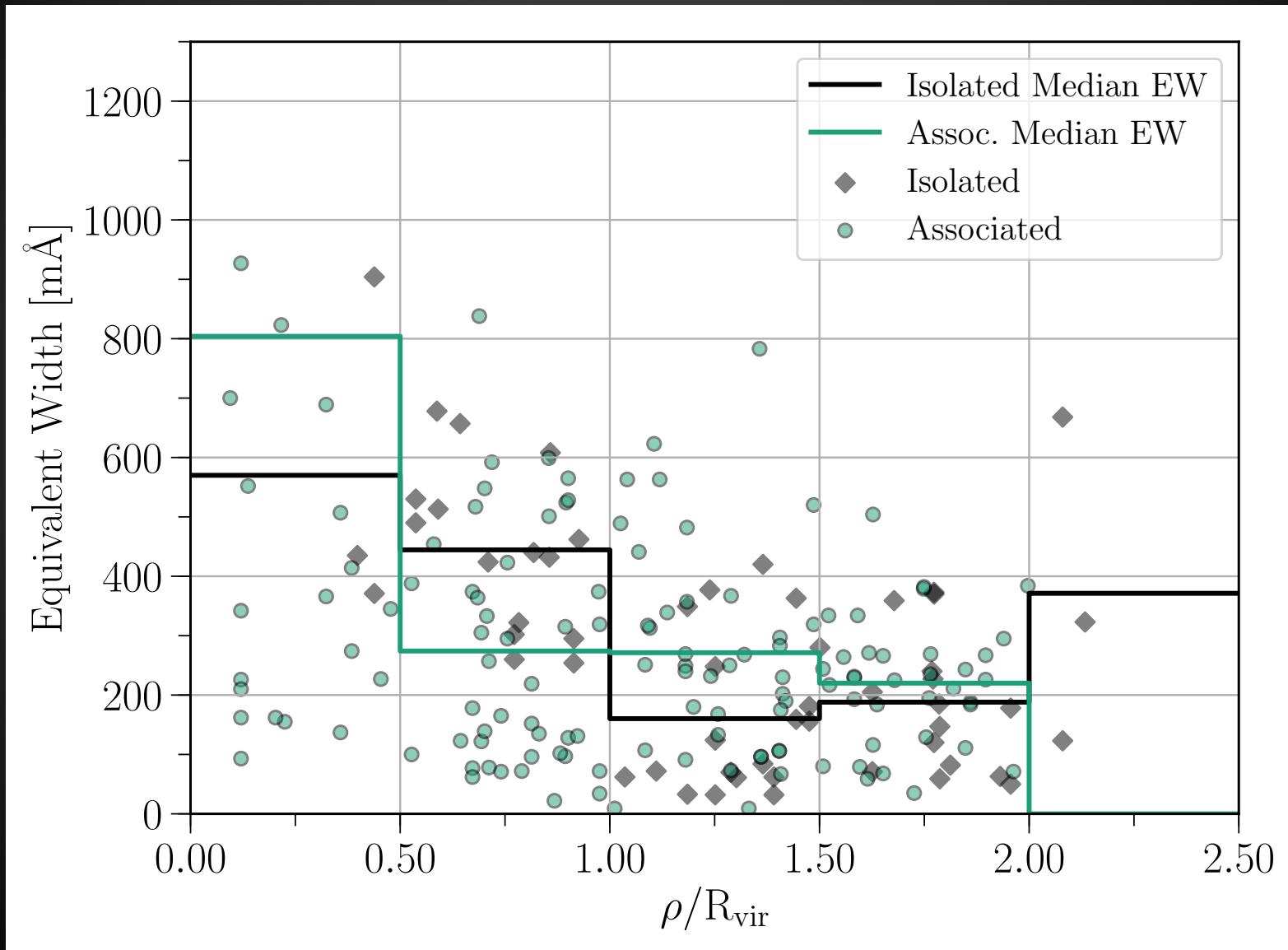
Ly-alpha co-rotation fraction

Co-rotation
fraction smoothly
decreases with
increasing L^*

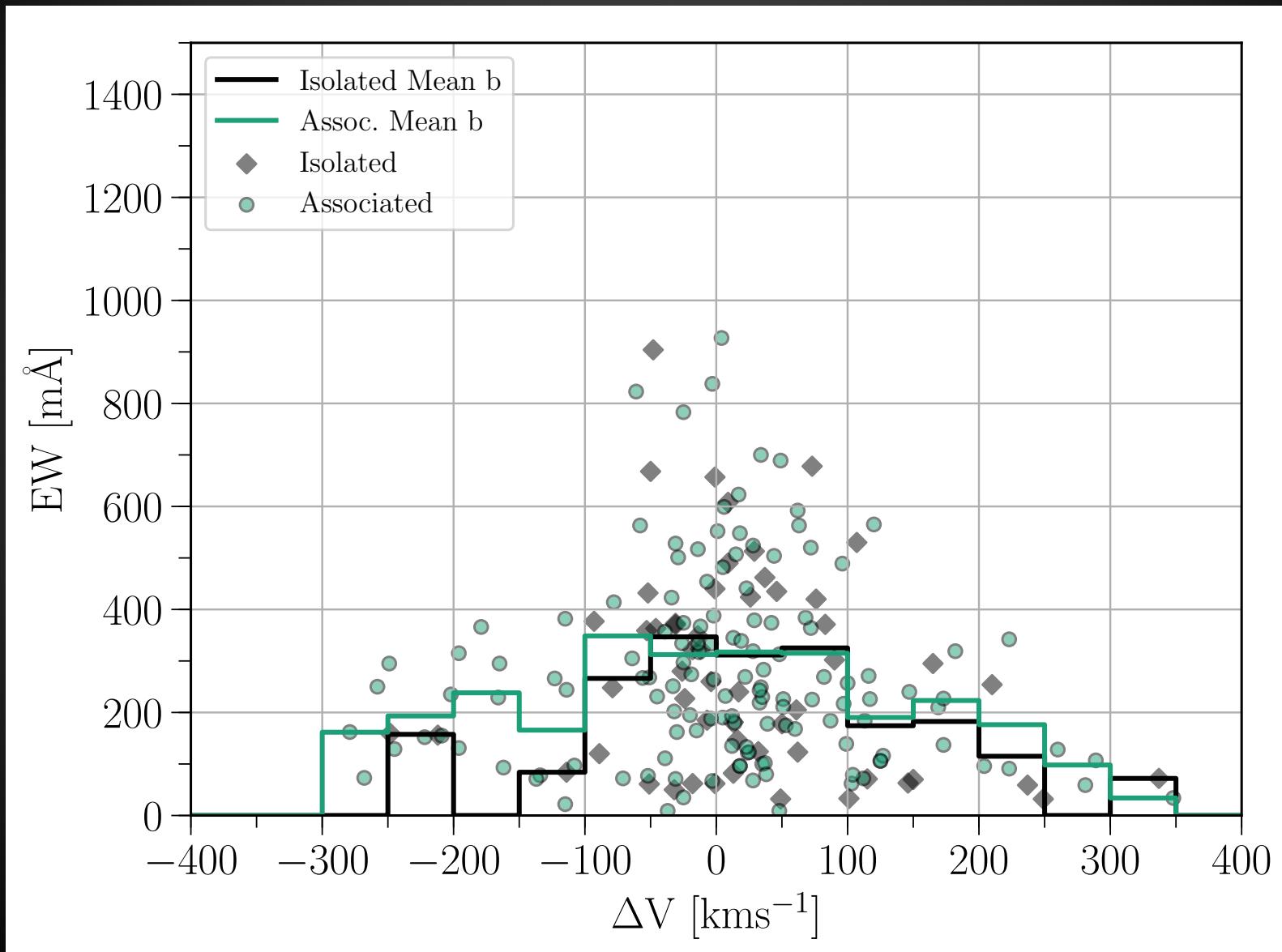
Model
independent



EW vs impact parameter

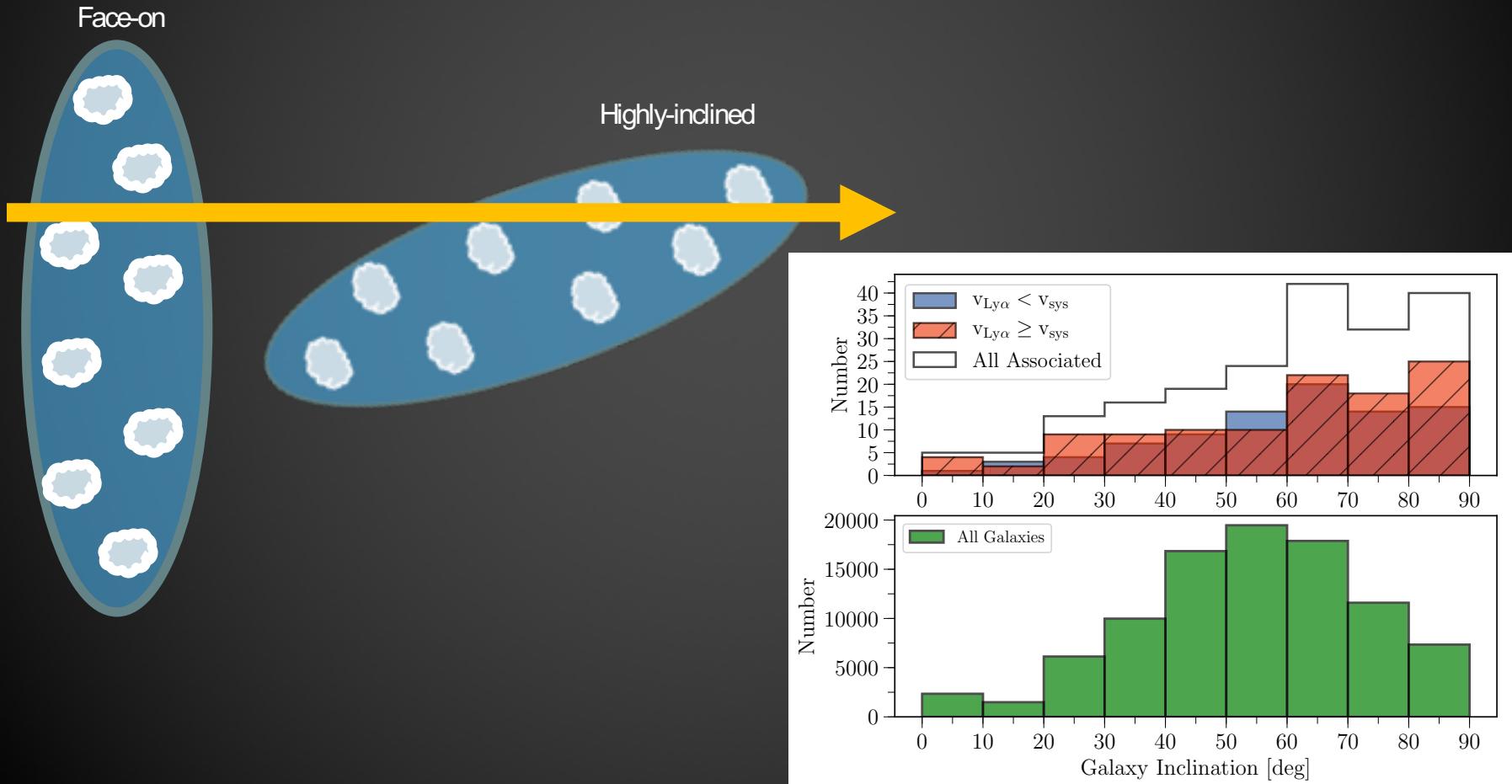


EW vs velocity separation



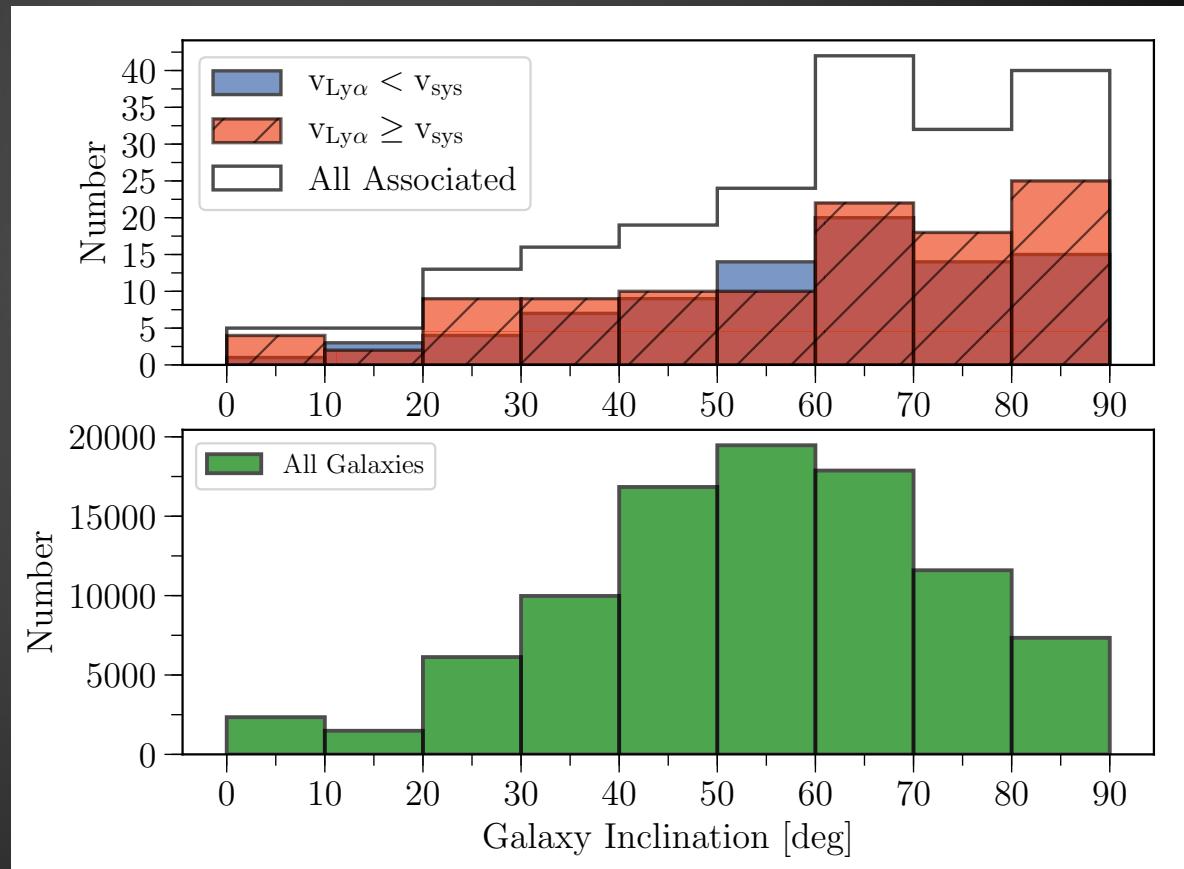
Inclination overabundance

- **Evidence of non-spherical halo?**
 - Covering fraction of Ly-alpha < 1



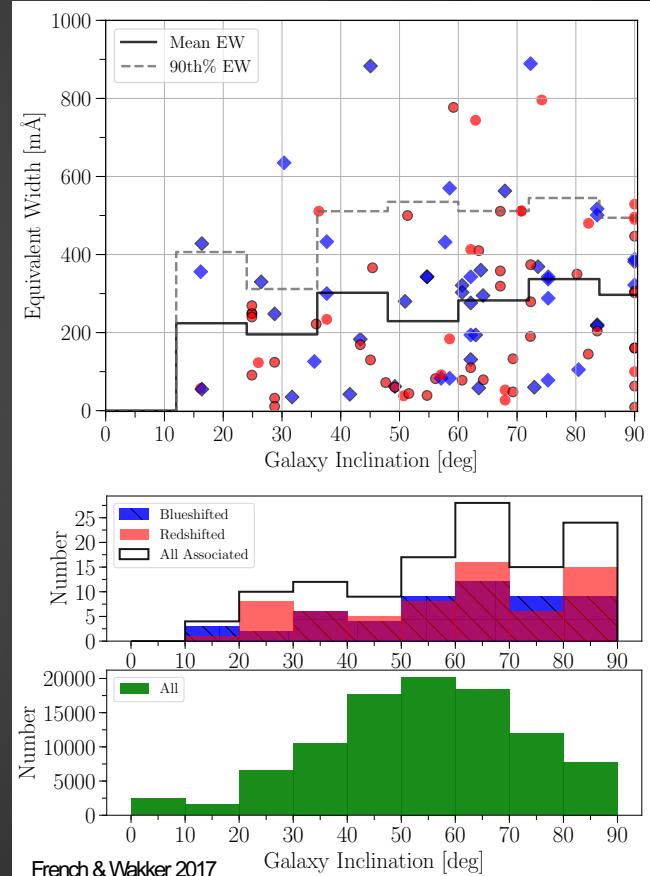
Preliminary Results

Inclinations:



Summary:

- **700+ COS spectra correlated with 130,000+ galaxies**
 - Expect ~3000 Ly-alpha absorbers
 - ~1000 absorber-galaxy pairs using likelihood method
 - Strong EW – ΔV correlation
 - Overabundance around highly inclined galaxies
- **Model sightline velocity structure**
 - Evidence for halo-disk kinematic connection?
- **Does CGM gas care about galaxies?**
 - It seems like it might!



French & Wakker 2017