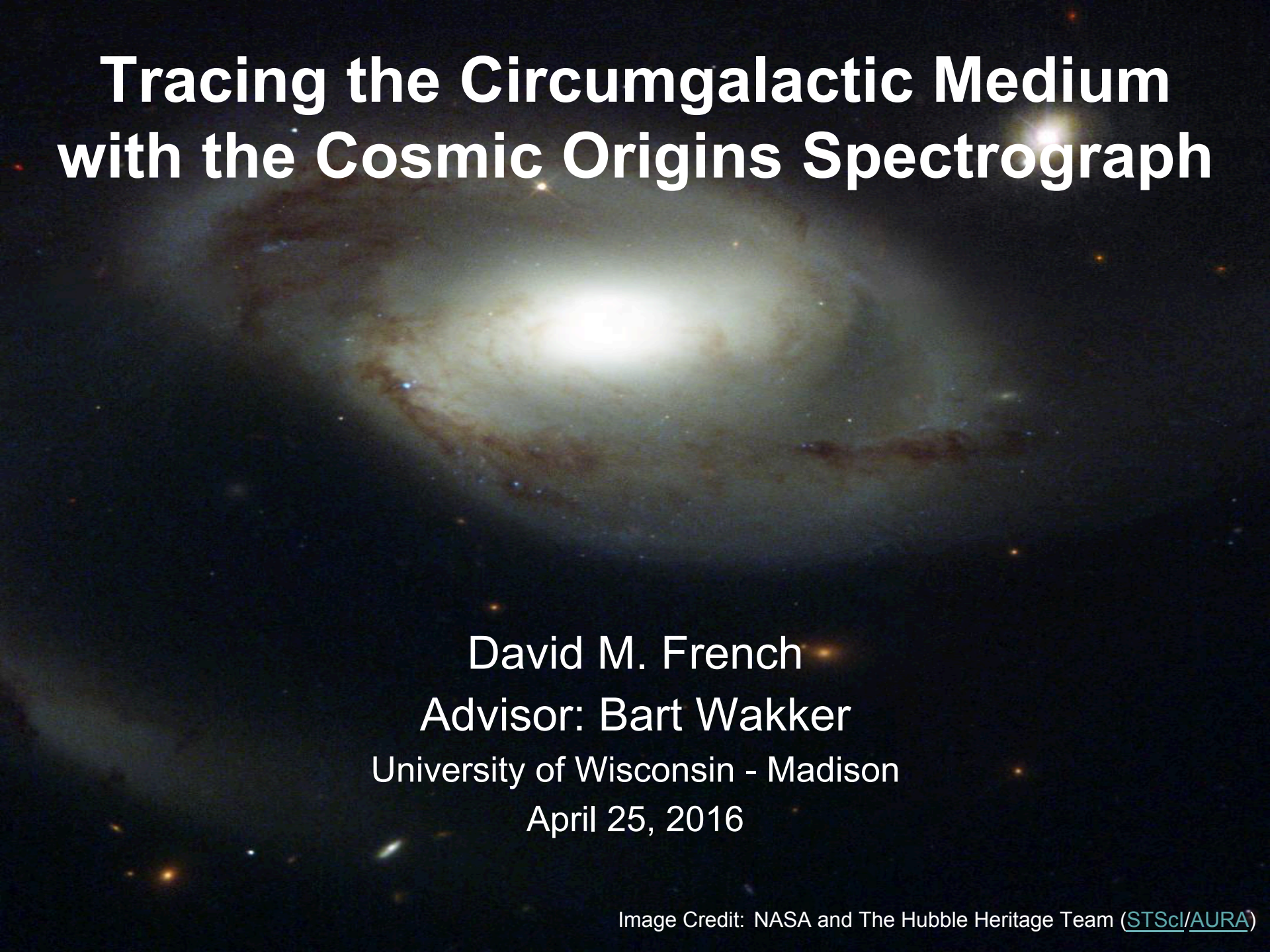
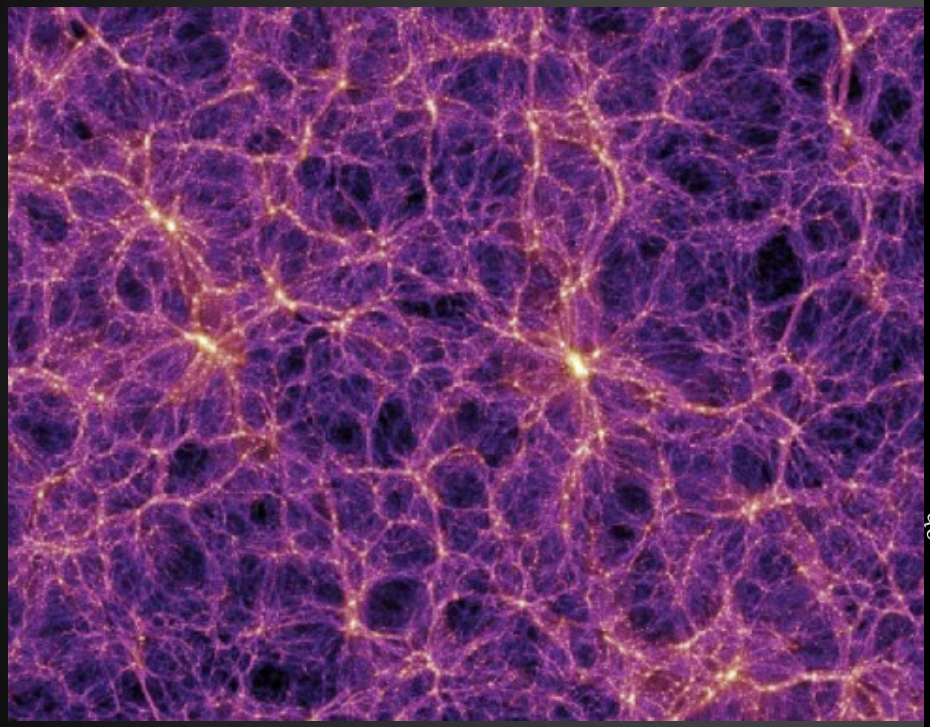
Tracing the Circumgalactic Medium with the Cosmic Origins Spectrograph



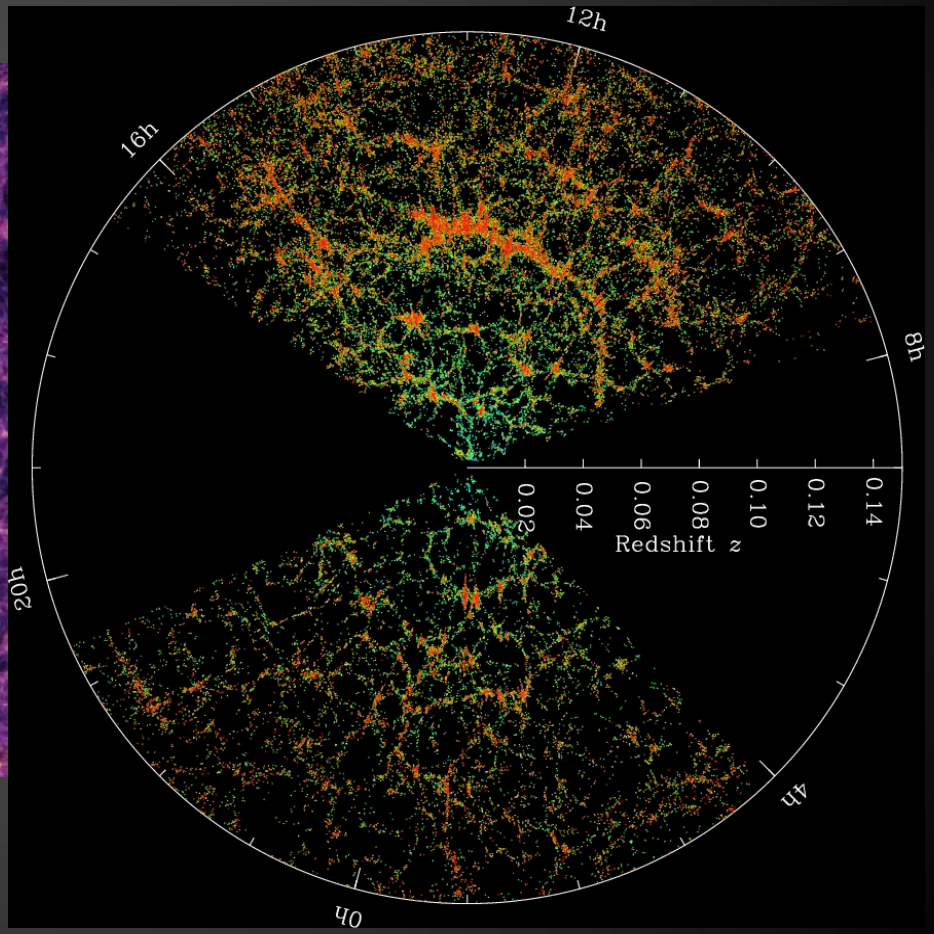
David M. French
Advisor: Bart Wakker
University of Wisconsin - Madison
April 25, 2016

Image Credit: NASA and The Hubble Heritage Team (STScI/AURA)

Gas in the Universe



The Millenium Simulation



SDSS Collaboration

The gas nearby galaxies

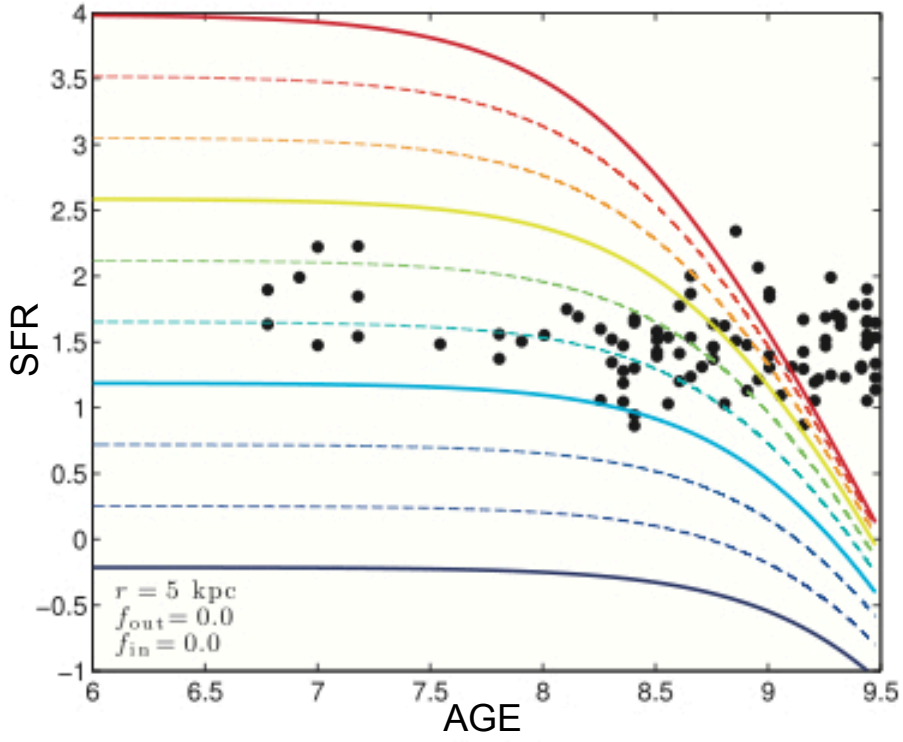
- Gas and galaxies both follow DM potential

- Do they “know” about each other?

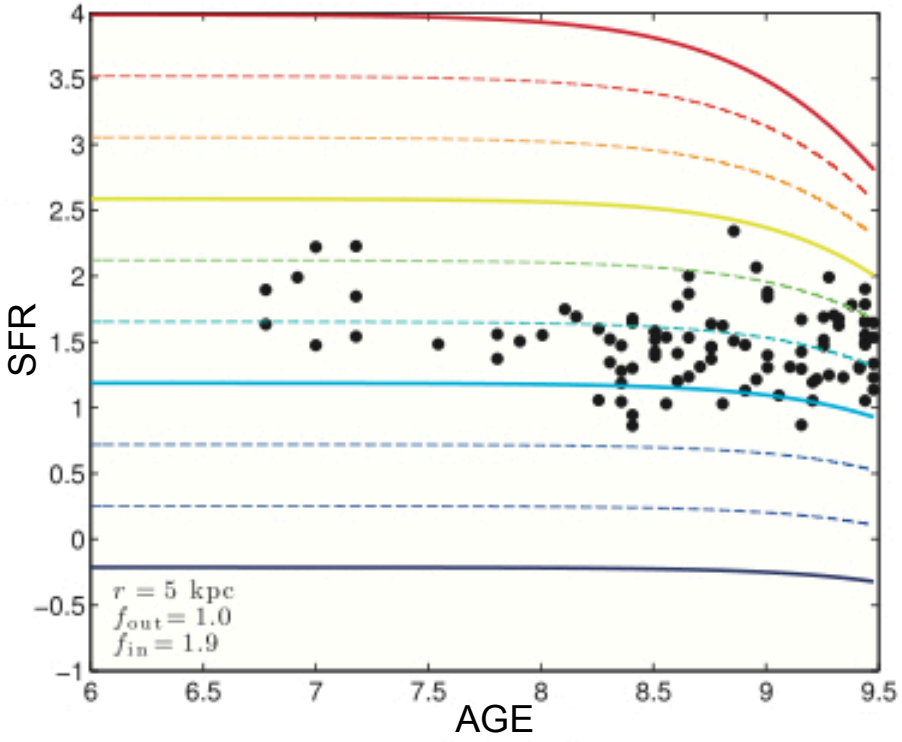
    - i.e. Do gas properties depend on galaxies?

Accretion required

With no accretion



With accretion



Erb 2008

Understanding the CGM

- Galaxies need to continue accreting gas over cosmic time to match observations

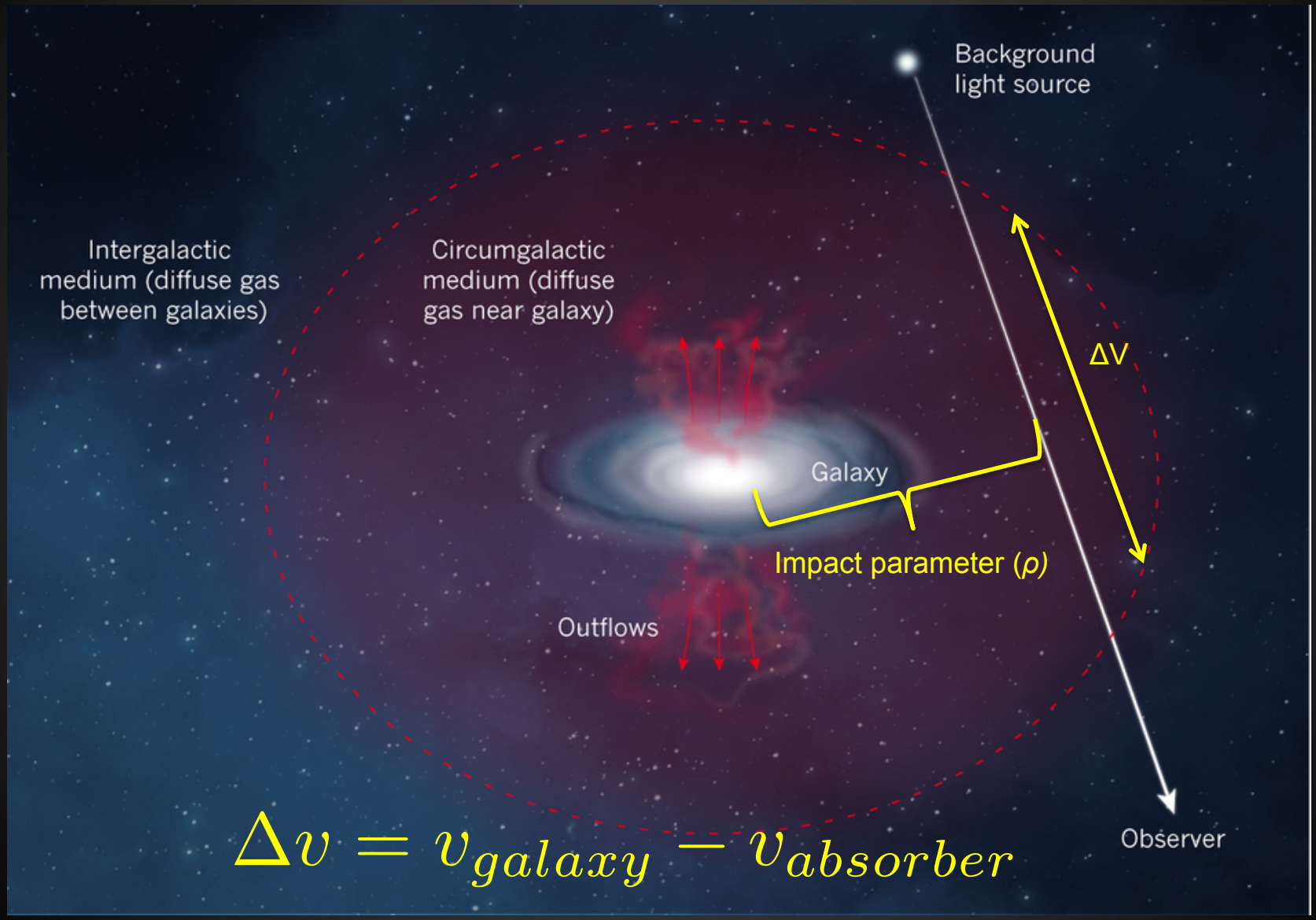
- Feedback kicks gas out of galaxies

How do the properties of gas correlate with associated galaxy properties?

Science Outline

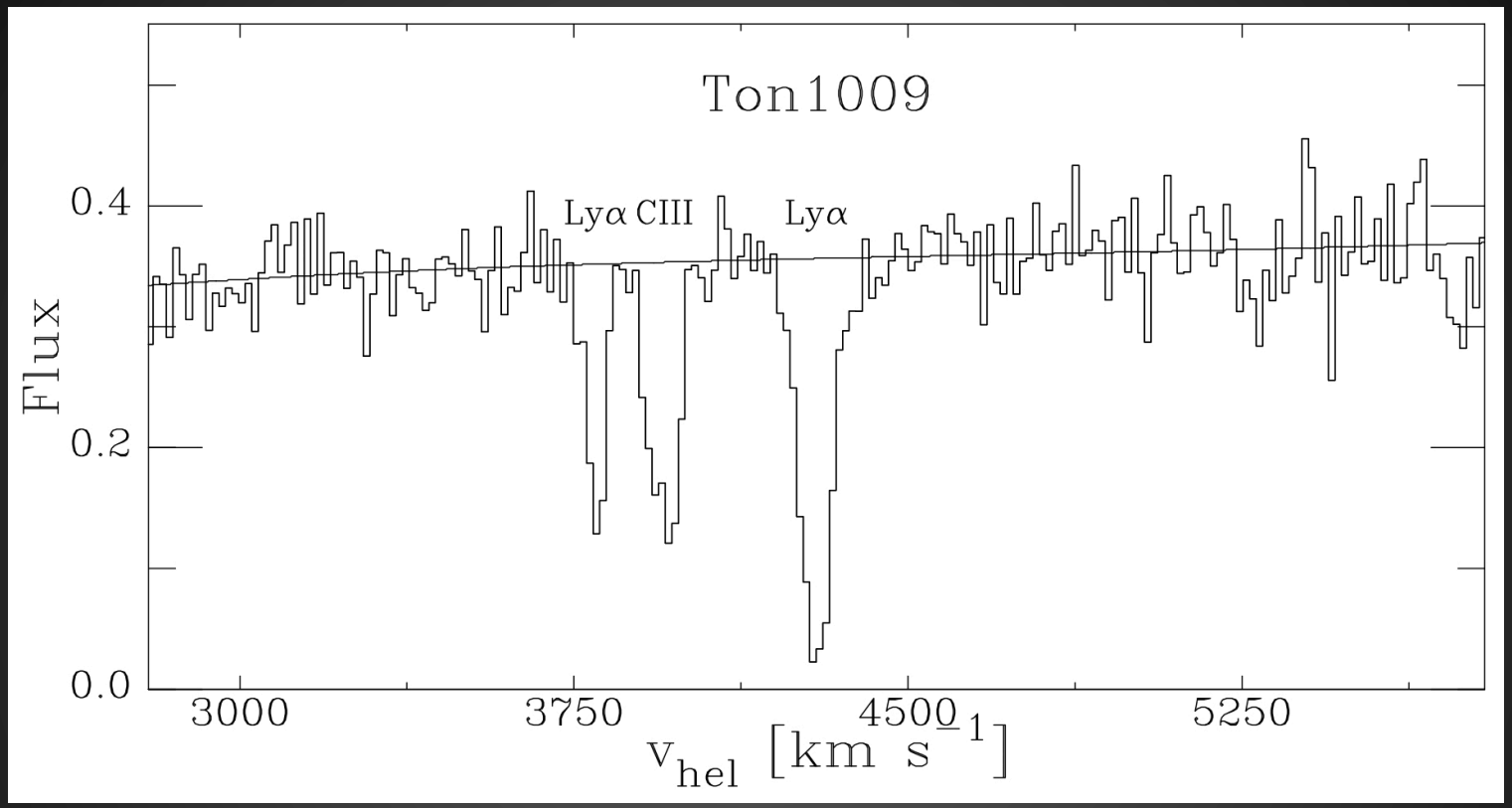
- *Use archival COS sightlines (~300)*
- *Stay close ($z < 0.034$, $cz < 10{,}000$ km/s)*
  - *Available galaxy data complete to ~0.1 L**
- *Automate associating galaxies – absorbers*
- *Ask: (absorber velocity, EW, frequency) as a function of (Galaxy size, orientation, position)*

Defining the CGM



Nature 517, 444

Associating galaxies with absorbers



Is this Lyα absorber associated with a galaxy?

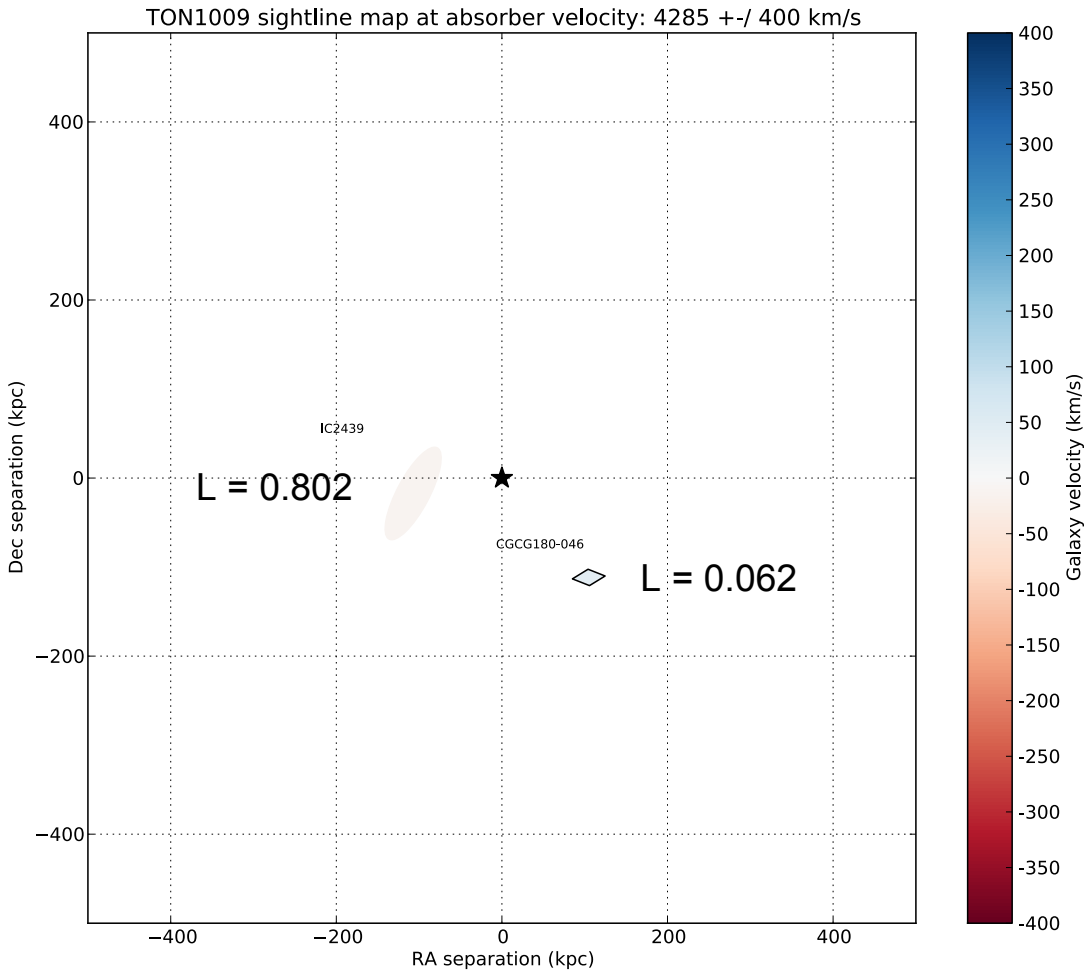
Associating galaxies with absorbers

- 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
- Require $\mathcal{L}_1 \geq 5 * \mathcal{L}_2$ and $\mathcal{L} \geq 0.001$

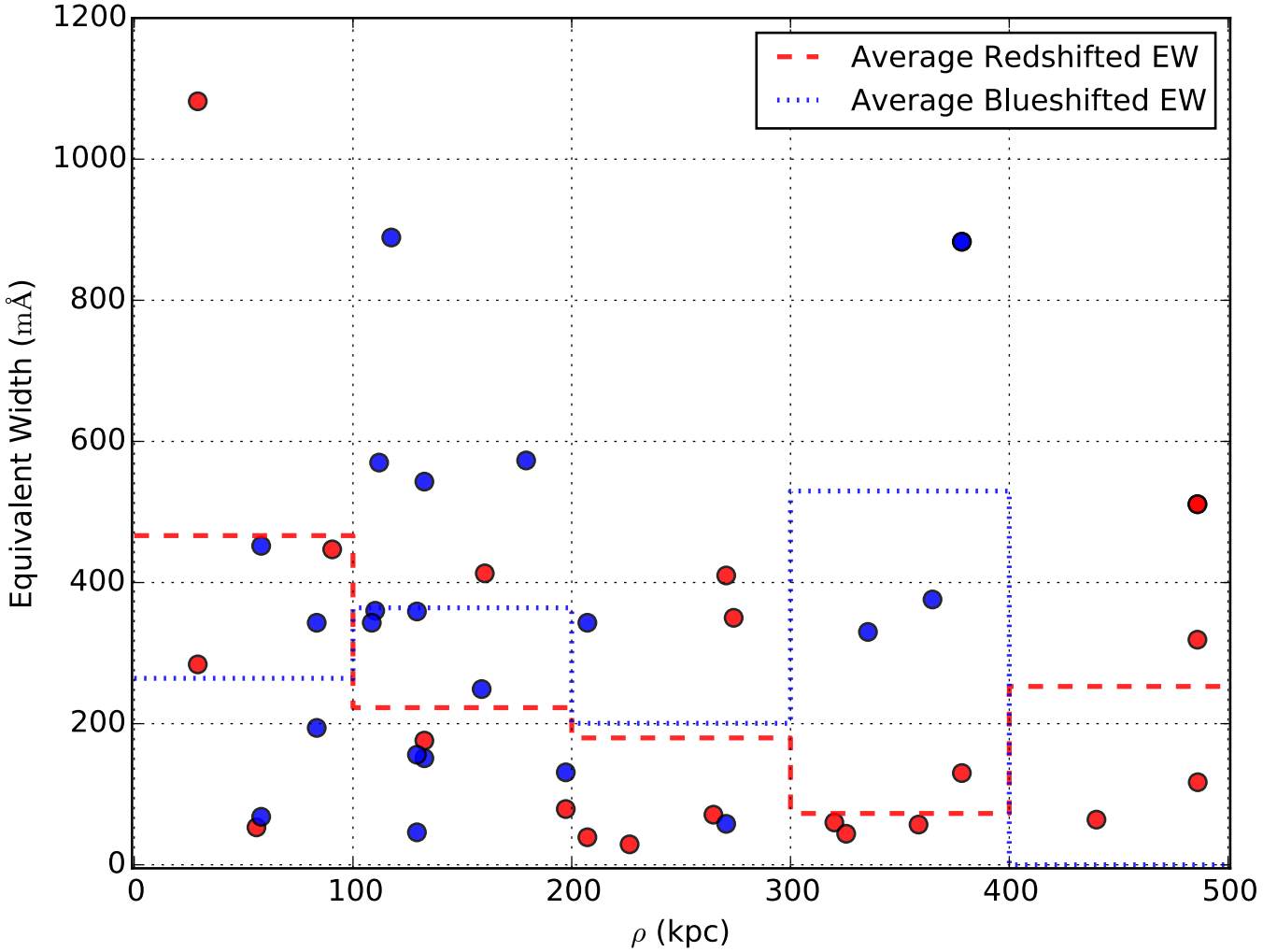
Associating galaxies with absorbers



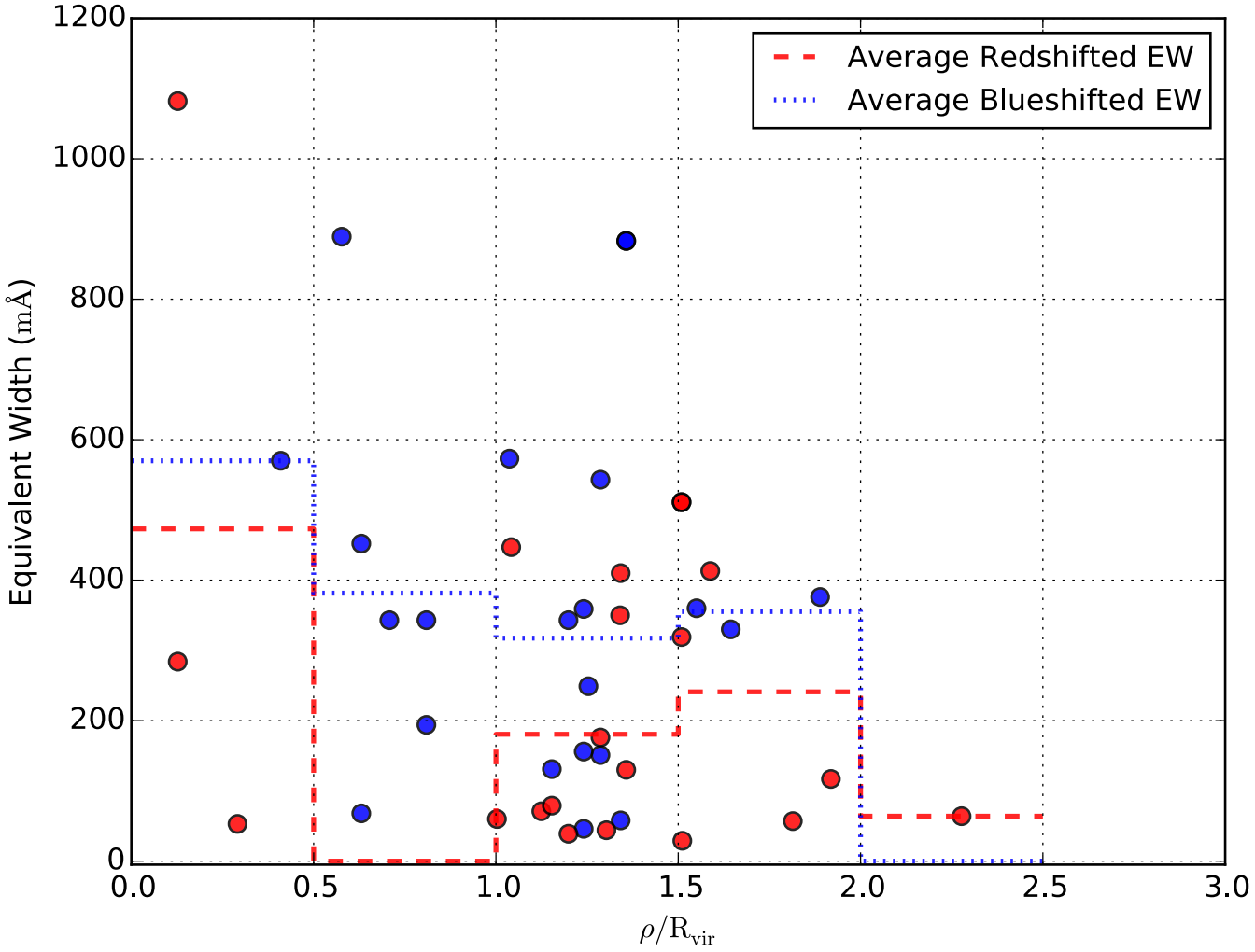
Results so far…

- 35 COS sightlines analyzed
- 175 Lyα lines
  - 41 associated
  - 44 ambiguous (no best match)
  - 88 IGM (no galaxies nearby)

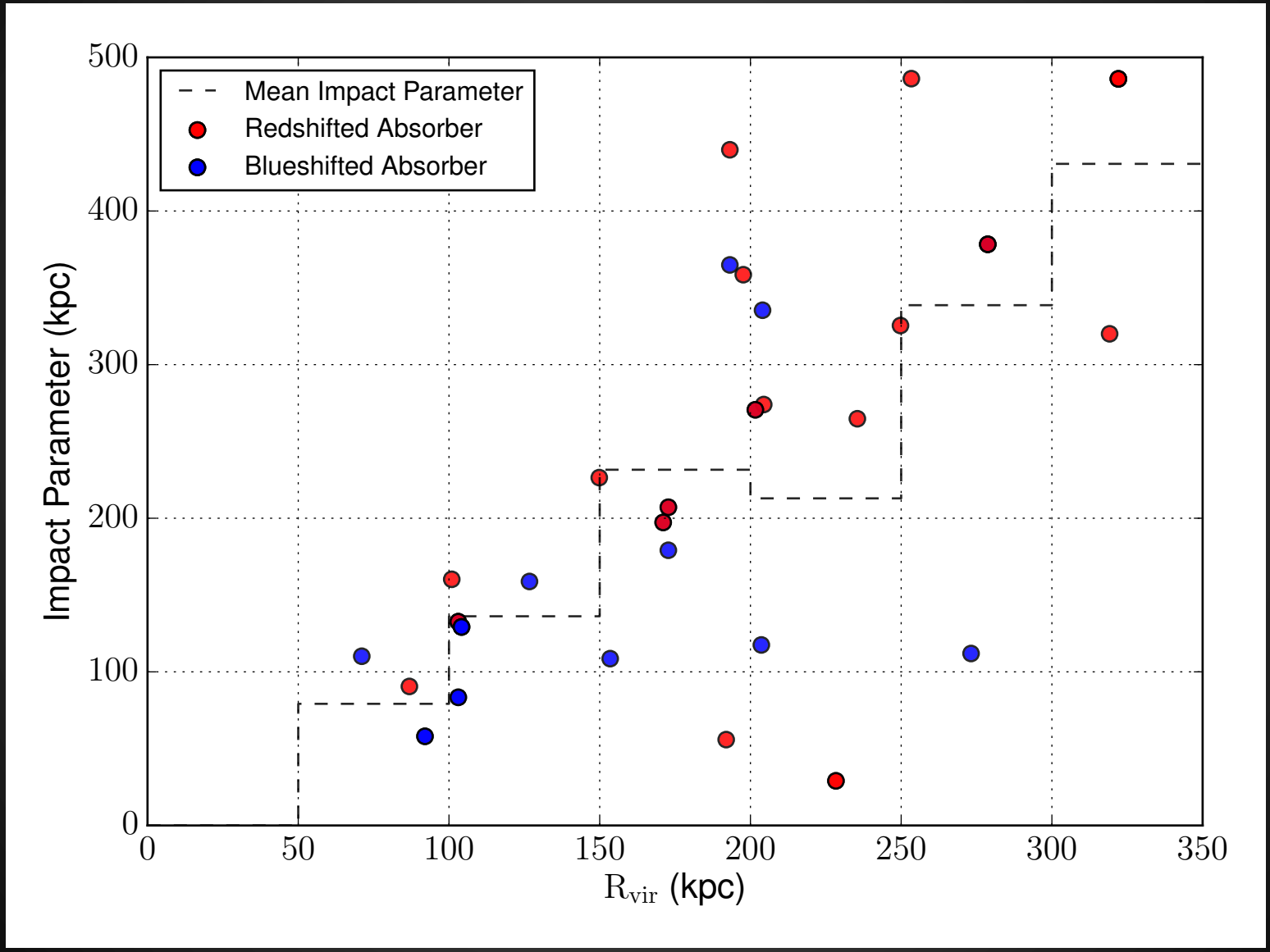
Impact parameter



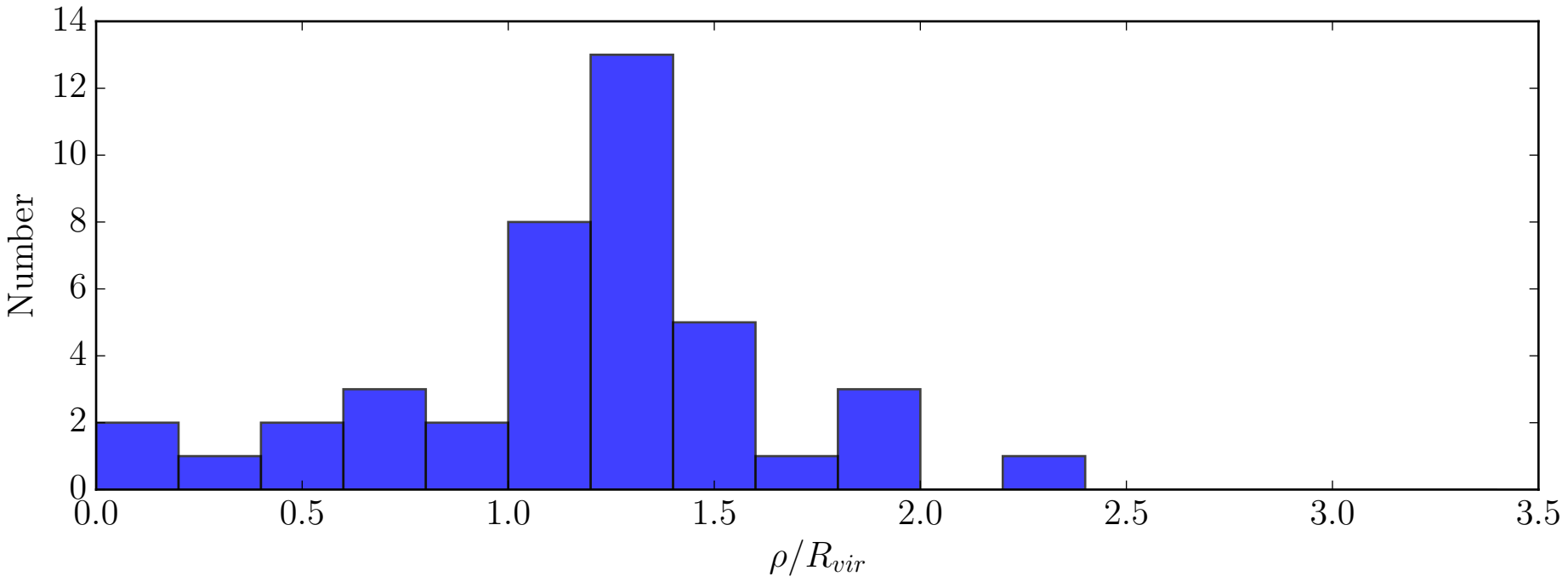
Impact parameter / R_{vir}



Impact parameter vs R_{vir}

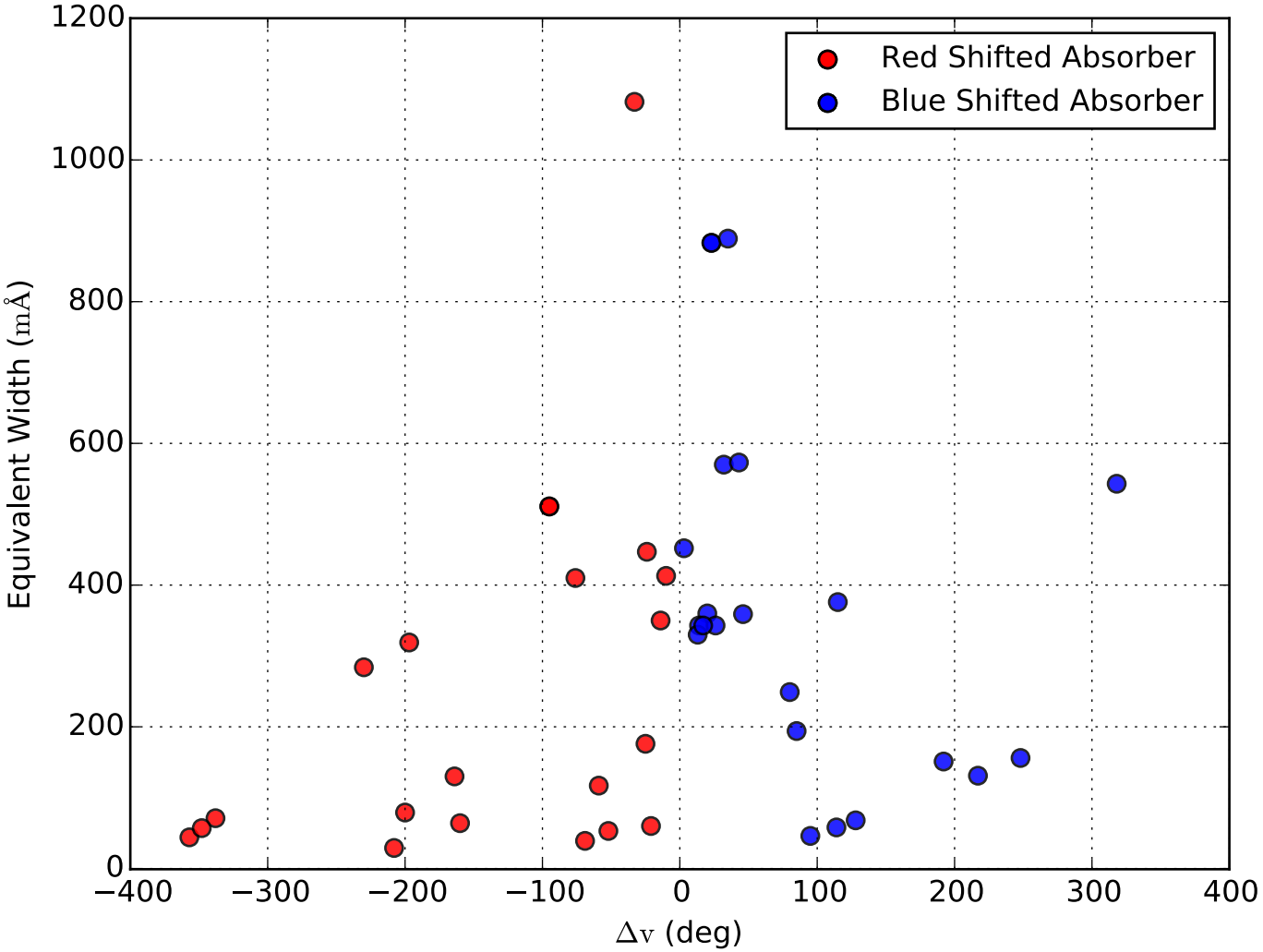


Impact parameter / R_{vir}



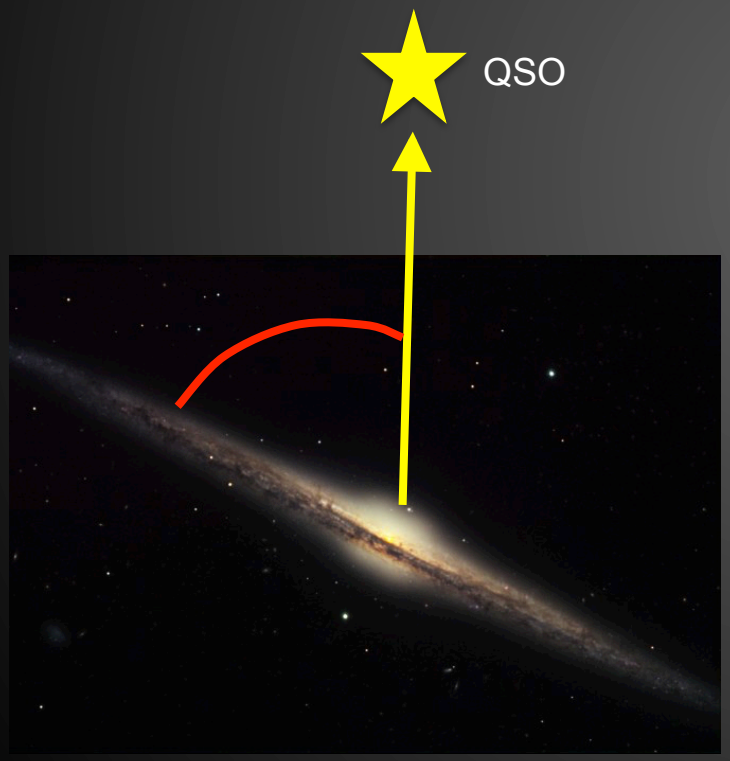
Most absorbers are found around $\frac{\rho}{\mathrm{R_{vir}}} = 1.2$

EW vs Δv

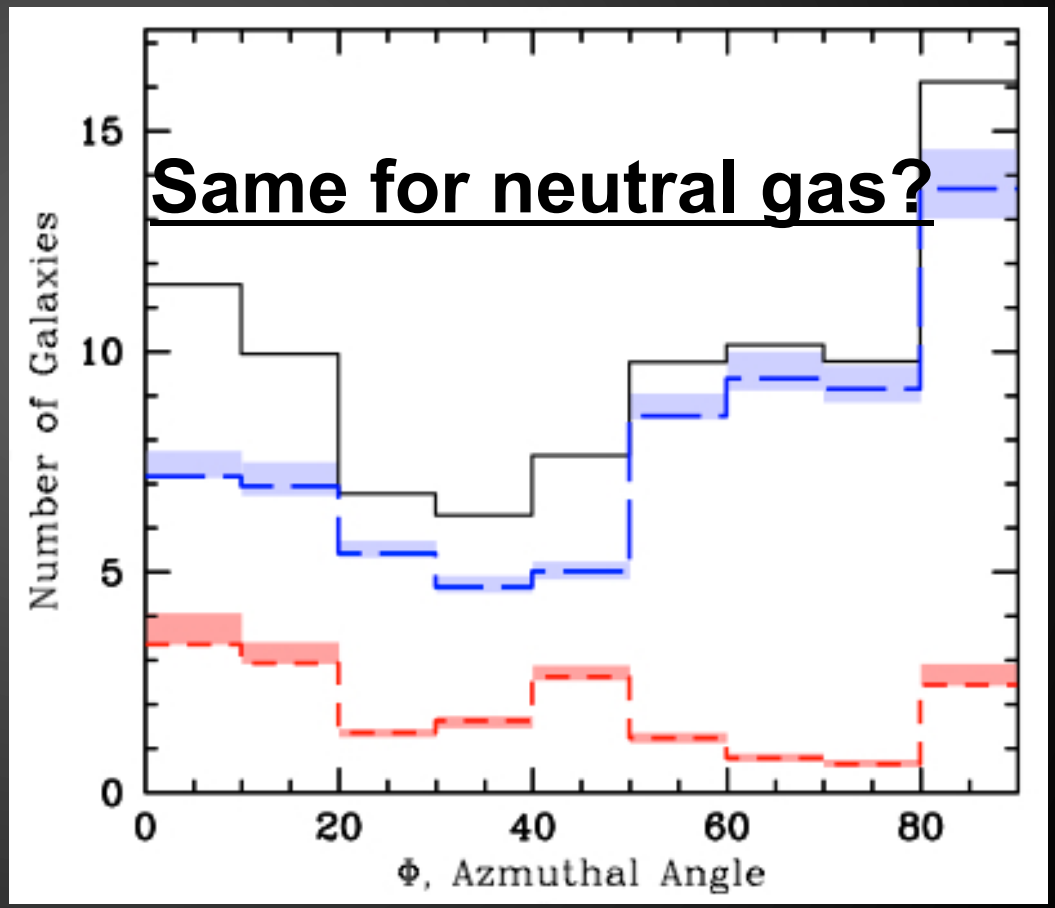

Red Shifted Absorber
Blue Shifted Absorber
Equivalent Width (mÅ)
Δv (deg)
1200
1000
800
600
400
200
0
−400
−300
−200
−100
0
100
200
300
400

How do CGM absorber properties depend on galaxy orientation?

- *Major vs minor?*



Credit: Bruce Hugo & Leslie Gaul, Adam Block, NOAO, AURA, NSF

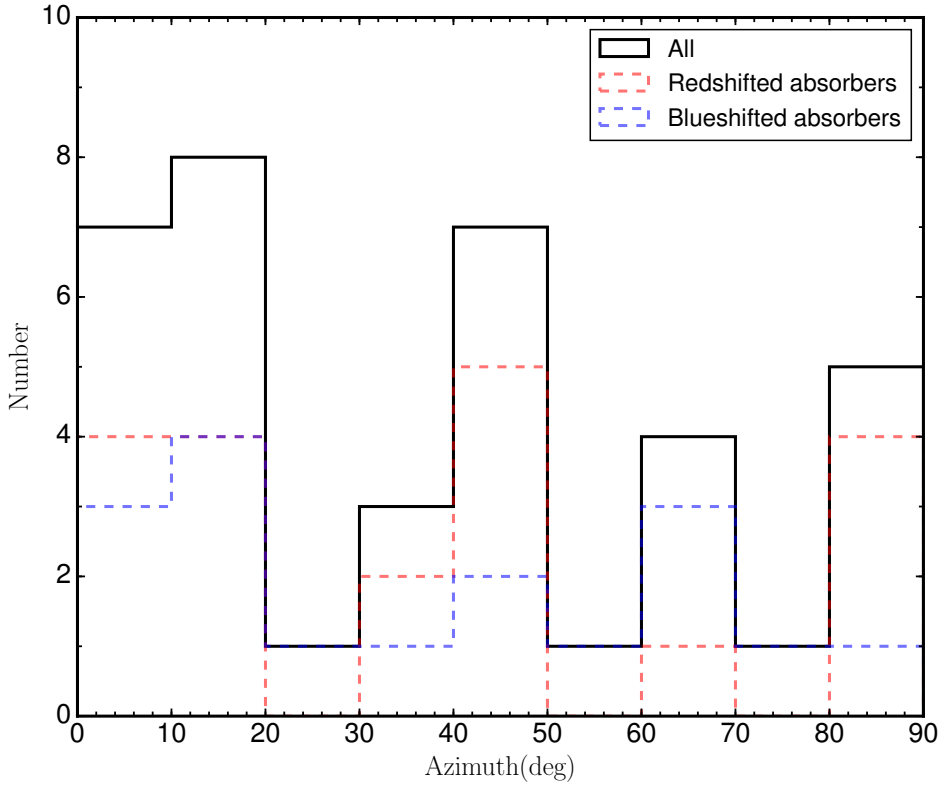


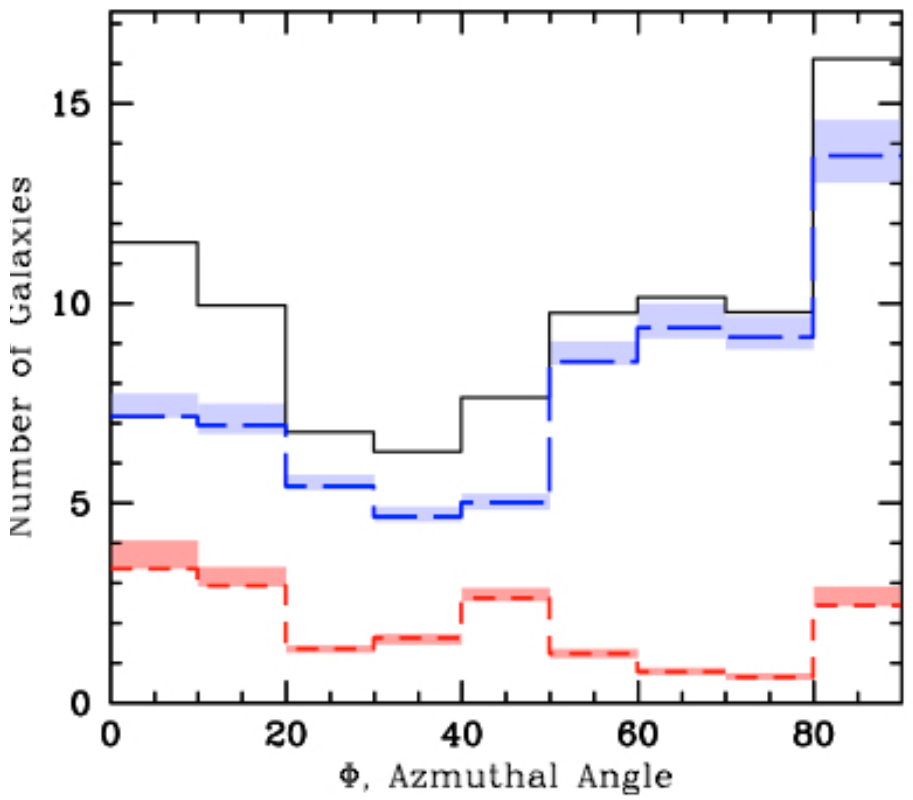
Kacprzak et al. 2012

How do CGM absorber properties depend on galaxy orientation?

Lyα

MgII

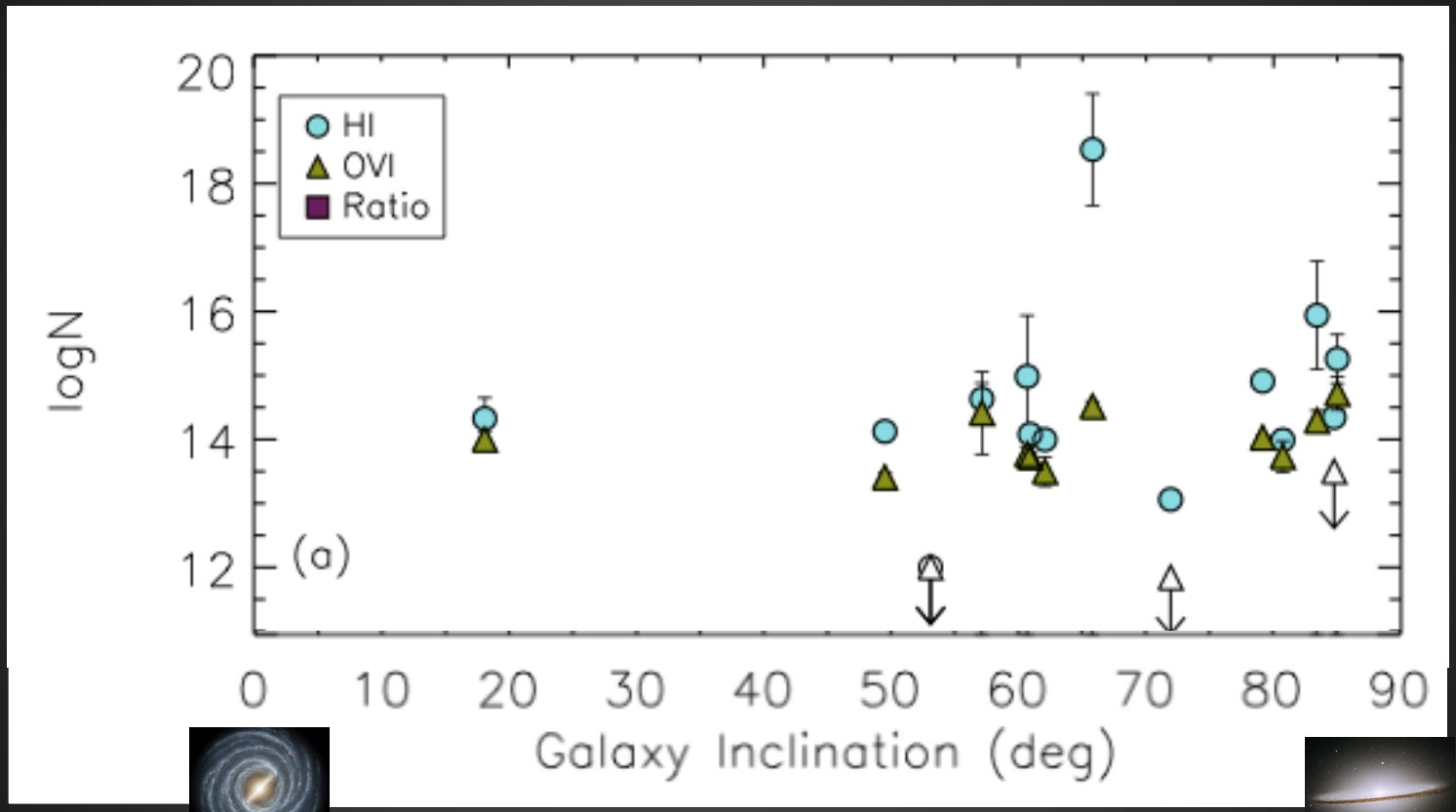




Kacprzak et al. 2012

Galaxy Inclination

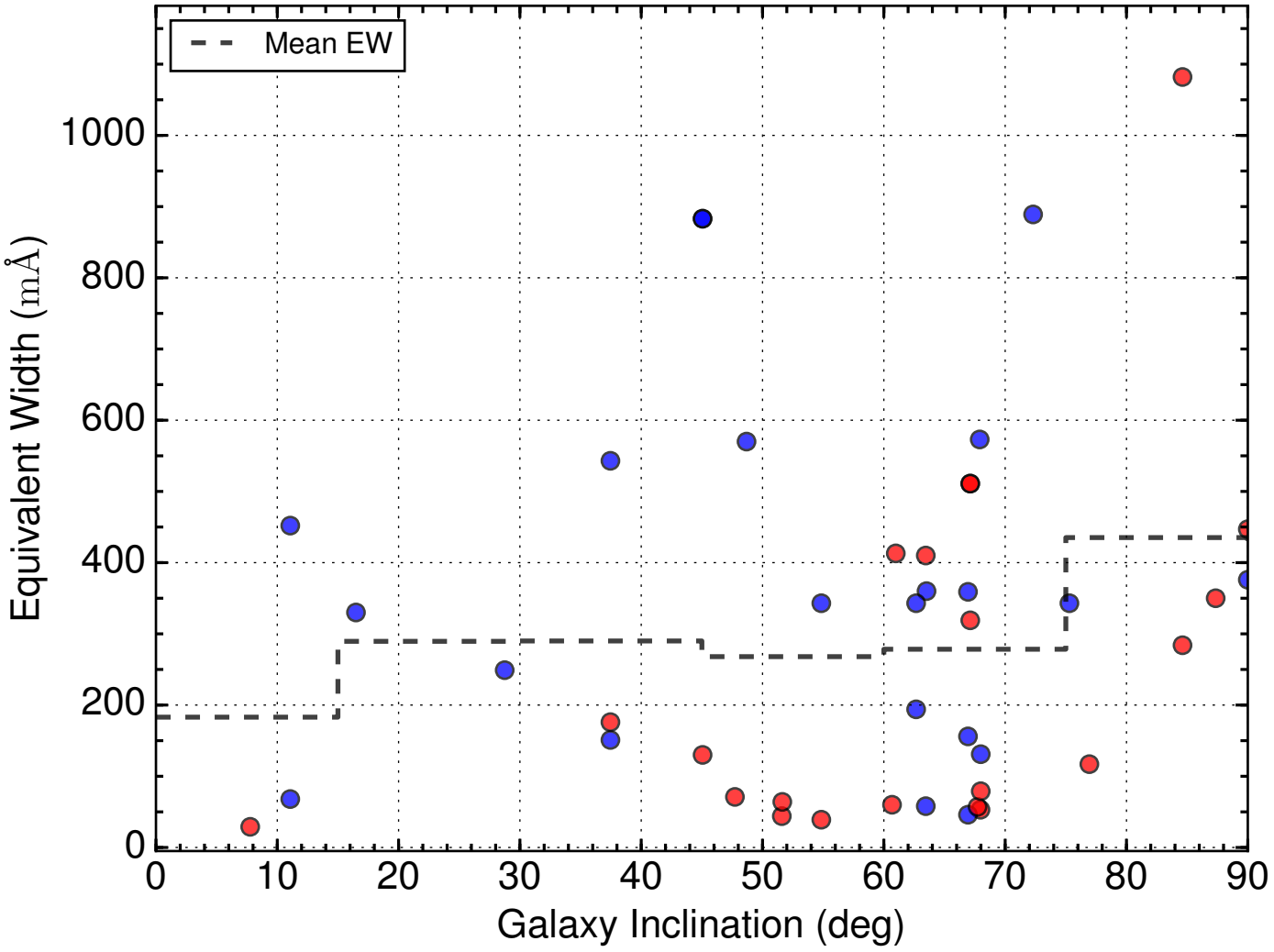
No?



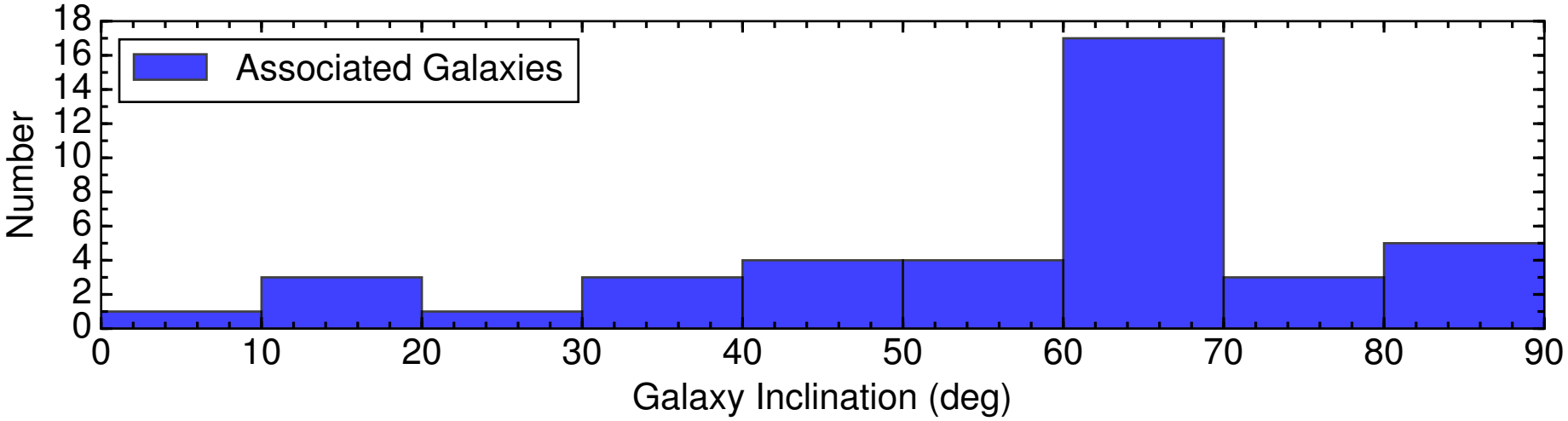
Mathes et al. 2014

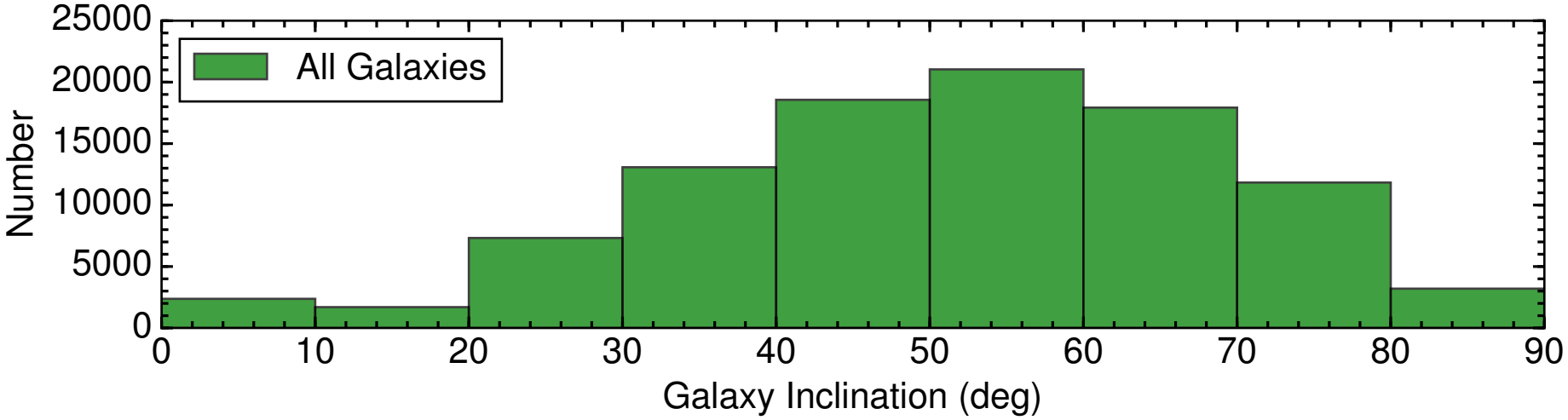
Galaxy Inclination

Maybe?

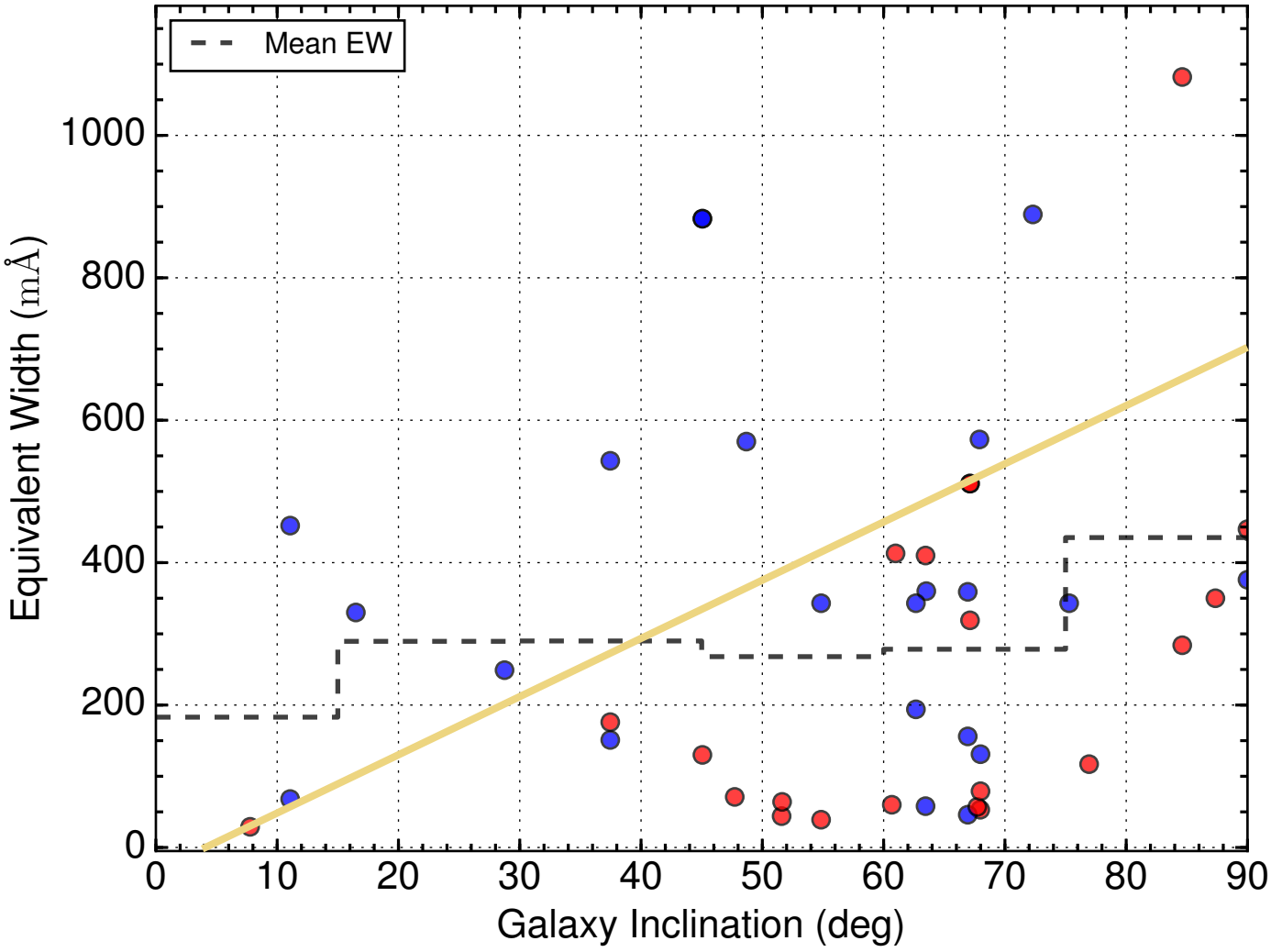


Galaxy Inclination





EW dichotomy



EW dichotomy

- Median EW(blueshifted) = 343 +/- 10 mÅ
- Average = 353 +/- 12 mÅ

- Median EW(redshifted) = 124+/- 9 mÅ
- Average = 236 +/- 16 mÅ

- The difference: KS p-value = 0.04

- Why?
  - Inflows/outflows?

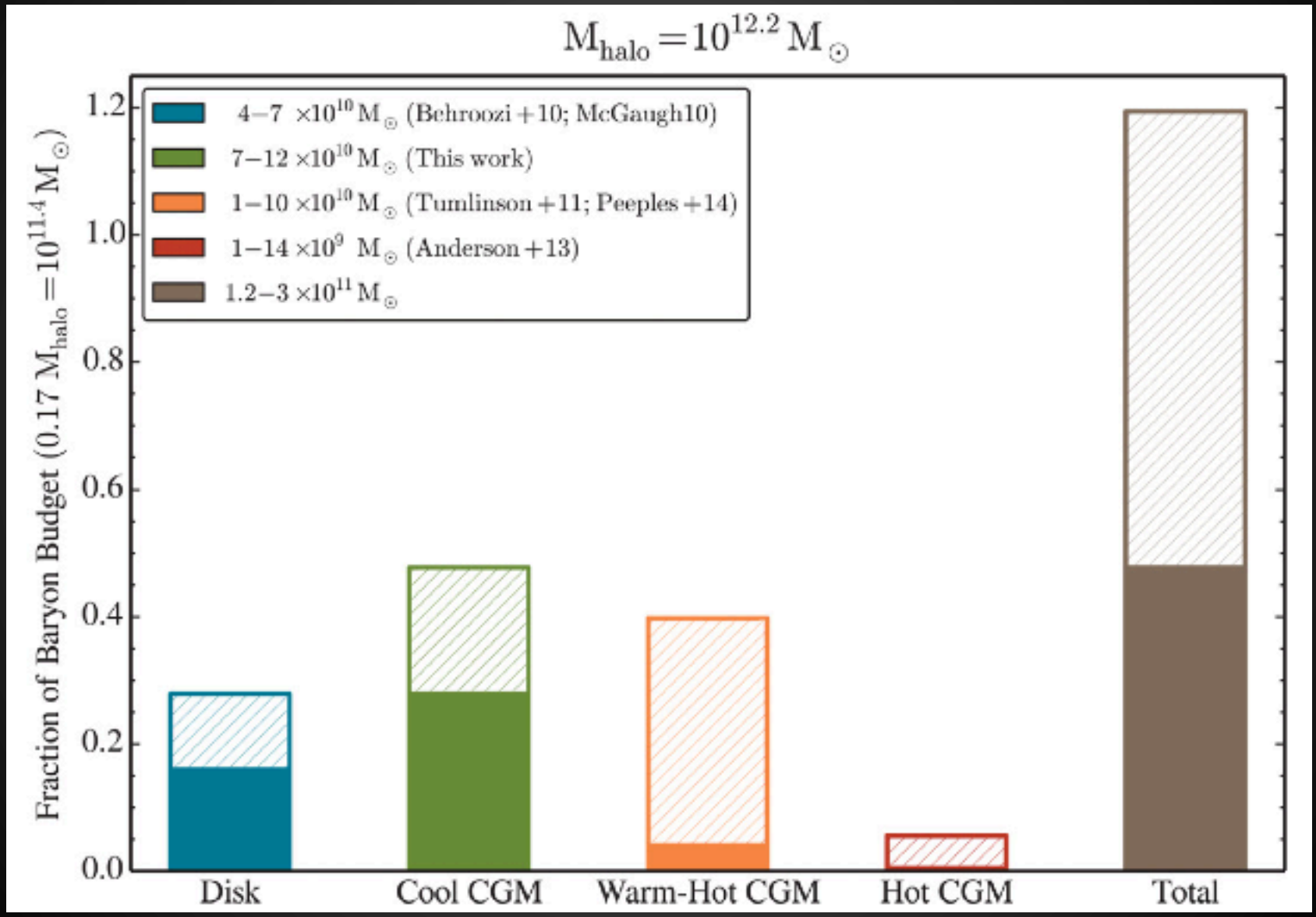
  - Rotation?

Summary:

- Define likelihood – a reproducible method for associating absorption with nearby galaxies
- EW – Impact parameter anti-correlation with R_{vir}
- Absorbers most commonly found near ρ ~ 1.2 R_{vir}
- Median EW increases with decreasing Δv
- Azimuth dependence is unclear
- Absorbers are more common near highly inclined galaxies
- Redshifted absorption weaker than blueshifted?

Questions?

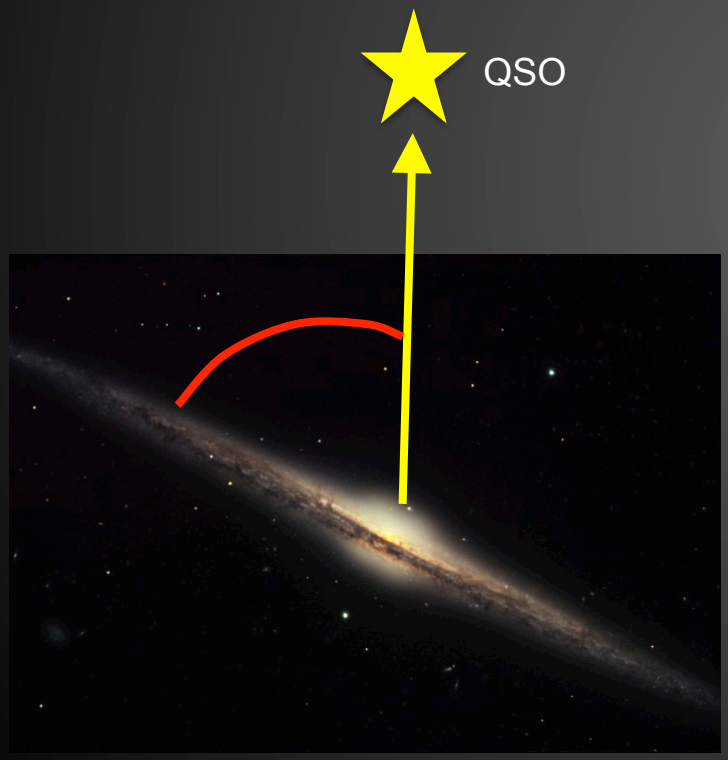
Baryon Budget



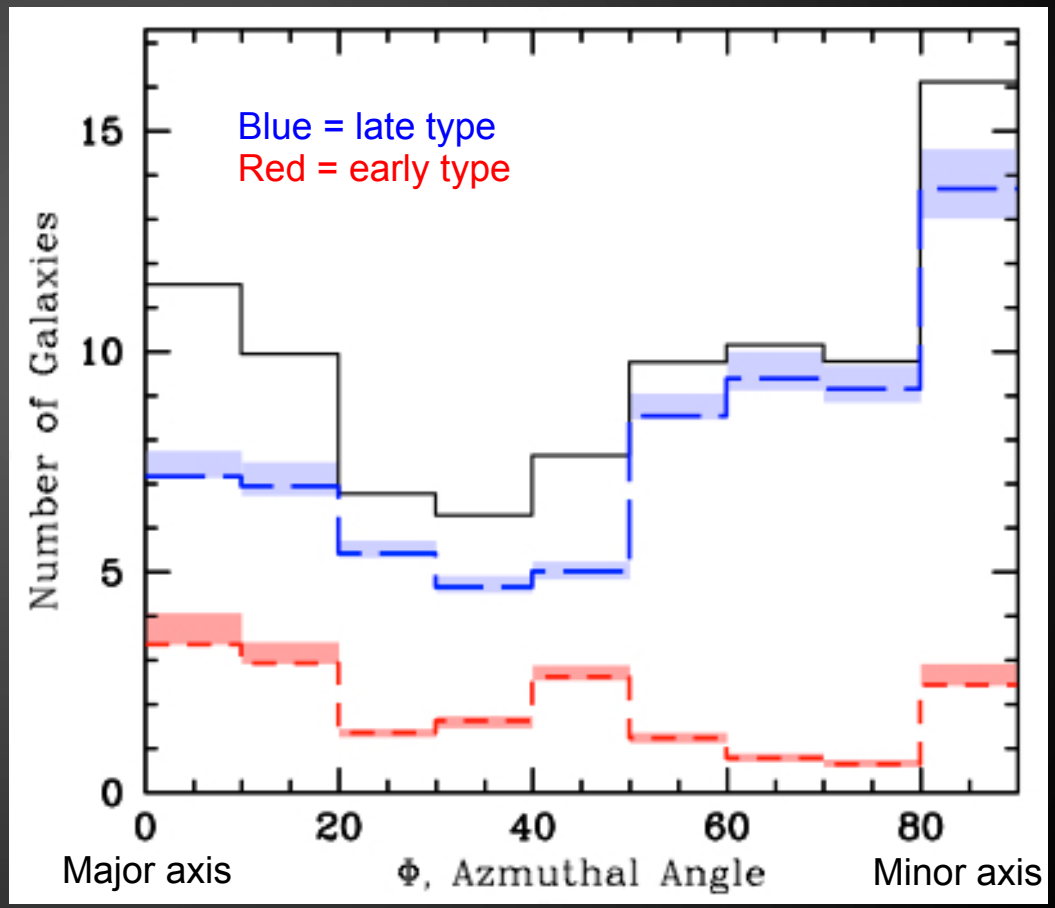
Werk et al. 2014, ApJ, 792, 128

How do CGM gas properties depend on galaxy orientation?

- *Kacprzak et al 2012 find bimodal MgII absorption*



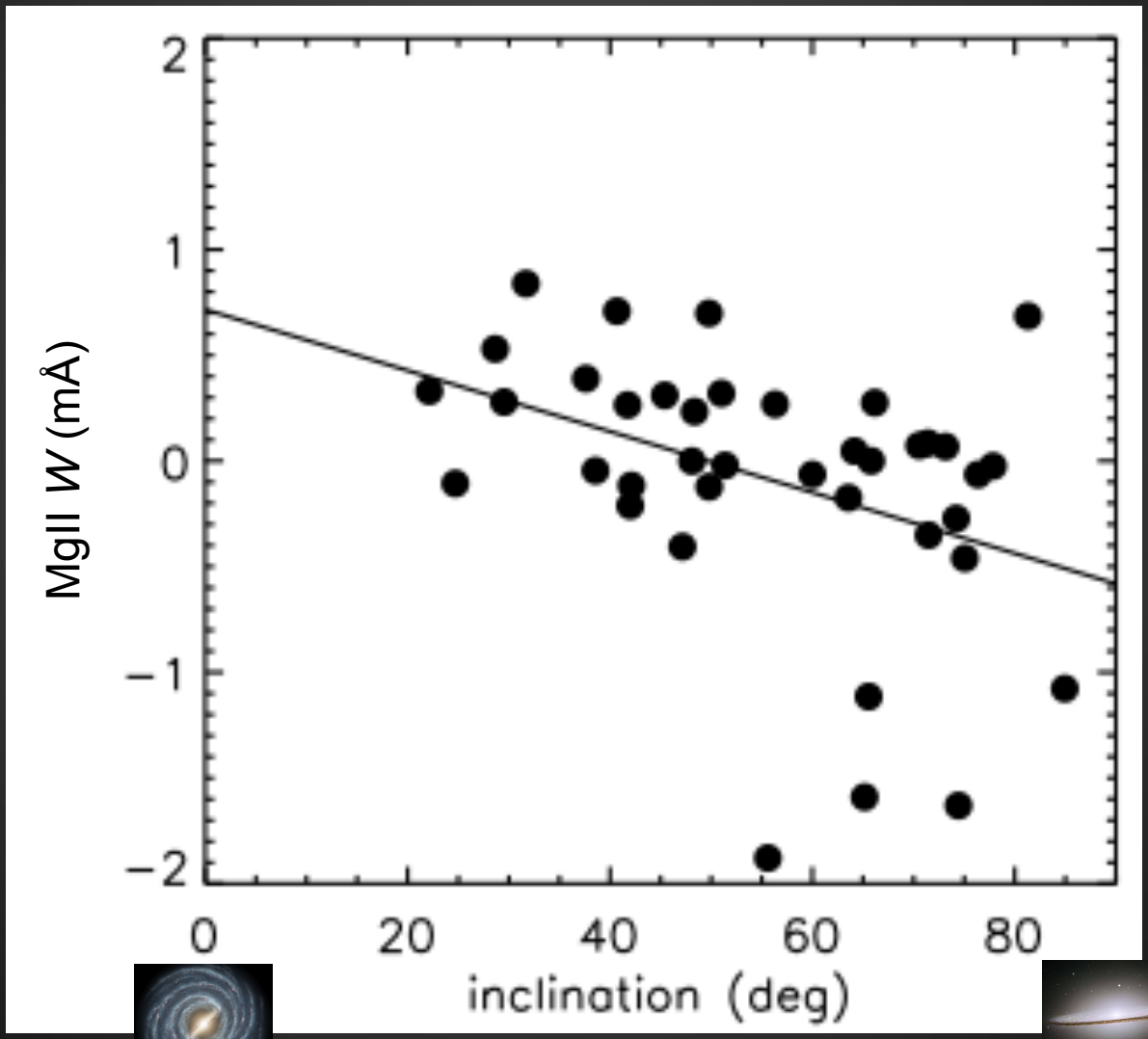
Credit: Bruce Hugo & Leslie Gaul, Adam Block, NOAO, AURA, NSF



Kacprzak et al. 2012

How do CGM gas properties depend on galaxy inclination?

Maybe?



Kacprzak et al. 2011

Associating galaxies with absorbers

- Define a likelihood:

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

$$\mathcal{L} = 0.27 \text{ for } \Delta v = 200 km/s, \rho = 1 R_{vir}$$