Measuring gas accretion on halo scales - A MEGAFLOW accretion study

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and MUSE collaboration

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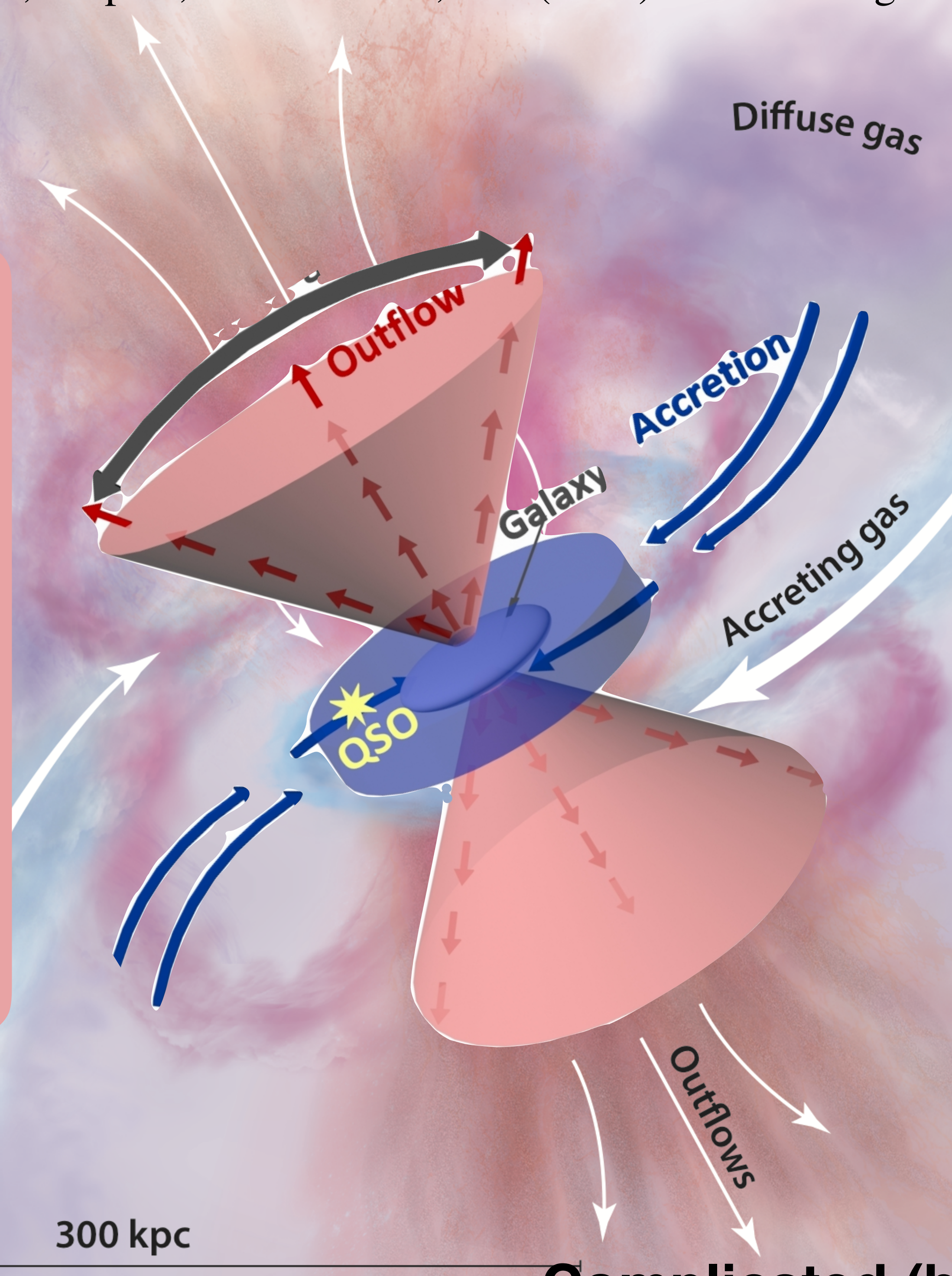
The Circumgalactic Medium (CGM)

Tumlinson, J., Peeples, M.S. & Werk, J.K. (2017) The Circumgalactic Medium

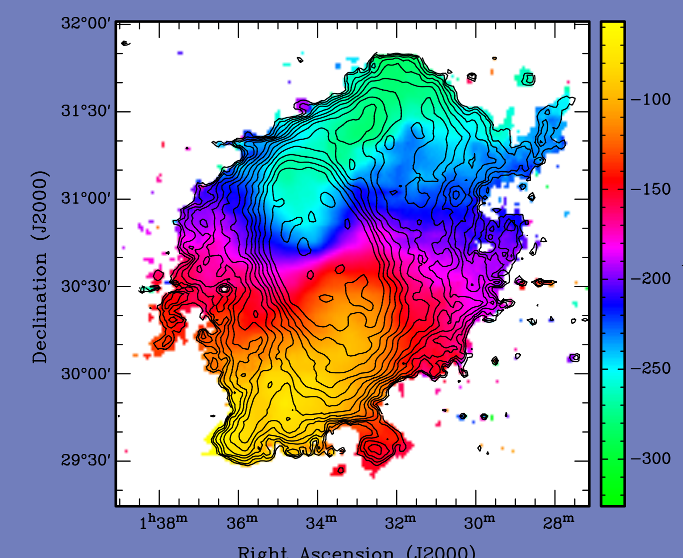


Outflow cones

Local example:

Extended gas disks

Local example:



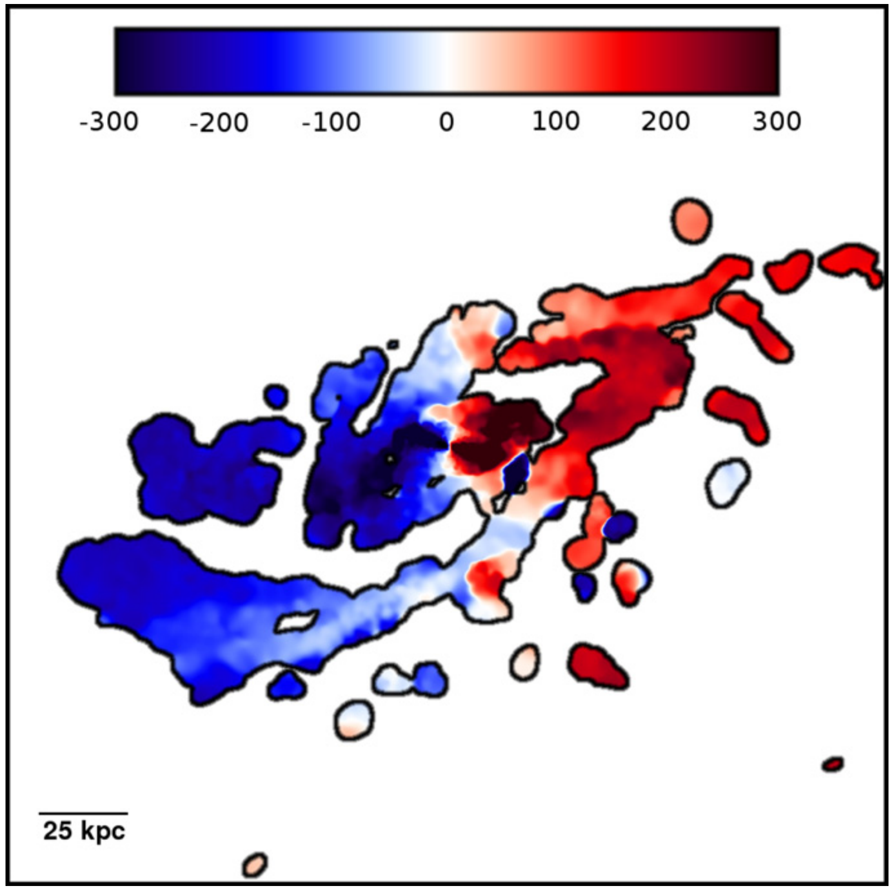
M33 Putman+09

Complicated (but not hopeless)!

Extended cold-flow disks

Example 1:

colour: Line of sight velocity [km/s]



Viewed nearly edge on

Figure from Stewart+11

Example 2:

Velocity vectors are indicated

Figure not included in exported version

colour: log(gas density)

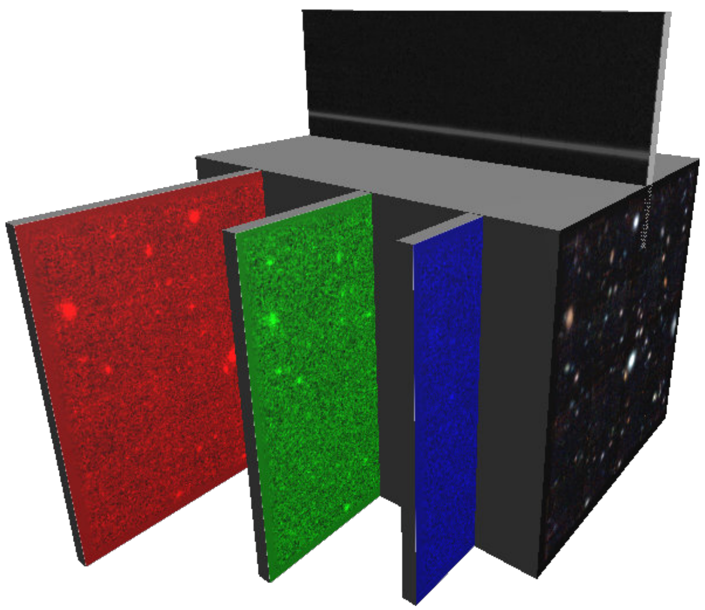
Viewed face on

See also: e.g. Pichon+11, Danovich+12,15; Stewart+17

The MEGAFLOW survey

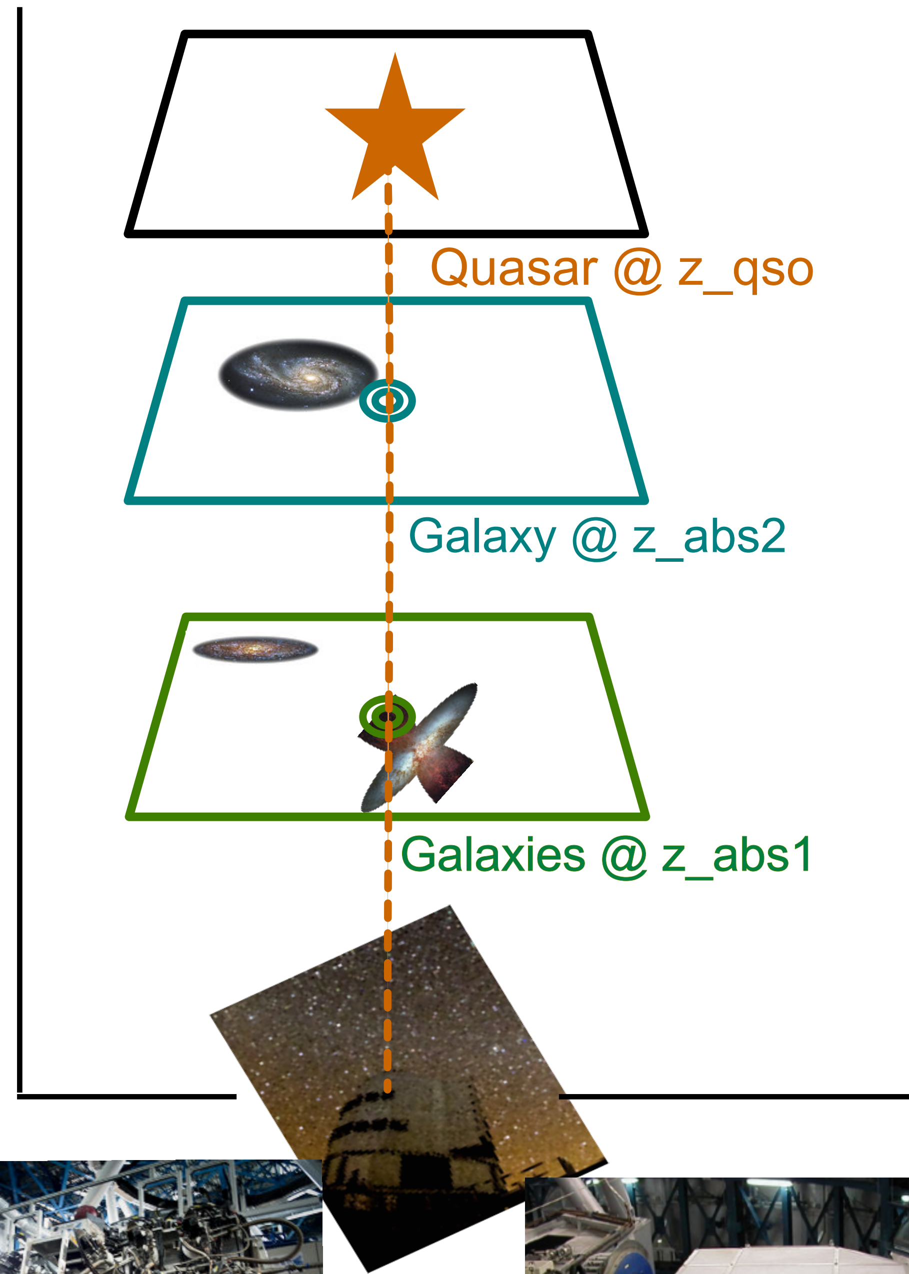
MusE GAs FLOw and Wind

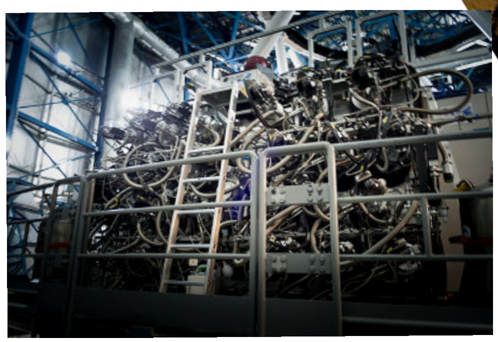
MUSE

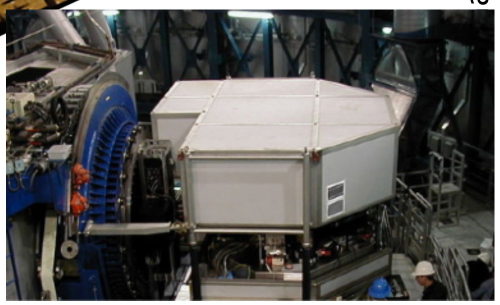


Muse datacube of MEGAFLOW field

- Ideal to search for galaxies associated to absorbers (especially star-forming, but also quiescent)
- Orientation and kinematics for all galaxies (using GalPaK^{3D} (Bouché+15)

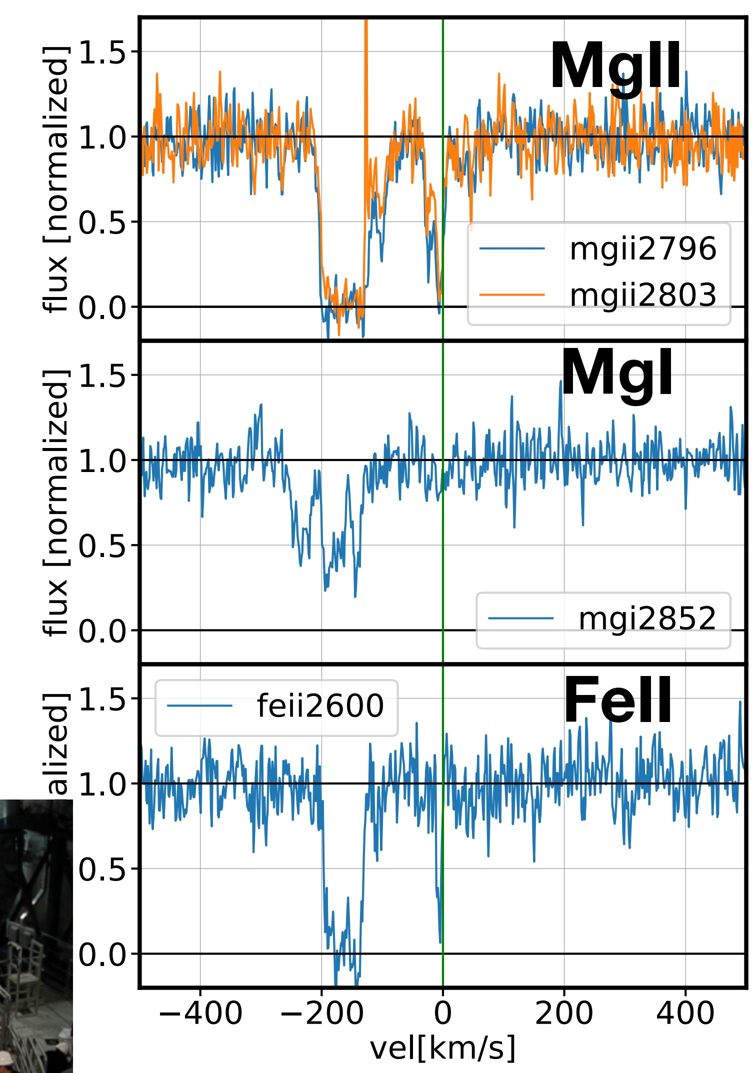






UVES

Measurement of gas velocity structure w. high spectral resolution (~8 km/s).



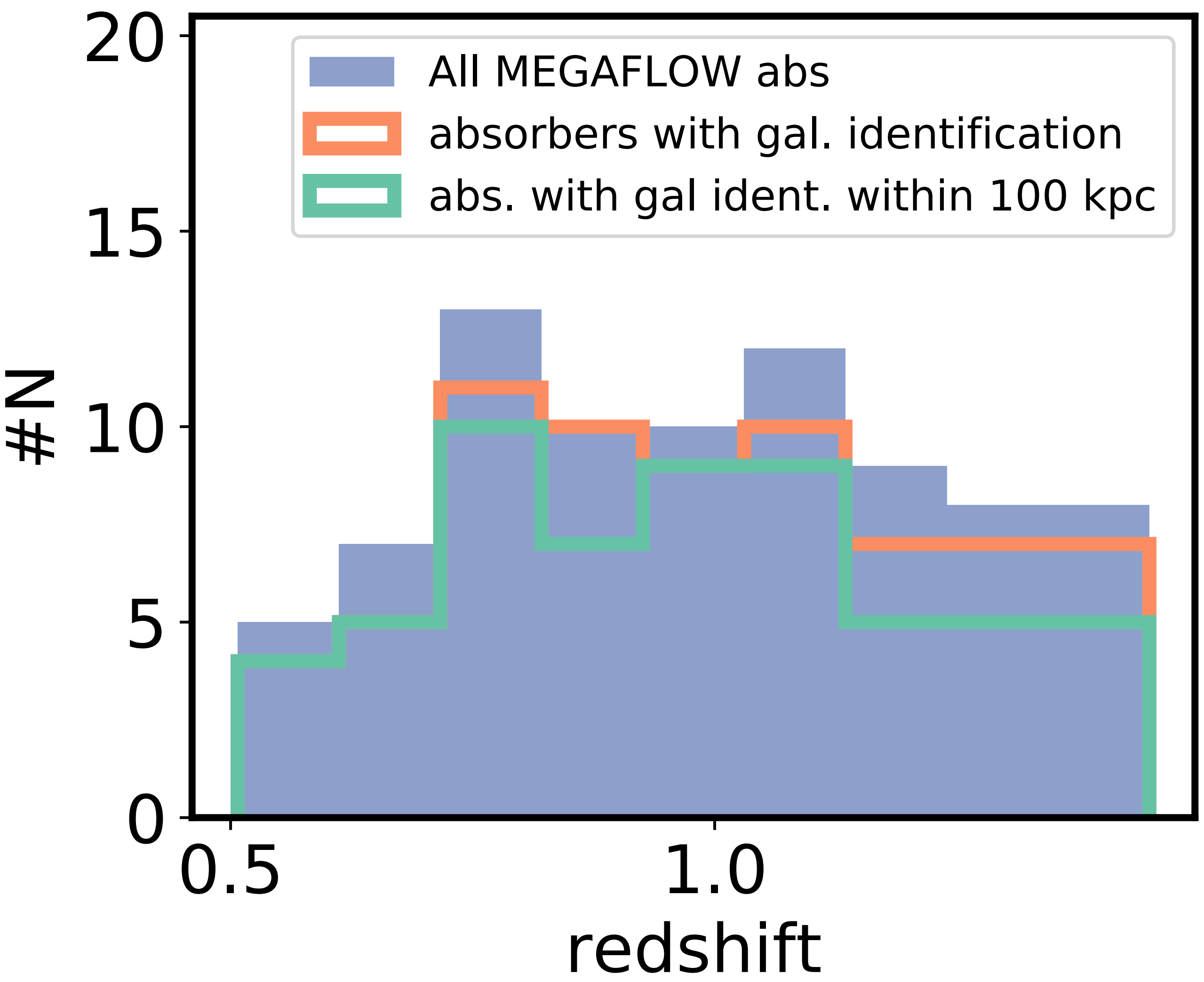
The MEGAFLOW survey

A MUSE GTO project; PI: N. Bouché

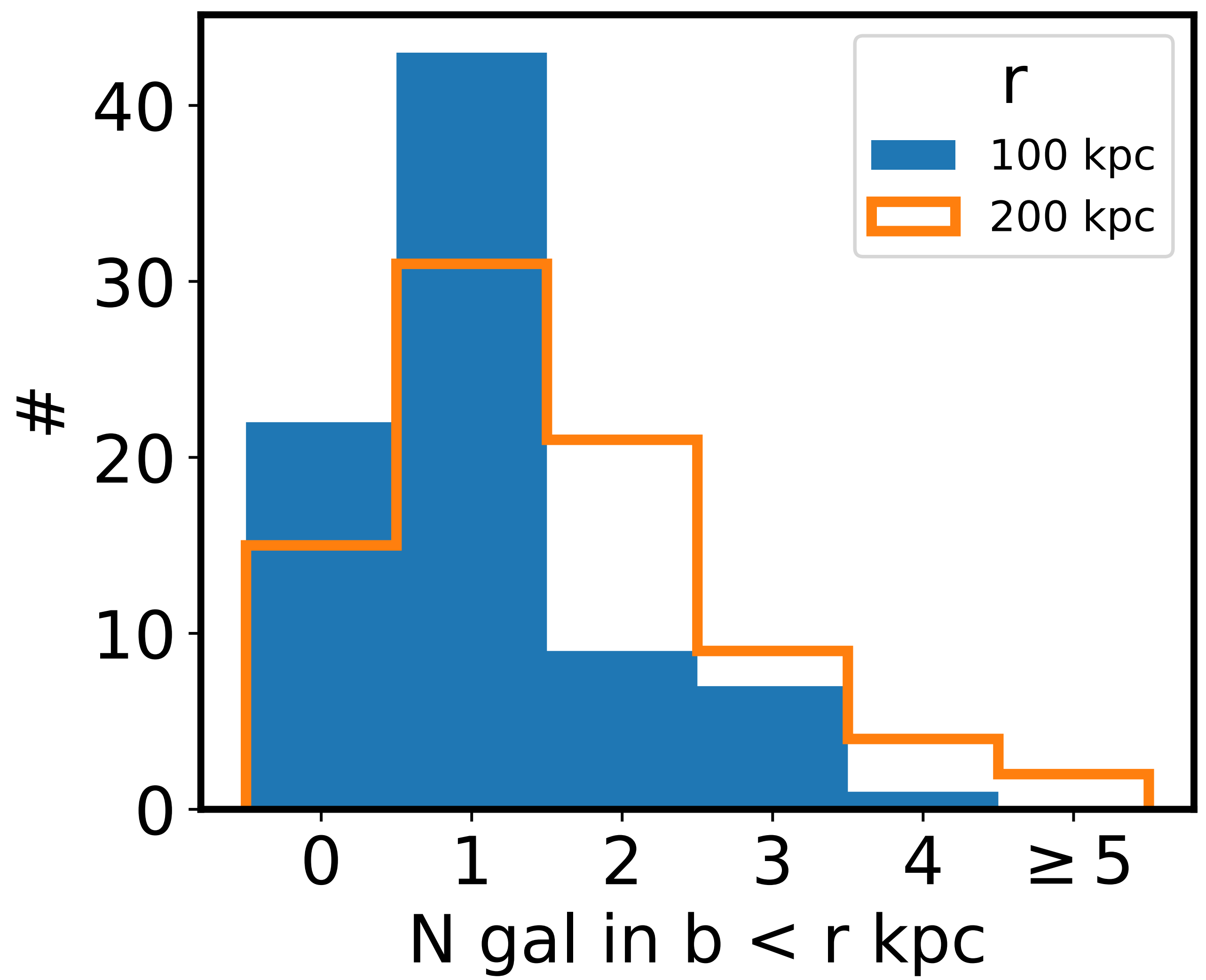
- 22 quasar fields selected
  - Each quasar N ≳ 3 MgII absorbers with rEW MgII λ2796 ≳ 0.8Å in redshift range $0.3 < z < 1.5$ —> [OII] in wavelength range of MUSE
  - Selection based on SDSS (JHU-SDSS catalog - Zhu & Ménard 13)
  - Total of 79 strong MgII absorbers with rEW 2796 ≥ 0.3Å
- Each quasar(field) followed up both with VLT/MUSE and VLT/UVES
  - ~2-4 hrs of MUSE time per field with two deep ~9hr fields (for final survey; presented results include data for all 22 fields, but not at final depth)
  - SFR limit based on [OII] (unobscured): $0.1 M_\odot yr^{-1}$ (4×10^{-18} erg s^{-1} cm^{-2}) for 6ks at z~1
  - UVES typically covering MgII, FeII, MgI and other weaker species

Identification status
(at depth of this work)

Redshift distribution of absorbers



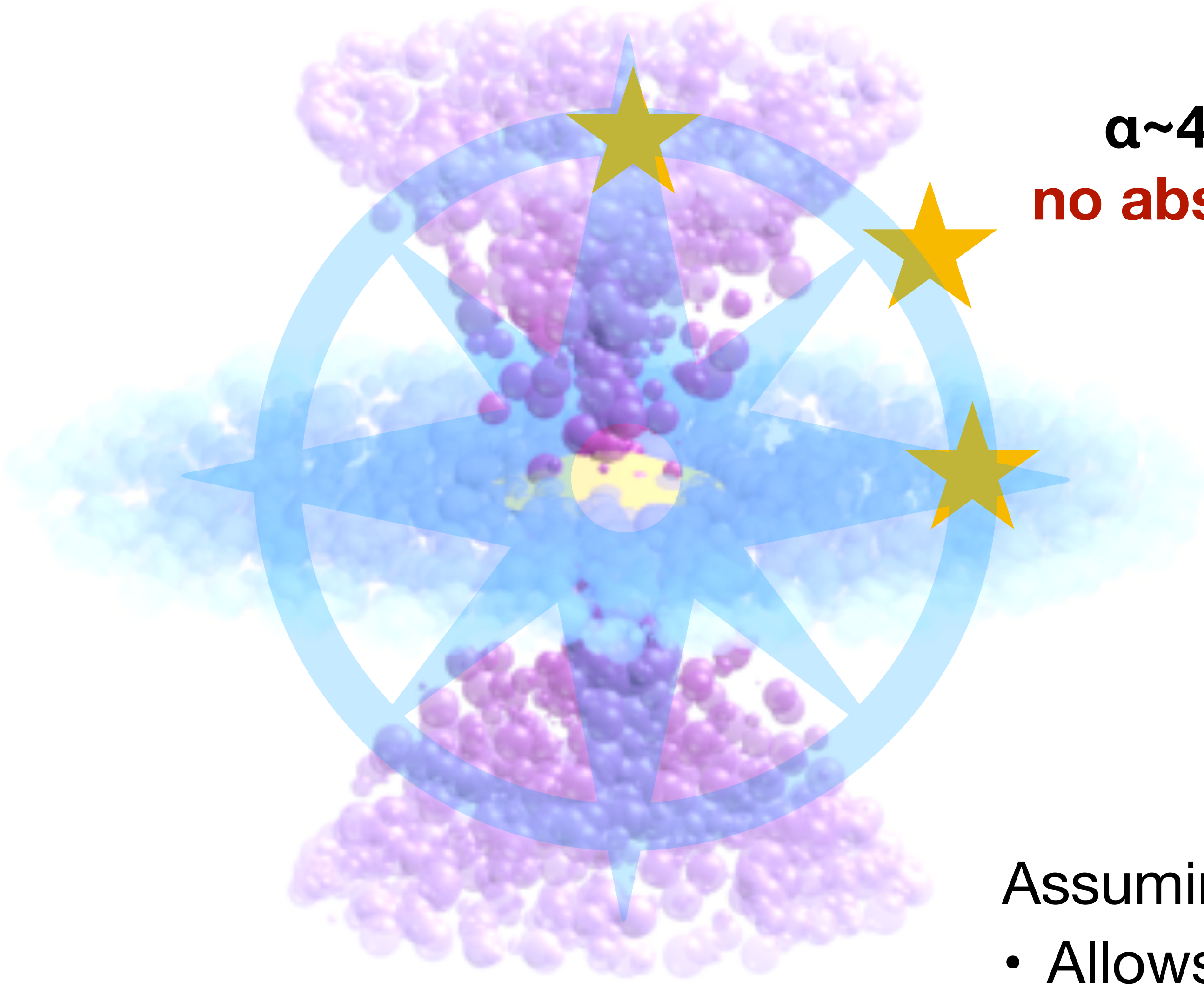
Number of identified galaxies per absorber



Based on known anti-correlation between impact parameter an rEW MgII2796 (e.g. Lanzetta & Bowen 90; Chen+10; Nielsen+13): Most of our galaxies expected to be at b<100kpc

Expectation for two component geometry

α=50-90°
absorption due to outflowing gas
(minor axis; wind case)



α~40-50°
no absorption

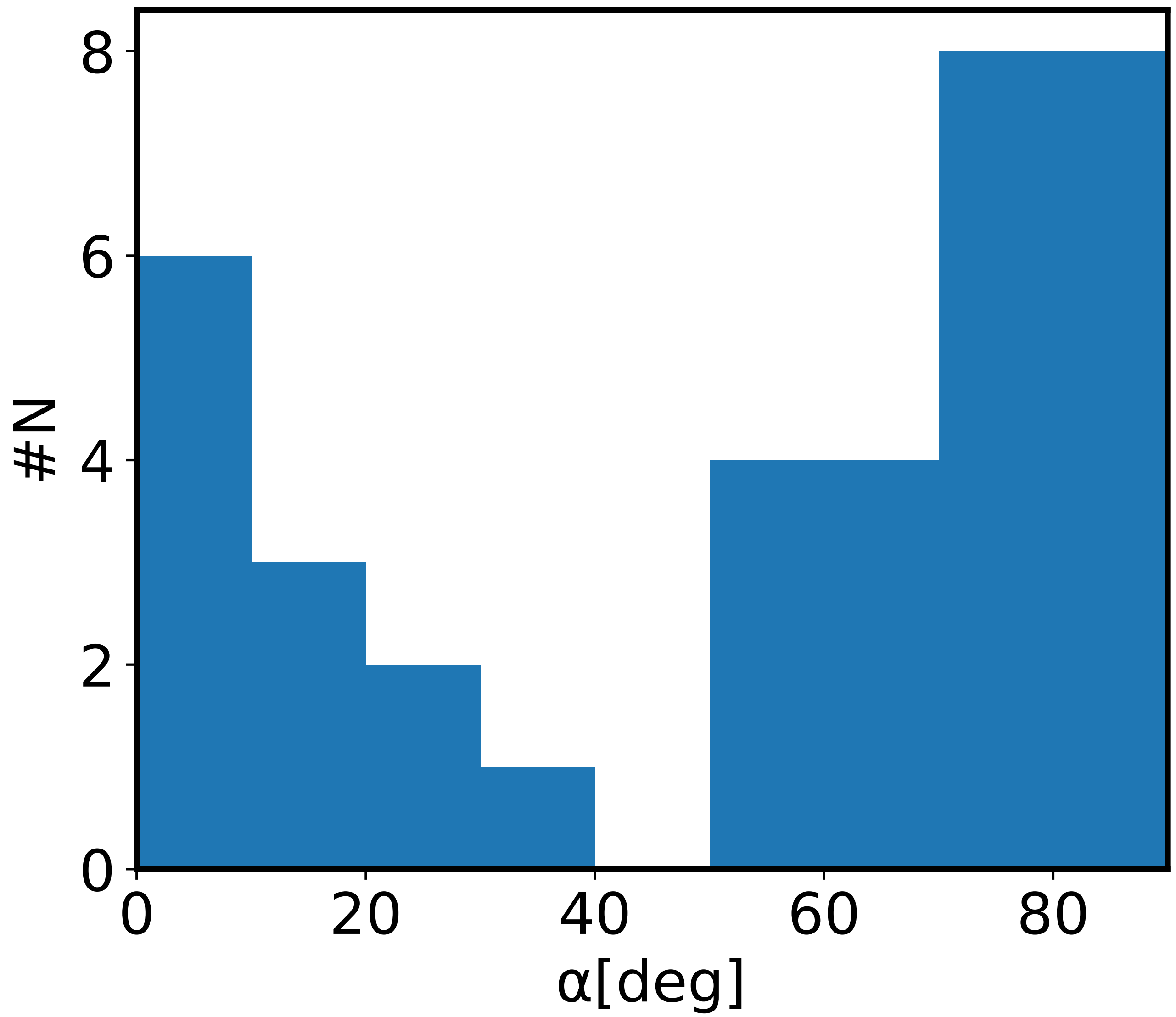
α~0-30°
absorption due to extended gas disk
(major axis; accretion case)

Assuming inclinations ≳ 40°:

- Allows for robust galaxy kinematics
- Mainly avoids cases with contribution **both** from outflow and disk

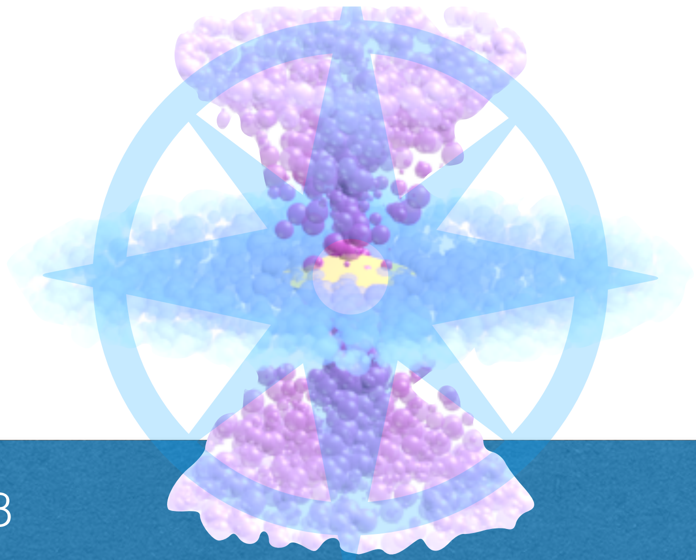
α: Azimuthal angle

Azimuthal distribution



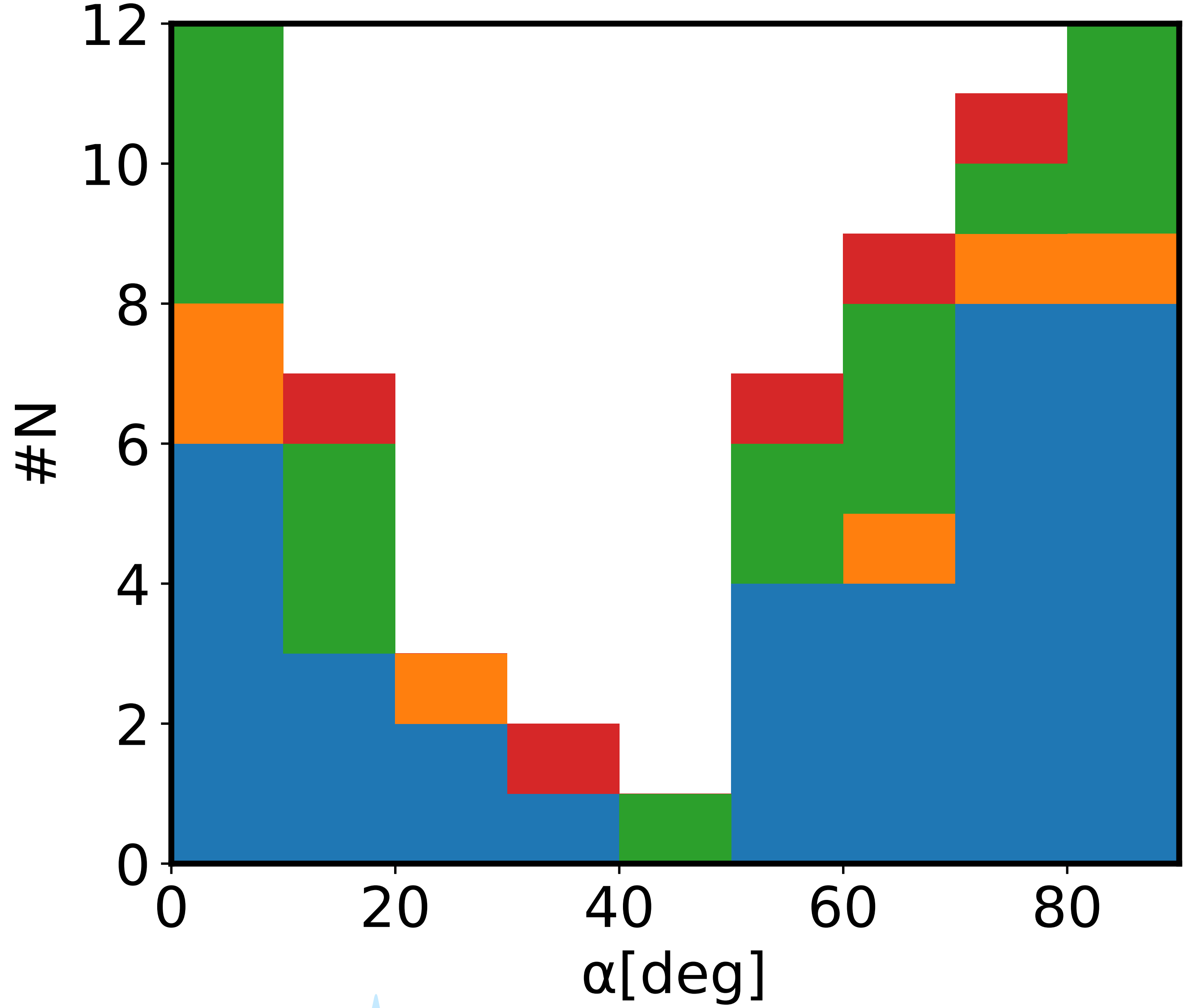
From MEGAFLOW using:

- b < 100 kpc
- strong MgII absorbers (rEW2796 > 0.3Å)
- clear identification of absorption with one main star-forming galaxy
- incl > 40°



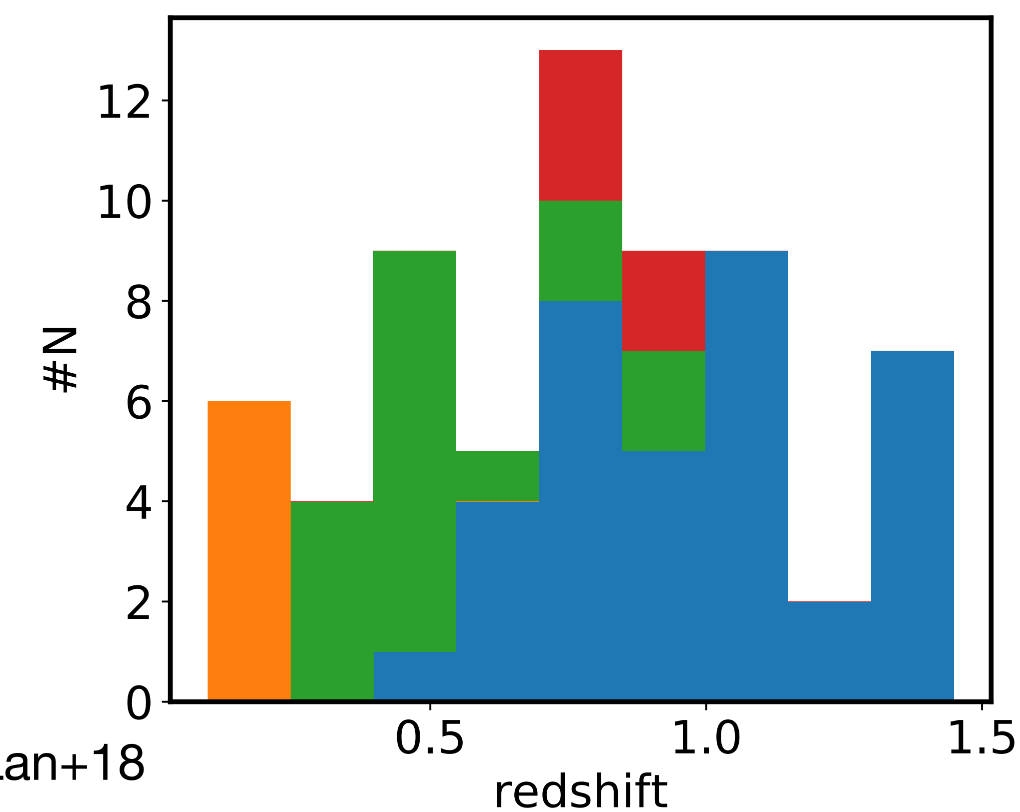
For similar results:
See e.g. also Bouché+12;
Kacprzak+12; Bordoloi+14, Lan+18

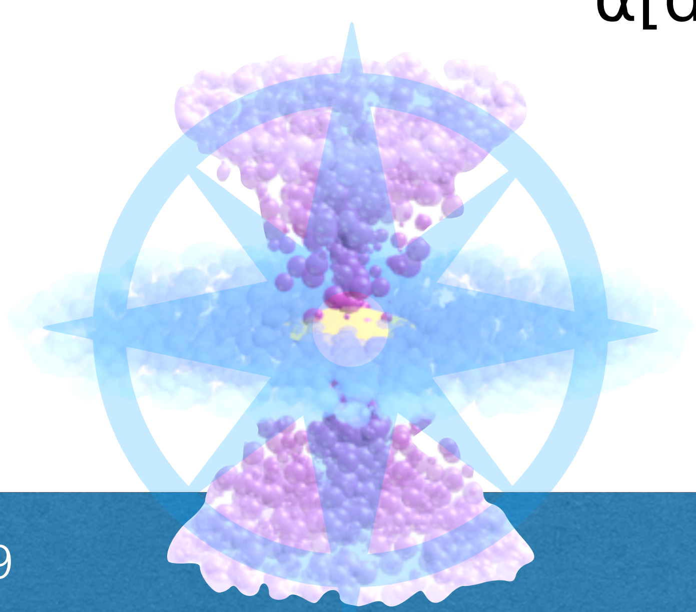
Azimuthal distribution



Including other samples (with same selection criteria):

- MEGAFLOW - this work
- Bouché+12 (sample from Kacprzak+11a)
- Kacprzak+11b
- SIMPLE (Schroetter+15, Bouché+07)





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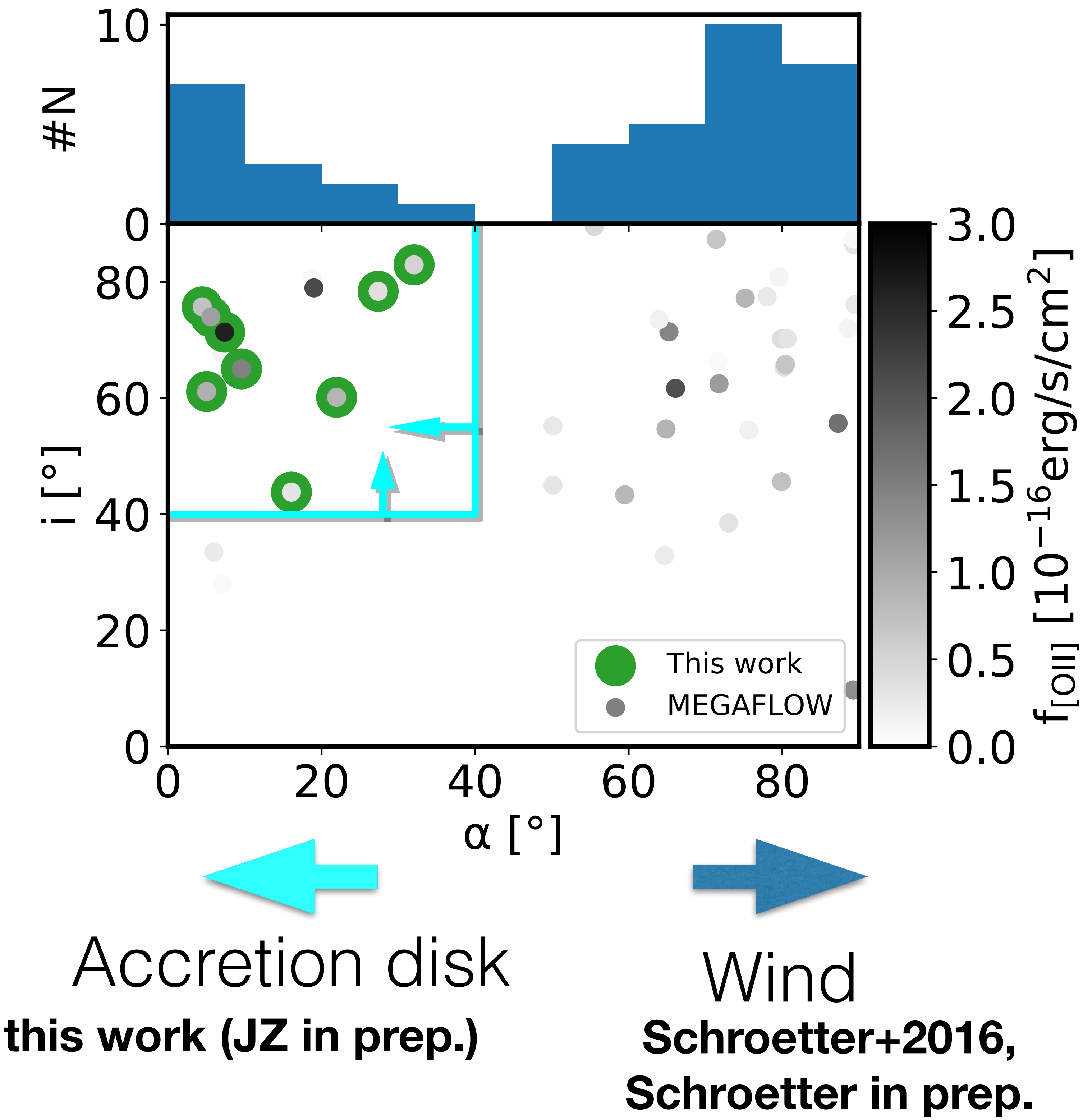
The MEGAFLOW accretion sample

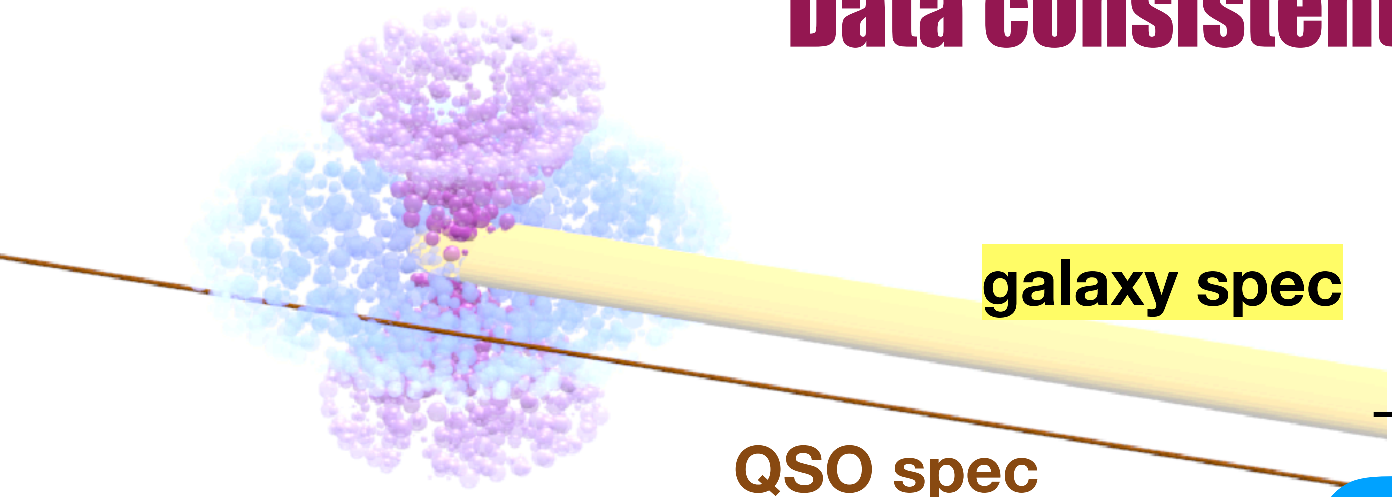


Accretion sample for this work:

- 9 galaxy-absorber pairs without strong AGN or merger signatures selected
- $9.3 < \log(M_\star) < 10.6$ (~0.1 to 1 M*)

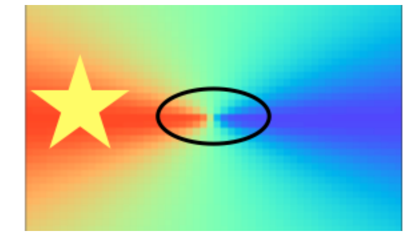
Data consistent with co-rotation?

An example



UVES

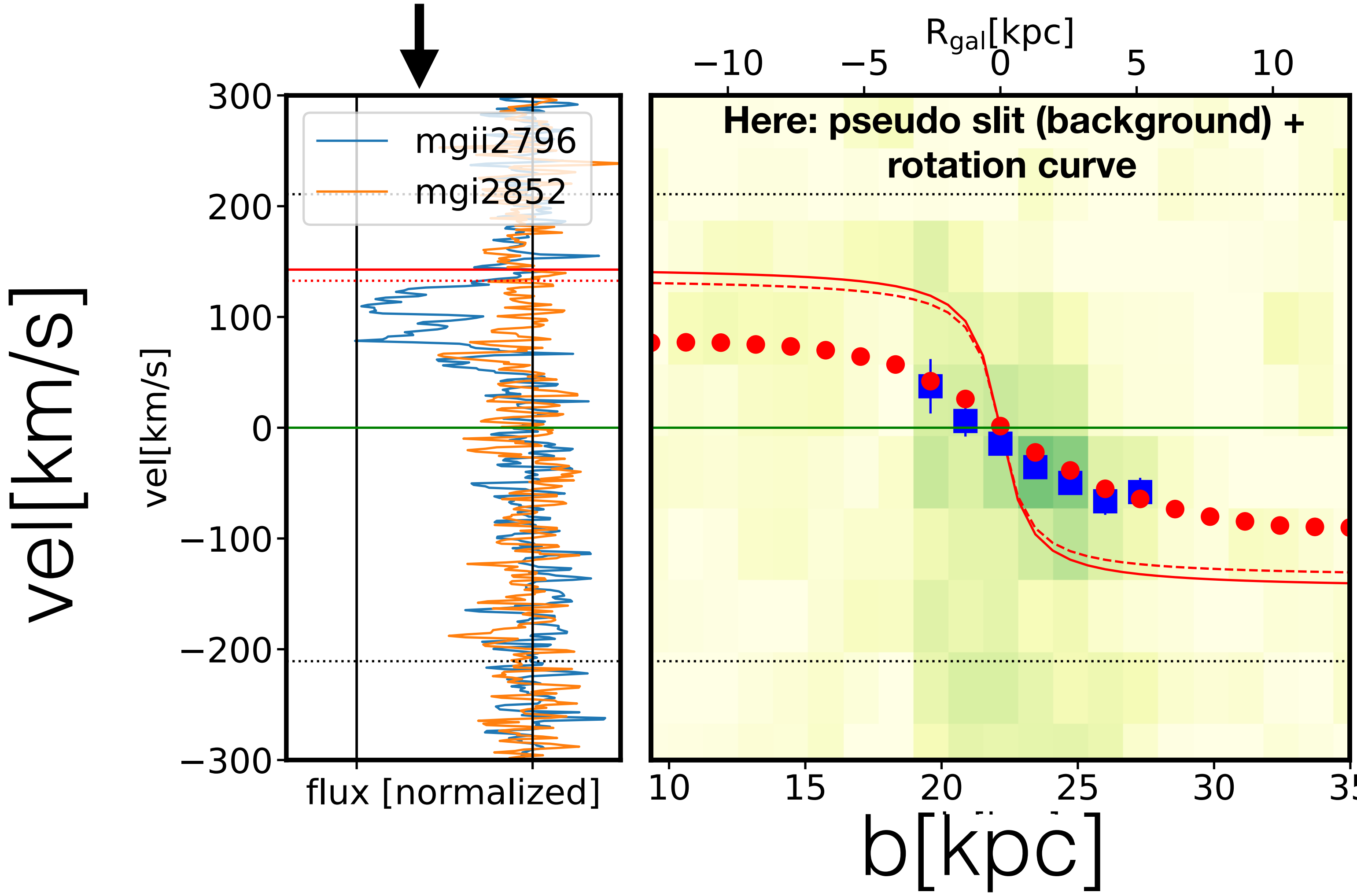
MUSE



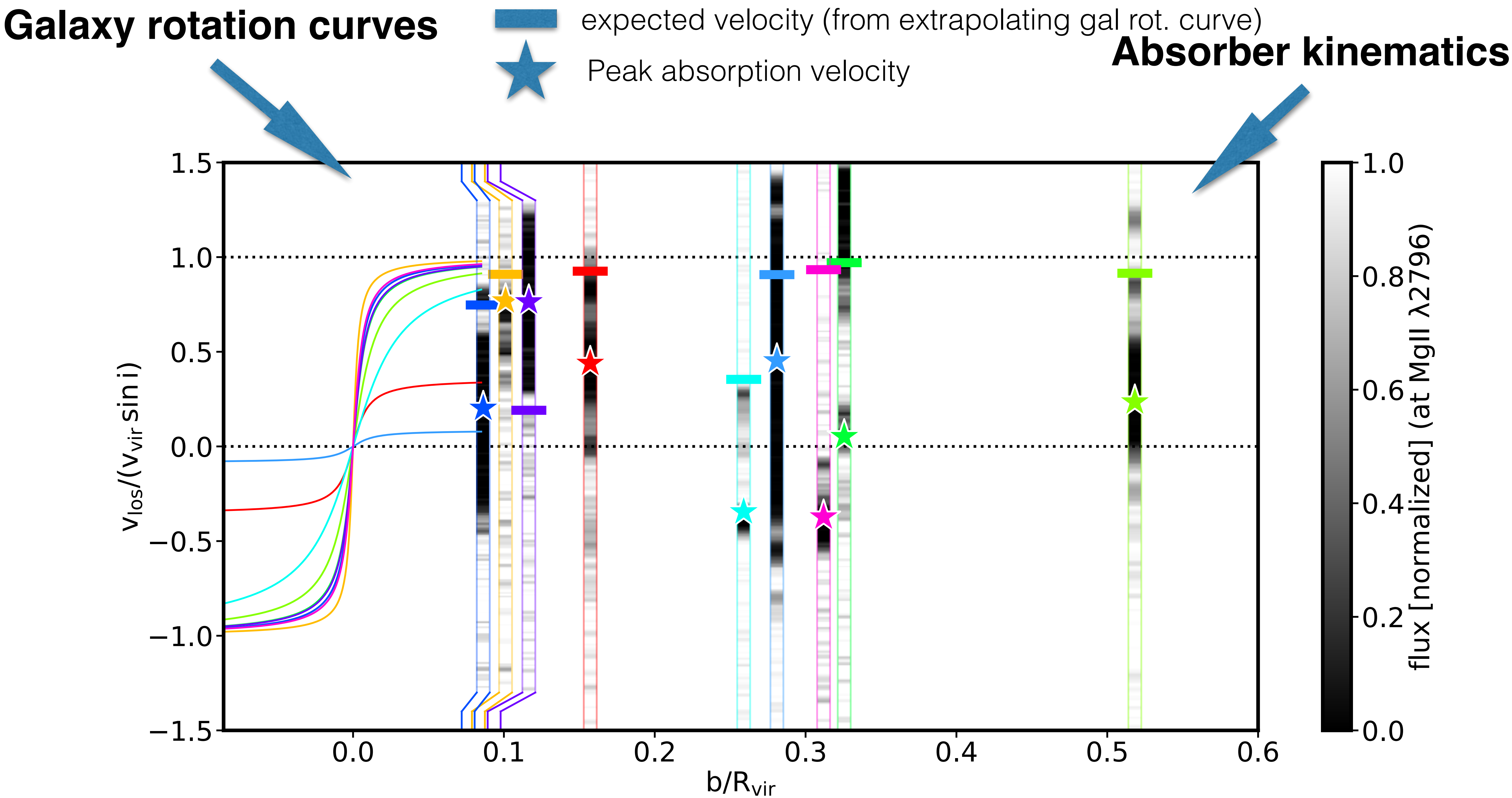
full 2D velocity field

Zeroth order check:
Does absorbing gas share orientation of angular momentum vector with galaxy?

Next order check:
Absorbing gas on circular orbit with circular velocity of halo?



Data consistent with co-rotation?

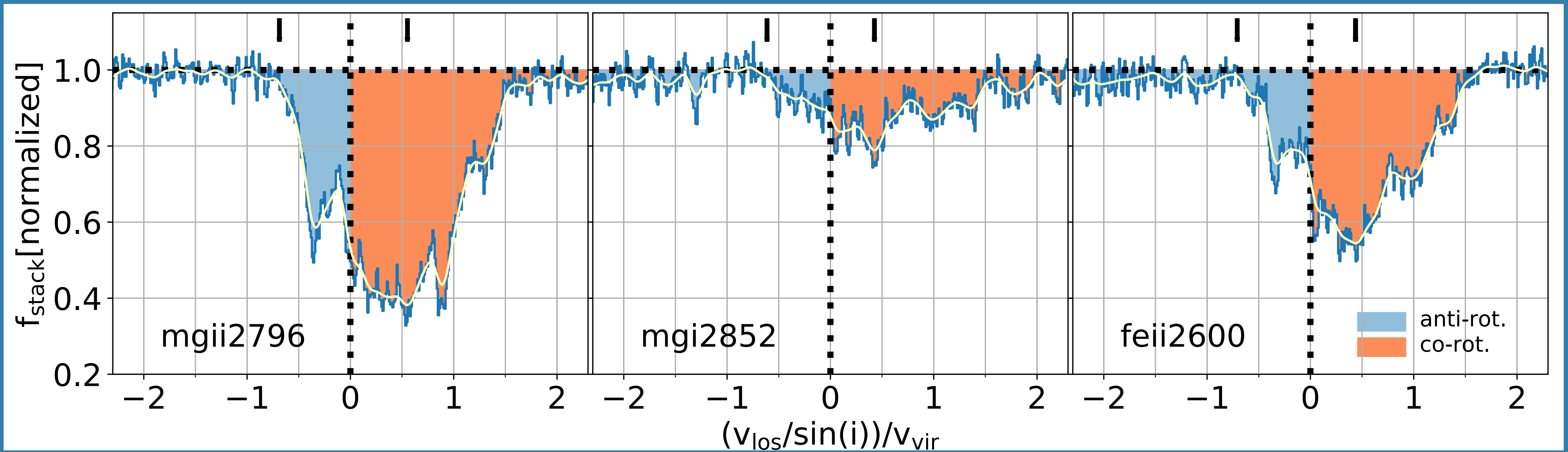


1. 7 out of 9 galaxies consistent with simple expectation of co-rotation (all 4 at small b)
2. $|v_{los}|$ smaller than expected for rotation on stable circular orbits in halo

Data consistent with co-rotation?

Ga... ...s

Stack of all nine absorbers



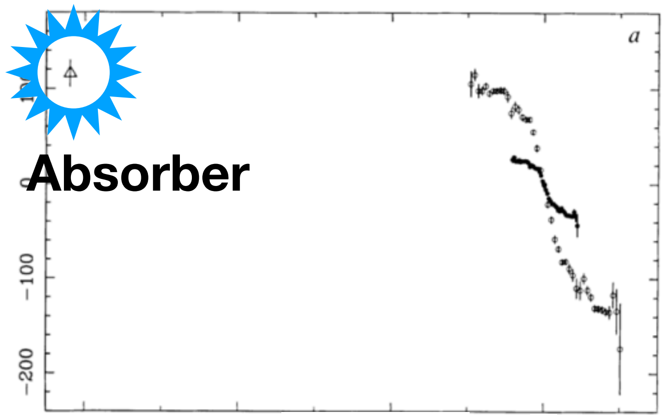
1...
2.

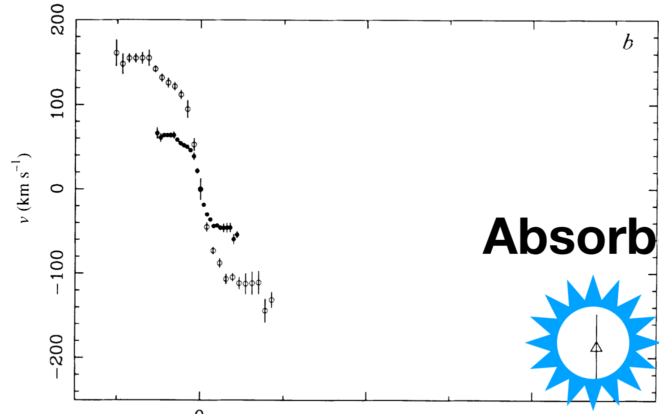
Comparison to literature

Early results

E.g. Barcons, Lanzetta, Webb 1995, Nature

z~0.1



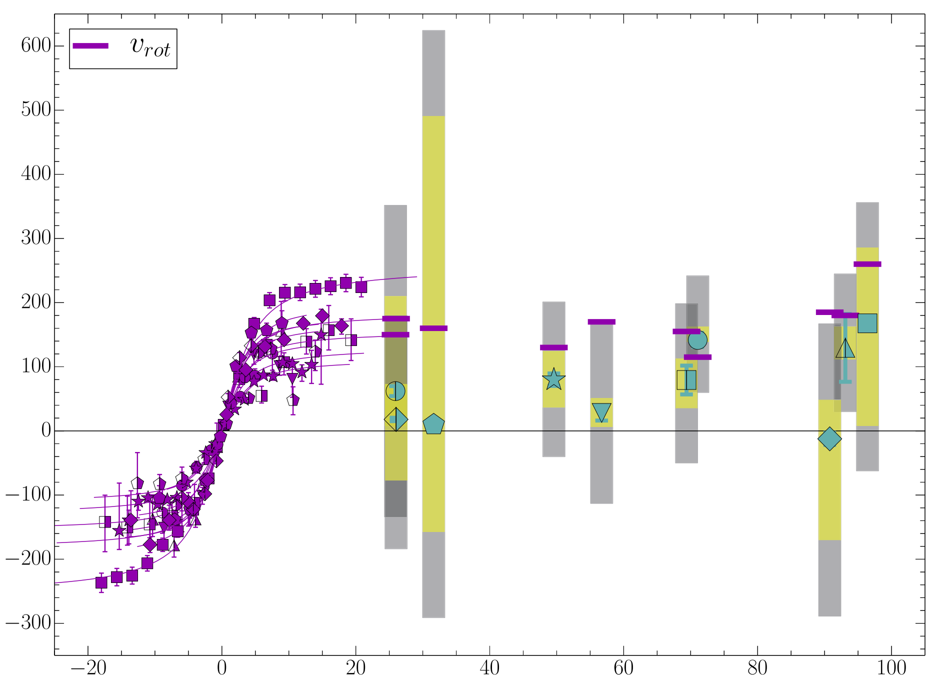


Others:
Steidel+02; Chen+05; Kacprzak+10,11; Bowen+16; Rahmani+18; and more

Low-z Universe

z=0.2

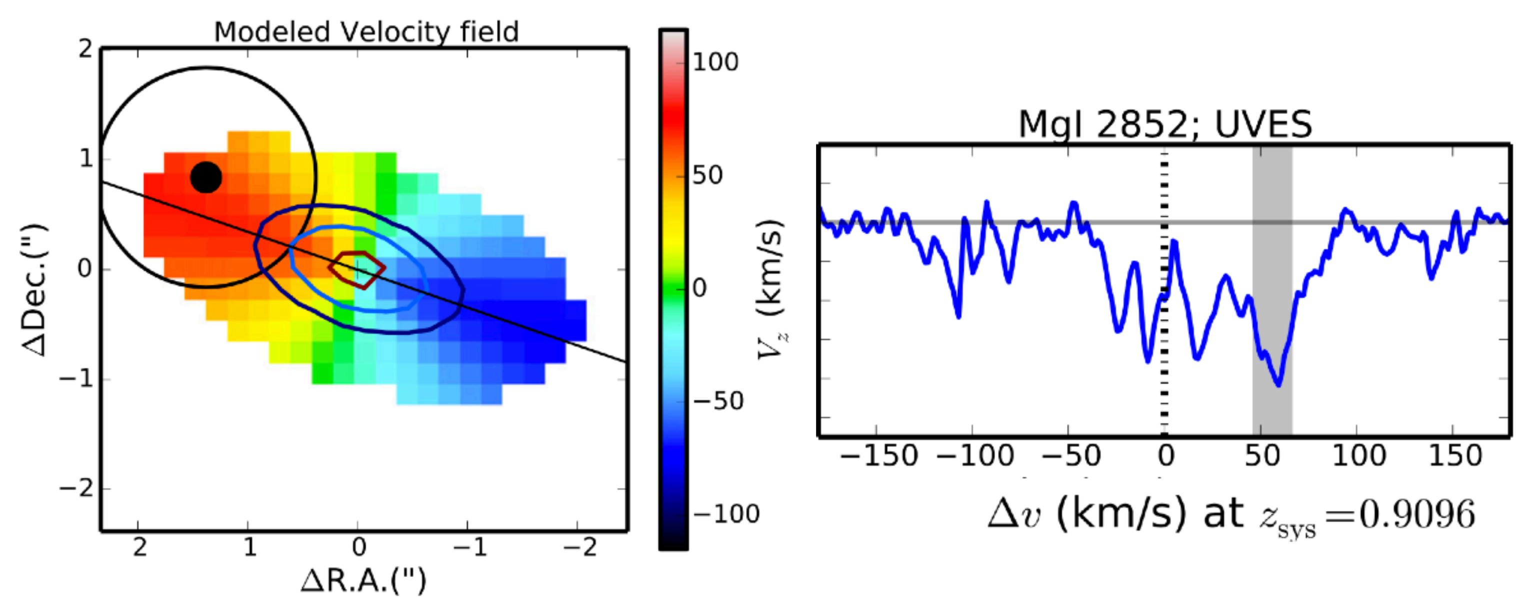
Ho+17: ~10 galaxy-absorbers pairs at z=0.2



High(er)-z Universe

(z≳0.3)

E.g. Bouché+ 13, **16**



Radial infall (accretion)?

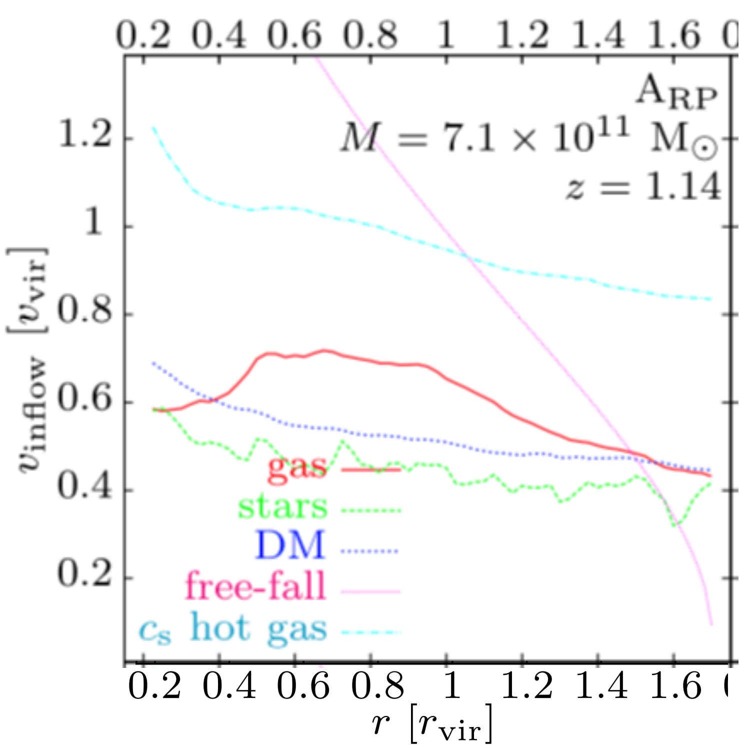
Assuming motion of gas in a disk (extension of galaxy disk) with rotational **and** inflow component:

$$v_{\rm los} = \overrightarrow{v}_{gas} \cdot \overrightarrow{\mathbf{L}} = \frac{v_\phi \cos\alpha \sin i \pm v_r \sin\alpha \tan i}{\sqrt{1 + \sin^2\alpha \tan^2 i}}$$

Problem: $v_{\rm los}, \alpha, i$ are measured $v_\phi, v_{\rm r}$ two unknowns

Input from sim. for v_r

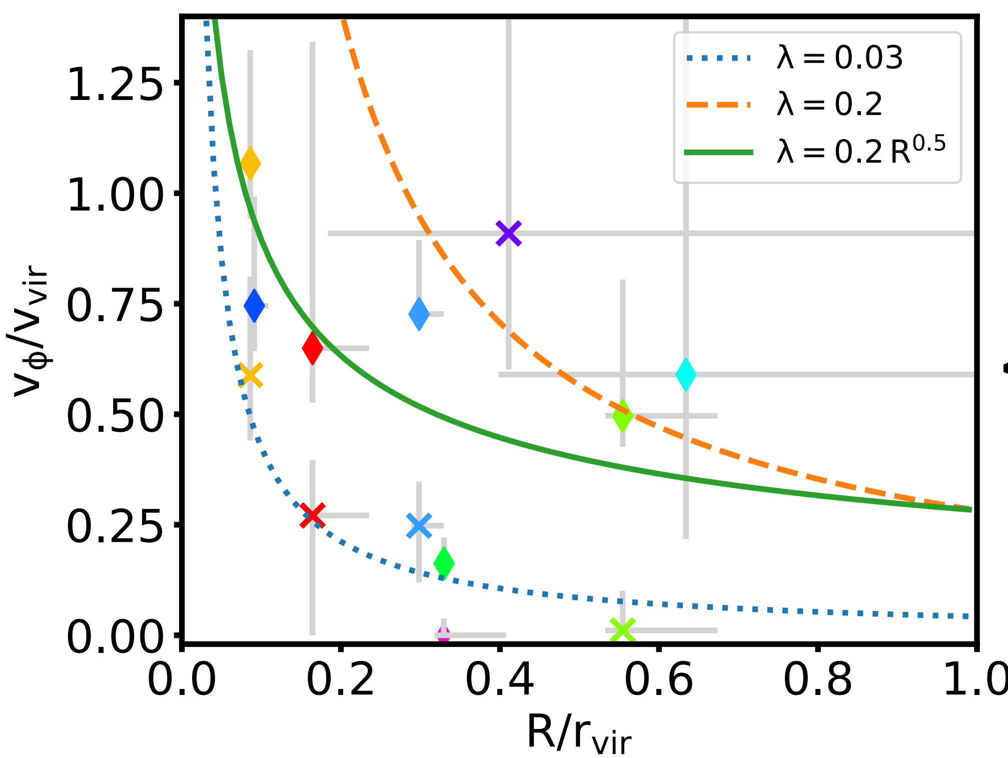
Goerdt+2015



$v_{\rm r} \sim -0.6\, v_{\rm vir}$

=>

Result



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Expectations for angular momdentum

$$\lambda = \frac{1}{\sqrt{2}} \frac{R}{r_{\rm vir}} \frac{v_\phi}{v_{\rm vir}}$$

Simulations:

DM (Halo averaged): λ~0.03

Cold gas expected to be higher:

$$\lambda \sim 0.2 \left(\frac{R}{r_{vir}}\right)^{0.5}$$

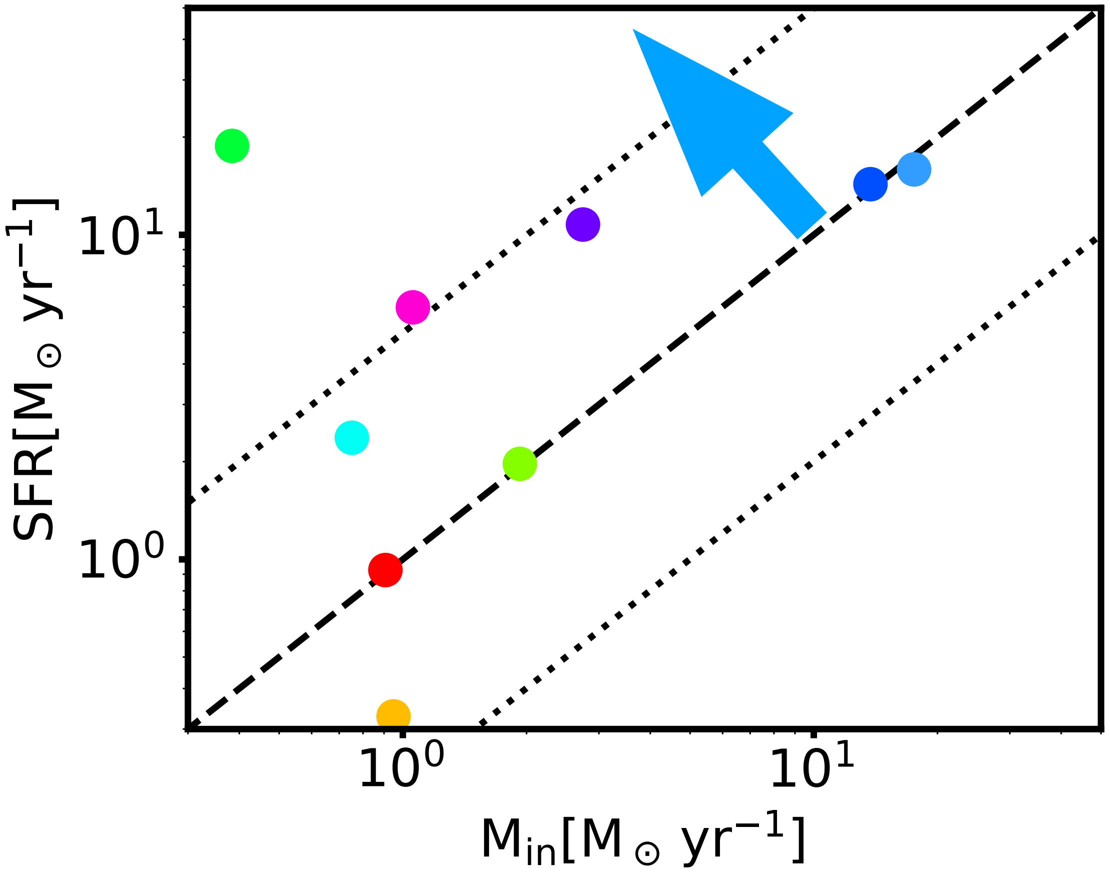
Danovich+2015

Accretion rate

Question: Would the infalling gas probed by MgII enough to balance the SFR

$$M_{\rm in}(R) = 2\pi R\, v_{\rm r}\, m_p\, \mu\, \cos(i)\, N_{\rm HI}$$

(N_{HI} from MgII to N_{HI} using relation from Menard & Chelouche (2009))



- 4 galaxies: Inflow rate almost exactly balances SFR
- 4 galaxies: SFR higher than inflow rate (several possible explanations)
- 1 galaxy: SFR lower than inflow rate

Main conclusions

- MEGAFLOW data consistent with a two component geometry for strong MgII absorption - biconical outflows & extended gas disks
- Majority of the “disk” sight-lines are co-rotating (7 out of 9; random chance 9%)
- For 8 out of 9 cases LOS velocities smaller than expectation from co-rotation with v_{vir}
- Possible explanation: Inflows. Data consistent with inflow velocity and angular momentum predicted in simulations.
- Inflow rates for about half of the sample sufficient to balance SFR

Thank you!