Galaxy Gas Flows at Cosmic Noon with KCWI

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SWIN BUR NE
CENTRE FOR ASTROPHYSICS AND SUPERCOMPUTING

Illustration credit: J. Josephides

MgII Circumgalactic Medium

At $z < 1$, attributed to baryon cycle processes:

Accretion along dark matter filaments, add angular momentum

e.g., Rubin+ 2012, Martin+ 2012

Outflows from SN feedback & stellar winds; bipolar

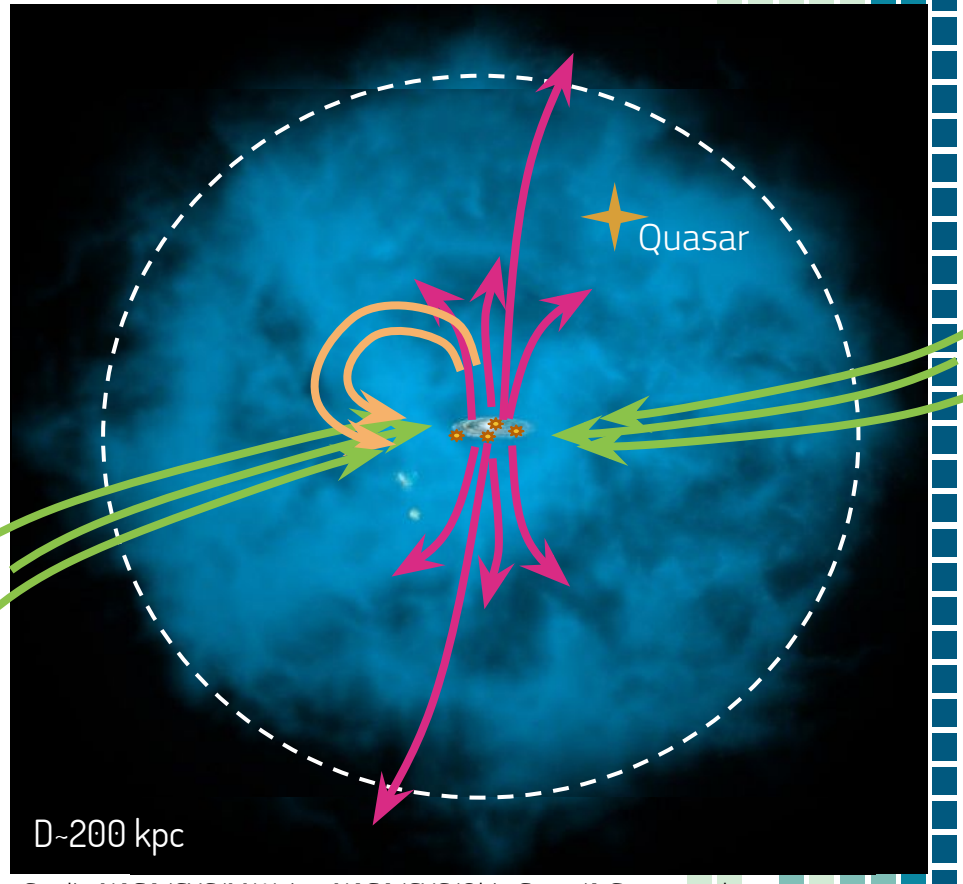
e.g., Bouche+ 2012, Bordoloi+ 2014, Rubin+ 2014, Schroetter+ 2016

Recycled Accretion as a galactic fountain

e.g., Ford+ 2014 (simulations)

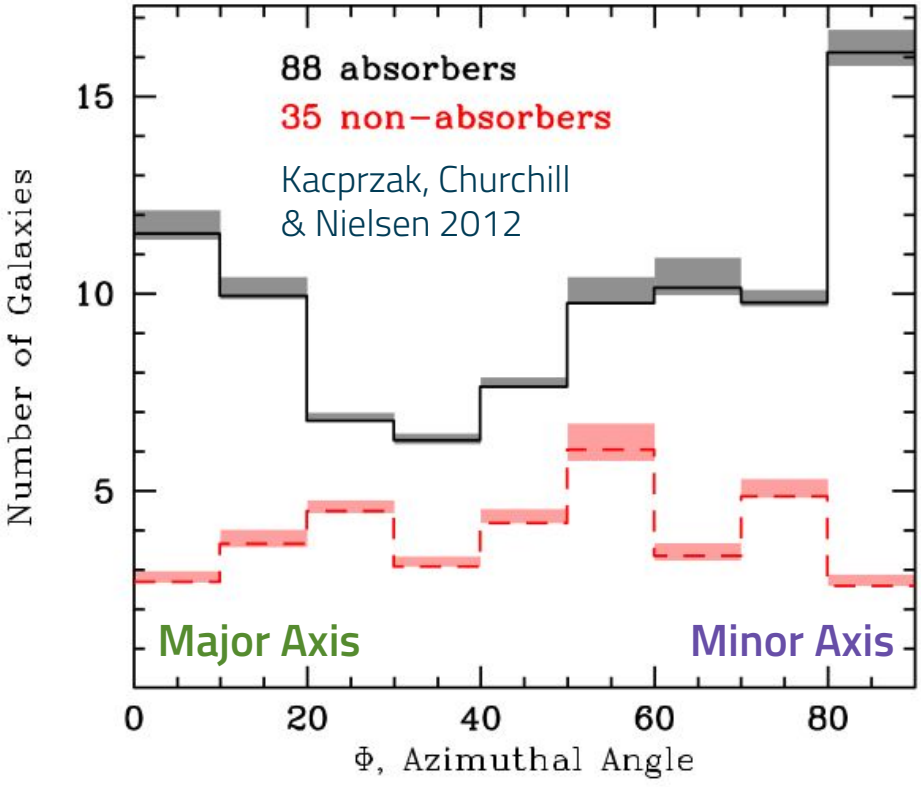
Merging satellite galaxies/intergalactic transfer

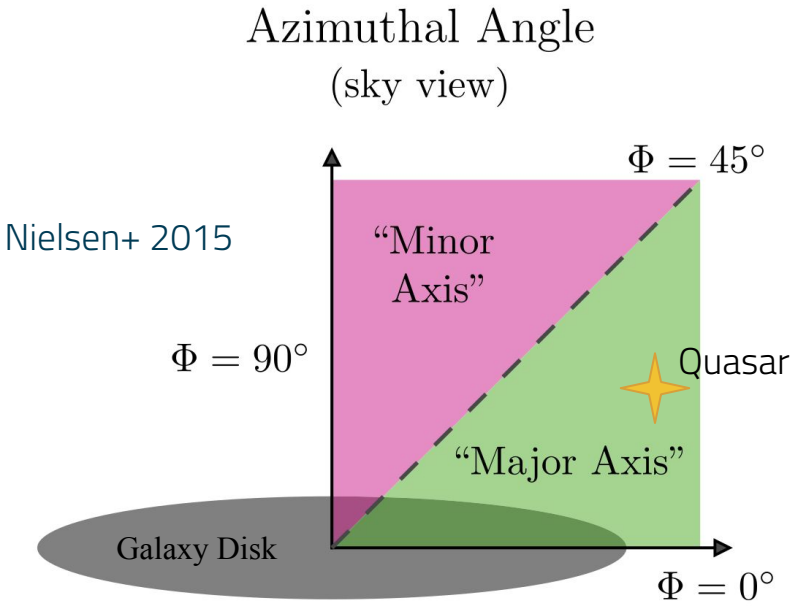
e.g., Martin+ 2012, Anglés-Alcázar+ 2017



Credit: NASA/CXC/M.Weiss; NASA/CXC/Ohio State/A.Gupta et al.

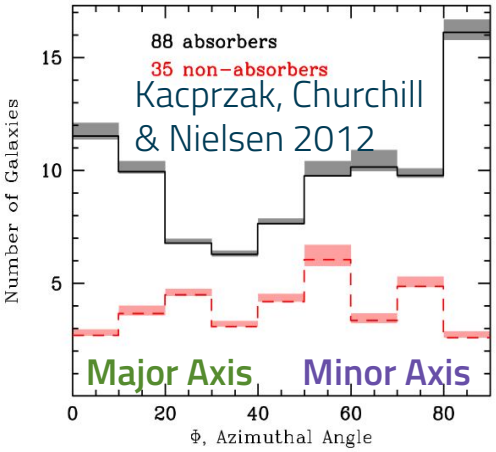
Further evidence of gas flows with MgII

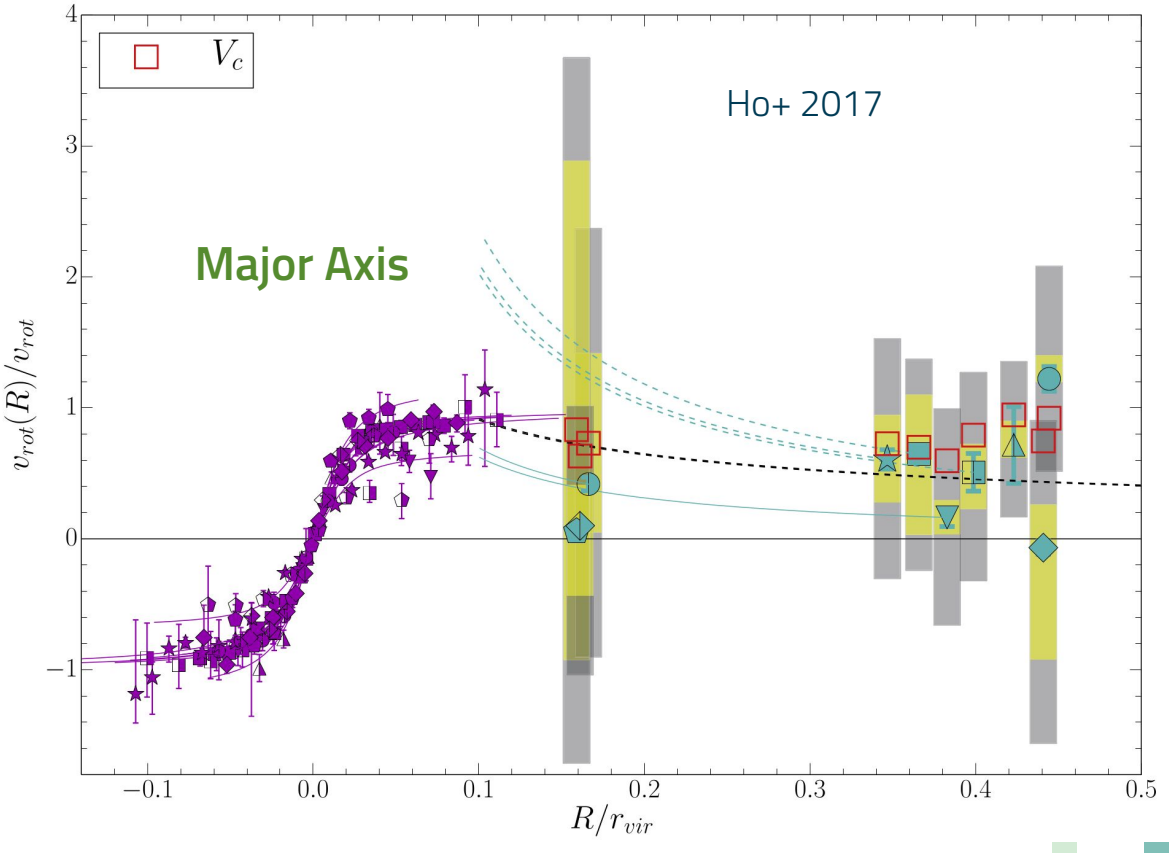




Also see Bouché+ 2012, Lan+ 2014

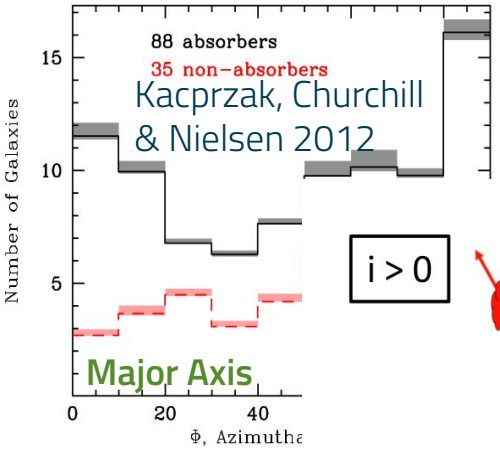
Further evidence of gas flows with MgII

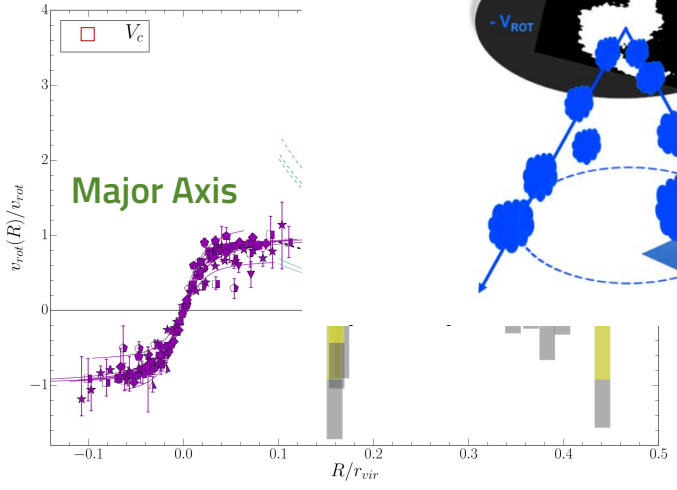




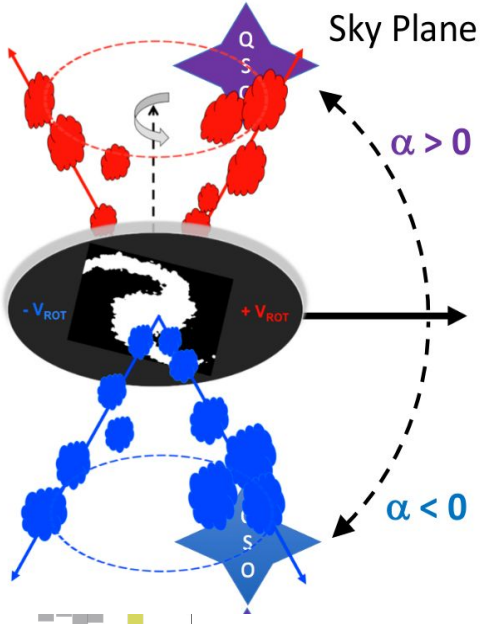
Also see Steidel+ 2002, Kacprzak+ 2010, Zabl+ 2019

Further evidence of gas flows with MgII





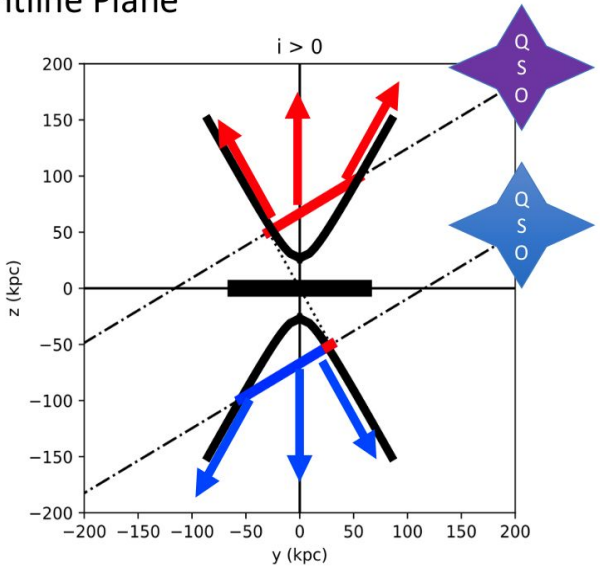
i > 0



Martin+ 2019

Minor Axis

observer

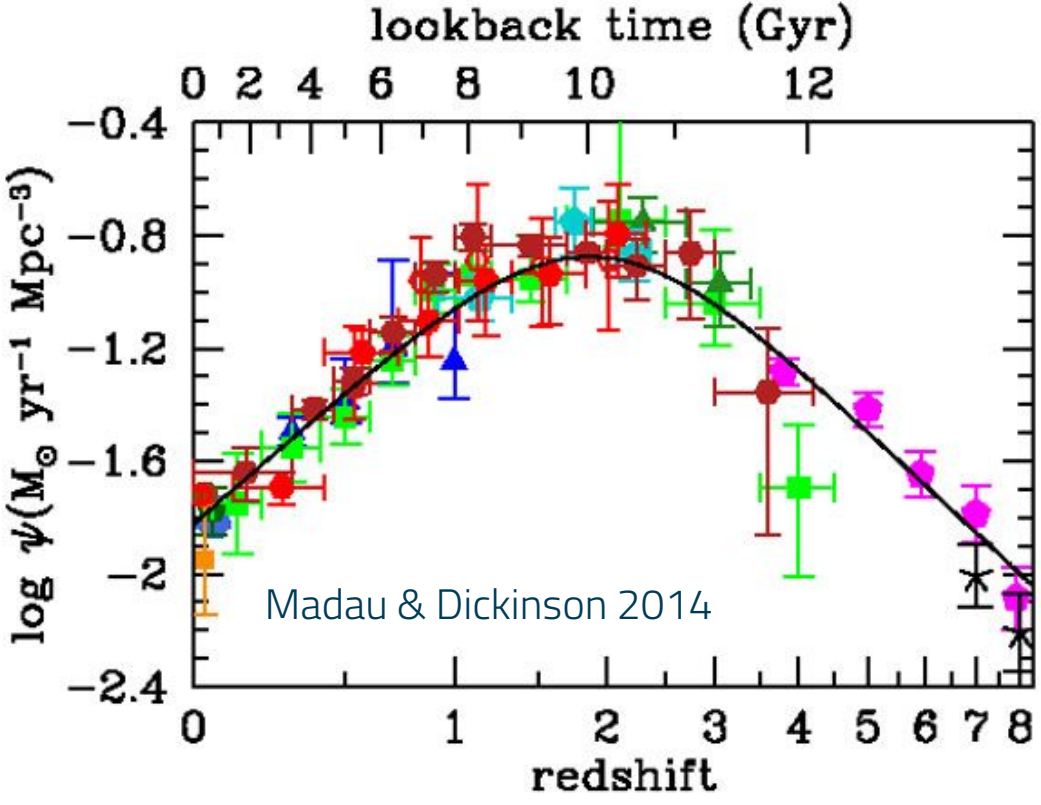


Also see Bouché+ 2012, Schroetter+ 2017,2019, Bordoloi+ 2014 ...

The baryon cycle is diminishing in strength

Much of the baryon cycle action is at $z = 2$

Outflows ubiquitous (Steidel+ 2010); Accretion rate greatest (van de Voort+ 2011)



MgII traces SFR evolution

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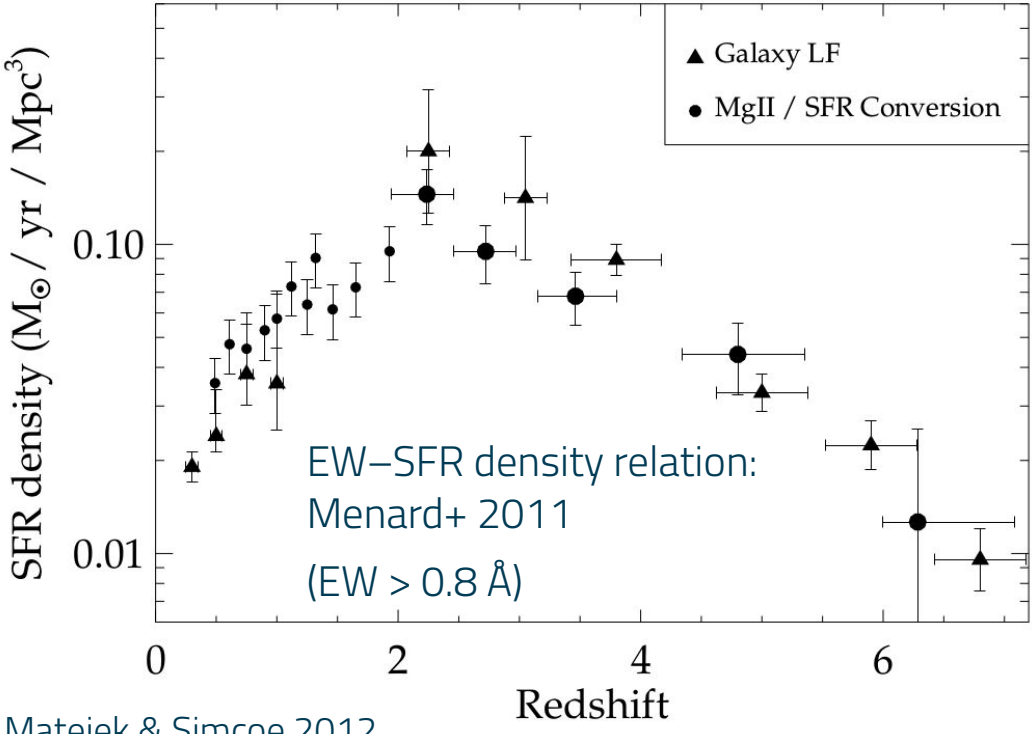

Also see Matejek & Simcoe 2012

Cosmic Noon Gas Flows:

The CGM at Cosmic Noon with KCWI: Outflows from an Edge-On Galaxy at $z = 2.071$

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Christopher W. Churchill,[3] and Romeel Davé[4]

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Submitted to ApJ on 5 September 2019

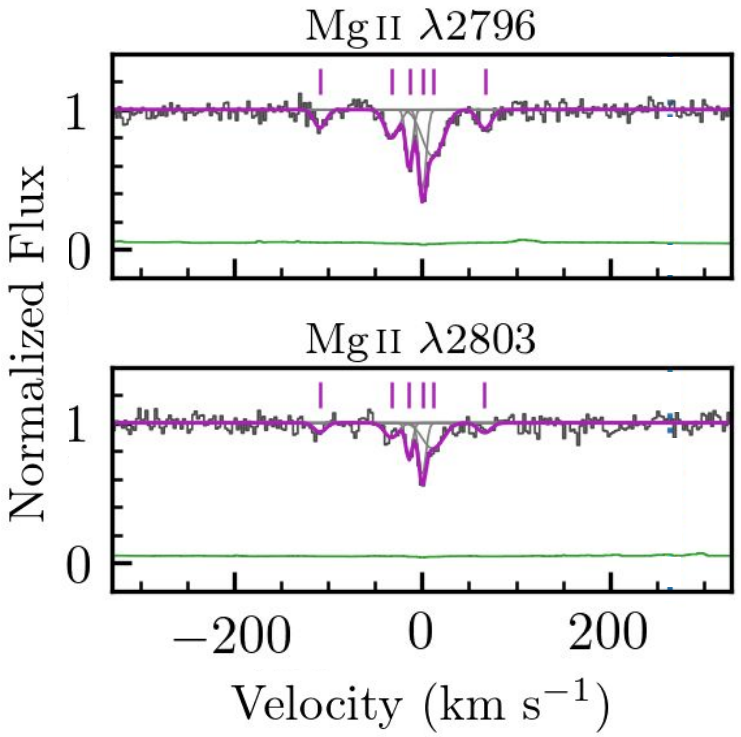
Cosmic Noon CGM Sample

13 fields with 2+ MgII absorbers at $1.9 < z < 2.6$ in each field (no restrictions on absorption strength)

For each field we have:

- HIRES/Keck or UVES/VLT quasar spectra
  - From KODIAQ, UVES Squad
  - R~40,000
  - Covers Lyα, MgII, CIV, +

J1430, z_{abs} = 2.0708



Nielsen+ ApJ, submitted

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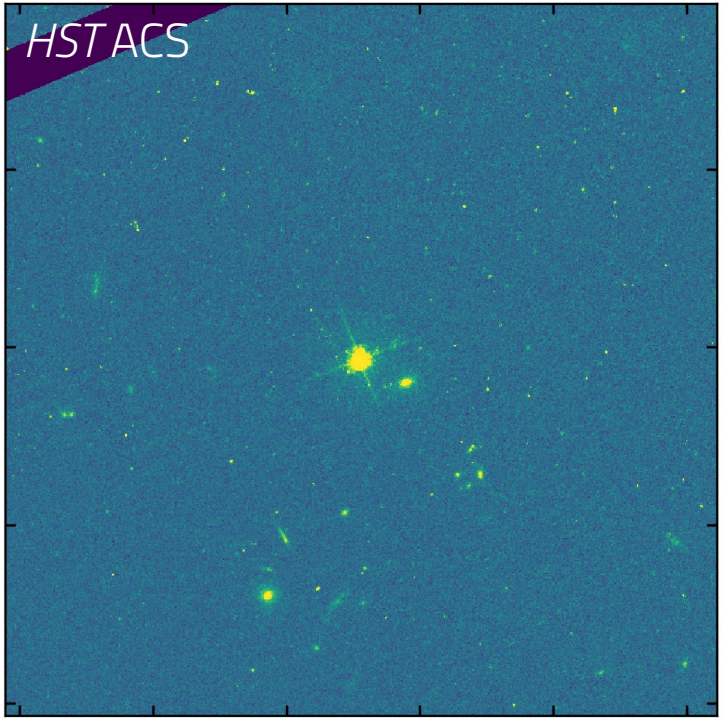

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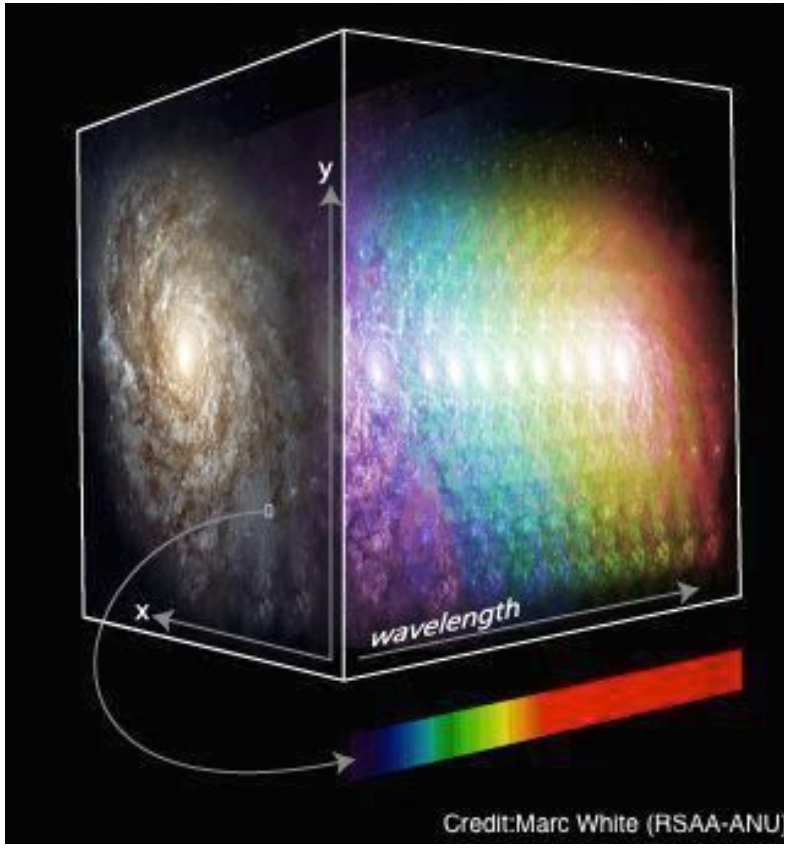


Need to identify the host galaxies, but it's time consuming…

Keck Baryonic Structure Survey with MOSFIRE (Steidel+ 2010, Rudie+ 2012, 2019…)

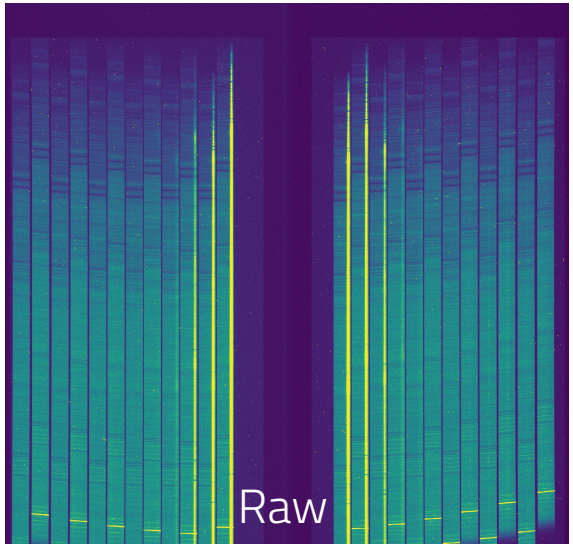
Integral field spectroscopy to the rescue!

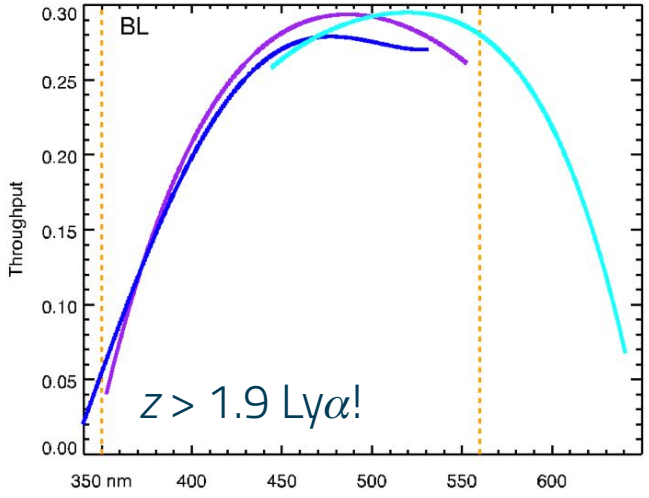
Nielsen+ ApJ, submitted

Keck Cosmic Web Imager

J1430, z_{abs}= 2.0708:

- Medium slicer, BL grating
- FOV: 16.5''x20.4'' (130kpc x 170kpc at z=2)
- Spatial resolution: 0.29''x0.69'' (2.5kpc x 6kpc)
- Spectral resolution~1800
- 3500 Å to 5500 Å
- Sensitive to SFR>0.1 M_{sun} yr^{-1}





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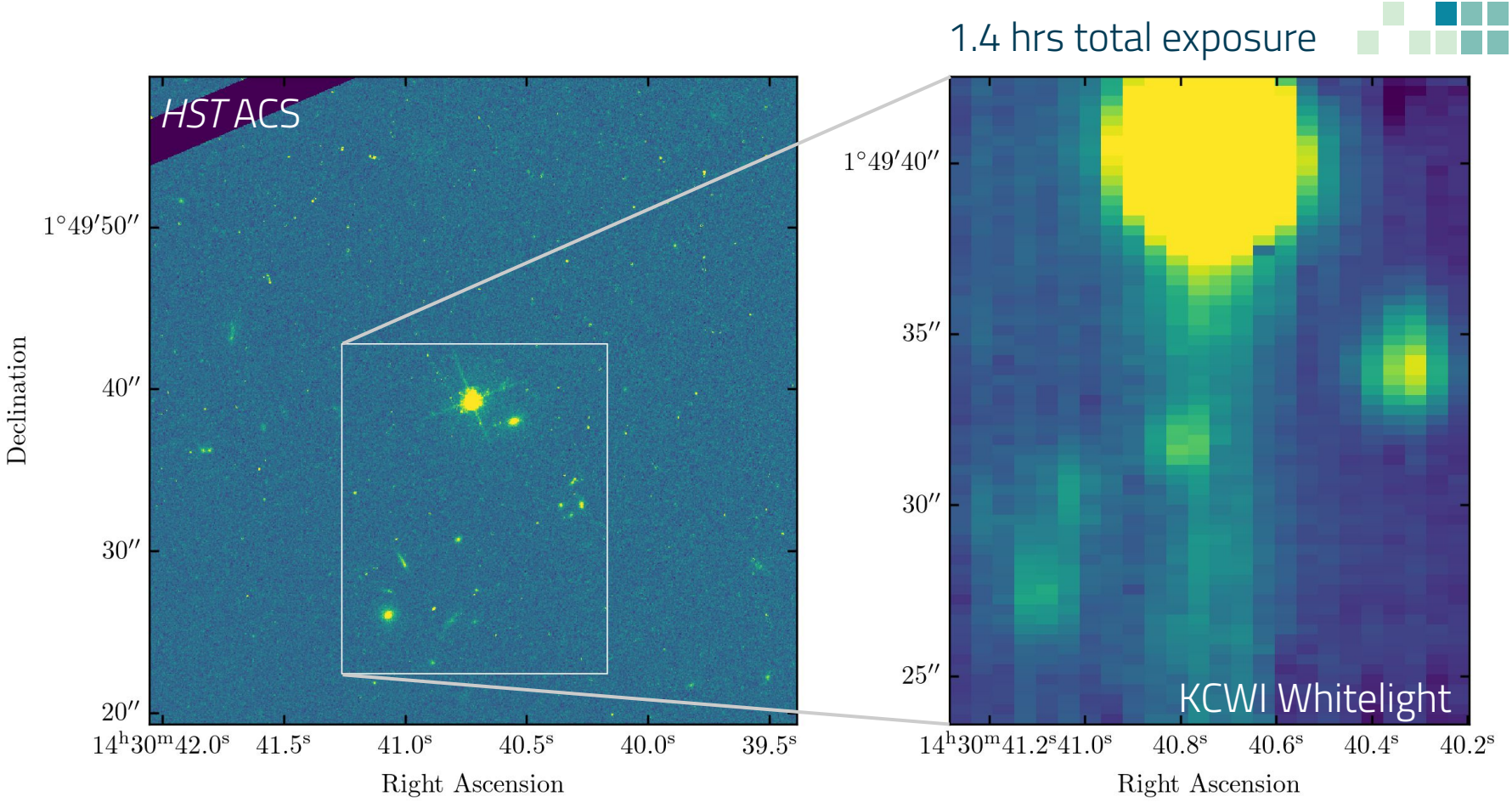
J1430: KCWI Field of View



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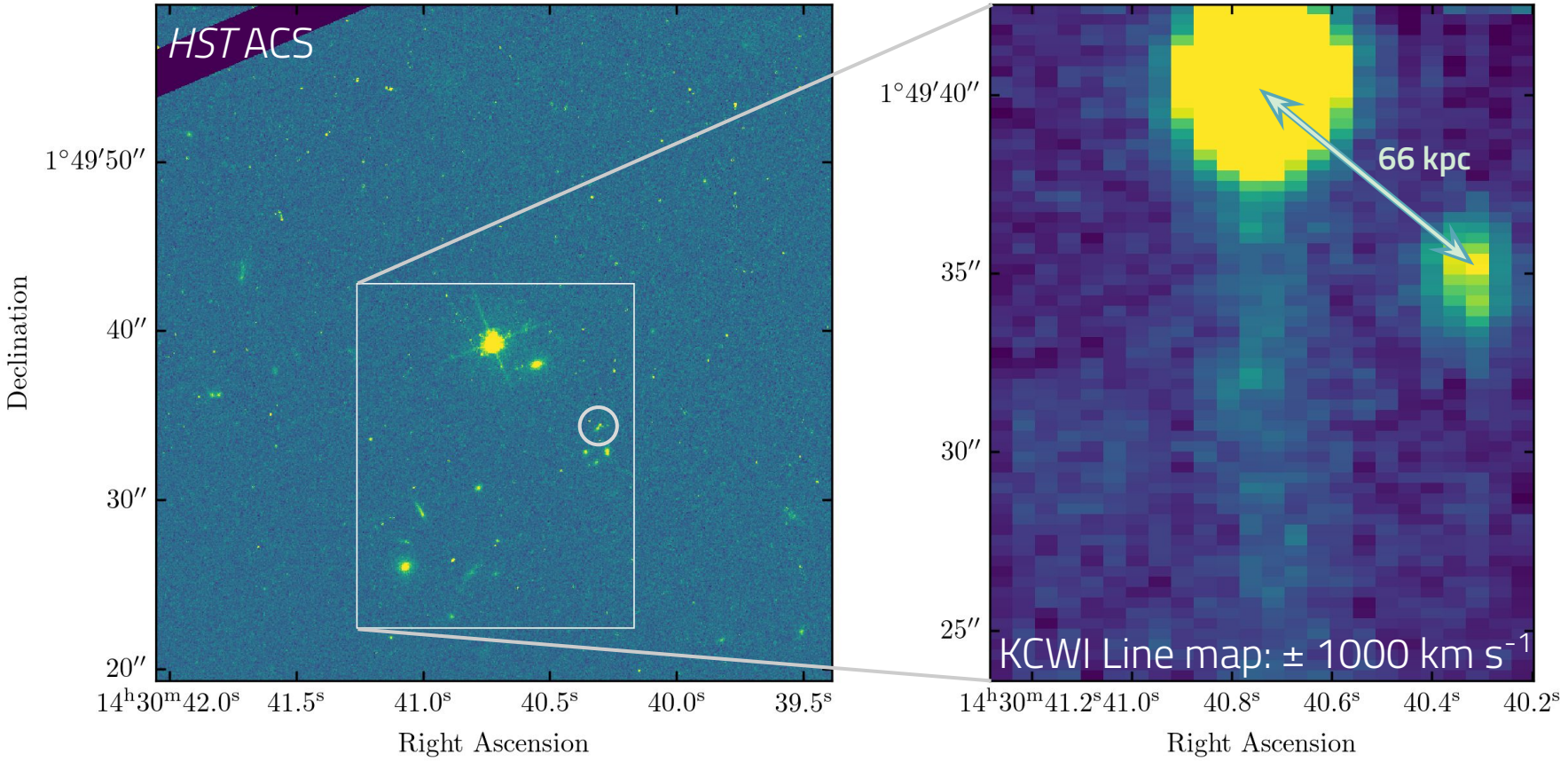
Searching for Lyα Galaxy Emission at z=2.071

1.4 hrs total exposure



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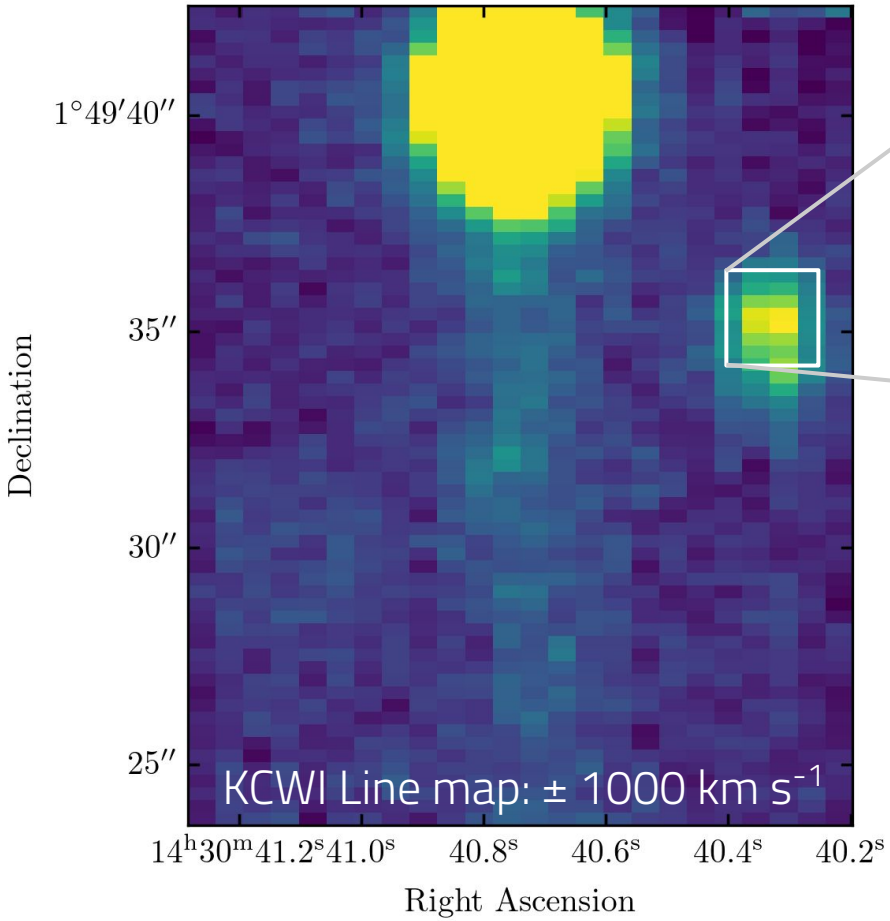
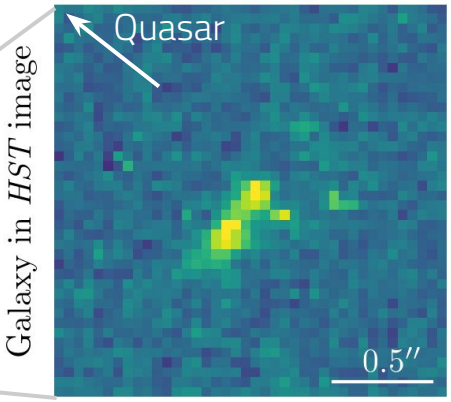
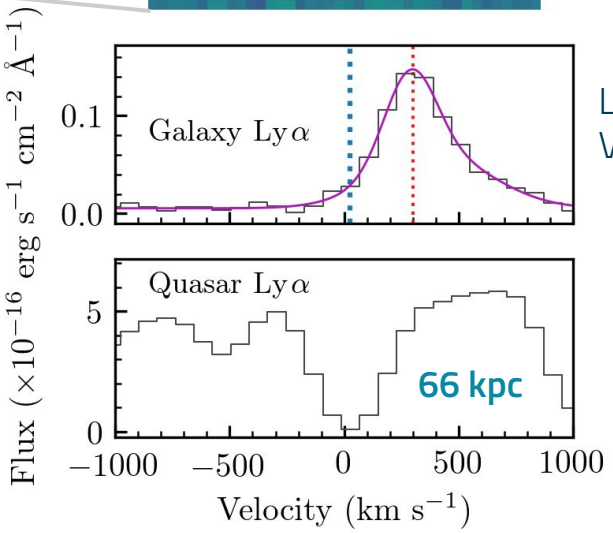
MgII-absorbing Galaxy: z_{gal}=2.0711







M_B = -23.5

3.7 L*

log (M_*/M_{sun}) = 11.1

i = 85°

ϕ = 89°

Lyα z_{gal} correction: Verhamme+ 2018

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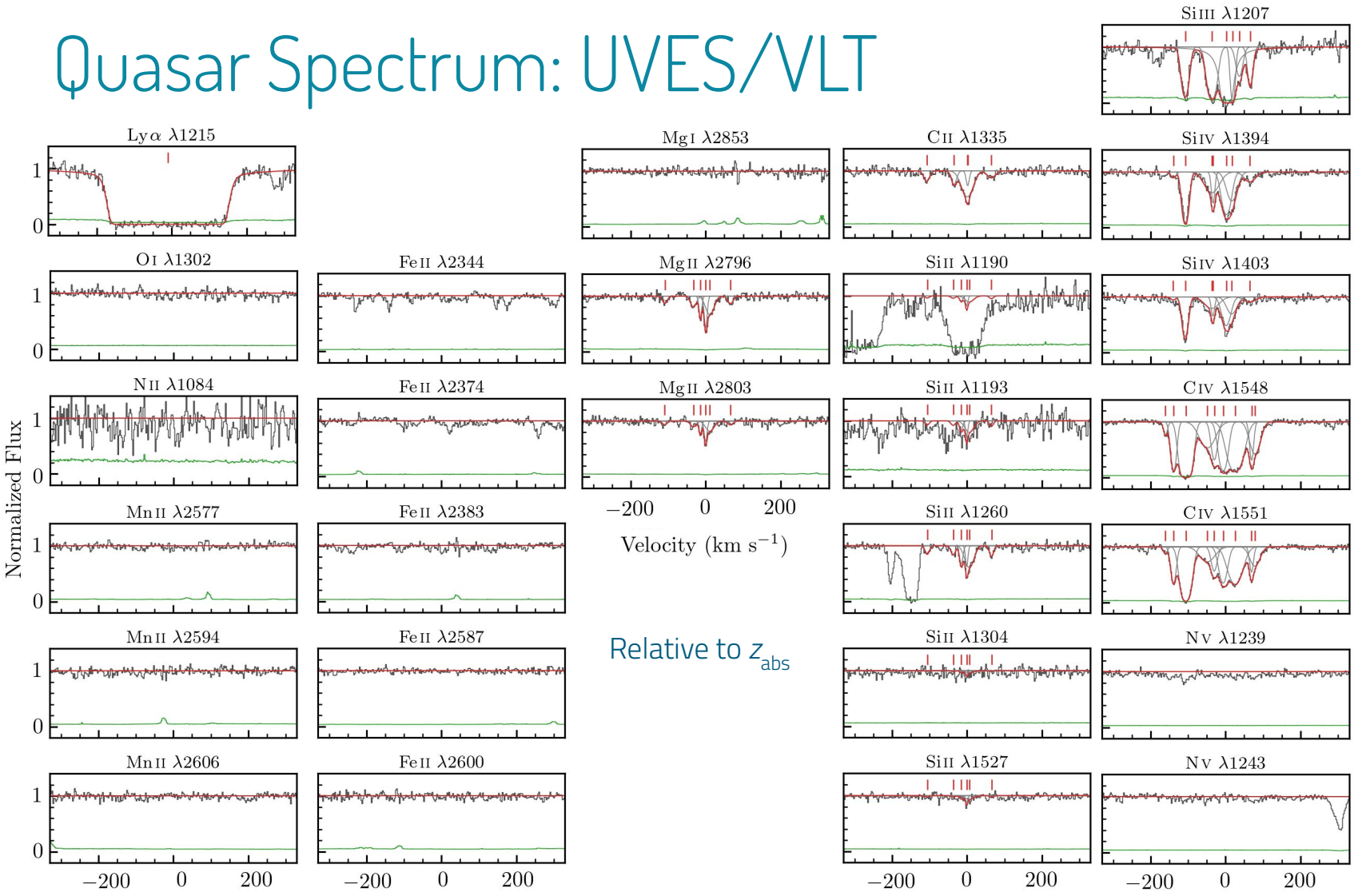
Quasar Spectrum: UVES/VLT



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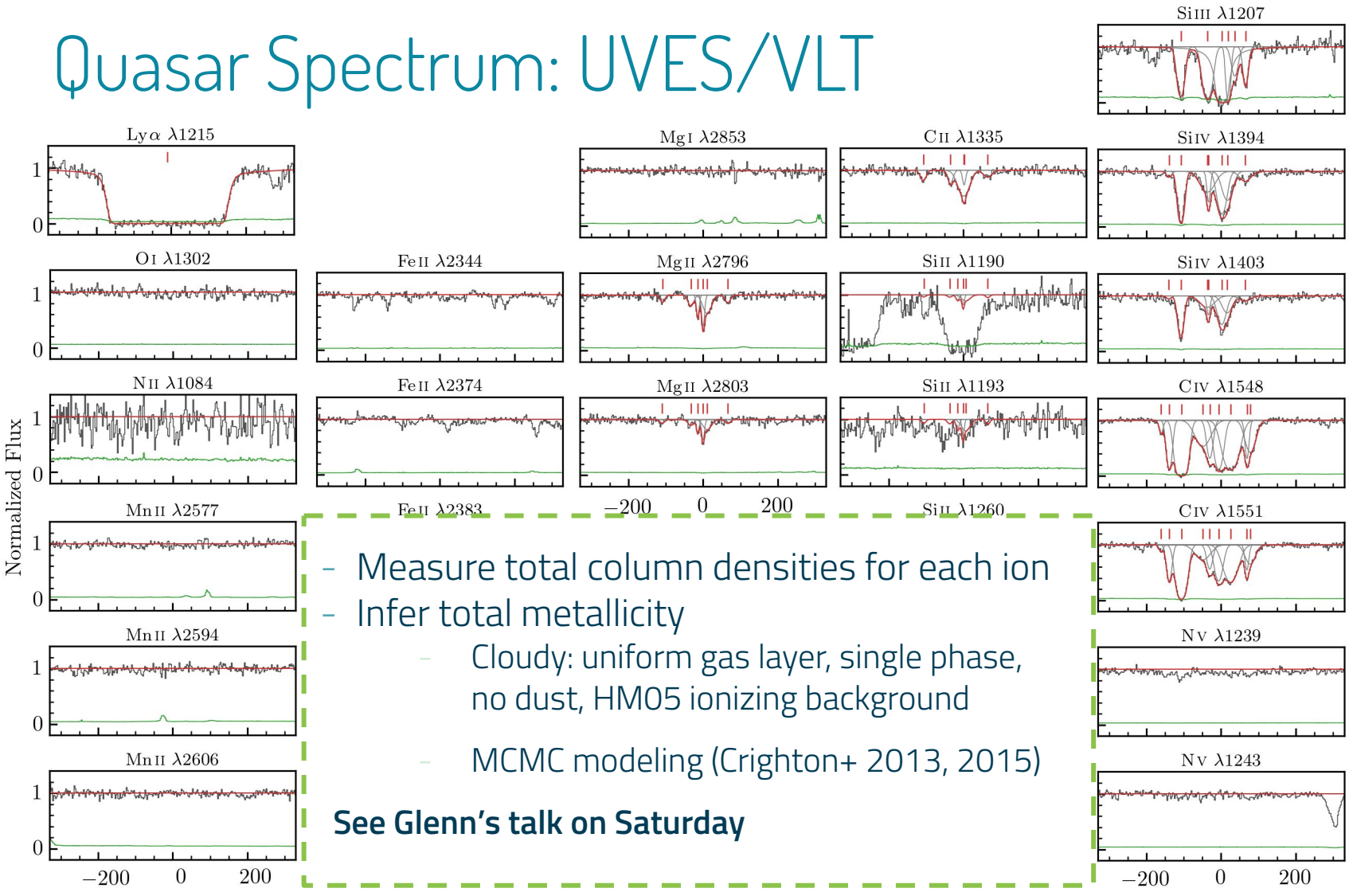
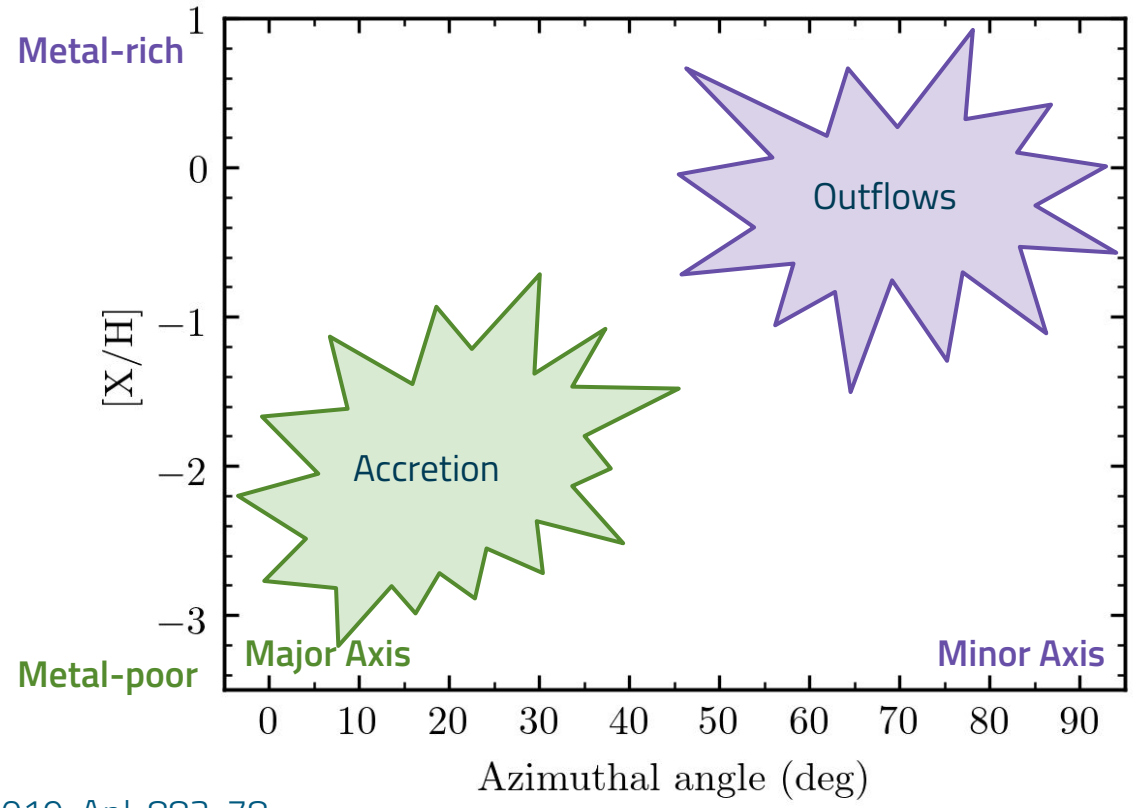


- Measure total column densities for each ion
- Infer total metallicity
  - Cloudy: uniform gas layer, single phase, no dust, HM05 ionizing background
  - MCMC modeling (Crighton+ 2013, 2015)

See Glenn's talk on Saturday

Nielsen+ ApJ, submitted

CGM Metallicity + Galaxy Orientation

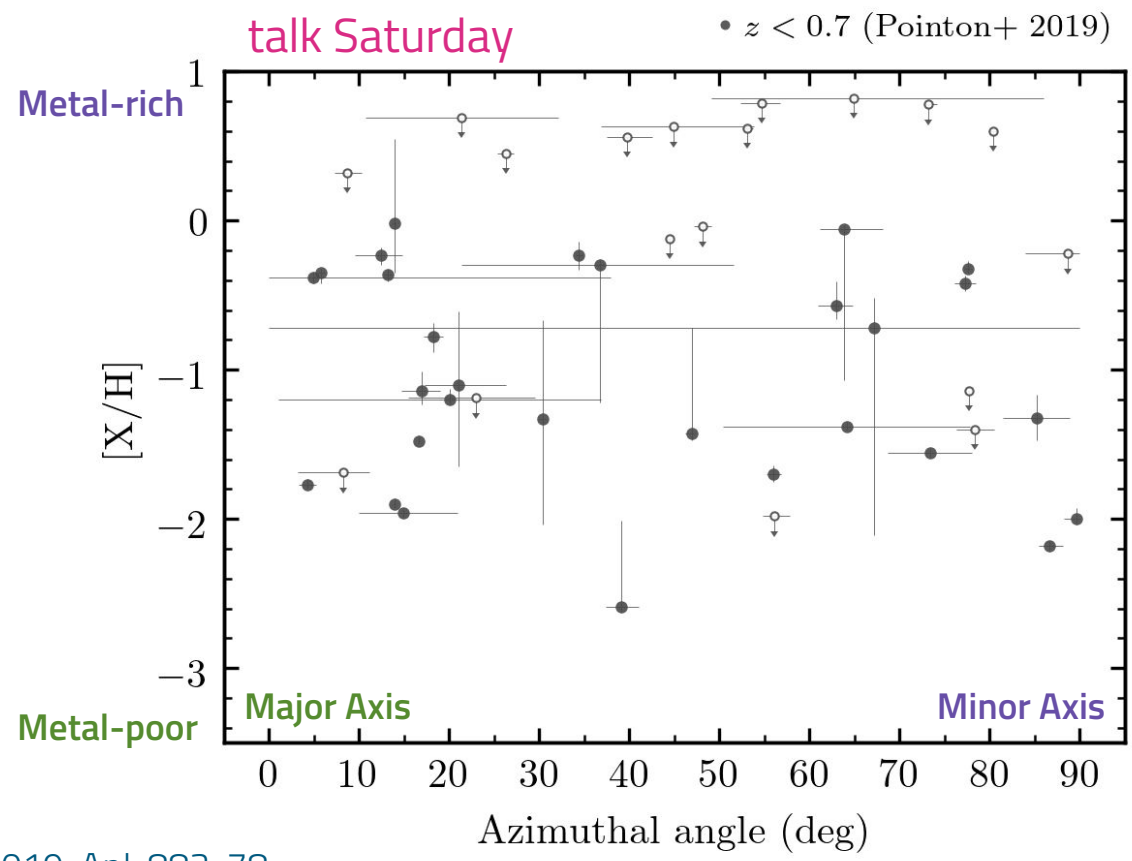


Pointon, GK, NN+ 2019, ApJ, 883, 78
Nielsen+ ApJ, submitted

CGM Metallicity + Galaxy Orientation

Stephanie Pointon

Low redshift! See Glenn's talk Saturday



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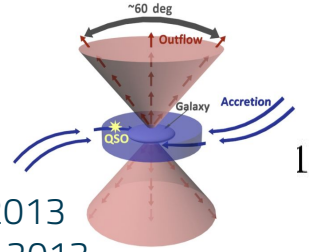


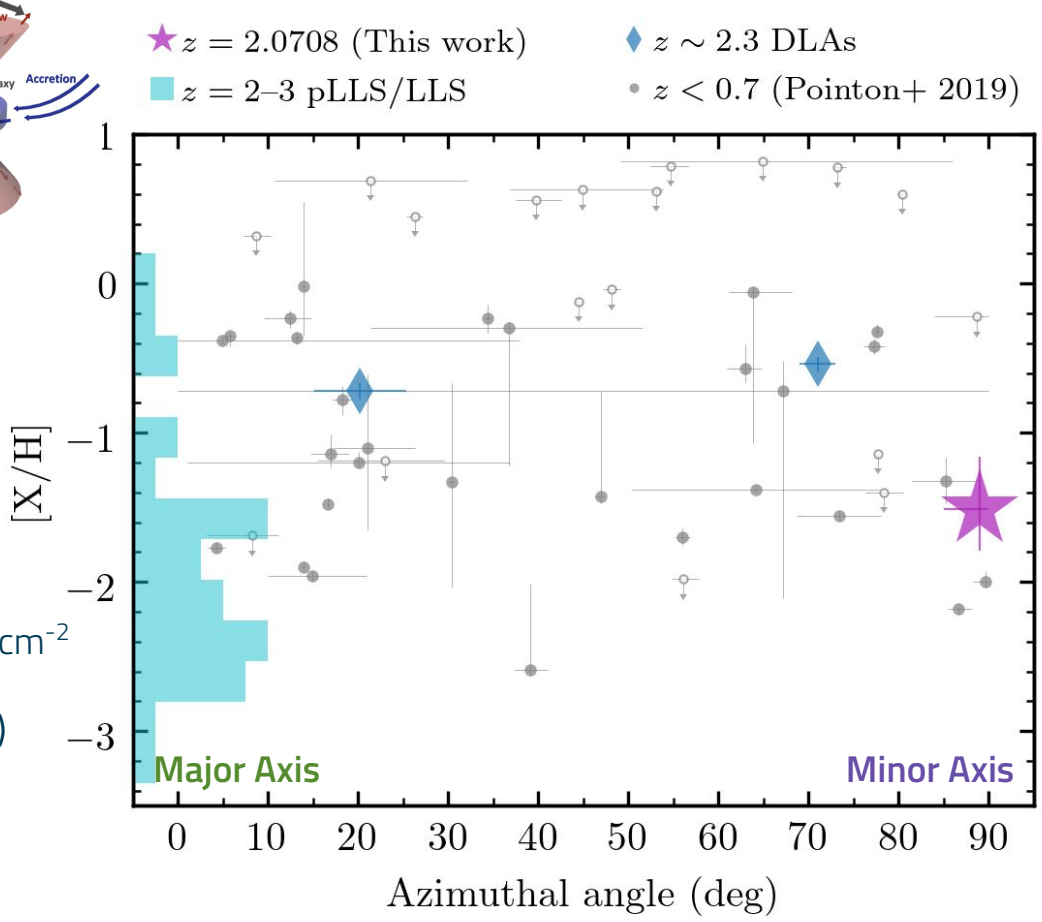
Bouché+ 2013
Krogager+ 2013

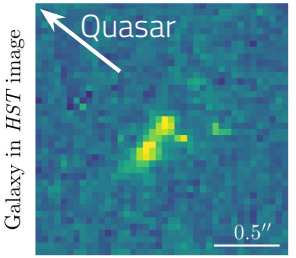
DLAs
log N(HI) > 20.3 cm^{-2}

Lyman Limit systems
16.2 < log N(HI) < 19.0 cm^{-2}

(no galaxy orientations)

Lehner+ 2014, 2016
Crighton+ 2013, 2015





pLLS/LLS

Nielsen+ ApJ, submitted

~~Accreting~~ or Outflowing gas?

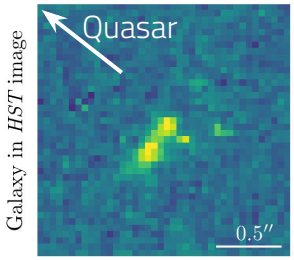
A recap and some new information:

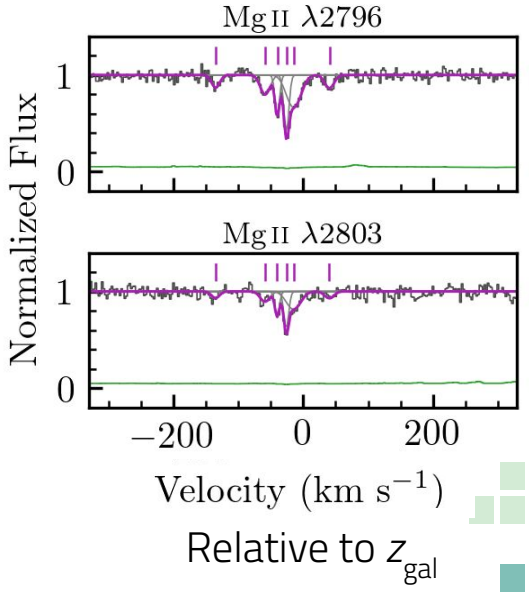
- Edge-on galaxy, $i = 85°$
- Quasar probes the galaxy's projected minor axis, ϕ=89°

- CGM gas is relatively metal-enriched for z=2, [Si/H]=-1.5

- Absorption offset from z_{gal} by only ~30 km/s
- Roughly symmetric absorption, reminiscent of the Milky Way Fermi Bubble profiles (Fox+ 2015)

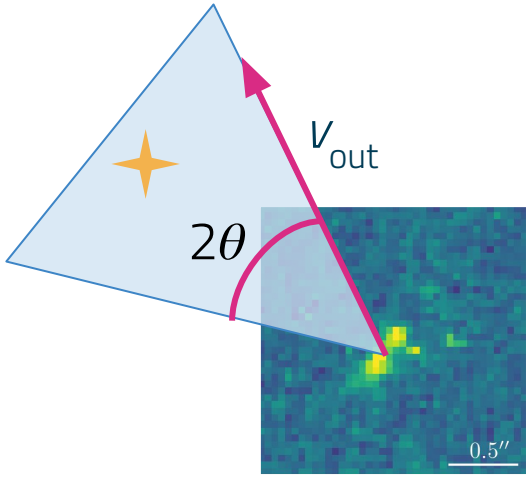
- $SFR_{Ly\alpha}$>10 M_{sun} yr^{-1} (Sobral & Mathee 2017)



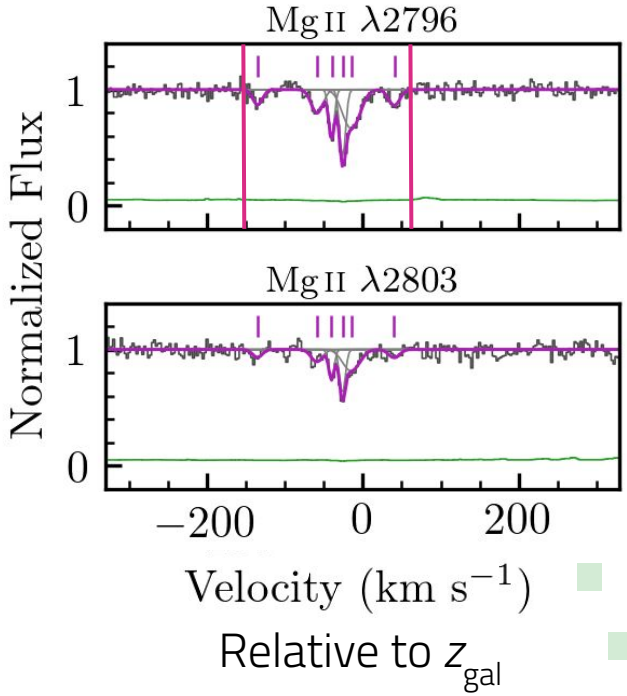


Nielsen+ ApJ, submitted

Modeling the Outflow

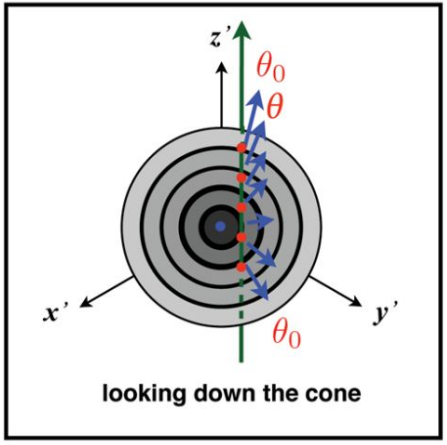


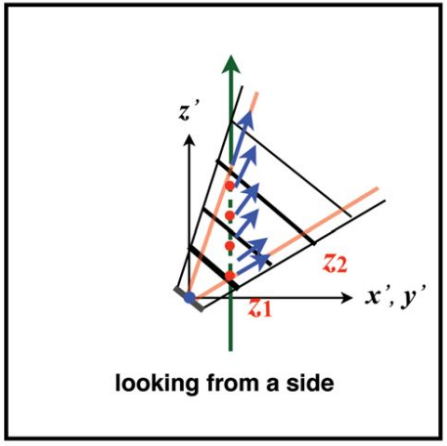
- Model outflow cone with half opening angle, θ
- Boundaries on cone defined by absorption bounds
- Constrain opening angles, outflow velocities, and mass outflow rates

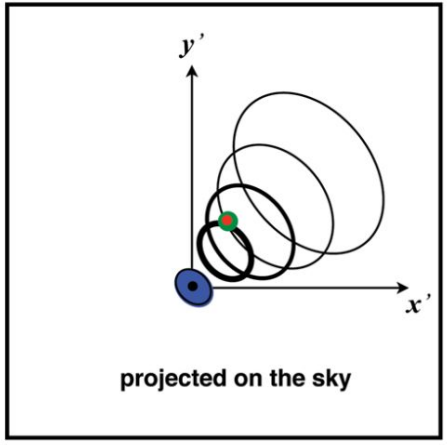


Nielsen+ ApJ, submitted

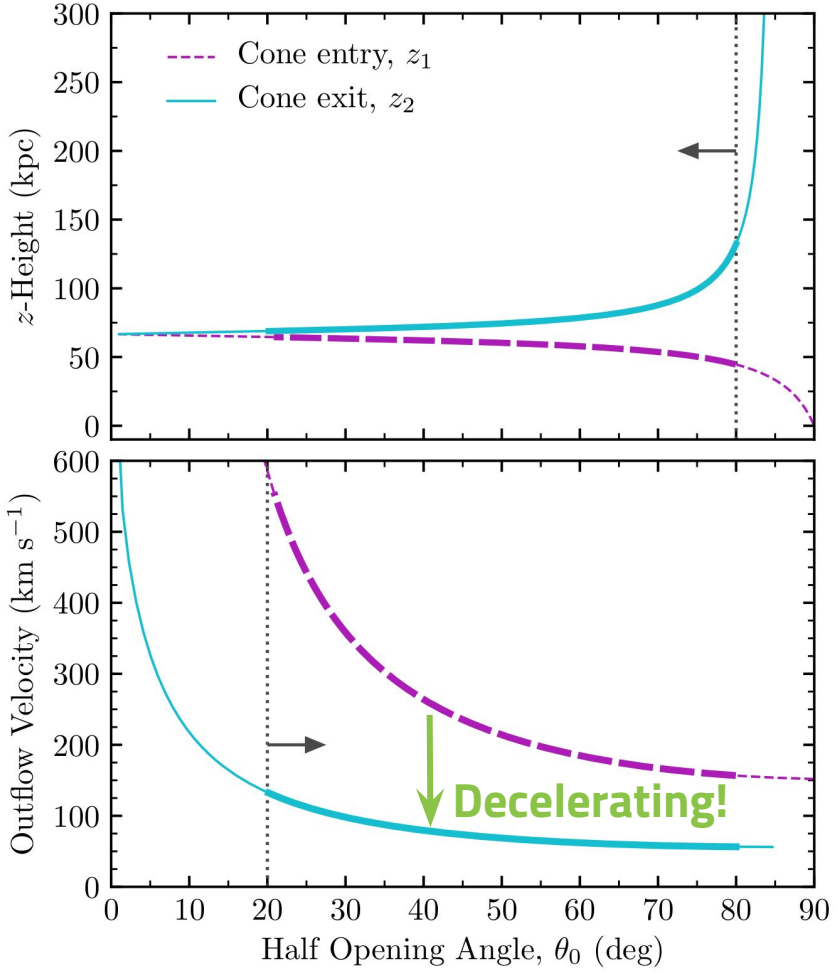
Outflow Model







Gauthier & Chen 2012



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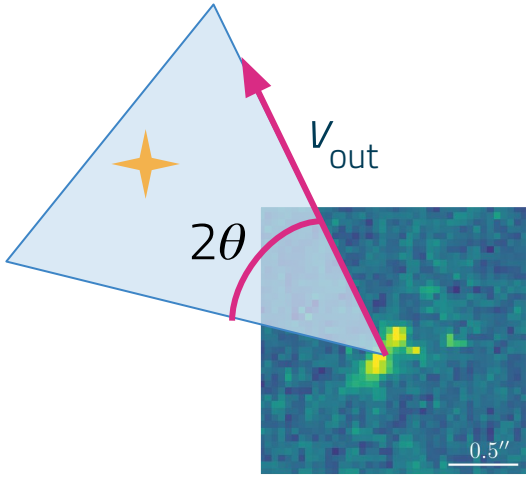
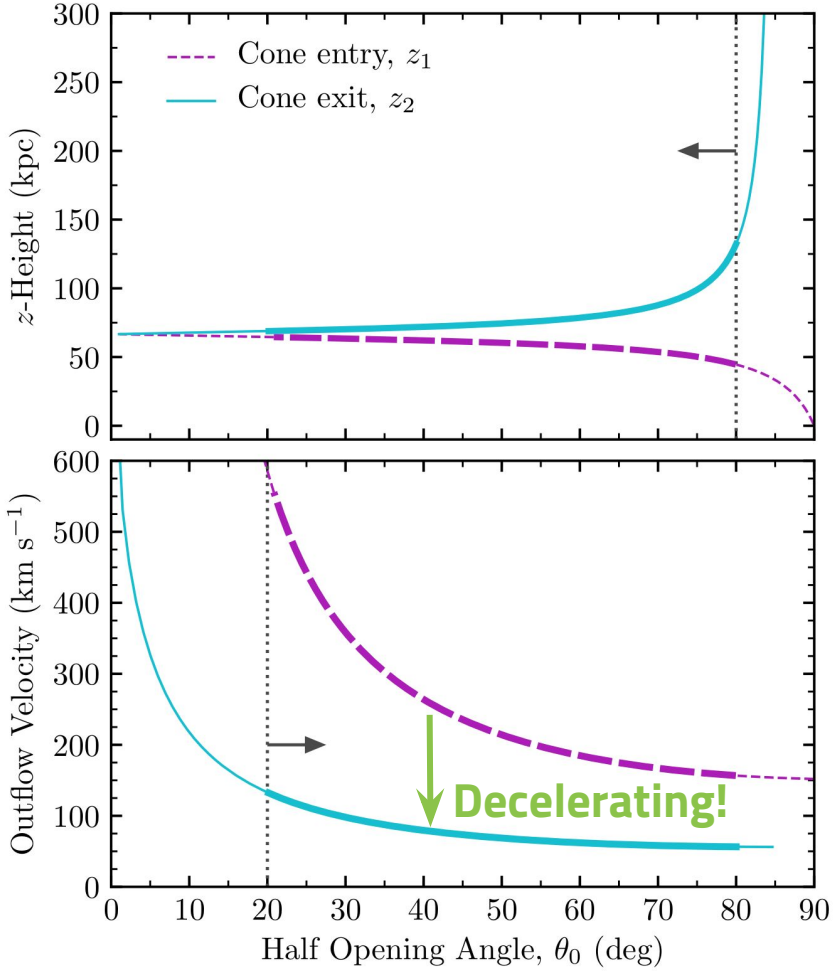


	Outflow timescale	Mass outflow rate	Mass loading factor
θ_0 (deg)	V_{out} (km s^{-1})	t_{out} (Myr)	$\dot{M}_{out}$ ($M_\odot$ yr^{-1})	η
20	350	190	45	< 4.5
80	100	650	51	< 5.1



Nielsen+ ApJ, submitted

Outflowing gas at z=2

Galaxy is currently star-forming: **$SFR_{Ly\alpha}$ >10 M_{sun} yr^{-1}**

Relatively metal-enriched for z = 2 CGM: **[Si/H]=-1.5**

Kinematically consistent with decelerating outflow: **v_{out}=100-350 km s^{-1}**

Ejection timescale consistent with recycling timescales: **200-650 Myr**

Mass outflow rate: **$\dot{M}_{out}$ ~ 50 M_{sun} yr^{-1}**

Stay tuned!

13 fields total; 21 MgII absorbers/galaxies

67 CIV absorbers

Countless nonabsorbers

Bonus z < 0.5 absorbers