Gas flows around galaxies: Mapping the CGM in absorption and in emission with BlueMUSE

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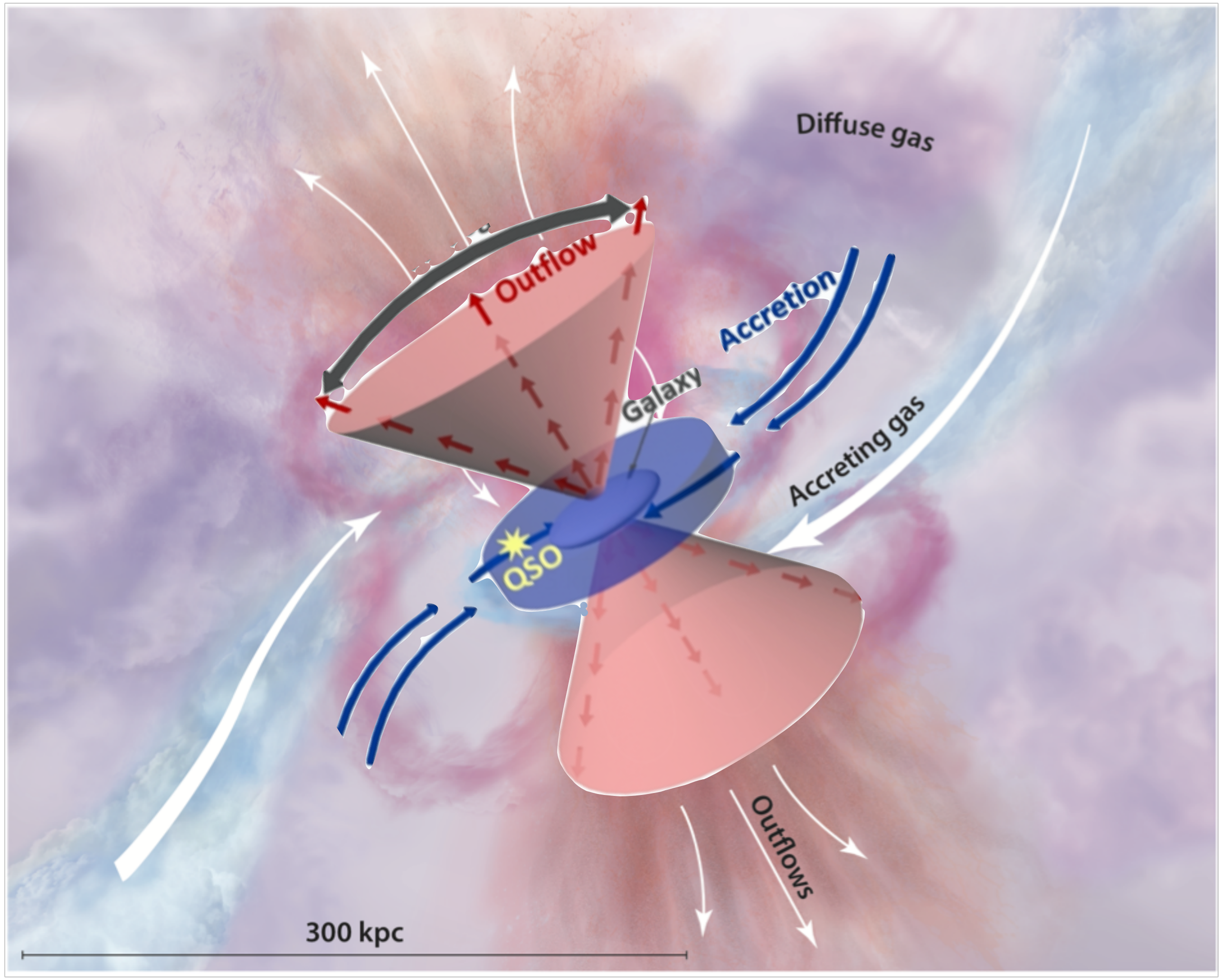
CGM – complex multiphase medium

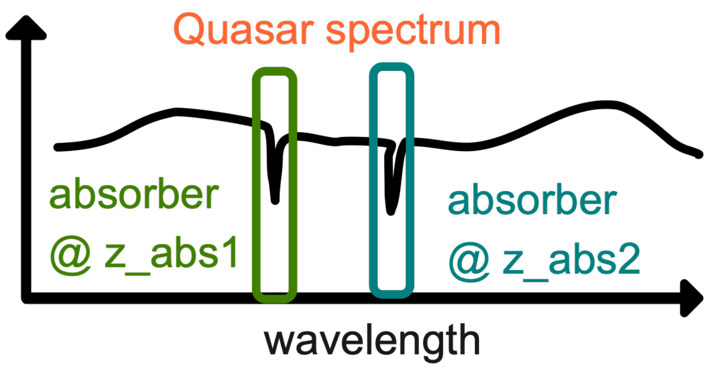
Complex (but there is some order)!



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

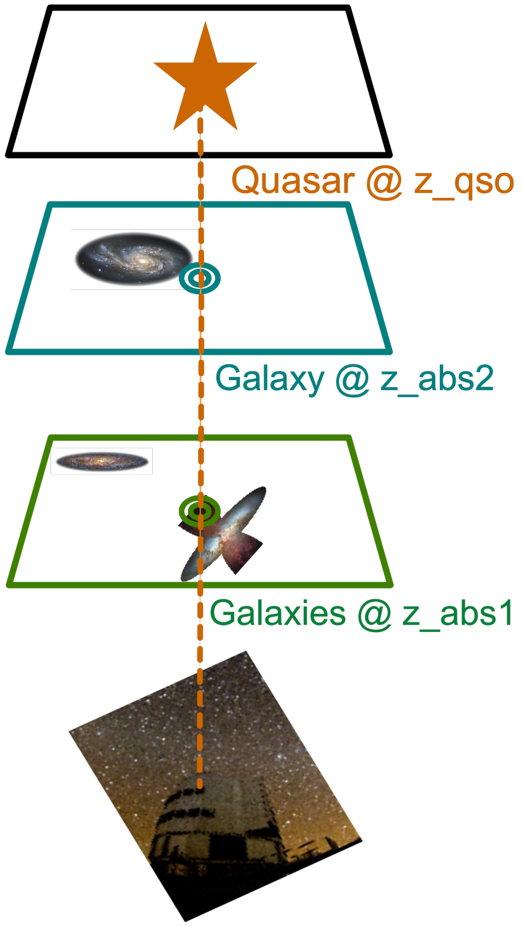
Characterizing outflows and inflows is crucial for understanding galaxy evolution.

Studying CGM in absorption



Allows to study low density / low column density gas

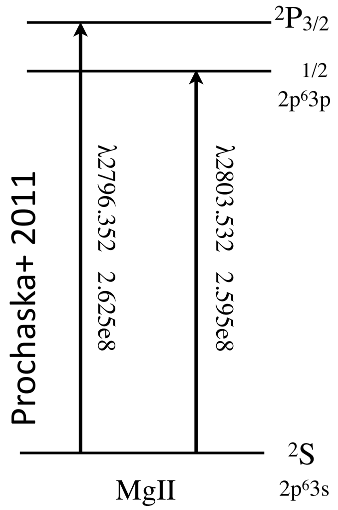
Quasar sight-lines



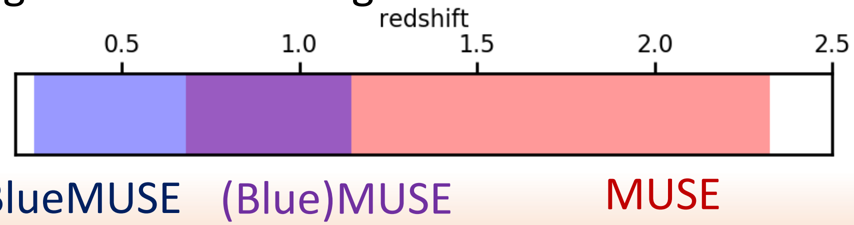
This talk: focus on MgII λλ 2796,2803

Useful tracer of the cool $T \approx 10^4\ K$ CGM, because ..

- Easy accesible from the ground for $z \gtrsim 0.2$
- Easy identifiable as a doublet
- Strong (high f_{osc} , Mg is a relatively abundant metal)

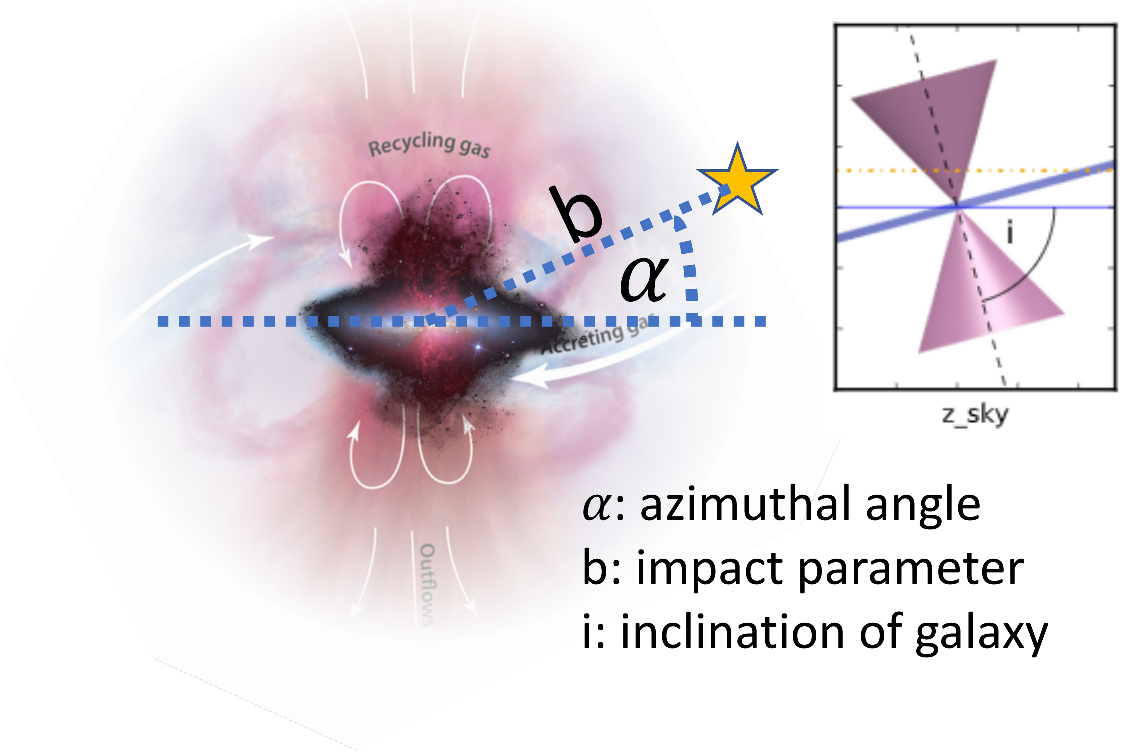


MgII redshift coverage:



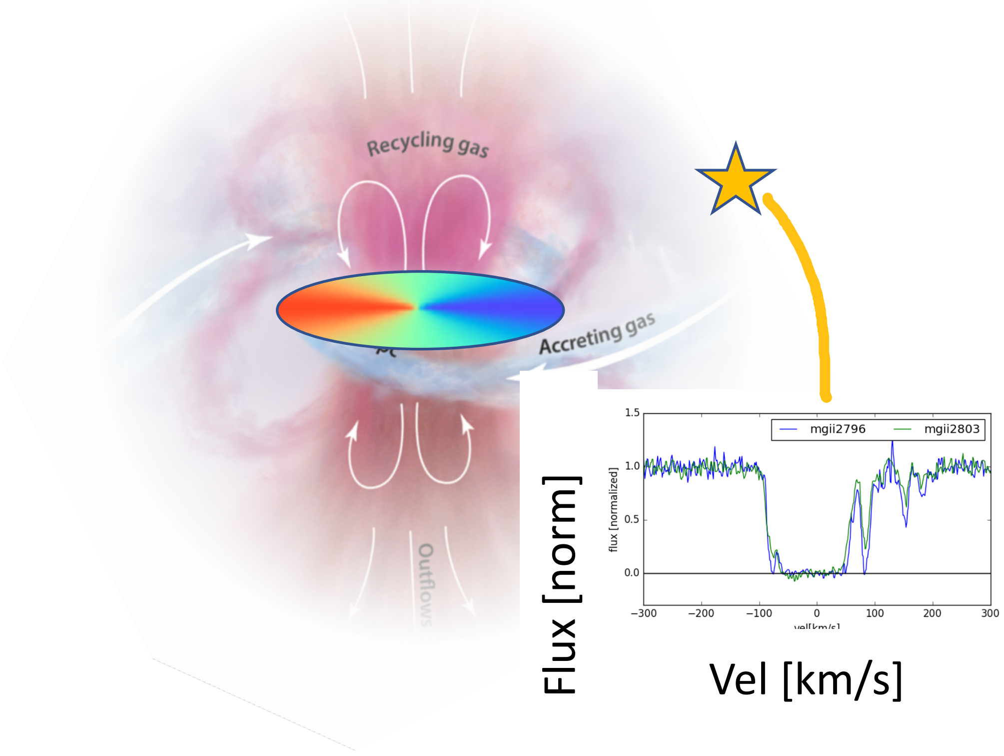
Interpreting absorption w.r.t. associated galaxy

Orientation of galaxy w.r.t. quasar sightline



α: azimuthal angle
b: impact parameter
i: inclination of galaxy

Kinematics of galaxy



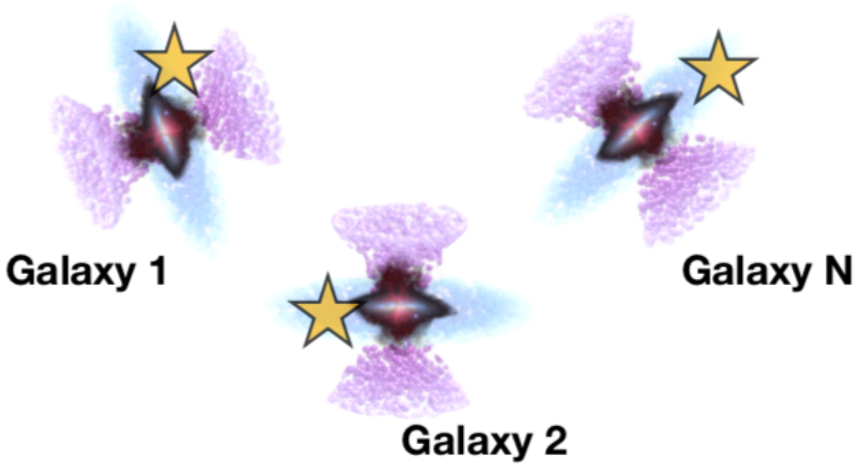
Panoramic IFU spectrographs (BlueMUSE) -> revolutionize(d) the efficiency of such observations

Several surveys: **MusE GAs FLow and Wind (MEGAFLOW) – 22 quasar fields – 79 strong MgII absorbers**

Also e.g.: Lofthouse+20, Dutta+20 (MAGG); Hamanowicz+20 (MUSE-ALMA); Muzahid+20 (MUSEQuBES); Chen+20 (CUBS)

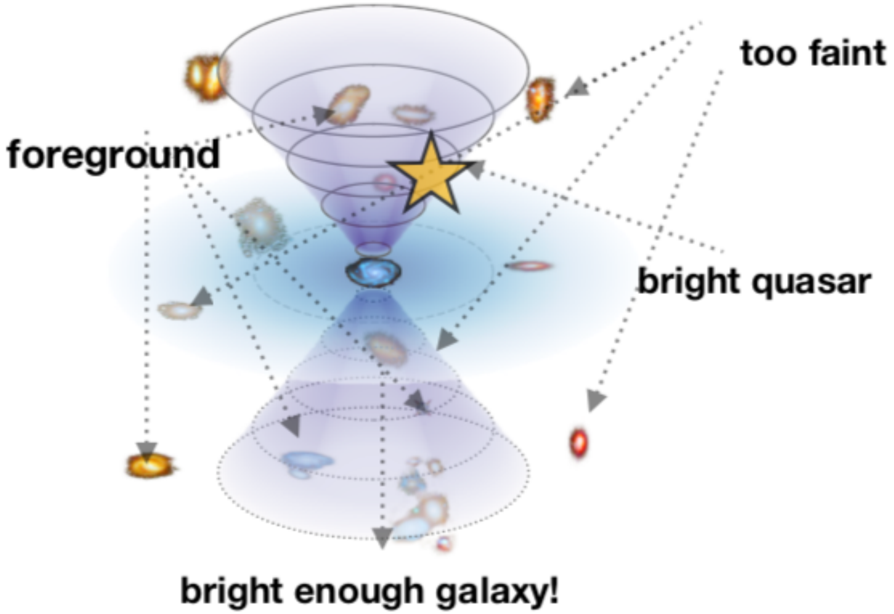
“One for all” vs “all for one”

One for all



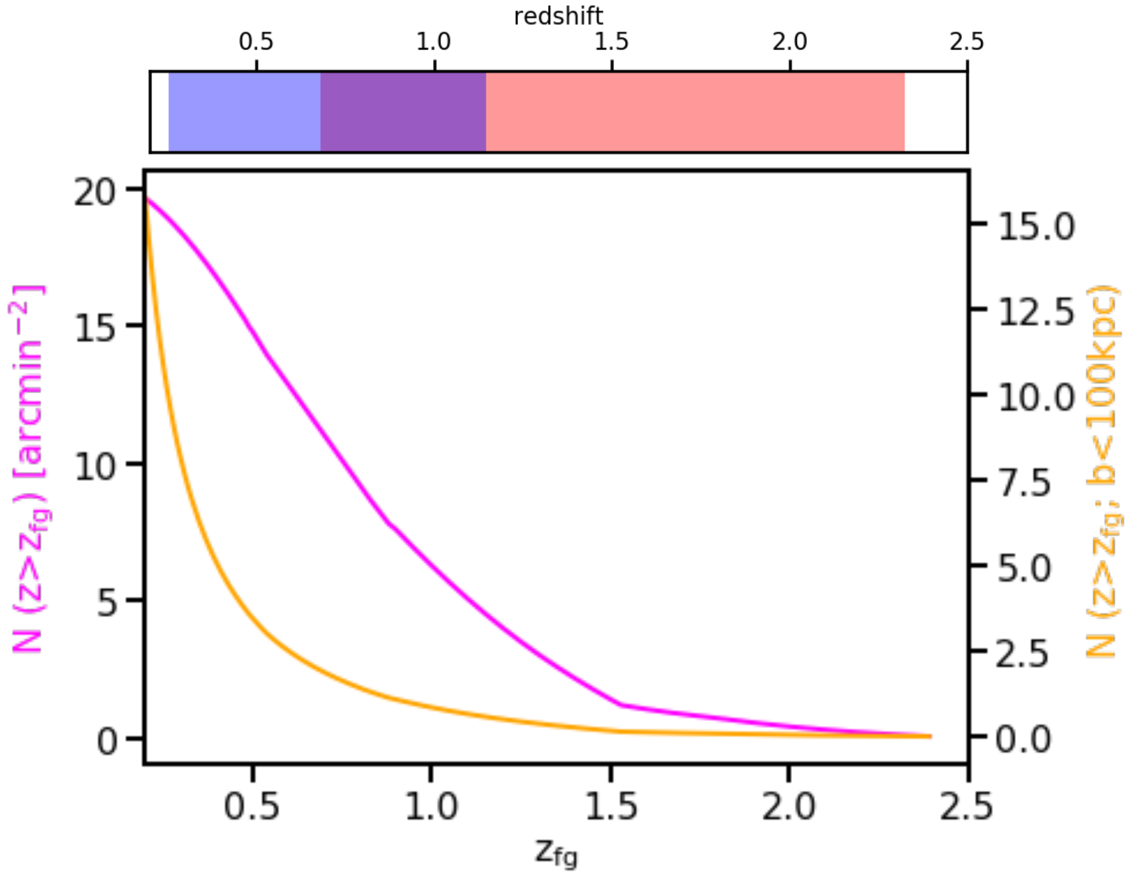
MEGAFLOW I (Schroetter+16)
MEGAFLOW II (Zabl+19),
MEGAFLOW III (Schroetter+19)
MEGAFLOW V (Wendt+20; ArXiv)
MEGAFLOW VI (Schroetter+; subm,)
MEGAFLOW VII (Freundlich+; subm)

All for one



Alternative : Multiple Background galaxies

How many background galaxies available?



For observerd magnitude limit I = 24 mag

In normal fields with BlueMUSE:
Multiple foreground galaxies with > 2 galaxies within 100kpc of the foreground galaxy.

Further boost:
Use groups and clusters as background sources.
BlueMUSE covers MgII below redshifts where groups/clusters are abundant.

Assuming LFs from Dahlen+05, Moutard+20

The importance of spectral resolution

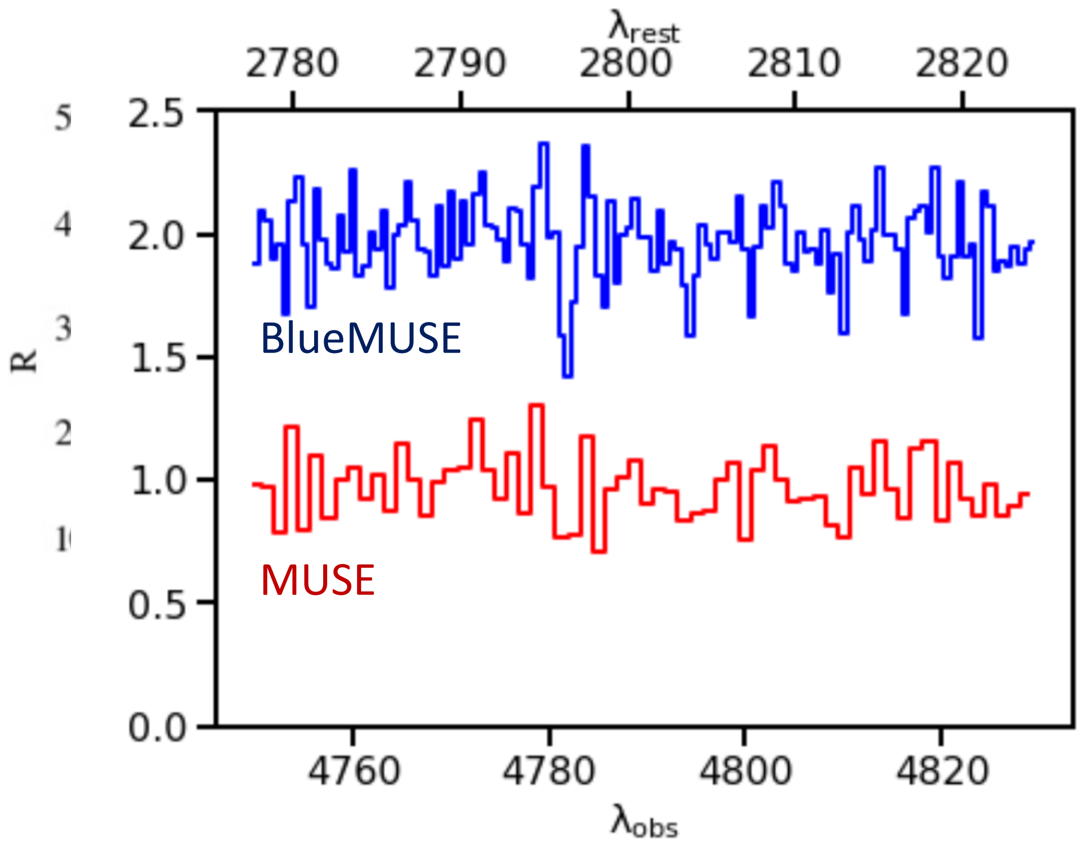
1. Allows to determine velocity more accurately
2. Allows to split velocity components
3. Improves detection limits

$$EW_{\text{limit}} = \frac{n_{\text{sig}}}{R\ SN}\lambda_0$$ Tumlinson+2002

- Spectral resolution $R = \lambda\ /\ \Delta\lambda$
- SN – signal to noise per spectral resolution element

For fixed exposure time (assuming photon noise limited):

$$\text{SN} \propto \frac{1}{\sqrt{R}} \quad \Rightarrow \; EW_{\text{limit}} \propto \frac{1}{\sqrt{R}}$$

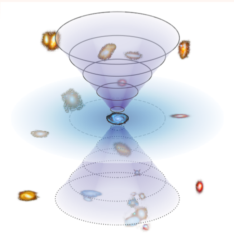


Example:

$rEW_{2796} = 0.3$ Å $\quad rEW_{2803} = 0.2$ Å

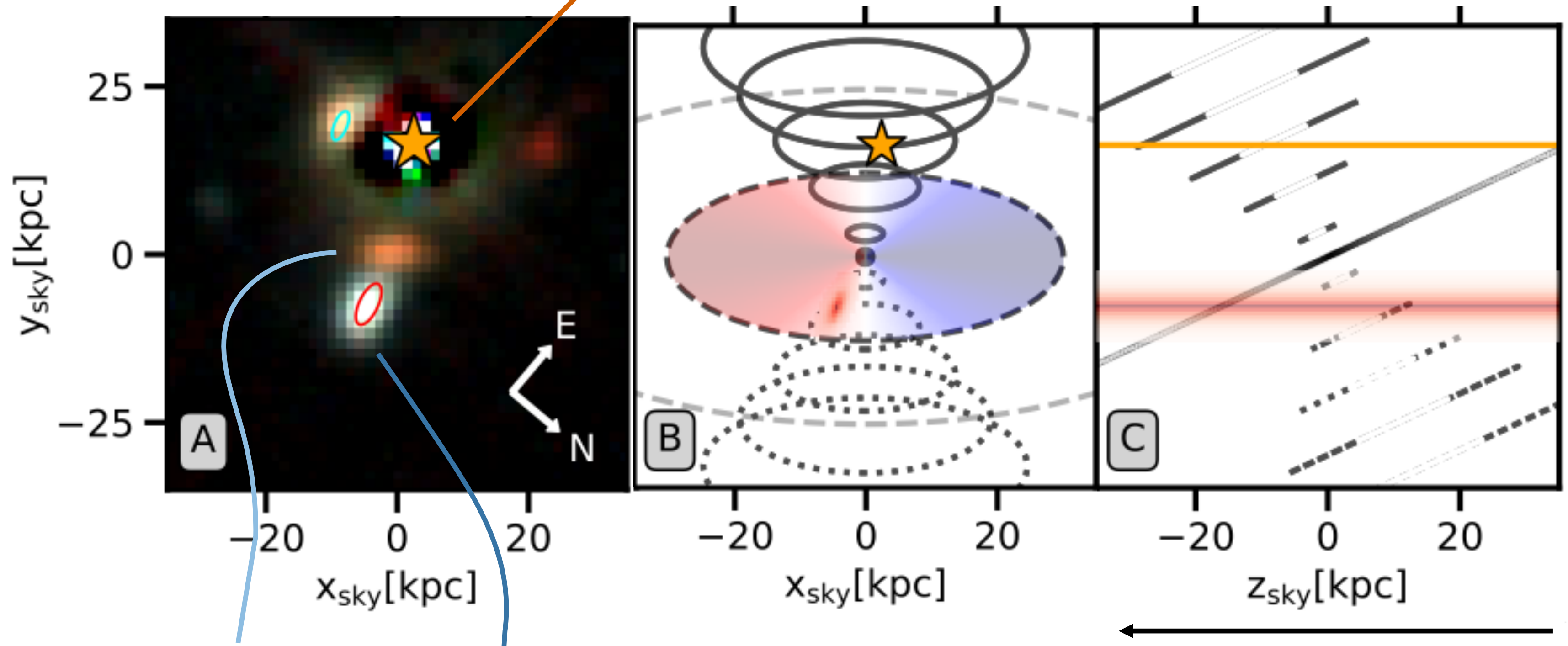
SN per resolution element: 10 / 12

Testing the biconical outflow model with two sightlines



MEGAFLOW IV: Zabl+ 2020

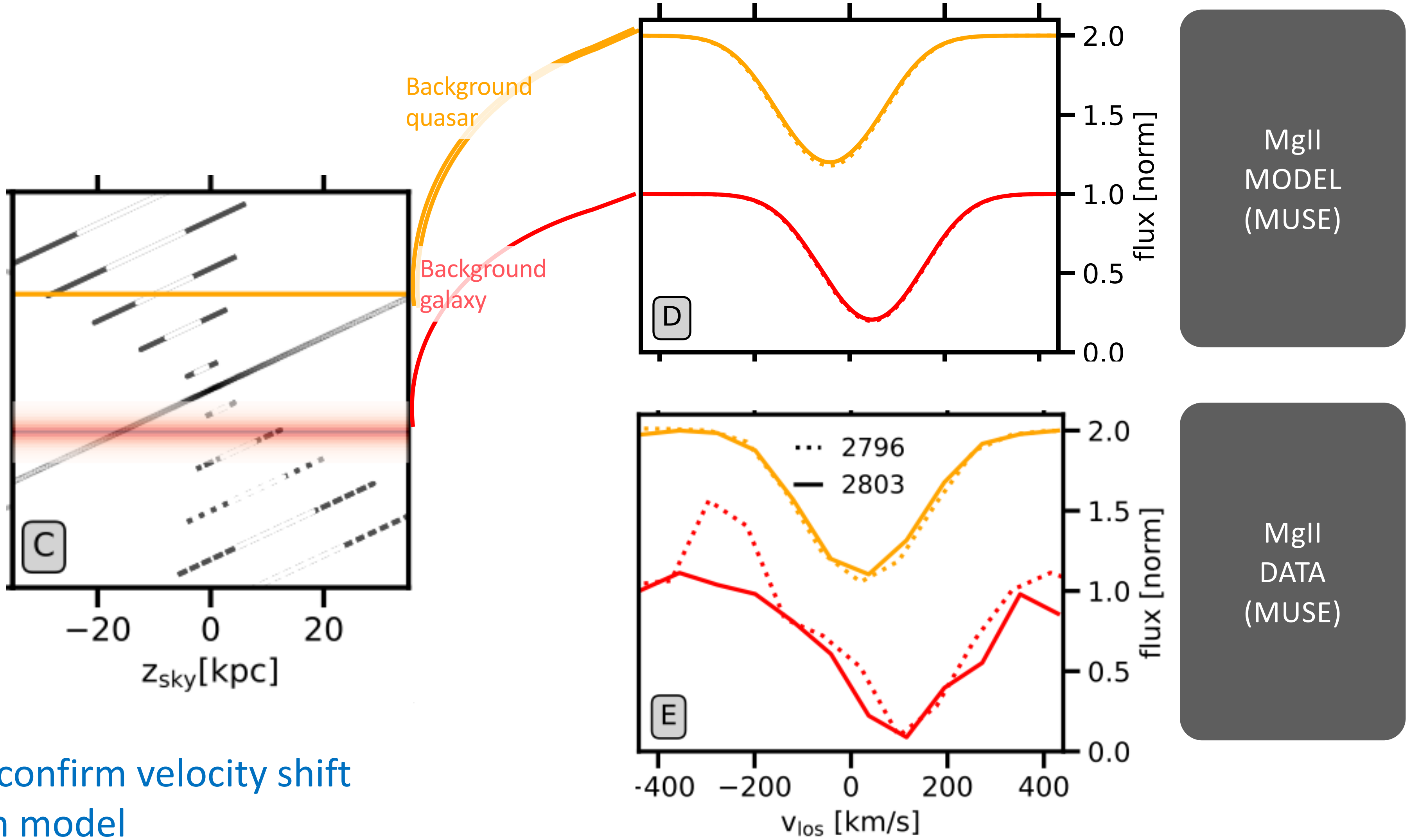
Background quasar (PSF subtracted)



z=0.7 galaxy

z=1.4 background galaxy

Testing the biconical outflow model with two sightlines

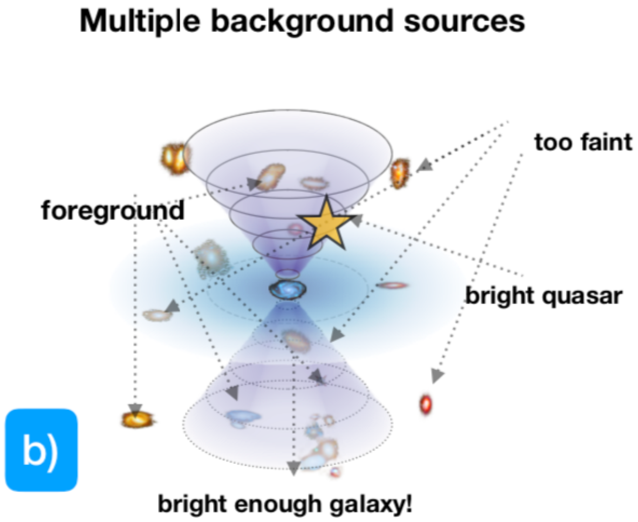


Observations confirm velocity shift expected from model

MgII in emission

One for all

All for one



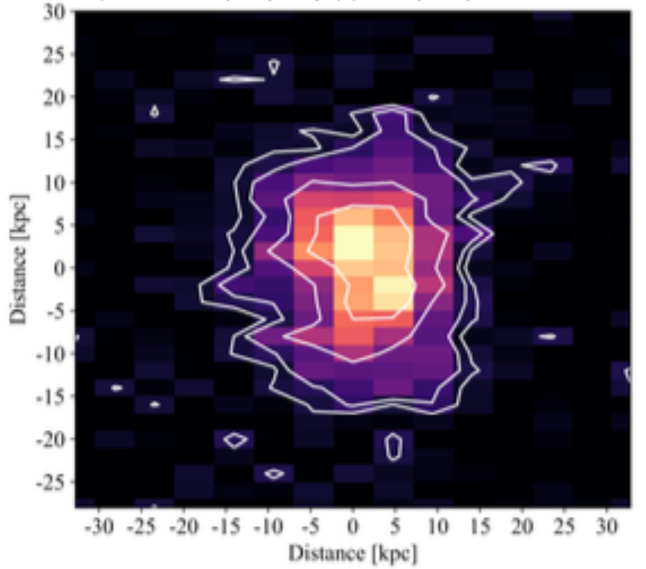
Not discussed: extended background sources:
e.g. Peroux+18; lensed background arcs, e.g. Lopez+18

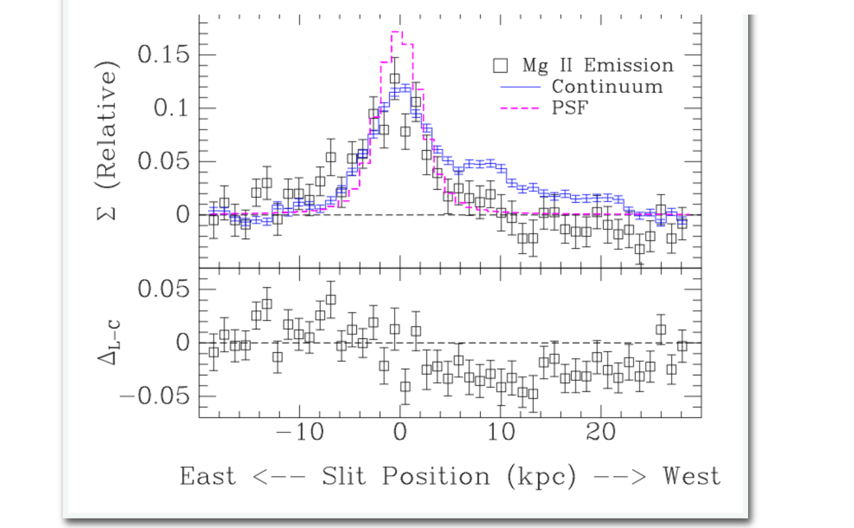
MgII in emission

Why can we expect extended MgII 2796, 2803 emission:

- Resonant line (like Lya): Photons originating from the galaxy scatter at the MgII in the CGM
- Additional MgII emission might be produced inplace in radiative shocks in the outflows (or tidally stripped gas)
- But emission expected to be faint (some early successes: Rubin+2011, Martin+2013; but also non-detections e.g. Rickards Vaught+2019)
- Situation changing thanks to IFUs (VLT/MUSE, Keck/KCWI)
- BlueMUSE: z=0.25 vs z=0.7 (MgII cut-off)
  -> w. cosmo. SB dimming $(1+z)^{-4}$
  -> factor of 3 in SB

KCWI: Burchett+2020



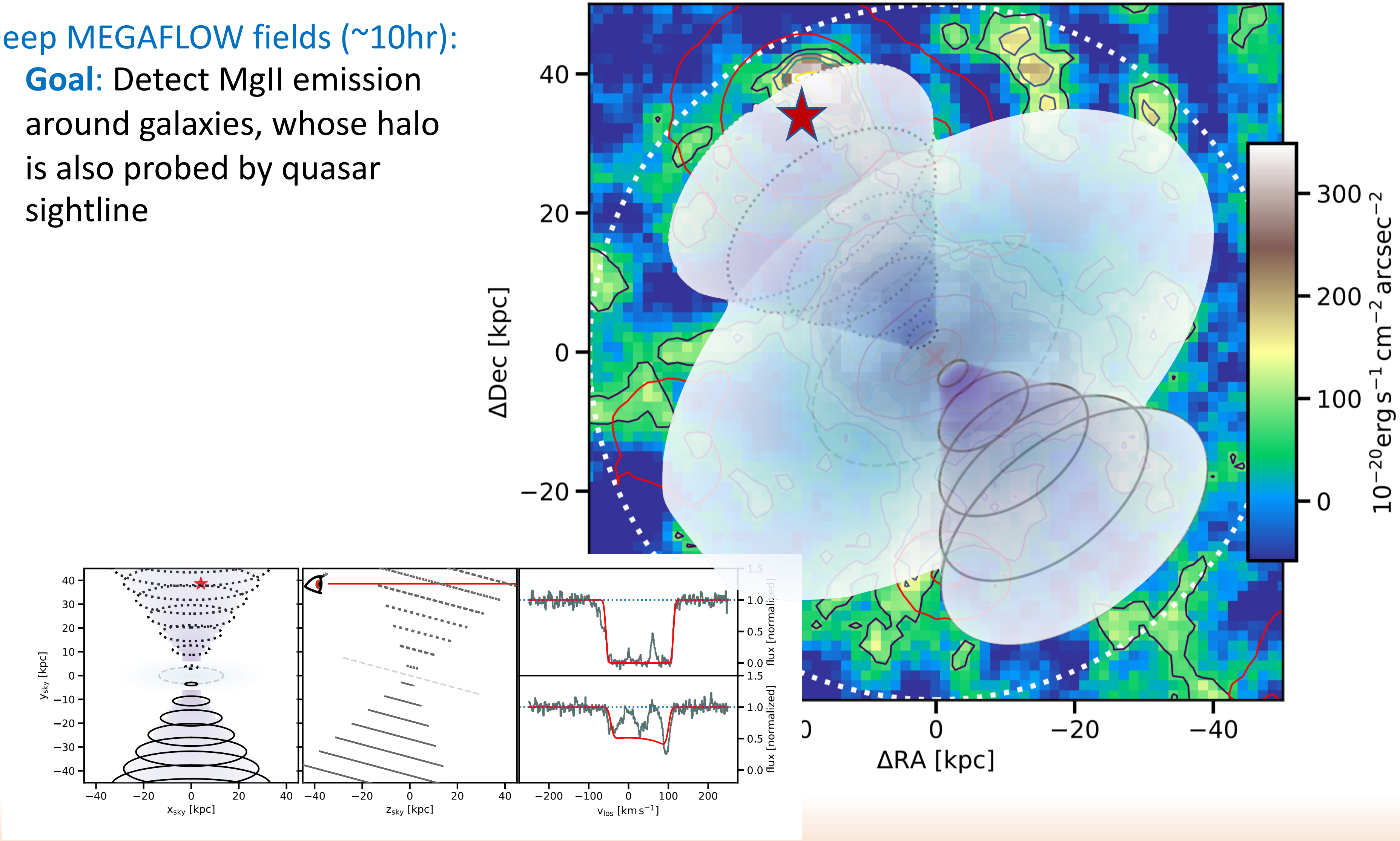


Martin+2013

MgII Emission at z=0.7?

Deep MEGAFLOW fields (~10hr):

- **Goal**: Detect MgII emission around galaxies, whose halo is also probed by quasar sightline

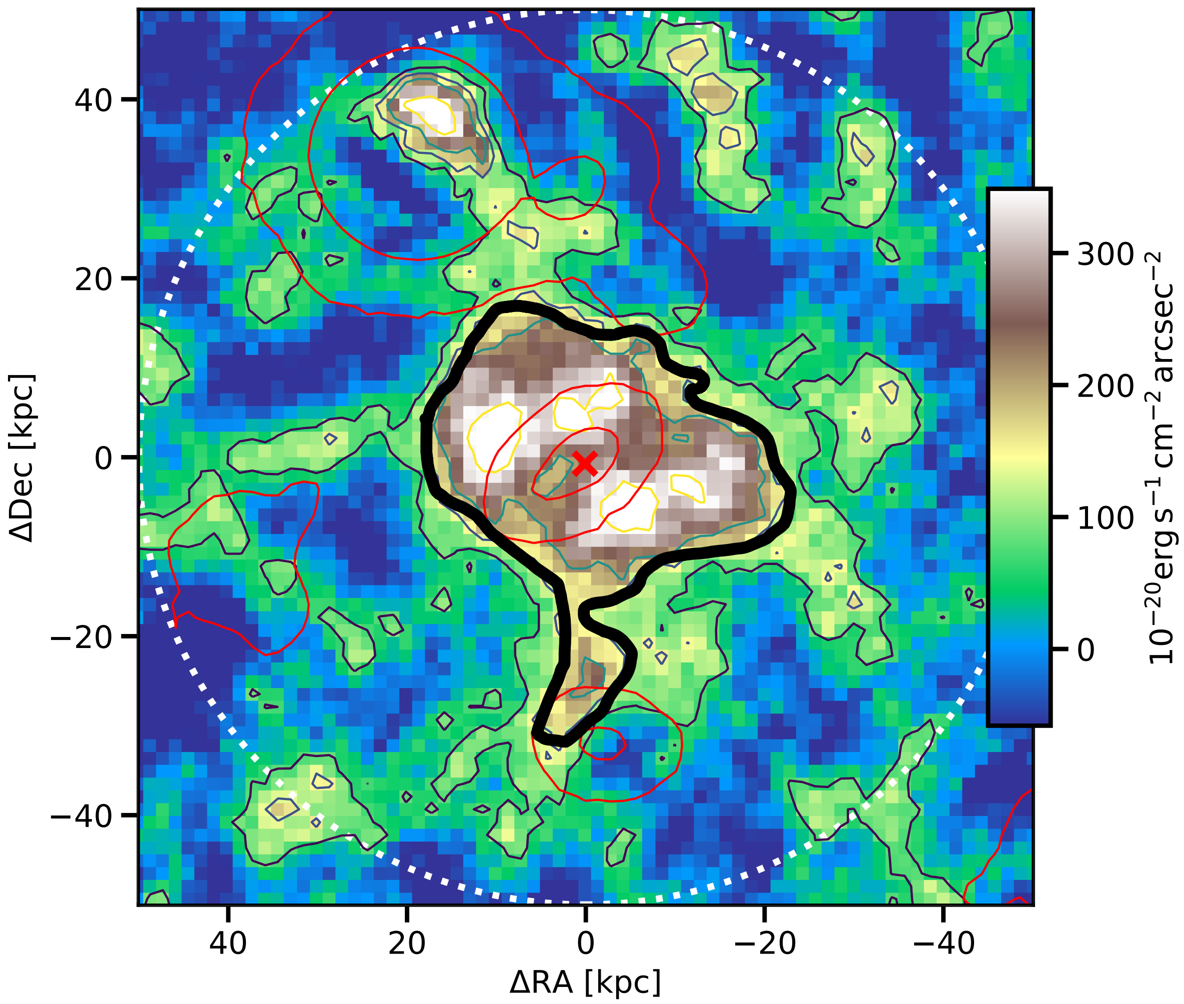


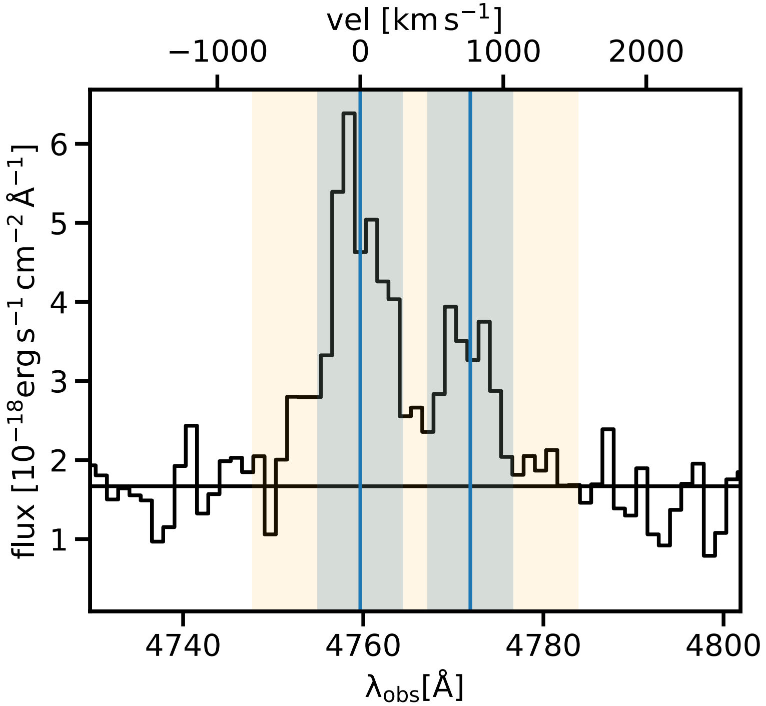
MEGAFLOW VIII - Zabl+ submitted

Other MUSE GTO MgII emission papers:
Wisotzki+ in prep
Leclercq + in prep

MgII spectra – Total

MEGAFLOW VIII - Zabl+ submitted





Quick facts:

Area: 10^3 kpc^2

(above $\mathrm{SB_{MgII}} = 14{\times}10^{-19}$erg s^{-1} cm^{-2}arcsec^{-2})

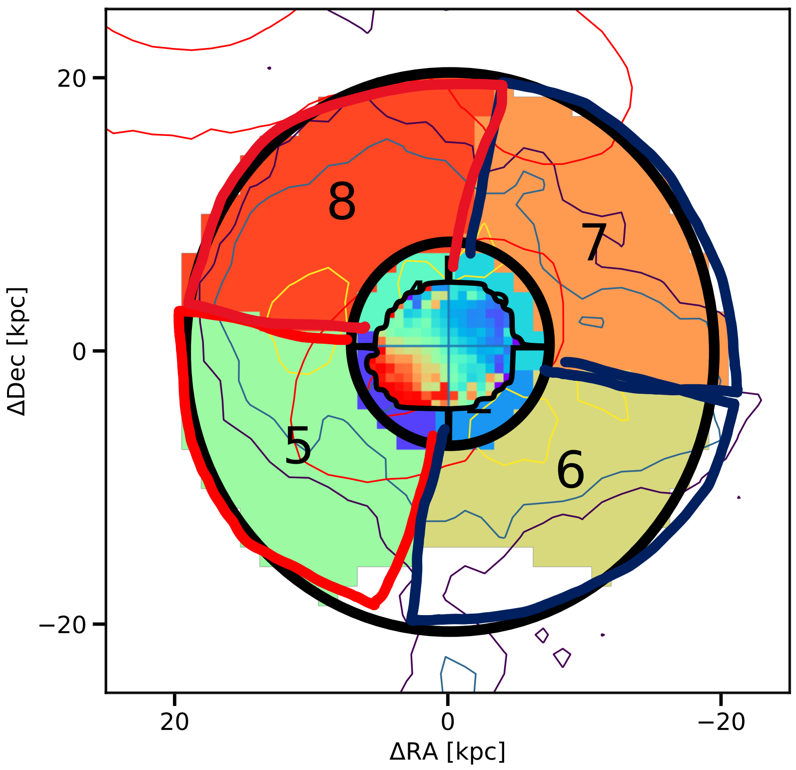
Flux: f_{MgII}(2796+2803) = $41{\times}10^{-19}$erg s^{-1} cm^{-2}

(L_{MgII}= $9{\times}10^{40}$erg s^{-1})

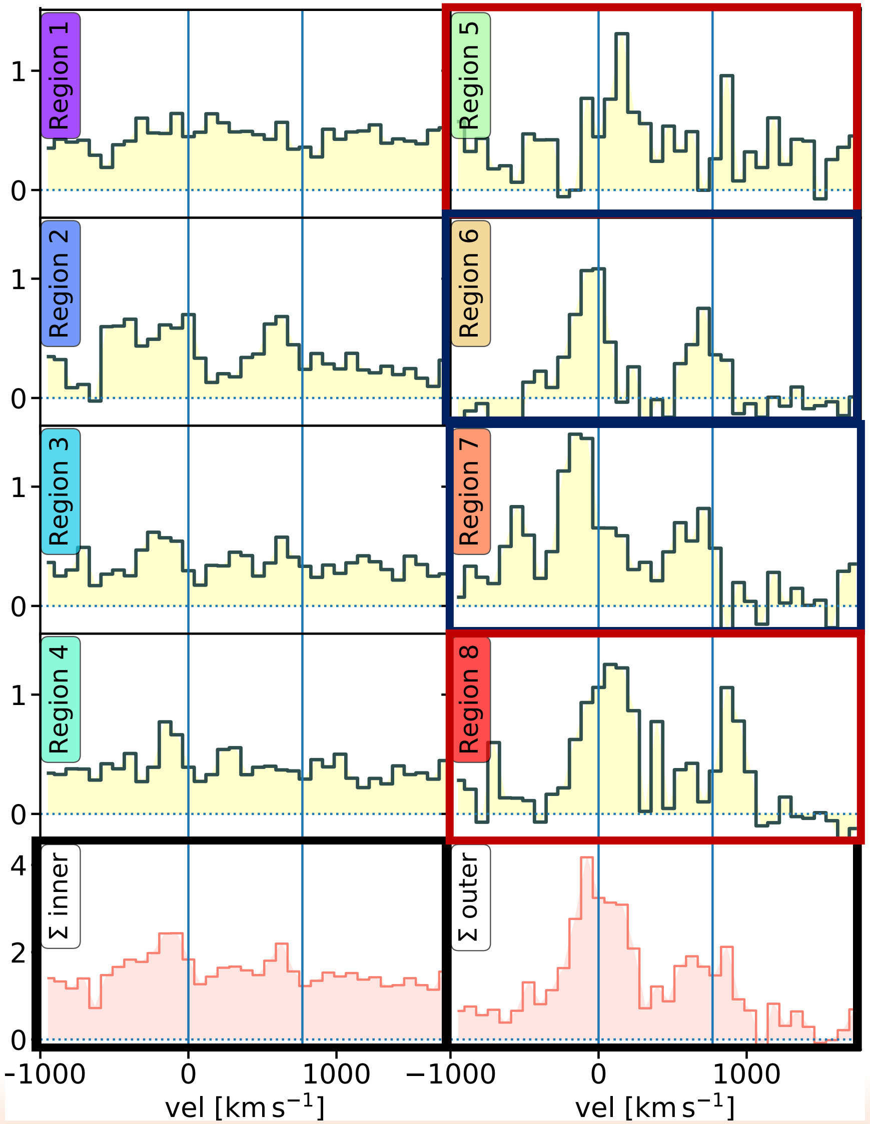
Doublet ratio: 1.9 ± 0.3 (-> optically thin scattering)

MgII spectra – spatially resolved

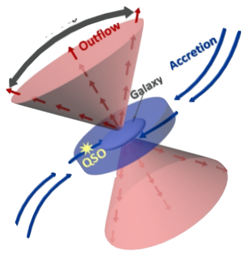
MEGAFLOW VIII - Zabl+ submitted



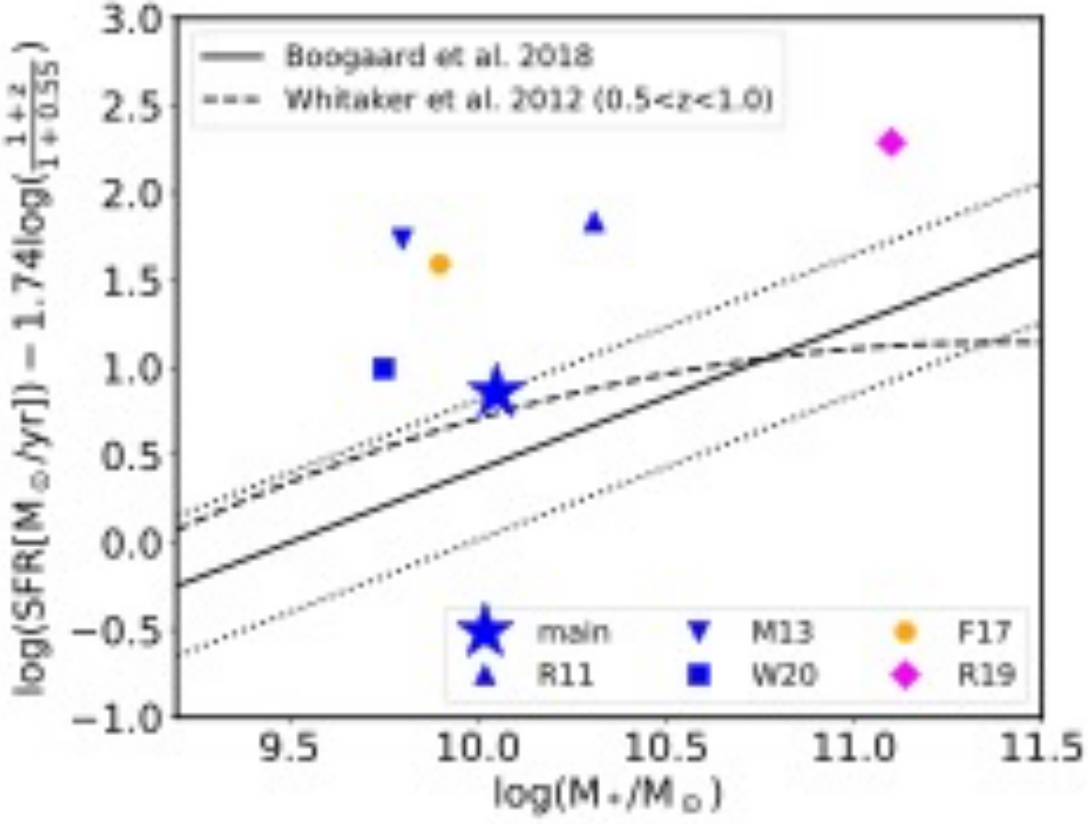
Regions 1-4: 0.0 < r < 7.2 kpc
Regions 5-8: 7.2 < r < 20 kpc



- Central spectrum shows little features
- Most of the emission comes from the outer part
- Major axis regions consistent with extension of galaxy rotation field
- Minor axis regions consistent with biconical outflow



Comparison to other objects in literature



- No need for (current) starburst
- No apparent inclination requirement (W20 face-on)
- Maybe preference for clumpy morphology?

MgII halos:

- main: this work
- R11: Rubin+11 (also Burchett 2020)
- M13: Martin+13
- W20: Wisotzki et al. in prep (MUSE)

[OII] halos

- R19: Rupke+19 (KCWI)

FeII* halos

- F17: Finley+17 (MUSE)

Conclusions

Mapping the cool CGM with MgII, either

with multiple background sources
or
in emission

is possible with MUSE.

But BlueMUSE will dramatically enhance the possibilities of such studies (by going to lower redshifts / higher spectral resolution.

Thanks for listening