Lyα Emission and the Circumgalactic Medium in Low Mass Galaxies

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Escape of Lyman radiation from galactic labyrinths
Kolymbari, Crete, 12 September 2018

Image: Tonia Klein

Danielle Berg (Friday!)
Matthew Auger
Max Pettini
David Kaplan
Gabriel Brammer

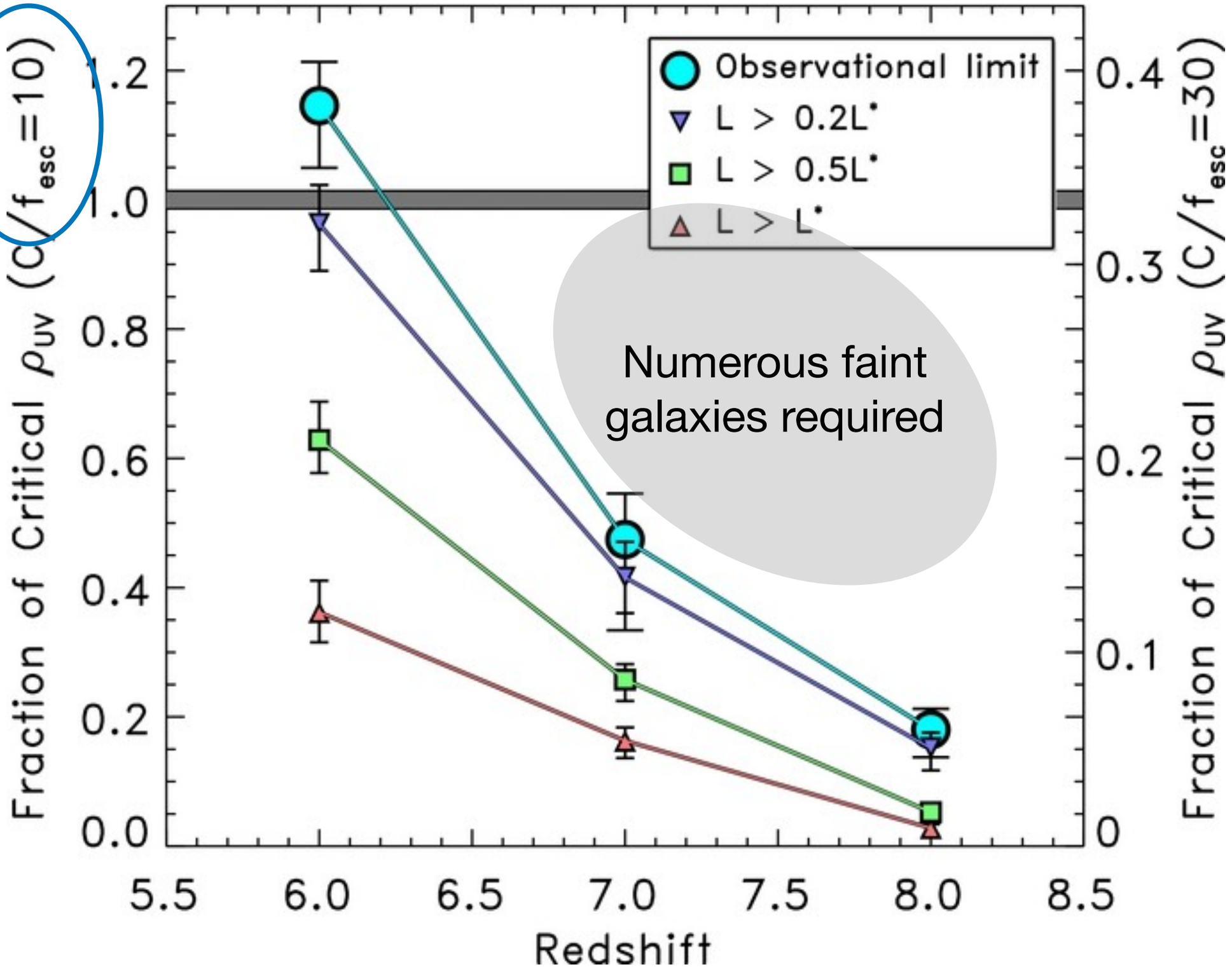
Chuck Steidel
Yuguang Chen

Escape of Lyman radiation from galactic labyrinths
Kolymbari, Crete, 12 September 2018

Image: Tonia Klein

Faint galaxies (probably) reionized the universe

Photons must escape galaxies



Finkelstein et al 2012

The CGM is crucial to Lyα and LyC escape

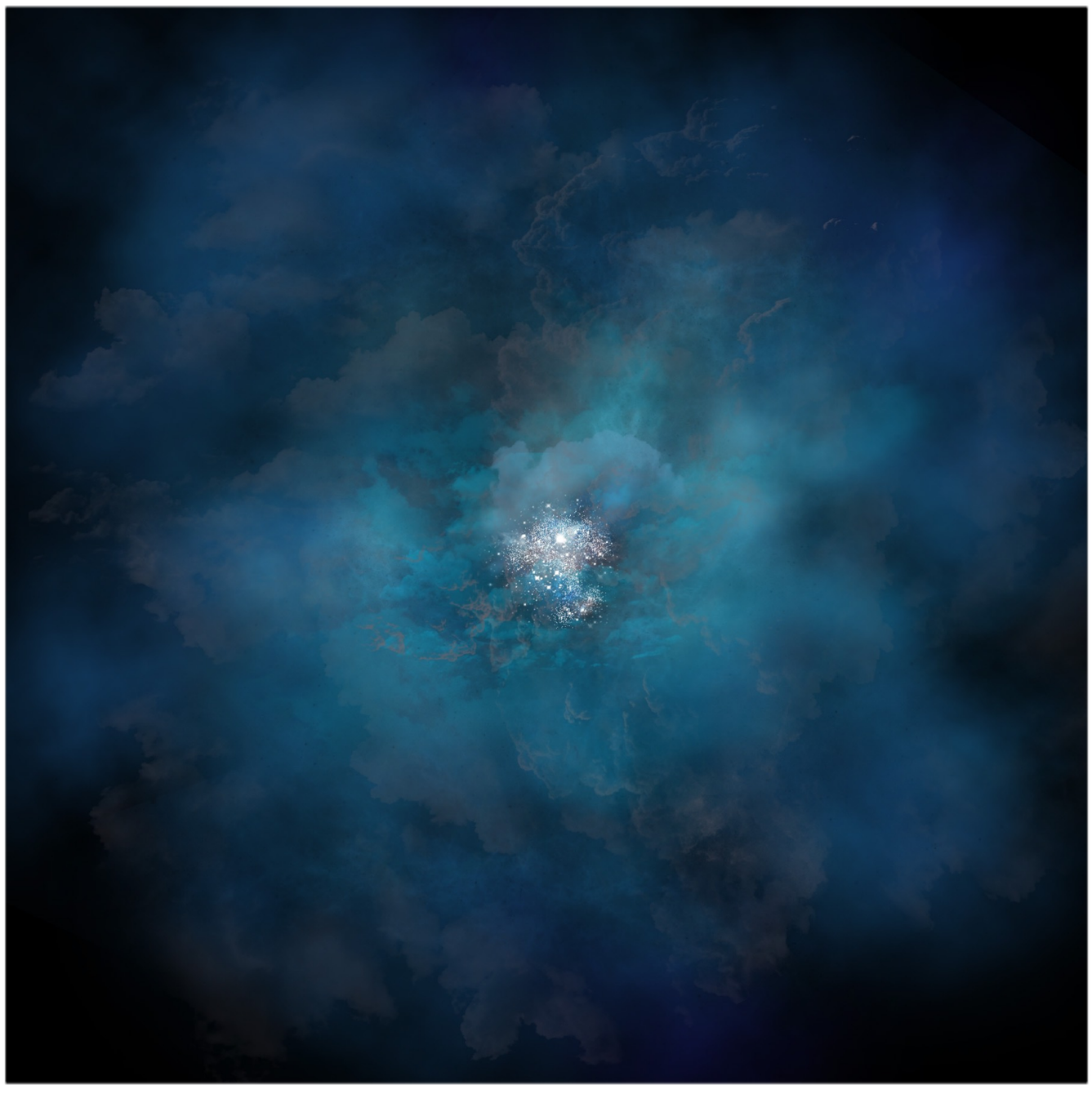


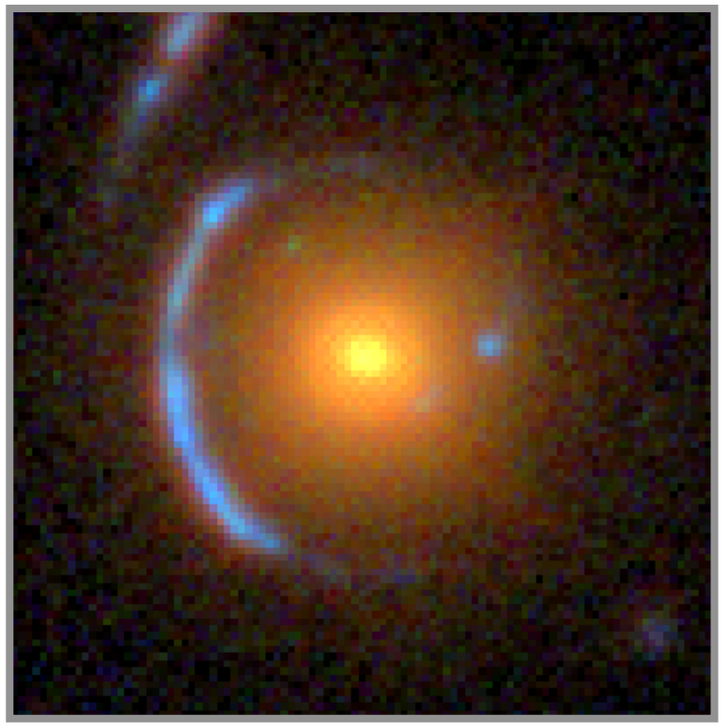
Image: Tonia Klein

Lyα-emitting galaxies tend to be compact, low mass, low metallicity and highly ionized

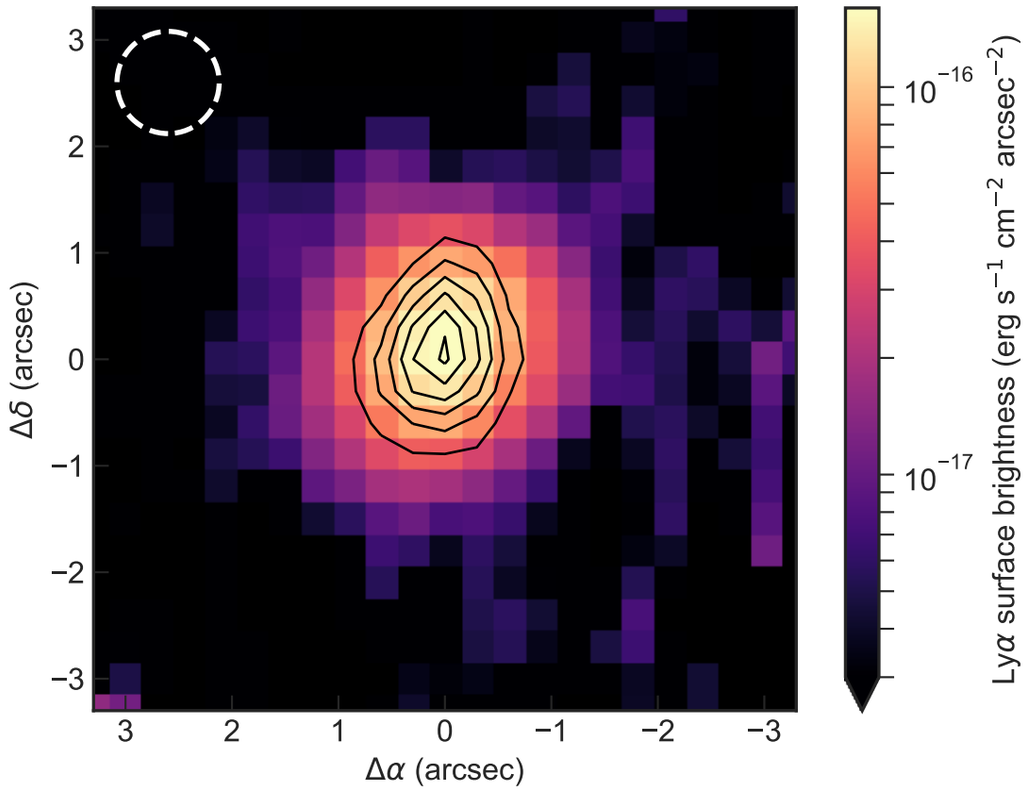
Ideal targets for detailed study of reionization-era analogs

Lyα is a tool for characterization of the CGM

Lyα emission in low mass galaxies at z~2

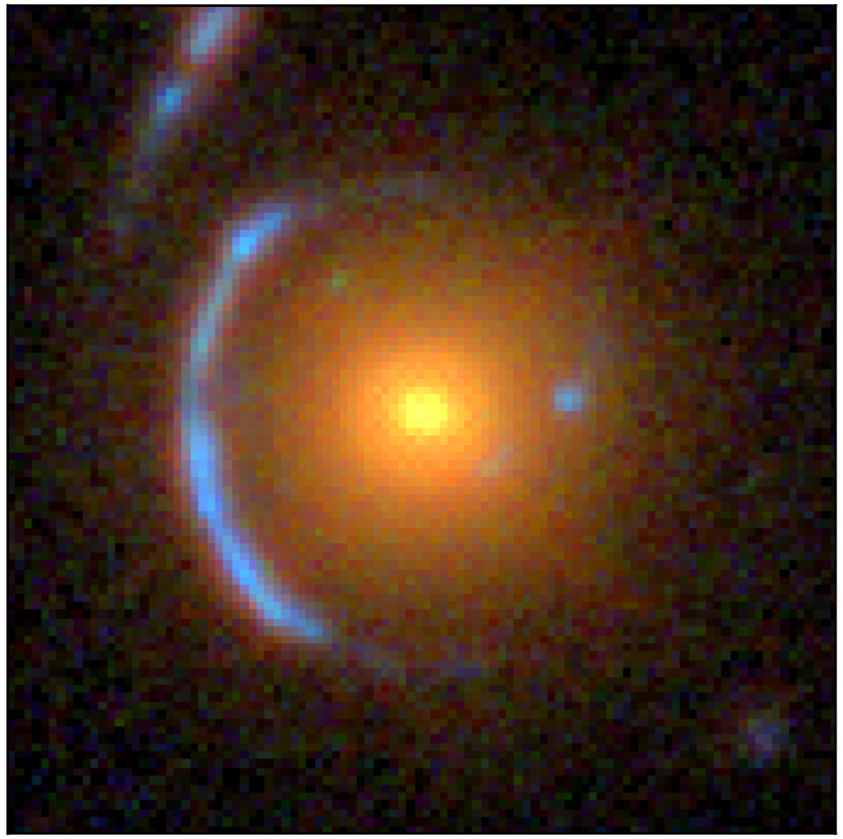


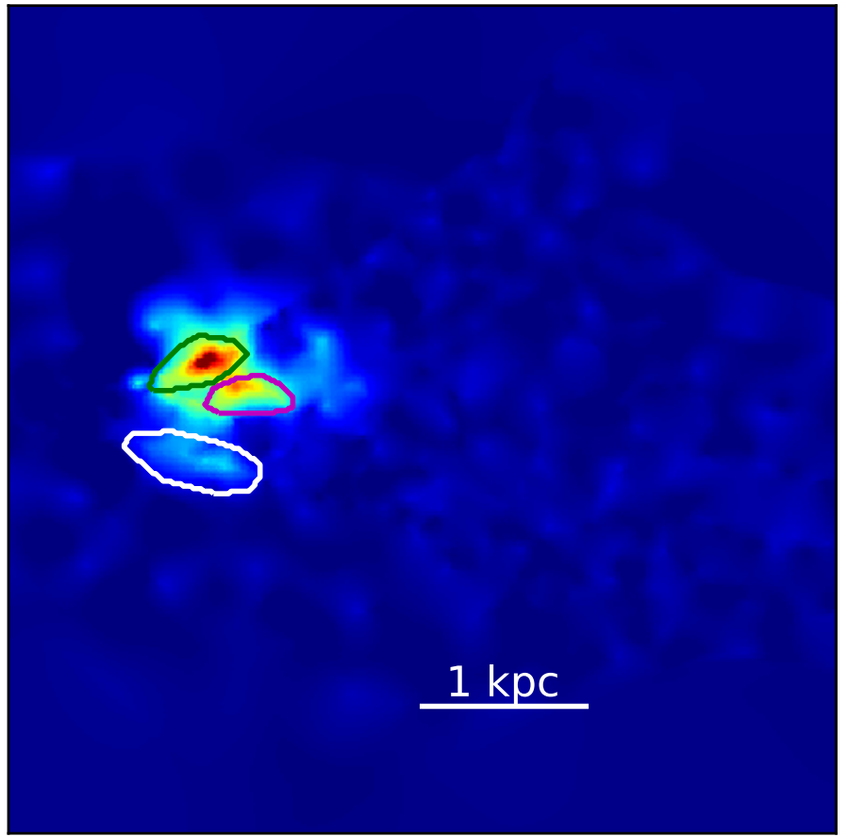
Reaching more extreme properties with gravitational lensing: new information brings new complications



Spatial + spectral information: studying the CGM with integral field spectroscopy of Lyα

Targeting extreme objects with lensing





SL2S J021737–051329, gravitationally lensed galaxy at z=1.85

$M\bigstar = 2 \times 10^8\ M_\odot$, $Z \sim 1/20\ Z_\odot$

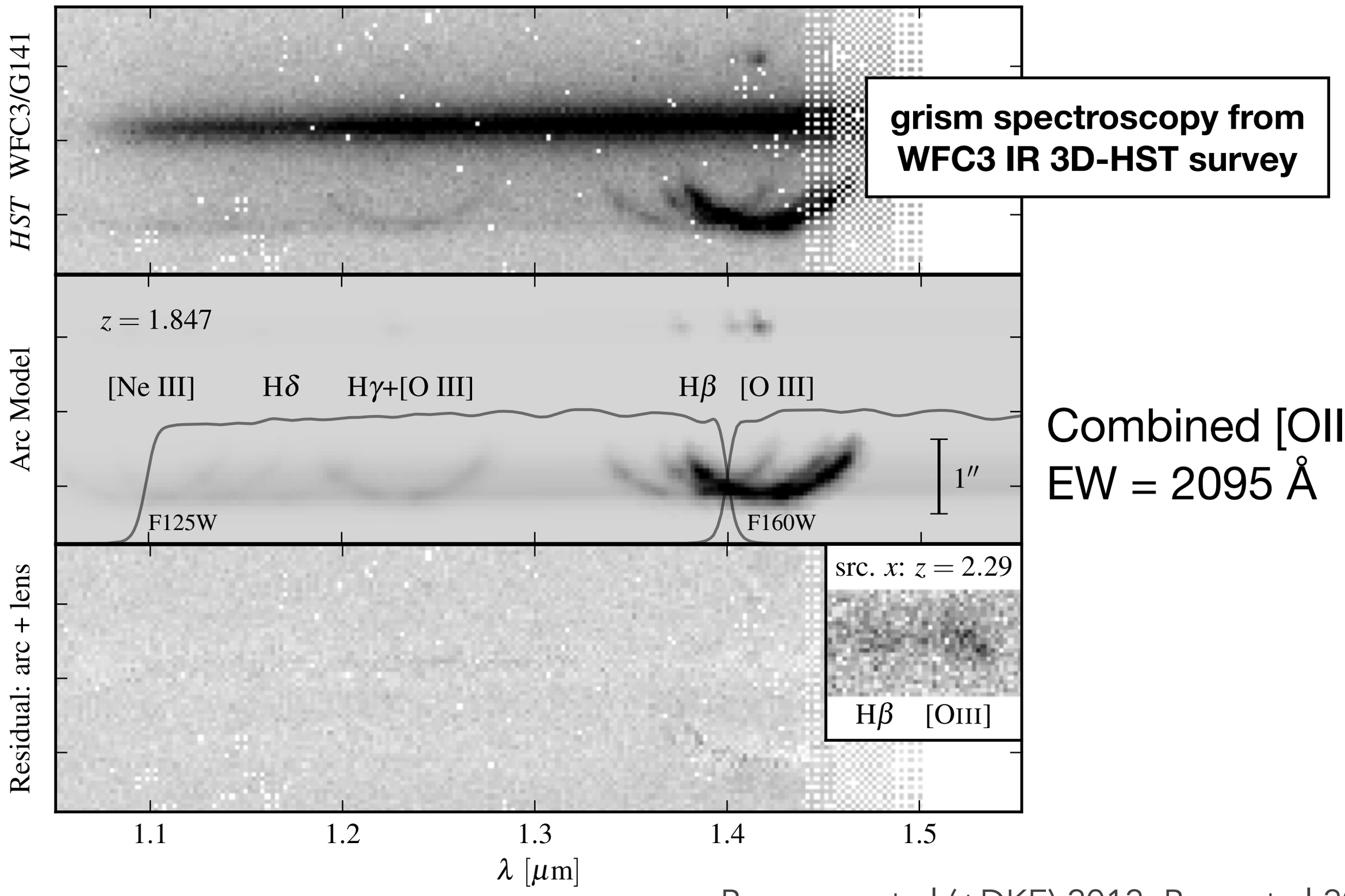
sSFR ~ 120 Gyr^{-1} (mass doubling time ~ 8 Myr)

SFR surface density ~ 58 $M_\odot\ yr^{-1}\ kpc^{-2}$

Blue UV slope, negligible extinction

Brammer et al (+DKE) 2012, Berg et al 2018

Extreme high equivalent width emission lines

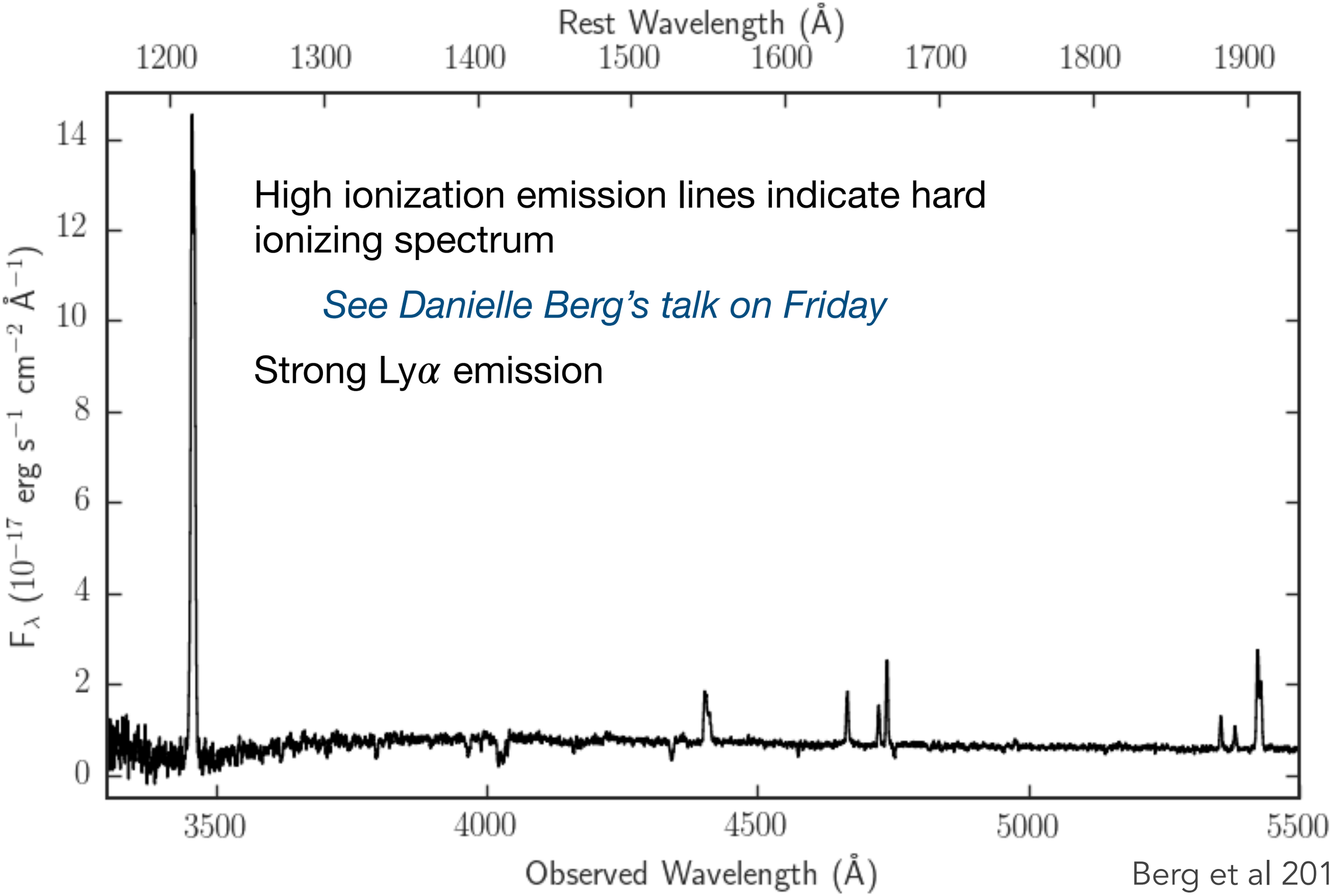


grism spectroscopy from WFC3 IR 3D-HST survey

Combined [OIII]
EW = 2095 Å

Brammer et al (+DKE) 2012, Berg et al 2018

Rest-frame UV spectrum



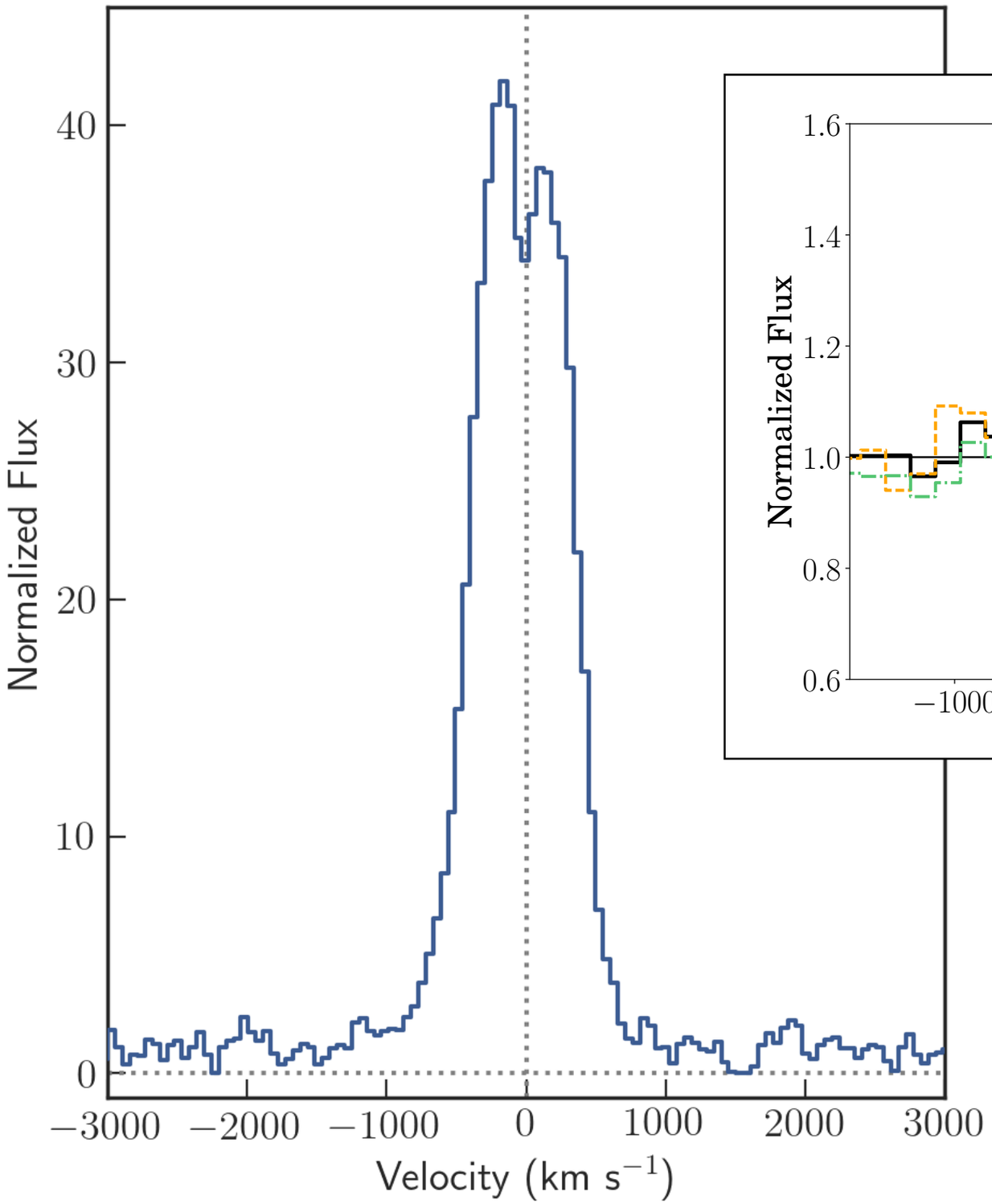
High ionization emission lines indicate hard ionizing spectrum

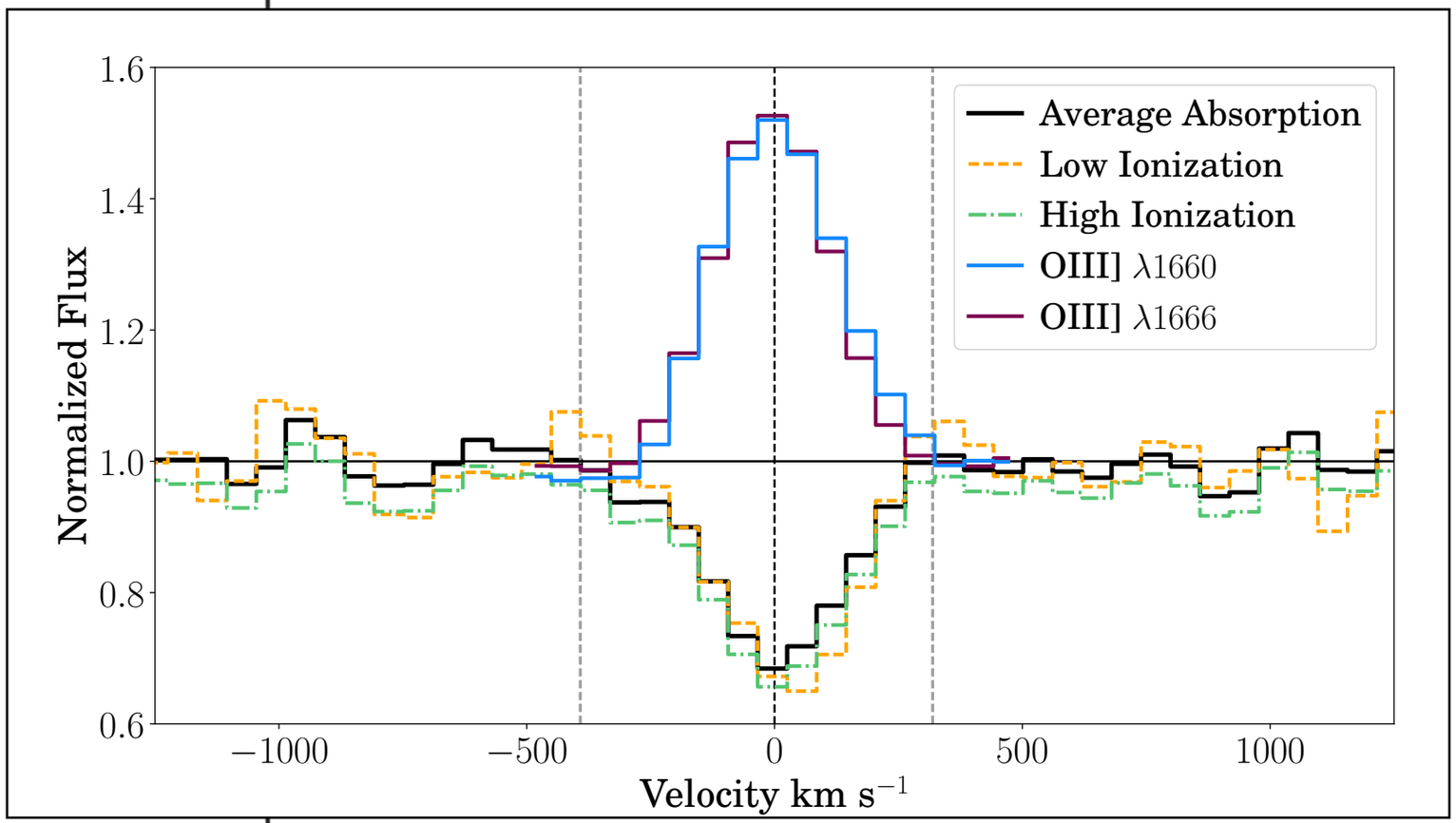
See Danielle Berg's talk on Friday

Strong Lyα emission

Berg et al 2018

No evidence for outflows





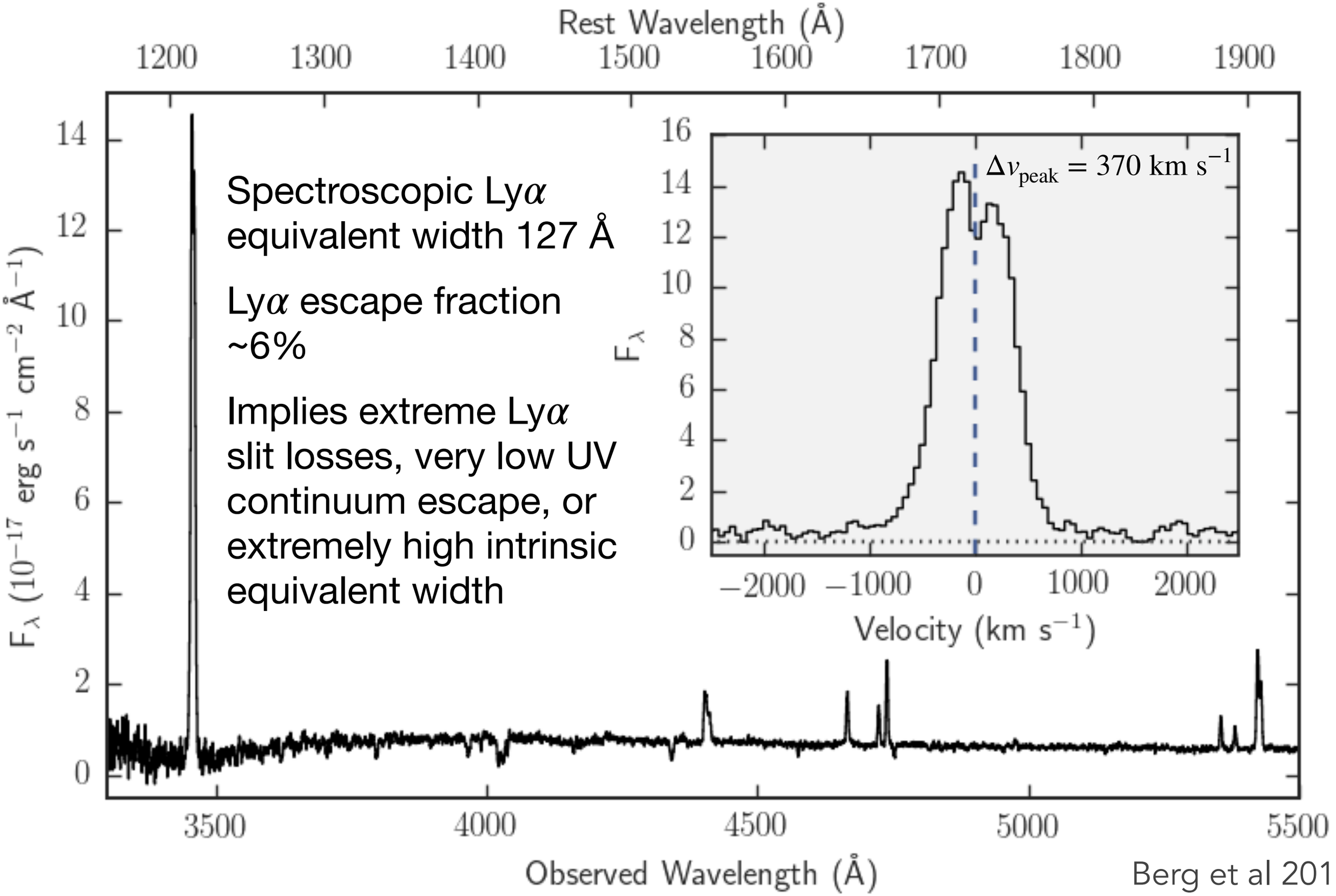
Σ_{SFR} ~ 60 $M_\odot$ yr^{-1} kpc^{-2}

Blue-peaked Lyα emission suggests inflow?

See also Jaskot et al 2017

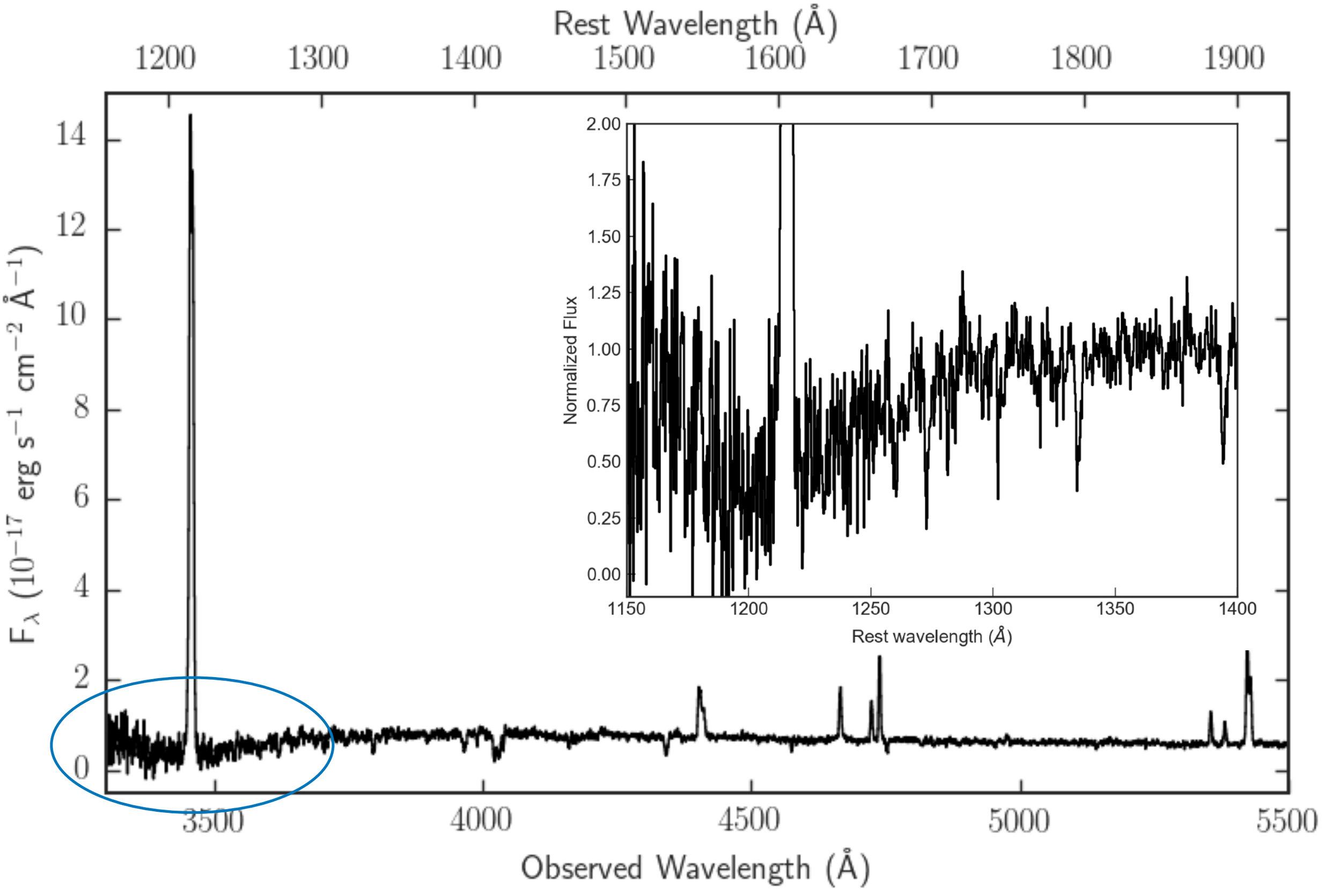
Berg et al 2018

Strong, blue-peaked Lyα emission

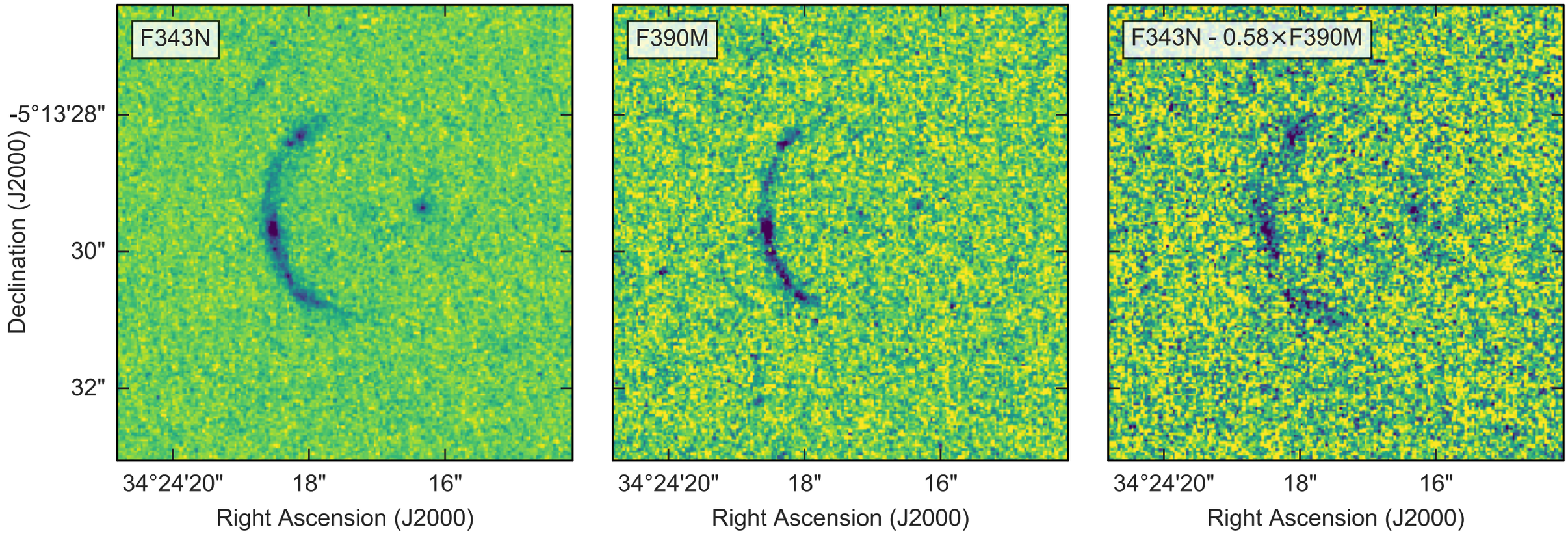


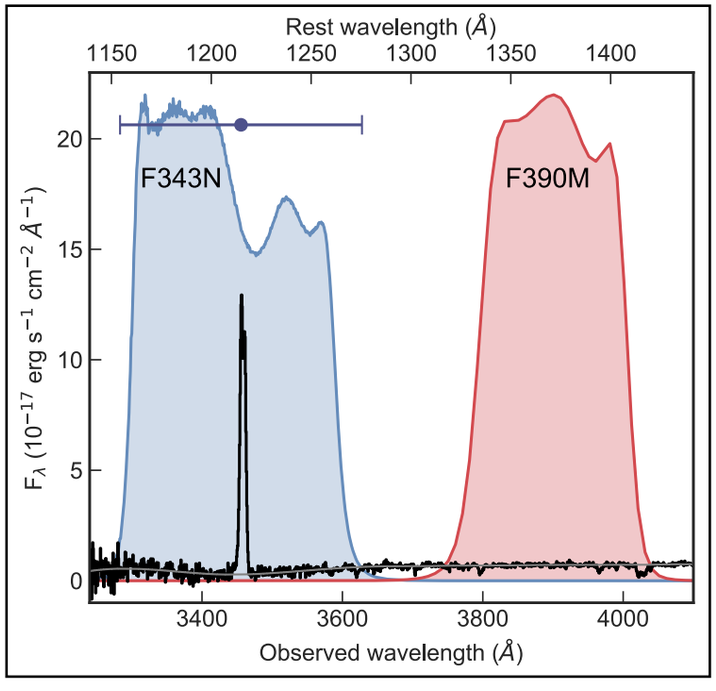
Berg et al 2018

Is there underlying Lyα absorption?



Narrow-band imaging of Lyα with HST





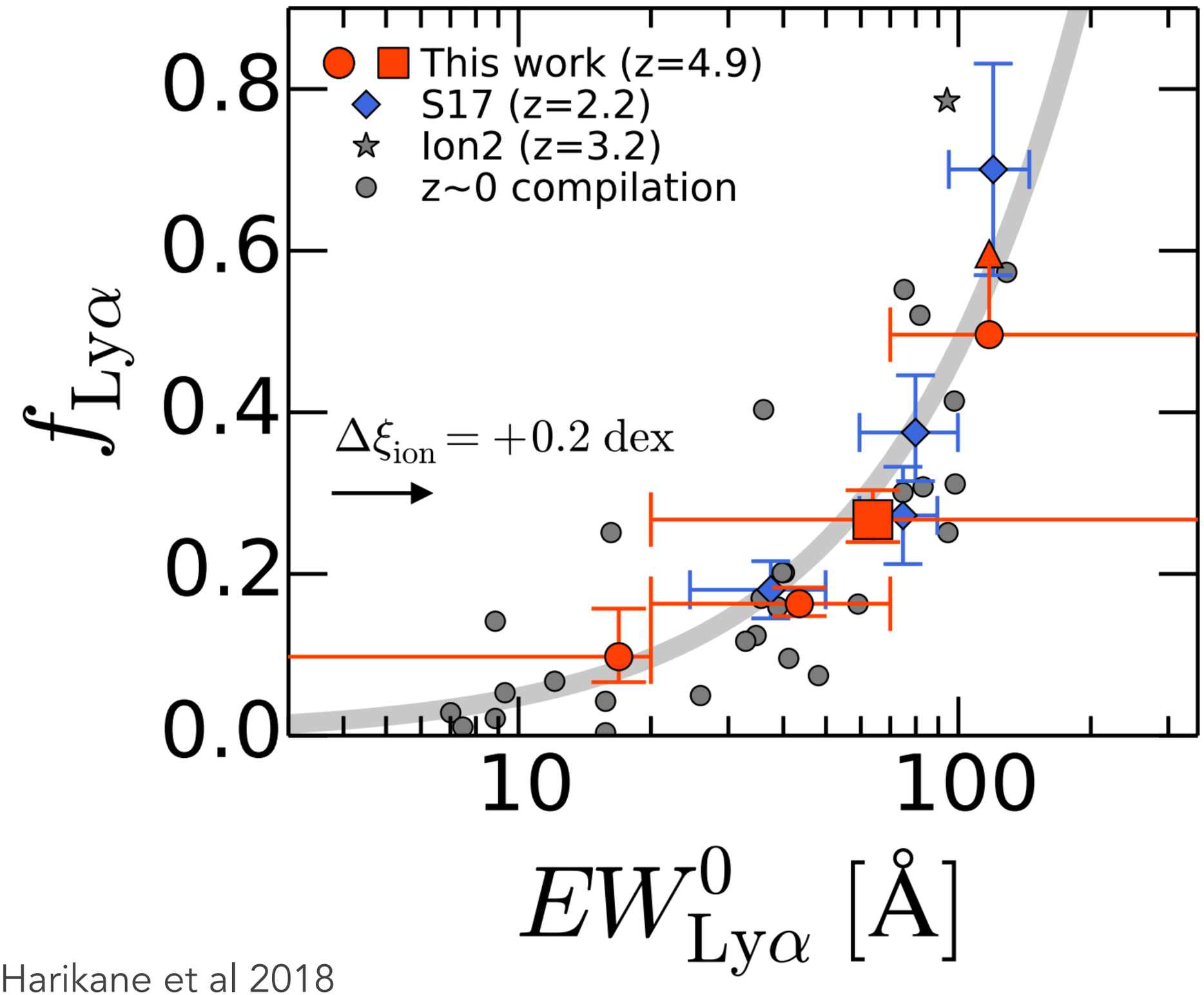
Total NB flux implies 33% slit losses

Photometric Lyα equivalent width 191 Å

Lyα escape fraction ~9%

Erb et al 2018b, in prep

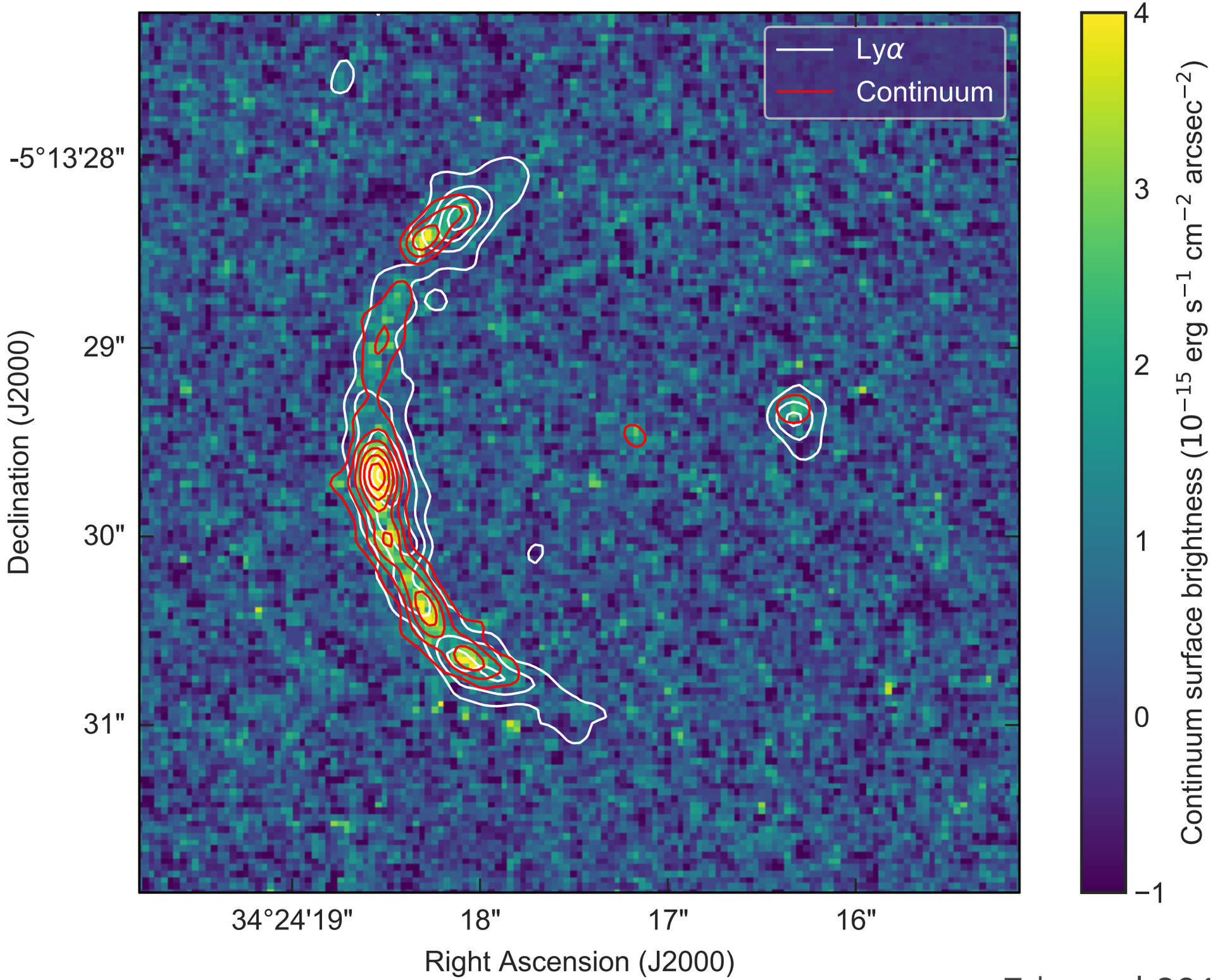
Lyα equivalent width vs escape fraction



SL2S J021737

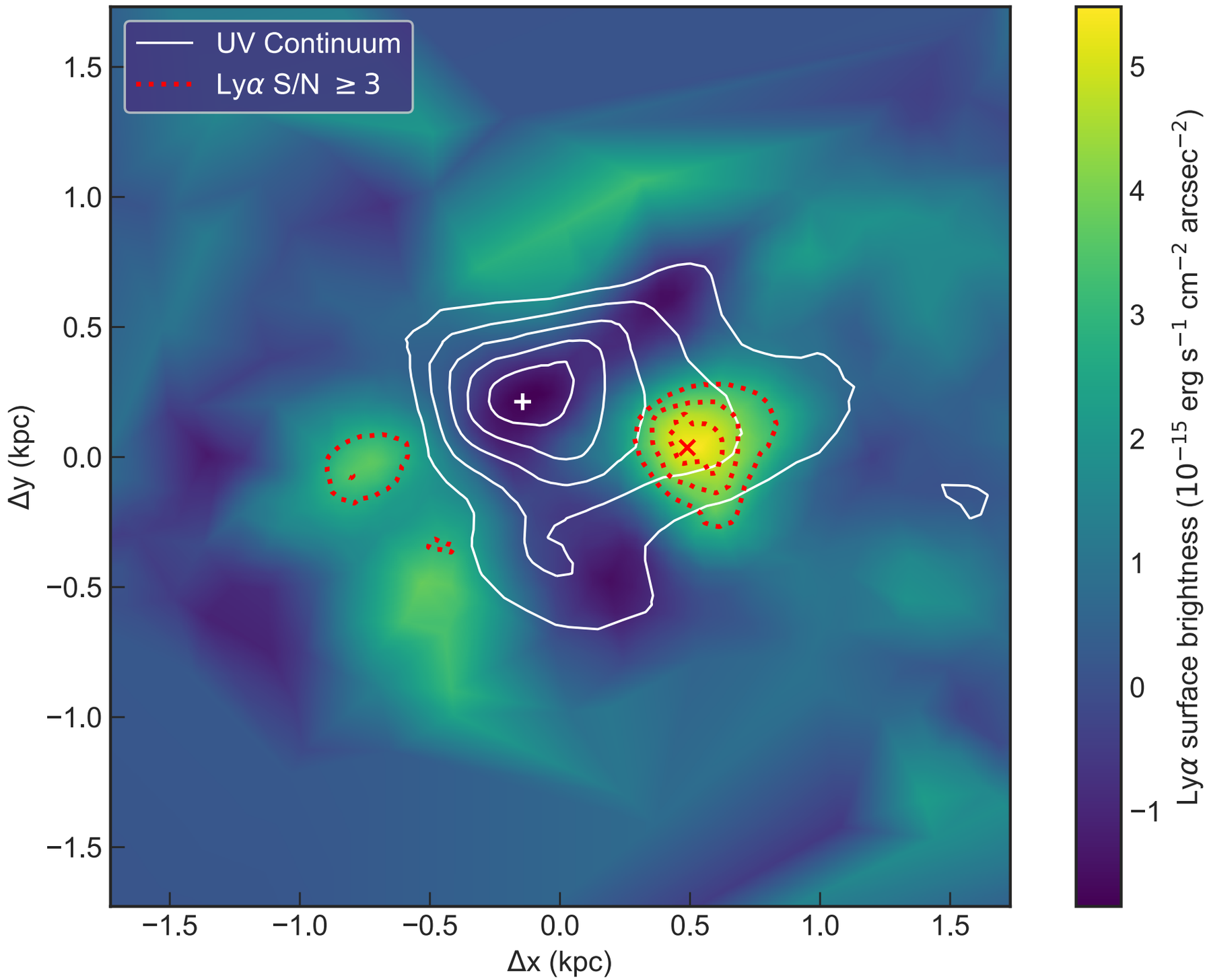
Harikane et al 2018

Spatial distribution of Lyα emission



Erb et al 2018b, in prep

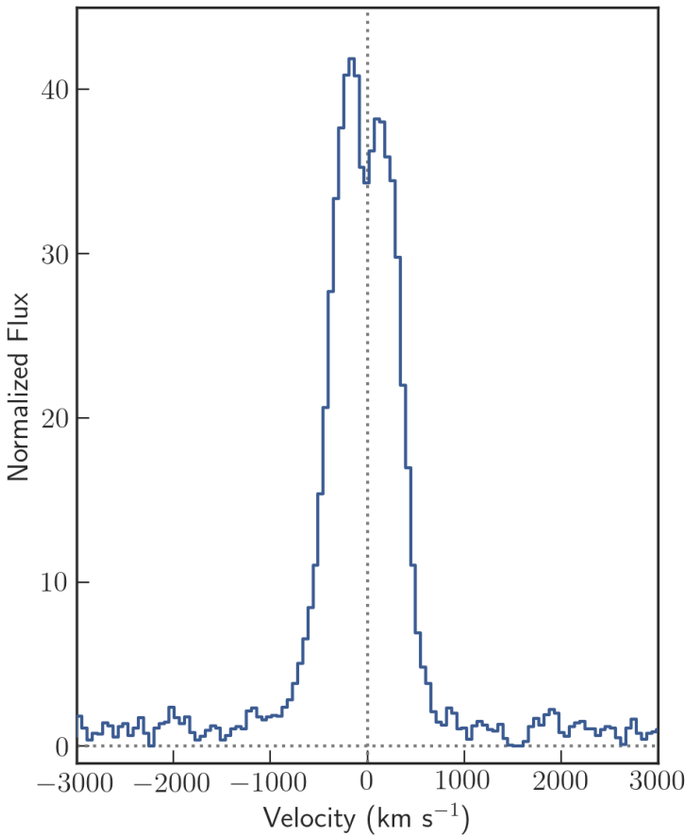
Source reconstruction

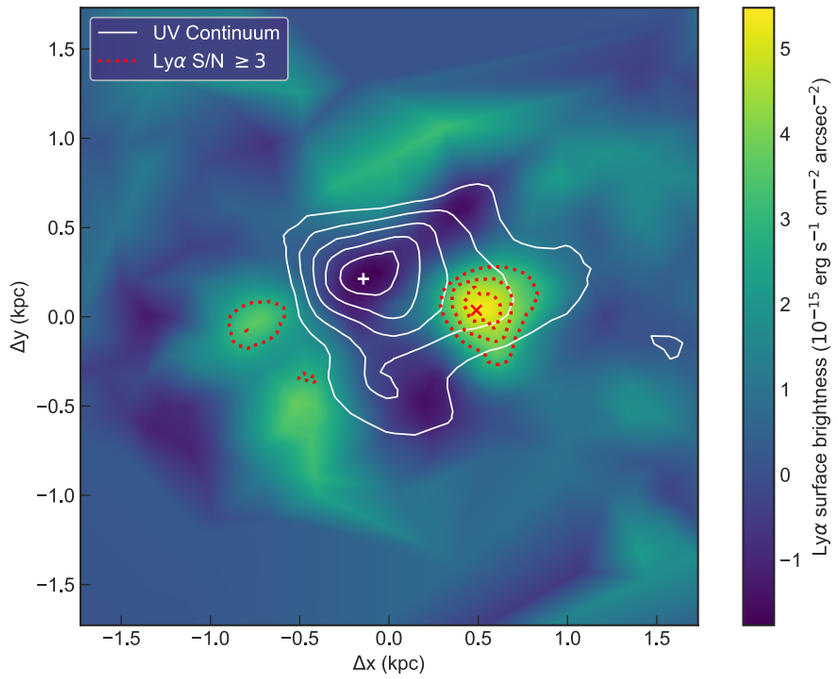


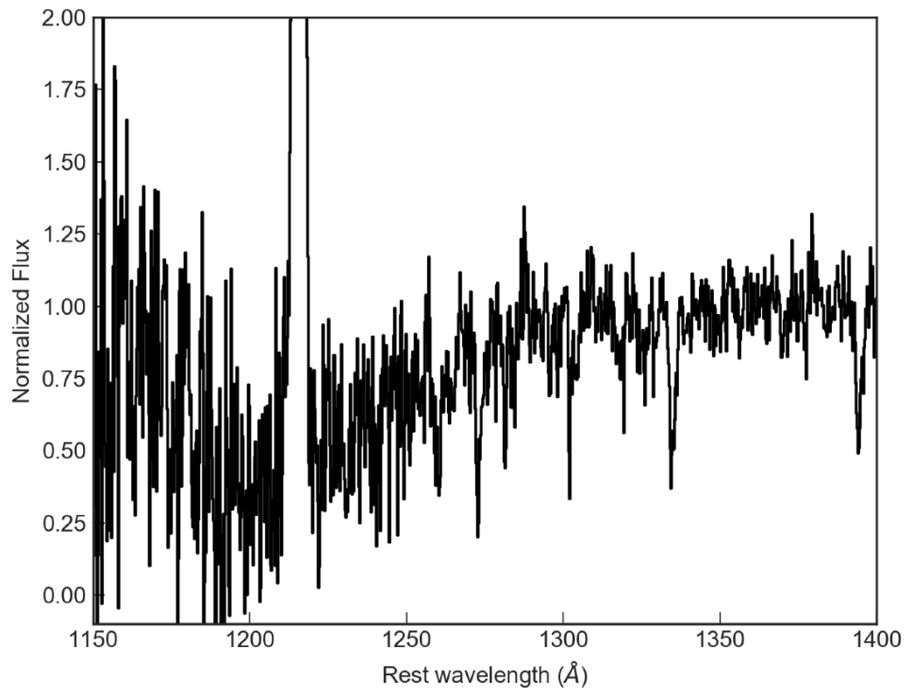
Lyα and UV continuum peaks offset by 650 pc in source plane

Erb et al 2018b, in prep

Lyα puzzles







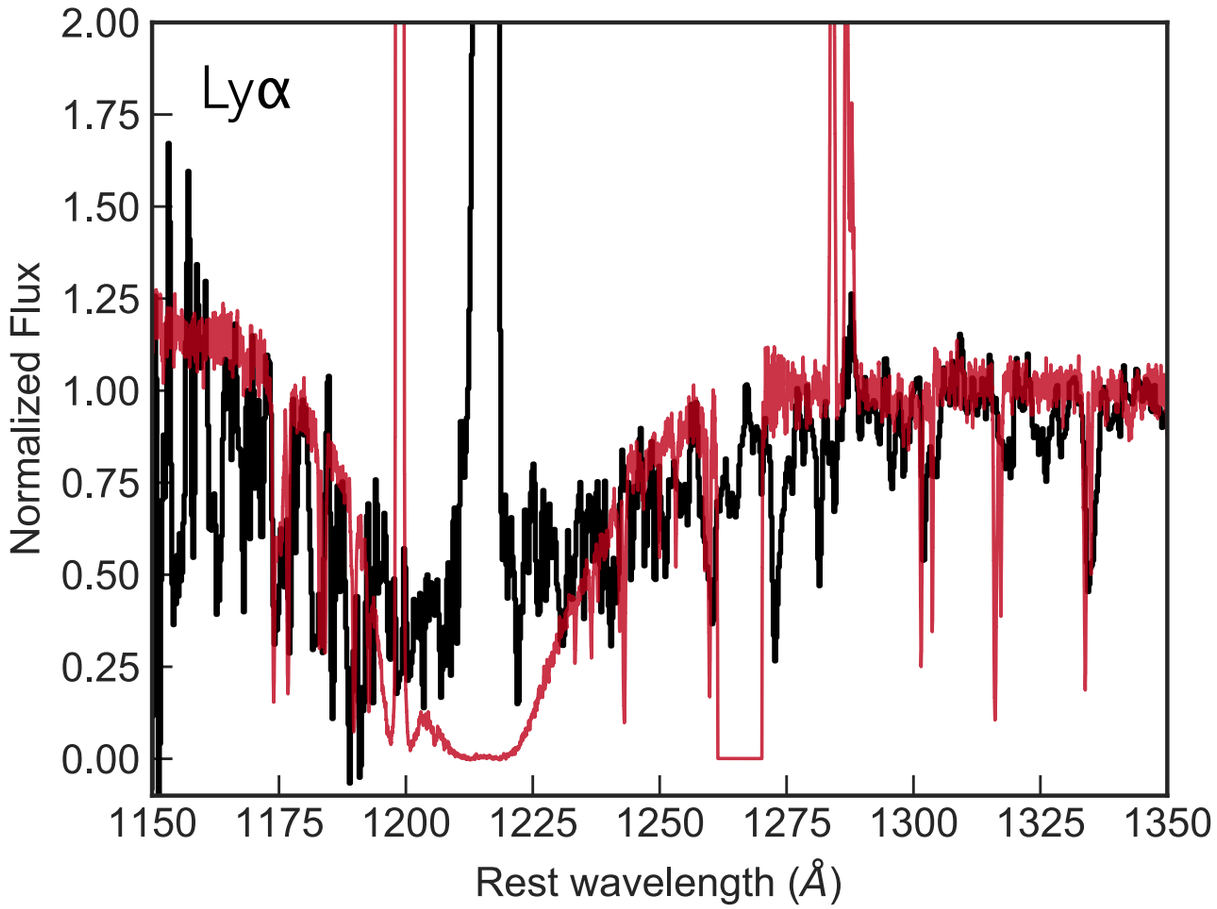
Total equivalent width 191 Å, escape fraction ~9%

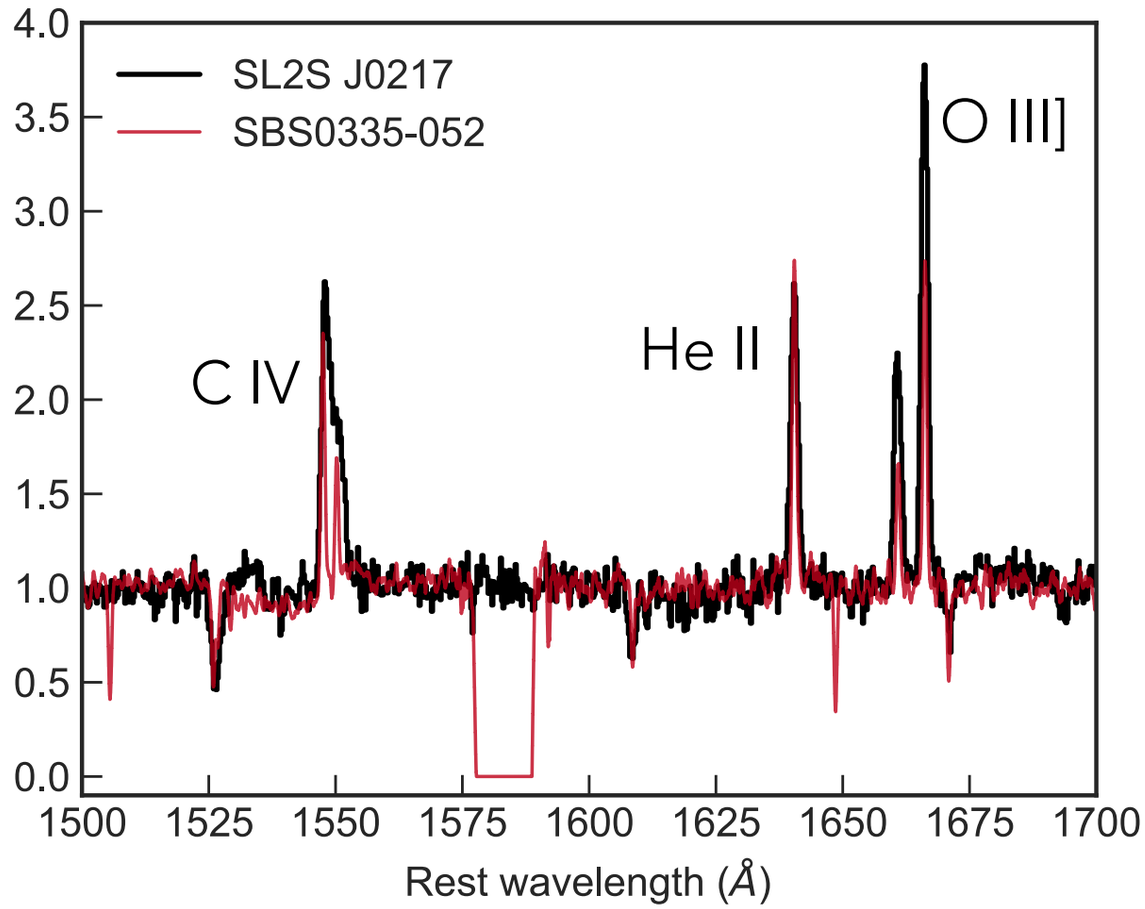
65 pc offset between Lyα and UV continuum peaks

Possible underlying absorption

Comparison with local analogs

Rare local, low metallicity blue compact dwarfs have similar SEDs and optical line ratios



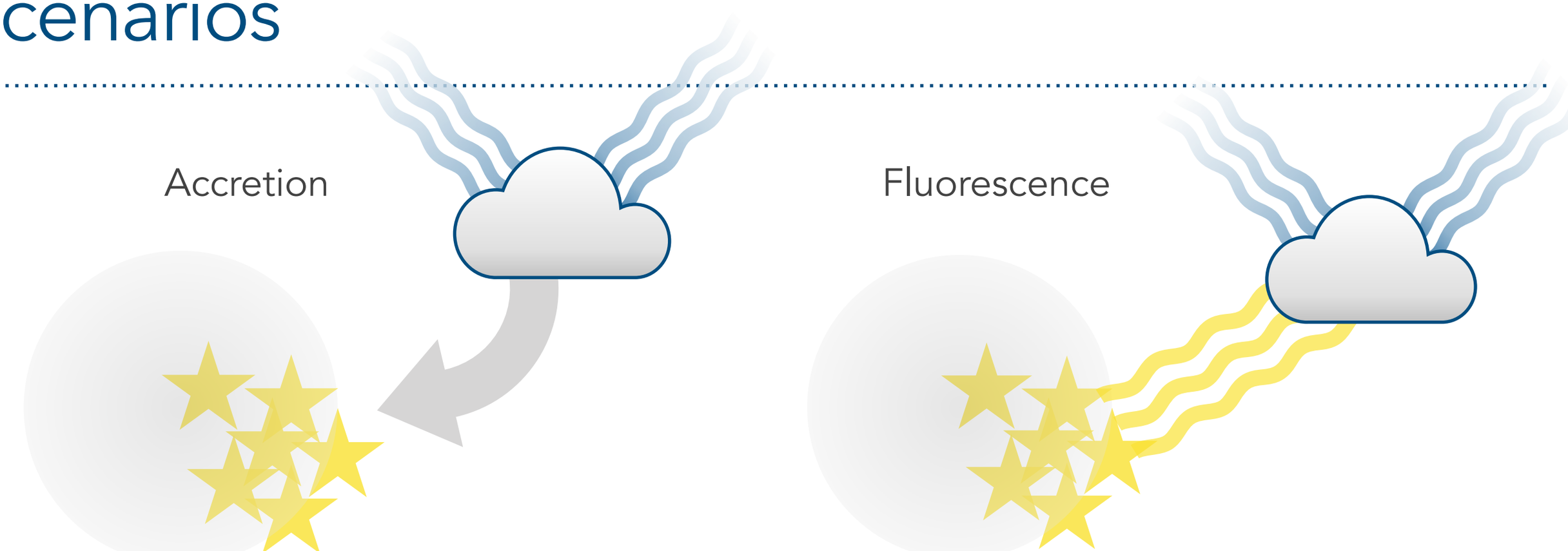


SBS 0335-052 has very similar high ionization lines, DLA

Does SL2S J021737 have a (partial) damped Lyα profile?

SBS 0335-052: James et al 2014

Scenarios



Need to spatially separate Lyα and UV continuum, decouple equivalent width and escape fraction

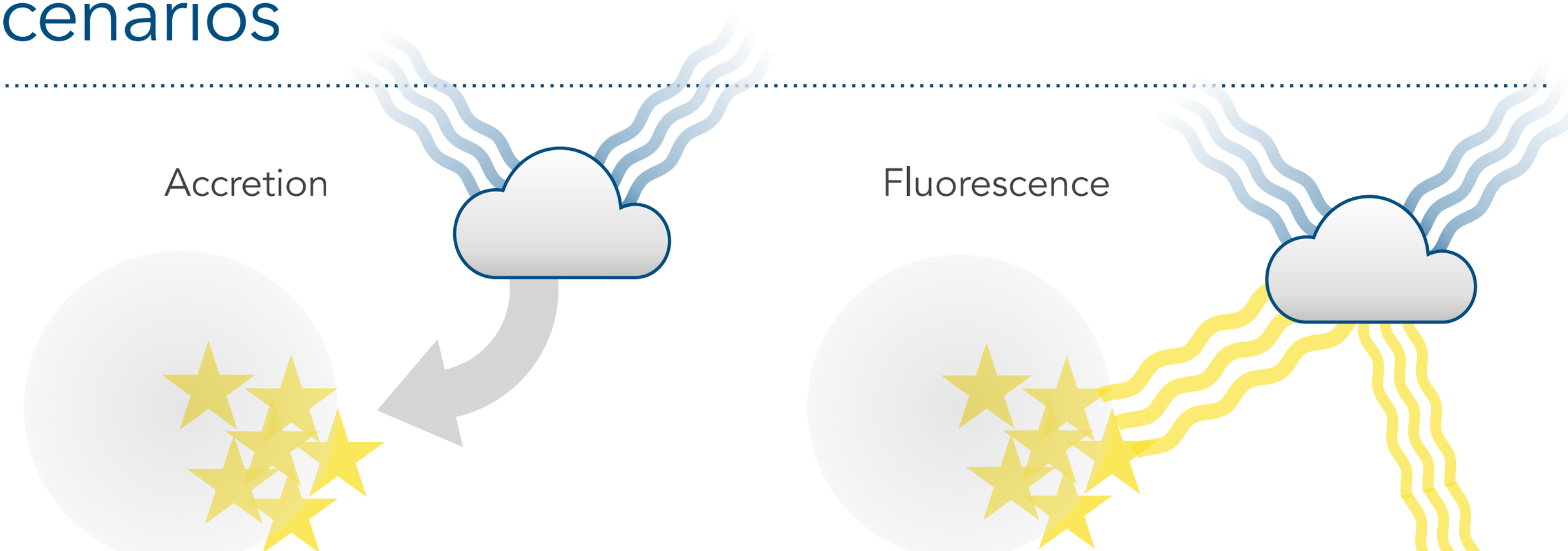
Lyα emission from accretion or fluorescence?

- Accretion may be consistent with blue Lyα peak, lack of outflows
- Additional ionizing source for fluorescence model?

Or intrinsic equivalent width is extreme, for a very short time?

Work in progress!

Scenarios



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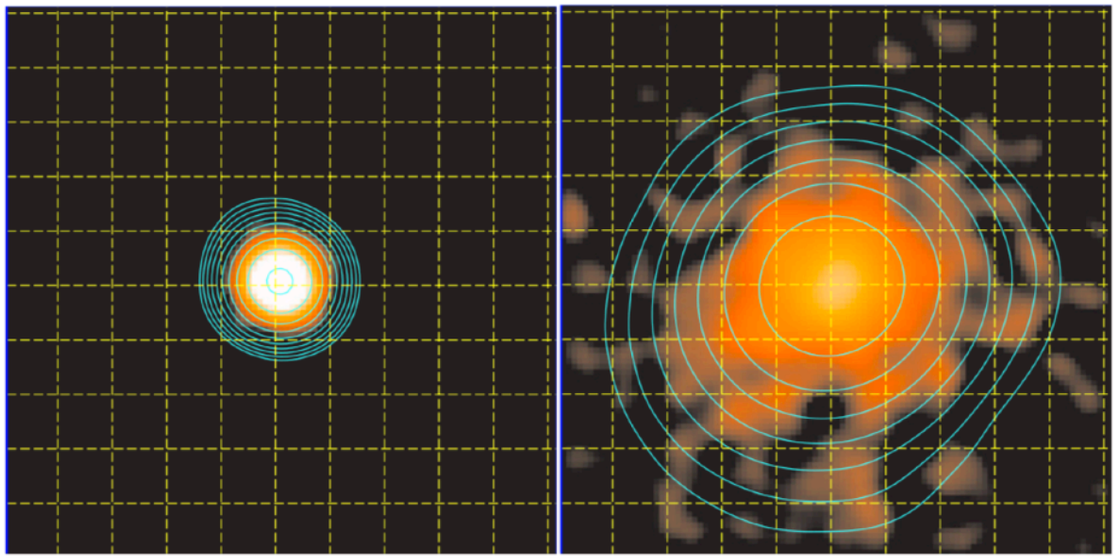
Work in progress!

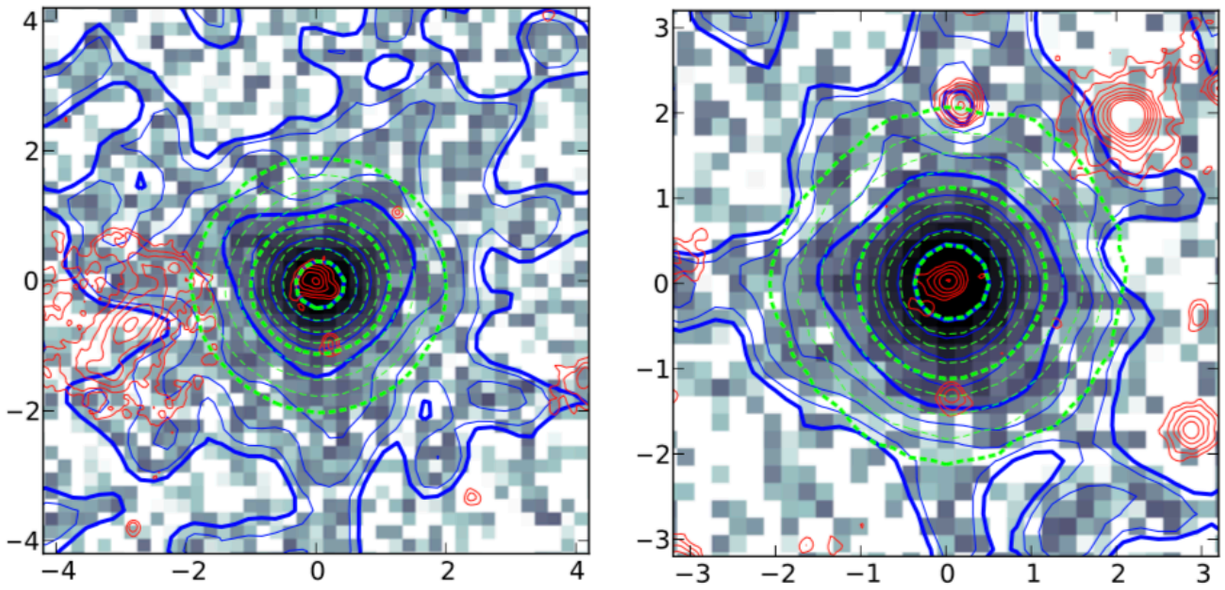
The power of Lyα: spectral + spatial

Extended Lyα halos from stacked NB imaging



Steidel et al 2011
see also Momose et al 2014, 2016, many others

MUSE reveals statistical samples of individual Lyα halos



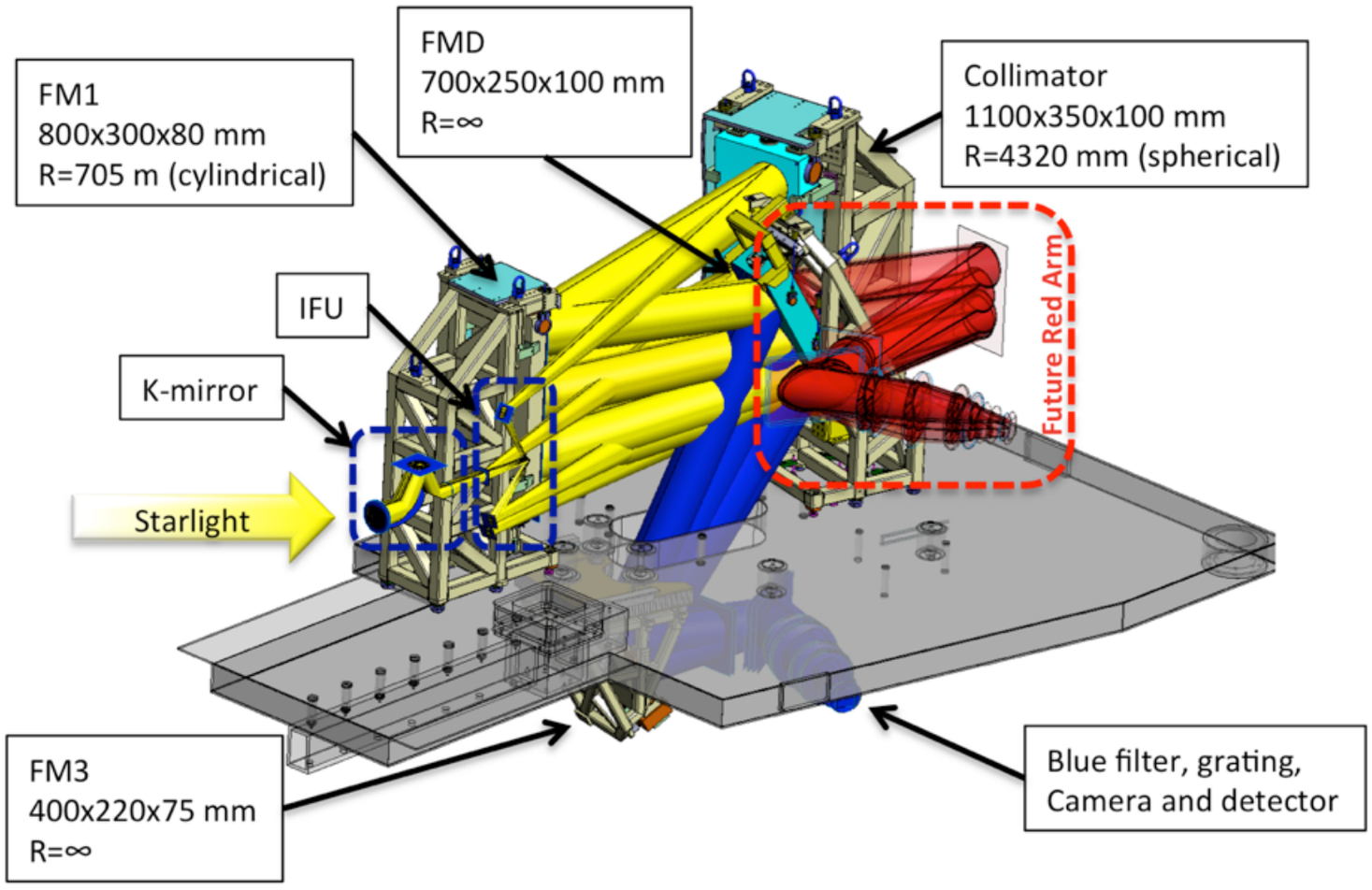
Wisotzki et al 2016
see also Leclercq et al 2017

Next step: spatially resolved spectroscopy

See also MUSE results, Floriane Leclerq's talk tomorrow

Highly ionized Lyα-emitting galaxies are prime targets for resolved spectroscopy of spatially-extended Lyα emission

The Keck Cosmic Web Imager (KCWI)



Optical IFU commissioned on Keck II, September 2017

Optimized for low surface brightness spectroscopy

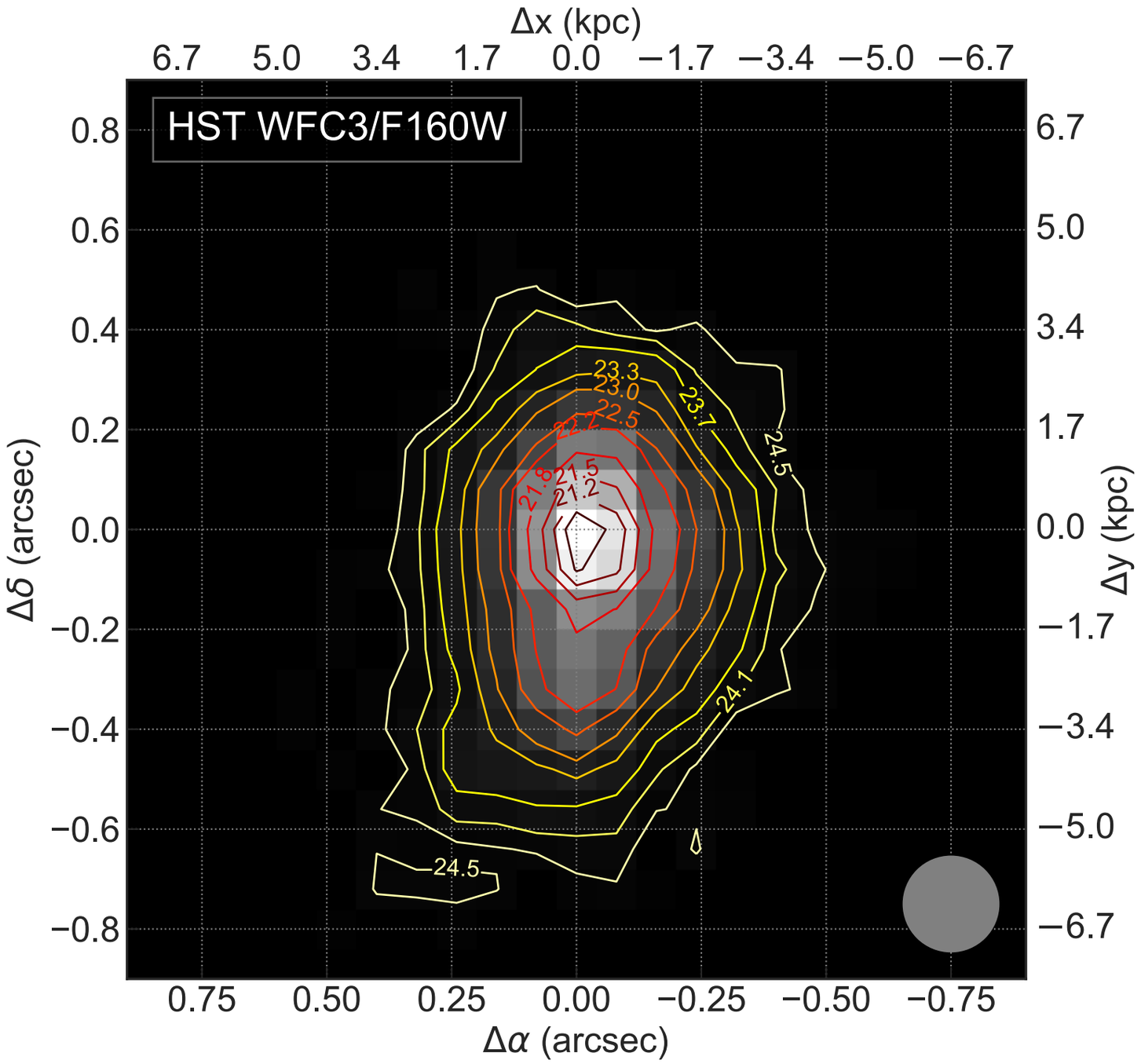
Blue channel: 3500-5600 Å

Multiple configurations

Medium scale image slicer: 16.5″× 20.4″ FOV

BL grating: Resolution 2.5 Å, R ~ 1400-2200

Q2343-BX418: a low mass galaxy at z=2.3



Half-light radius ~ 1.5 kpc

$M_\star = 5 \times 10^8\ M_\odot$

SFR = 50 $M_\odot\ yr^{-1}$

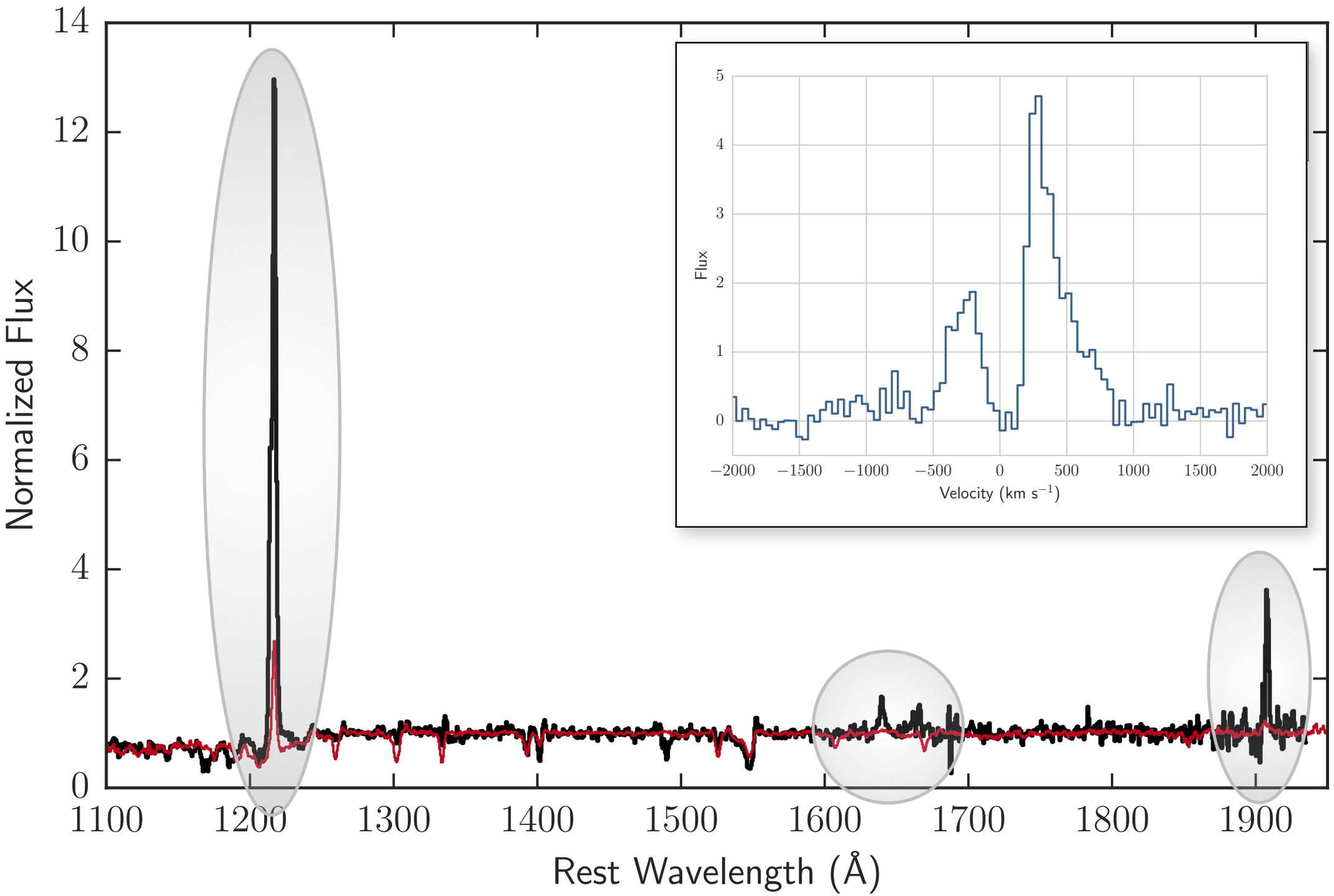
sSFR = 18 Gyr^{-1}

12 + log(O/H) = 8.08 (T_e)

O32 = 9.66

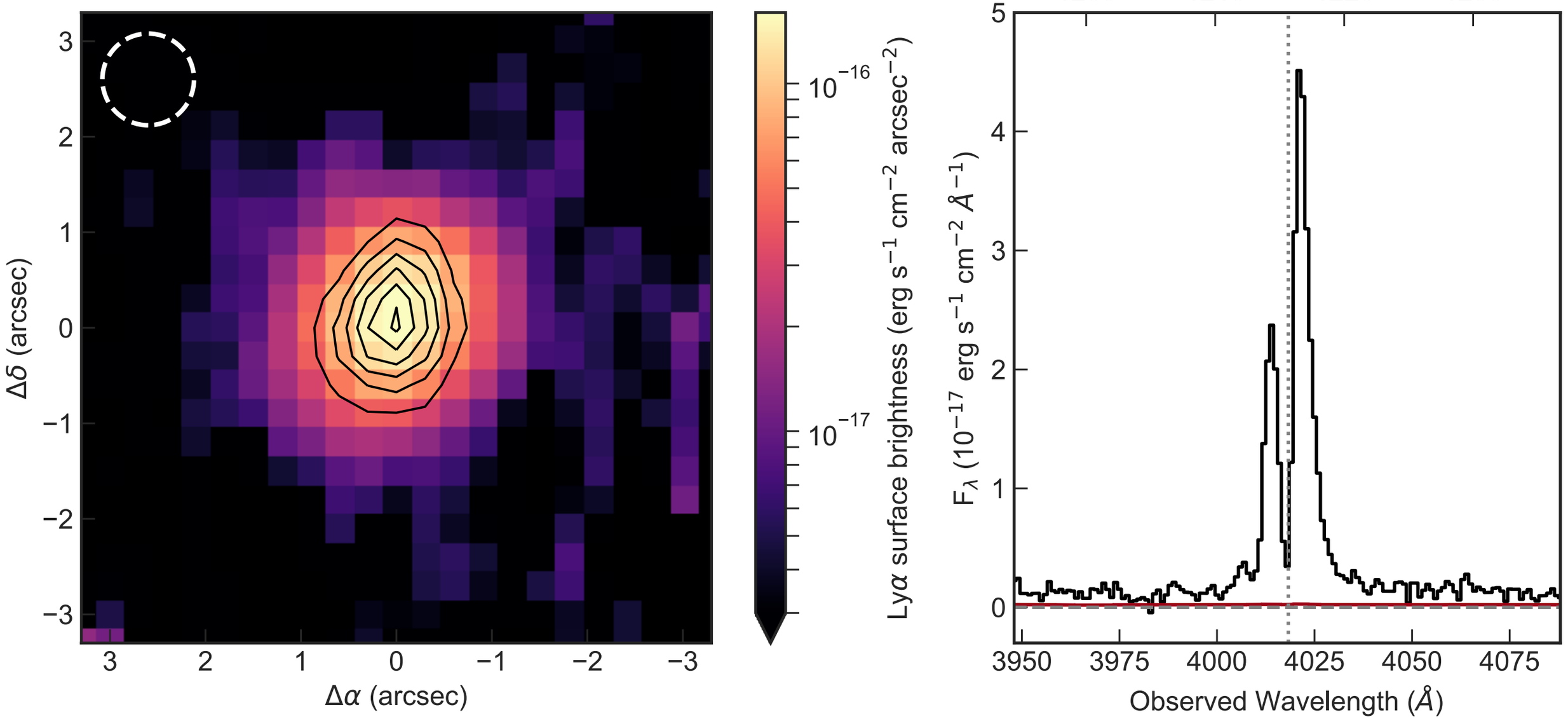
Erb et al 2010, 2018; Steidel et al 2014

Q2343-BX418: a low mass galaxy at z=2.3



Erb et al 2010

The Lyα halo of BX418 as seen with KCWI



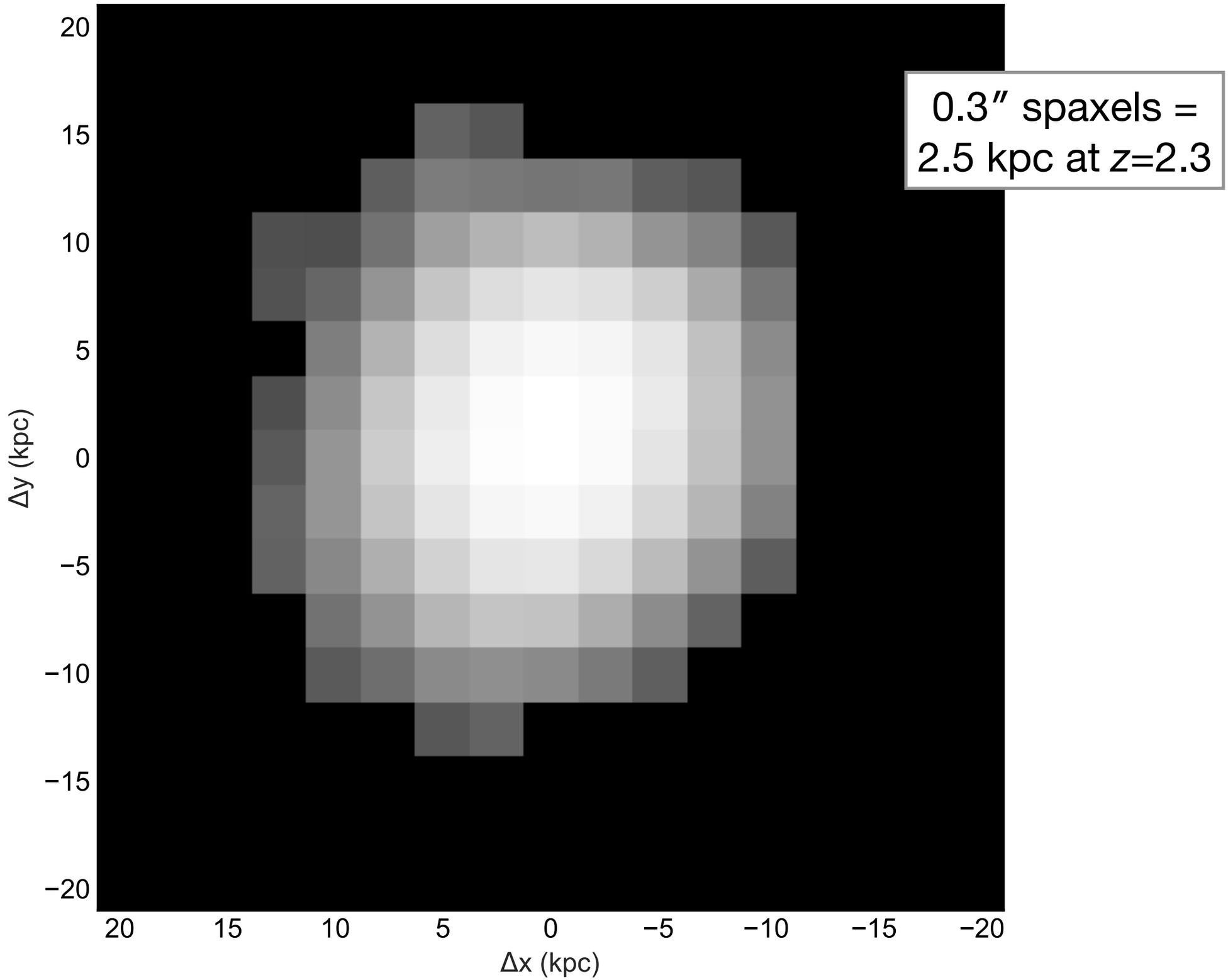
Observed with KCWI during commissioning, September 2017

9 × 1200s (3 hr) integration

Lyα detected with S/N ≥ 3 (1) per pixel to a radius of 16 (20) kpc

Erb et al 2018

Spatially resolved spectroscopy



Erb et al 2018

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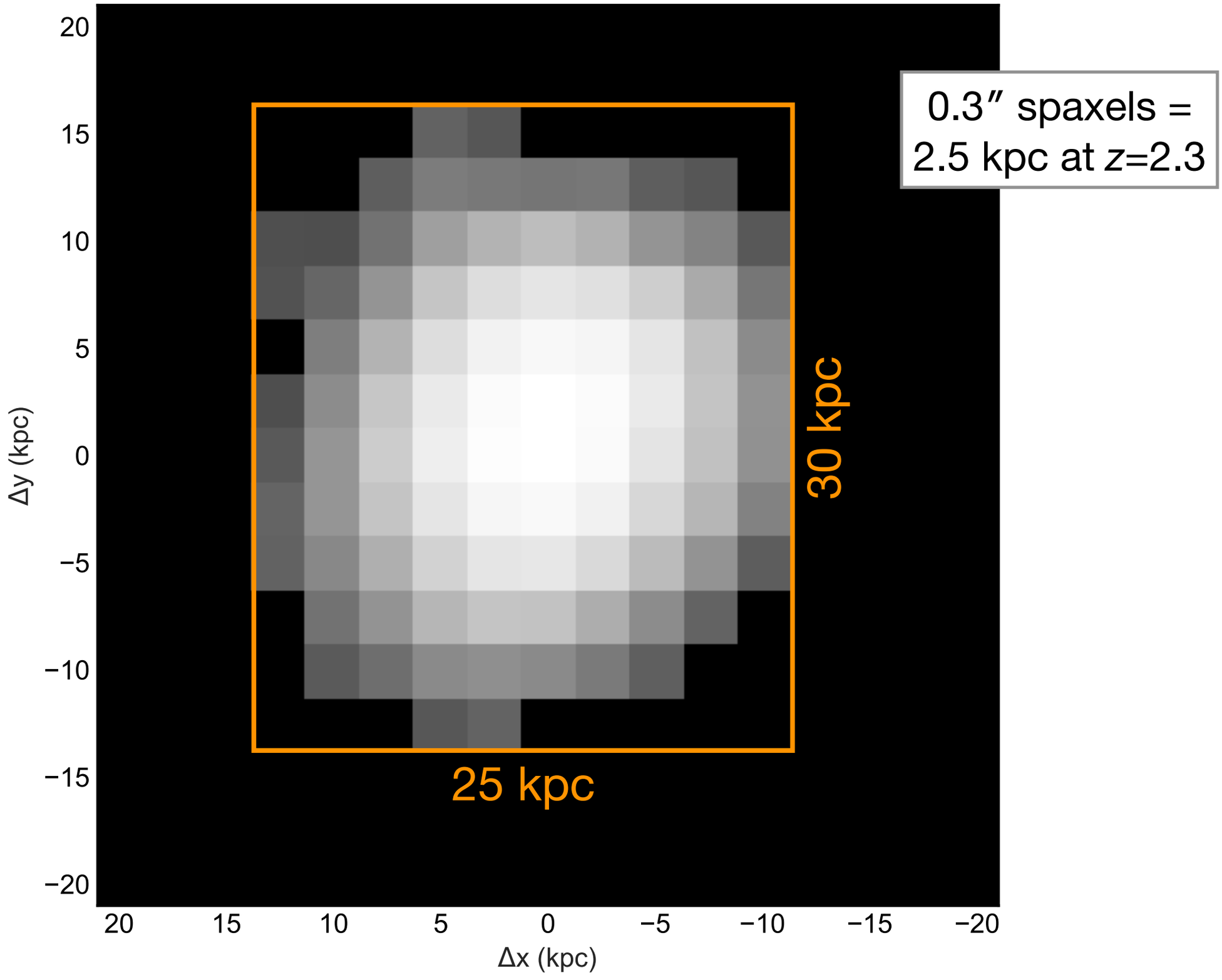
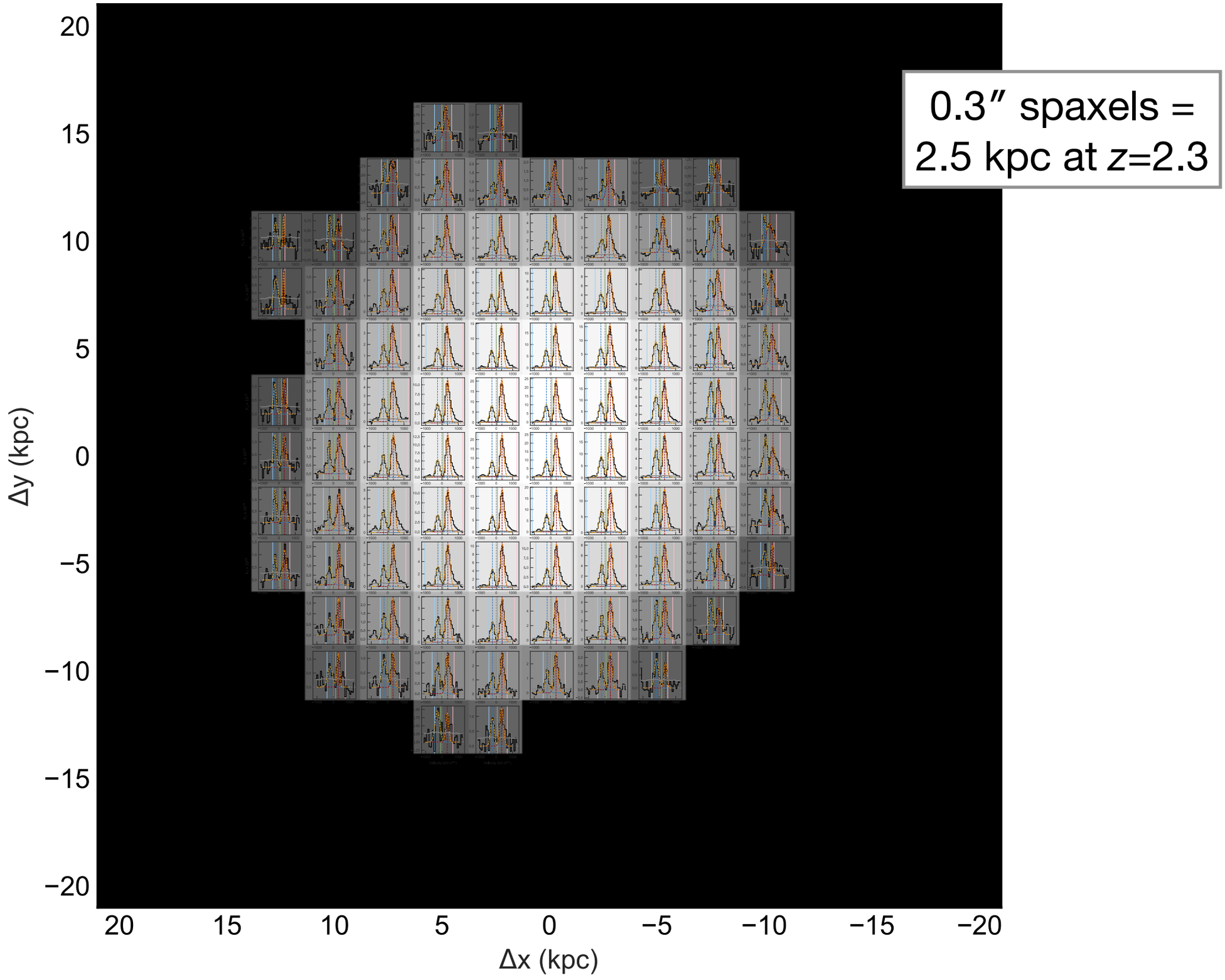
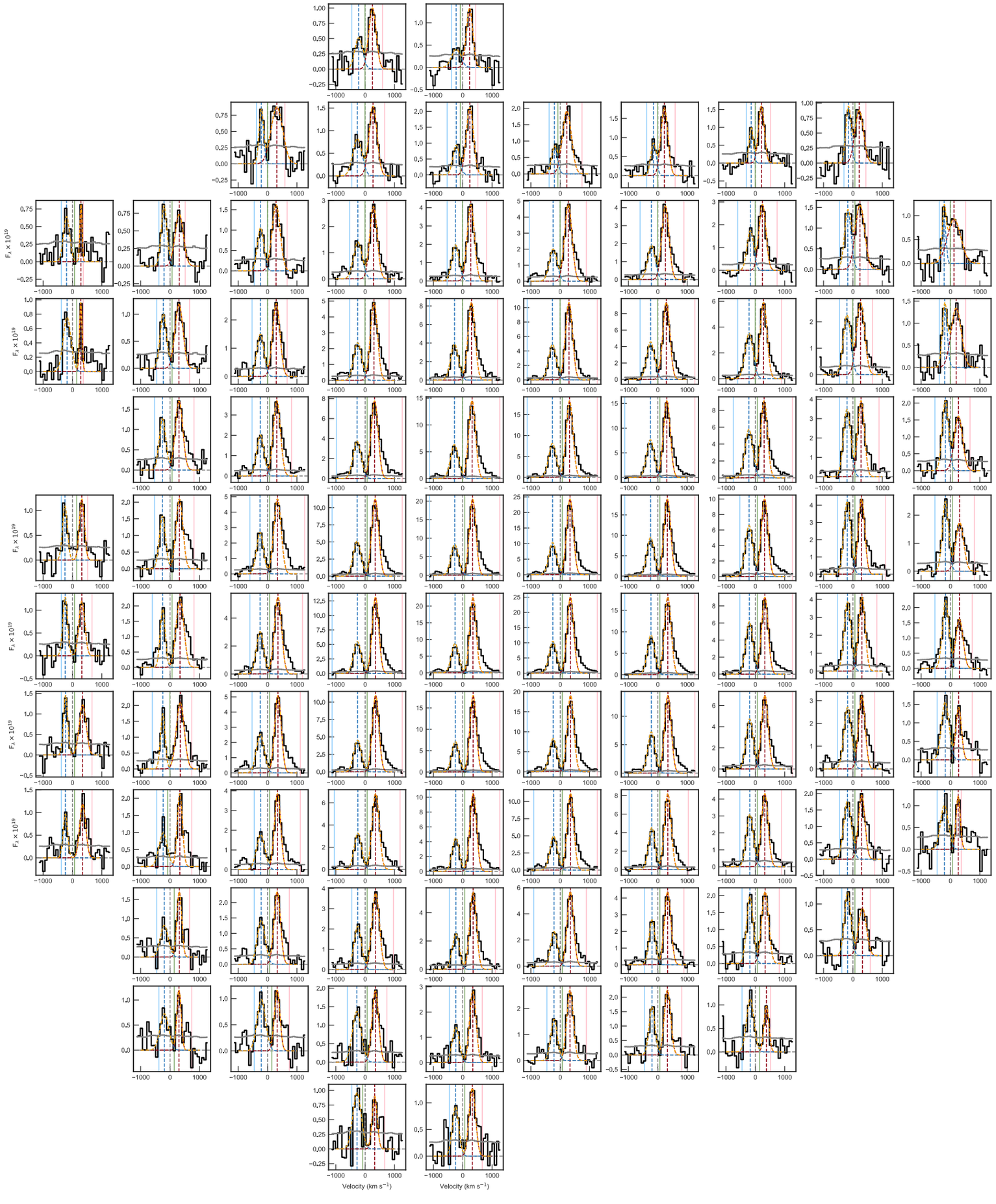


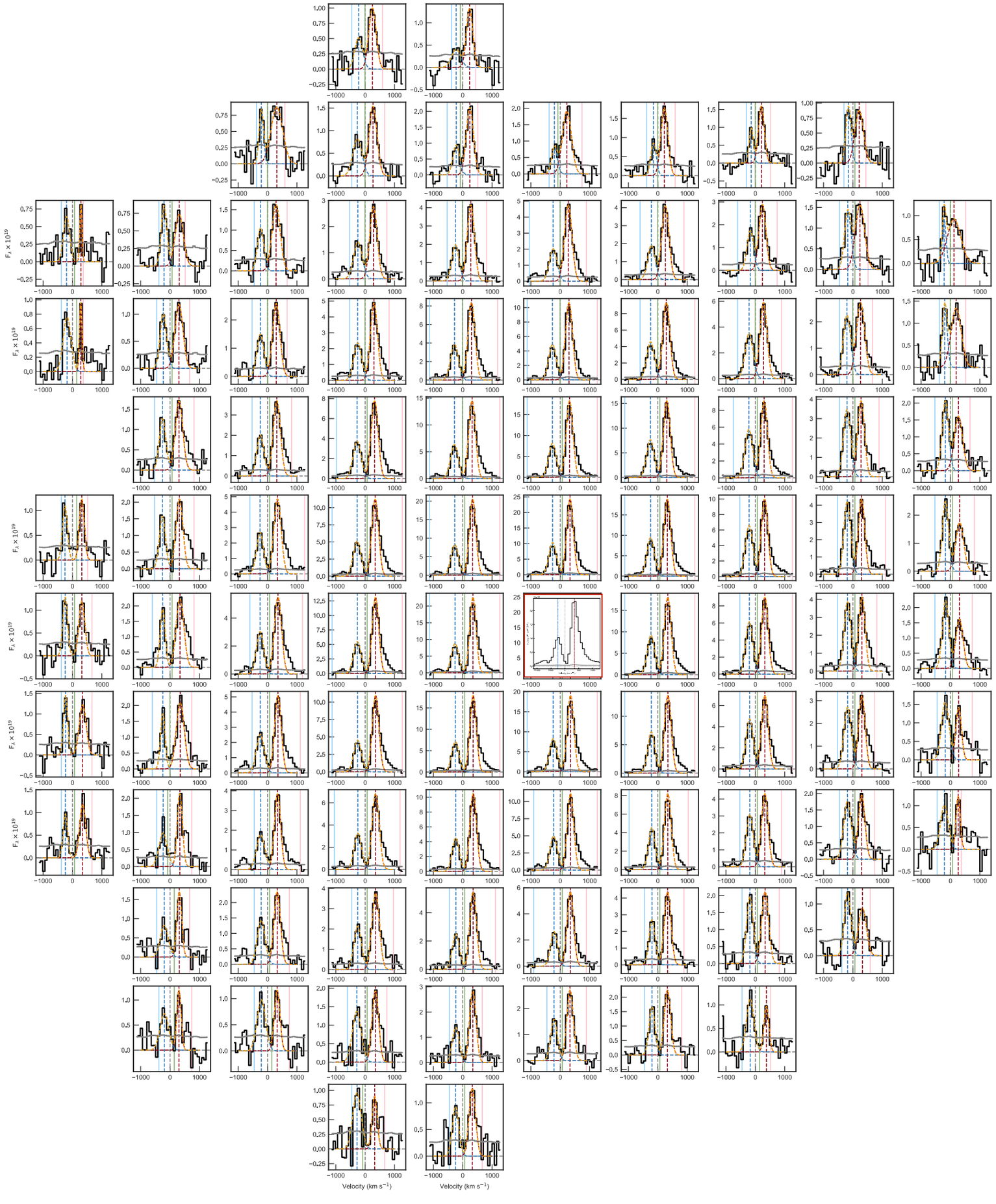
Erb et al 2018

Spatially resolved spectroscopy



Erb et al 2018


Velocity (km s^{-1})
Velocity (km s^{-1})
$F_\lambda \times 10^{19}$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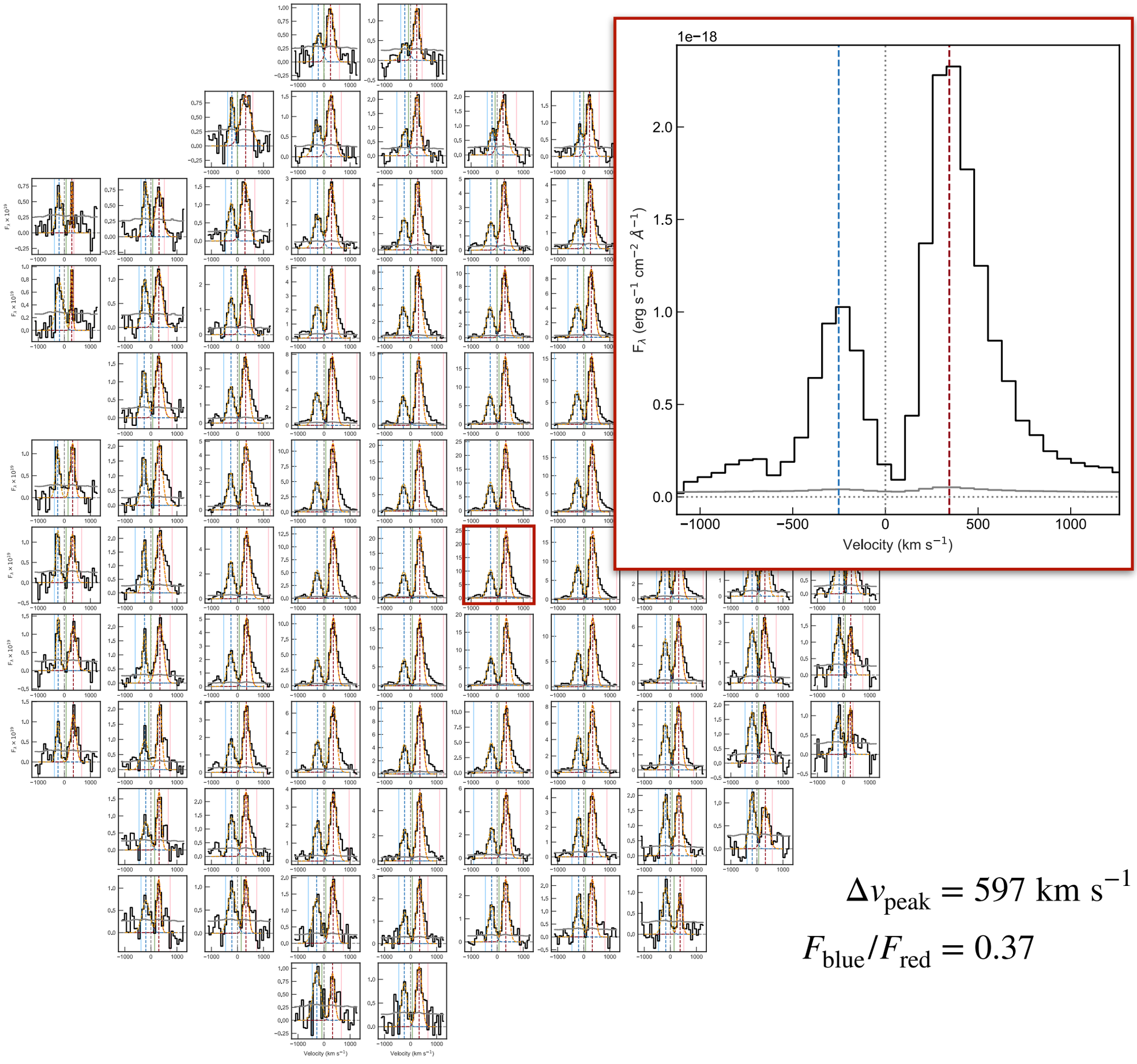
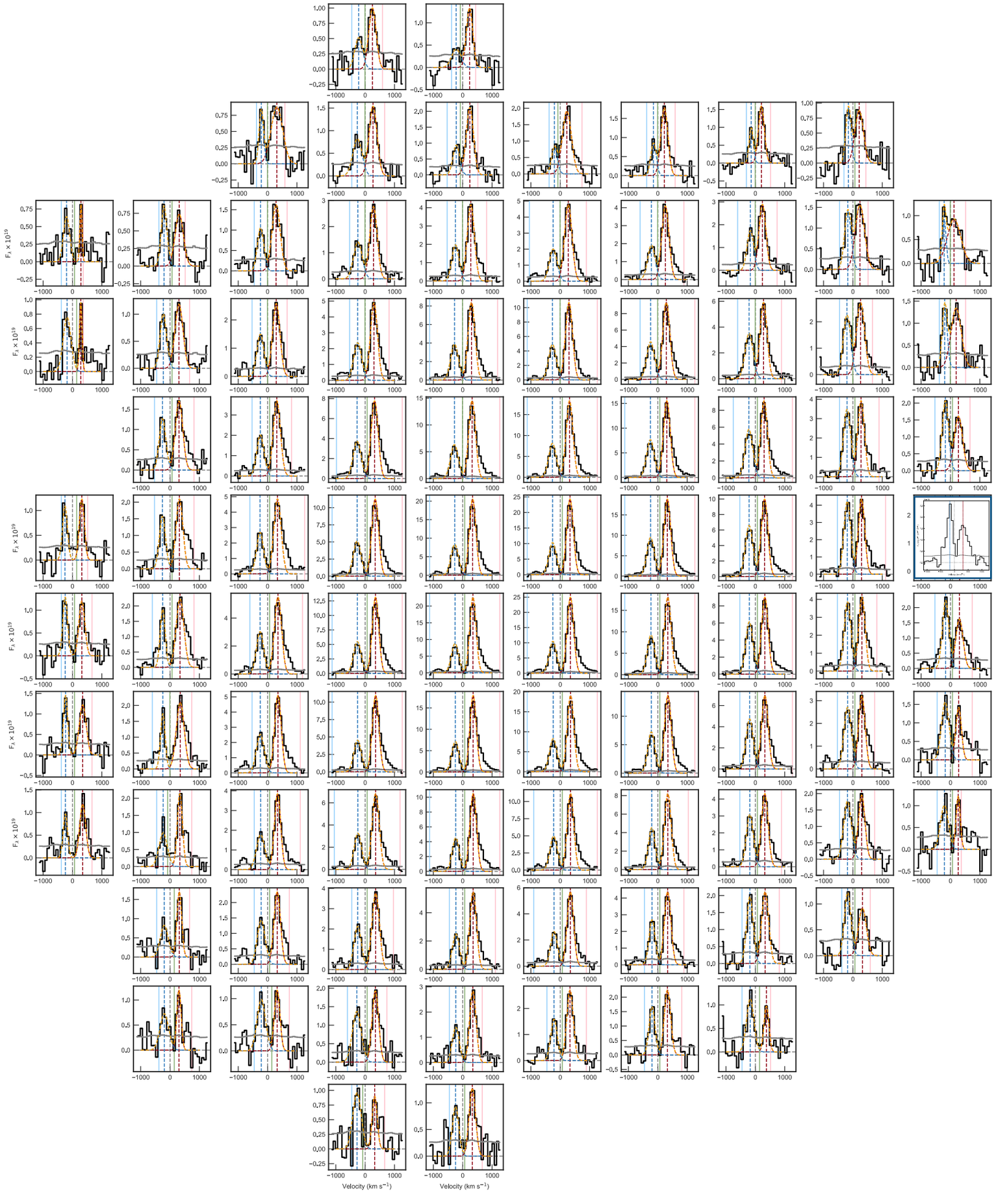


$$\Delta v_{\rm peak} = 597 \text{ km s}^{-1}$$

$$F_{\rm blue}/F_{\rm red} = 0.37$$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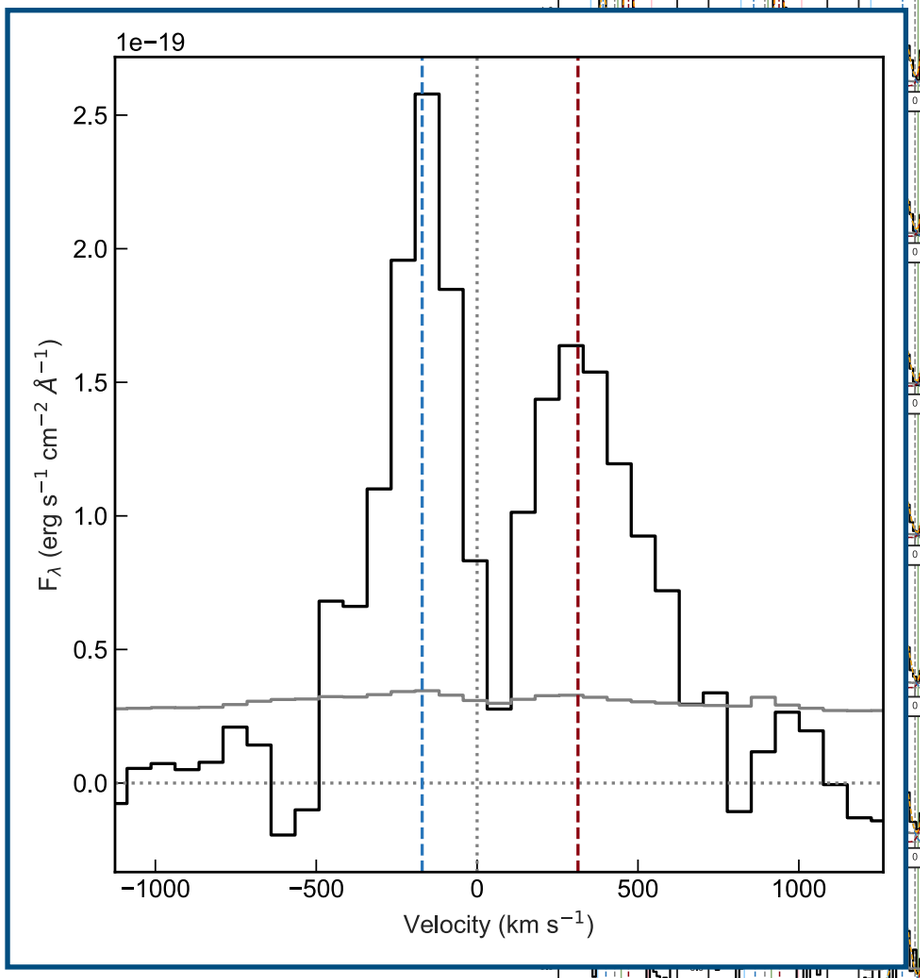
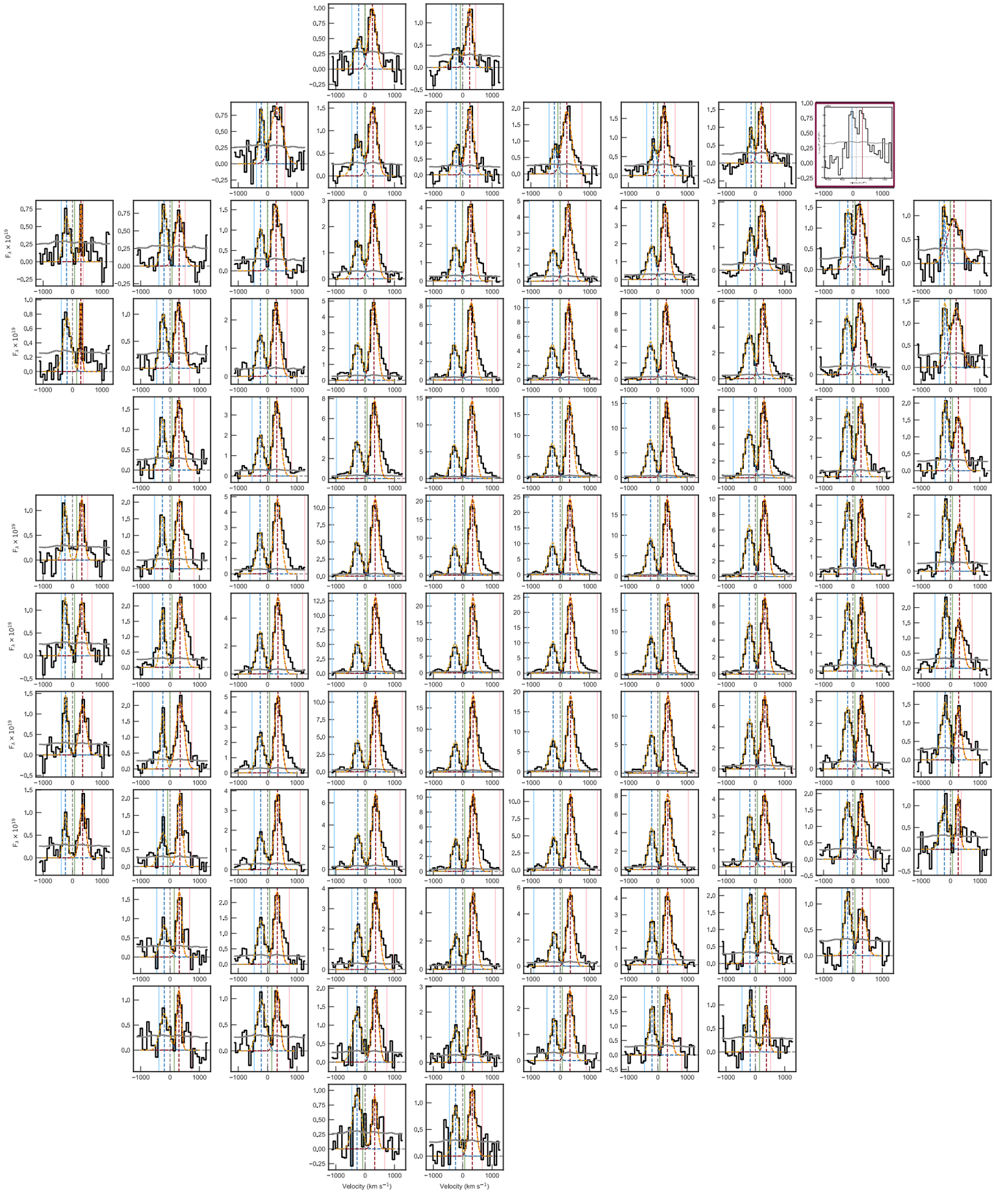
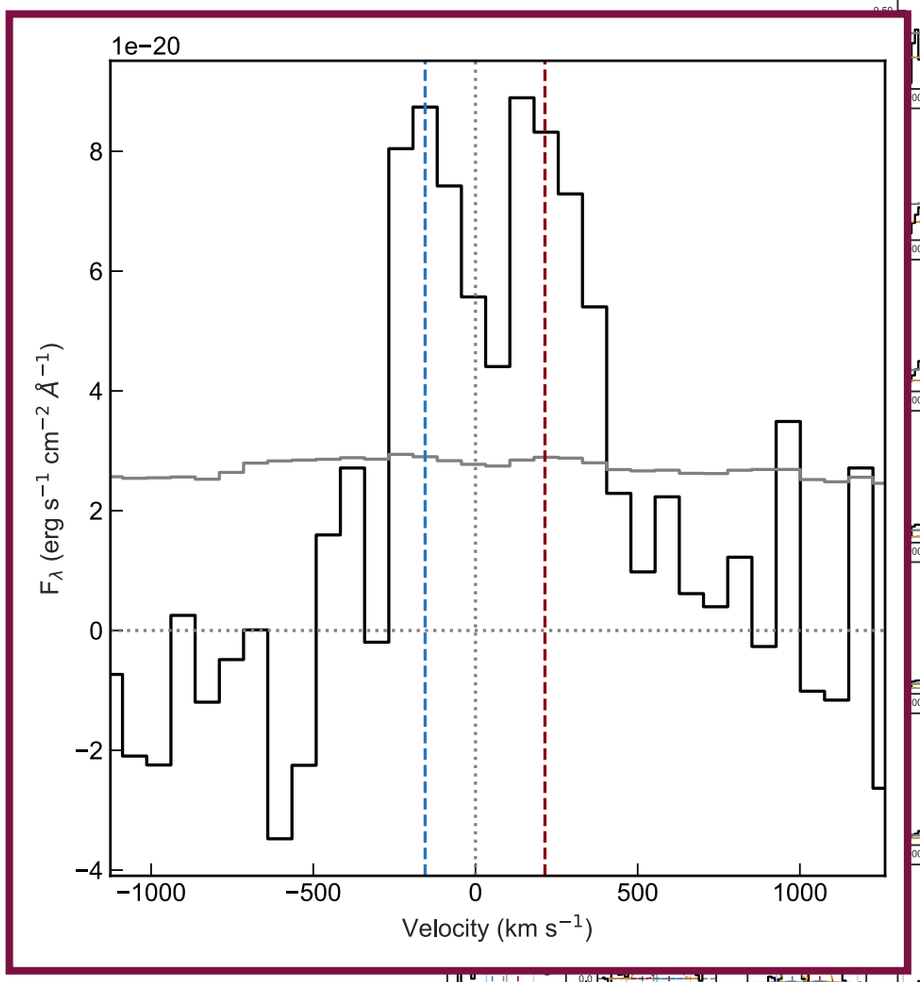


$$\Delta v_{\rm peak} = 484 \text{ km s}^{-1}$$

$$F_{\rm blue}/F_{\rm red} = 1.03$$

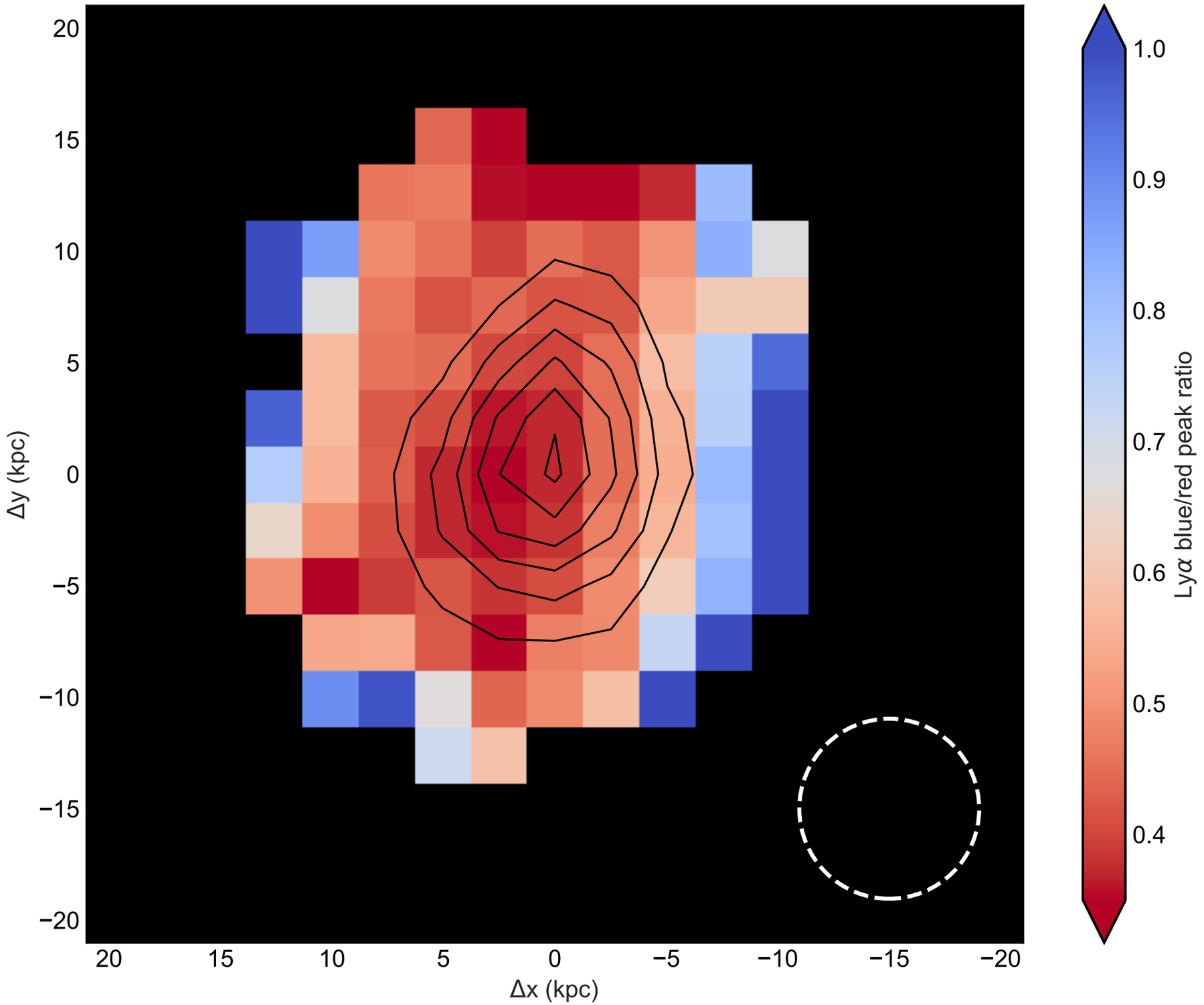

Velocity (km s^{-1})
Velocity (km s^{-1})
$F_\lambda \times 10^{19}$



$$\Delta v_{\rm peak} = 369 \text{ km s}^{-1}$$

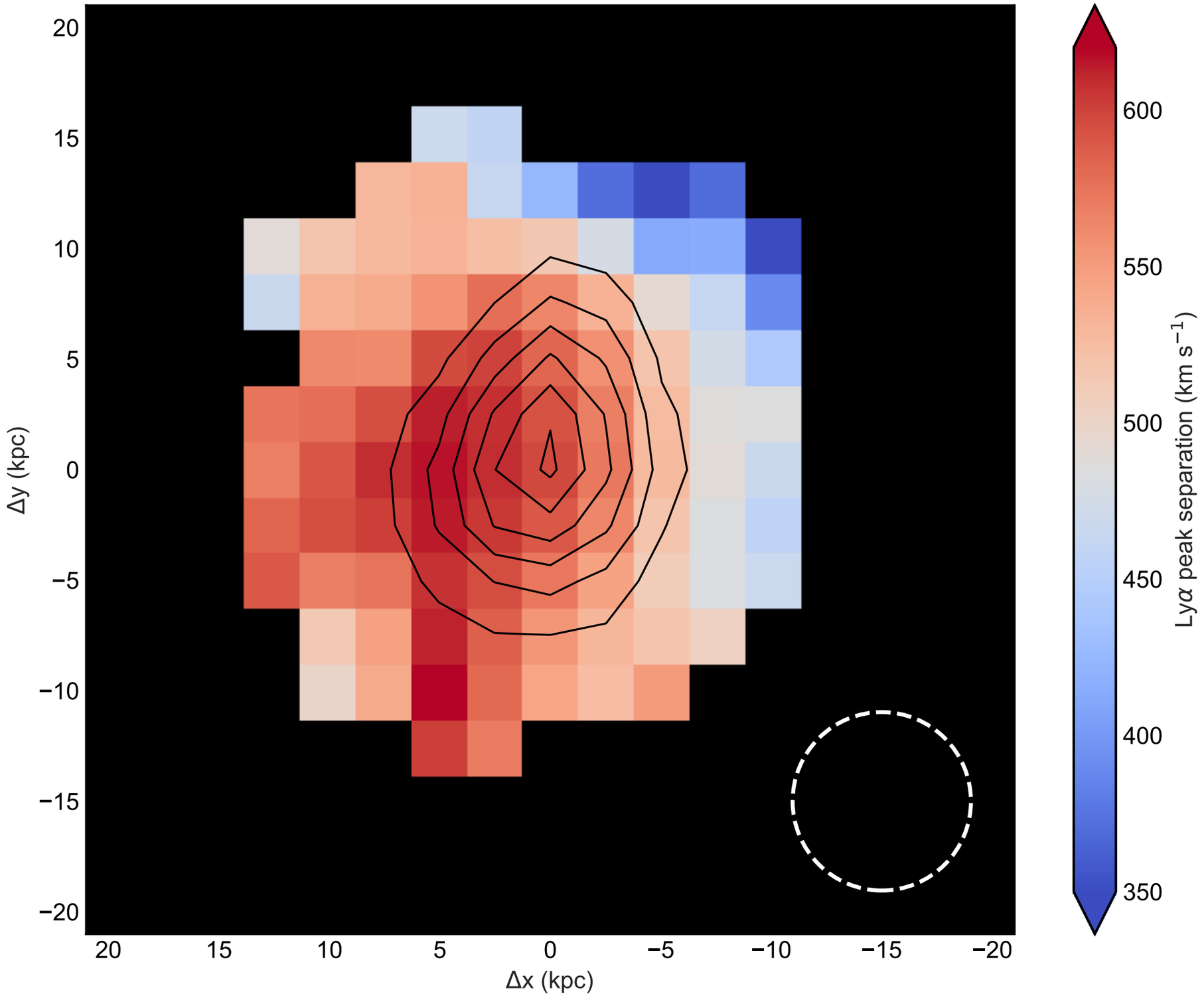
$$F_{\rm blue}/F_{\rm red} = 0.81$$

Mapping the Lyα peak ratio



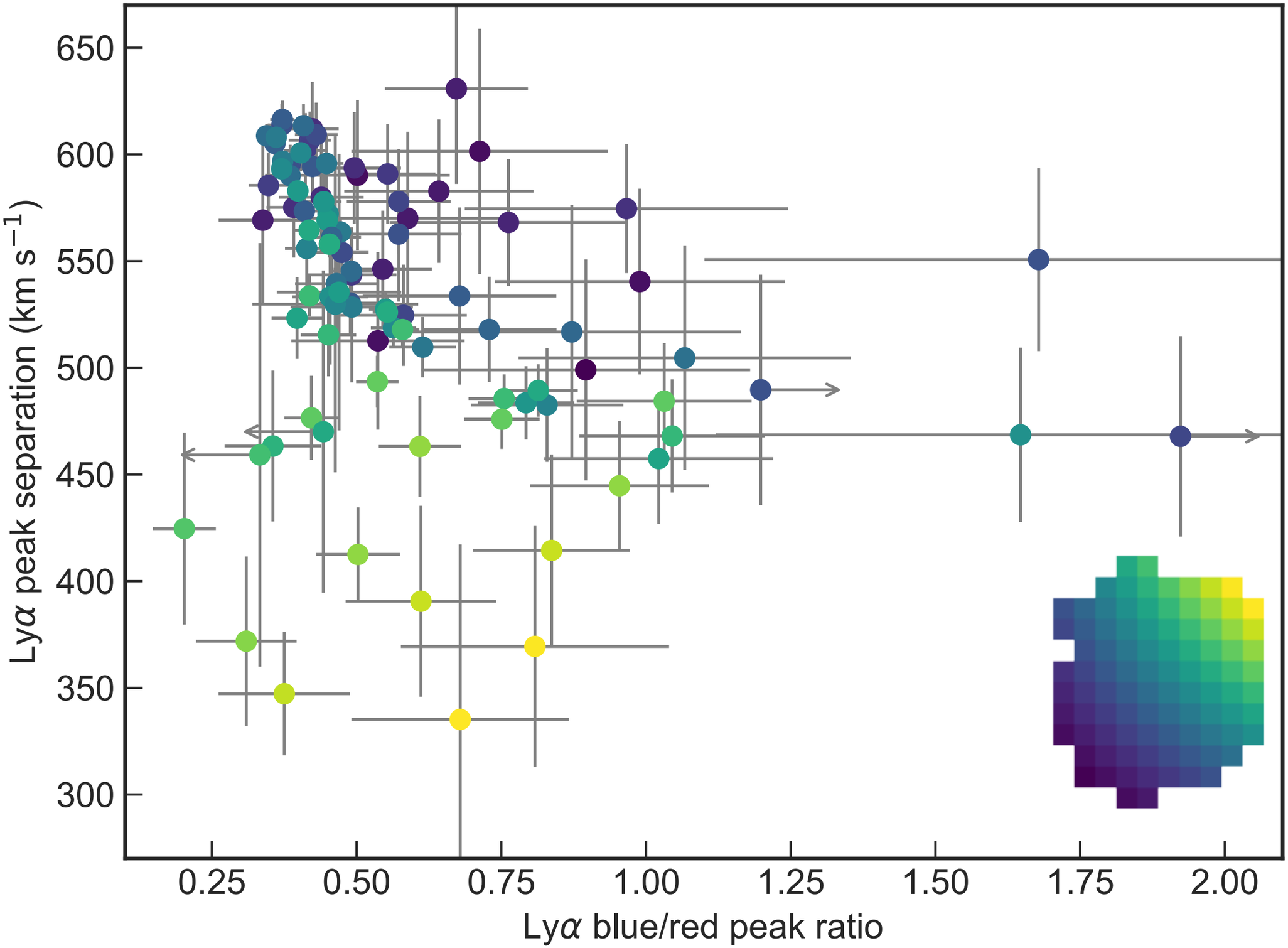
Erb et al 2018

Mapping the Lyα peak separation



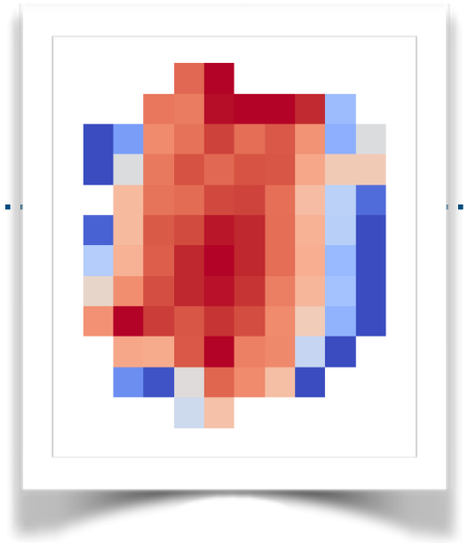
Erb et al 2018

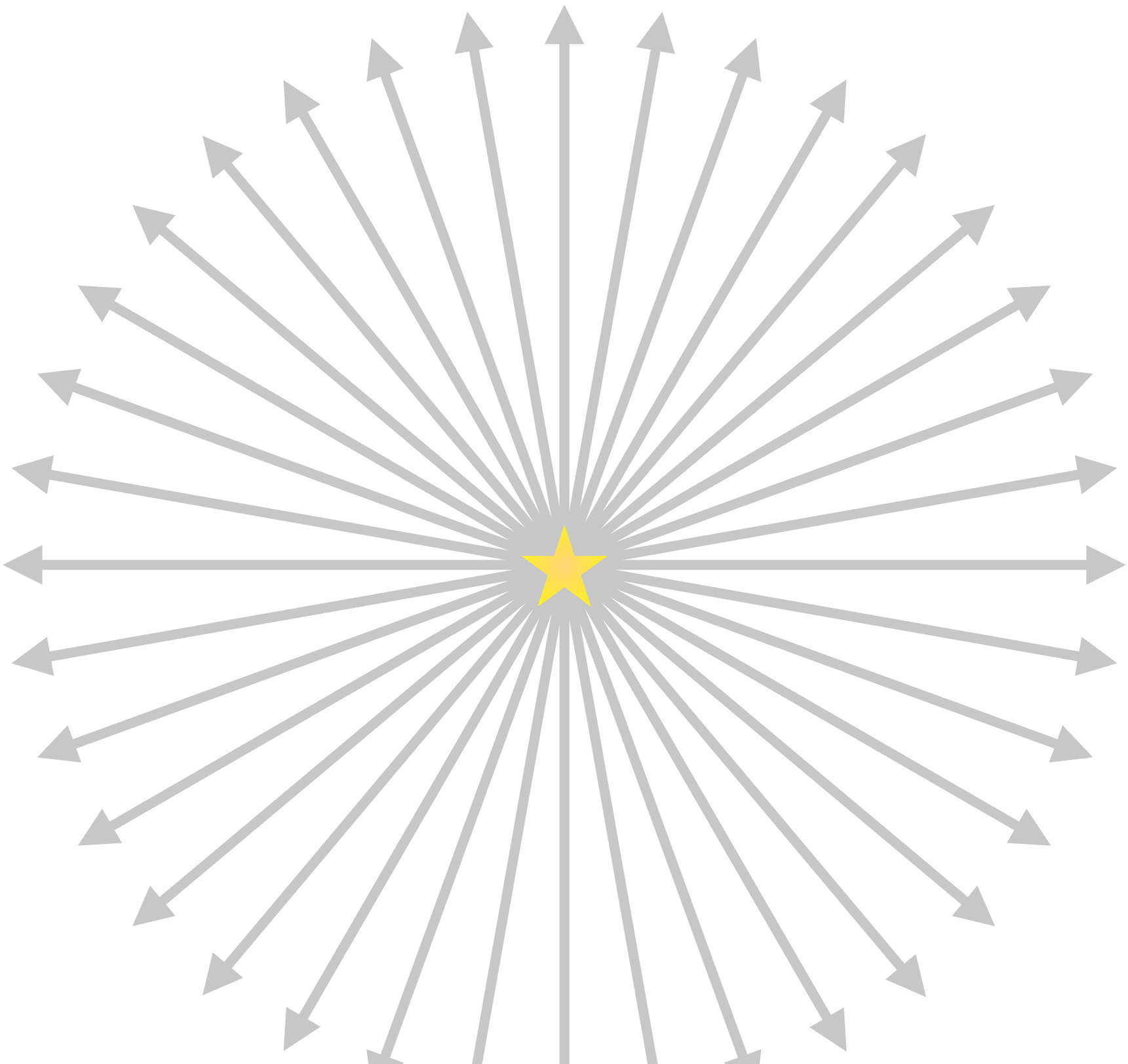
Peak ratio vs peak separation



Erb et al 2018

Lyα peak ratio and radial outflows





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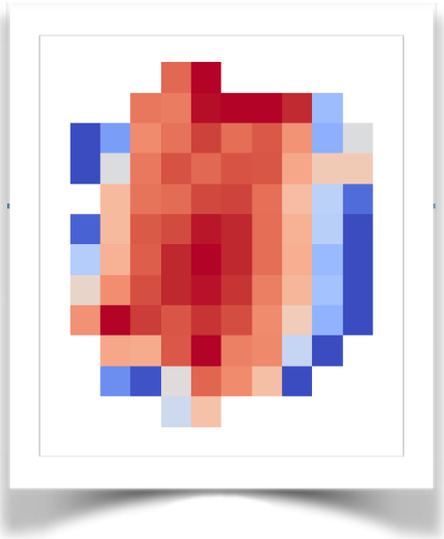
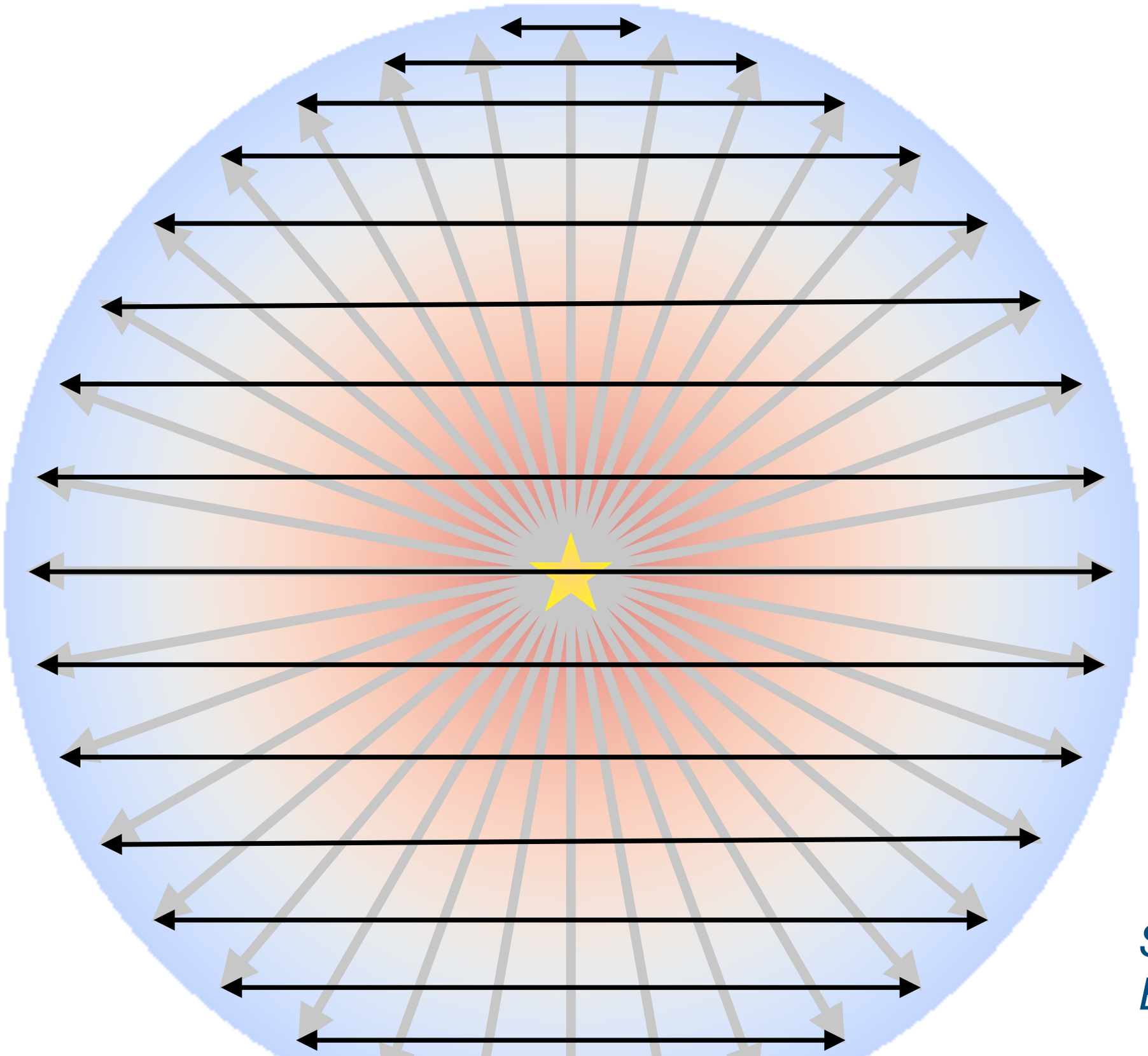
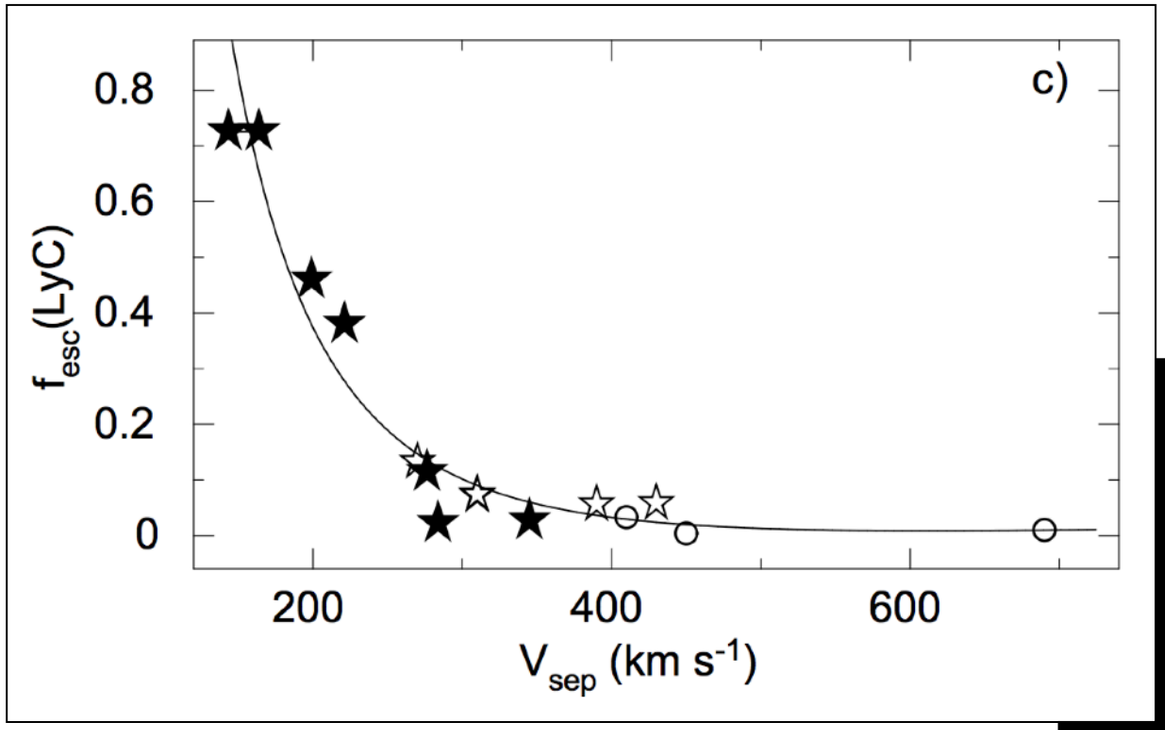


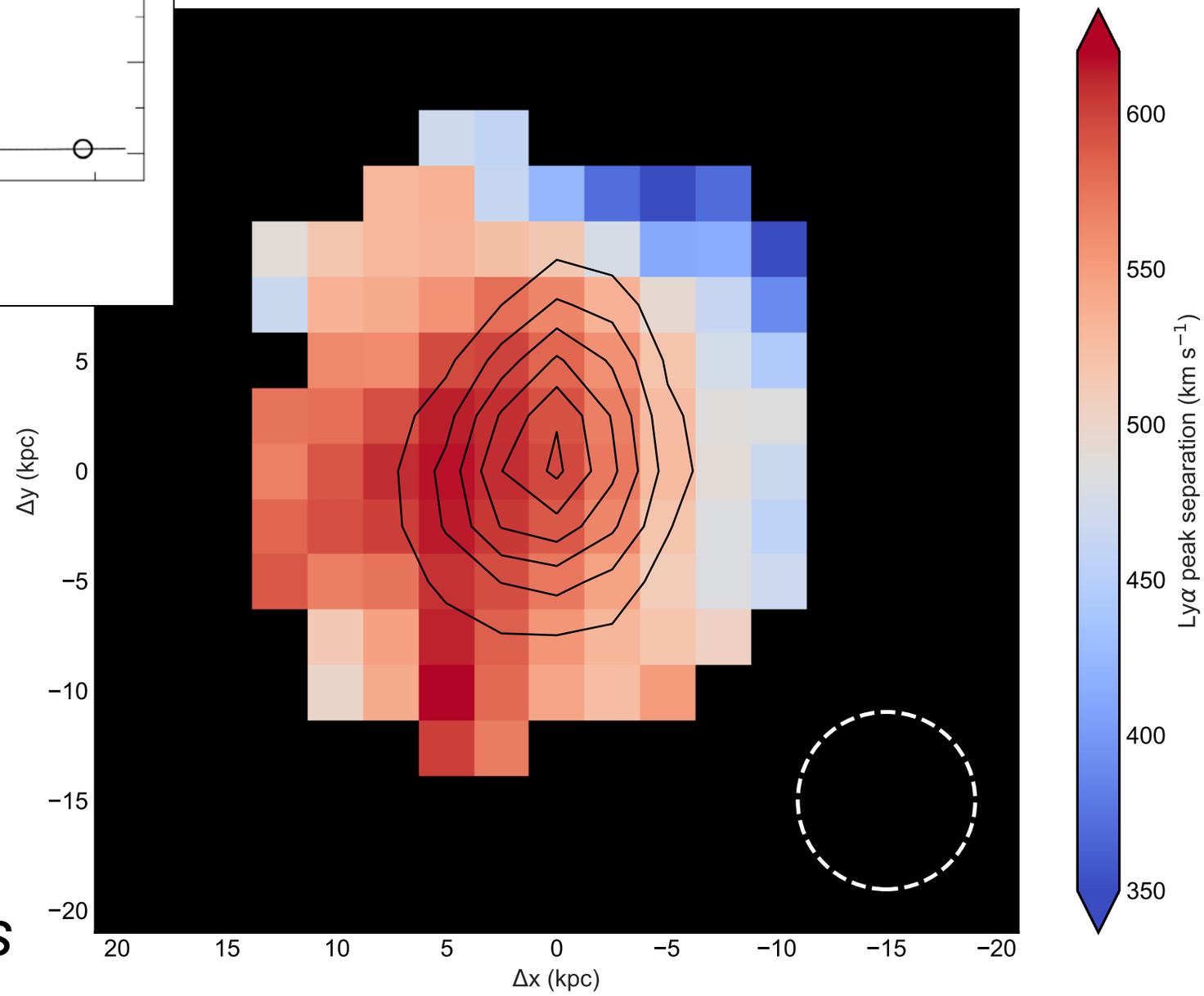


See also Marius Berge Eide's talk yesterday

Lyα peak separation



Izotov et al
2018

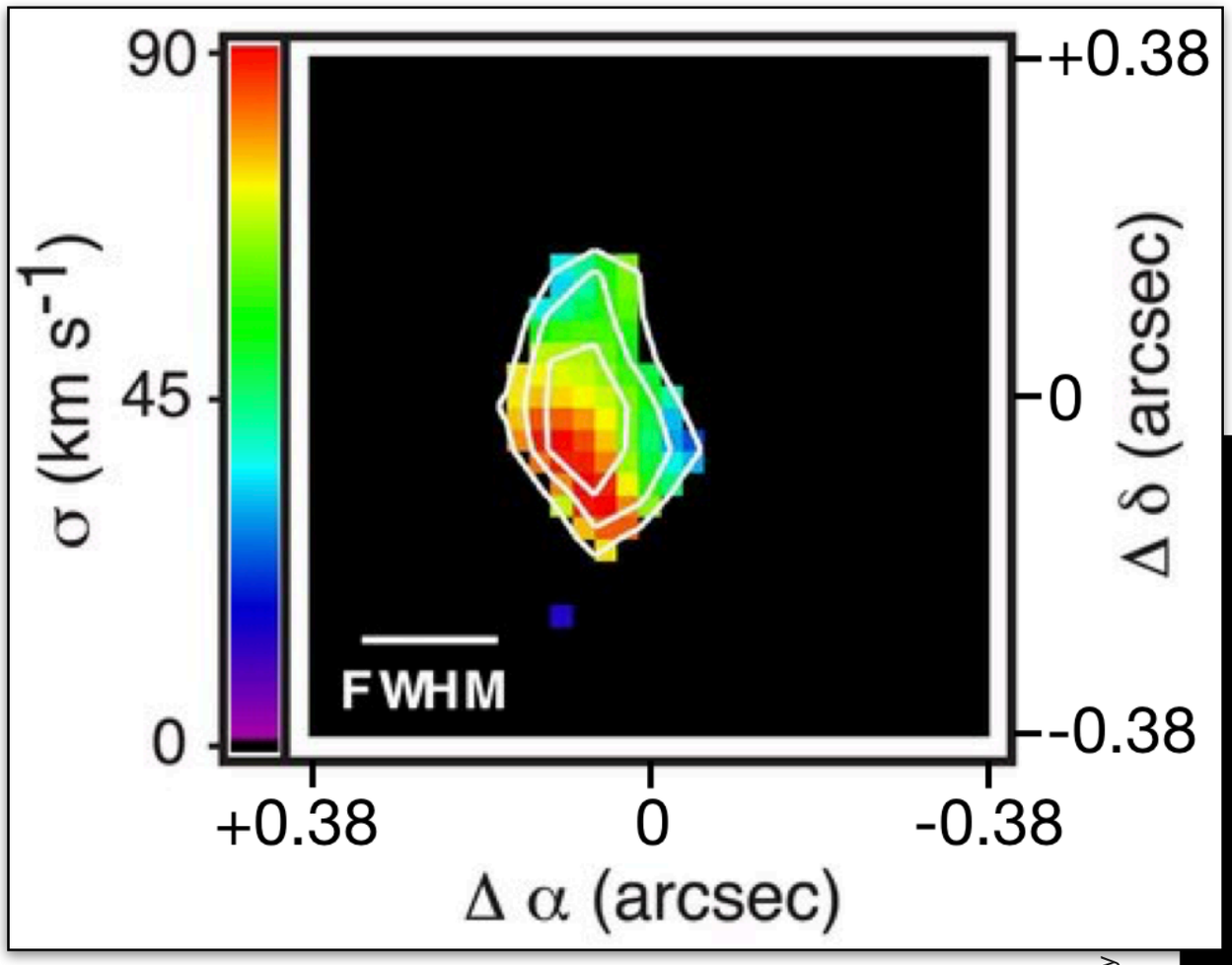


Lyα peak separation correlates with LyC escape fraction

Reflects HI column density and/or covering fraction

CGM is not homogeneous

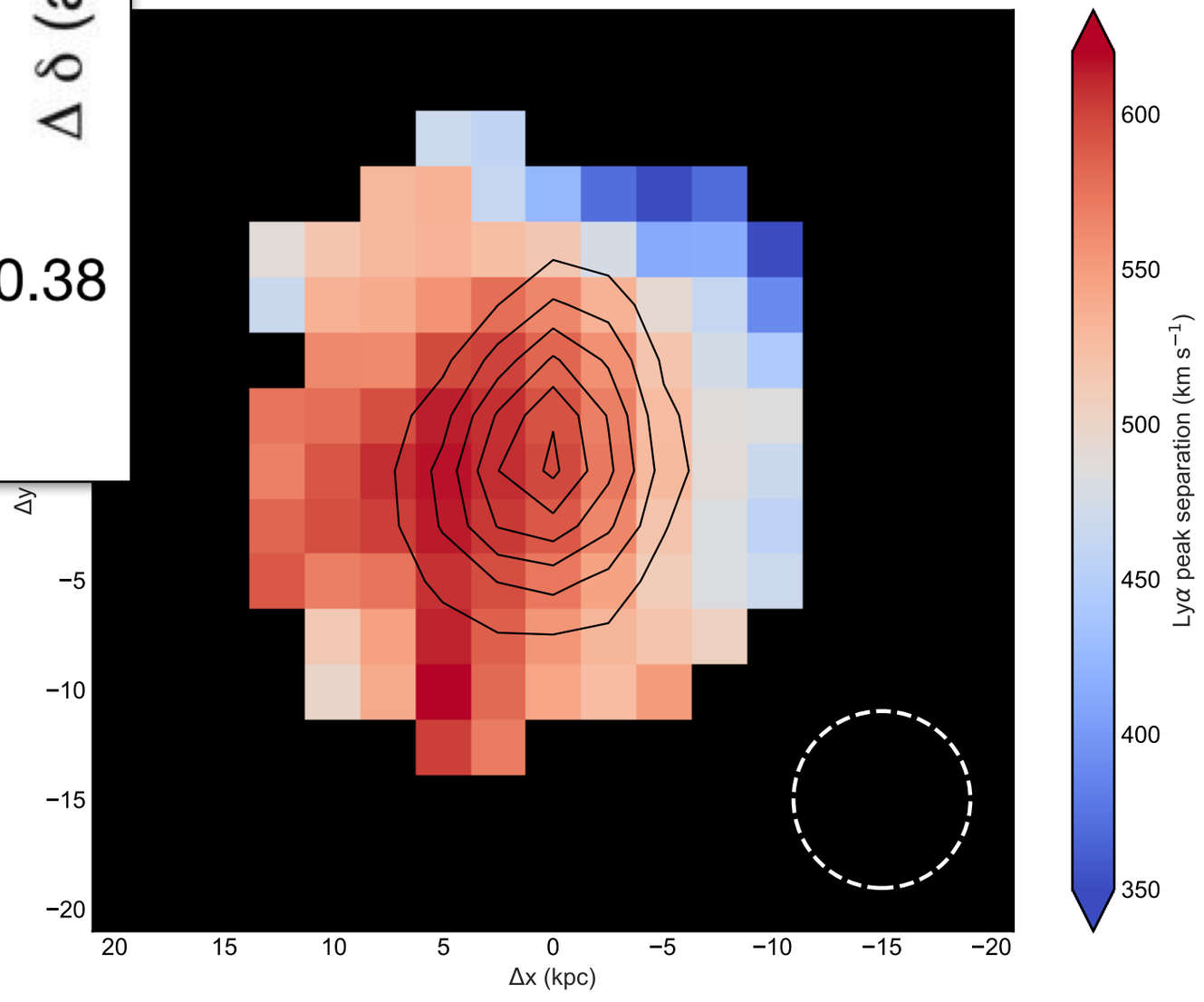
Lyα peak separation and Hα velocity dispersion



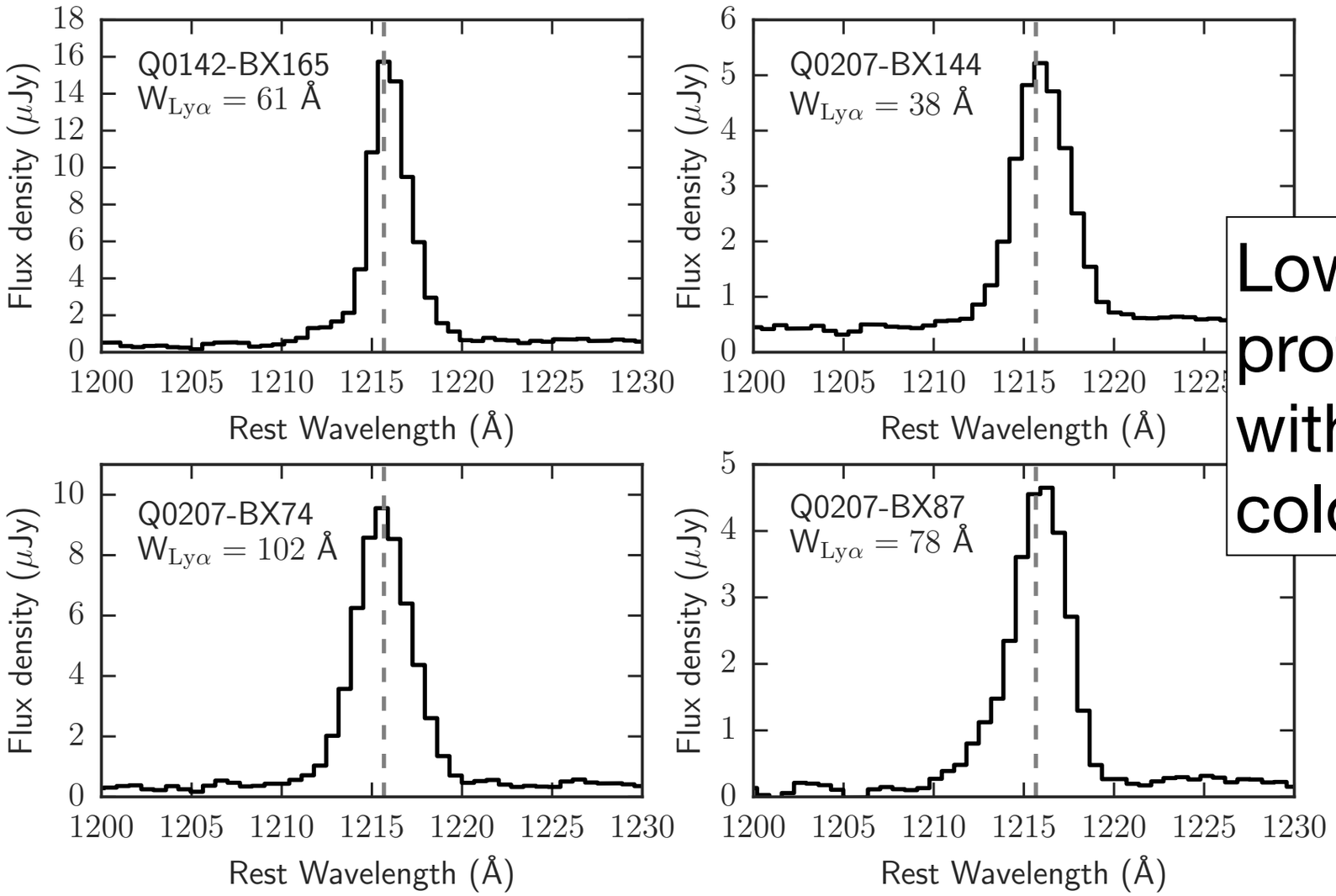
Keck/OSIRIS with AO

Law et al 2009

Does Lyα peak separation reflect velocity dispersion of ISM? (Steidel et al 2010)



More observations + more models needed



Low resolution Lyα profiles of z~2 galaxies with line ratios, masses, colors similar to BX418

Observations of similar targets underway this fall

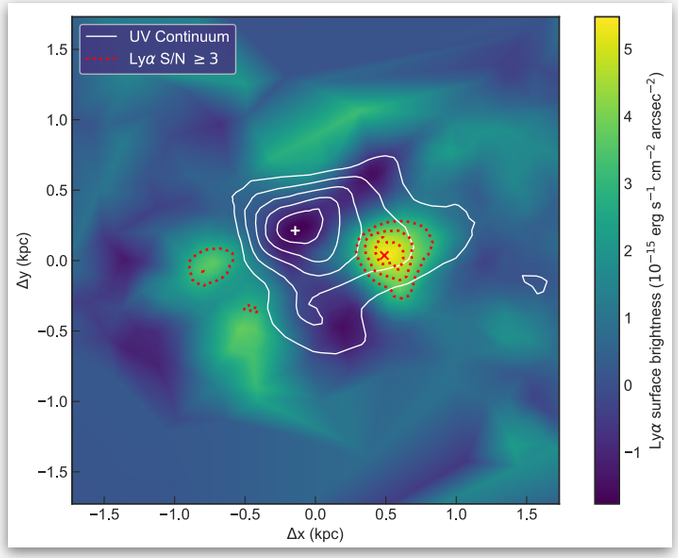
Are BX418's patterns of peak ratio and separation typical?

Spatially resolved radiative transfer models required

Summary

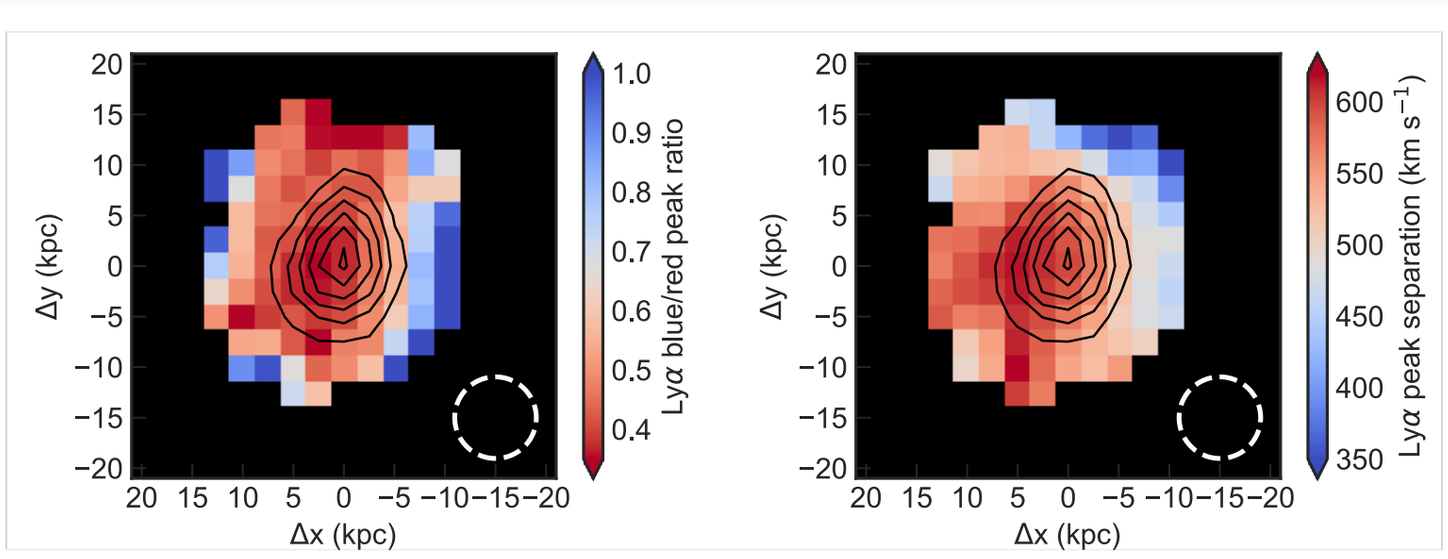
Lyα emission is a powerful tool for the characterization of the gas in and around galaxies

Reionization-era analogs are prime targets



Gravitational lensing enables the study of more extreme objects at higher spatial (and spectral) resolution

More information = more challenges!



Spatially resolved spectroscopy is the next step

More data + more models required