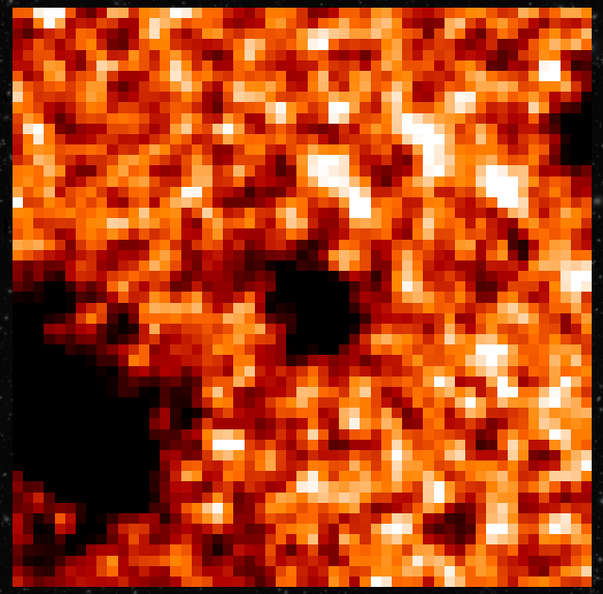
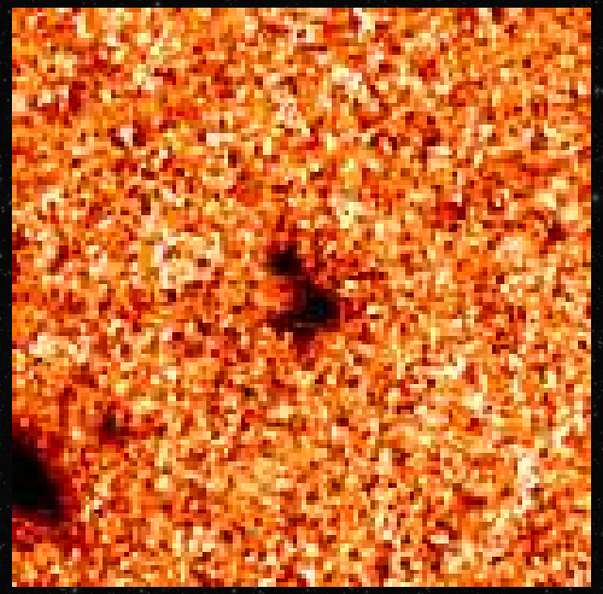
Unveiling the nature of the brightest z > 6 galaxies with multi-object spectroscopy


Rebecca Bowler
Hintze Fellow, University of Oxford
Nicholas Kurti Junior Fellow, Brasenose College

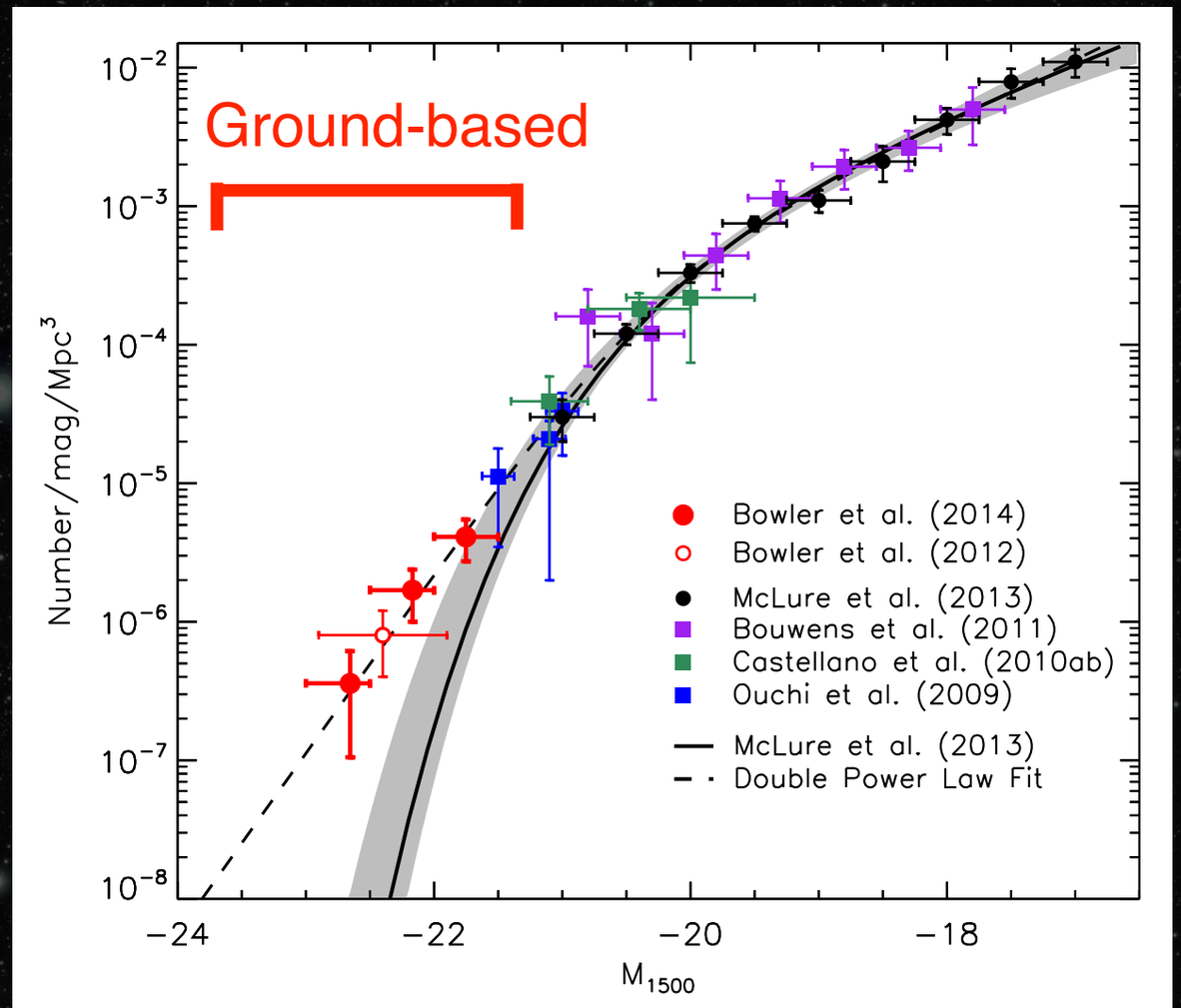
with Jim Dunlop, Ross McLure, Derek McLeod, Matt Jarvis, Elizabeth Stanway, JJ Eldridge, and the UltraVISTA and VIDEO teams

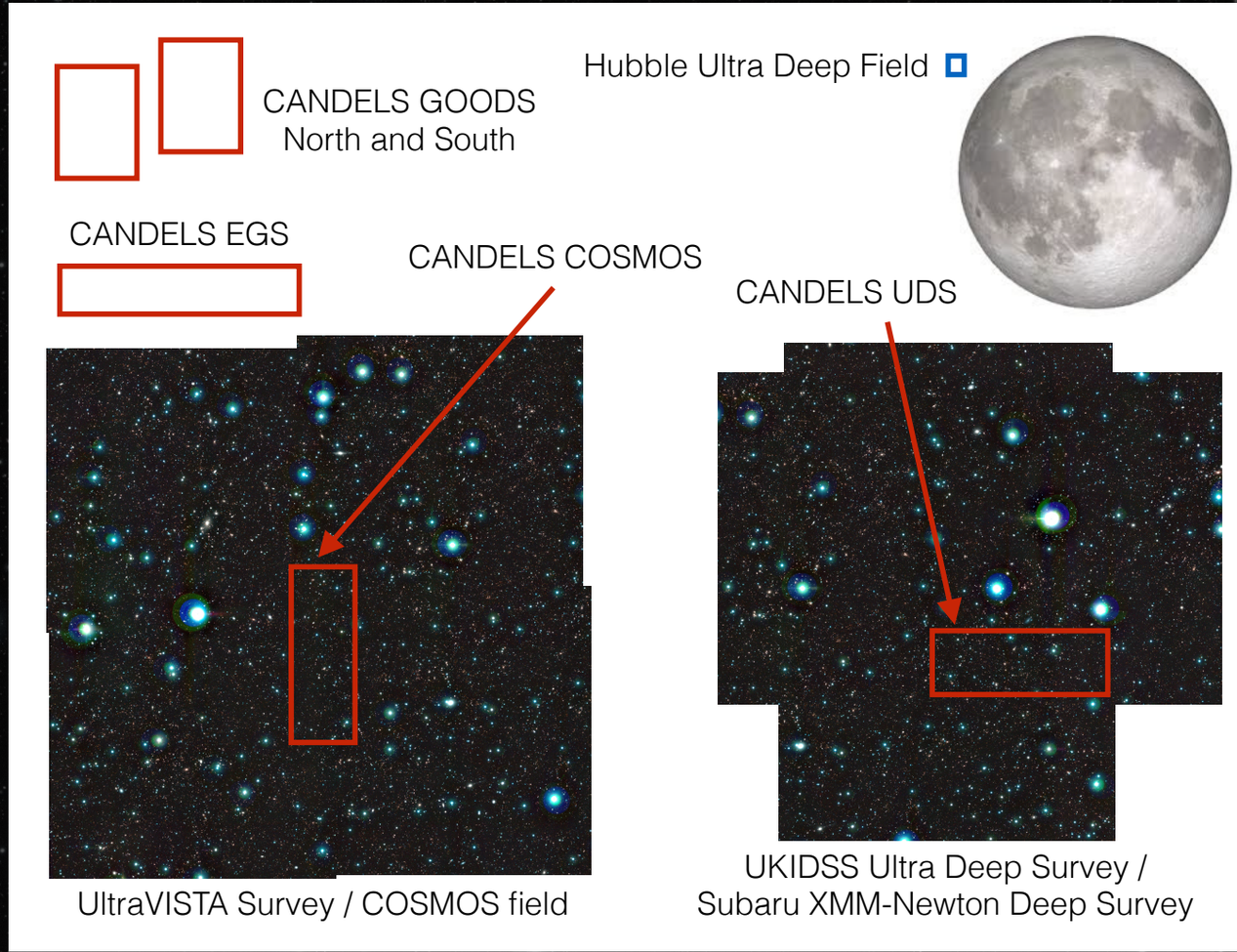
Pushing to wider areas from the ground

Lyman-break galaxies as bright as m_{AB} = 24, without lensing

~ few per sq. degree for the brightest LBGs

HST surveys
e.g. CANDELS, UDF+

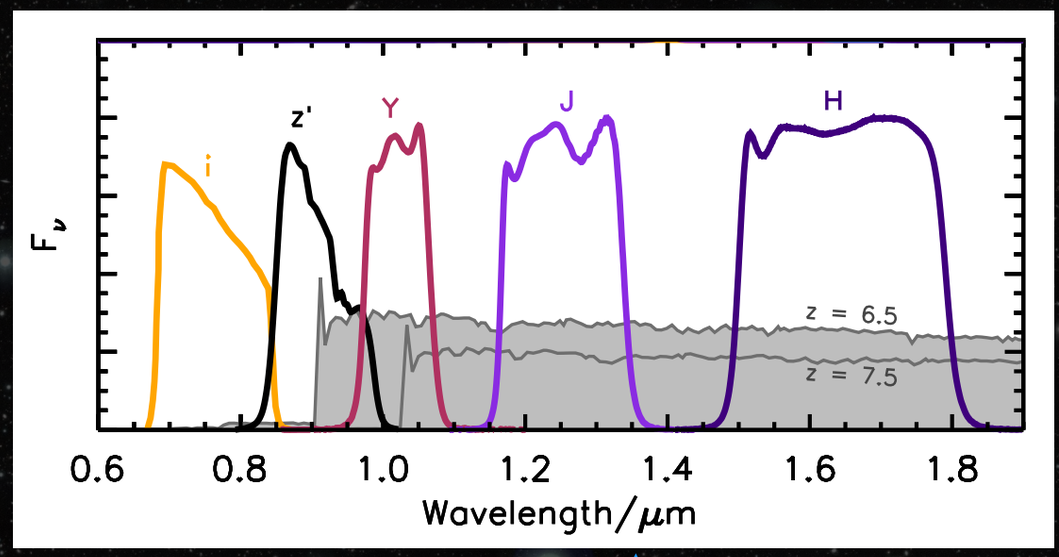


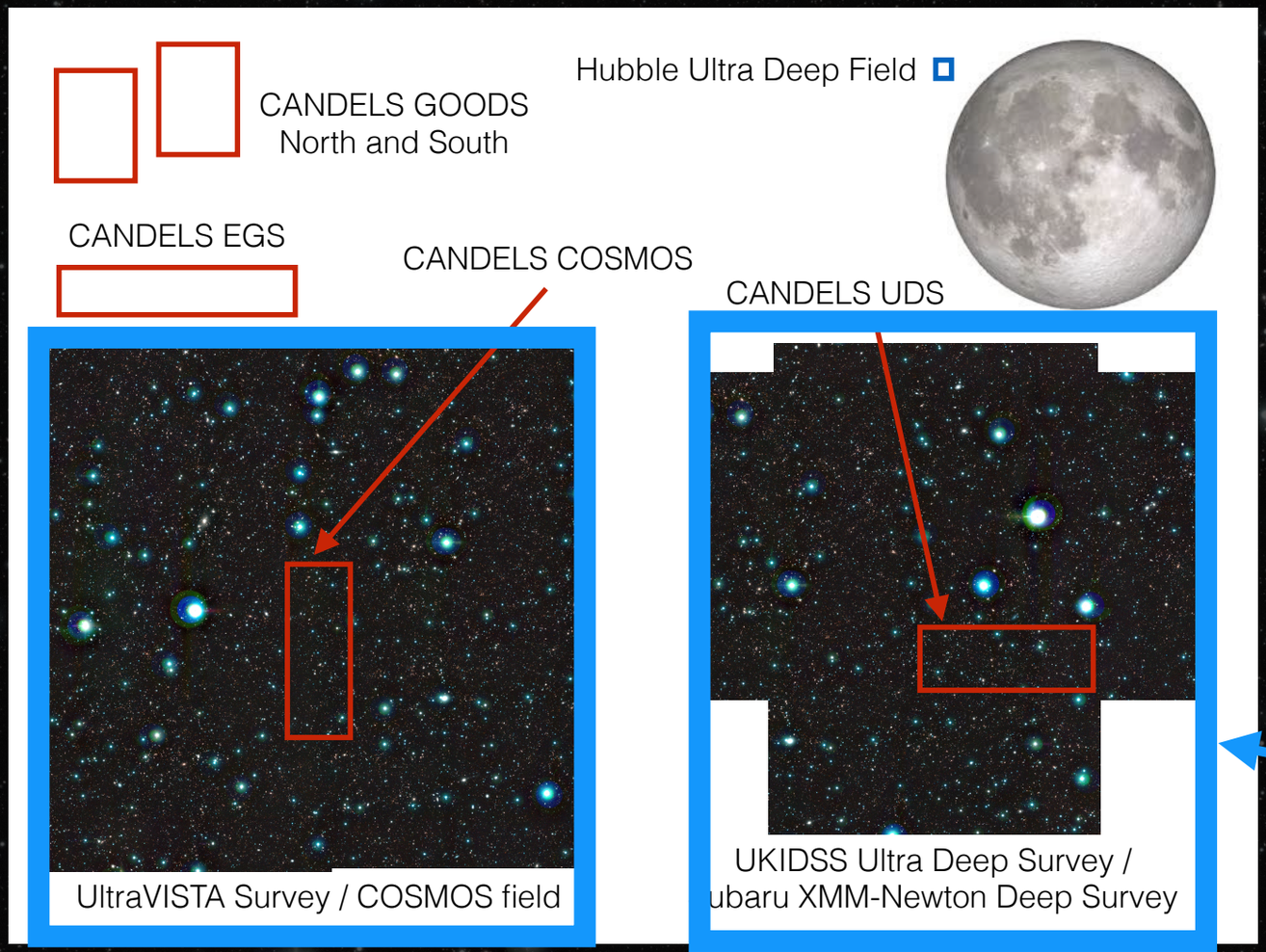


Degree-scale optical + near-IR datasets

Optical: Subaru, CFHT

NIR: UKIRT, VISTA



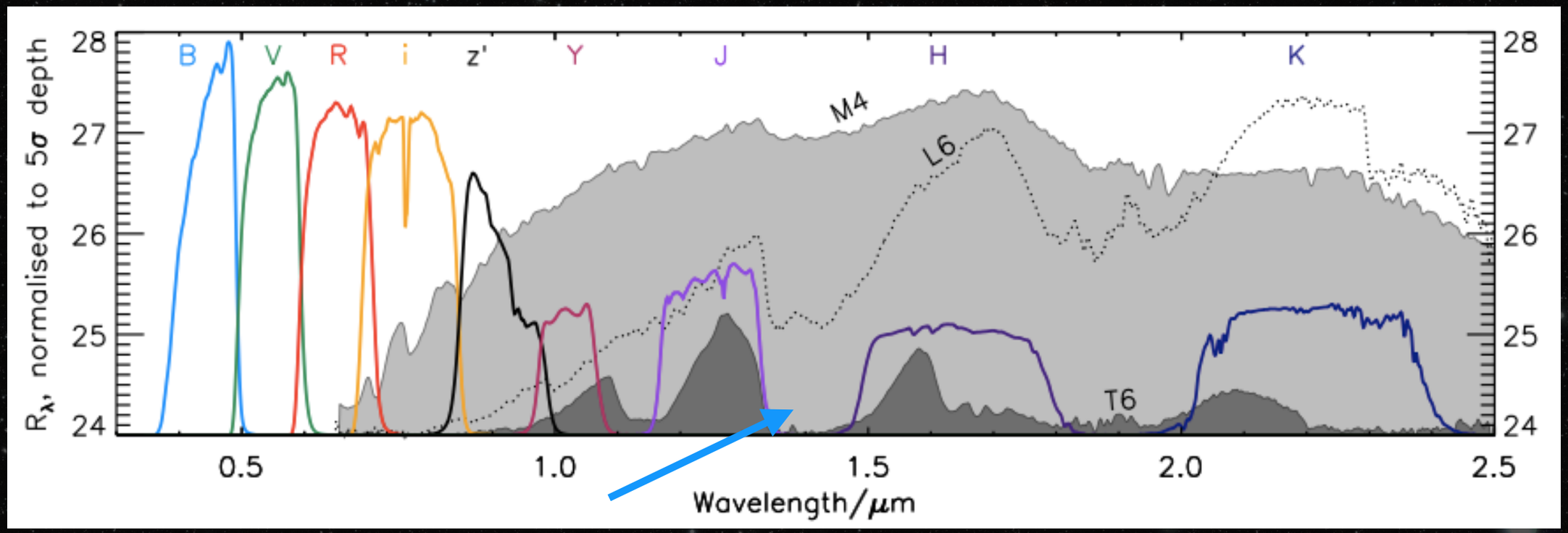


Ground-based near-infrared data from: UltraVISTA* in COSMOS, UKIDSS and VIDEO* in the UDS

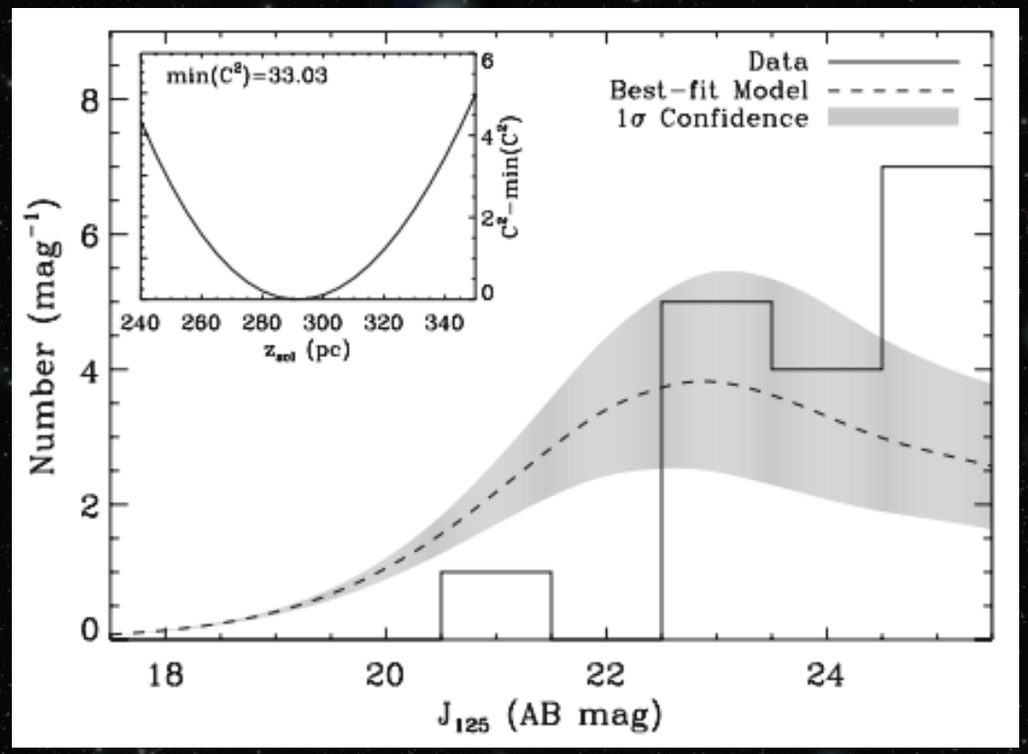
Total area = 1.7 sq. deg

*ESO Public Surveys

Contamination by cool galactic brown dwarfs



Water + methane absorption



Ryan et al. 2011 also see Bowler+15

★ Red colour of M and T dwarfs around 1 micron can mimic the Lyman-break

★ Need to measure both a strong break and blue colours into the observed NIR for clean selection at z = 6, 7 and 8

★ e.g. at z = 7 having z, Y and J is essential

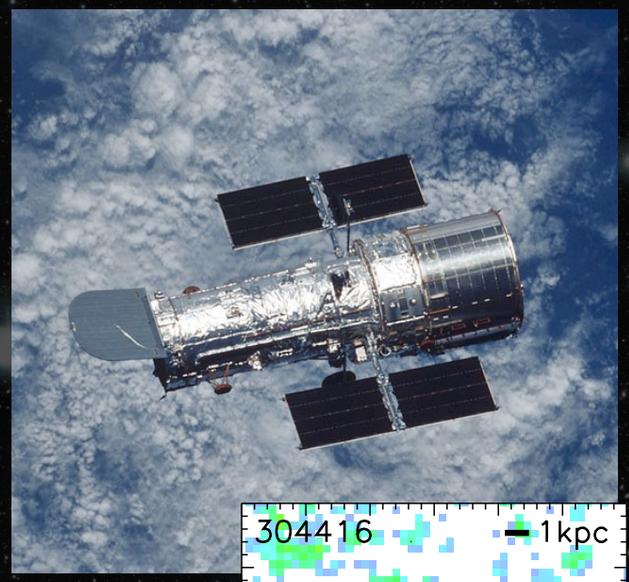
Follow-up imaging and spectroscopy possible now

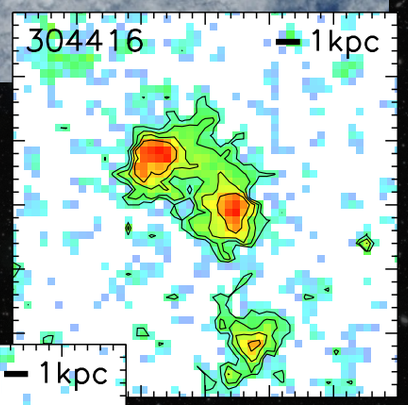
These samples, and others from HSC, narrow-band searches and CANDELS include the **brightest** known z ~ 7 galaxies, which are natural targets for detailed follow-up.

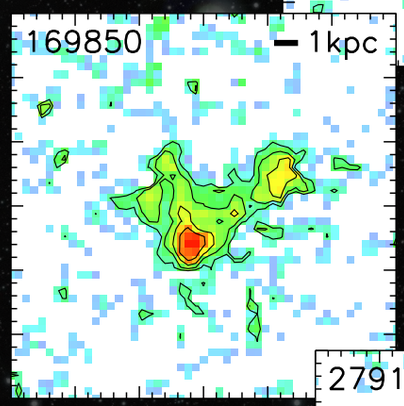
Surface densities of

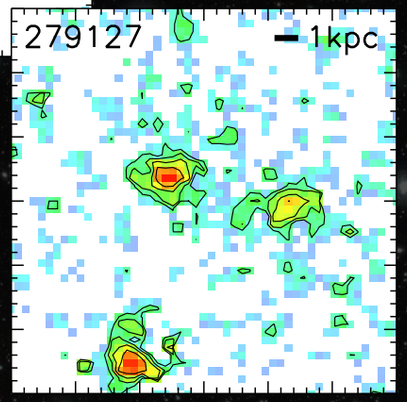
- hundreds per deg^2 at z = 6 to z = 26.0
- tens per deg^2 at z = 7 to Y = 25.5
- ideal targets for upcoming degree-scale MOS!

Follow-up imaging and spectroscopy possible now









WFC3
F140W

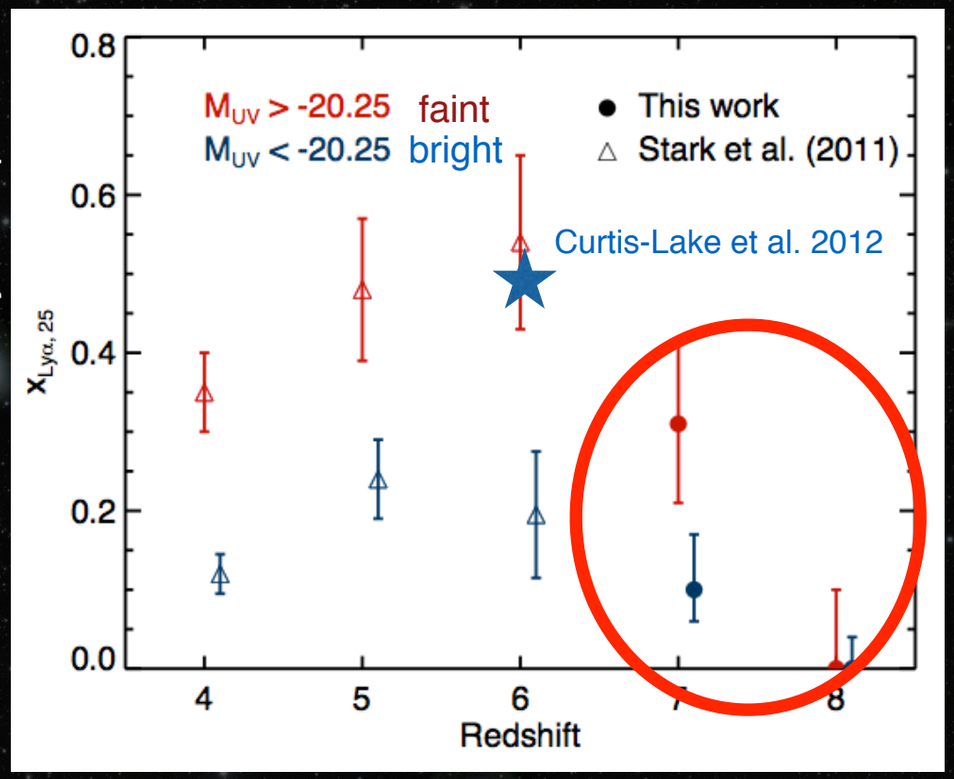
Bowler et al. 2017a

Dust continuum with ALMA

3”/16kpc

Rest-frame UV
spectroscopy

Detecting rest-UV emission lines: Lyman-α

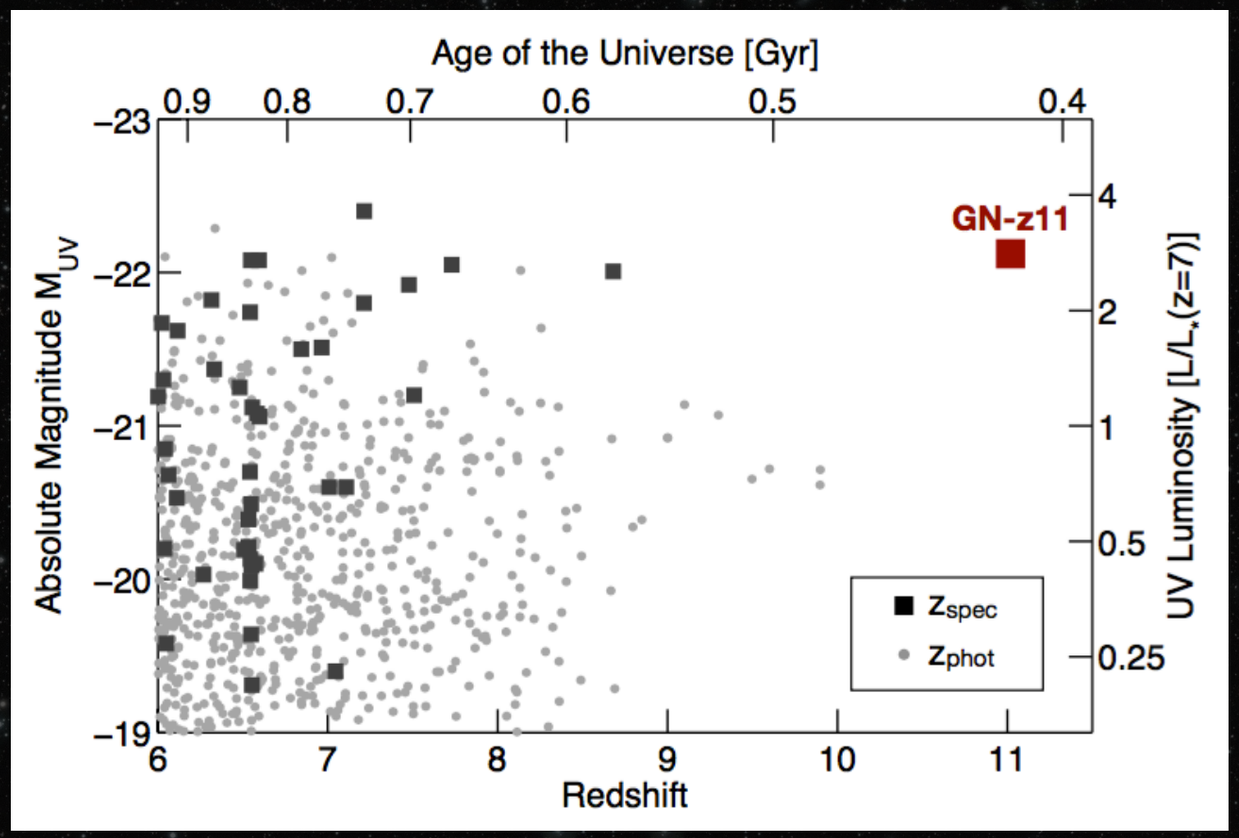


Schenker et al. 2014

A wider area/shallower observational strategy for Lyman-α may be optimal e.g. as allowed by MOS

e.g Unexpected detections in bright LBGs:

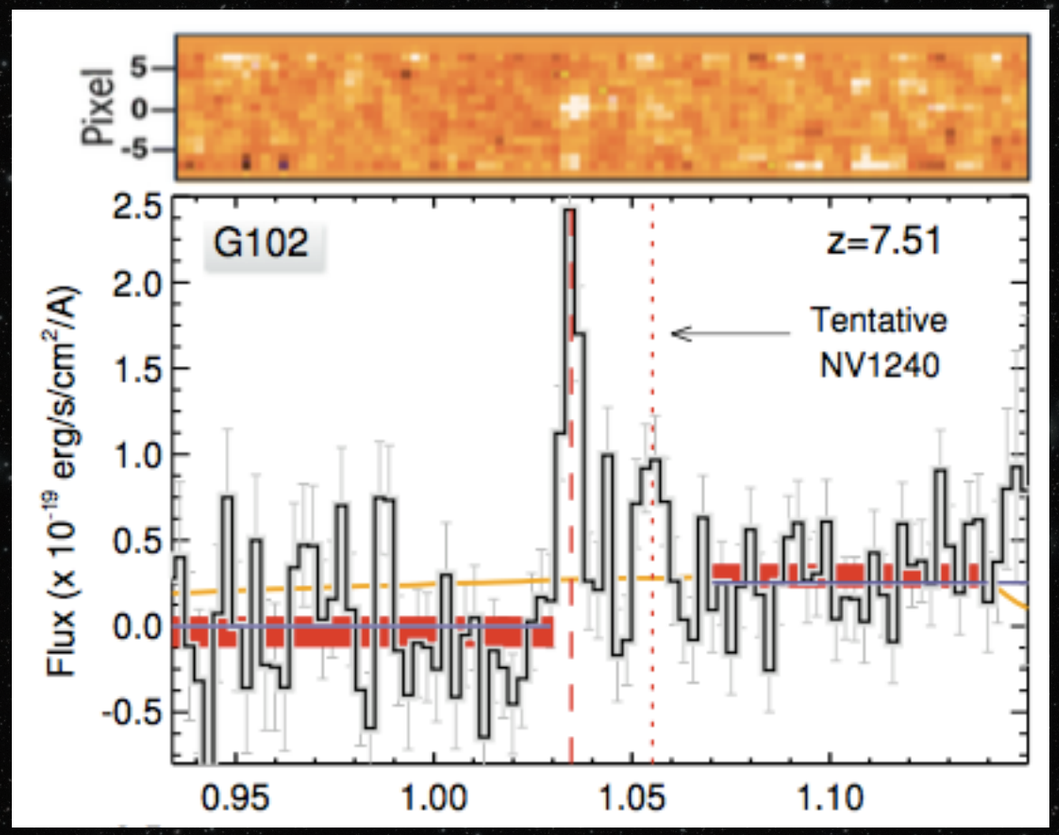
★ EGS-zs8-1 @ z = 7.73 (Oesch+15, Stark+17)
★ EGS8p7 @ z = 8.68 (Zitrin+15)
★ H band magnitudes of 25.0-26.0
★ Strong IRAC colours
★ Probing the most ionised regions into the EoR?



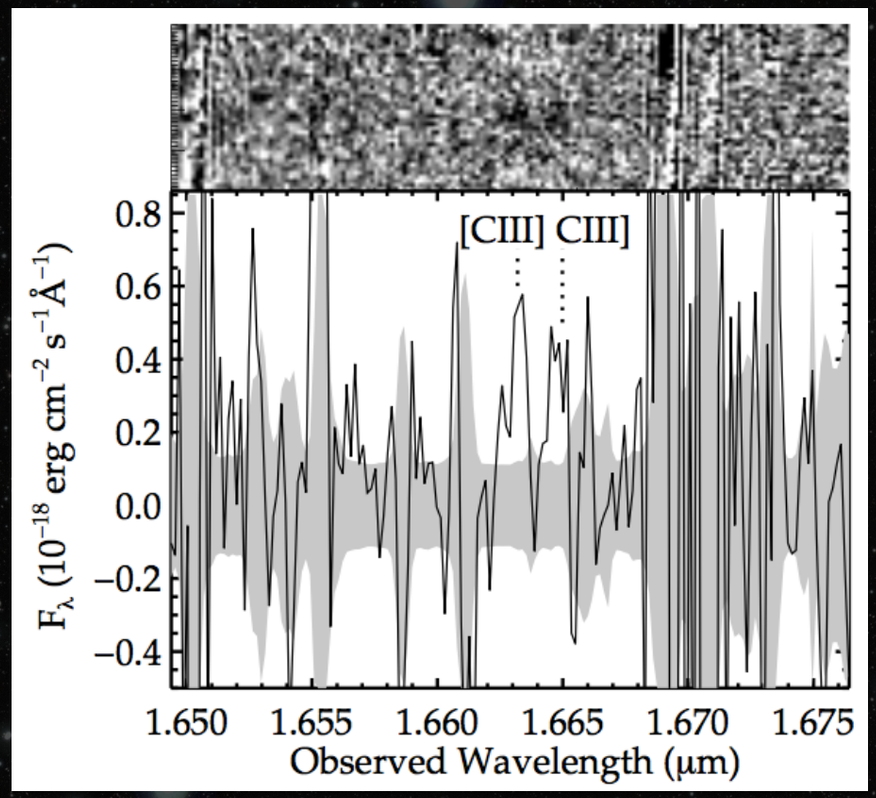
Oesch+16 also Stark+16, Roberts-Borsani+16, Zitrin+16

Detecting rest-UV emission lines: other species

	z	Species	Refs.
COS-zs7-1	7.15	NV, HeII 1640	Laporte+17, Stark+17
FIGS_GN1_1291	**7.51**	**NV**	**Tilvi+16**
EGS-zs8-1	7.73	[CIII], CIII] 1907	Stark+17, Roberts-Borsani+16
CR7	6.6	He II	Sobral+15 [see also Shibuya+17]
……			



Tilvi et al. 2016



Stark et al. 2017, also Stark et al. 15, 16

Detecting rest-UV emission lines: other species

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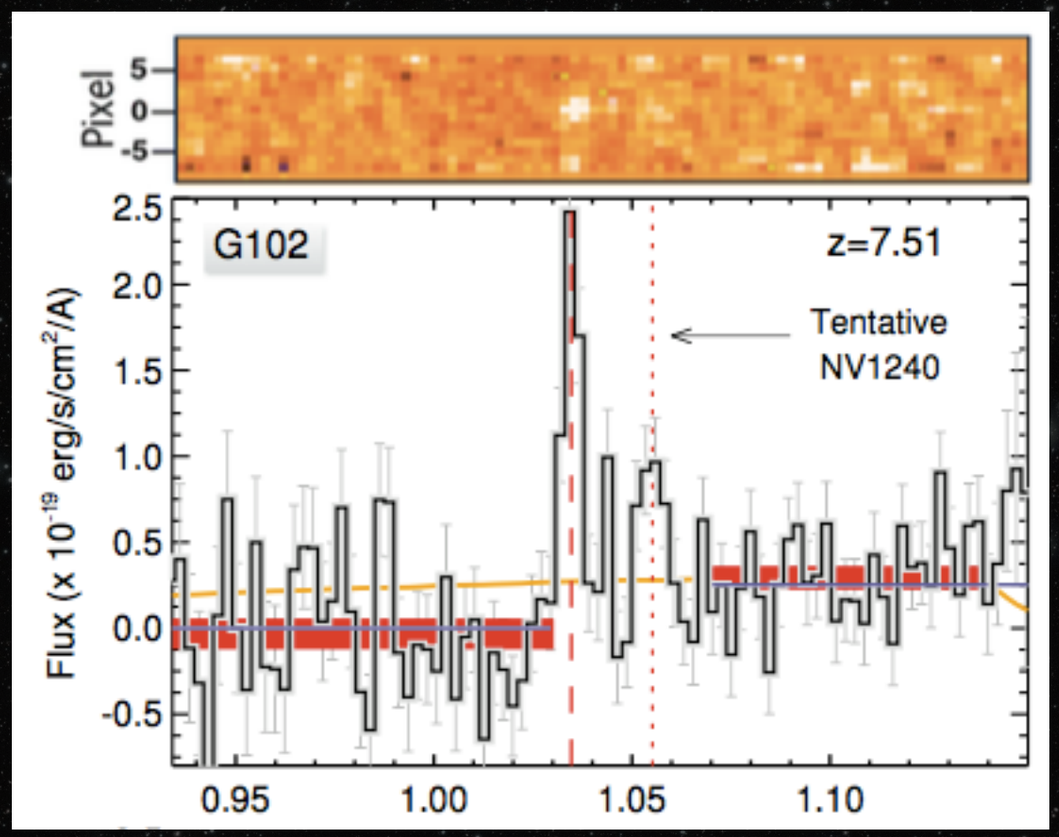
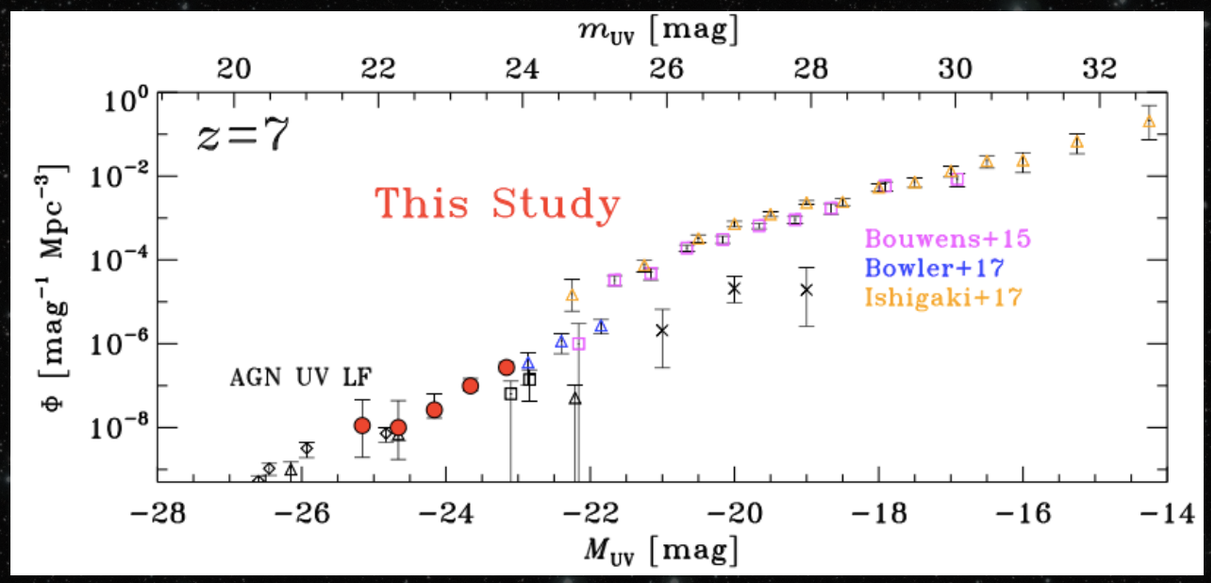


Tilvi et al. 2016

★ Starting to overlap with the faint-end of the AGN luminosity function?

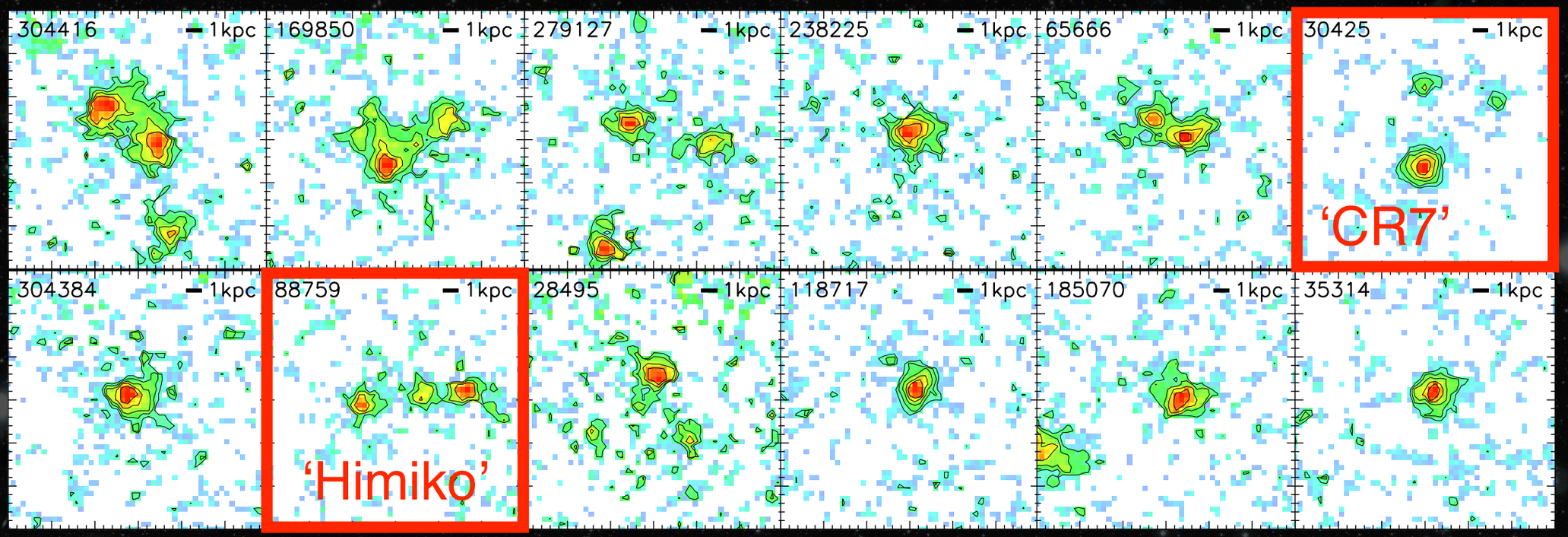


Ono et al. 2016

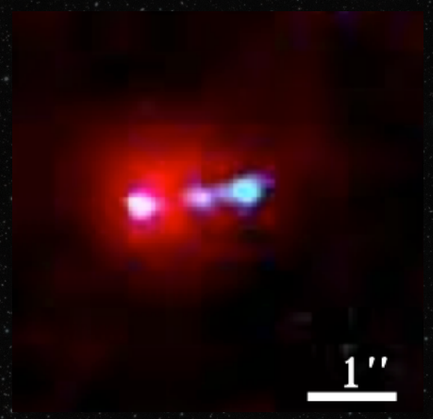
The connection between LBGs and extreme LAEs

★ Extreme narrow-band emitters are also selected as Lyman-break galaxies
★ Similar UV continuum magnitudes and clumpy morphology
★ Are there more of these extreme emitters in broad-band samples at high-z?

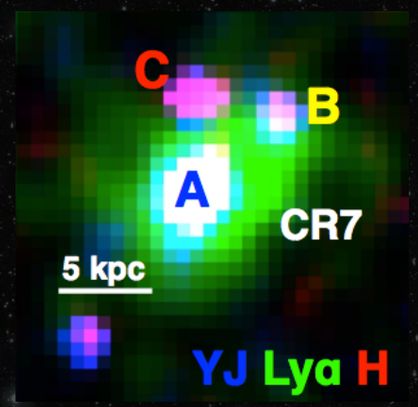
Muv = -23.0



Muv = -21.5

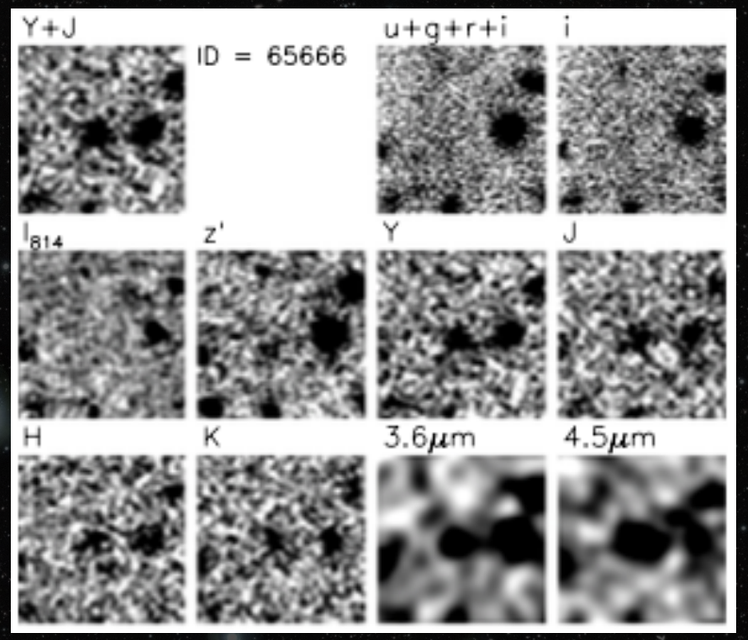


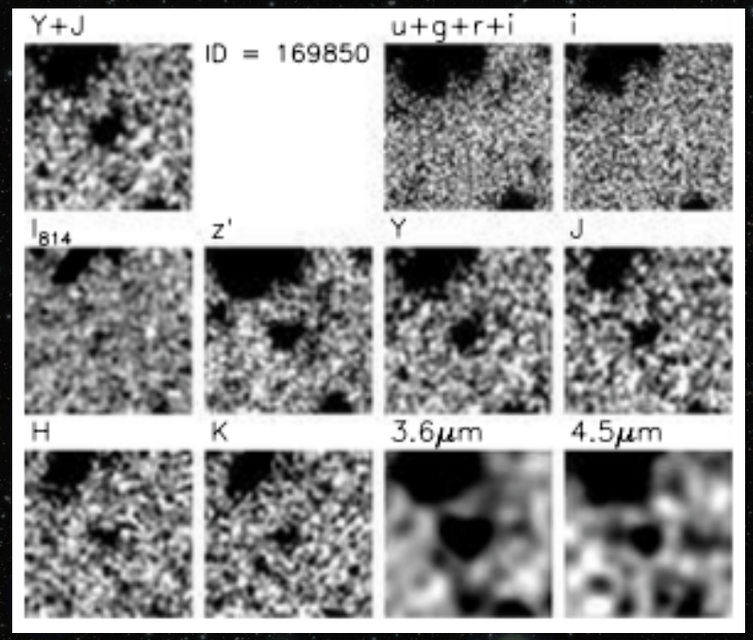
Ouchi et al. 2009, 2013



Sobral et al. 2015

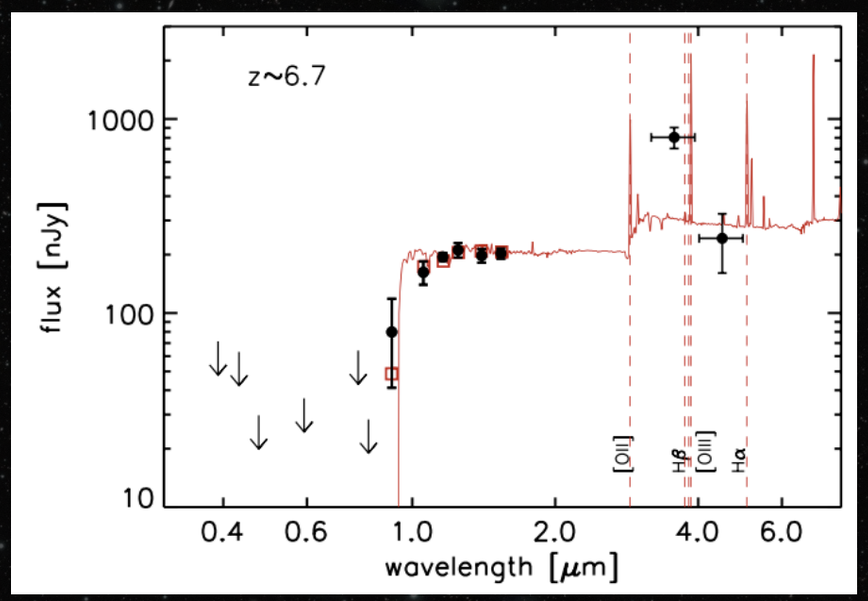
Rest-frame optical emission as probed by Spitzer/IRAC

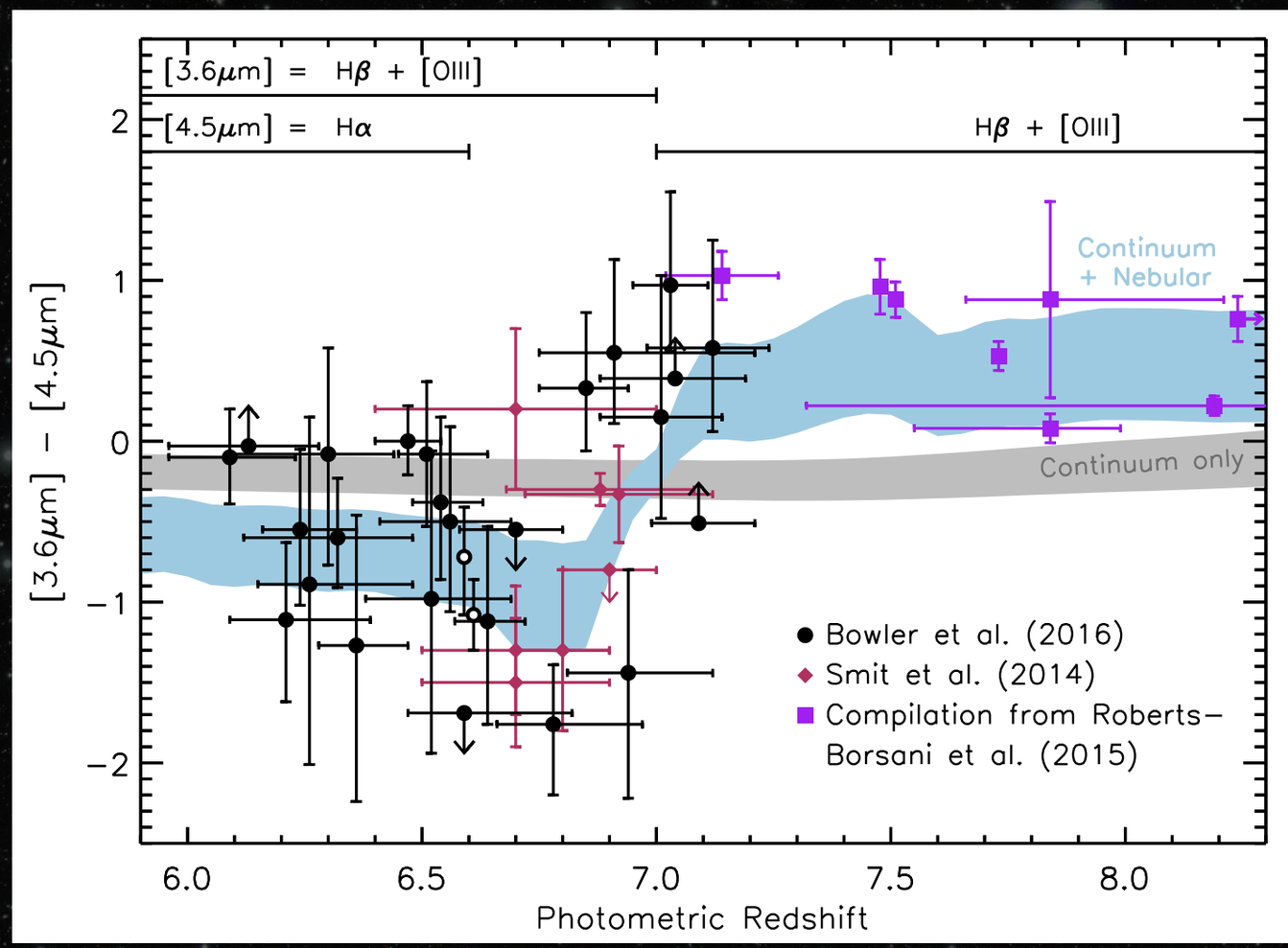




Evidence that strong rest-optical lines may be common in both faint and bright UV selected galaxies at high-z

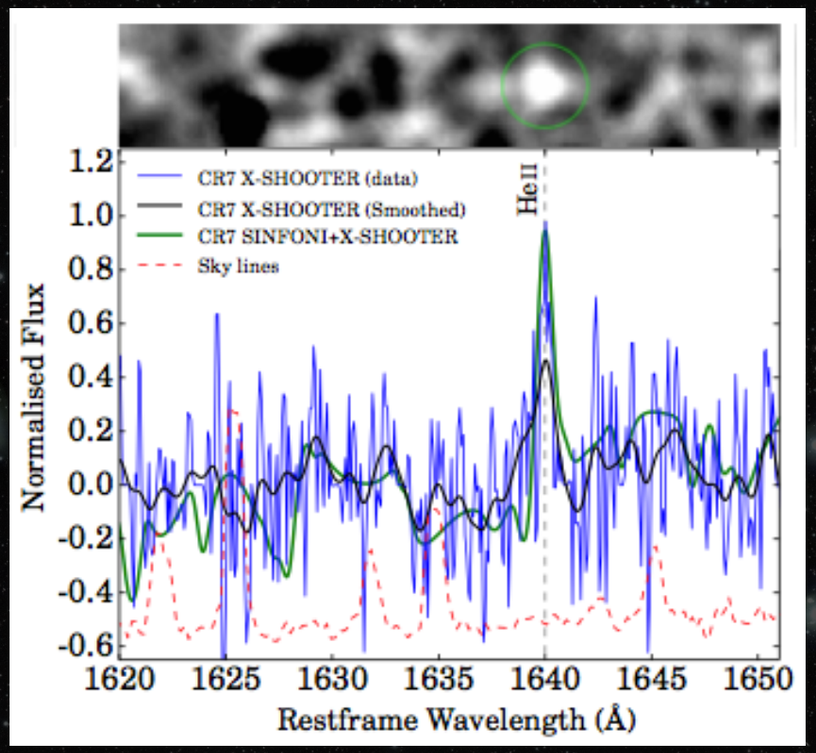
Smit et al. 2014





Pop III/DCBH signatures in CR7 @ z = 6.6?

[Direct collapse black hole]

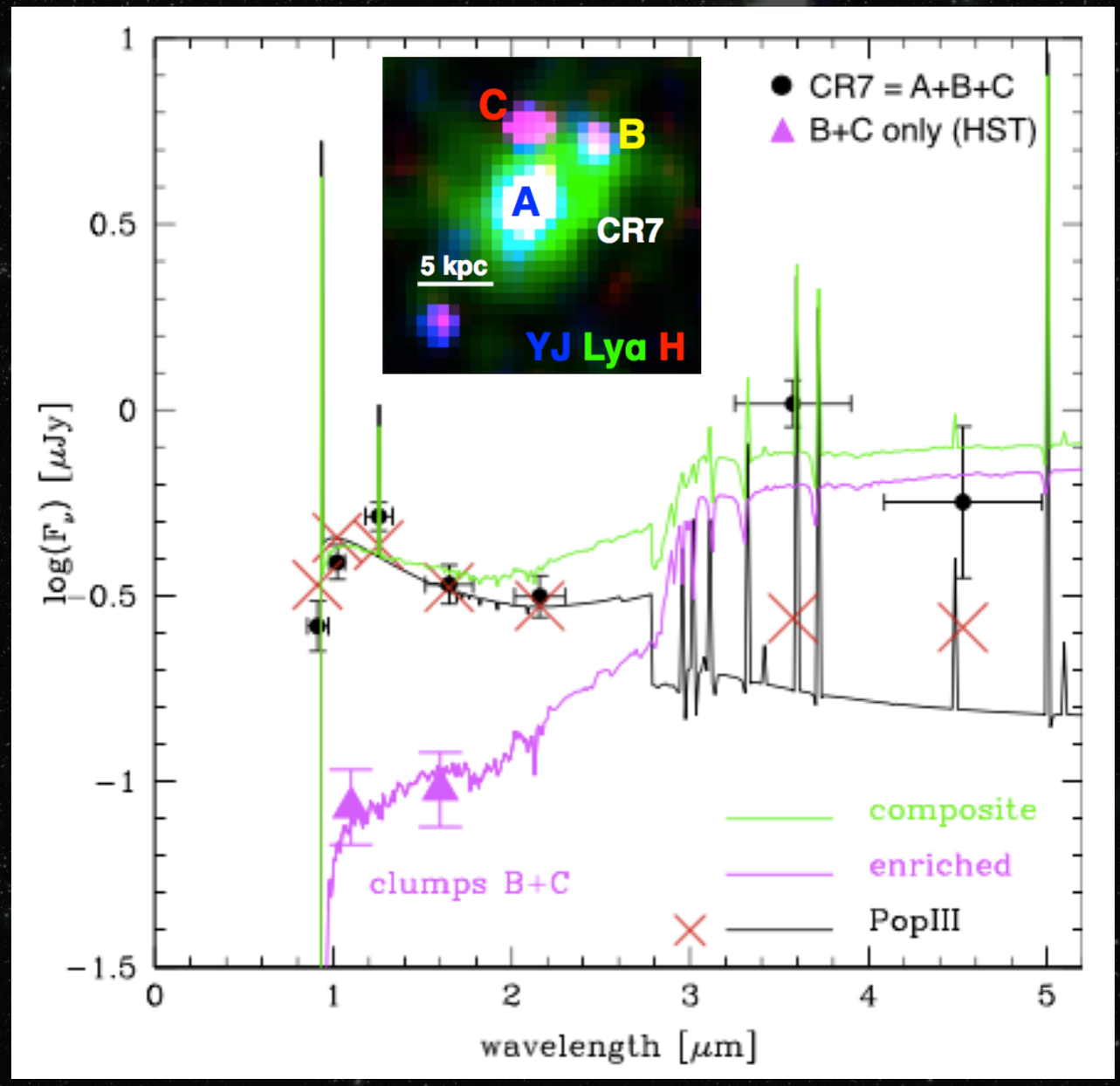


★ CR7 is extreme LAE @ z = 6.6 in COSMOS

★ He II 1640 line observed EW0 = 80±20A

★ He II is strong and narrow, no metal lines….

Sobral et al. 2015



…

➡ Pop III ?

➡ DCBH ?

➡ other ?

Sobral et al. 2015

Visbal et al. 2016

Pallottini et al. 2015

Hartwig et al. 2015

Agarwal et al. 2016

Smidt et al. 2016

Smith et al. 2016

Dijkstra et al. 2016

Pacucci et al. 2017

Agarwal et al. 2017

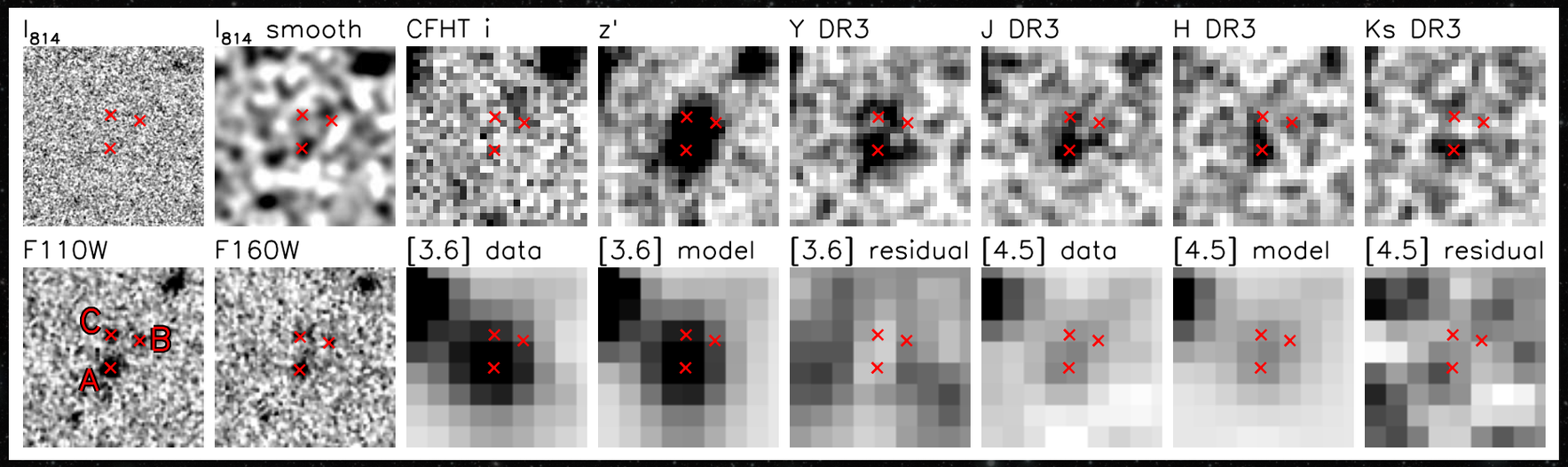
Bowler et al. 2017b → Weaker He II, evidence for [OIII]

Shibuya et al. 2017

Matthee et al. today → No He II?

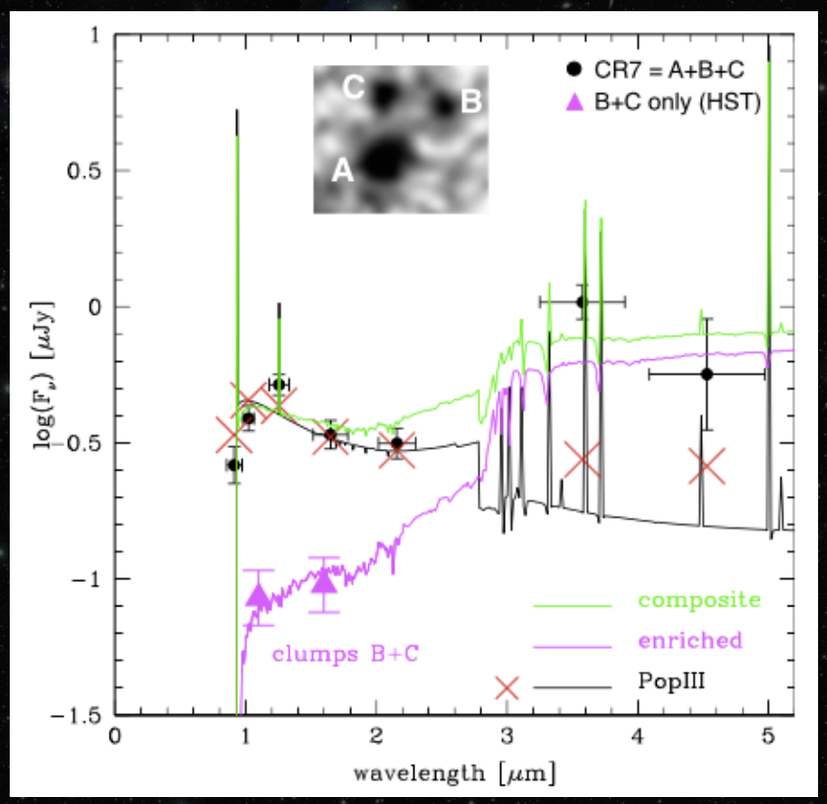
C+

A closer look at the photometric data for CR7



★ UltraVISTA DR3 + deconfused Spitzer SPLASH data

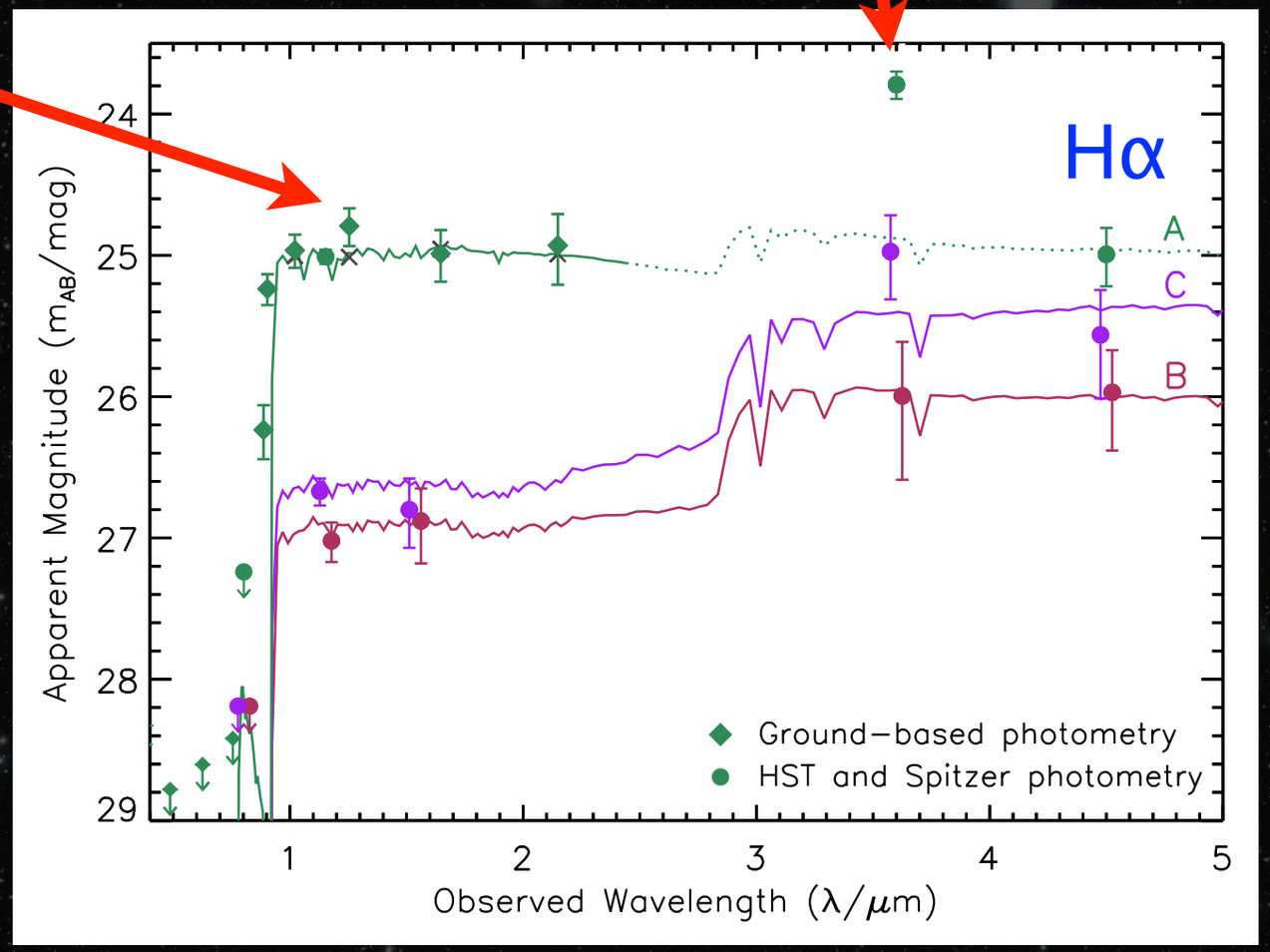
Lower HeII EW = 40±30A



Sobral et al. 2015

Hβ

[OIII] 4959, 5007

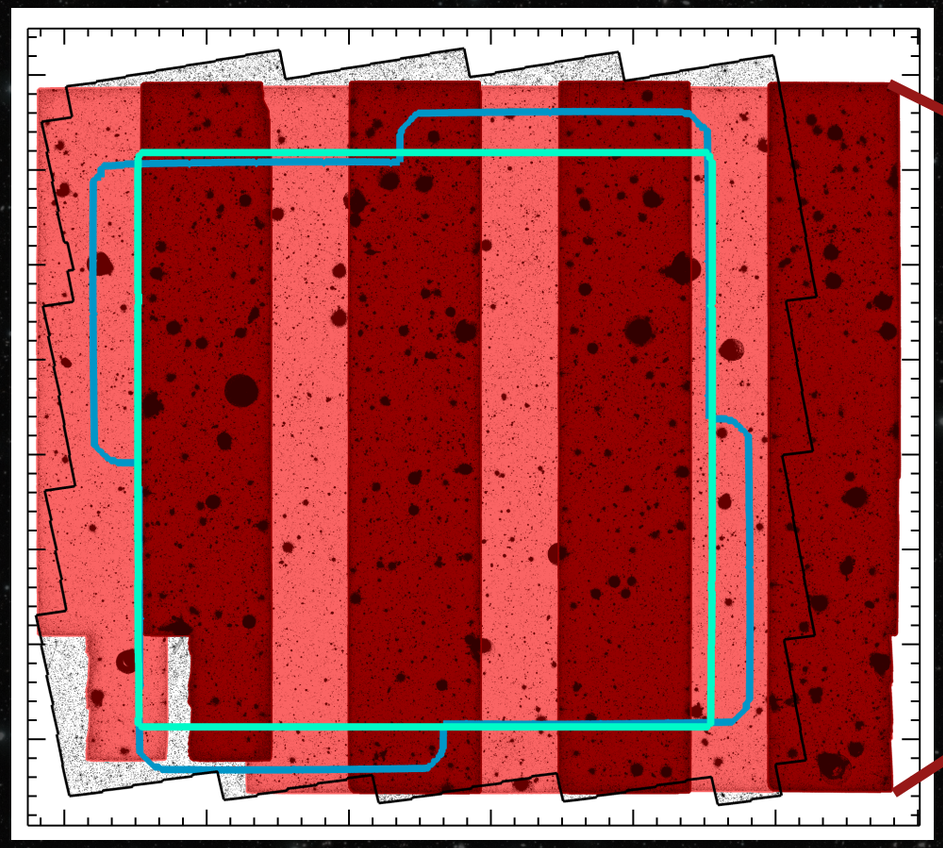


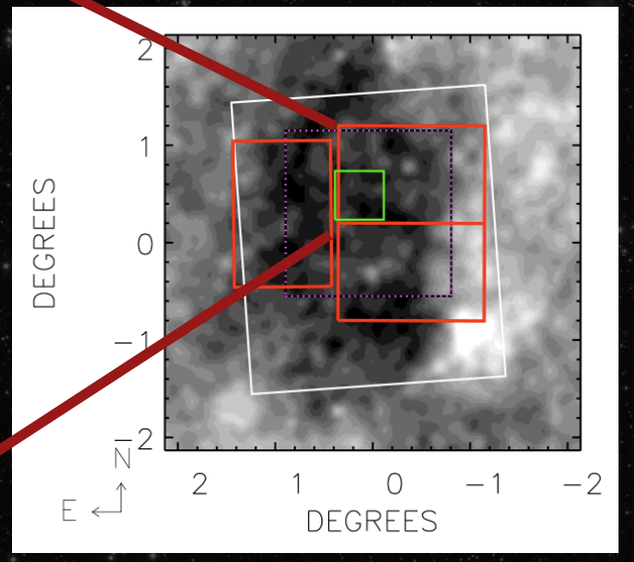
Bowler et al. 2017b

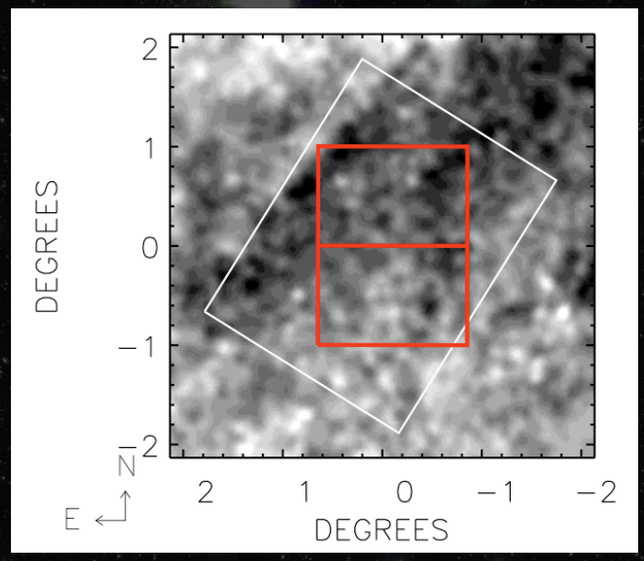
Upcoming wide and deep near-infrared surveys

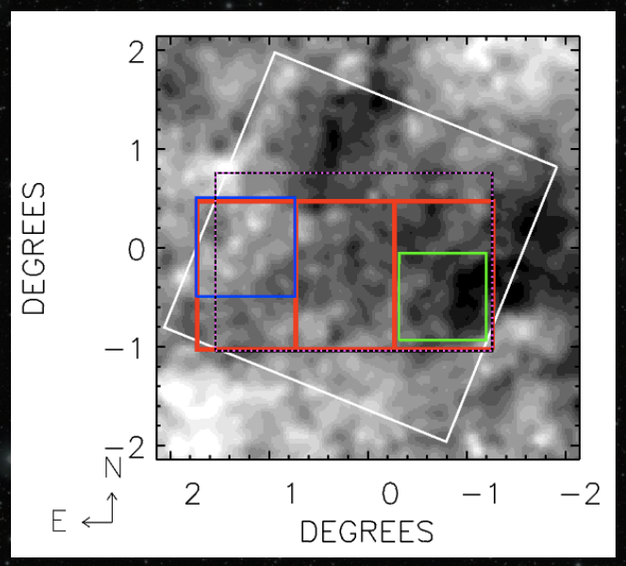
★ UltraVISTA
Extension will fill in ‘gaps’ to provide complete 1.5 deg^2 to 25-26 JHKs (y from HSC)

★ VIDEO -> VEILS
CDFS, Elias-S1, XMM-LSS
12 deg^2 to ~ 23.5-24.5 YJHKs
Extension will double area







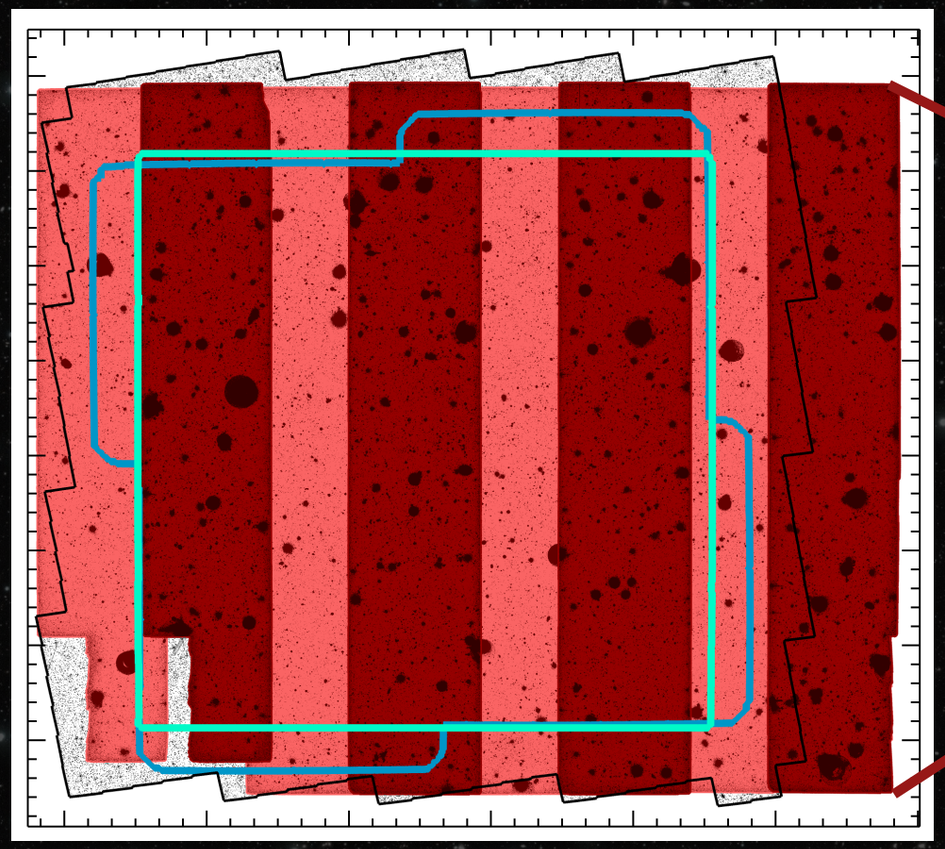


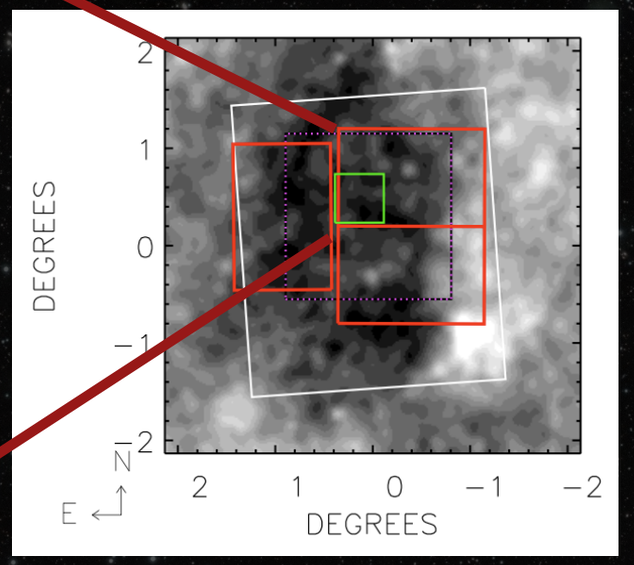
★ Euclid - 40 deg^2 in deep fields should detect >3000 LBGs @ z ~ 7 (and ~ 1000 in wide fields)

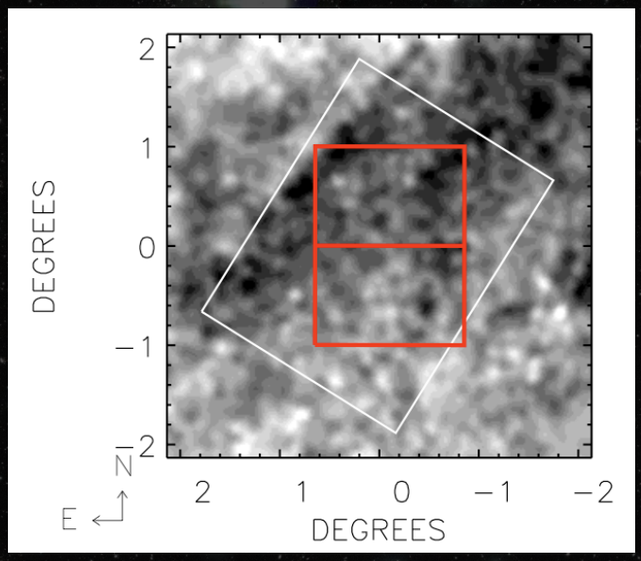
Multi-object spectroscopy for bright LBGs

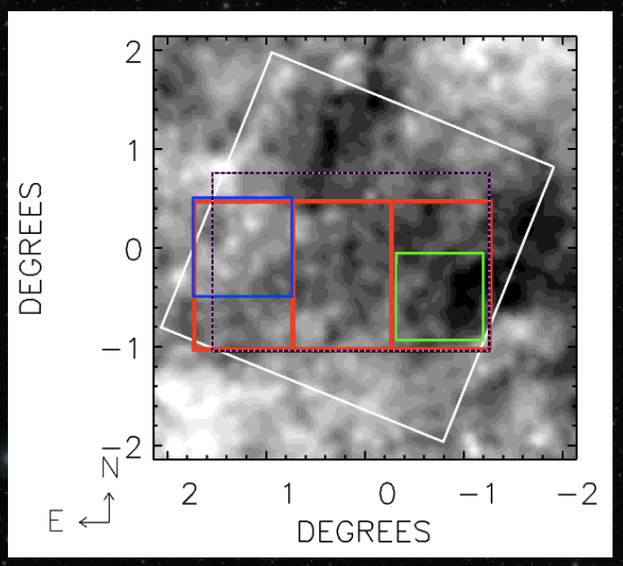
- ➡ VLT/MOONS [0.14 deg²]
- ➡ Subaru/PSF [1.4 deg²]
- ➡ VISTA/4MOST [4 deg²]

Surface densities of
- hundreds per deg² at z = 6 to z = 26.0
- tens per deg² at z = 7 to Y = 25.5
- ideal targets for upcoming degree-scale MOS!









★ Euclid - 40 deg² in deep fields should detect >3000 LBGs @ z ~ 7 (and ~ 1000 in wide fields)

Summary

➡ Bright z > 6 galaxies from ground-based data are fantastic sources to study with follow-up HST, ALMA, VLT, JWST…… and degree-scale MOS facilities!

These bright galaxies have:

➡ Strong rest-optical emission lines as hinted at by Spitzer

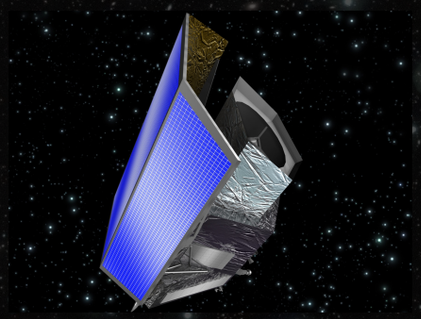
➡ Similar continuum properties/morphologies to extreme Lyman-emitters

➡ Signatures of AGN and/or low-Z stellar populations with massive binaries

MOS will transform the study of these galaxies from tens to thousands

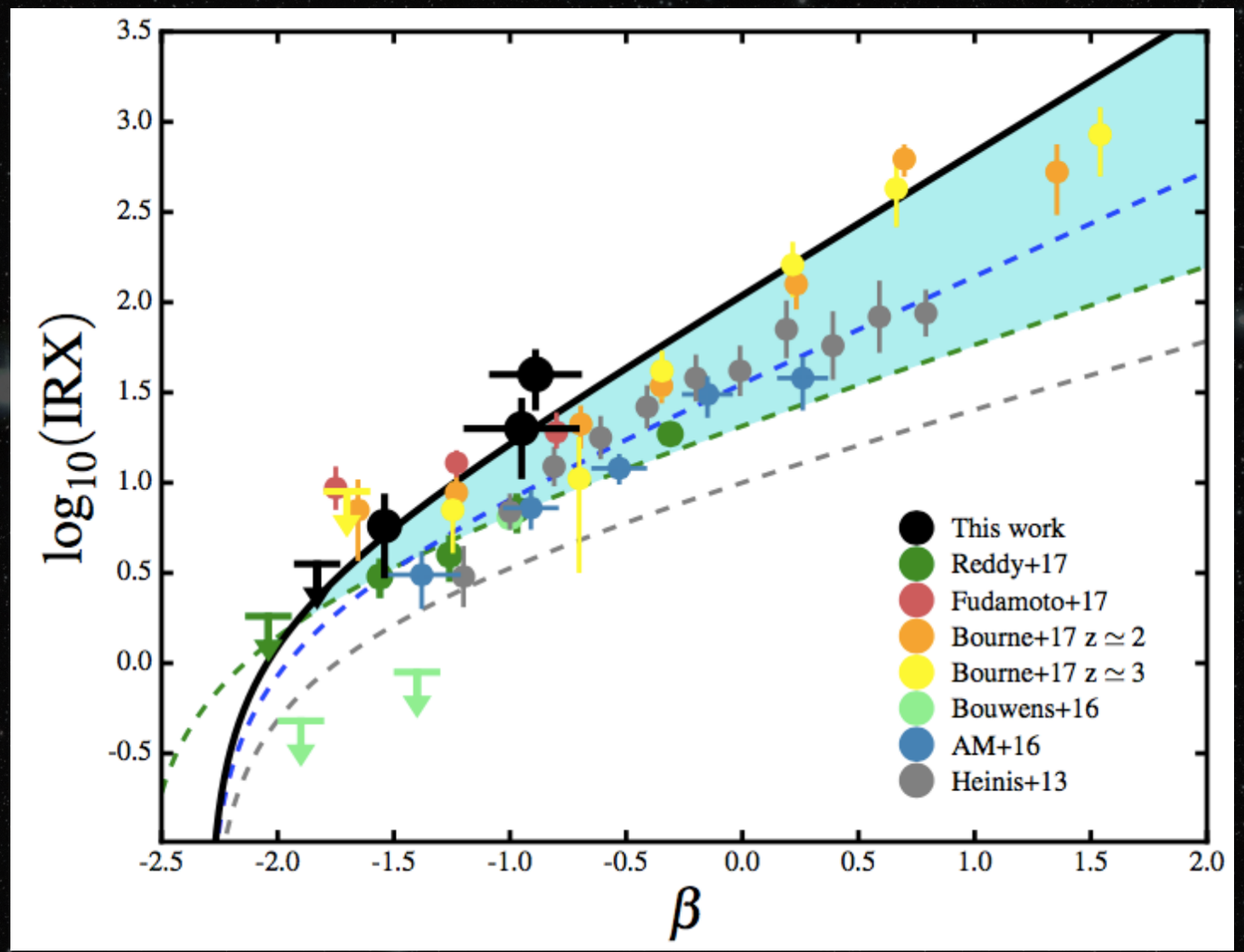




★ Euclid + LSST/DES/HSC will detect > 3000 similarly bright LBGs at z = 7

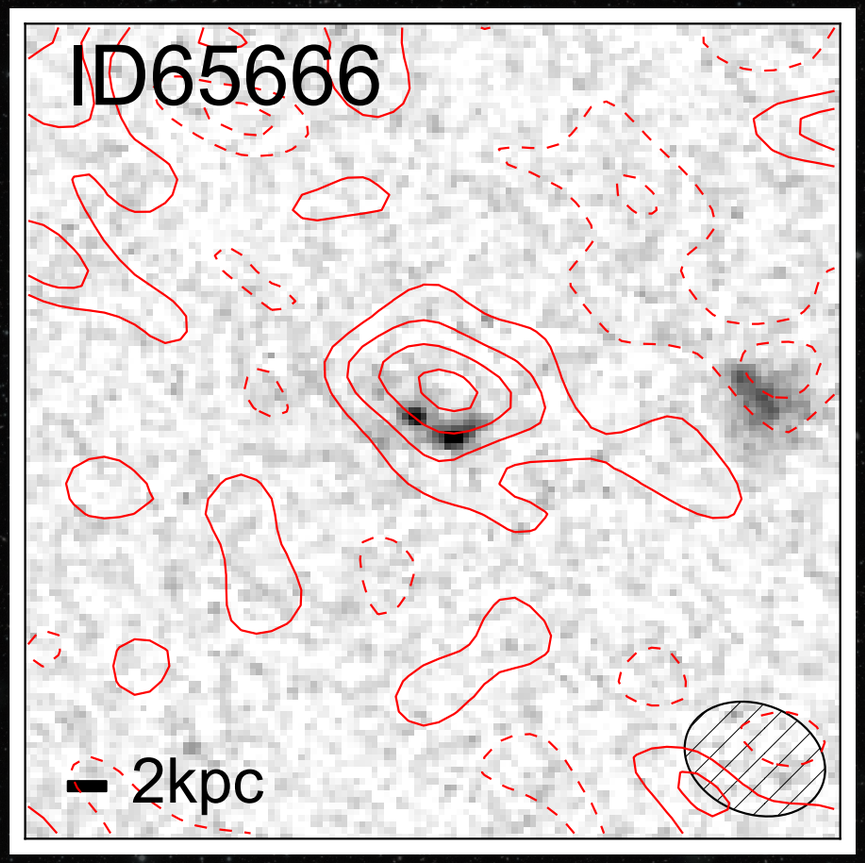
Dust continuum emission in bright z = 7 LBGs



McLure et al. 2017

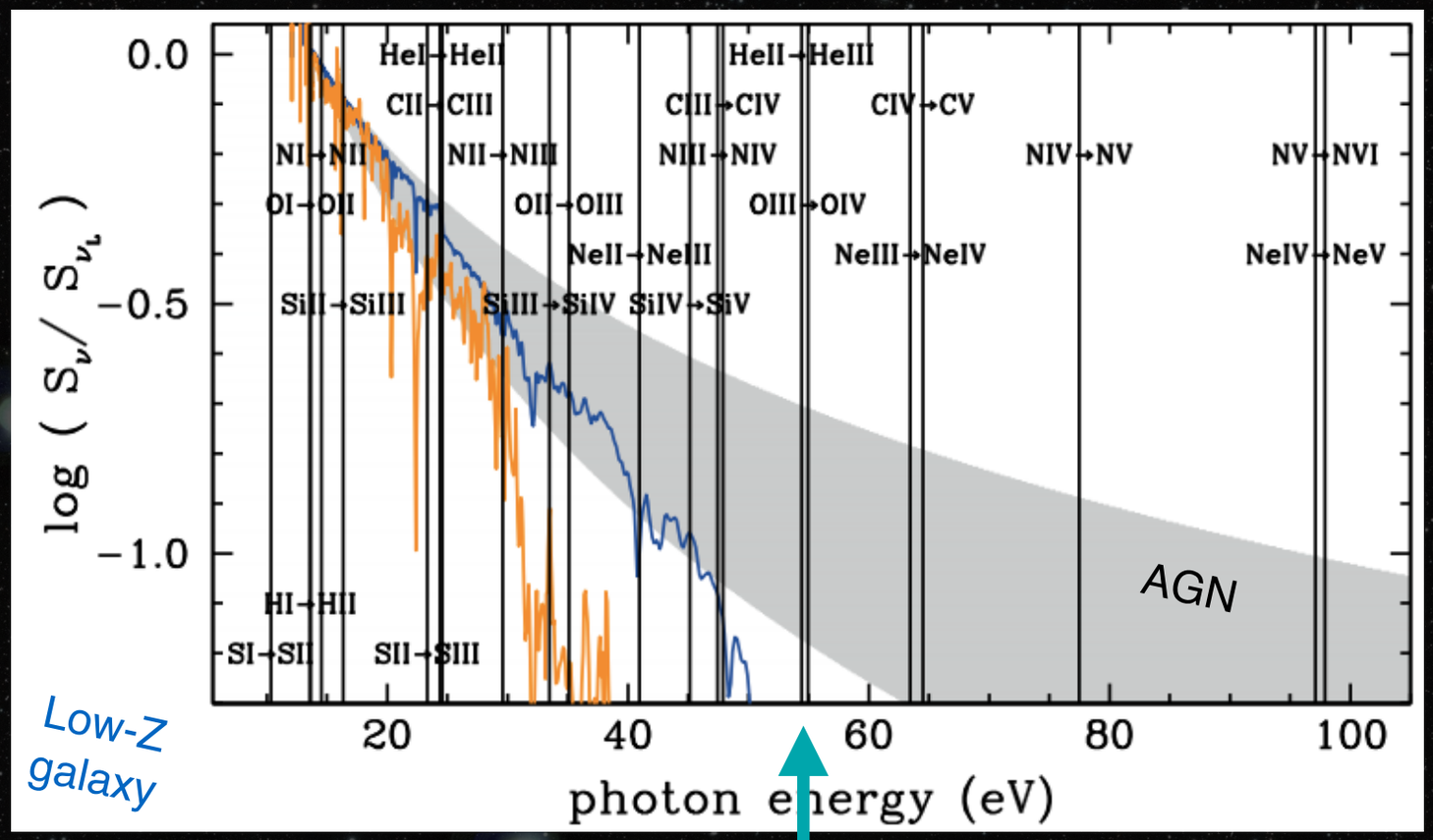
- ★ Spatial offsets between dust and UV
- ★ Also seen at lower redshifts (Koprowski+15, Casey+14)
- ★ Cause of scatter in IRX-beta?
- ★ ALMA - GMT synergies

- ★ How you bin matters for IRX-beta
- ★ Upcoming results from McLure+17 show z ~ 2 LBGs are consistent with local starburst relation if you bin by stellar mass (not beta).



Bowler et al. in prep.

Possible origins of He II 1640 in high-redshift objects



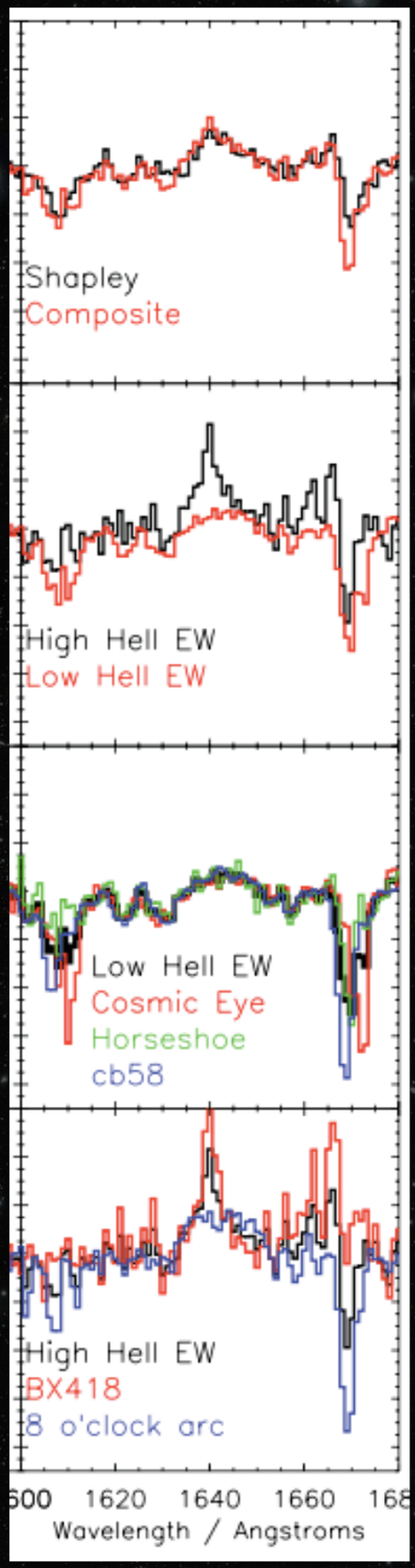
Feltre et al. 2016

(2) WR

- ★ Wolf-Rayet stars produce He II
- ★ Typically 2-3A
- ★ Broad line

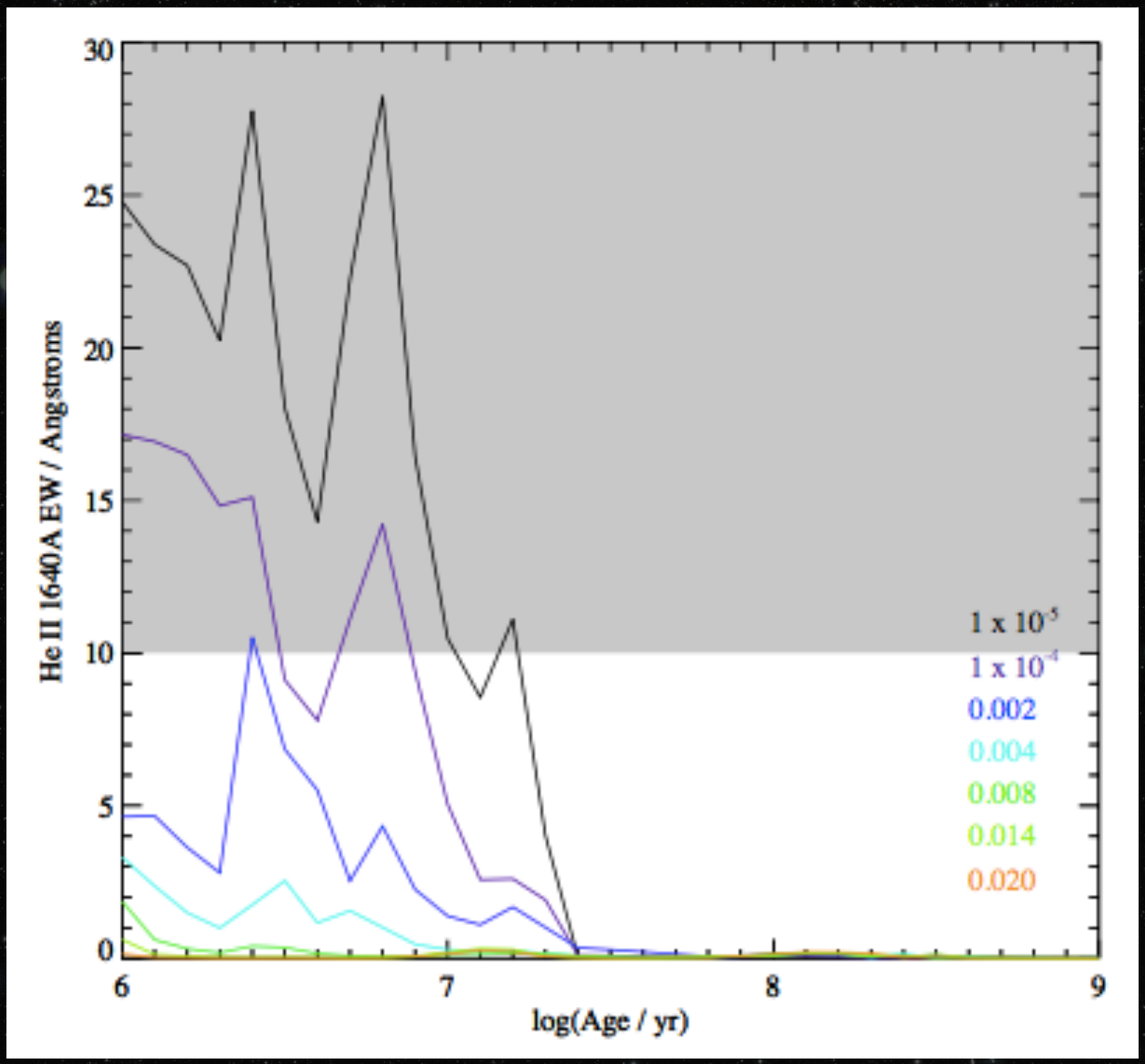
(1) AGN

- ★ The He II 1640A recombination line requires a hard ionizing spectrum
- ★ Typically associated with quasars, not galaxies
- ★ but quasar line strength is typically EW0 ~ 20A not 80A
- ★ usually have broader lines



Eldridge & Stanway et al. 2012

How to reproduce a strong and narrow He II 1640 line?



Bowler et al. 2017b

➡ Binary stars!

Binary populations and stellar synthesis models (BPASS) v2.0

Include binary stellar pathways, rotation and quasi-homogenous evolution

Produce sufficient ionizing flux for ~10Myrs

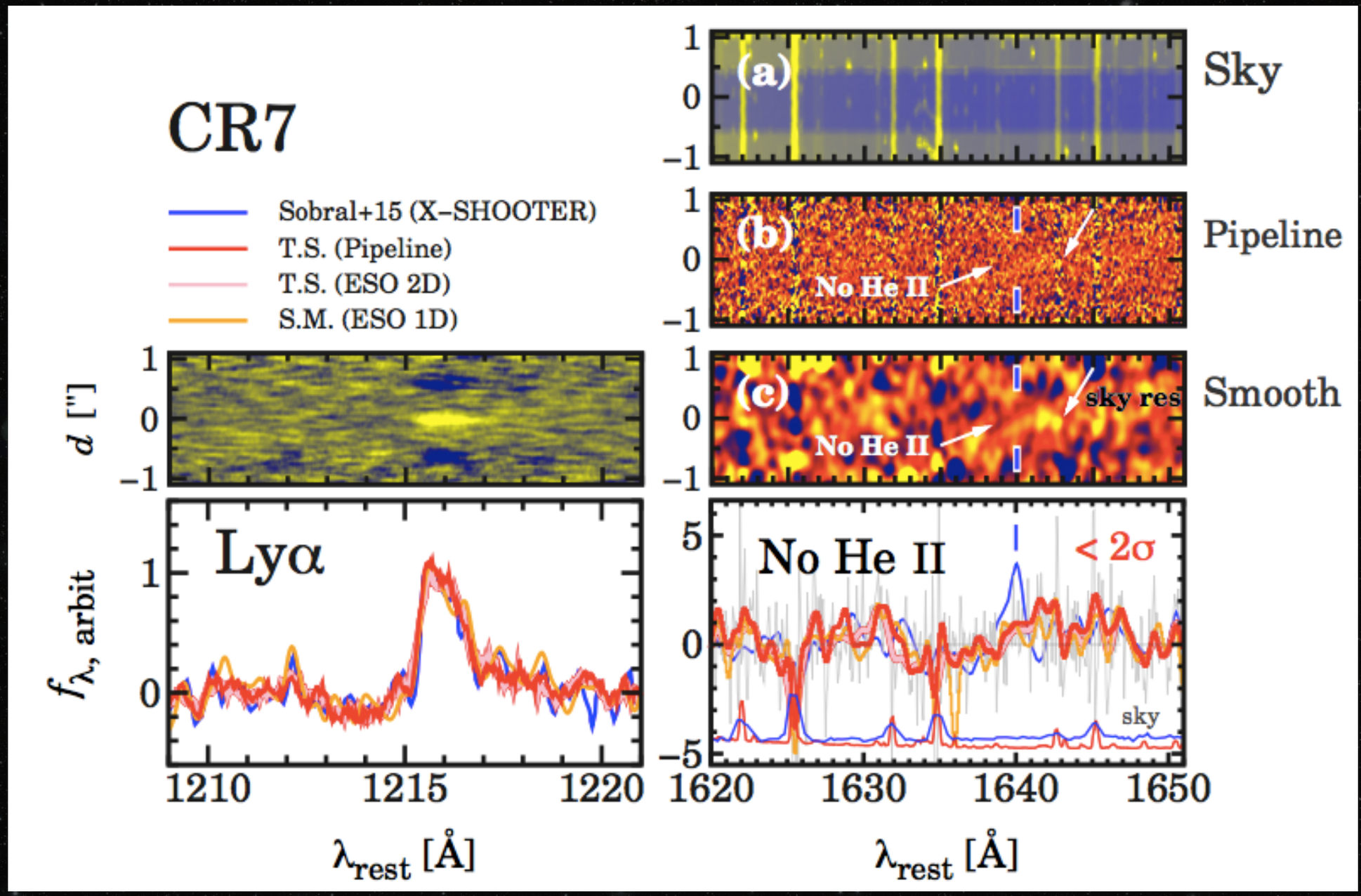
Include nebular emission with CLOUDY

Line width is narrow

Models at 1/200 and 1/2000 Zsun can reproduce EW of HeII

★ Alpha enhancement may also be necessary (and likely)

Recent observations of CR7 and similar objects at high-z



Shibuya et al. 2017

★ Spectroscopy of 7 similarly bright Lyman-**α** emitters found with new Hyper-Suprime-Cam surveys shows EW0 < 2-3A for HeII 1640

Pushing to wider areas from the ground