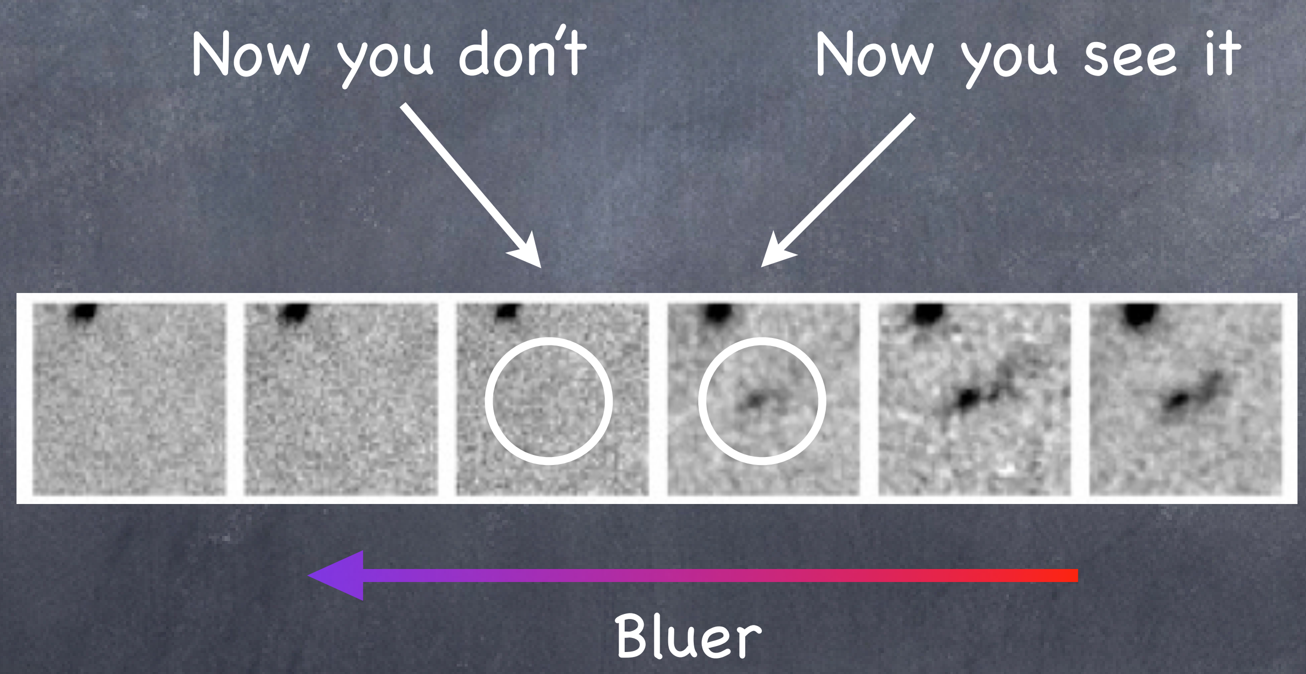
Spectroscopic Analysis of Primeval Galaxy Candidates

- Joseph Caruana -

Andrew Bunker, Stephen Wilkins, Silvio Lorenzoni

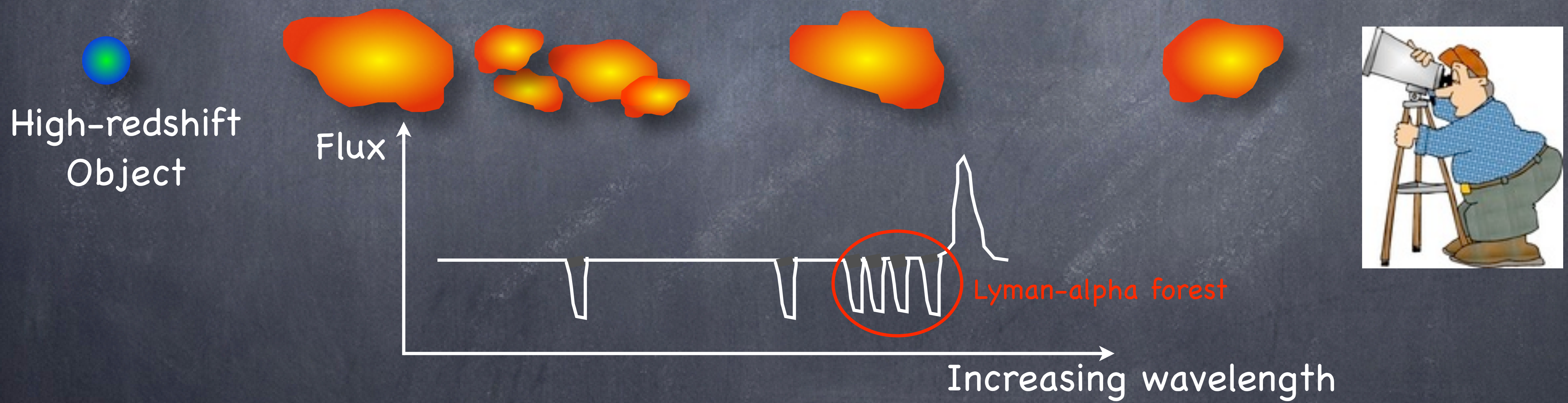
Candidate Selection

Lyman-break technique:

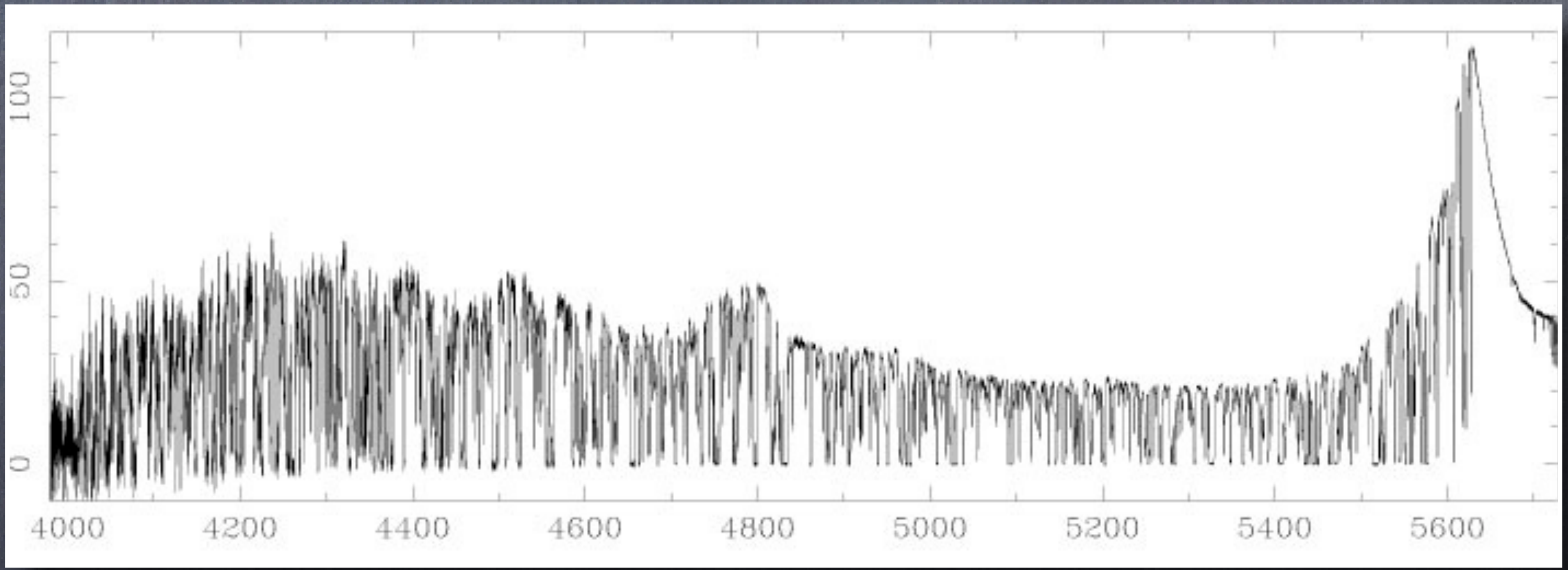


Candidate Selection

Lyman-break technique:



Candidate Selection



High resolution spectrum of QSO 1422+23 (Womble et al. 1996)

Spectroscopically confirmed sample

Vanzella et al. (2011): 2 at about z=7
Schenker et al. (2011): 3 at about z=7
Iye et al. (2011): 1 at about z=7
Ono et al. (2011): 2 at about z=7
Pentericci et al. (2011): 5 at about z=7

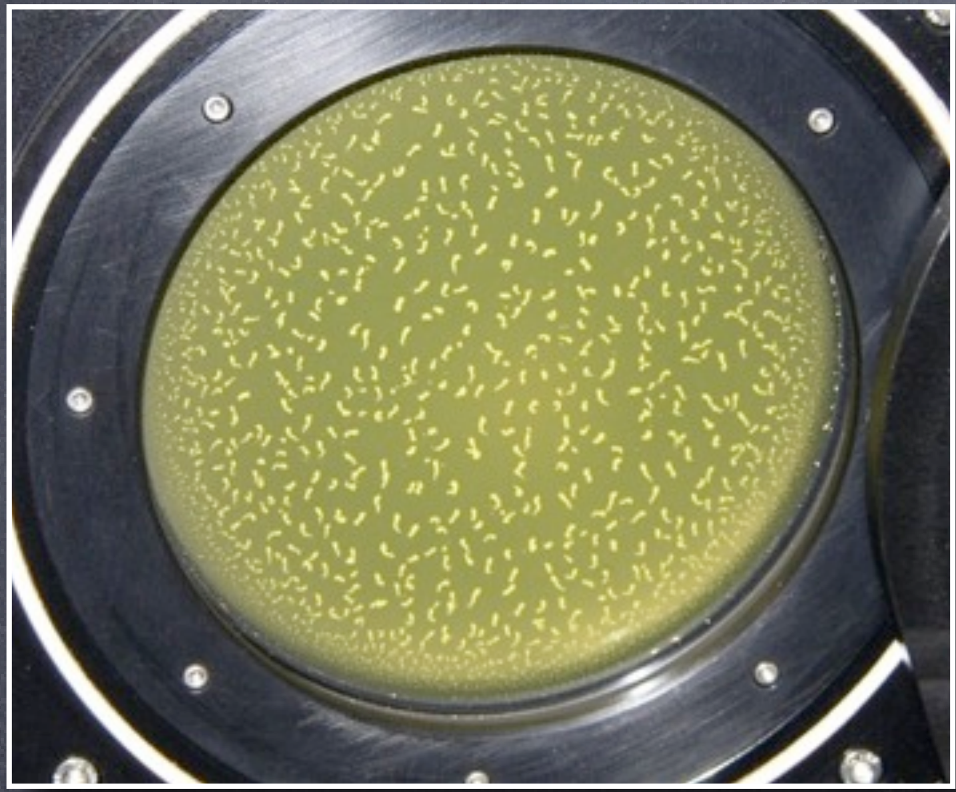
Total: 13 spectroscopically confirmed objects at about z=7

Spectroscopy with GEMINI/GNIRS

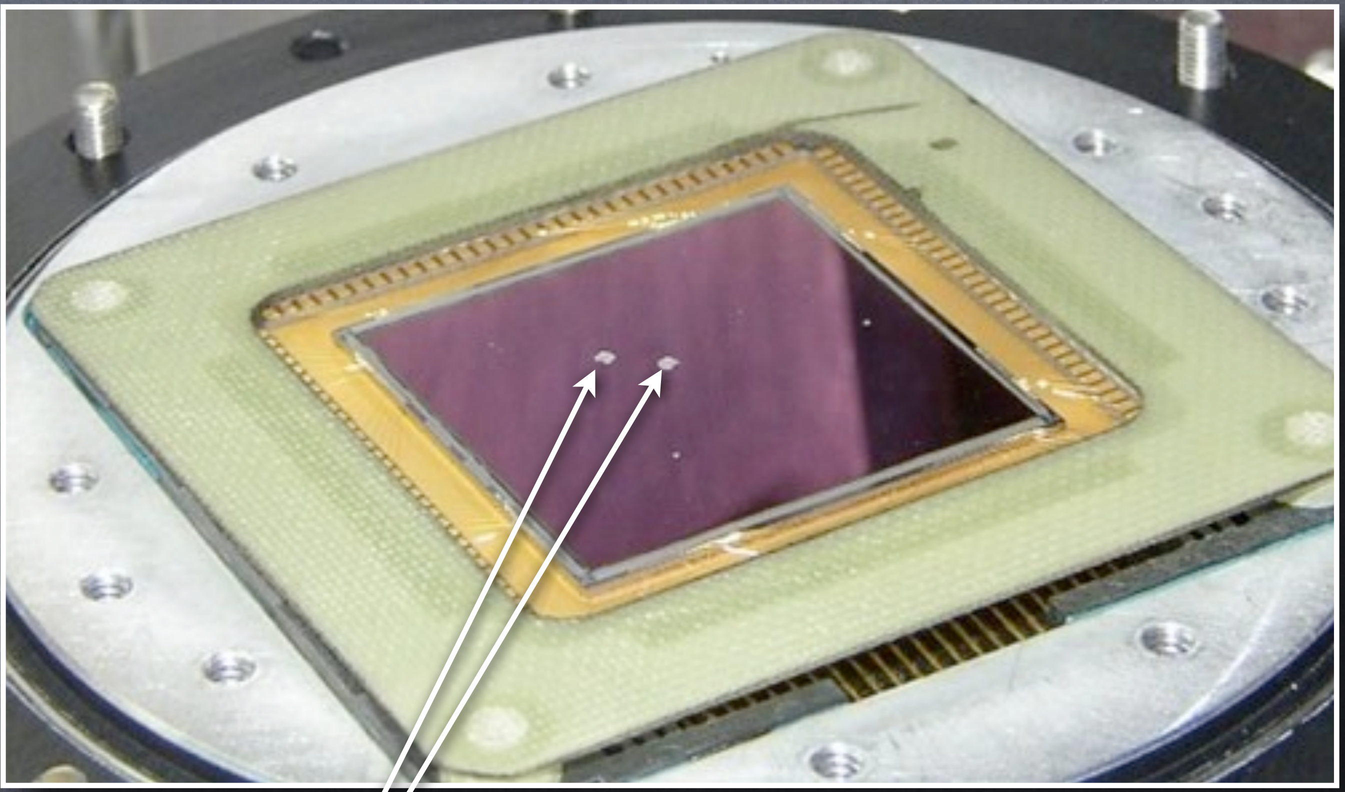
Gemini South

Gemini Near Infrared Spectrograph (GNIRS)

Spectroscopy with GEMINI/GNIRS



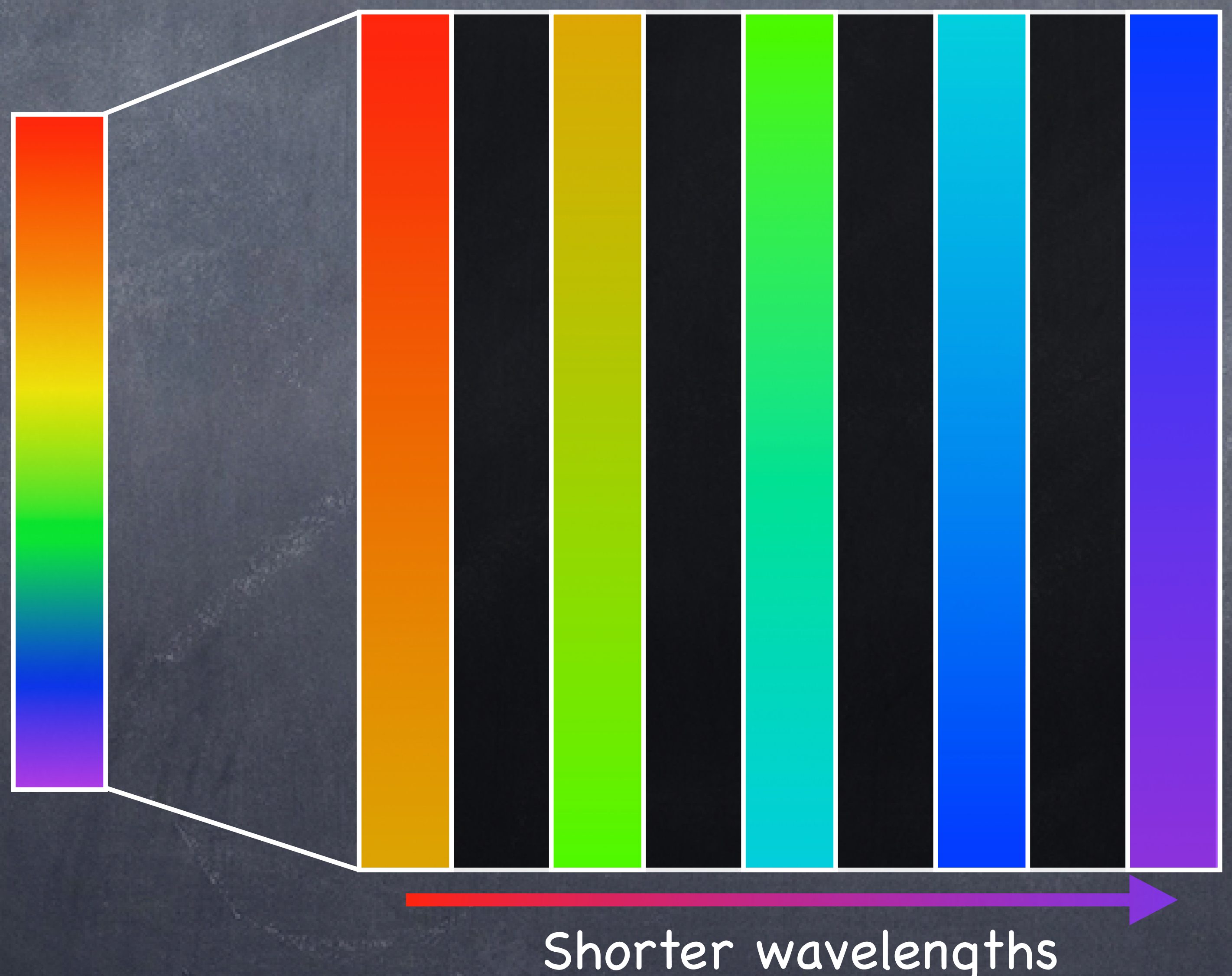
Contamination on the inside of the window



Holes in detector

Spectroscopy with GEMINI/GNIRS

- The data approximately span the wavelength region between 0.84 and 2.4 Angstroms.
- The data were obtained in cross-dispersed mode.

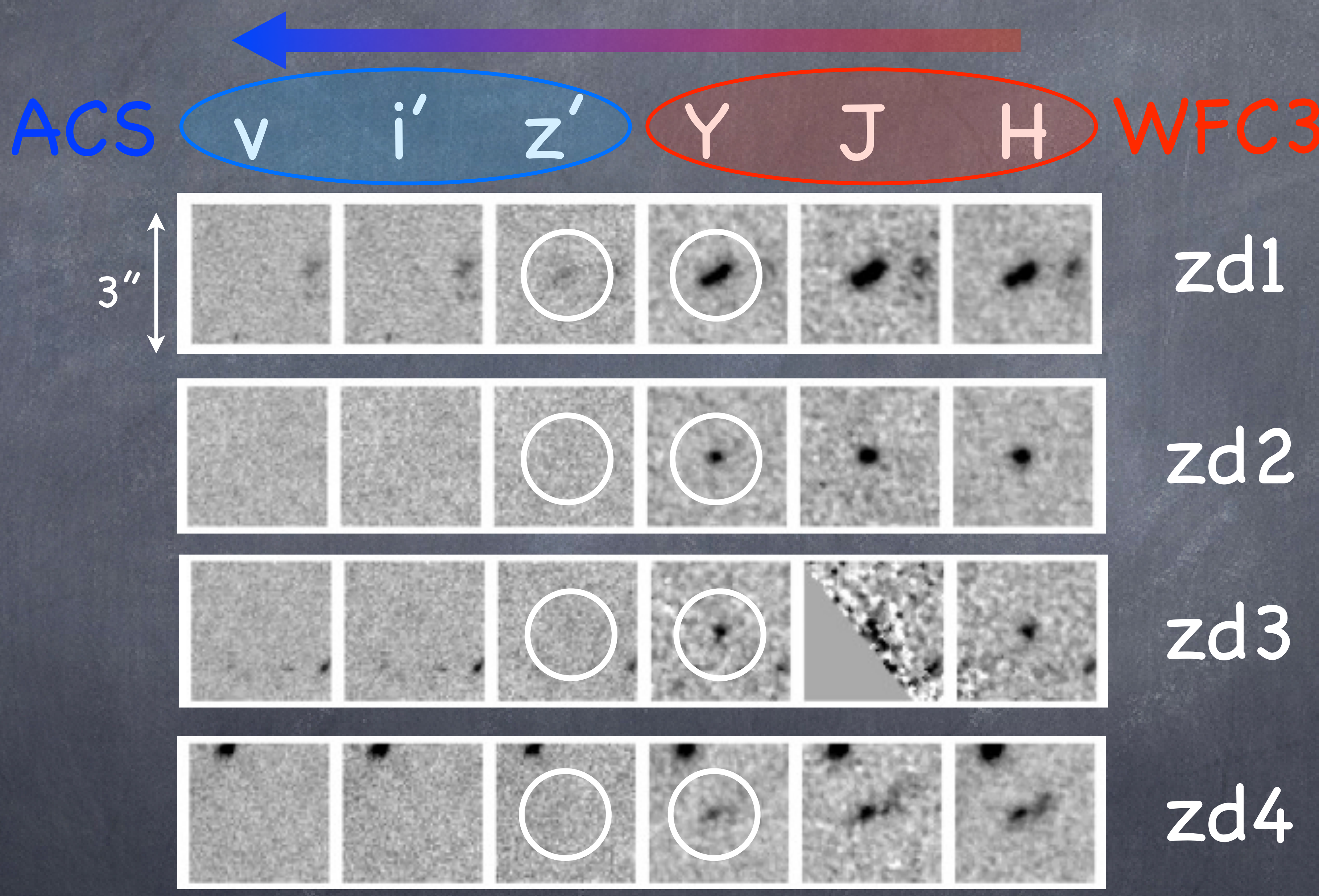


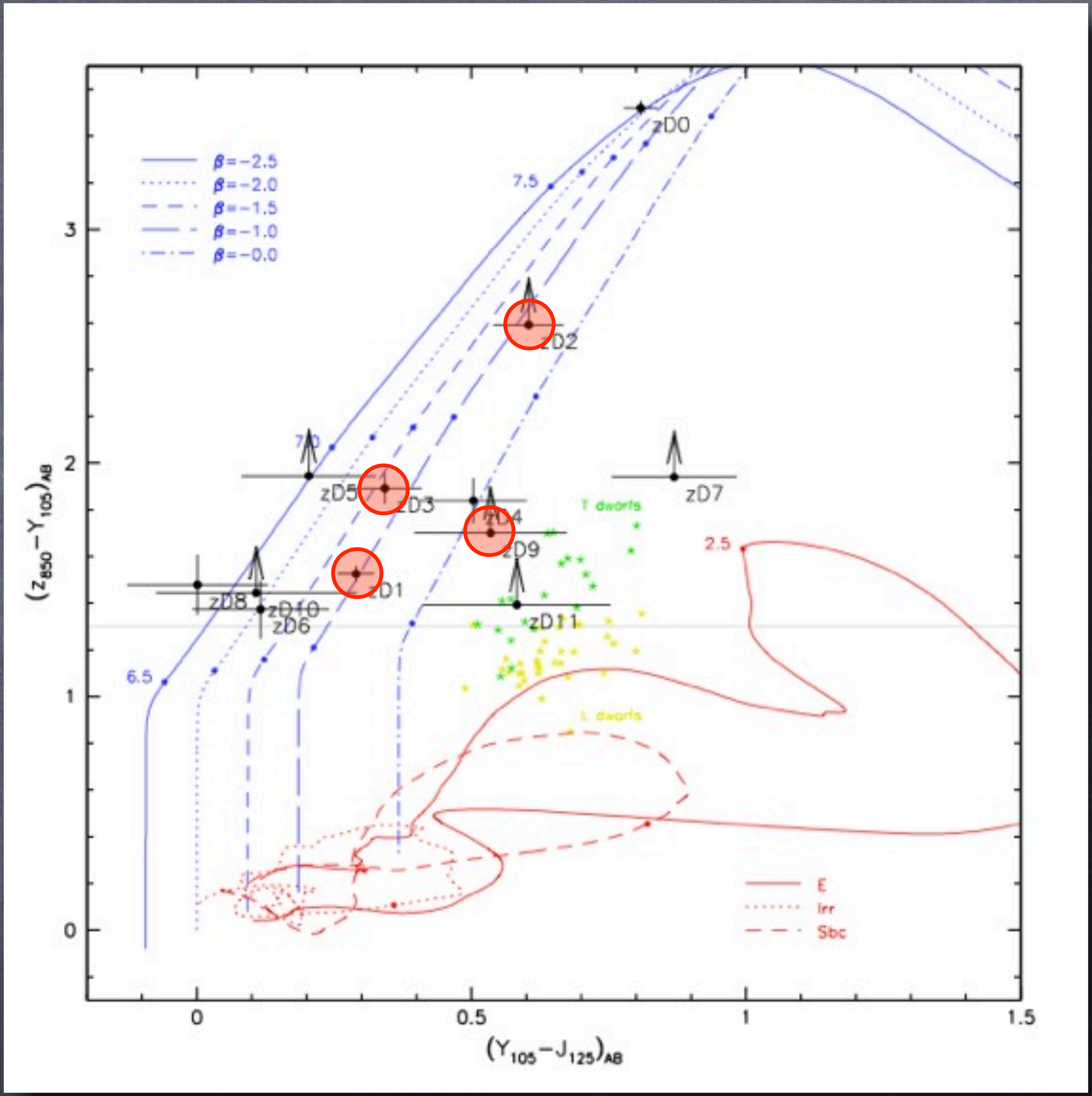
Spectroscopy with GEMINI/GNIRS

Object	Y-magnitude
HUDF.ZD1	26.71 ± 0.03 (Y_{098m}/Y105W)
HUDF.ZD2	27.48 ± 0.06 (Y_{098m}/Y105W)
HUDF.ZD3	27.5 ± 0.07 (Y_{098m}/Y105W)
HUDF.ZD4	27.84 ± 0.09 (Y_{AB})

zdrop2, zdrop5, UDF.572, UDF.845

Candidate Selection





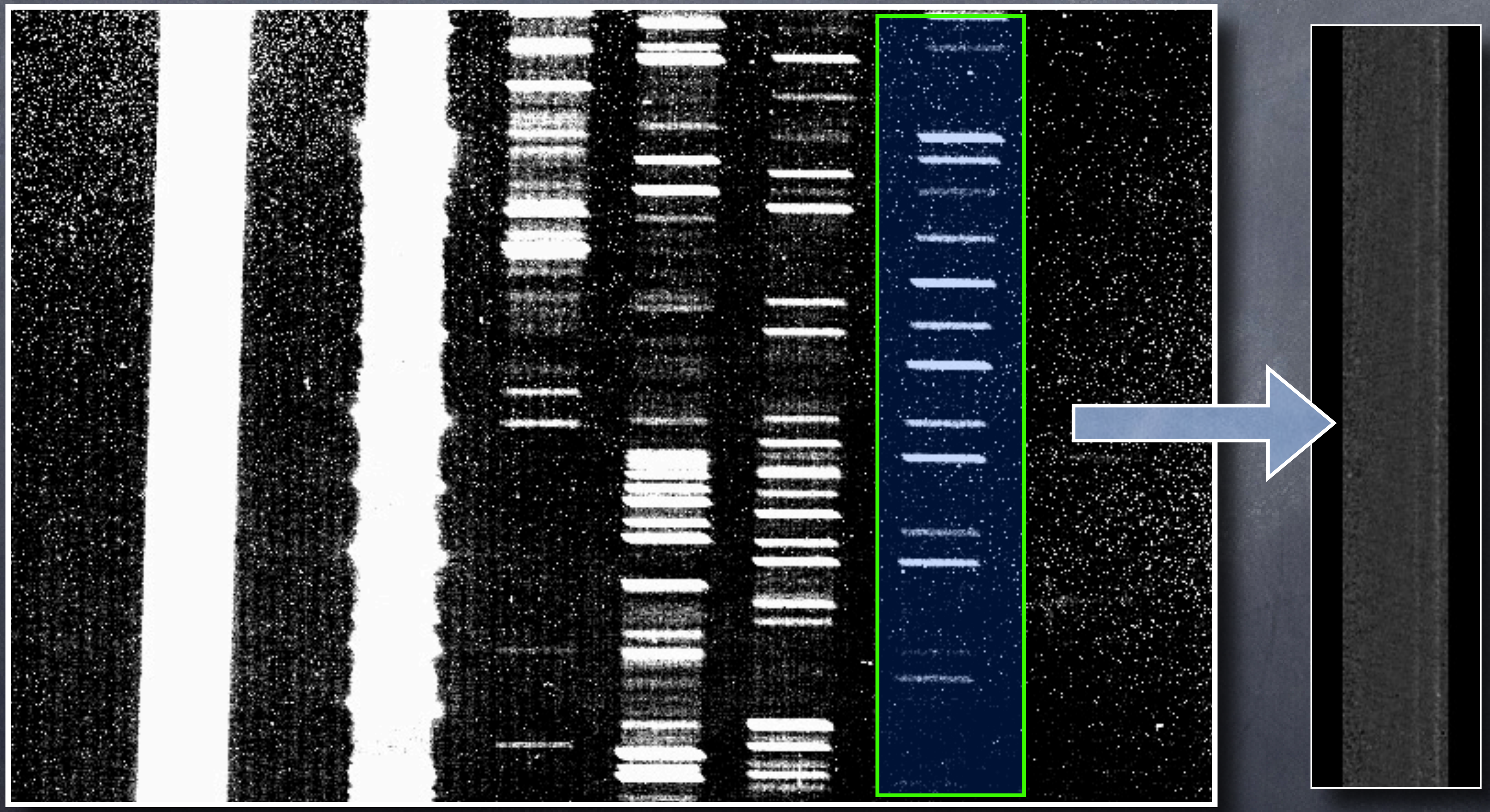
Bunker et al 2010

Spectroscopy at high-z

- Near IR spectroscopy is not quite easy.
- Higher readout noise and dark current
- OH lines (having better resolution helps)
- Atmospheric sky background is very variable
  Necessitates frequent sky dithering to obtain good background subtraction.

Spectroscopy with GEMINI/GNIRS

Data Reduction



Spectroscopy with GEMINI/GNIRS

Assess the noise

Use Poisson Statistics to predict the noise

Measure actual noise

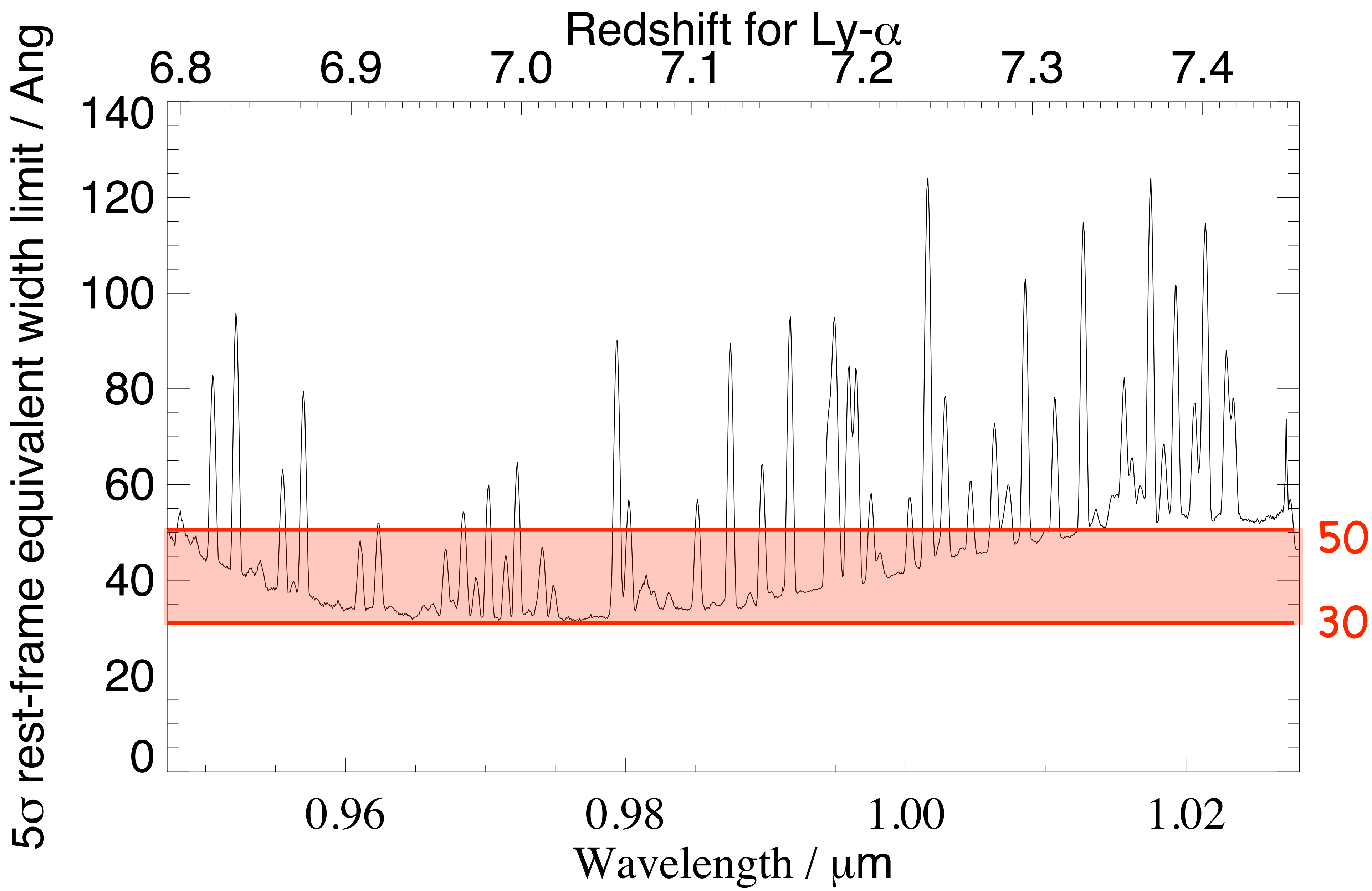
Spectroscopy with GEMINI/GNIRS

In brief:

We do not detect any Lyman-α emission

zD1

Caruana et al., in prep

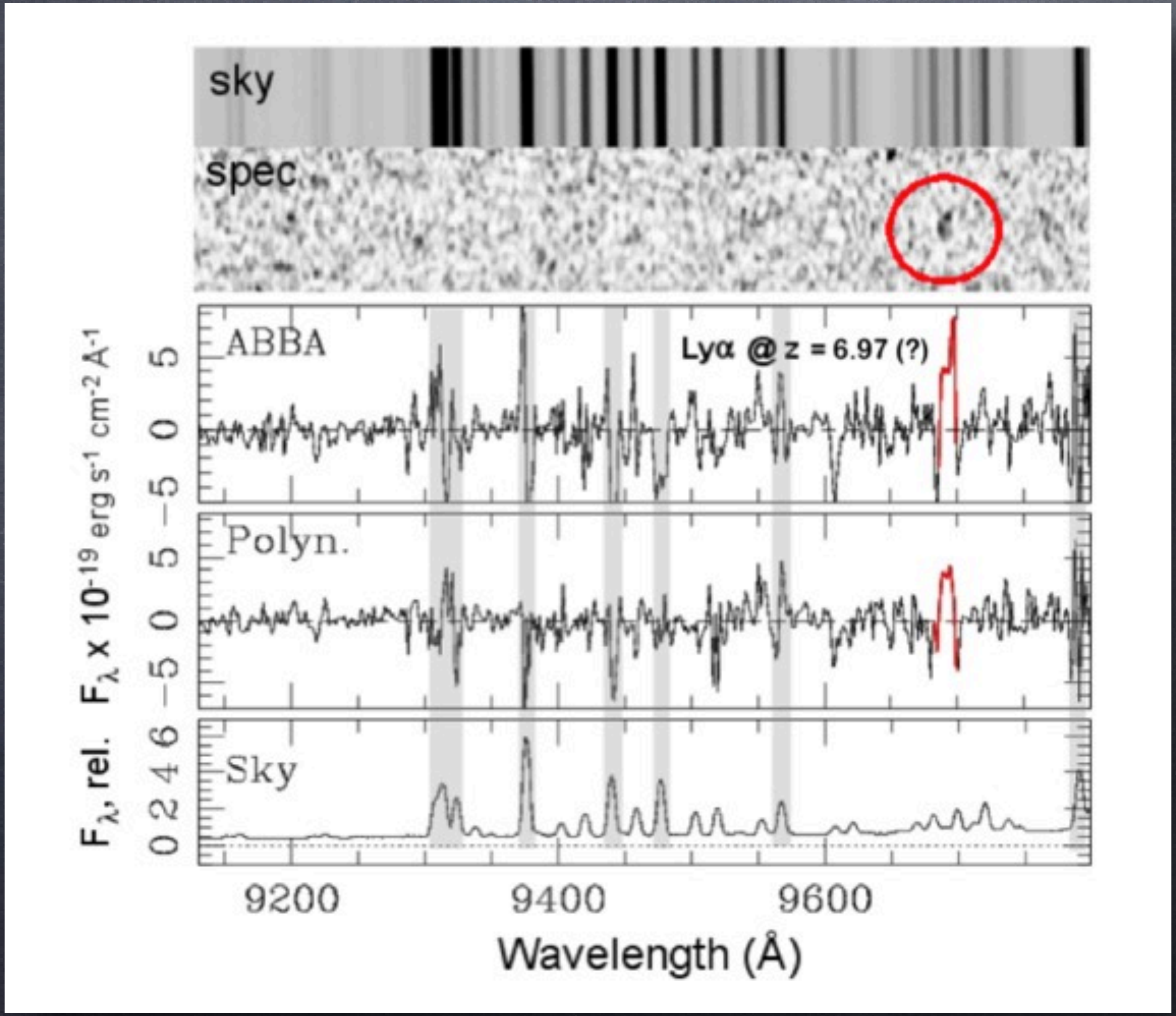


5 σ rest frame EW limit

Comparison with Fontana et al. (2010)

- Ultradeep optical spectroscopy obtained with FORS2 on VLT of seven Lyman-break galaxy (LBG) candidates at $z > 6.5$
- One tentative emission line, placing the object at $z=6.97$

Comparison with Fontana et al. (2010)



G2-1408
(zD1)

Detect a low significance emission line (S/N < 7)

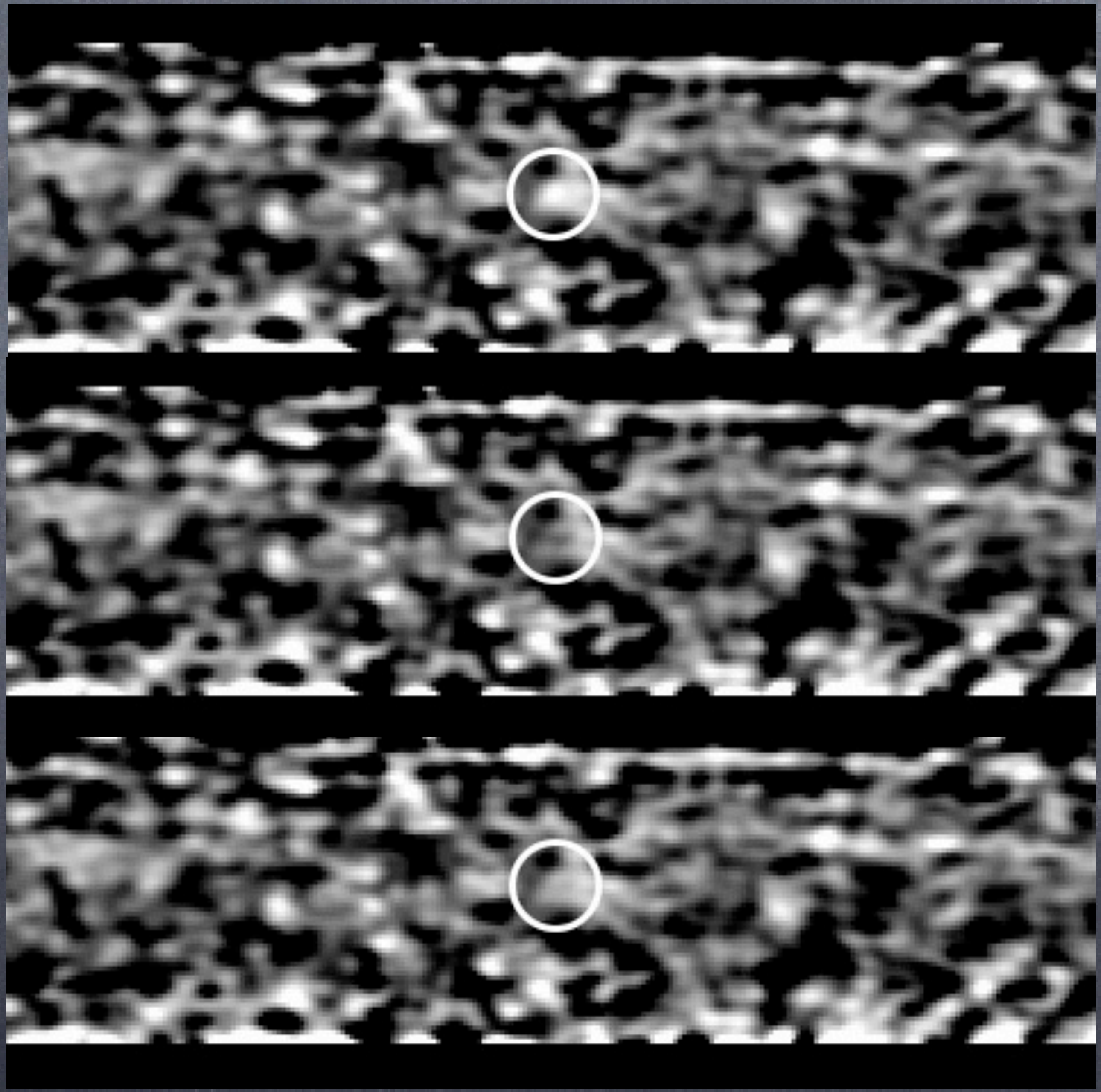
Flux:
3.4 x 10^(-18)erg/cm^2/s

Comparison with Fontana et al. (2010)

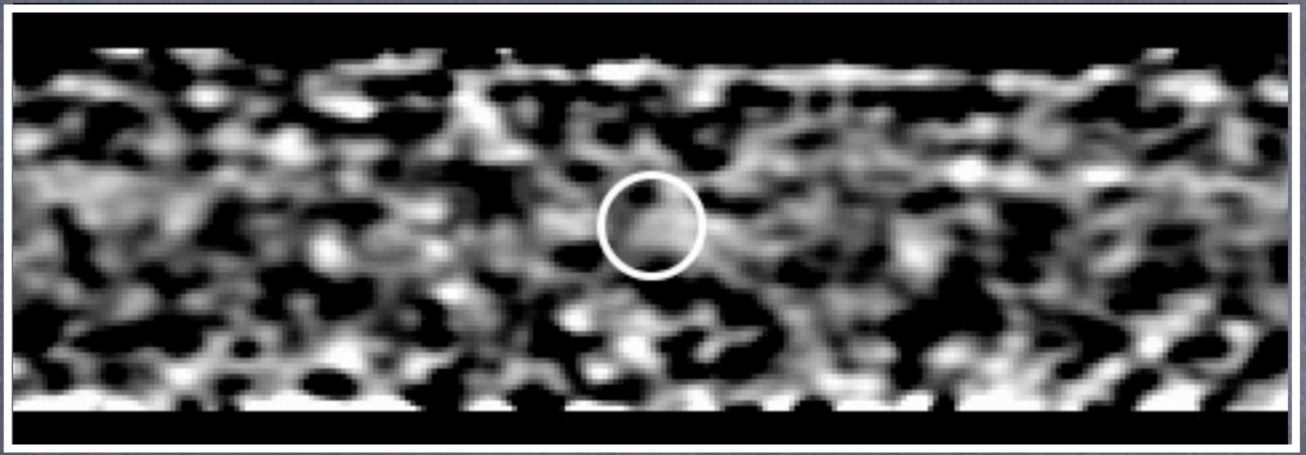
5-sigma

Observed

Fontana et al.

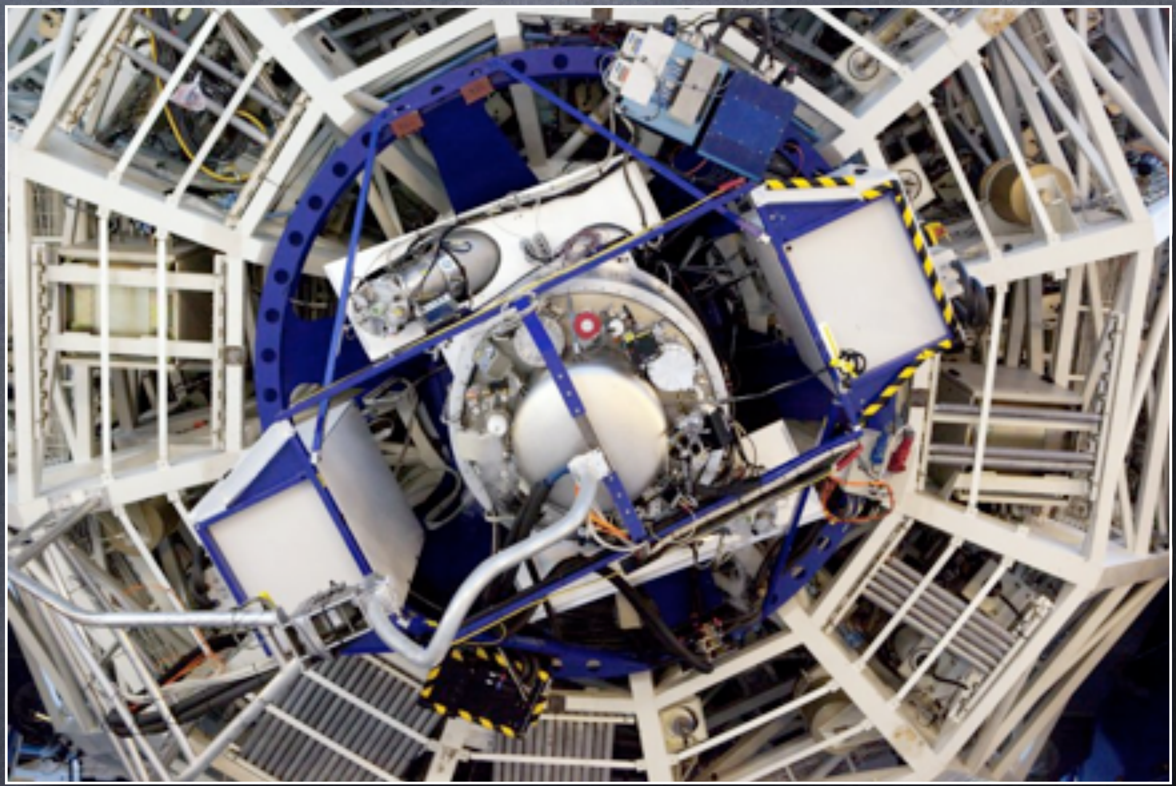


Comparison with Fontana et al. (2010)



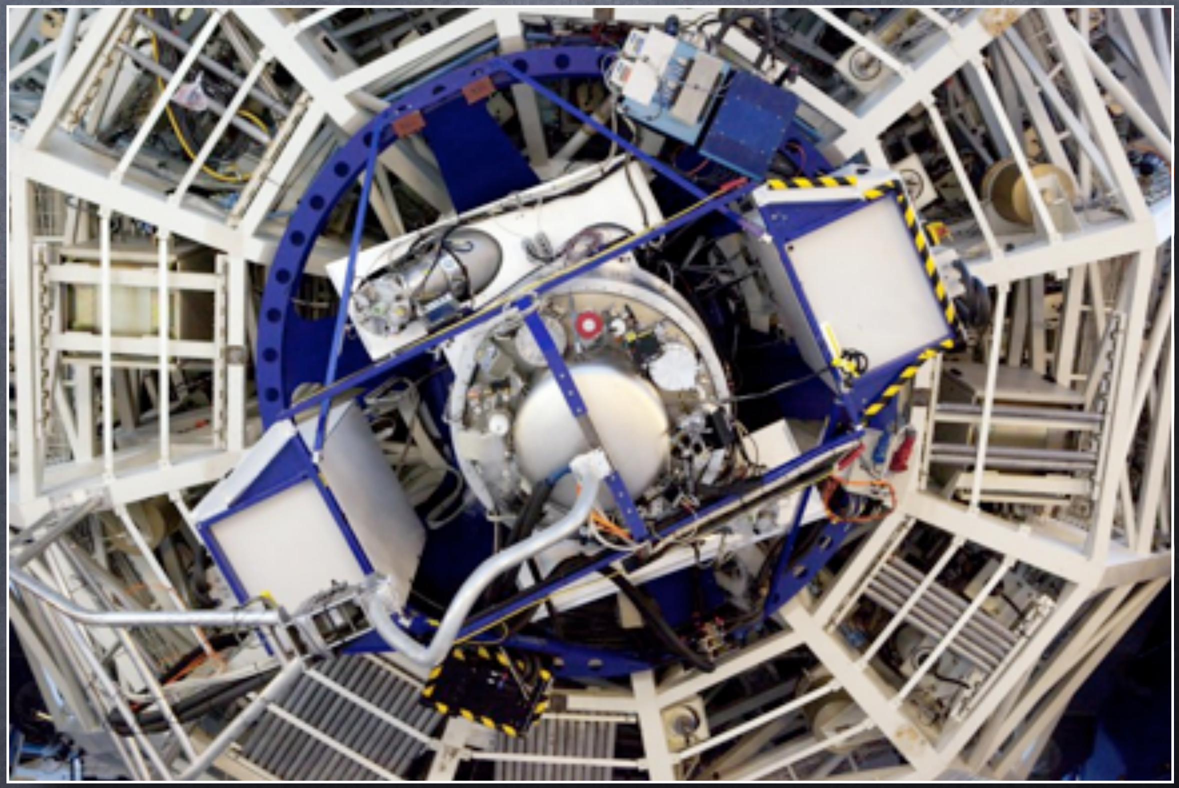
Spectroscopy with VLT/XSHOOTER

086.A-0968(B) (PI: A. Bunker)

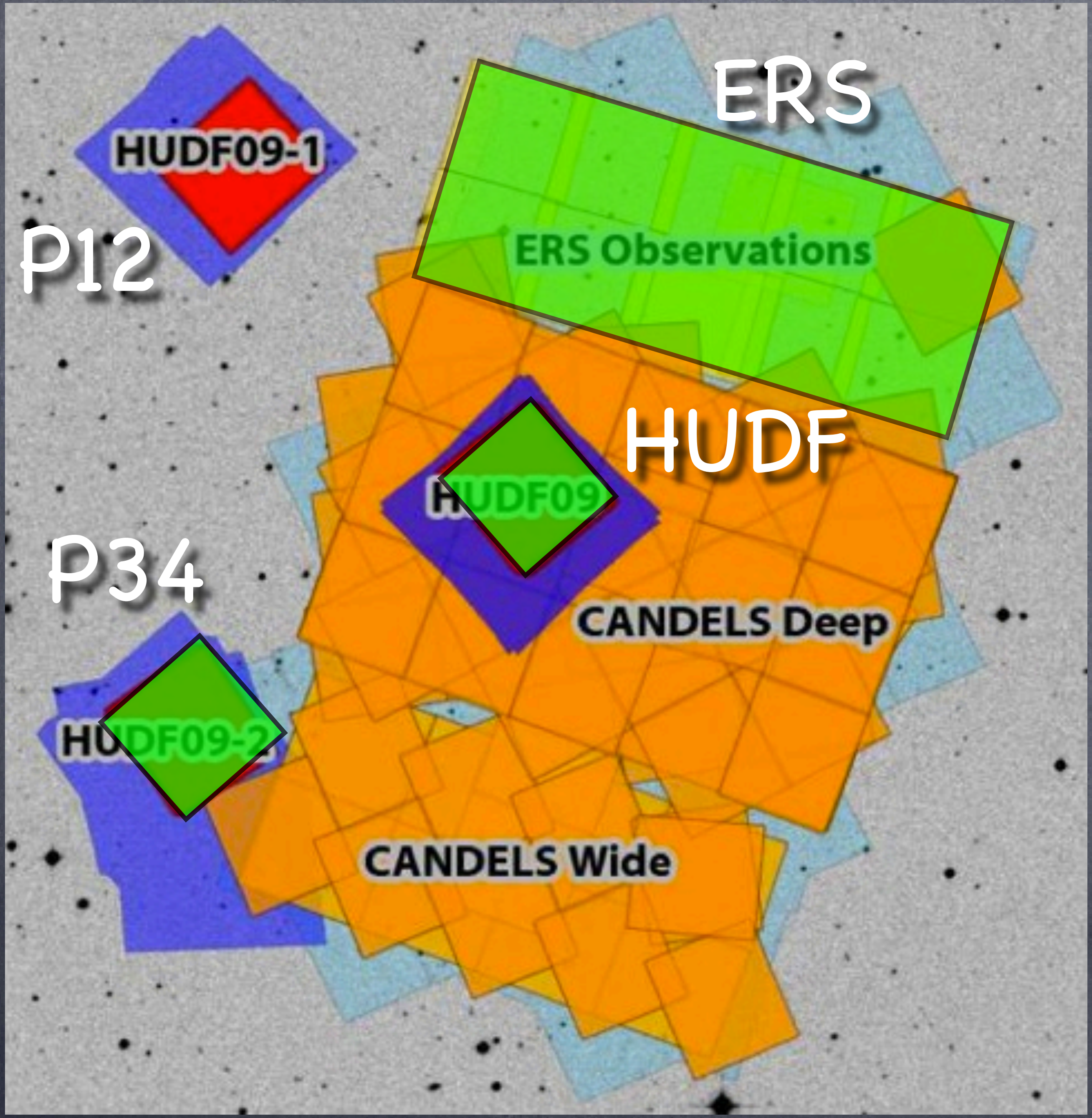


Spectroscopy with VLT/XSHOOTER

- XSHOOTER is an echelle spectrograph
- UV, visible and near-IR channels
- Near-continuous spectroscopy between $0.3\mu m$ and $2.48\mu m$.
- We used the near-IR channel



Spectroscopy with VLT/XSHOOTER

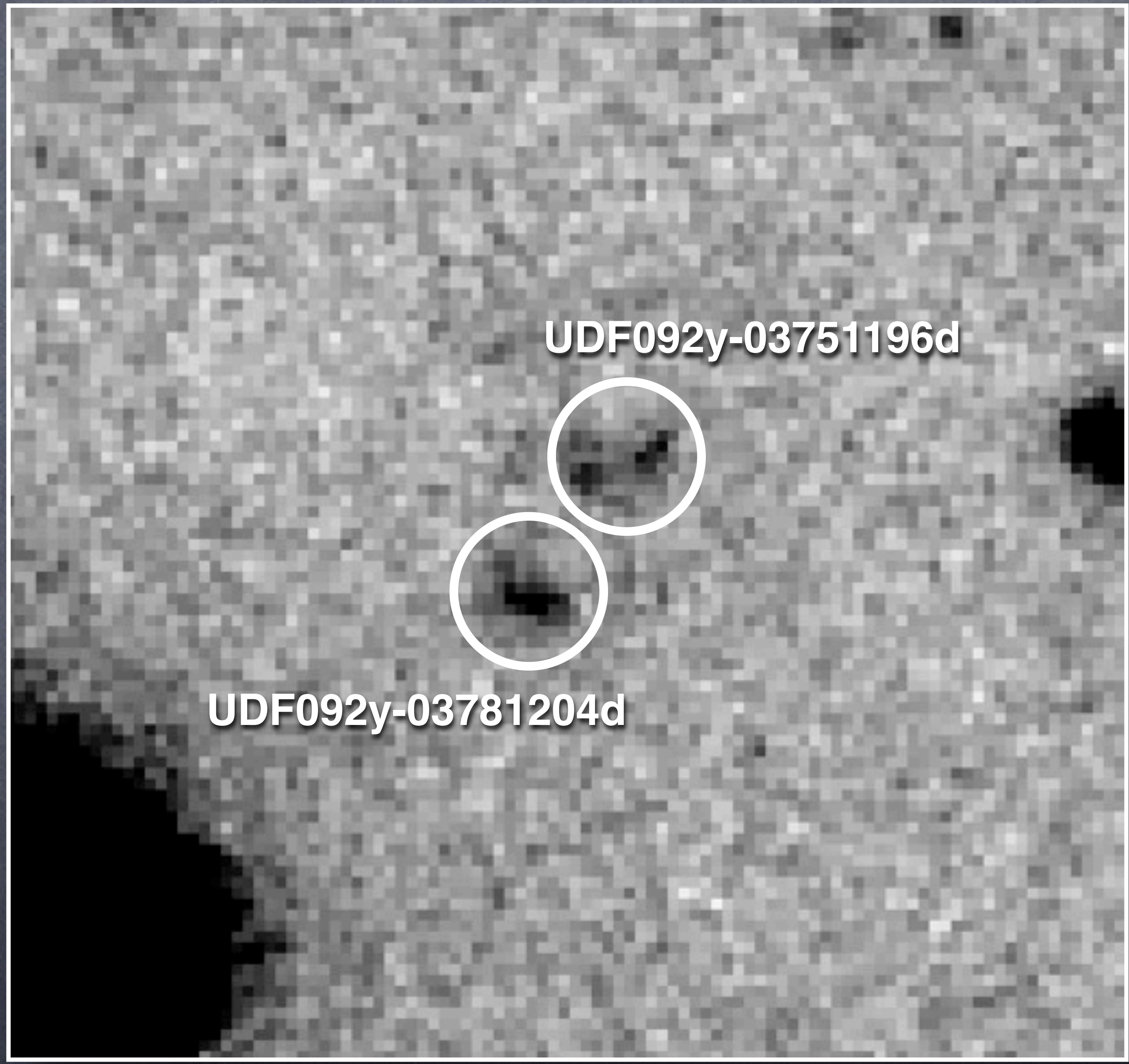


Bouwens et al. (2011)

- HUDF.YD3
- ERS.YD2
- → P34.Z.4809

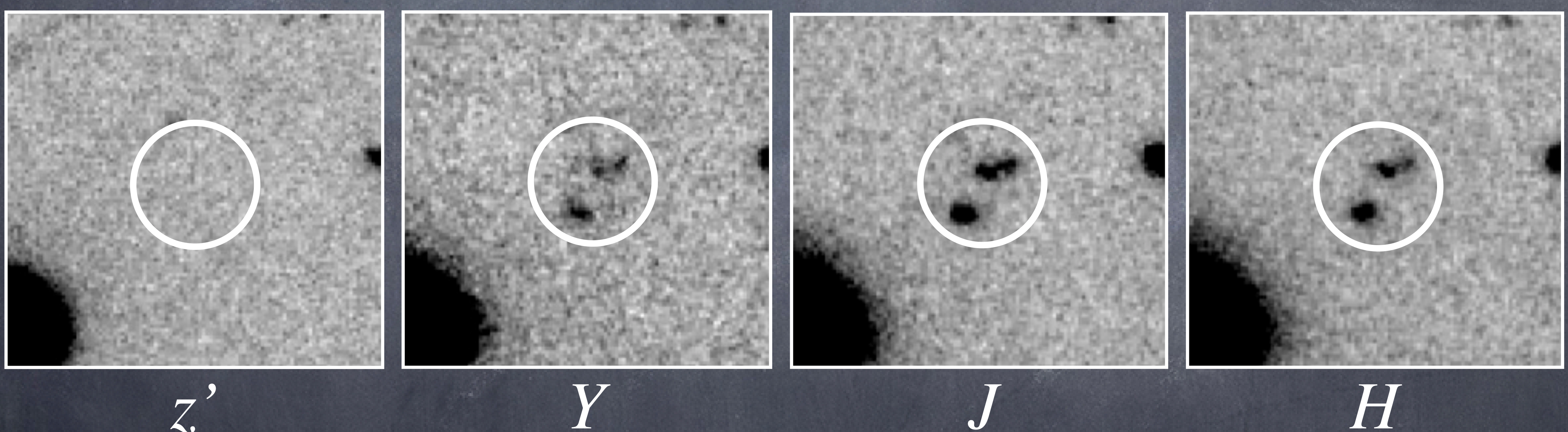
Spectroscopy with VLT/XSHOOTER

P34.Z.4809 (Wilkins et al. 2010)



Spectroscopy with VLT/XSHOOTER

P34.Z.4809 (Wilkins et al. 2010)



Spectroscopy with VLT/XSHOOTER

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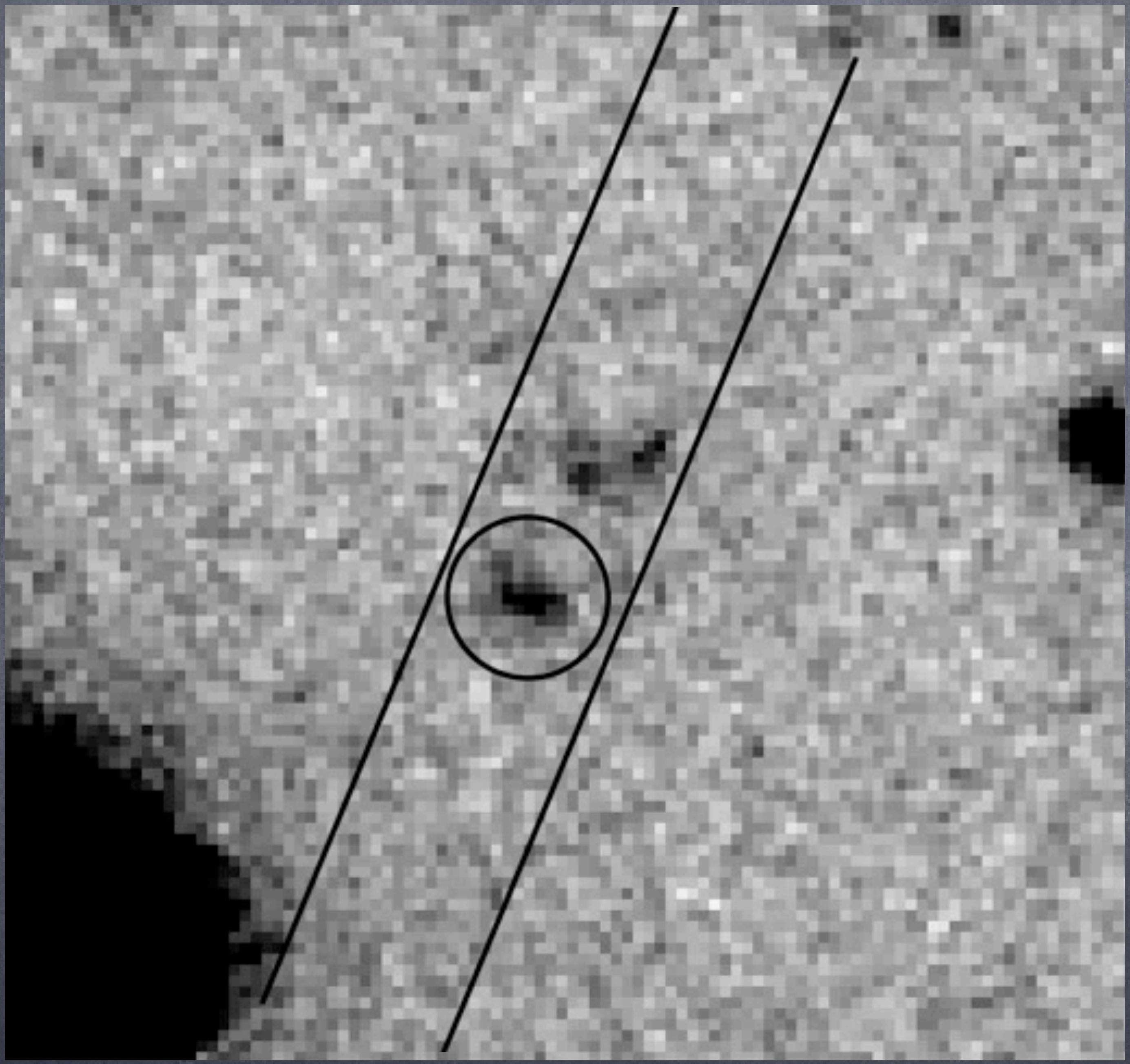
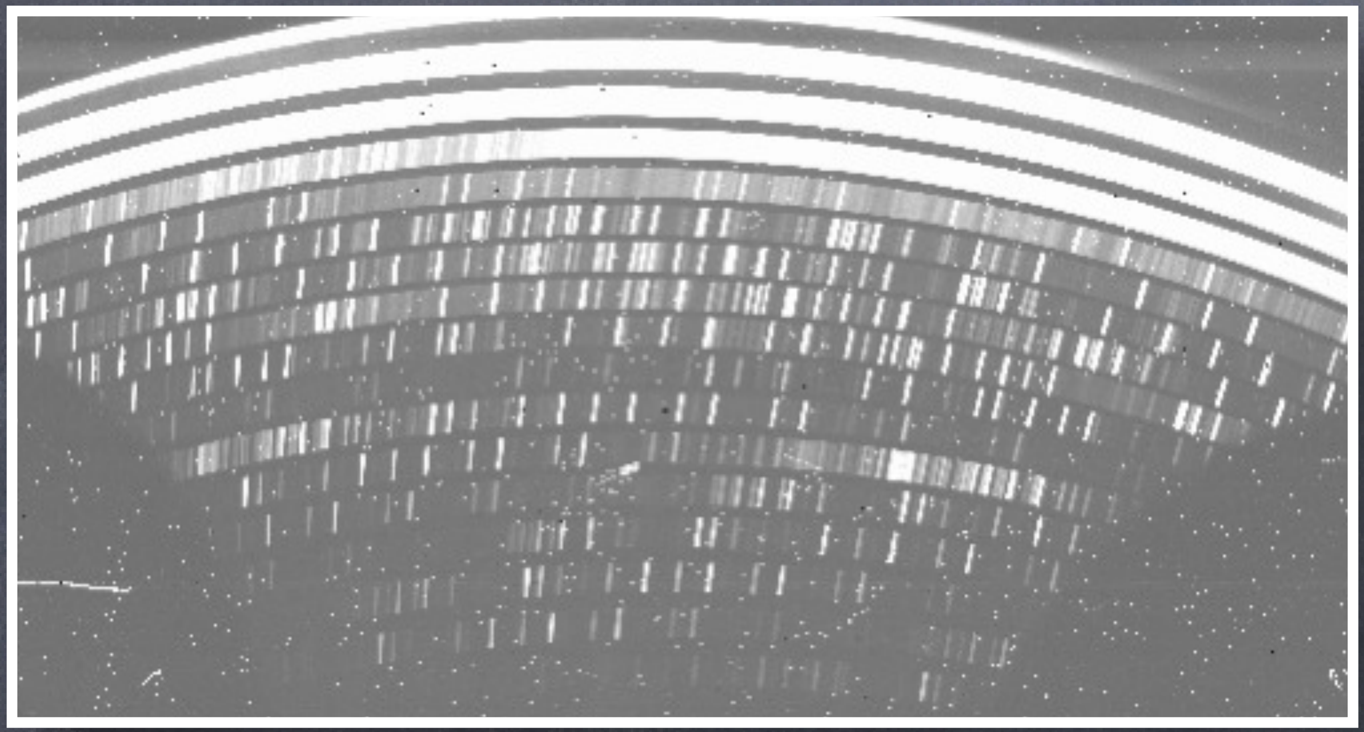
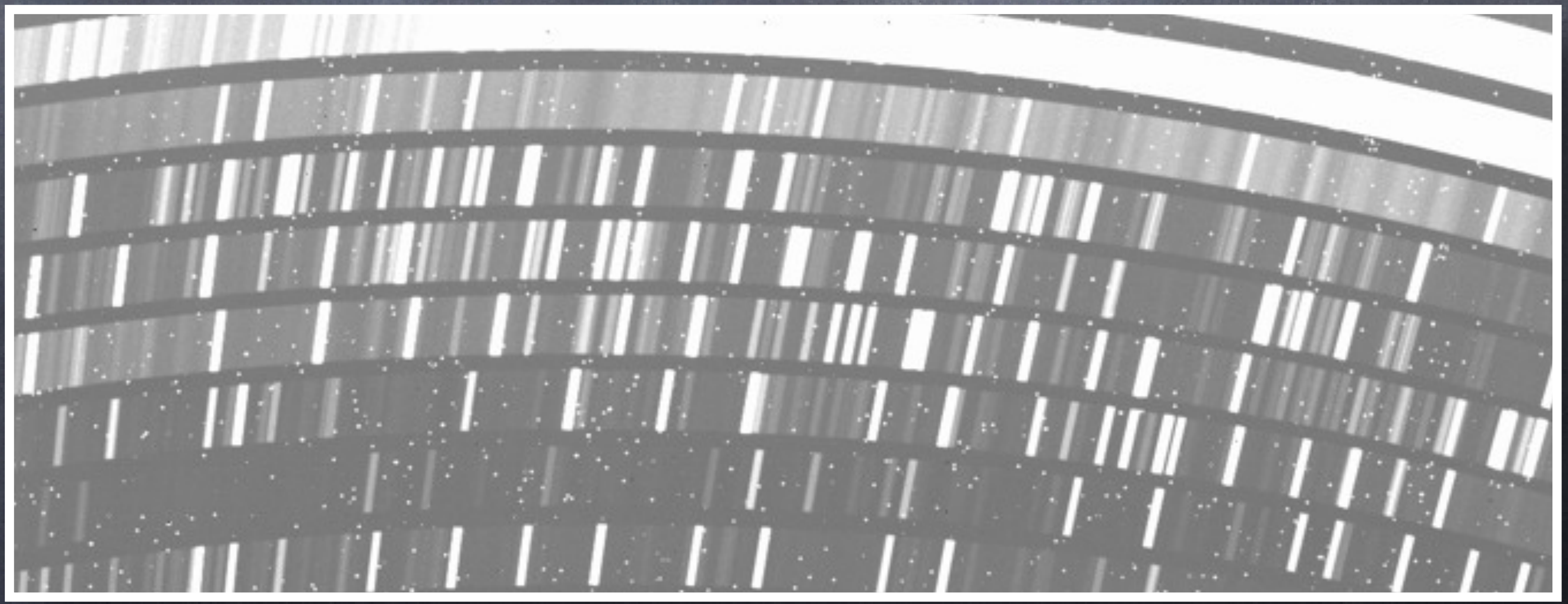


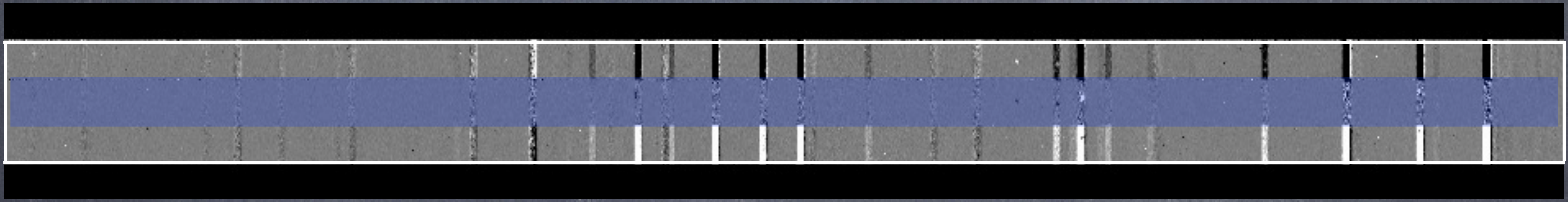
Spectroscopy with VLT/XSHOOTER





Spectroscopy with VLT/XSHOOTER

P34.Z.4809 (Wilkins et al. 2010)

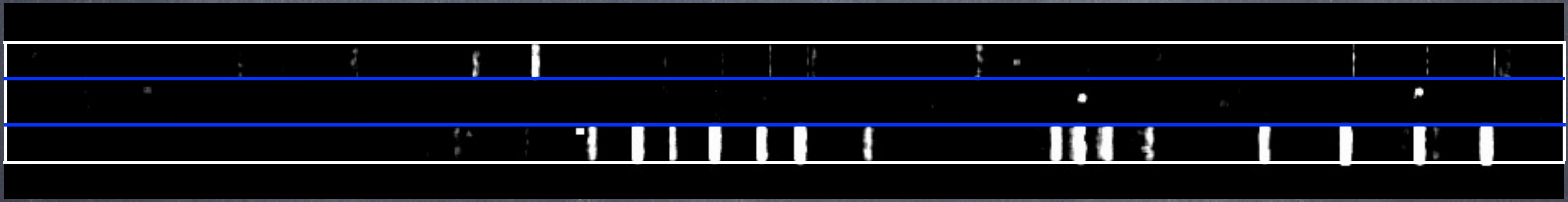


Caruana et al., in prep.

2D combined spectrum
We do NOT detect Lyman-
α

Spectroscopy with VLT/XSHOOTER

P34.Z.4809 (Wilkins et al. 2010)



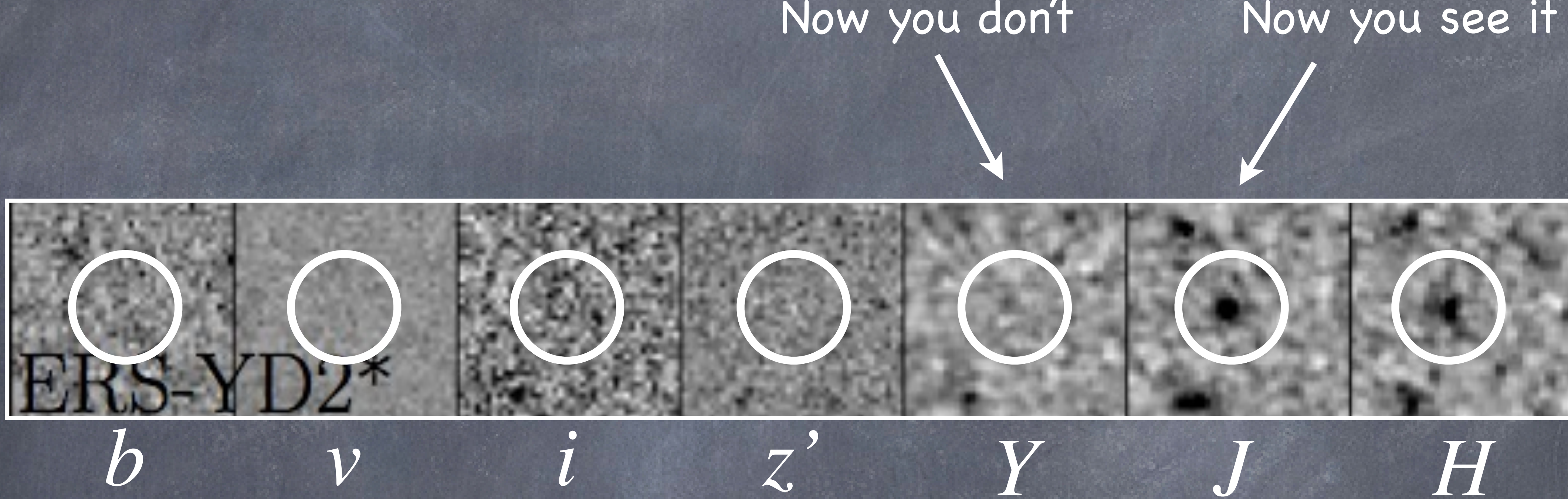
Caruana et al., in prep.

Thresholding above a certain σ

Insert fake sources to test recoverability

Spectroscopy with VLT/XSHOOTER

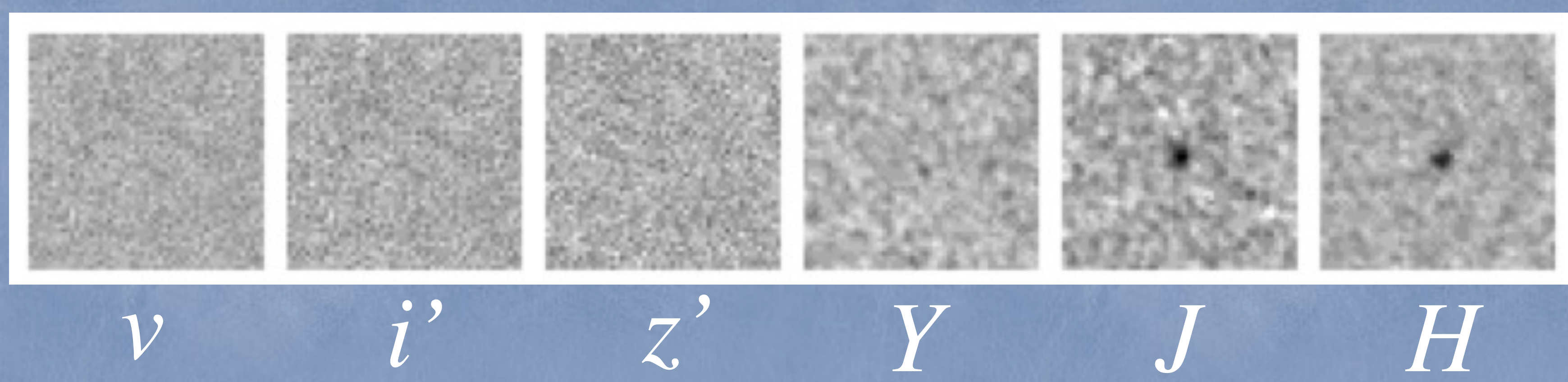
ERS.YD2 (Lorenzoni et al. 2011)



We do NOT detect Lyman-α emission

HUDF.YD3

HUDF.YD3 in Bunker et al. 2010



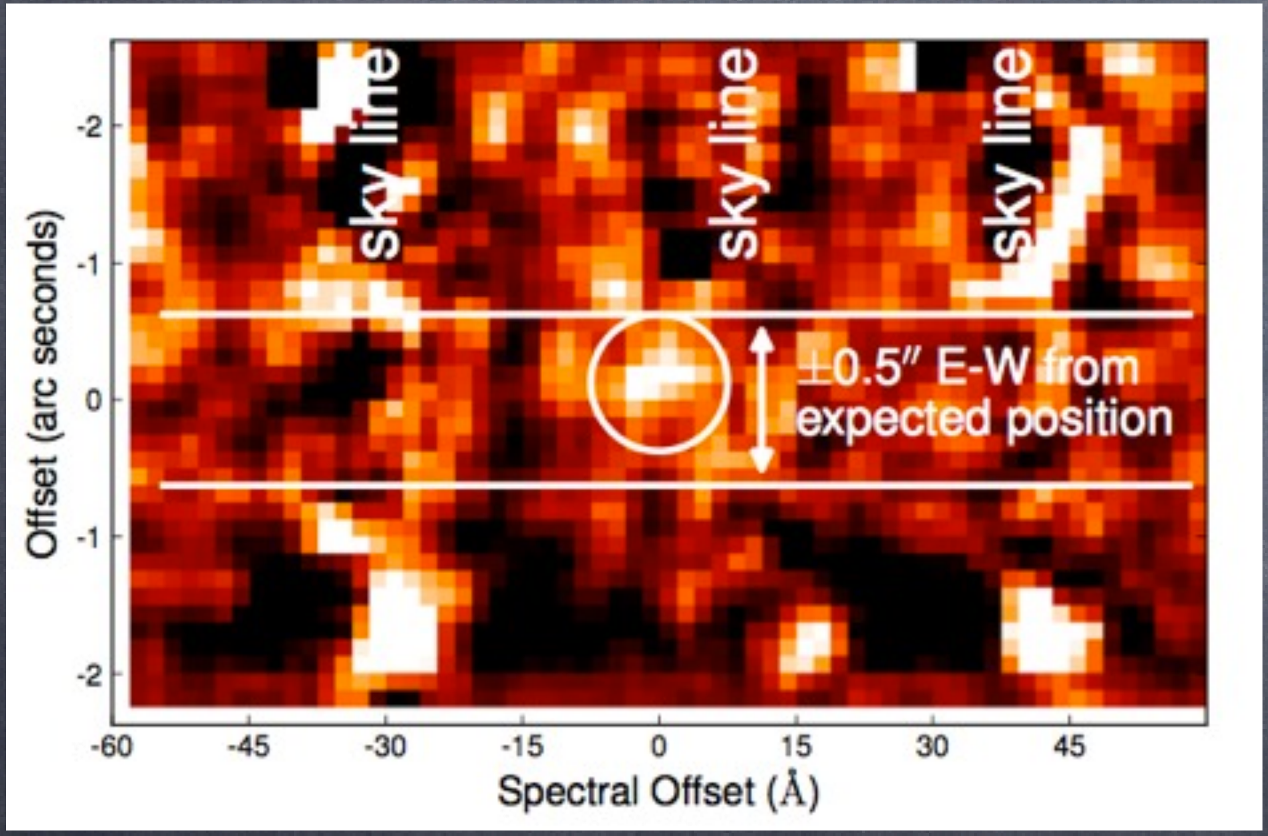
Object 1721 in McLure et al. 2010

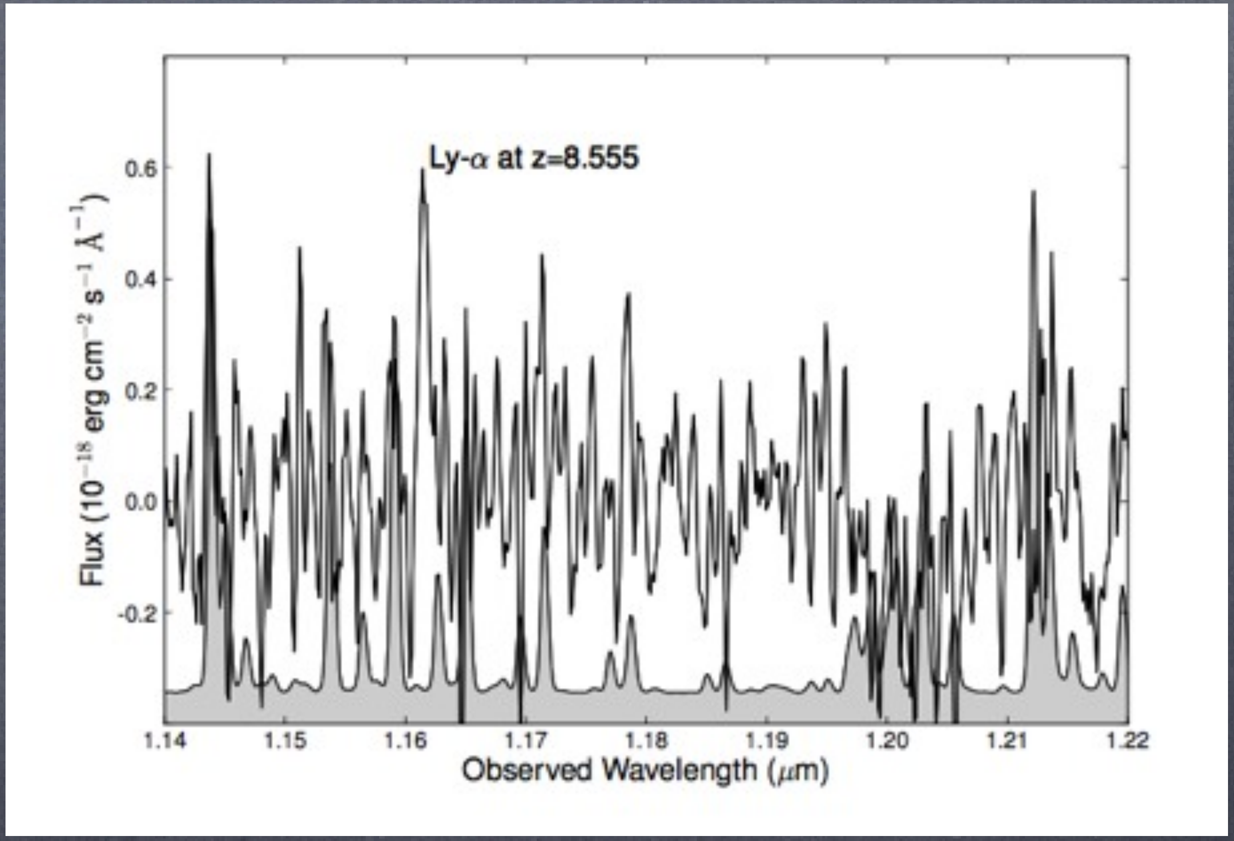
UDFy-38135539 in Bouwens et al. 2010

HUDF.YD3

Lehnert et al. (2010)

VLT/SINFONI





Claim a 6-sigma detection placing the object at z=8.55

Flux: $(6.1\pm1.0)\times10{-}18$ erg cm^{-2} s^{-1}

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20 October 2010 Last updated at 17:44 GMT

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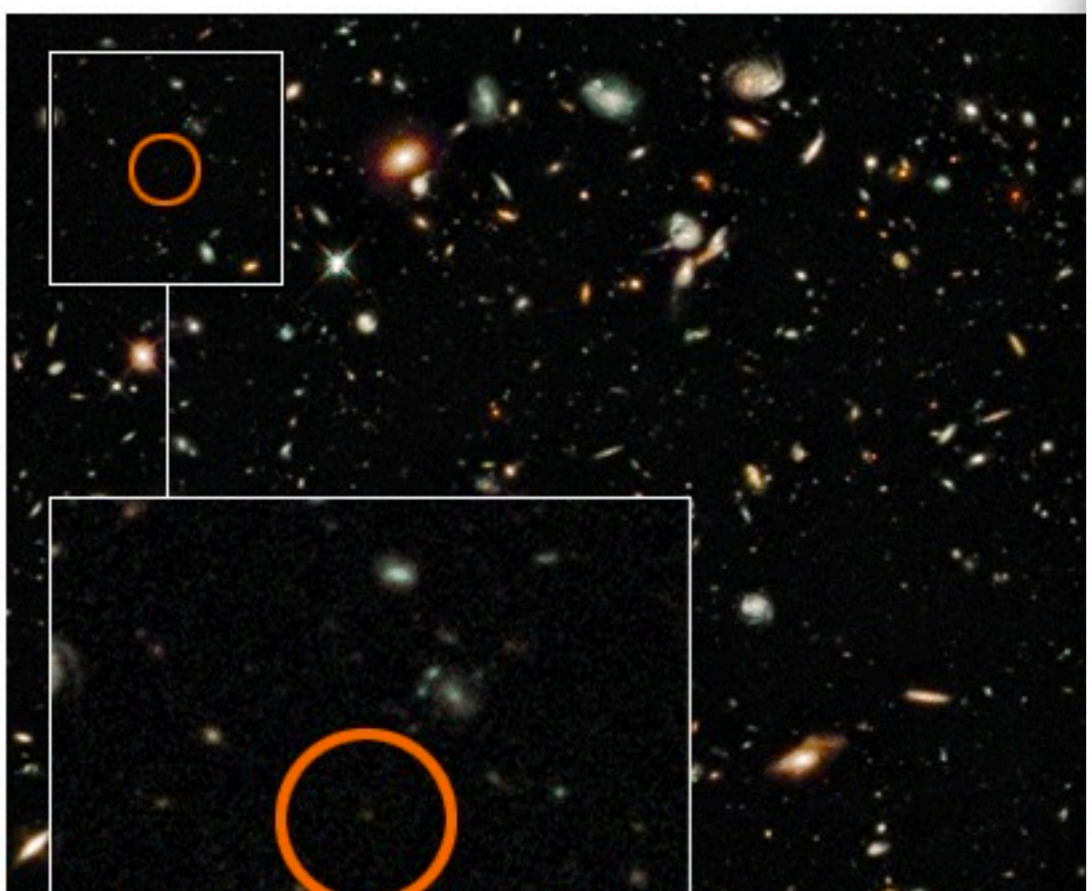
Galaxy is most distant object yet

By Jonathan Amos
Science correspondent, BBC News



News

Most distant galaxy ever found sheds light on infant cosmos

Object allows astronomers a glimpse of Universe's era of 'reionization'.

Zeeya Merali

Observations of the most distant object yet discovered go a long way in supporting astronomers' models of the early Universe. But the far-flung galaxy, details of which are published in *Nature* today[1], also raises questions about the source of the first light in the cosmos.

Light from the galaxy, named UDFy-38135539, left the object just 600 million years after the Big

Light from a distant galaxy has provided a snapshot of the early universe.

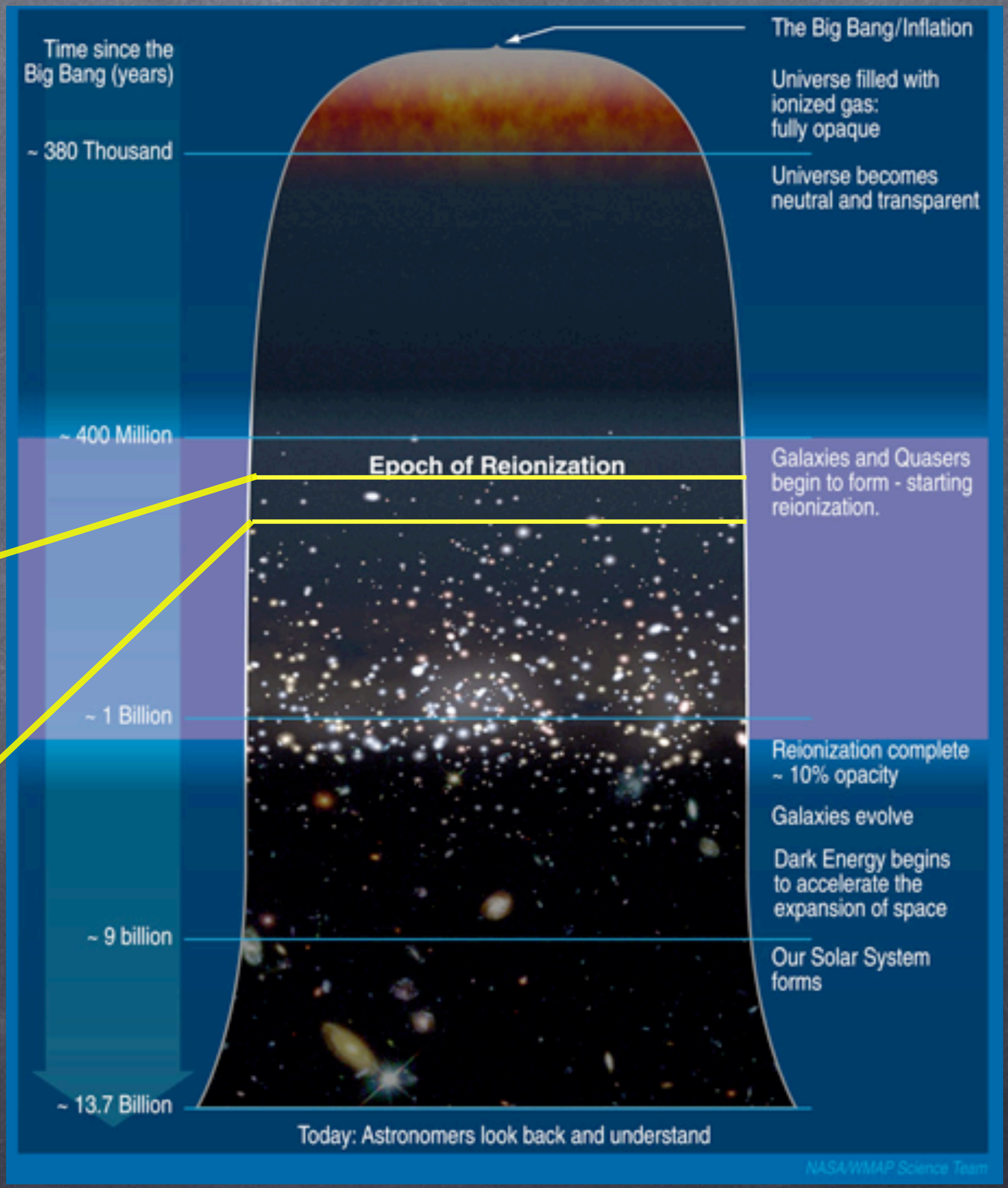
ESO/L. Calçada

HUDF.YD3

Lyman-α might still be a useful redshift diagnostic for very distant galaxies, even at a time when most of the Universe is optically thick to this line.

Lehnert et al. (2010)
Age of the Universe: 574 Myr

Vanzella et al. (2011)
Age of the Universe: 735 Myr



HUDF.YD3 with VLT/XSHOOTER

- We dithered the observations in an ABBA sequence.
- Observed in 6 blocks of an hour each (49mins on source).
- 4.9-hour integration
- Lehnert et al. (2010)
  4.1 hours in good seeing: 0.″5–0.″6 FWHM
  0.8 hours in worse seeing (1″.2 FWHM)
  From HST imaging we conclude it is unresolved in our observations.
- Reduced data twice
  Run 1: All frames
  Run 2: Only those frames acquired in good seeing

HUDF.YD3 with VLT/XSHOOTER

- $R = \lambda / \Delta\lambda_{FWHM} = 5000$ R=1580 in Lehnert et al. (2010)

  $\Delta\lambda_{FWHM}$=2.3Å $\Delta\lambda_{FWHM}$=7.34Å

- Reduction done in two ways:

  (1) ESO Pipeline (Modigliani et al. 2010)
  Correlates noise due to interpolation

  (2) Our own custom reduction in IRAF
  Keeps each pixel statistically independent

HUDF.YD3 with VLT/XSHOOTER

Upper limits on the Lyman-alpha Flux at z=8.55

Case 1:
Line is unresolved

It is possible that resonantly-scattered Lyman-alpha emission comes from a larger halo than the stellar continuum.
(Bunker, Moustakas & Davis 2000; Steidel et al. 2011)

But line is unresolved in Lehnert et al. (2010)

Line profile:

XSHOOTER resolution 2.3Å X 0.6" Our seeing

Using a 5Å X 0.84" aperture we capture 87% of the flux

Case 2:
Line is resolved

Deconvolving Lehnert et al. marginally-resolved spectral width of 9.2Å by SINFONI resolution (7.34Å) we get an:

Intrinsic Line-width of 5.5Å (140km/s)

Convolve with XSHOOTER resolution (2.3Å)

Our observed line-width: 6Å

Line profile:
6Å X 0.6"

We capture 66% of the flux

HUDF.YD3 with VLT/XSHOOTER

Upper limits on the Lyman-alpha Flux at z=8.55

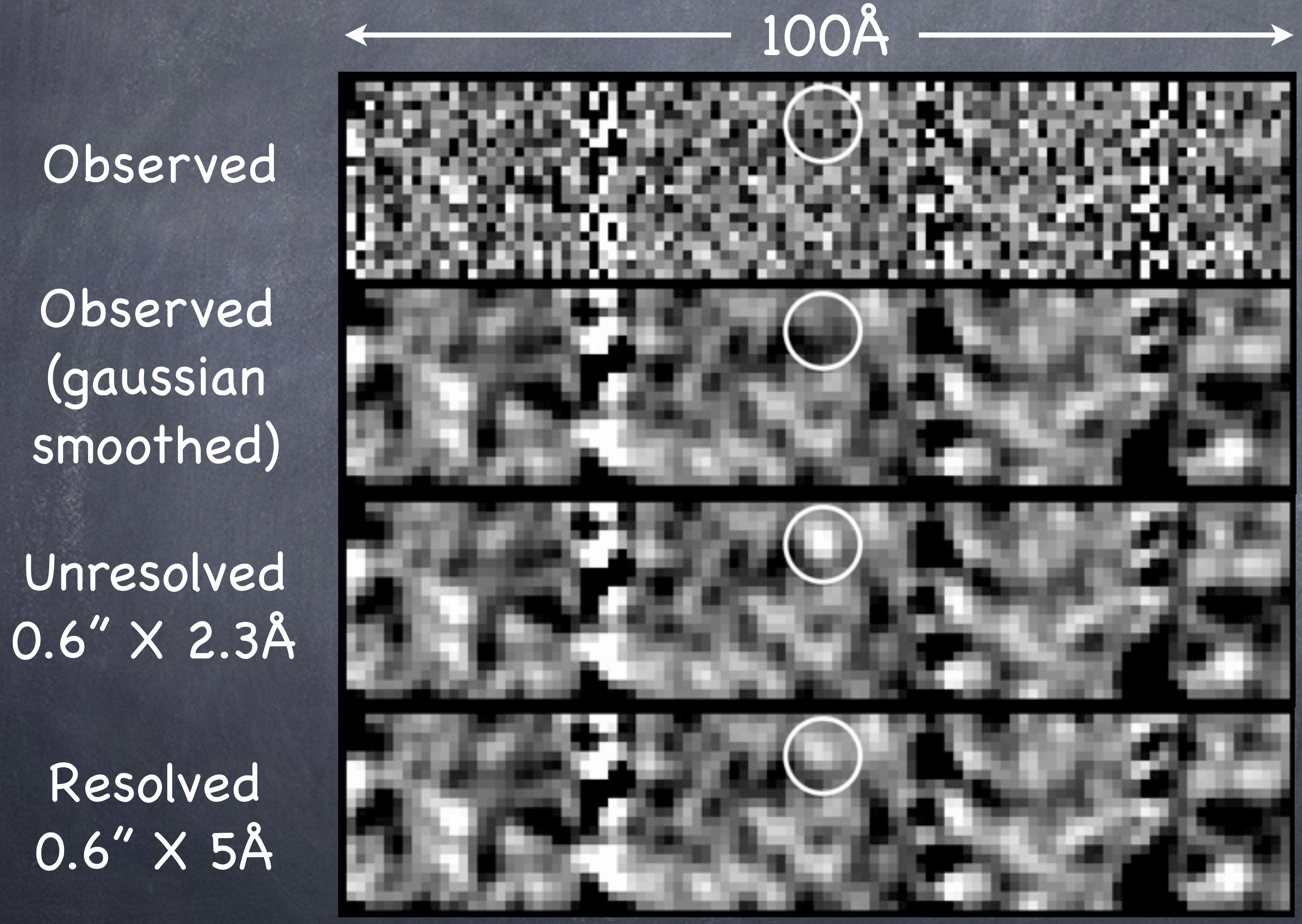
Case 1:
Line is unresolved

We expect a
4.5 σ detection

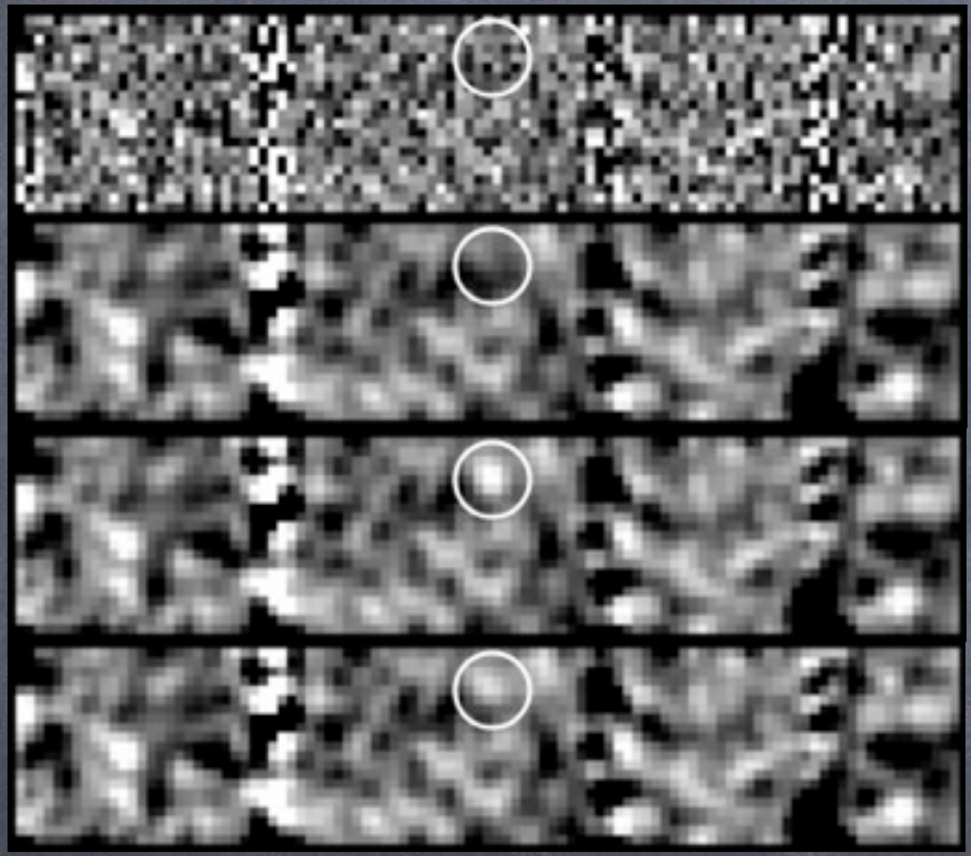
Case 2:
Line is resolved

We expect a
3.5 σ detection

HUDF.YD3 with VLT/XSHOOTER



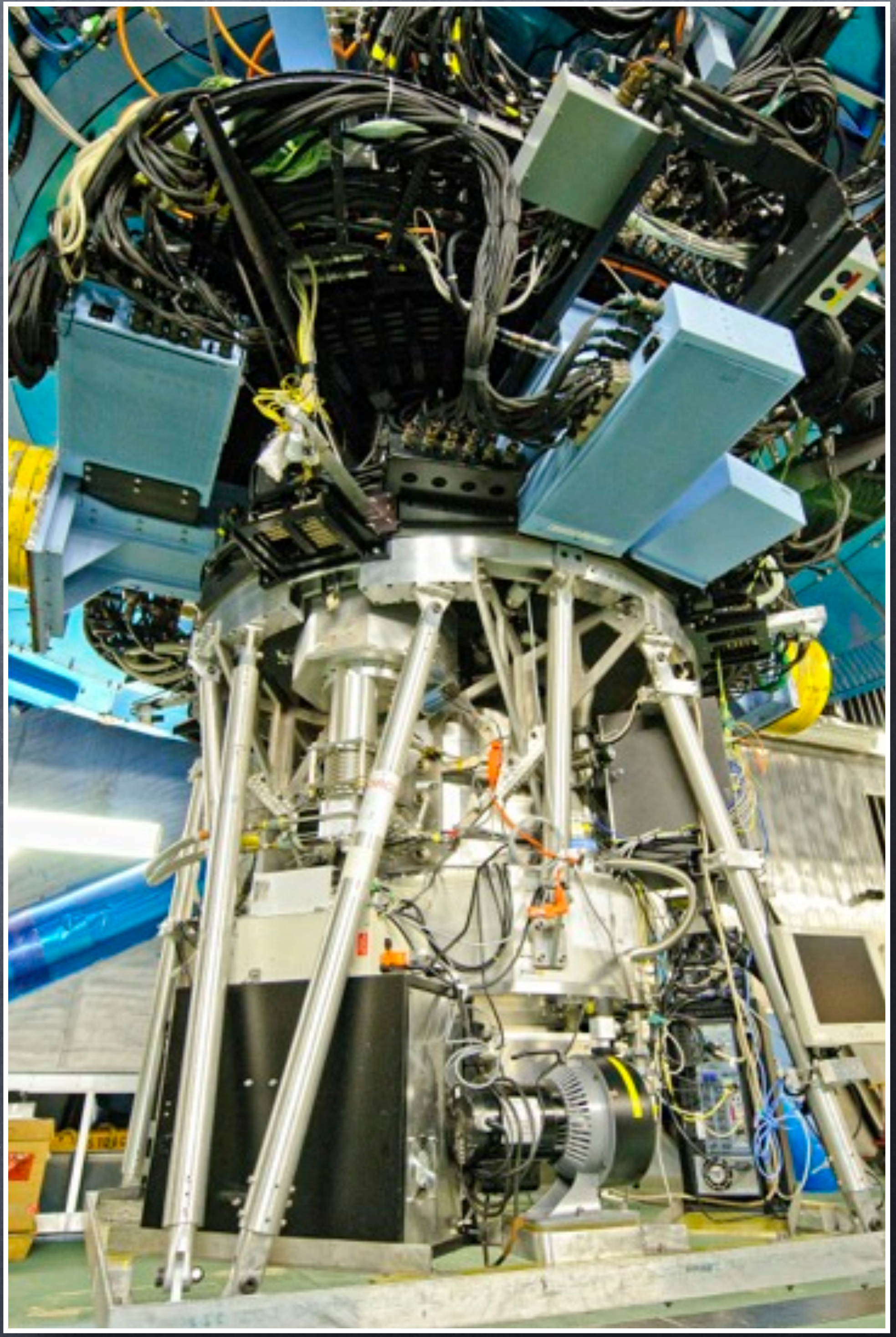
HUDF.YD3 with VLT/XSHOOTER



We do NOT see an emission line anywhere else either.

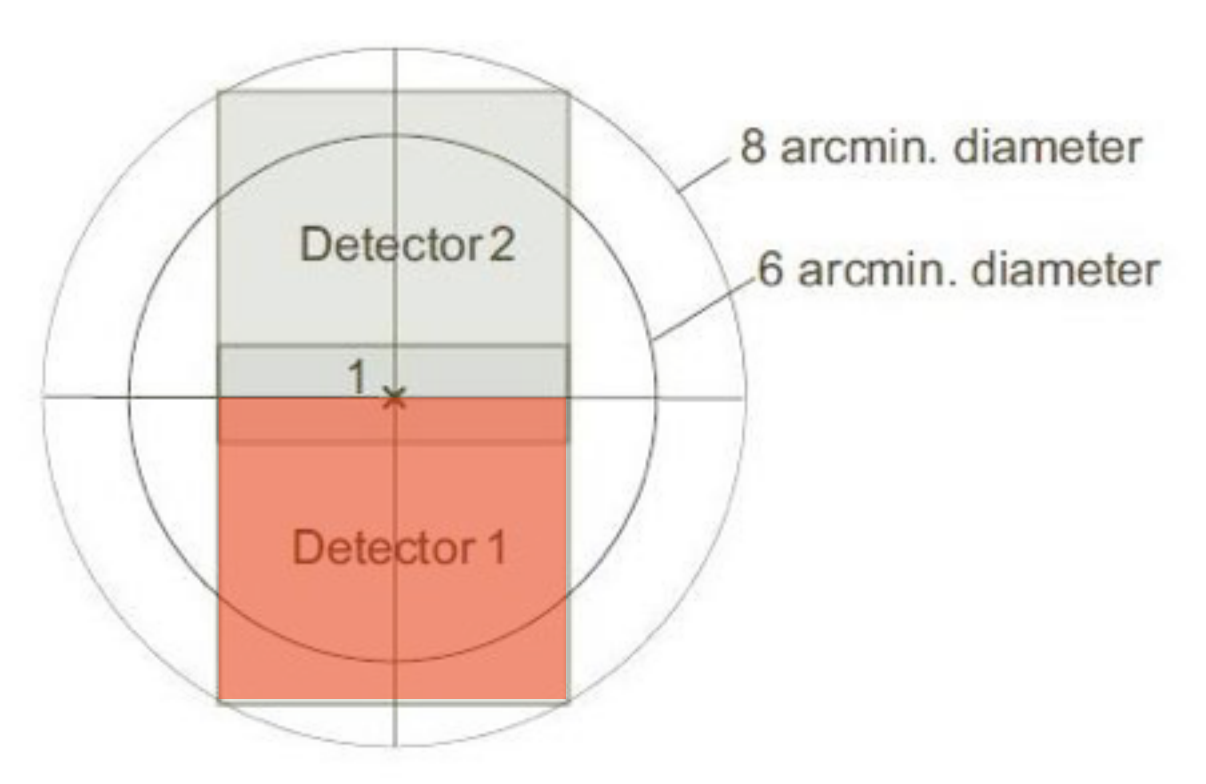
Meanwhile, up on a mountain...

HUDF.YD3 with SUBARU/MOIRCS



HUDF.YD3 with SUBARU/MOIRCS

- Multi-Object InfraRed Camera and Spectrograph (MOIRCS)
- Wide-field imaging and long-slit / multi-object (MOS) spectroscopic capabilities.
- Can acquire about 40 object spectra simultaneously.
- 0.9 – 2.5 μm spectral range.
- 4′×7′ field of view which is covered by two Hawaii-2 2048×2048 detectors.



HUDF.YD3 with SUBARU/MOIRCS

- Used the zJ500 Grism
- Centered 5 stars to an accuracy of 0.″1
- $R = \lambda / \Delta\lambda_{FWHM} = 300$, but given seeing of 0.5″, R=500

October 21 2010	October 22 2010	December 07 2010
Seeing: 0.″5	Seeing: 0.″5	Seeing: 0.″5
Slit-width: 1″.0	Slit-width: 1″.0	Slit-width: 0″.7
8 X 1200sec (2.67hrs)	12 X 1200sec (4hrs)	12 X 1200sec (4hrs)
2.″5 dither in ABABAB	2.″0 dither in ABABAB	2.″0 dither in ABABAB

HUDF.YD3 with SUBARU/MOIRCS

Using an aperture of 0.″6 X 2.8Å
(slightly larger than a resolution element)

We capture 68% of the flux

We expect a 2.7 σ detection.

2 σ from December data using the narrower slit.	0.7 σ from October data.

SUBARU/MOIRCS less deep than VLT/XSHOOTER

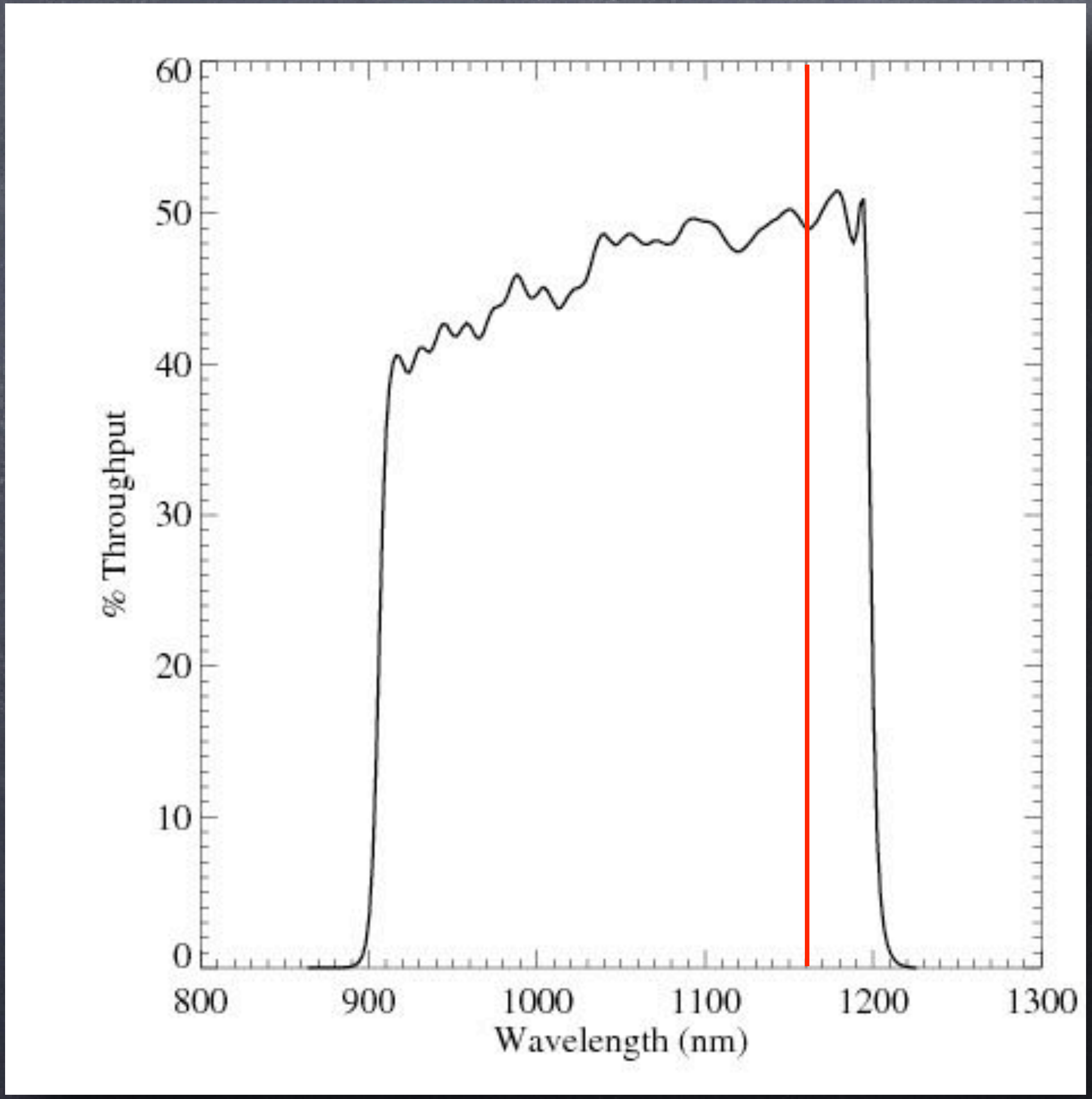
HUDF.YD3 with SUBARU/MOIRCS with VLT/XSHOOTER

2.7 σ with SUBARU/MOIRCS

3.5-4.5 σ with VLT/XSHOOTER

We rule out the Lehnert et al. (2010) line flux at the 5 σ level from our spectroscopy.

HUDF.YD3 with HST/WFC3 photometry



Expect:

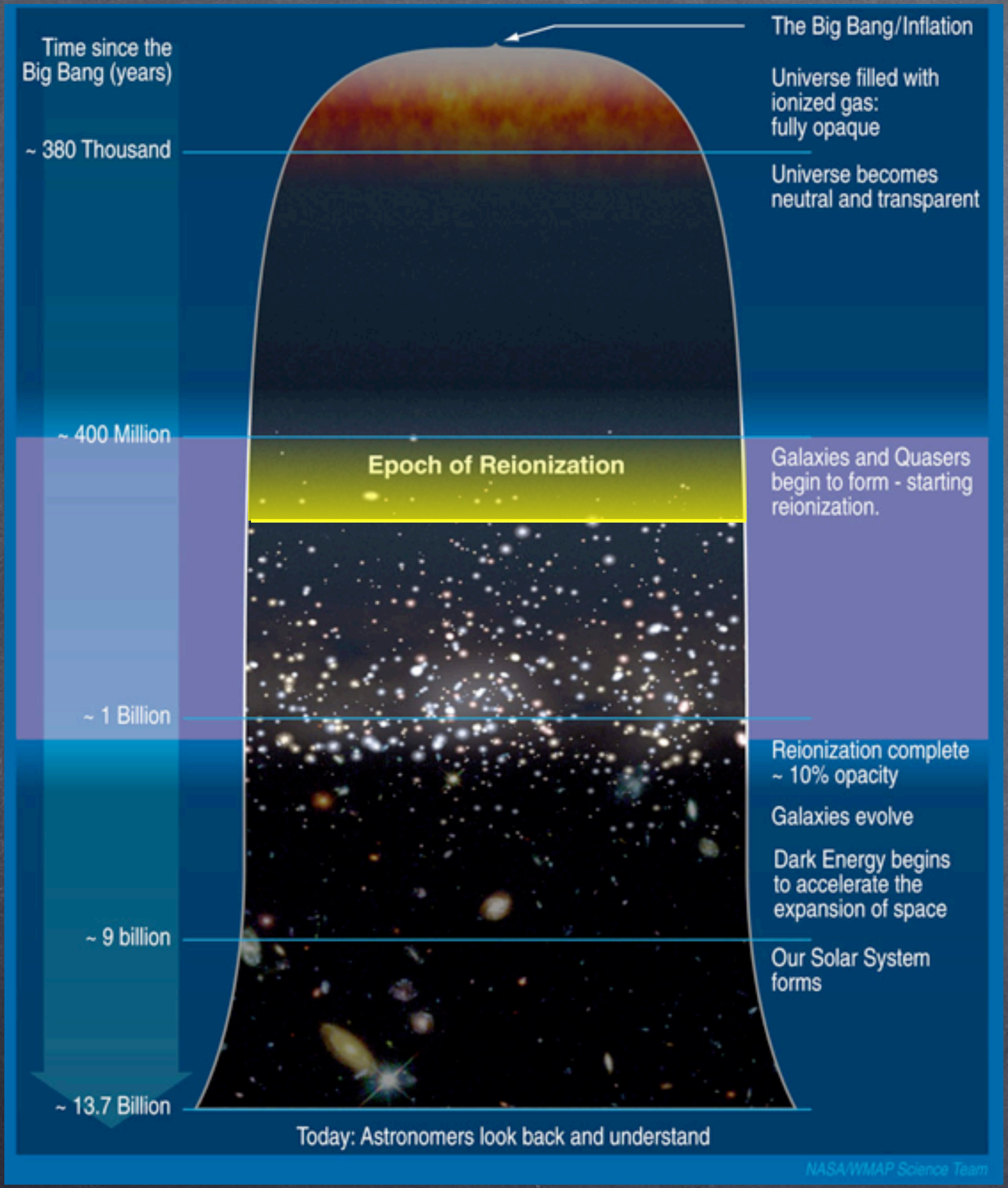
(from claimed line and continuum)

Y_{AB}=28.57

Undetected

Y_{AB} (2σ) =29.65

Inconsistent



Struggling to find Lyman-α emission

at z about 7

No evidence for Lyman-α

emission at z >

Some questions
(a.k.a. conclusions)

1) Spectroscopy of these high-z objects is tough
(need to be especially careful since we might not be able to have the S/N to measure the line profile as with lower redshift sources)

2) Could the increasingly difficult task / lack of Ly-α detections imply physical evolution of the galaxies? In particular, we want to establish whether the EW distribution at $z > 7$ differs from that at lower redshifts.

If not...

(Some) questions & conclusions

Is Lyman-alpha not emerging because of physical evolution in the IGM? (After all, the Ly-alpha line is a diagnostic for the process of reionization.)

IGM absorption increases a lot when the Universe is not fully ionized and consequently Lyman-α is significantly absorbed.

(Dayal et al. 2010)

It is a possibility that Lyman-α does not escape galaxies at higher redshifts, where the Gunn-Peterson absorption renders the Universe optically thick to this line. However, deeper spectroscopy on a larger sample of candidate $z > 7$ galaxies will be needed to test this hypothesis.

(Some) questions & conclusions

Fontana et al. (2010)

Only 1 tentative emission line.

Probability of observing no galaxies (with S/N > 10) in data is about 2%.

Probability of obsering only one galaxy (with S/N=5) out of 7 is about 4%.

Schenker et al. (2011)

2 convincing and 1 possible out of 19.

Pentericci et al. (2011)

5 galaxies at $6.7 < z < 7.1$ out of 20.
Probability of this result is below 2%.

Spectroscopy with SUBARU/MOIRCS

October 21 2010	October 22 2010	December 07 2010
Seeing: 0.″5	Seeing: 0.″5	Seeing: 0.″5
Slit-width: 1″.0	Slit-width: 1″.0	Slit-width: 0″.7
8 X 1200sec (2.67hrs)	12 X 1200sec (4hrs)	12 X 1200sec (4hrs)
2.″5 dither in ABABAB	2.″0 dither in ABABAB	2.″0 dither in ABABAB

- 11 zdrops
- 7 ydrops
- 32 X 1200sec (10.7hrs)

Spectroscopy with VLT/FORS2

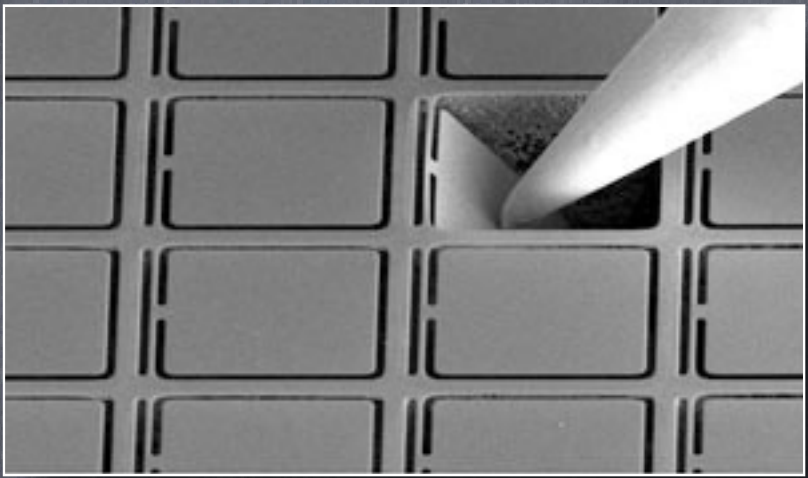
- 22 z-drops (HUDF)
- 16 i-drops
- 24 X 1400sec (9.3hrs)
- Awarded 26 hours of additional observing time in 2011/2012
- Keeping the same mask design and targeting the same objects, obtaining ultra deep spectroscopy.
  Total: 35hrs of spectroscopy on these sources

Future prospects for spectroscopic efforts

- Does Lyman-alpha emerge during the Gunn-Peterson era?
- Lyman-alpha is currently the only way of confirming these high-z sources.

As we push to even higher redshifts...

...(potentially very) far future



If no Ly-alpha, then we could try OII.


That's all Folks!