
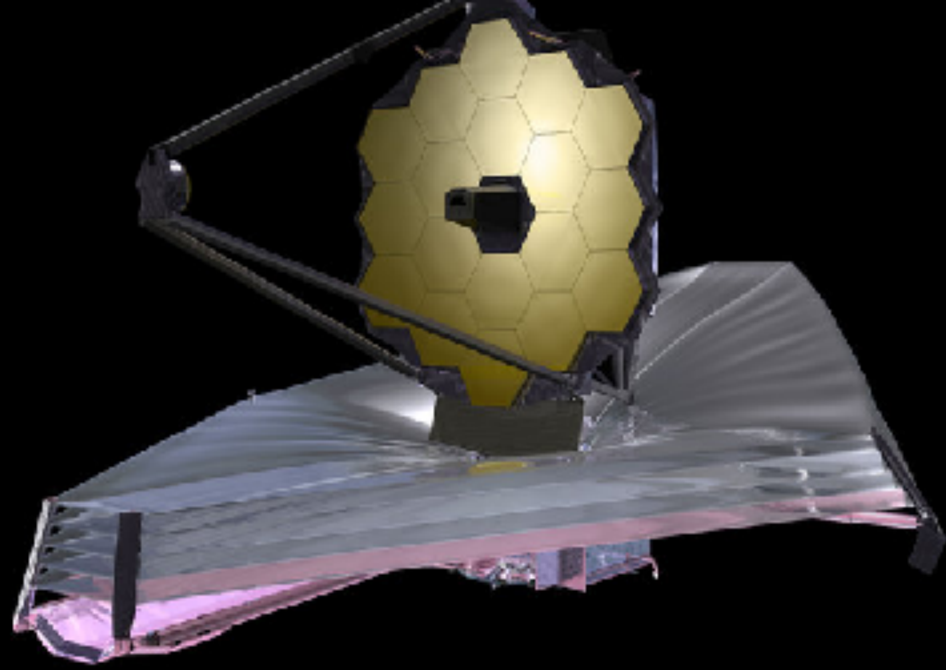


Resolved Star Formation in Galaxies Using Slitless Spectroscopy

N. Pirzkal (STScI)
and
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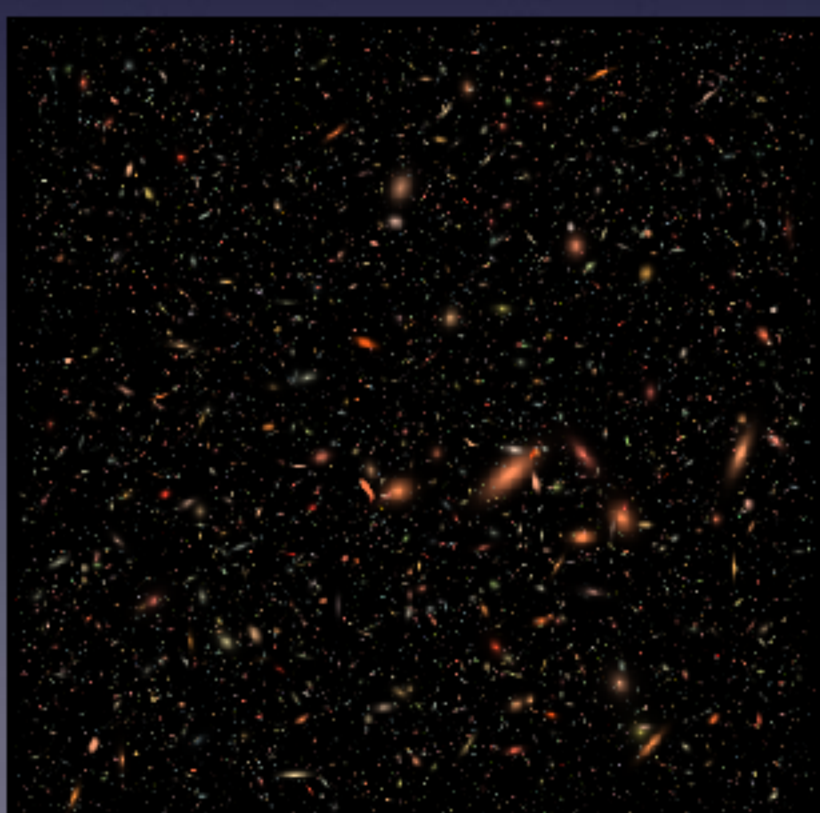
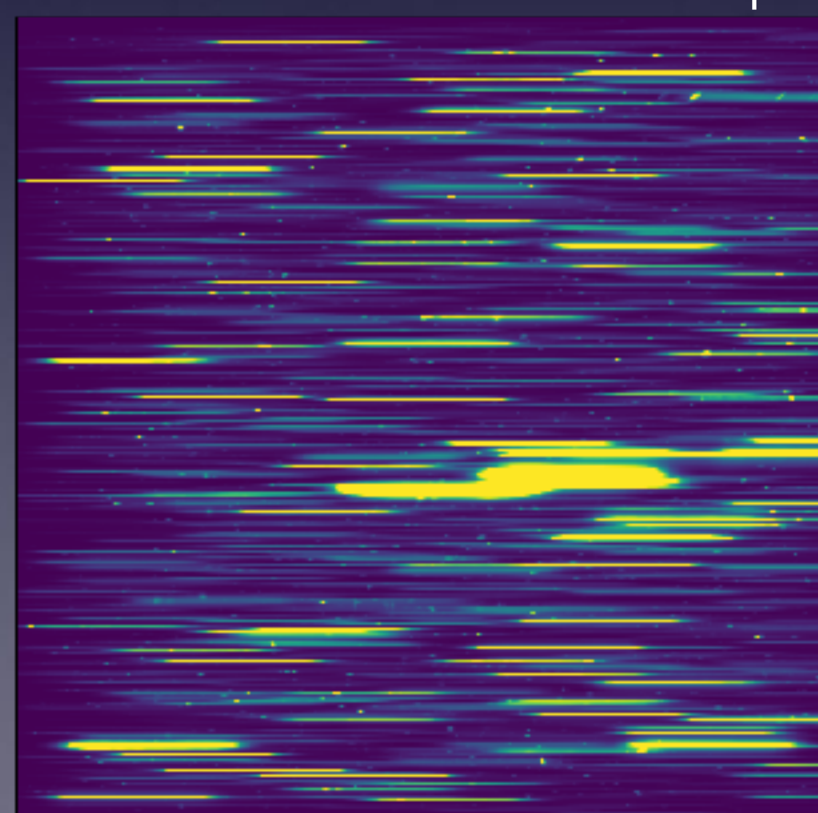
S. Malhotra, N. Grogin, A. M. Koekemoer, J. Rhoads, L. Christensen, A. Cimatti, I. Ferreras, J. P. Gardner, C. Gronwall, N. P. Hathi, P. Hibon, B. Joshi, H. Kuntschner, G. R. Meurer, R. W. O'Connell, G. Oestlin, A. Pasquali, J. Pharo, A. N. Straughn, J. R. Walsh, D. Watson, R. A. Windhorst, N. L Zakamska, A. Zirm

Wide Field Slitless Spectroscopy

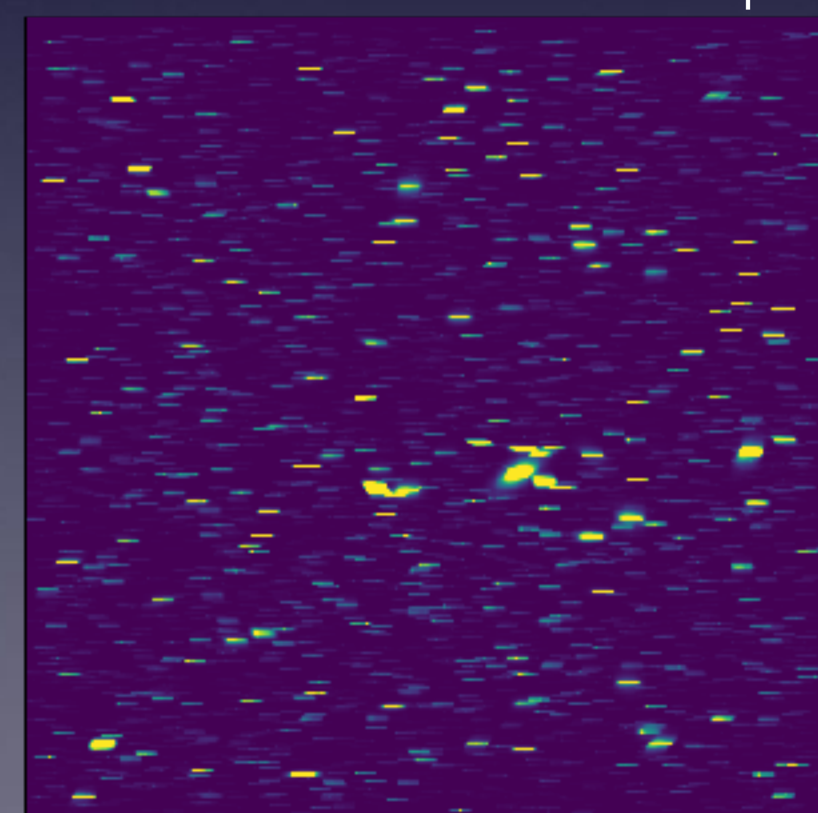
- Efficient blind emission line searches
- Large multiplexing
- Wide, un-interrupted wavelength (redshifts) ranges
- Successfully used with NICMOS, ACS, WFC3 (GRAPES, PEARS, 3D-HST, FIGS)
- Future missions (JWST, WFIRST)



JWST NIRCAM ~ 4.1μm

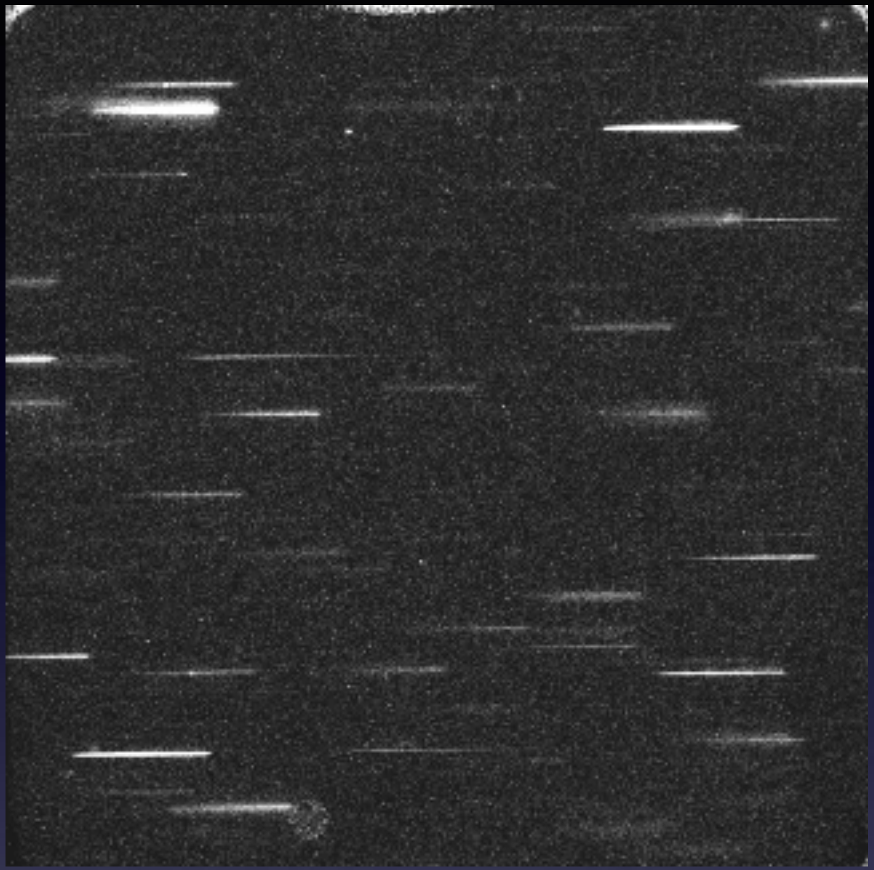


JWST NIRISS ~ 1.5μm



Looking for Ly-α and emission lines using Simulation Based Extraction (SBE)

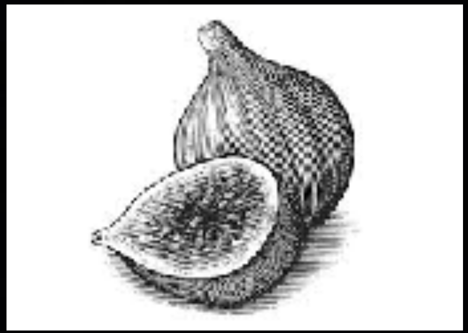
- “Classic” slitless extraction
- Starts with being able to simulate individual observations:
  - Improved contamination correction
  - Improved flux calibration
  - Based on deep imaging and source catalogs from ancillary data
- Really still just an improved simple box extraction



Single exposure

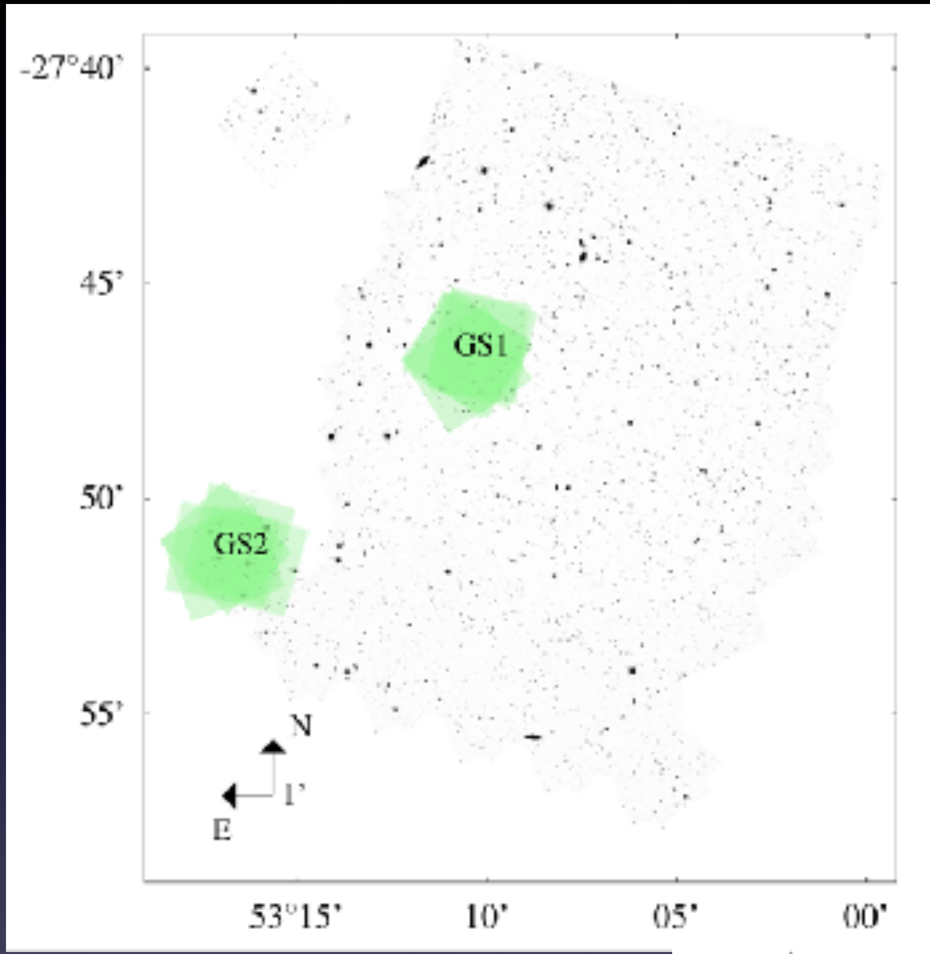
Pirzkal et al. 2017

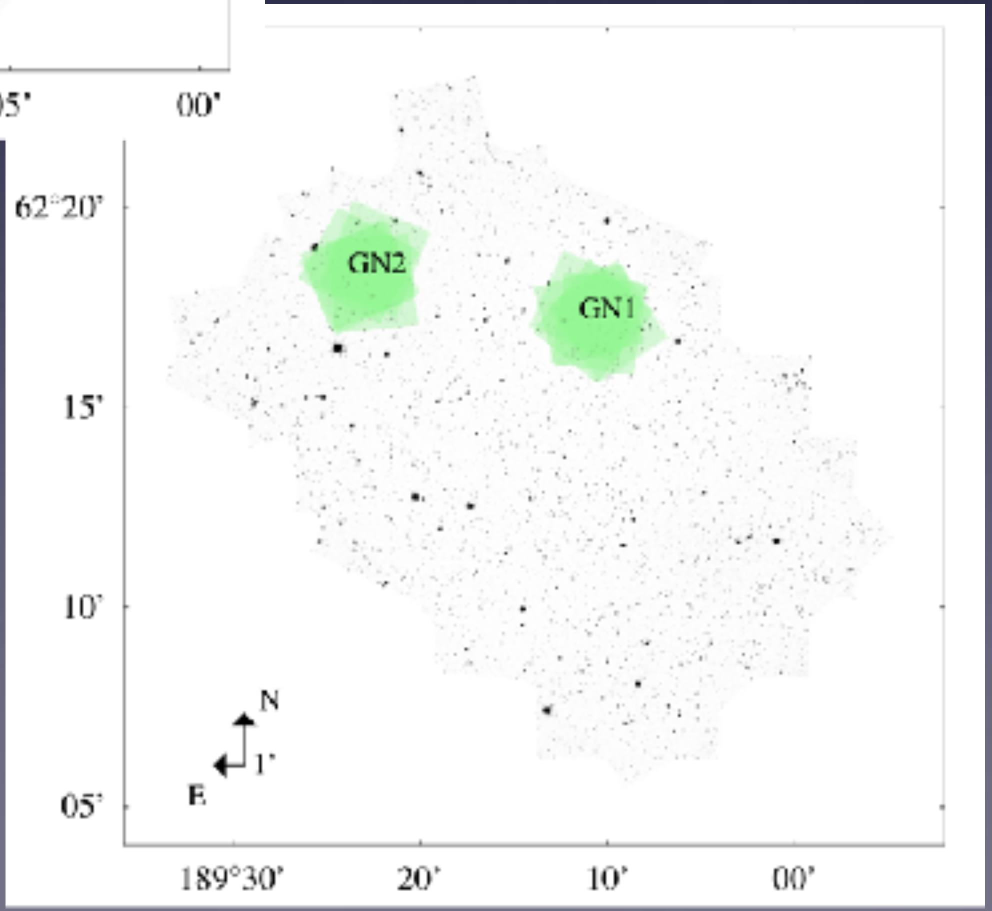
Simulation



WFS using HST/WFC3: FIGS, Faint Infrared Grism Survey

- Deepest WFC3 G102 grism observations
- R=150, 8000Å<λ<11500Å
- 4 pointings/fields, 40 orbits depth
- 5 PAs per field
- 18 arcmin^2
- Science goals: high-z Ly-α, old massive galaxies, intermediate redshift Hα, [OIII], and [OII] emitters.

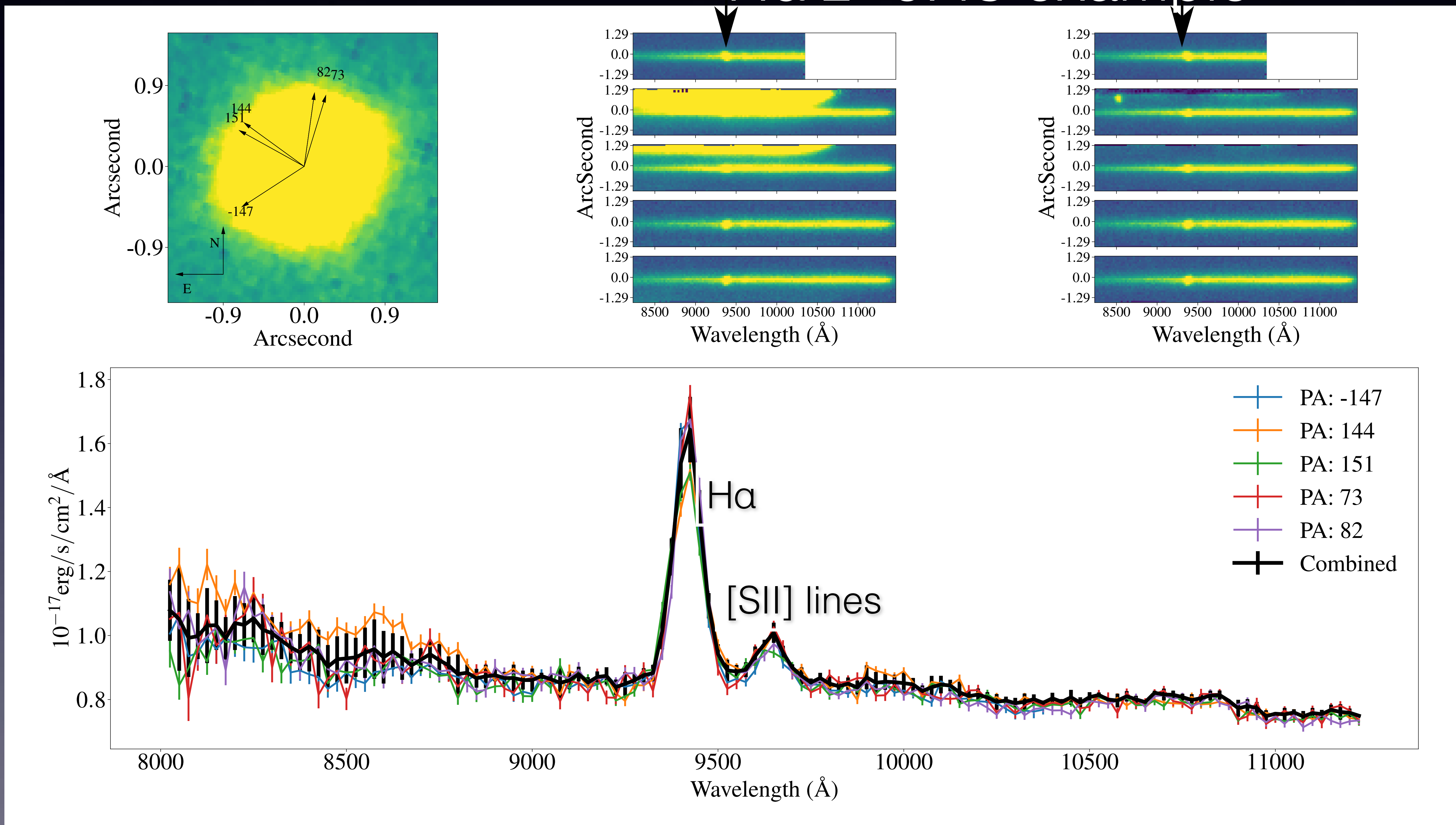




Pirzkal et al. 2017a

FIGS, Simulation Based Extraction
Low-z sources

Hα z=0.43 example



Pirzkal et al. 2017

FIGS, Simulation Based Extraction
Two z~7.5 Ly-α galaxies

EW~50A

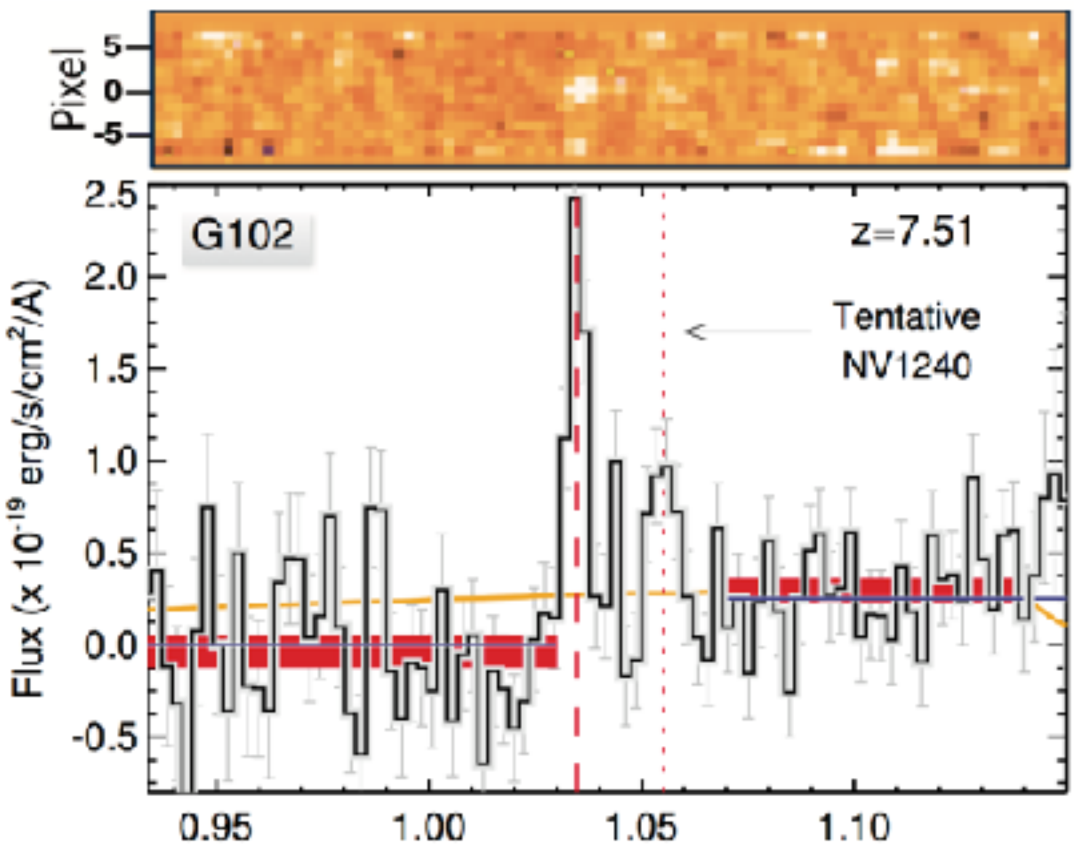


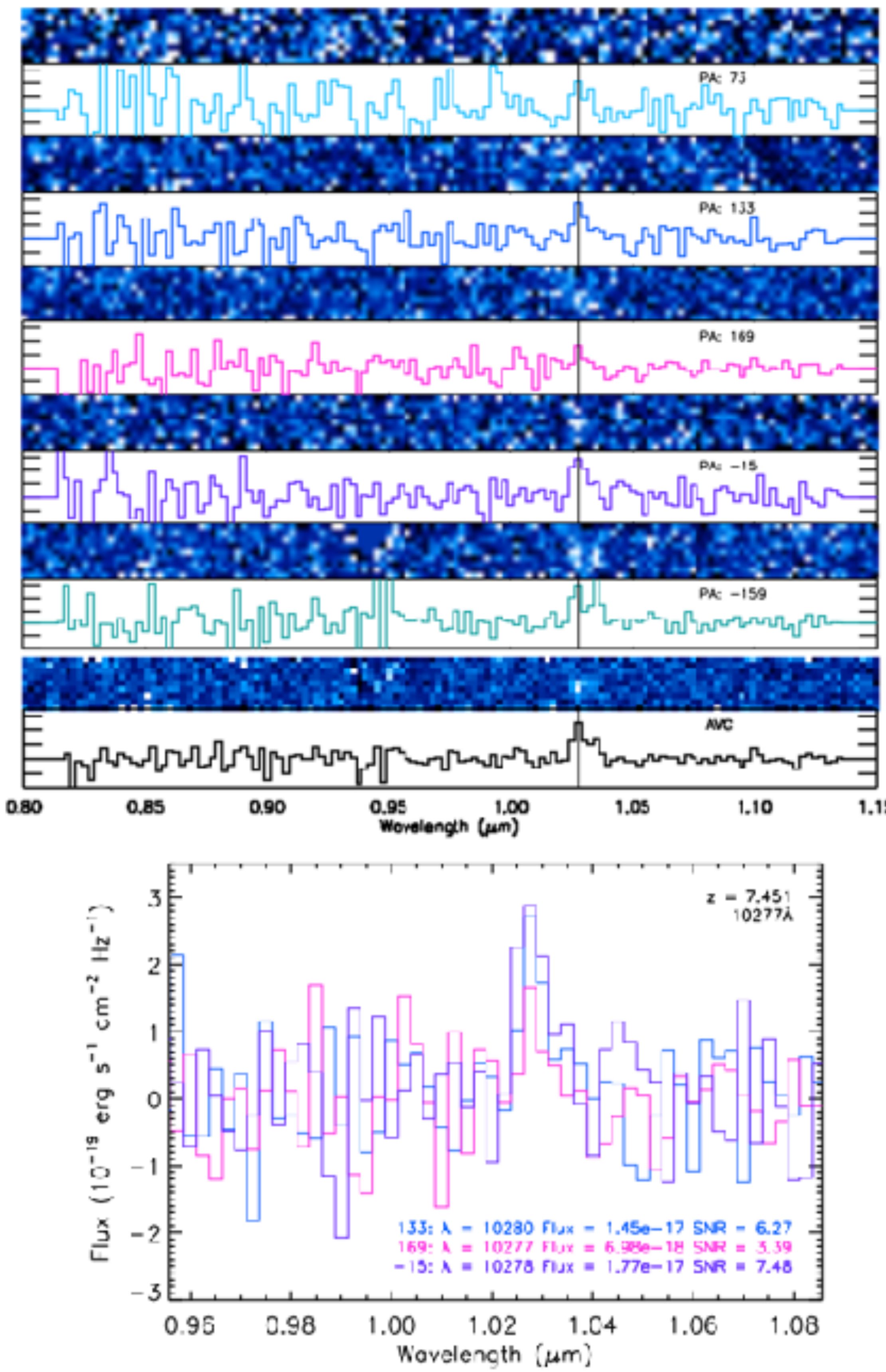
TABLE 1
PROPERTIES OF FIGS_GN1_1292

	Grism	MOSFIRE[a]
RA, DEC	12:36:37.913 +62:18:08.60	
$\lambda_{Ly\alpha}$ (μm)	1.0347±0.005	1.0343± 0.0004
$z_{Ly\alpha}$	7.512±0.004	7.5078± 0.0004
$z_{Lyman-break}$	7.512	–
$f_{Ly\alpha}$ (10^{-17} erg s^{-1}cm^{-2})	1.06±0.19	0.264± 0.034
$f_{\lambda>1.07\ \mu m}$ (10^{-20} erg s^{-1}cm^{-2})	2.52±0.59	–
$W_{Ly\alpha(rest)}$ (Å)	49.3±8.9	7.5± 1.5
FWHM (Å)	44±9	7.7± 1
$L_{Ly\alpha}$ (10^{42} erg s^{-1})	7.1±1.3	1.77± 0.36
Y_{F105W} (mag)	26.7±0.2	–
Lyman-break significance (σ)[b]	4.8	–

[a] From Finkelstein et al. (2013).
[b] Based on bootstrap technique (see §3.5).

Tilvi+2016

EW~150A

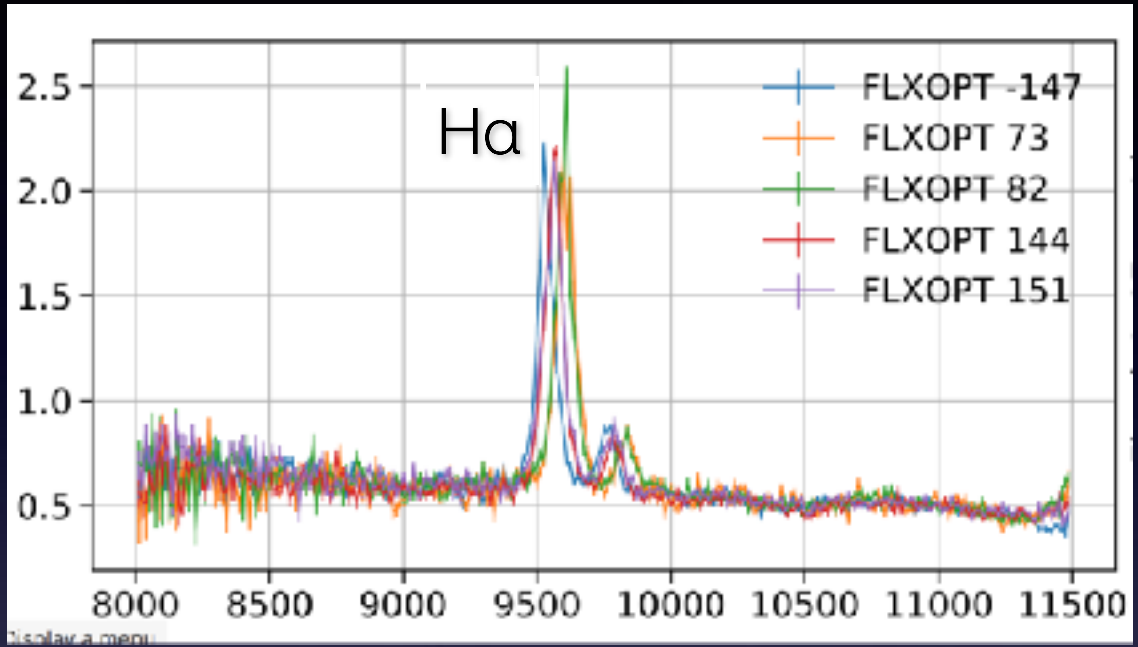


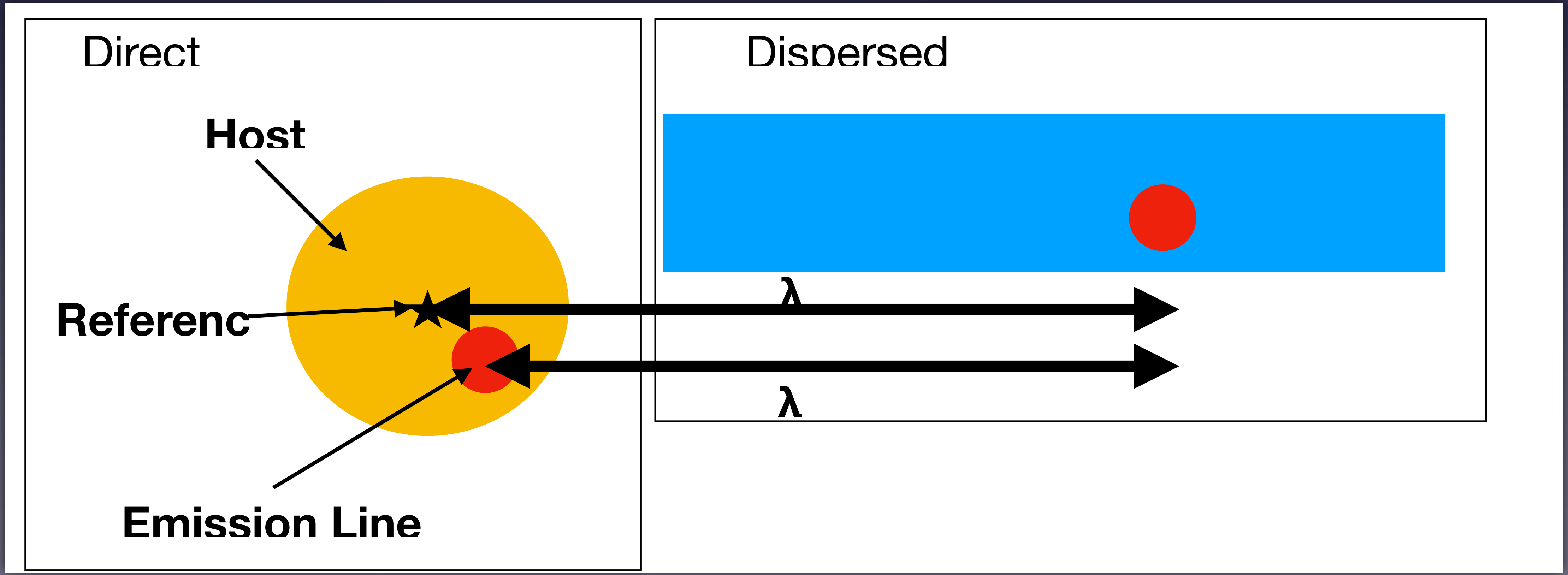
N. Pirzkal, Tokyo 3/28/18

Larson+2017

Resolving star formation: EM2D

- Location, location, location!
- Importance of deriving the exact source of emission lines
- Impact on wavelength calibration and combination of multi-PA observations





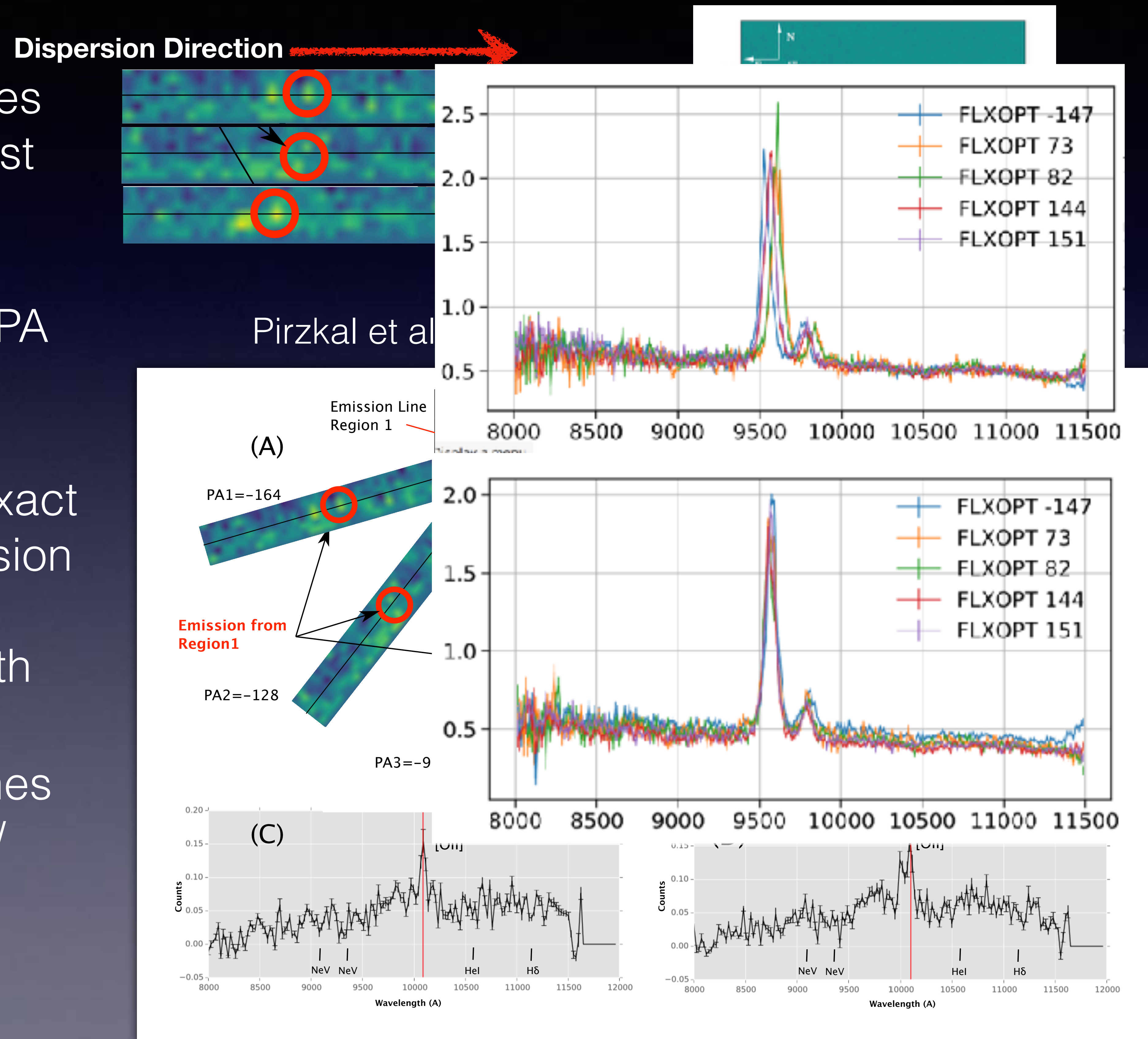
Resolving star formation: EM2D

- Identify emission lines independently of host galaxy

- Leverages multiple PA observations

- We determine the exact location of the emission line region AND its observed wavelength

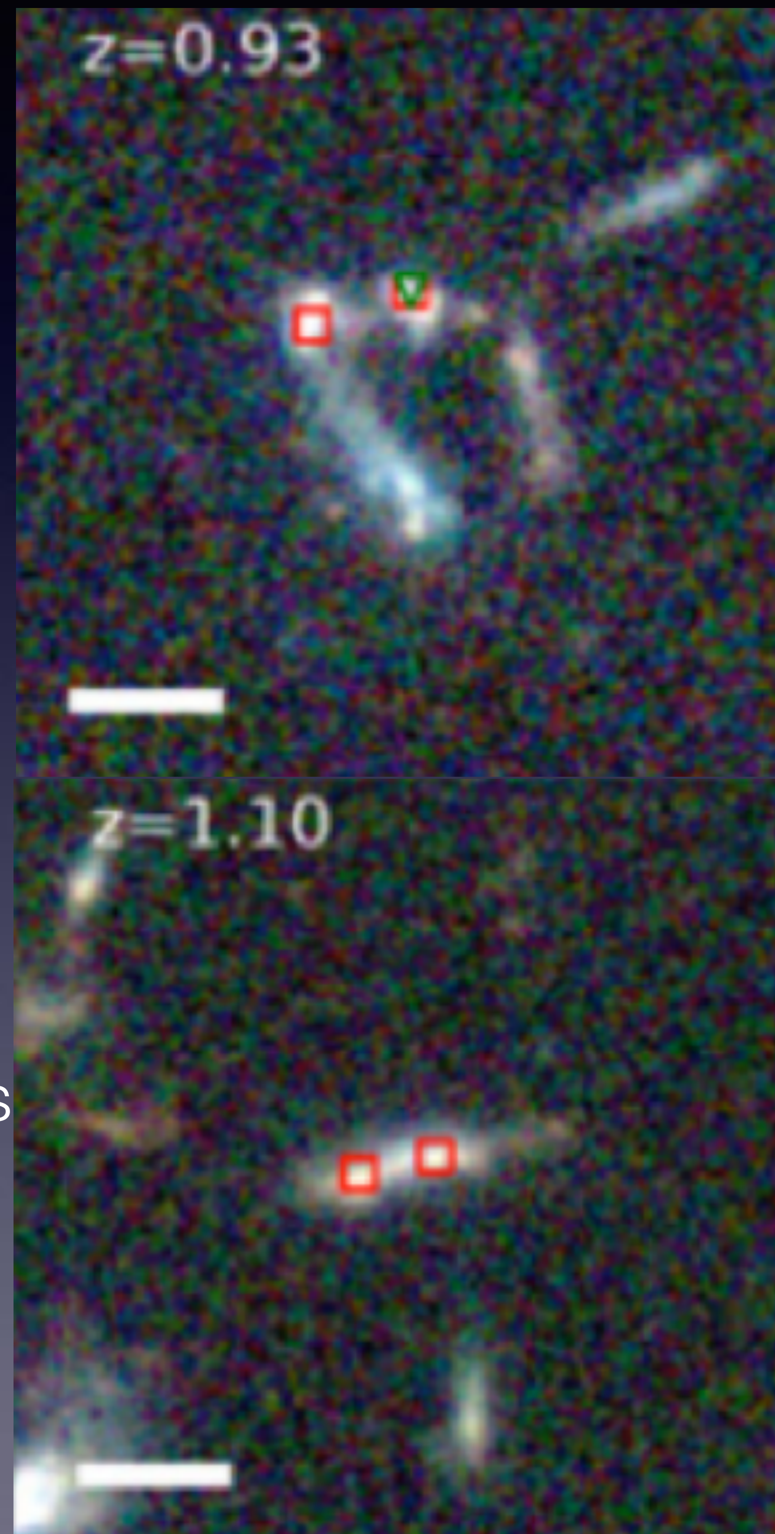
- Multiple emission lines (e.g. [OIII]/Hα, [OII]/[OIII]) detected separately



Locating star formation: EM2D

WFSS in the optical using ACS

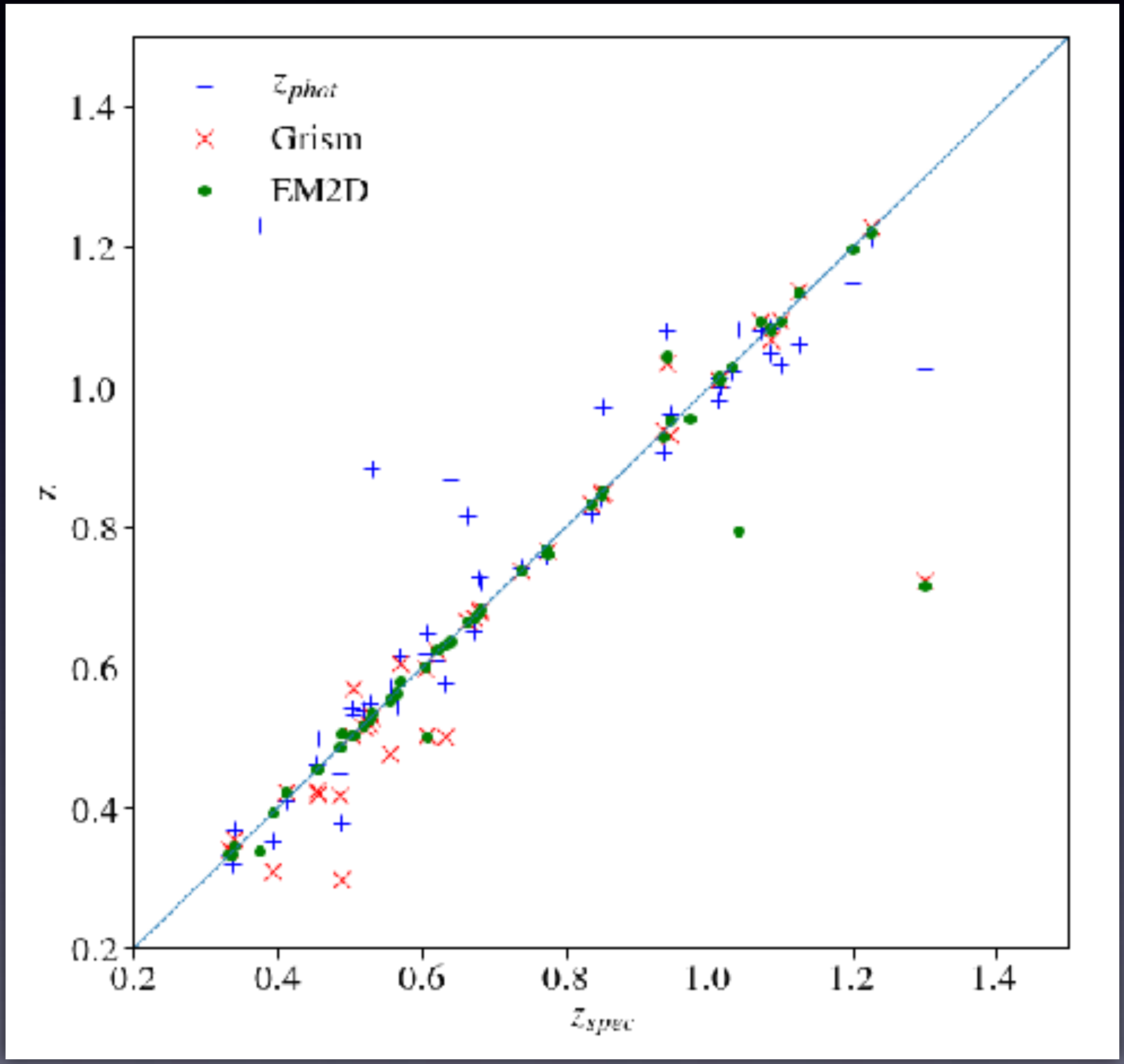
- PEARS, ACS grism survey
- 1162 emission lines
- $z<1.5$
- flux limit of $\sim 10^{-17}$ erg/s/cm^2
- Multiple star forming regions AND line species
- Spectral extraction of individual star forming regions
- Allows for studying properties (SFR etc..) of individual star forming regions! (Pirzkal+2013)



Locating star formation: EM2D

WFSS Spec-Z improvement

- FIGS, WFC3 grism survey (NIR)
- 303 emission line regions
- 237 galaxies
- Hα (134), [OIII] (115), [OII] (58)
- Lyα (1): z=7.5 independently detected (Larson et al. 2017 source)
- z<3
- flux limit of $\sim 10^{-17}$ erg/s/cm^2
- Position of emission line regions $\sim e^{-0.8x}$
- Significant correction with 30% of sources $\delta z/(1+z) > 0.005$

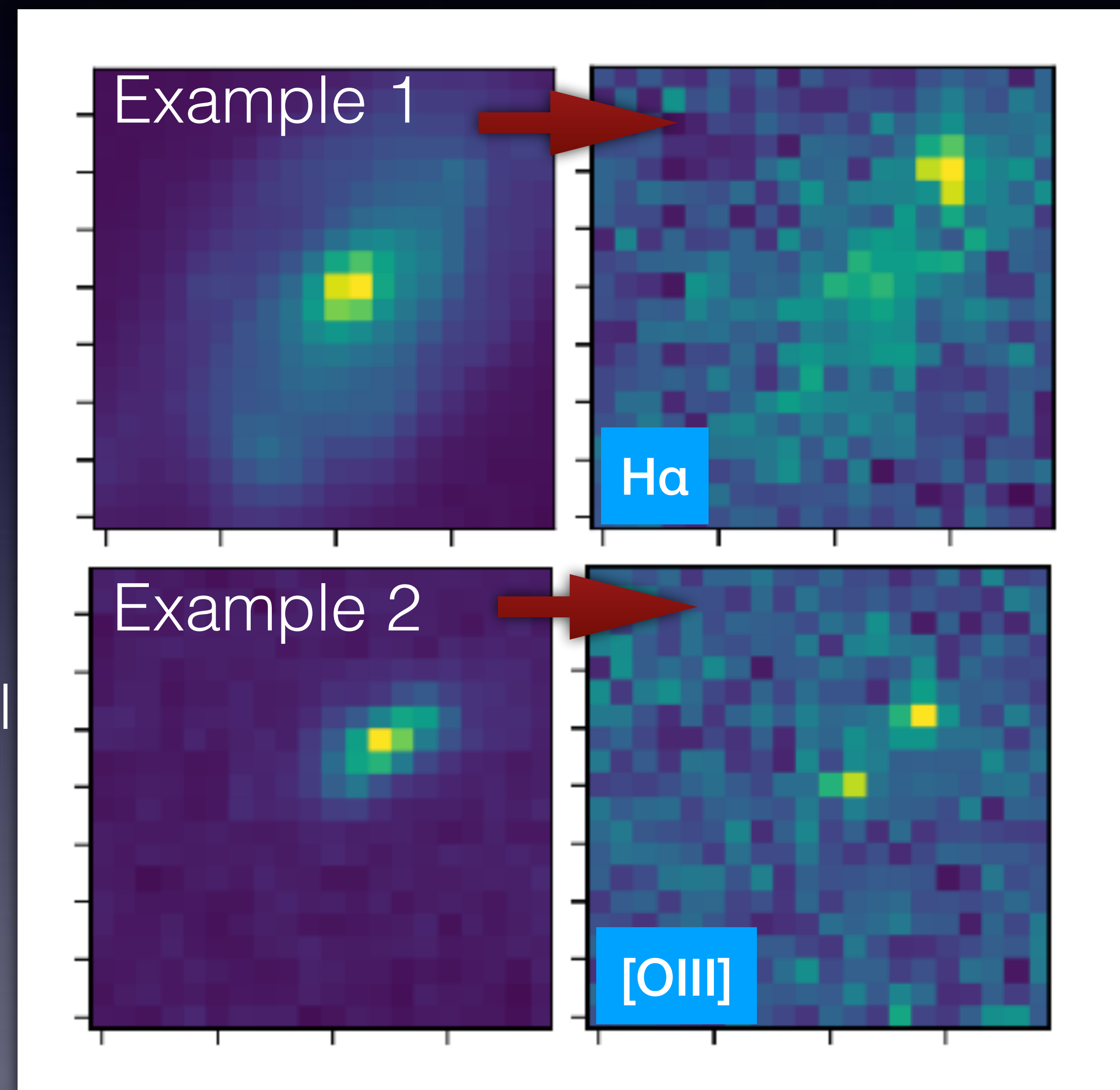


Pirzkal+18a in prep

Resolving star formation: MAP2D

- Once an accurate observed wavelength is know, we can build full 2D maps of the emission features
- Forward model each individual, continuum subtracted spectra
- Enables a more intricate look at star formation in these objects
- Detection of diffuse star formation as well as fainter multiple star forming regions
- Applicable to JWST observations taken using multiple orientations, i.e. much higher redshifts (z<9) than we currently reach with HST/WFC3

Broadband 2DMAP



Pirzkal+18b in prep

Resolving star formation: MAP2D

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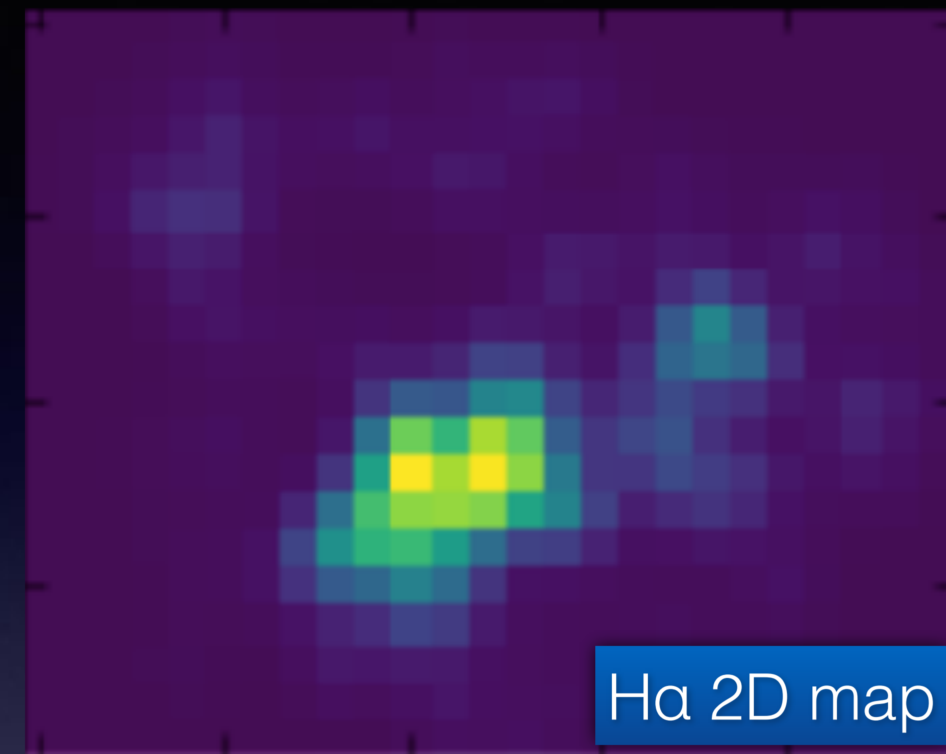
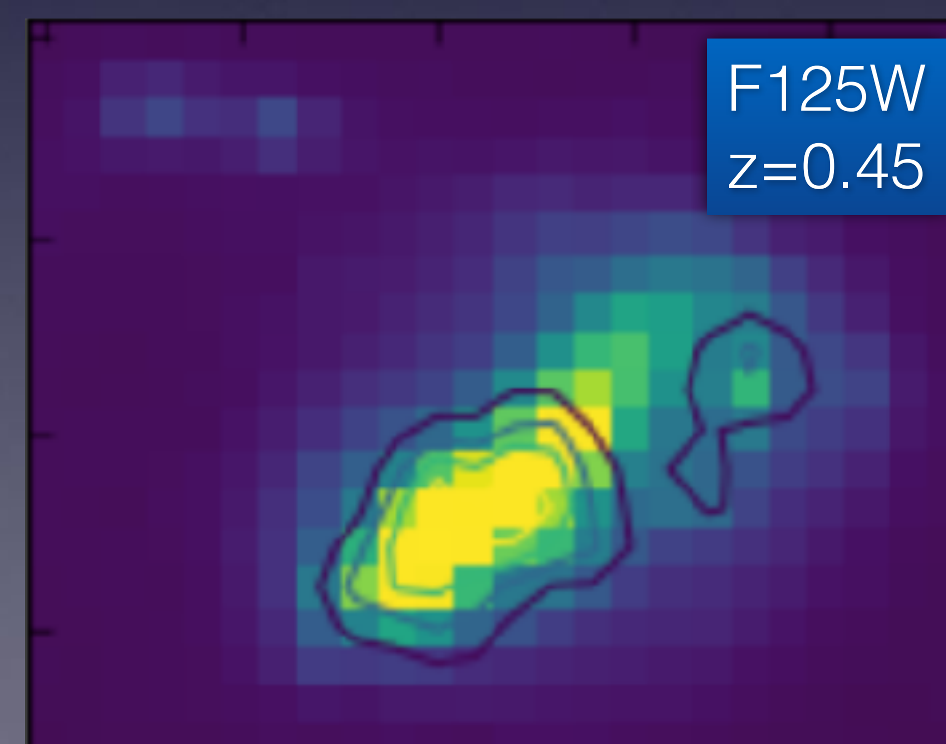


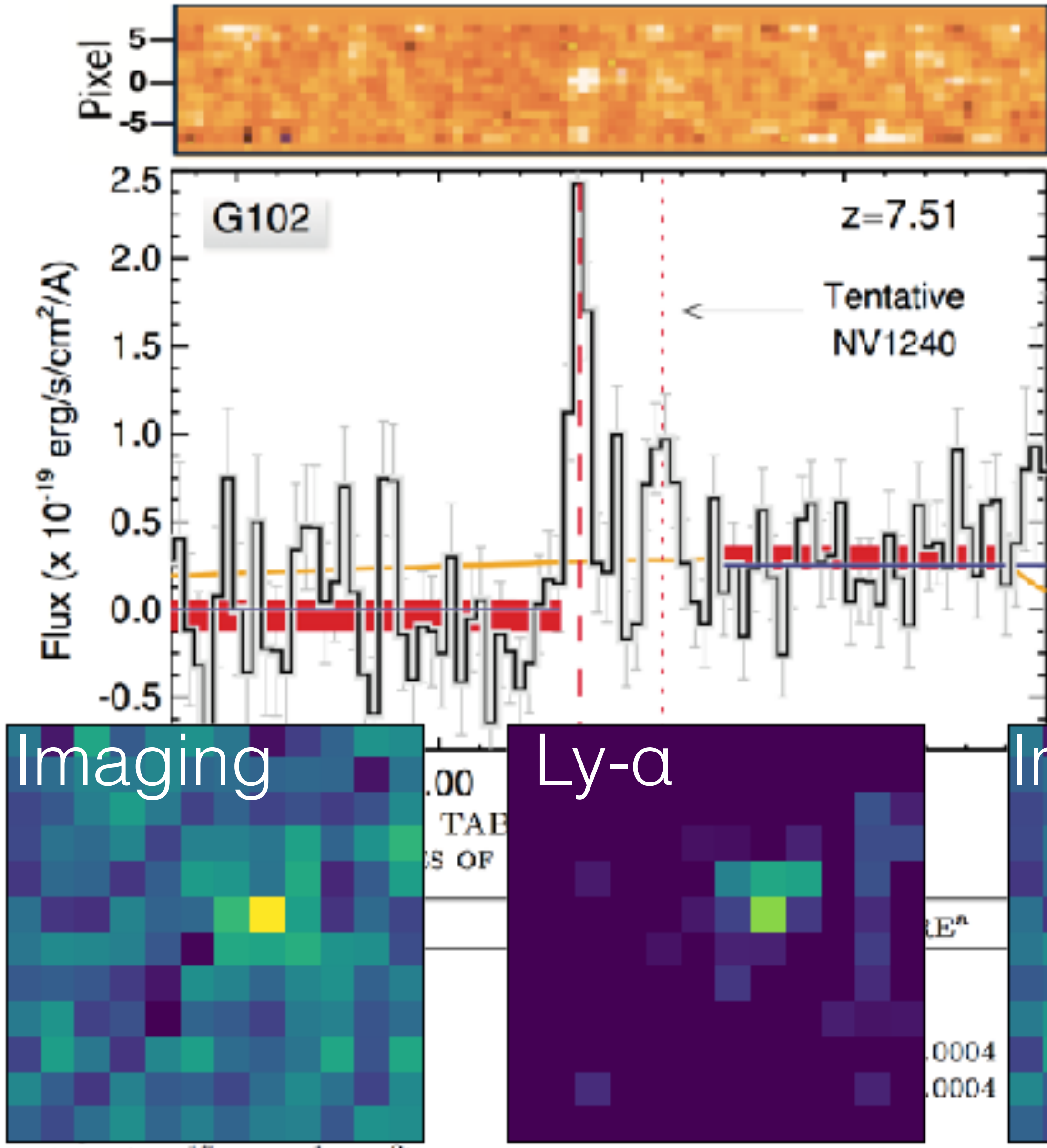


Pirzkal+18b in prep

MAP2D: Ly-α sources at z~7.5

EW~50A

EW~150A



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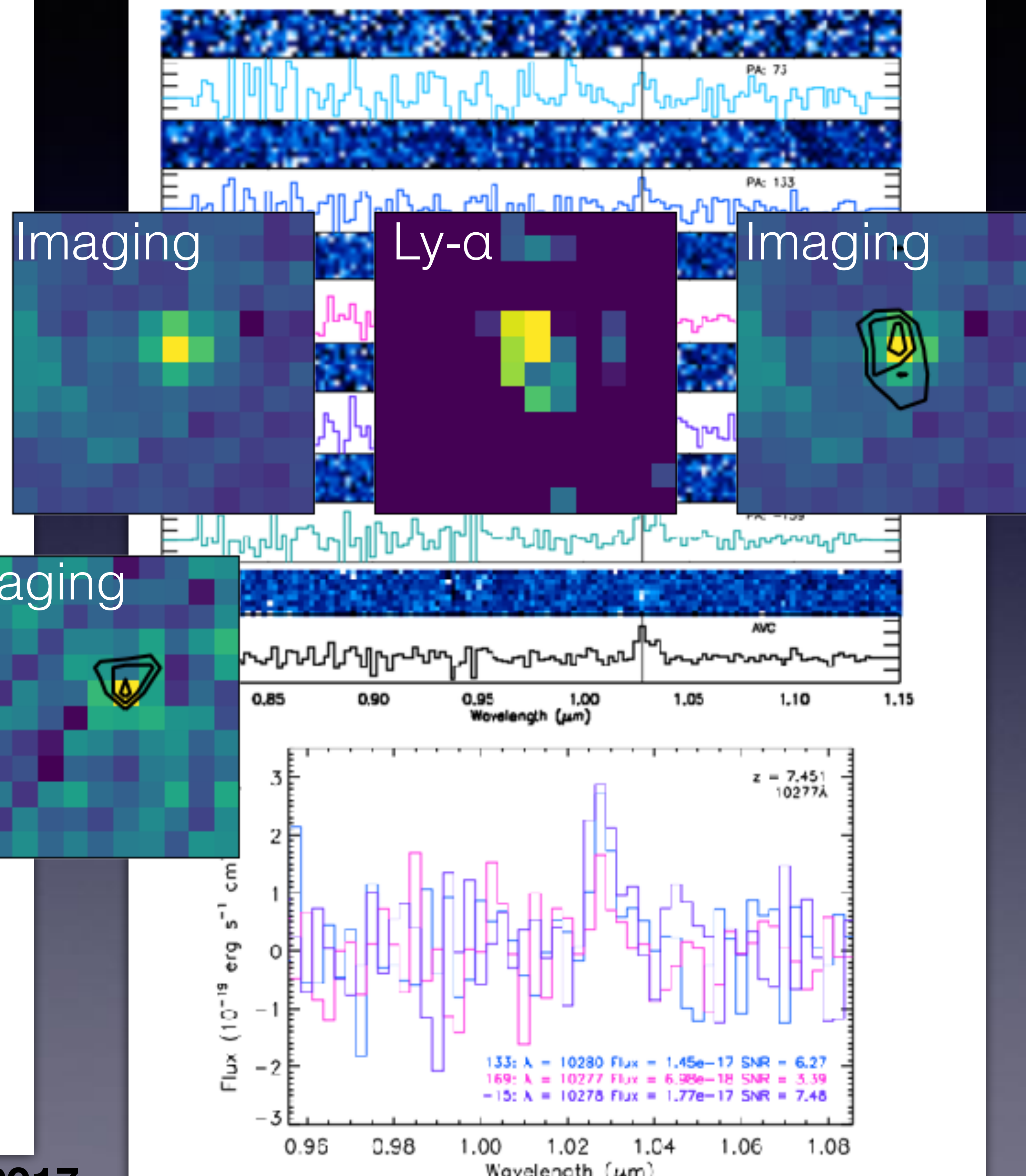
Tilvi+2016



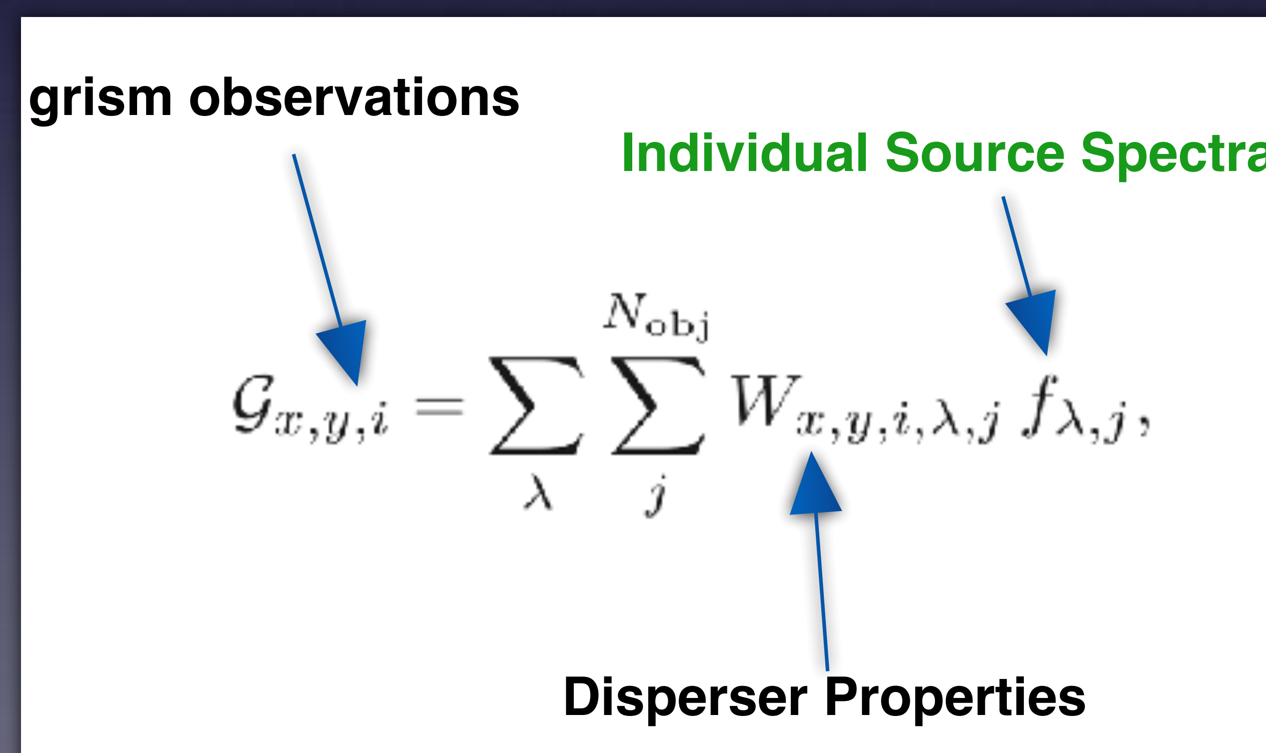
N. Pirzkal, Tokyo 3/28/18

Larson+2017

Finding faint Ly-α emitters: LINEAR

- Extraction of faint emission line from WFSS data requires an optimal approach to maximize S/N:
  - LINEAR: non parametric forward modeling
  - Resolves the problem of contamination

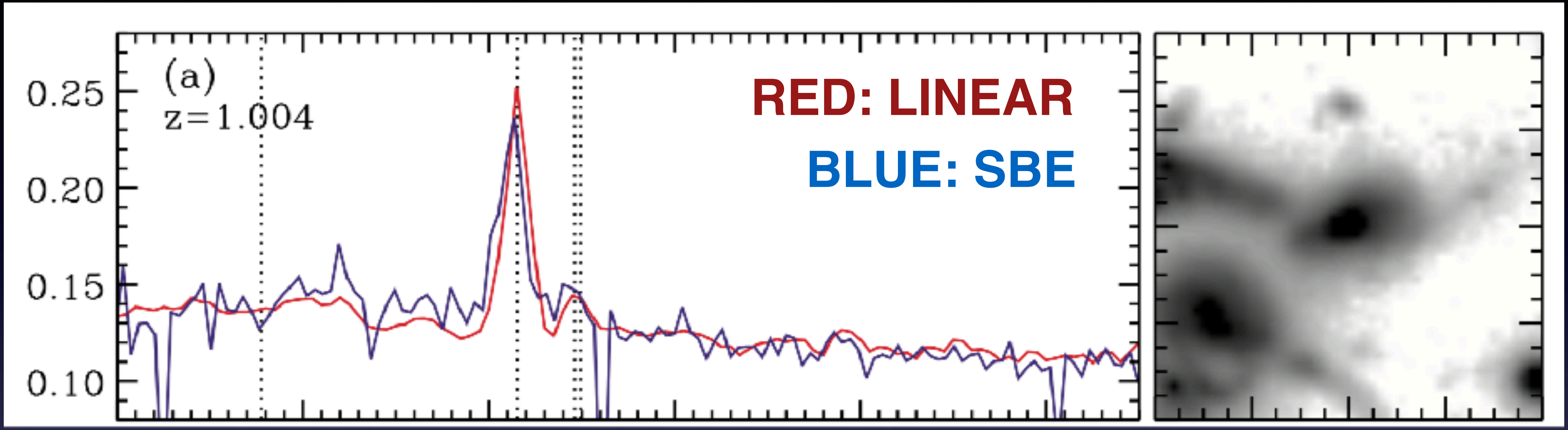
- Overlapping spectra (contamination) has up to now been solved using modeling (SBE)
- Problem can be framed as a large matrix operation
- Non-parametric reconstruction of the spectra in the field
- Arbitrary spectral resolution can be tailored to specific cases (lower resolution for faintest spectra)
- FIGS: 100 images, 10^6 pixels each, with 1000 objects with 100 spectral element spectra
- Problem is one of a VERY large matrix inversion (10^8 x 10^5)
- But most elements are zero (>99.9%)
- Can be handled using modern computers and LQSR algorithm
- This is now implemented in LINEAR!!!



$$\mathcal{G}_{x,y,i} = \sum_{\lambda} \sum_{j}^{N_{\rm obj}} W_{x,y,i,\lambda,j} \, f_{\lambda,j},$$

Ryan, Casertano and Pirzkal+17

LINEAR examples

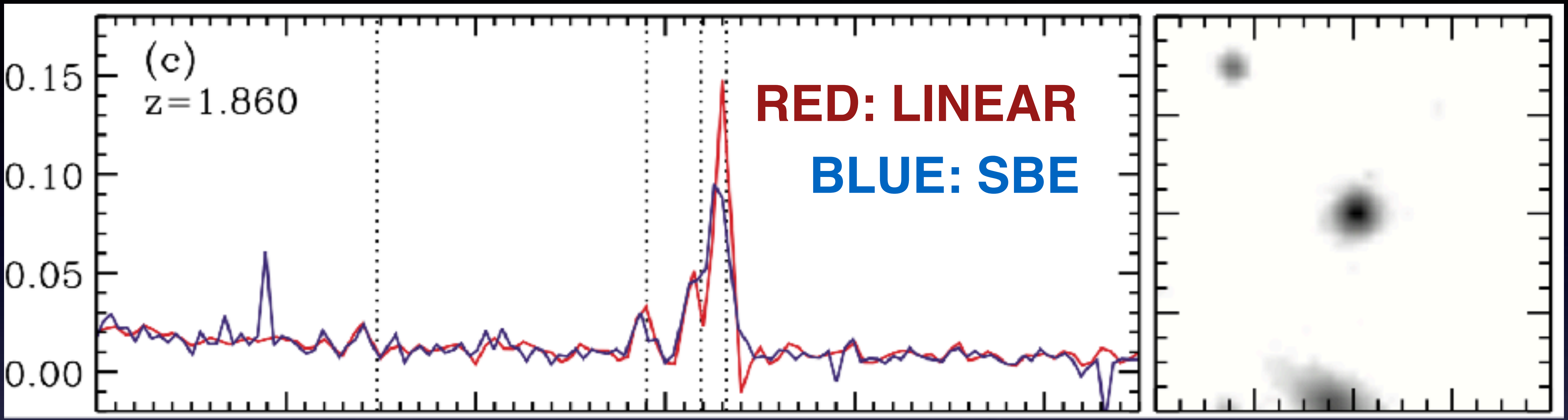


Ryan, Casertano, Pirzkal 2017

- LINEAR non-parametric reconstruction significantly improves on current state-of-the-art SBE extraction (e.g. Pirzkal et al. 2017a)
  - Resolution can be improved in high signal to noise case
  - Signal-to-noise can be increased by reconstructing lower resolution spectra

Ryan, Casertano and Pirzkal+17

LINEAR examples



Ryan, Casertano, Pirzkal 2017

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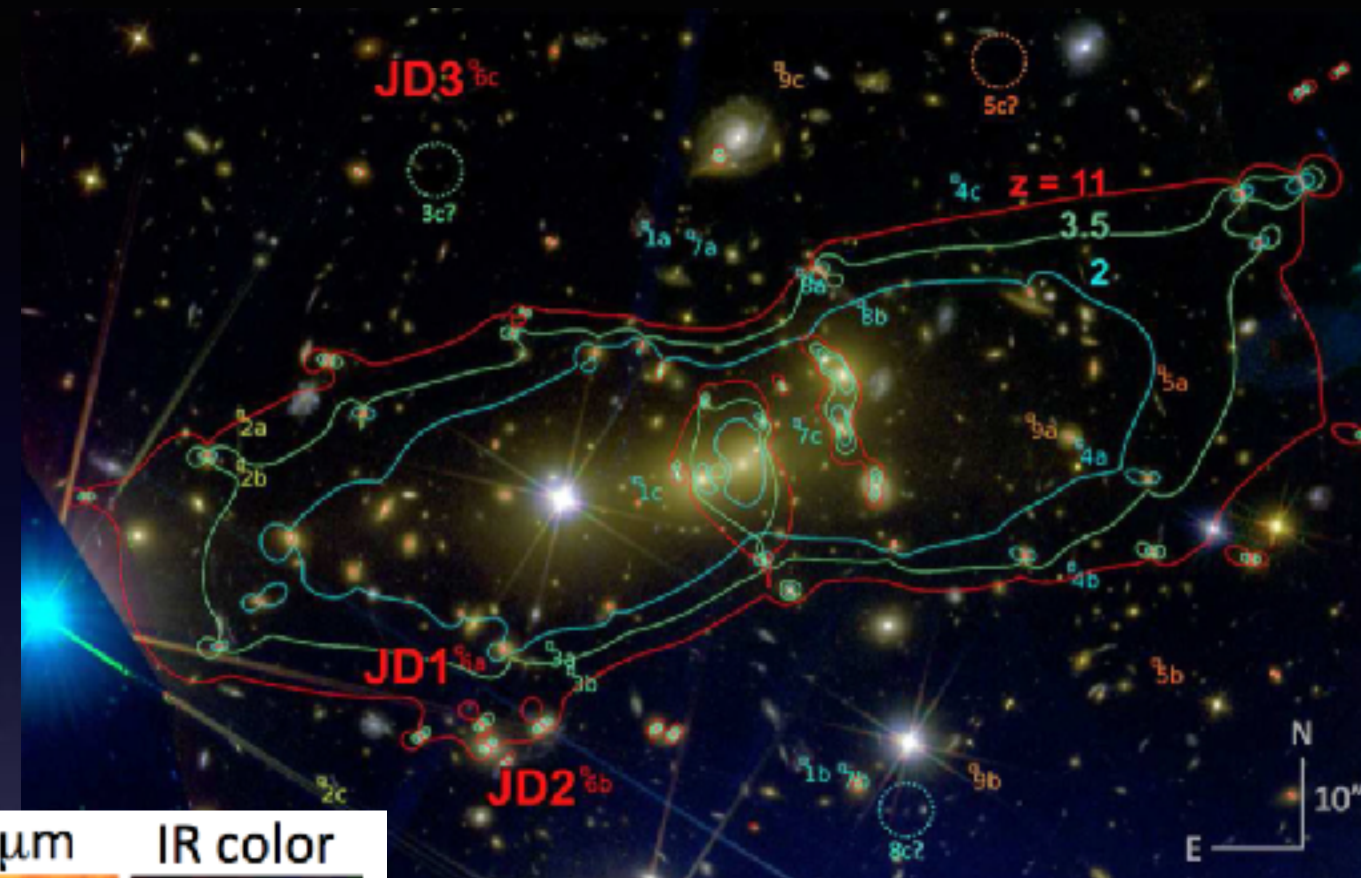
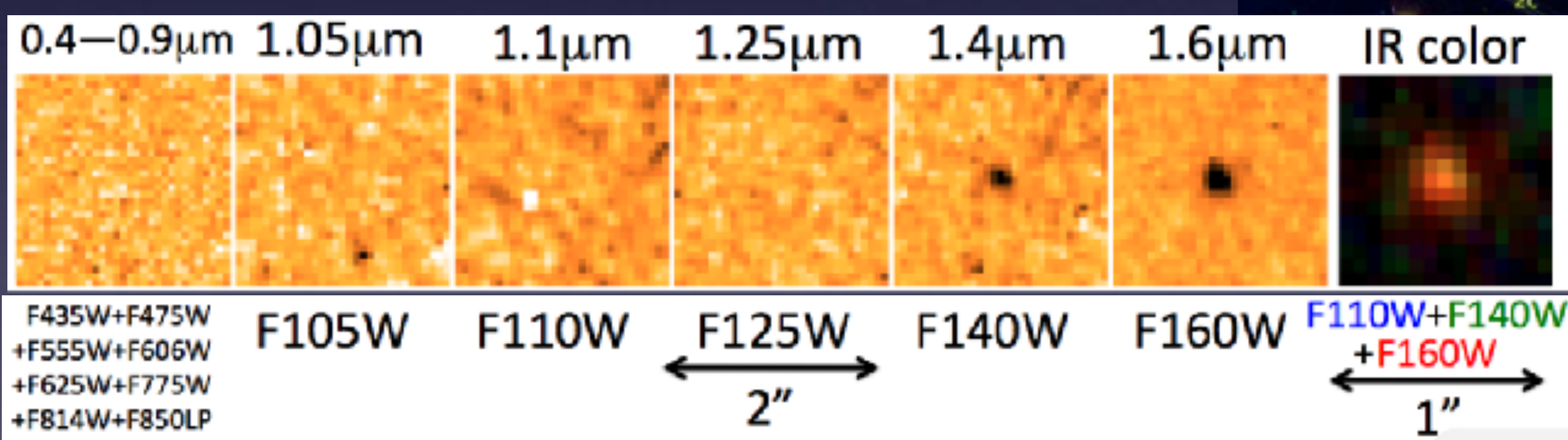
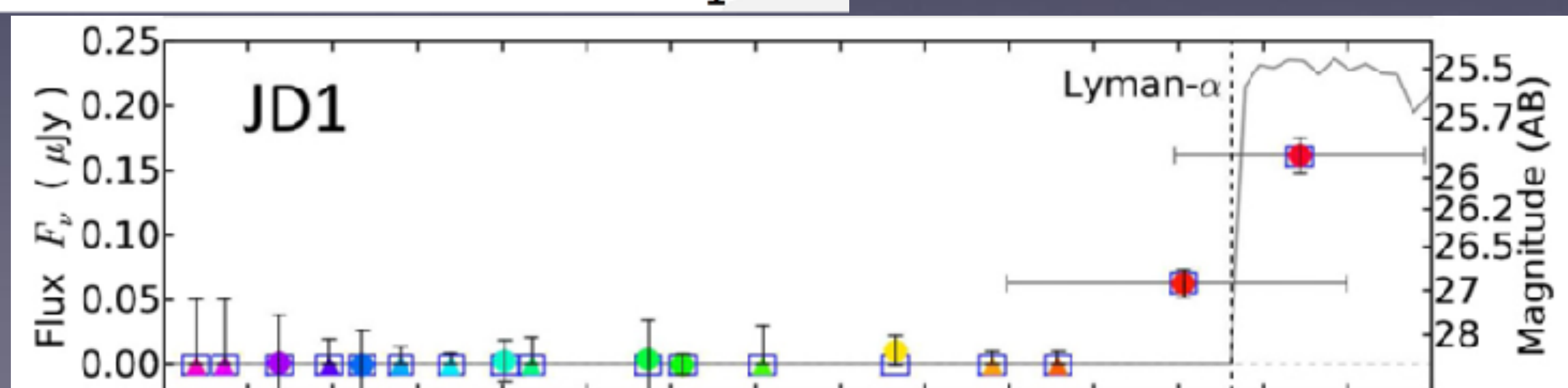
Ryan, Casertano and Pirzkal+17

LINEAR and very high-z LBG WFSS

- z~11 triple lensed dropout in MACS0647-JD (Coe+13)
  - Very faint source (AB=26.)
  - z=10.7 +0.6/-0.4
  - 10^8-10^9 M☉

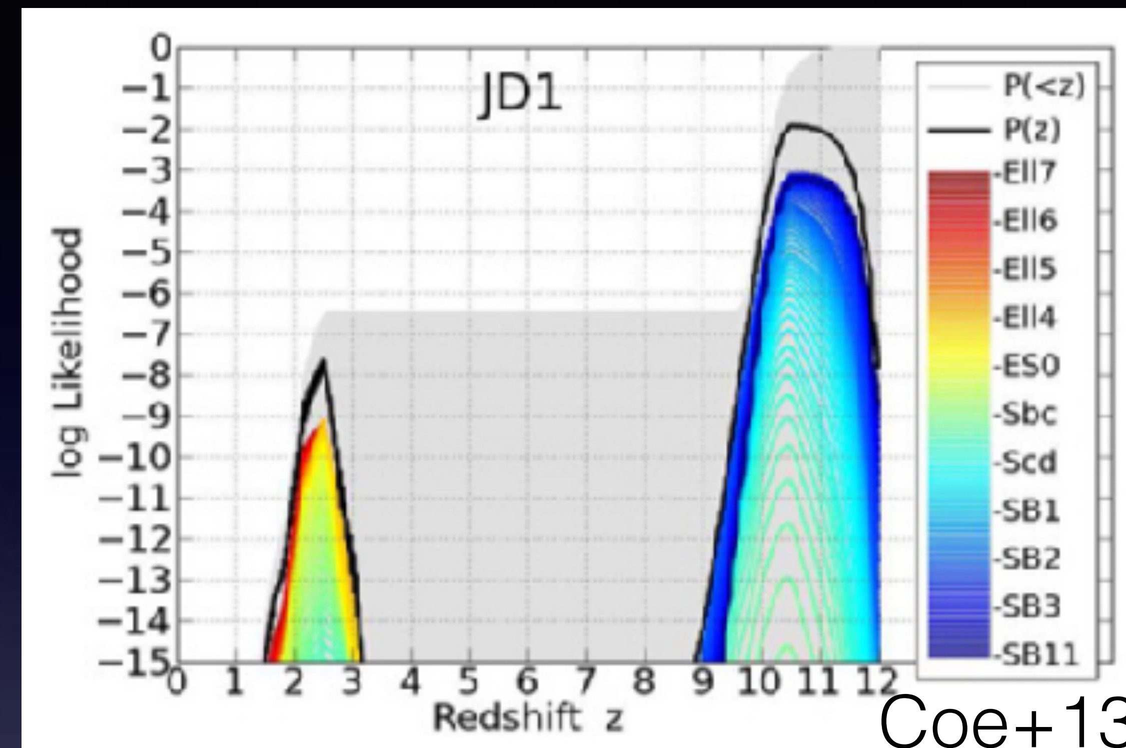


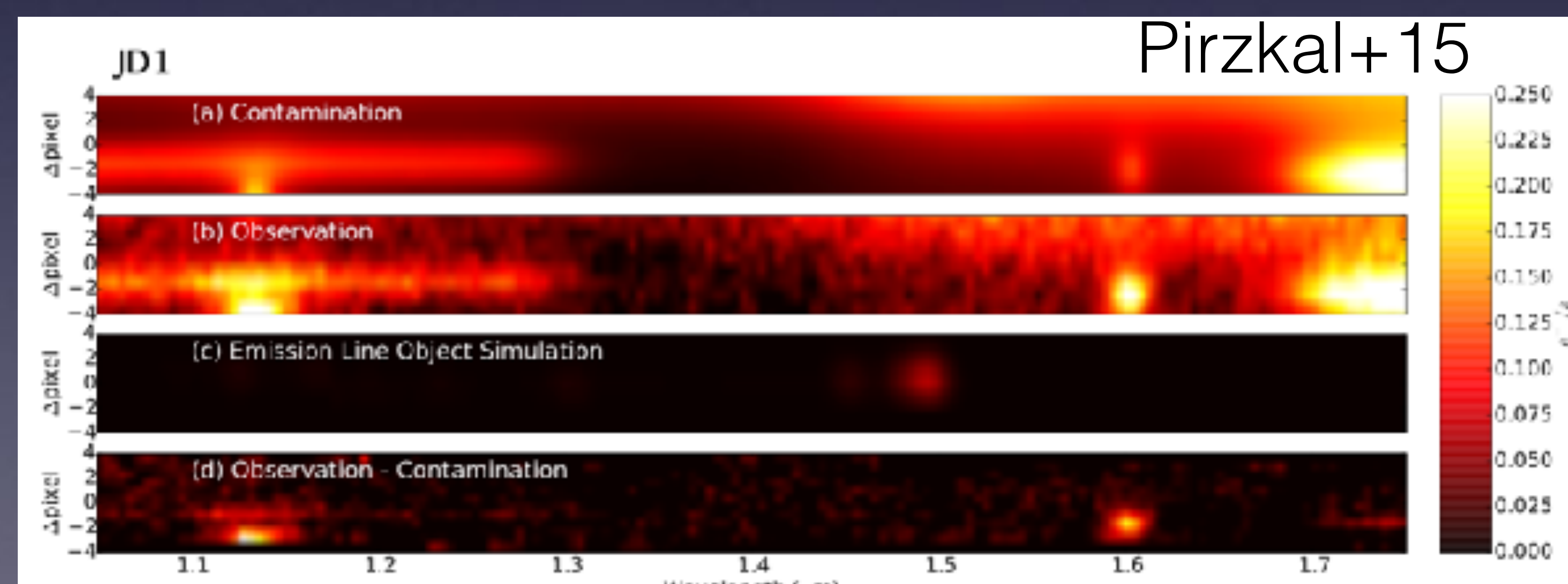




LINEAR and very high-z LBG WFSS

- Photometrically more likely to be at high redshift BUT a low redshift solution existed
- Observed using 12 orbits WFC3/G141 grism observation
- Low redshift interloper **ruled out** using just the first 4 orbits:
  - No high EW emission lines!
- Very crowded, contaminated field and faintness of this source makes SBE extractions challenging
- Good case for LINEAR

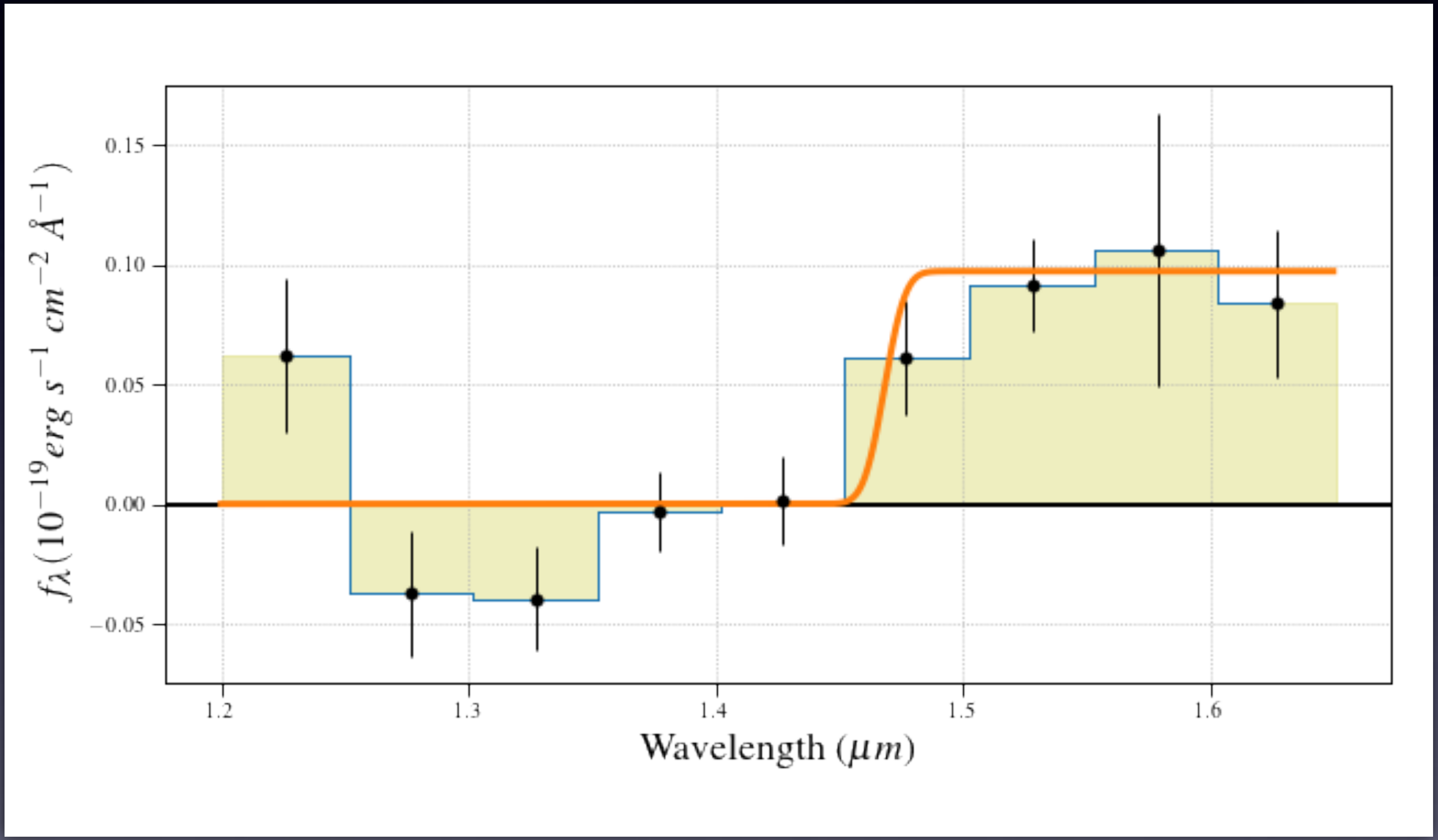




- Pirzkal et al. 2015

LINEAR and very high-z LBG WFSS

- Spectral reconstruction using LINEAR
- Detection of a spectral break at the expected wavelength
- Fitting this spectra to a lyman-break, we estimate this source to be at z~11.1+/-0.1
- Break detected at 5.5σ
- **This low mass, z=11 source will be "easily" detected using JWST!!(*)**



(*) one day

Summary

- "Classical" extraction method simply sums the fluxes from multiple PAs, losing spatial information and degrading redshift accuracy.
- SBE improves extraction of faint sources by handling contamination better.
- EM2D and MAP2D fully realize the potential of slitless observations by improving redshift accuracy AND resolving individual SF regions.
- LINEAR's breakthrough is a robust reconstruction of the crowded fields - for example, finally confirming a faint lensed galaxy at z~11 that could only be inferred before.
- All of these approaches will allow an optimal use of JWST WFSS