PEARS 2D: Finding star forming galaxies in slitless surveys

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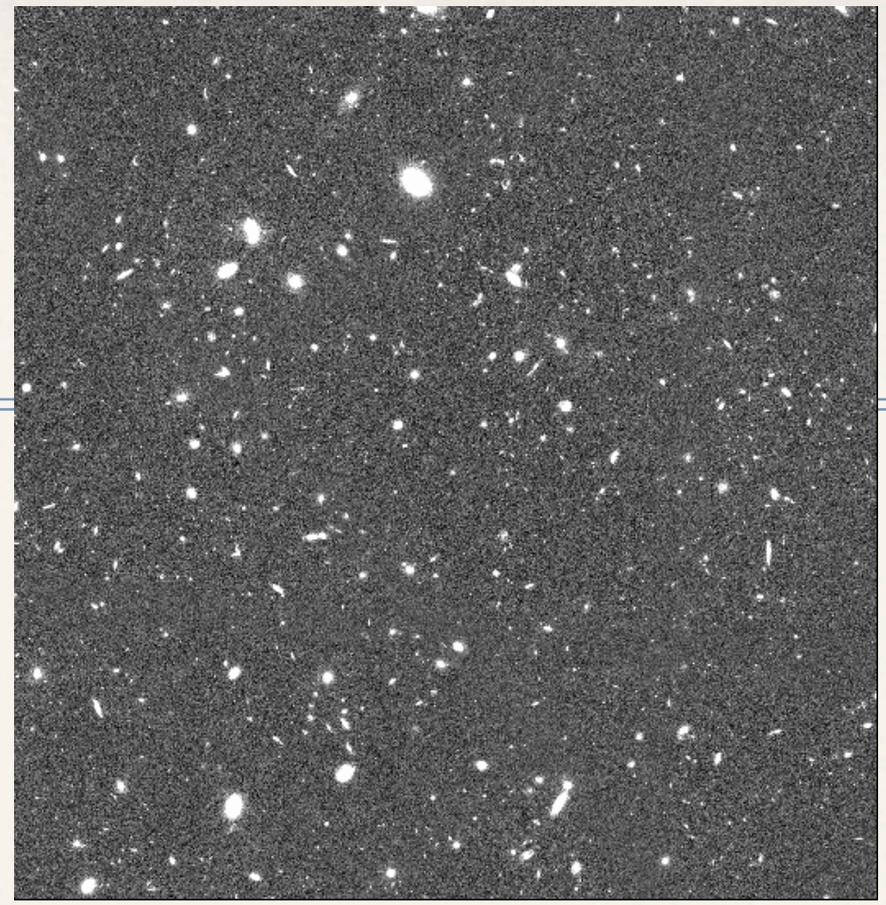
May 25, 2011, "Galaxies Near And Far" Villa Aureli

GRISM and HST

- HST is a good environment for spectroscopy:
  - Stable optical system and PSF
  - Lower sky background
- Slitless spectroscopy available to HST users since the beginning (WFPC1) and on nearly all instruments since (STIS, NICMOS, ACS, WFC3)
- First regular use of slitless grism was with NICMOS: IR spectroscopy but small field of view
- Dramatic increase of grism use with ACS (optical) and now WFC3 (NIR). In fact, HST has more orbits allocated to spectroscopy than imaging!

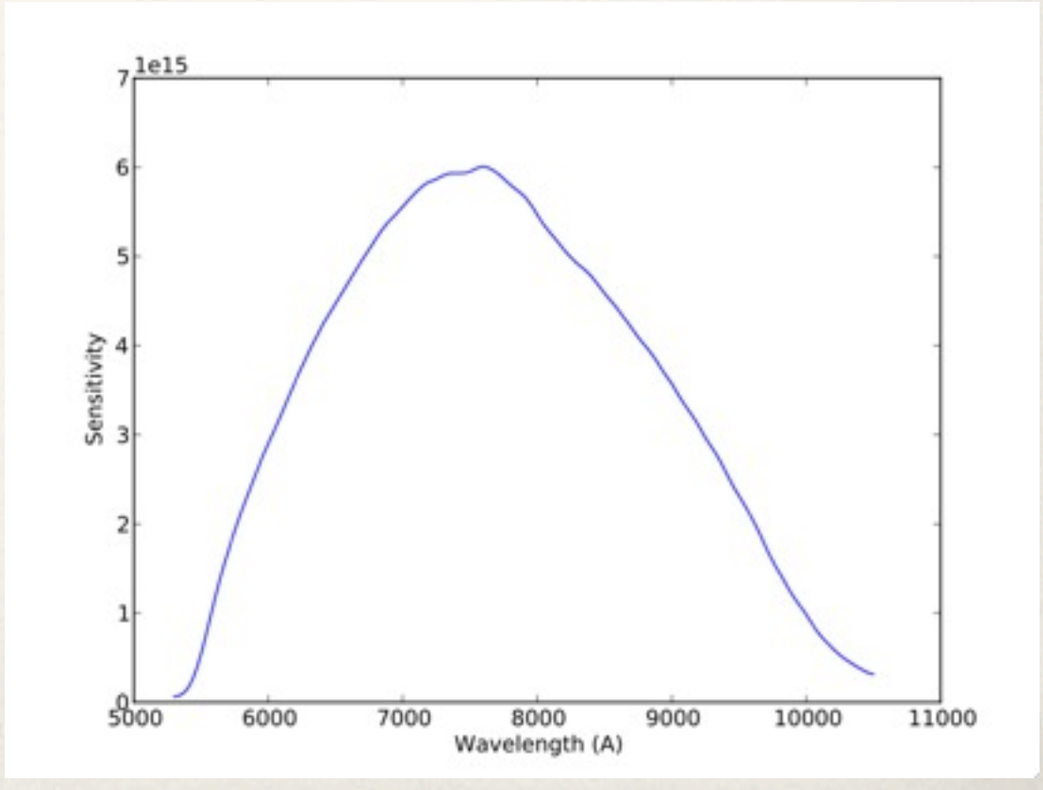
ACS G800L:



- Large field of view (11.5 arcmin^2)
- 40 Å/pix resolution
- High sensitivity:
  - continuum detection down to Z_{AB}>27
  - Emission lines down to few 10^{-18} erg/s/cm^2

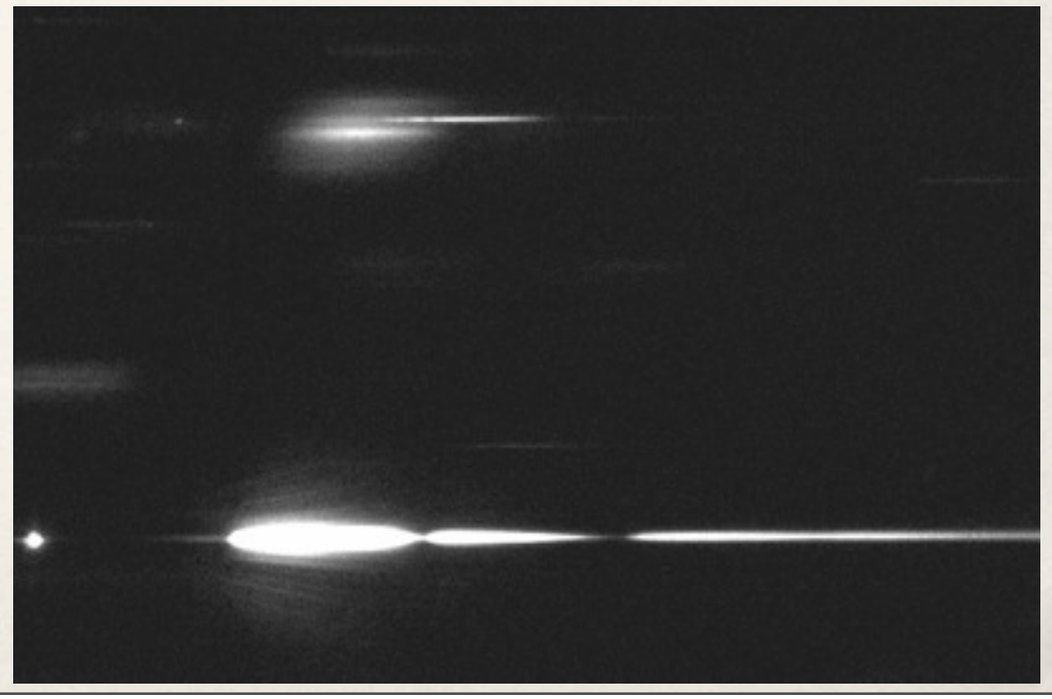
PEARS: Il Buono

- Large field of view: several arcmin^2
- Broad wavelength coverage: broad uninterrupted redshift coverage
- High multiplexing: several hundreds of spectra per exposure
- Low, stable background
- Stable dispersion and characteristics
- High sensitivity



PEARS: Il Cattivo

- No slits: blending of nearby sources, contamination, multiple orders
- Extraction and calibration requires some *care*
- What you gain with HST with low background you loose with lack of slit
- Low resolution (R~100)
- Difficult flux calibration (few % at best)



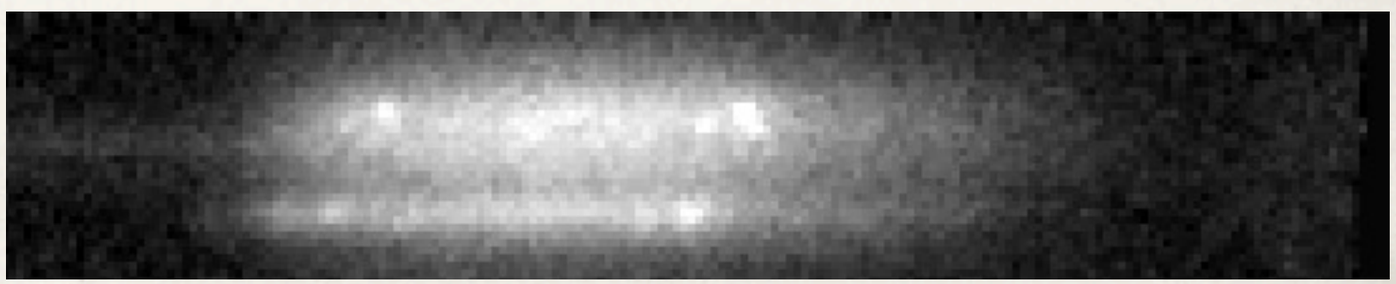
PEARS: Il Brutto

- Standard extraction based on object catalogs. This defines wavelength calibration and to some extend the flux calibration.

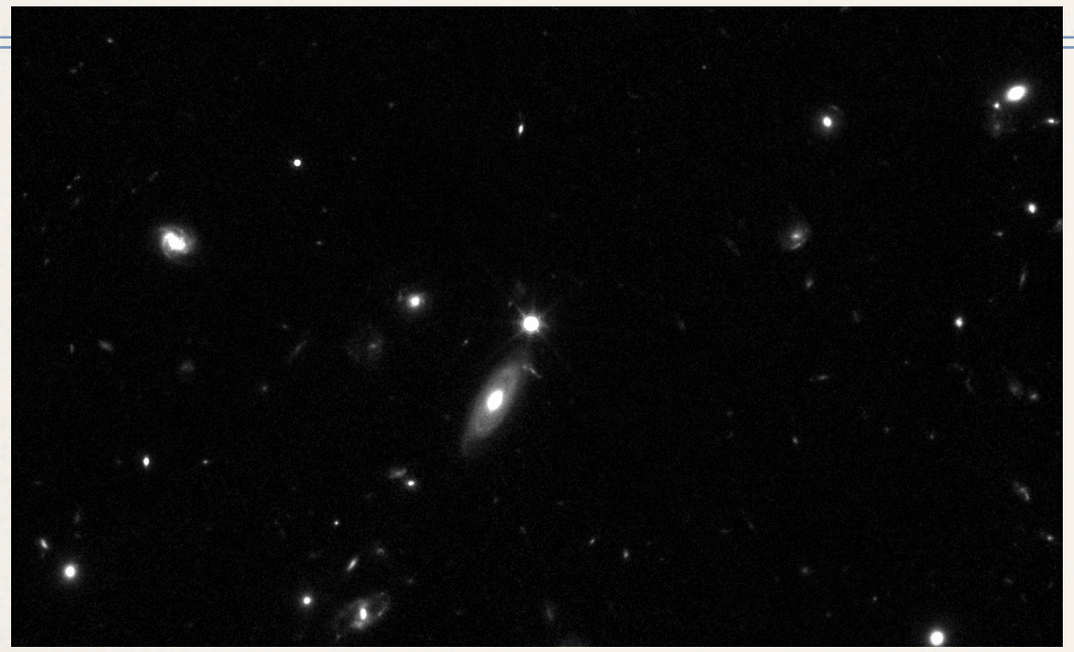
- No slit, so must pick a reference, e.g. object centroid

- Wavelength and flux calibration does not account for "self-contamination": different parts of complex resolved objects are all blended together

- Multiple emission line regions are all blended together in resolved objects



Traditional Line Search:



- Catalog driven
- Centers the extraction of the center of the source
- Look for lines in extracted spectra
- But this is not optimal in cases of:
  - Extended objects
  - Faint emission lines

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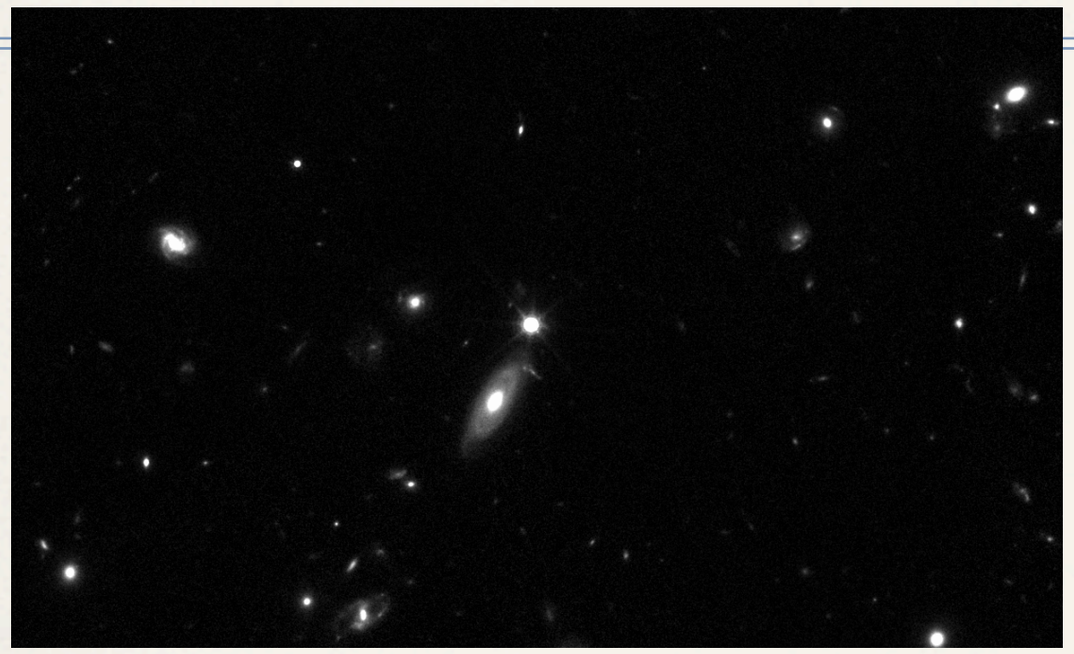

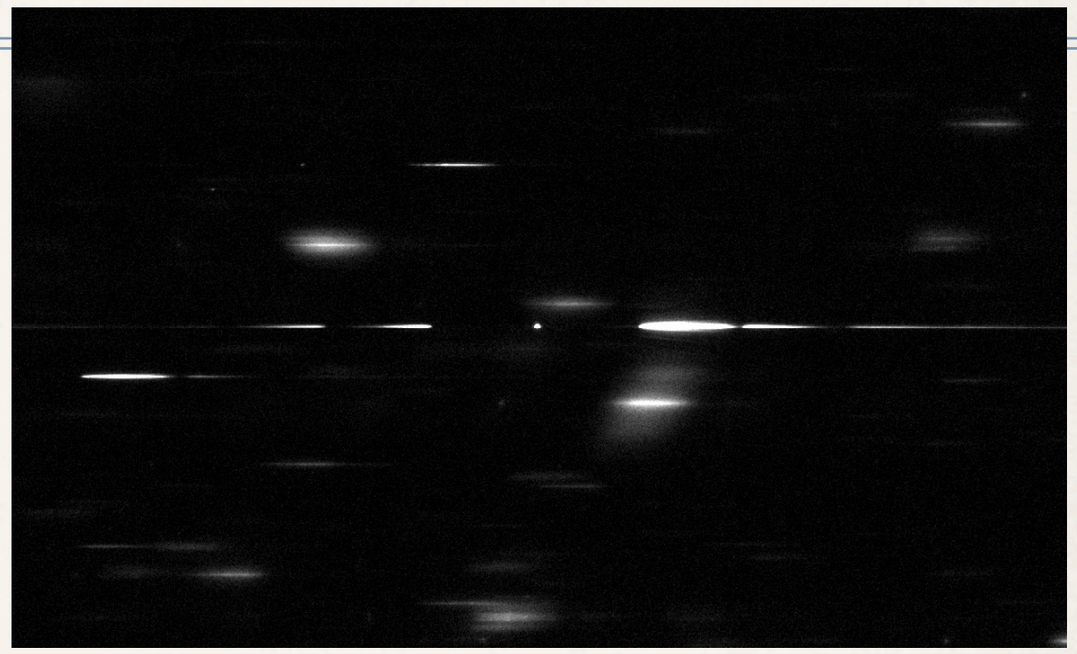

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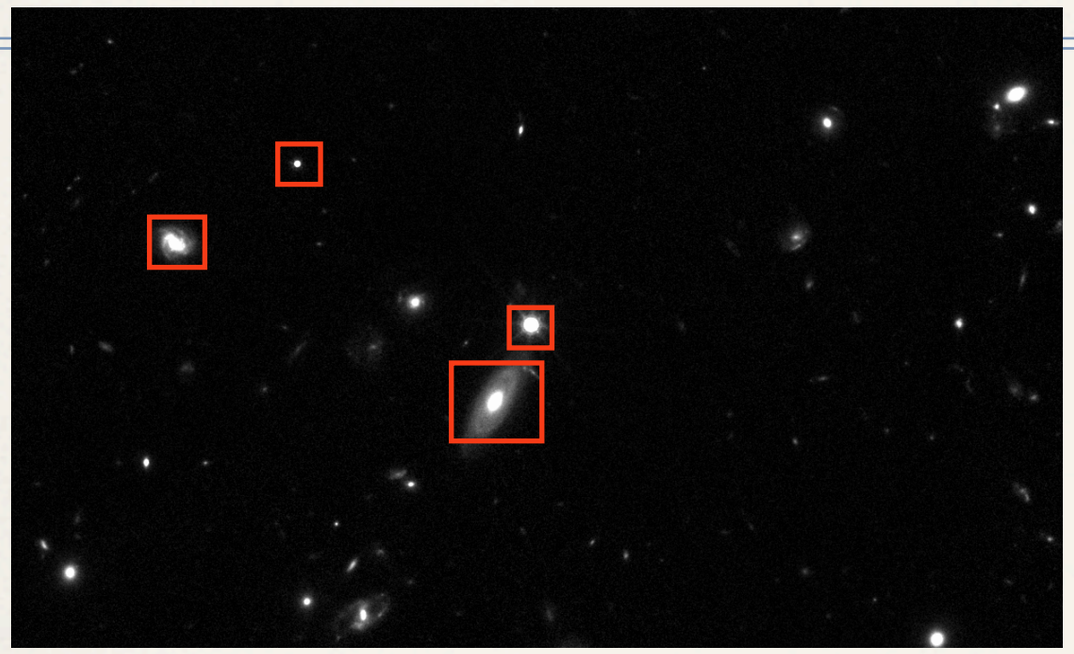

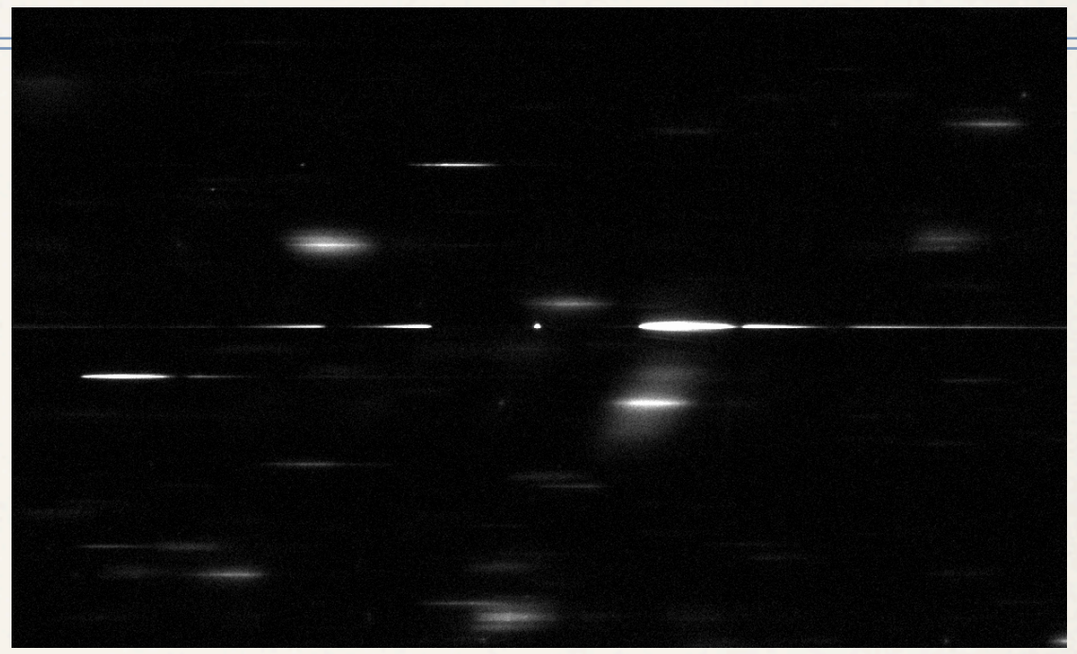

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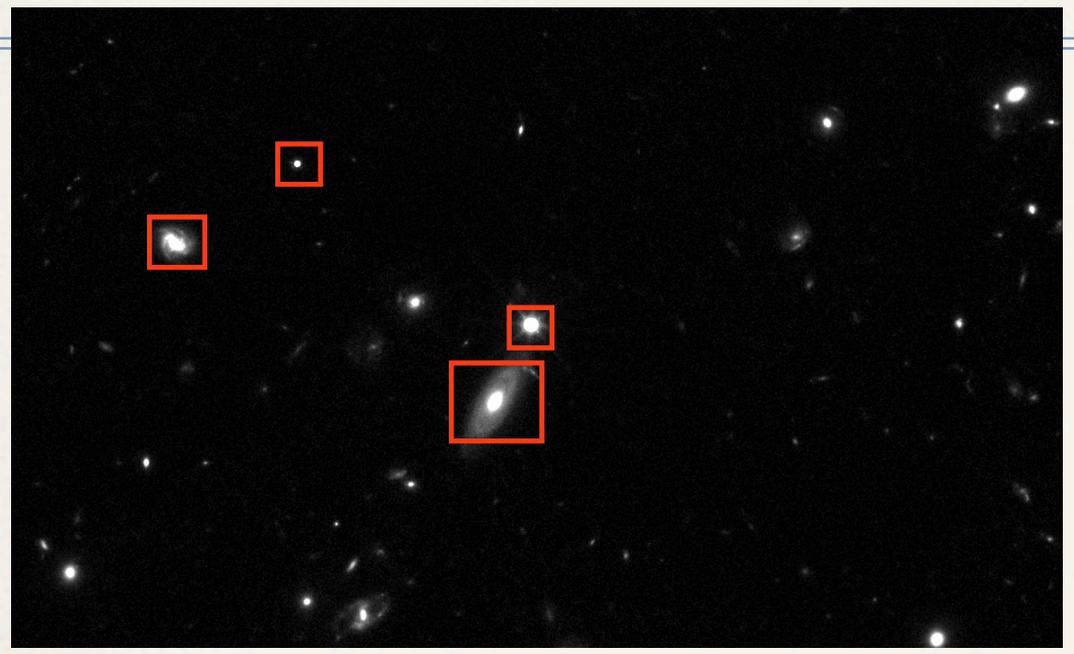

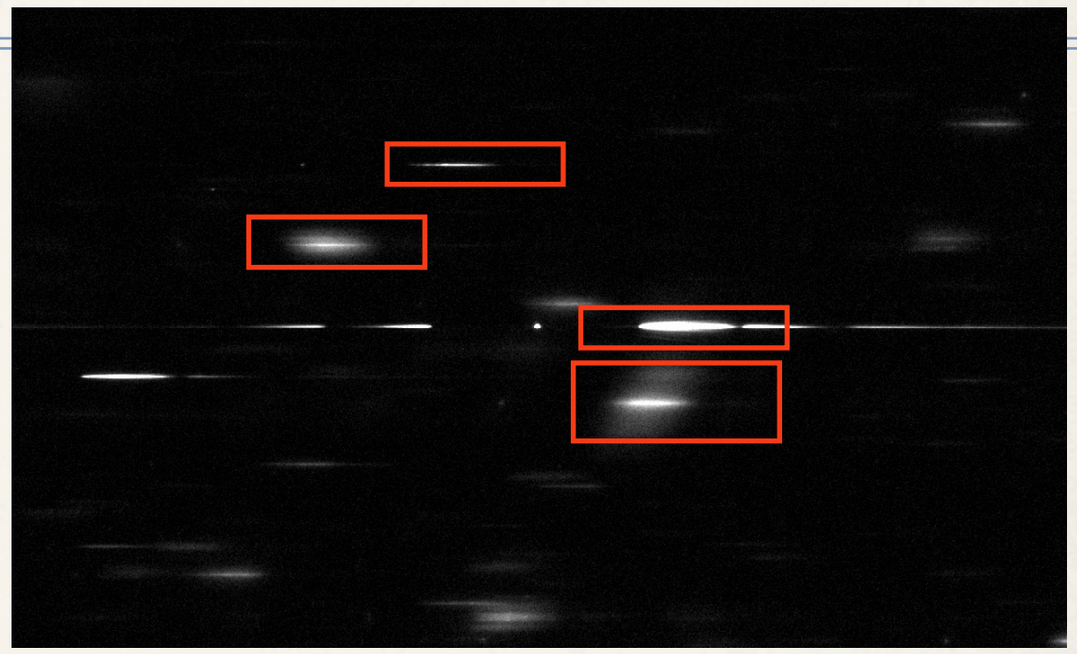

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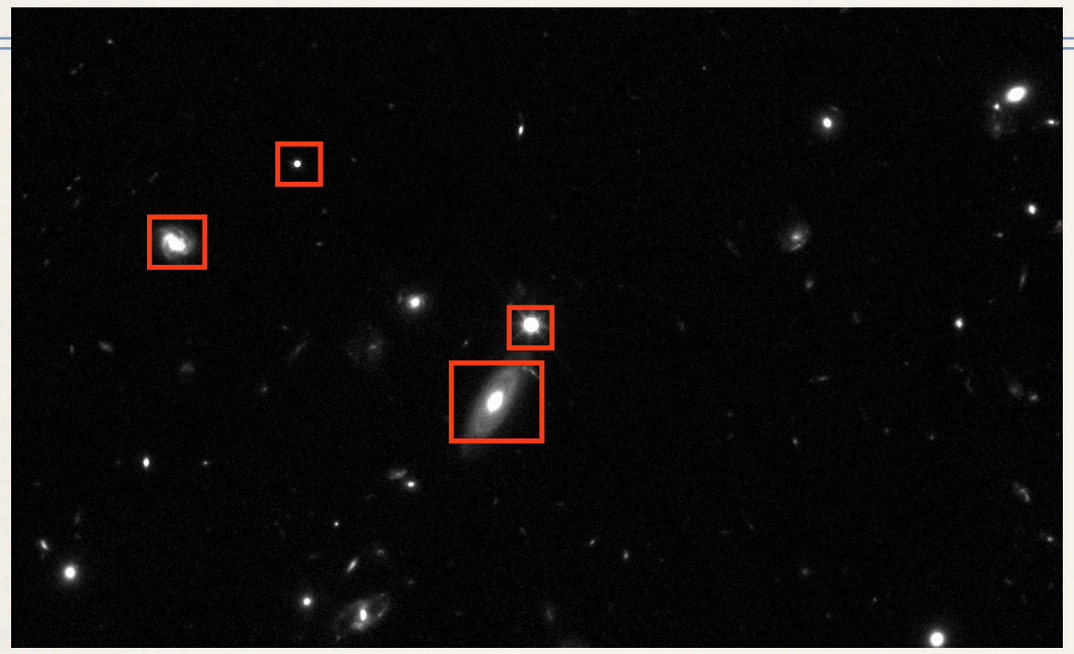

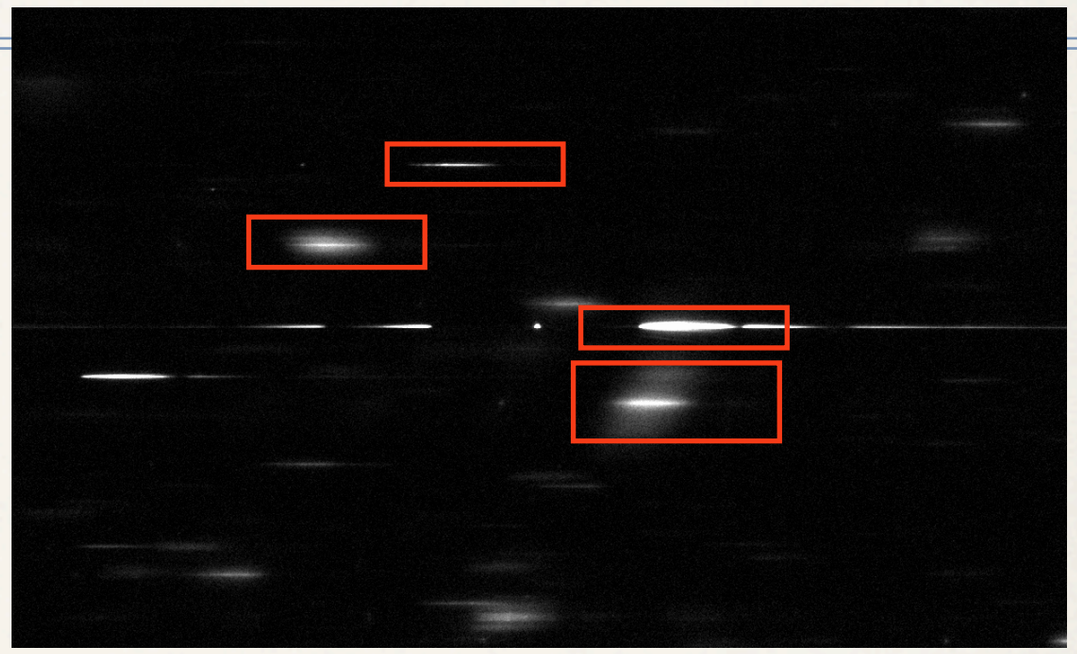

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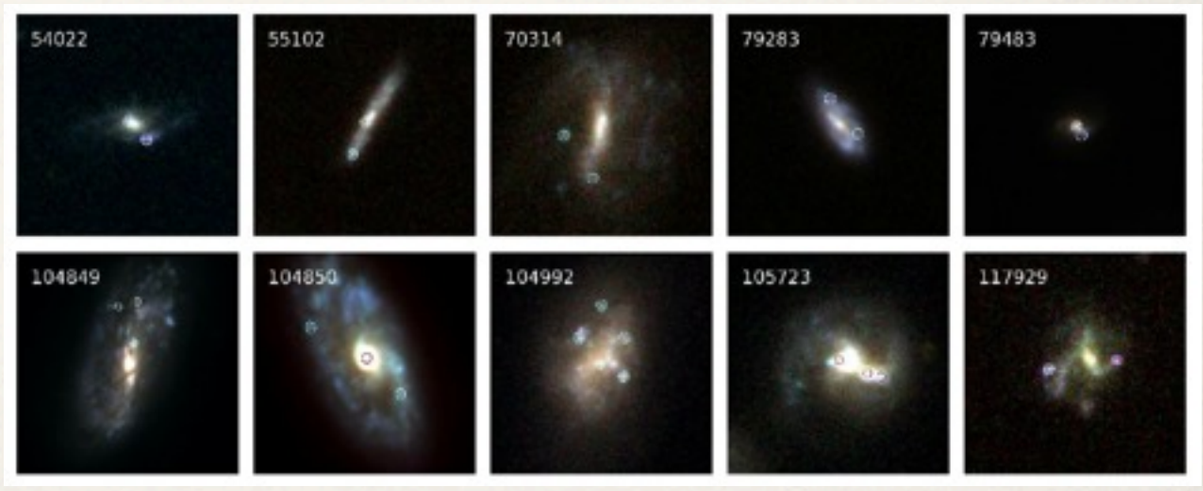
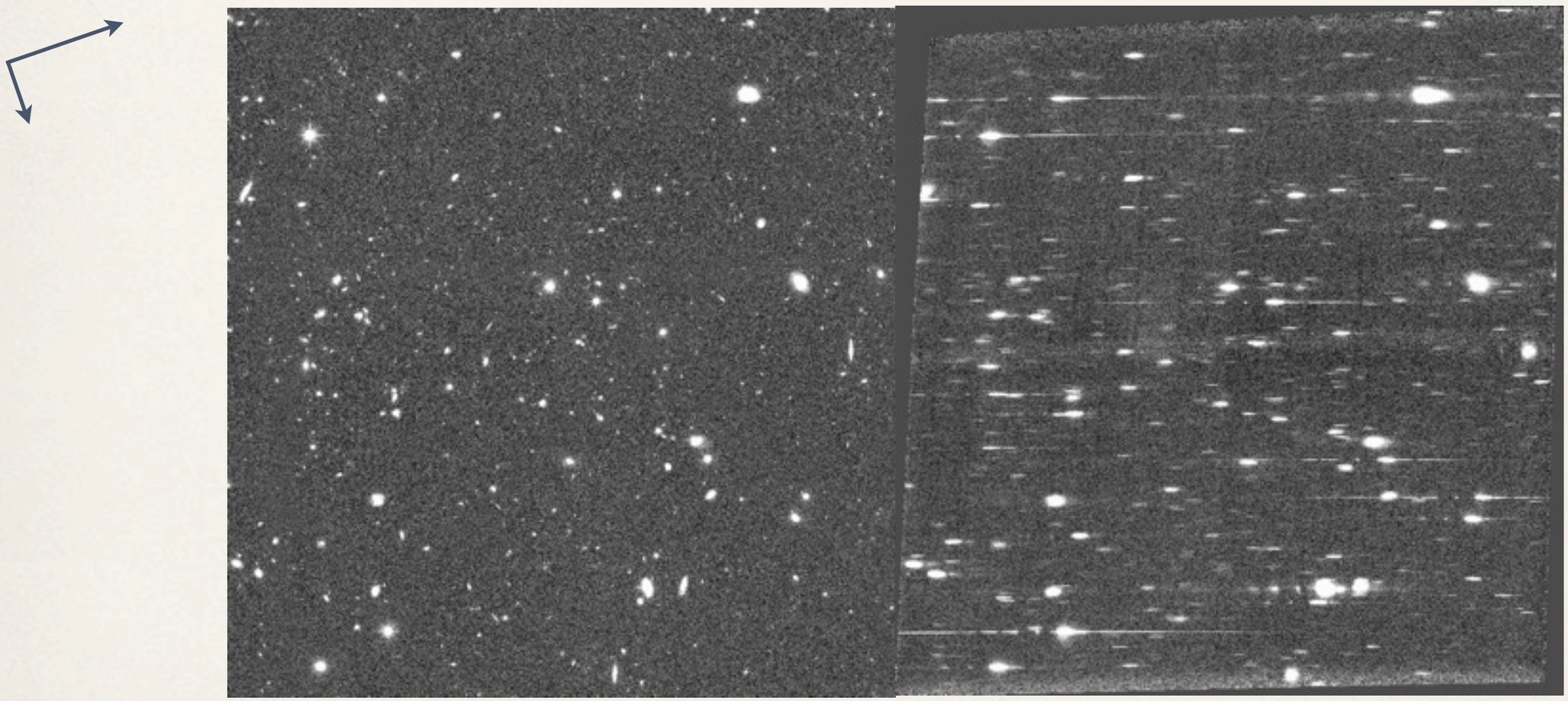


PEARS 2D: Line search with multiple orients



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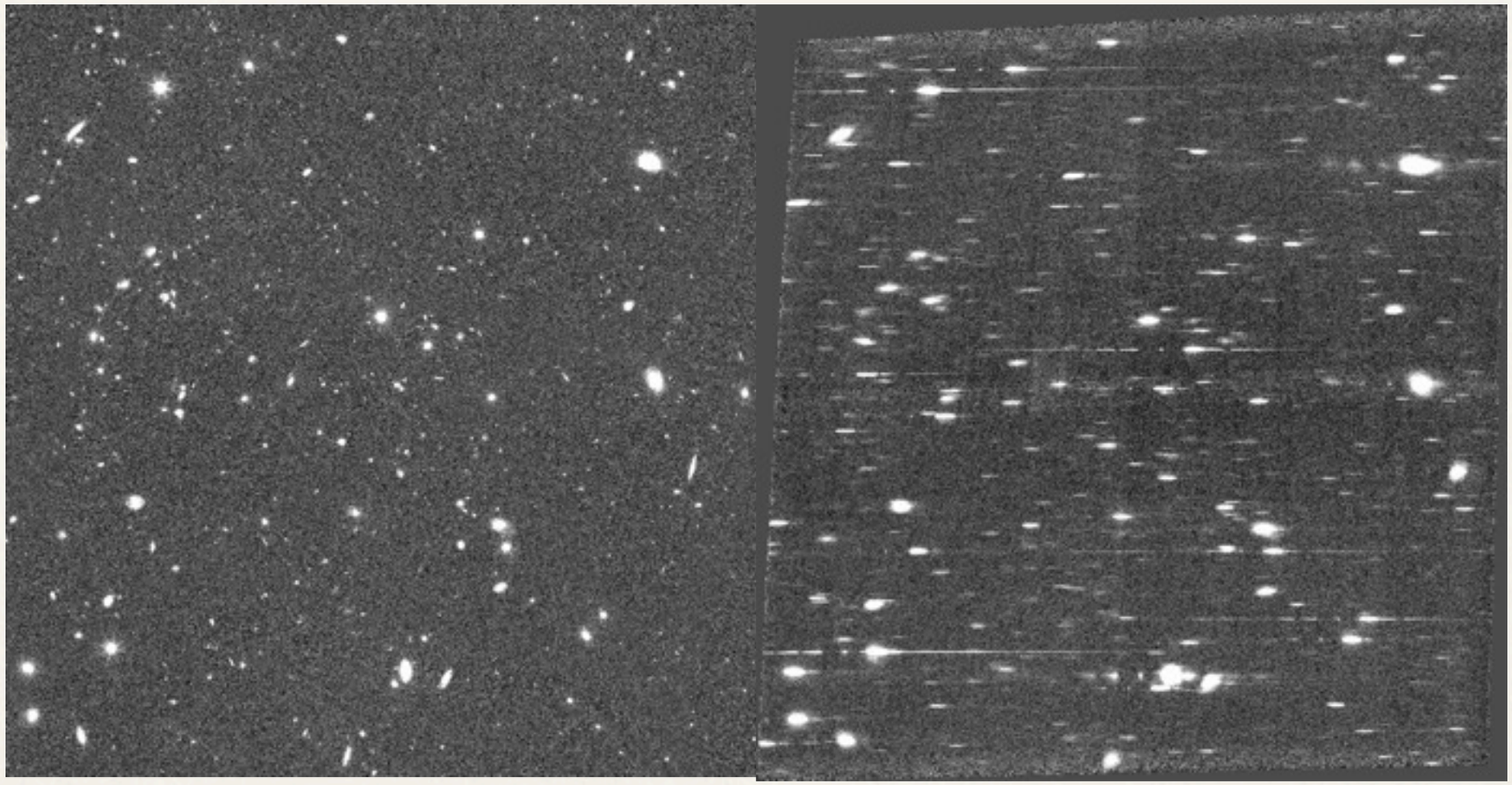

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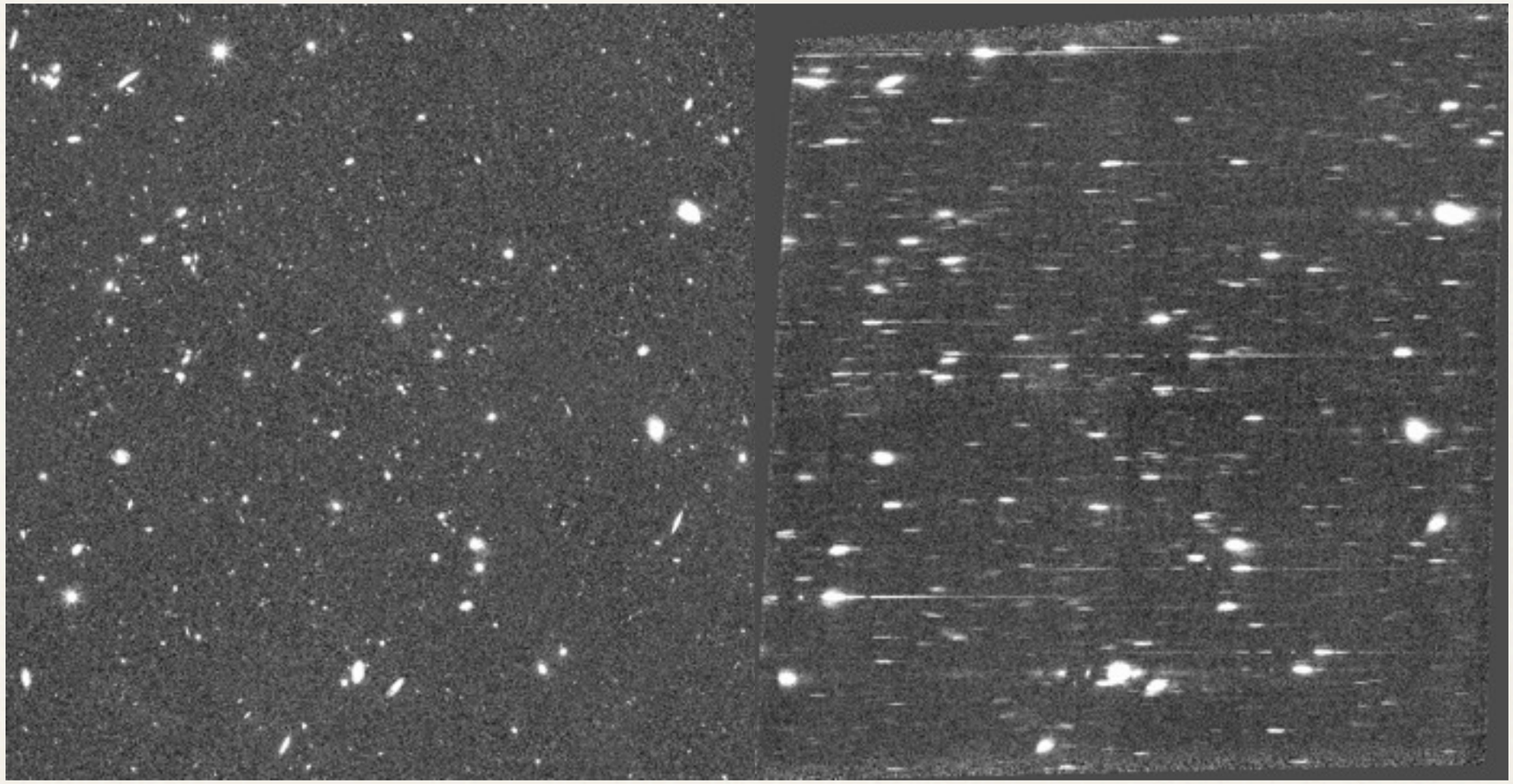
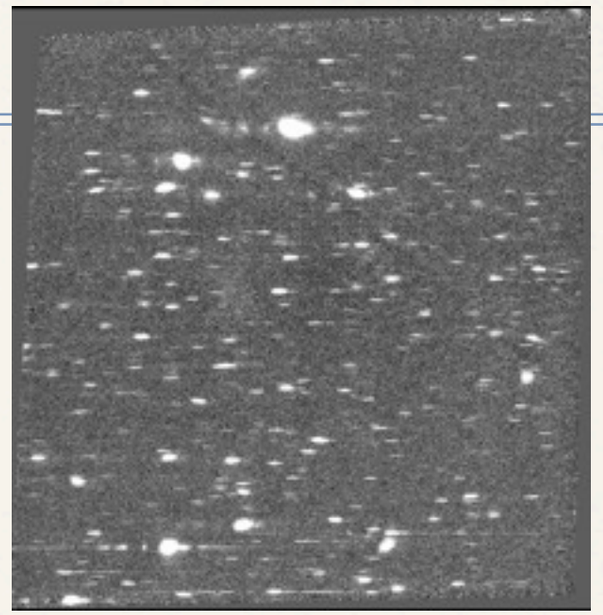
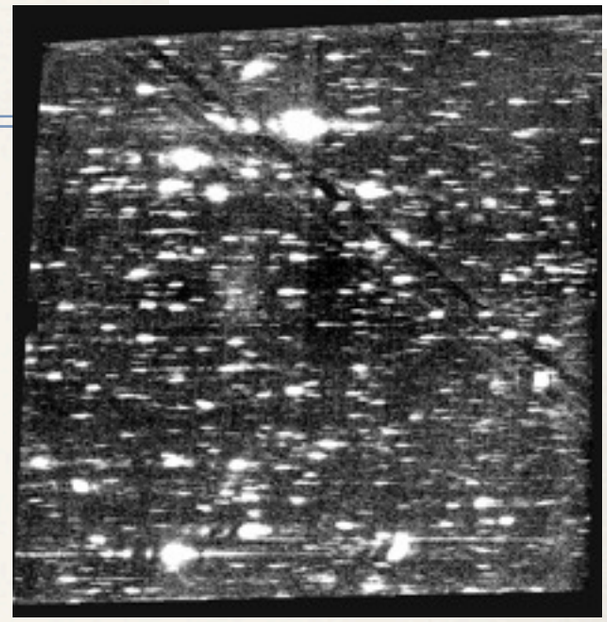
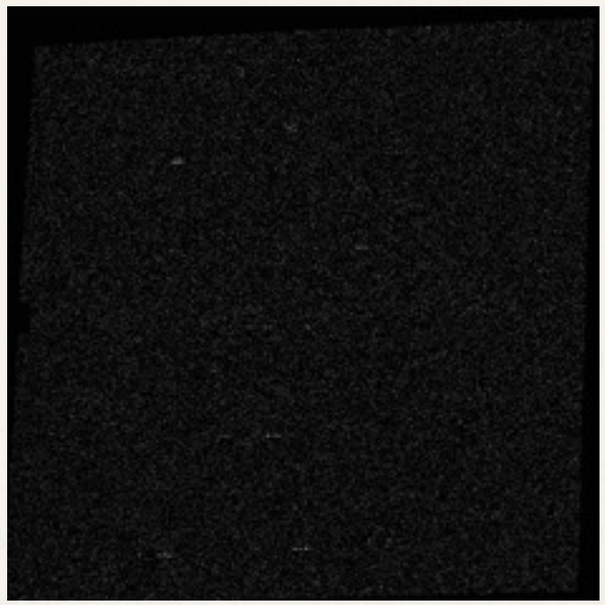


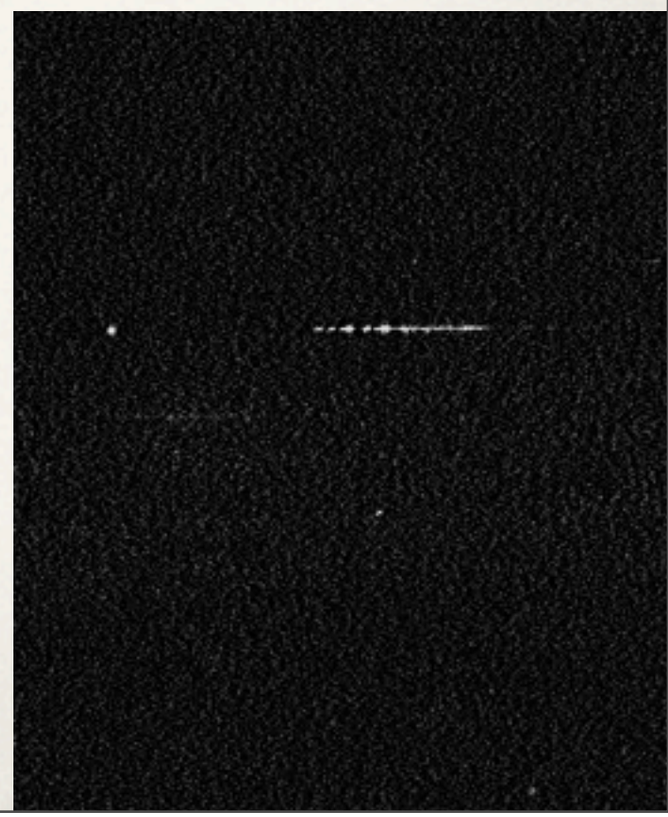
PEARS-2D Line Search:

- **Object catalog independent extraction**
- **Relies on observations taken using multiple orientations on the sky**
- Fully utilizes knowledge of disperser properties:
  - Combine all available data at a given position angle
  - Smooth and subtract
  - Detect emission and break features in 2D continuum subtracted image
  - Generate a catalog of candidate lines at each orientation









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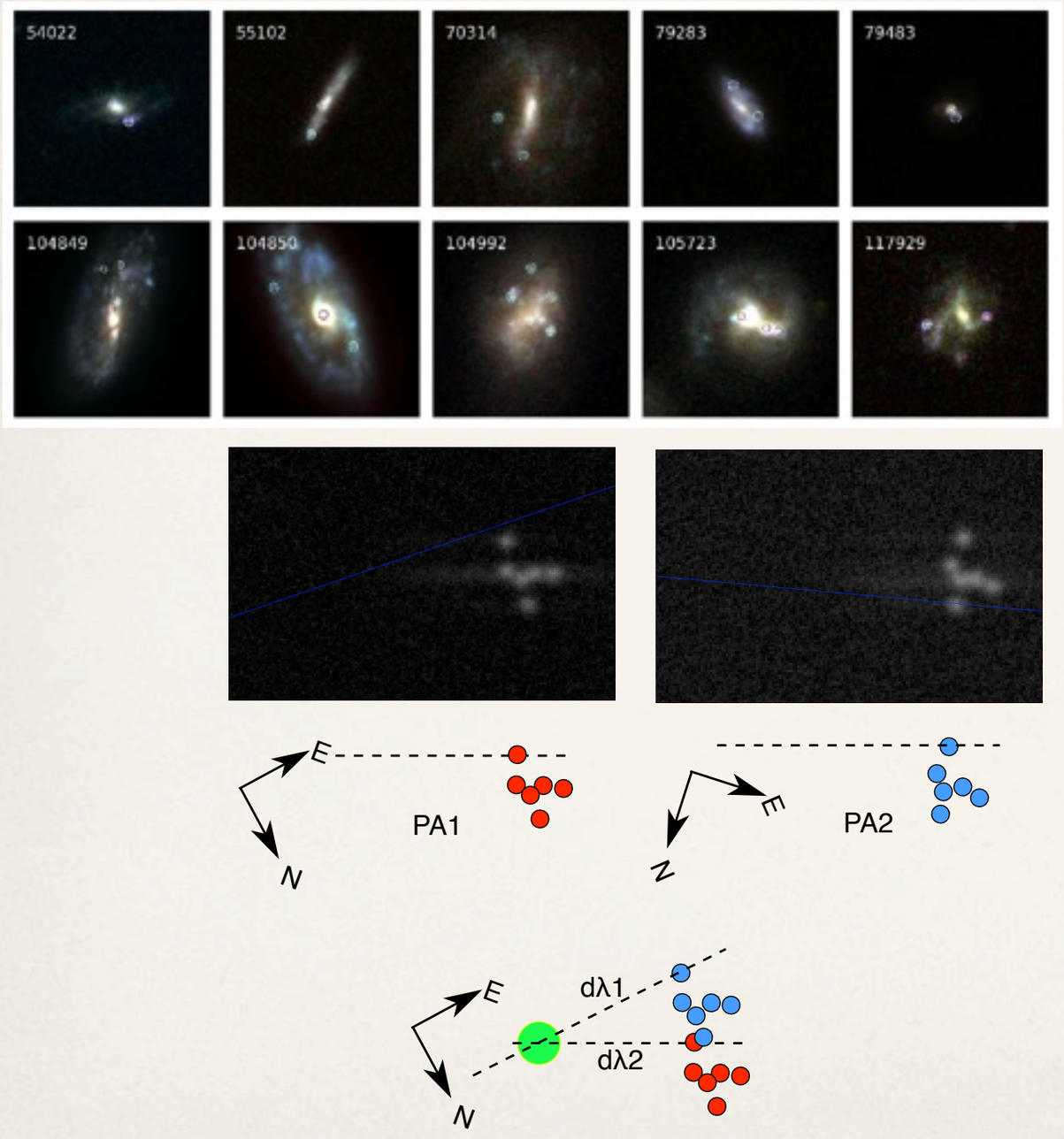


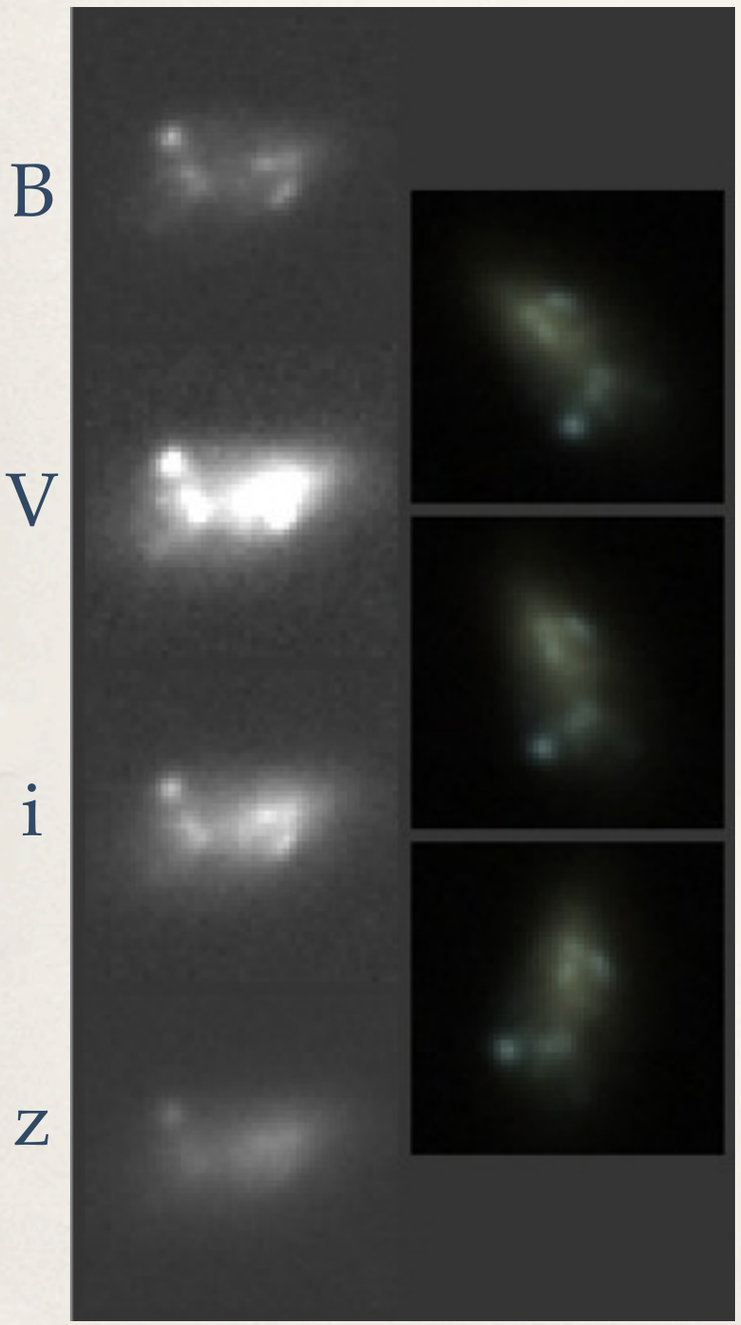
- Use candidates found using 2 or more orientations to determine the origin of the feature on the sky (knot).
- Perform optimal slitless extraction of each knot:
  - One extraction per available orientation
- Search for emission lines aggressively in 2D images
- Weed out false positive with manual grading R
- Reach very low line luminosities

PEARS 2D: Example 2

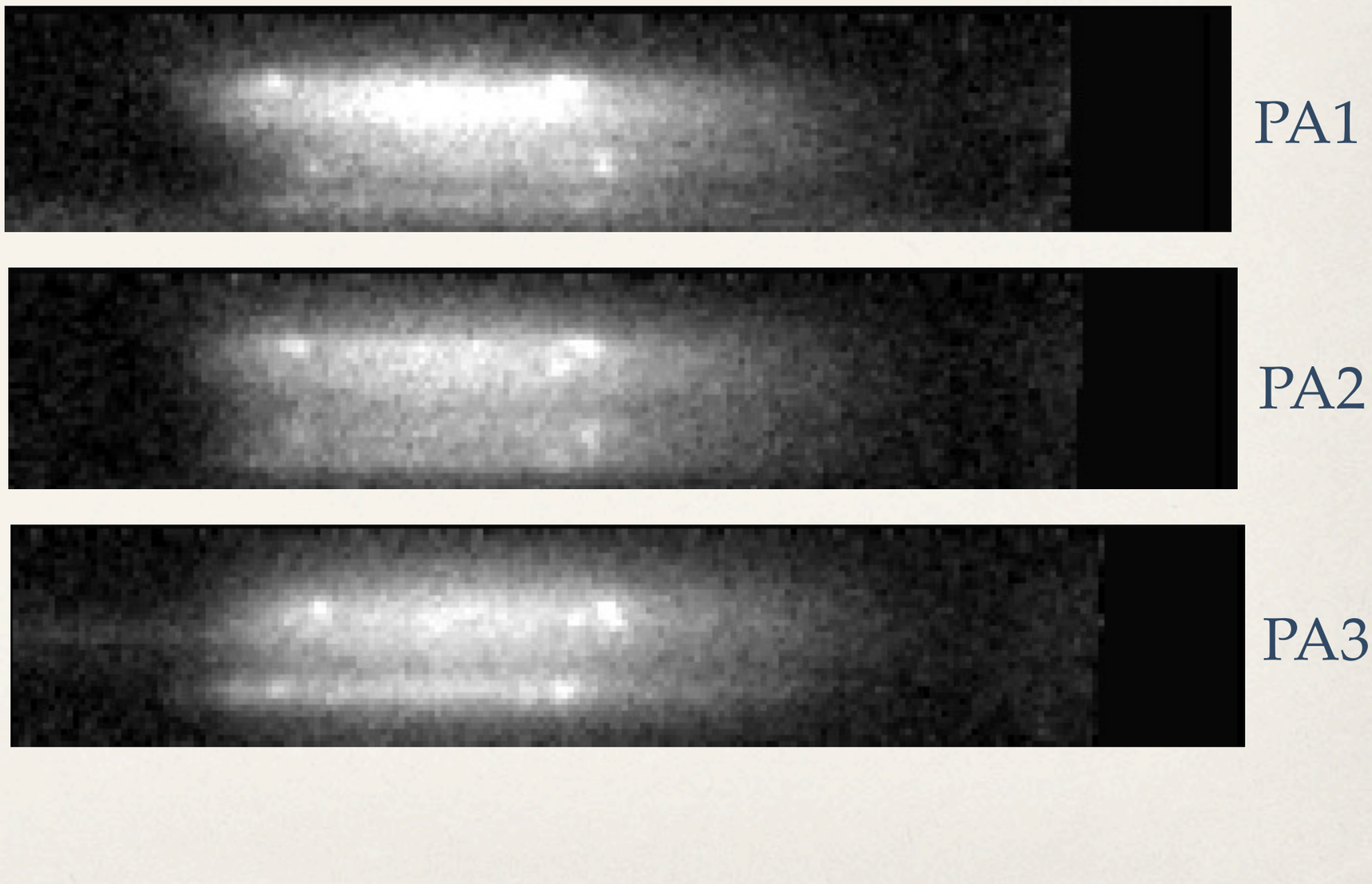
$z=0.2$

$H\alpha$ $7x10^{-17}$ erg/s/cm^2

$z_{AB}=21.09$



Direct images



Grism Observations

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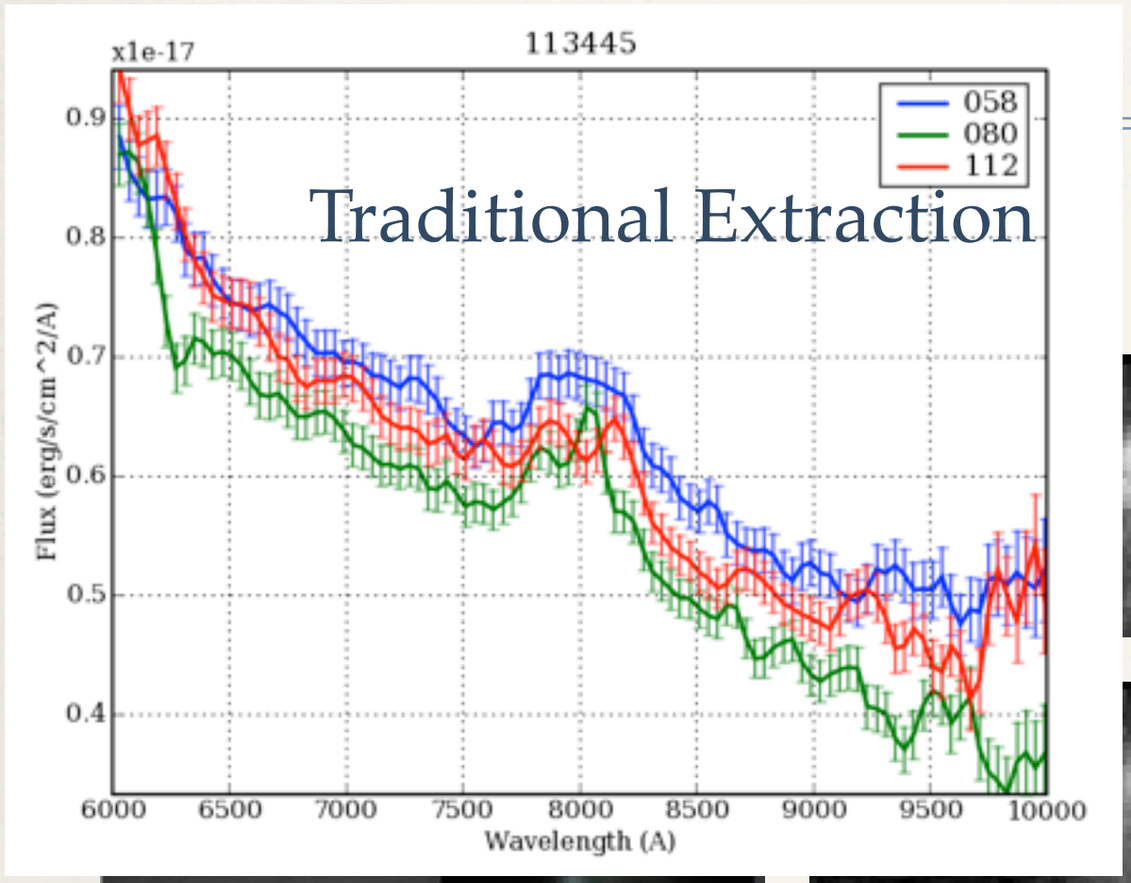
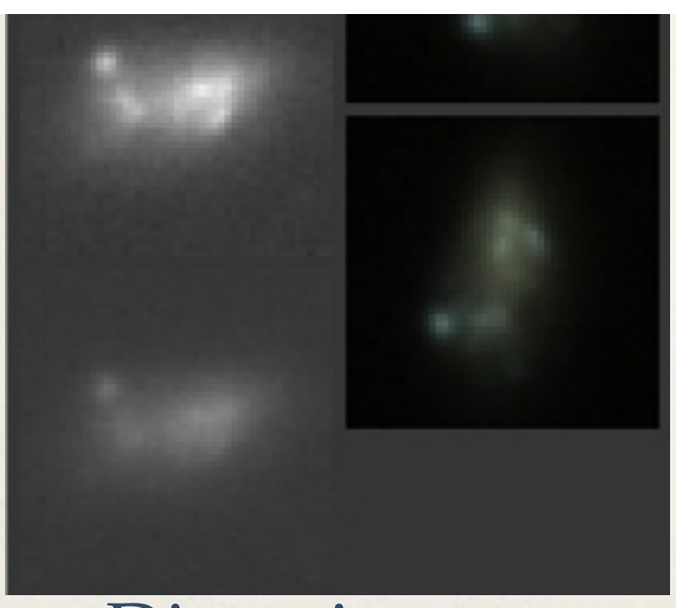


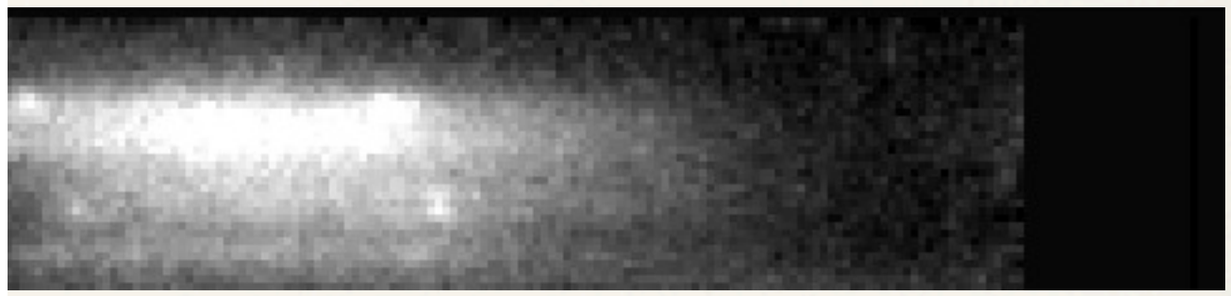
Traditional Extraction



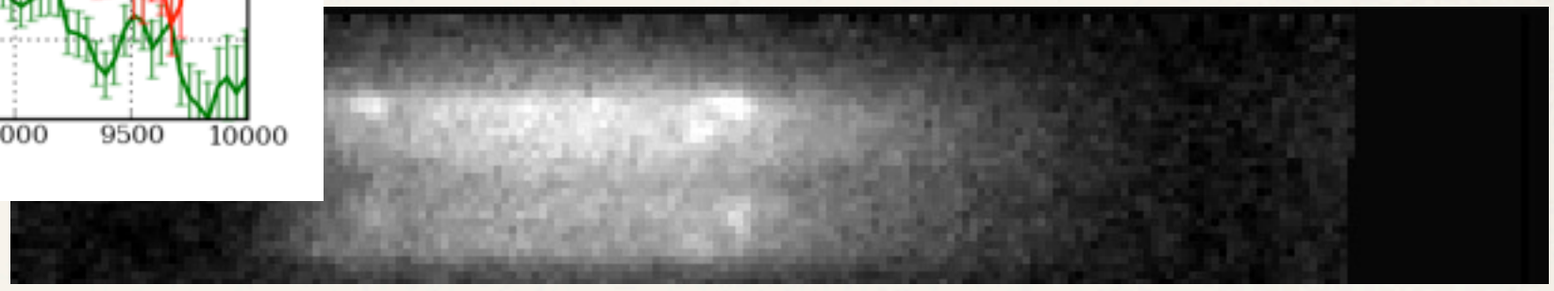
i

z

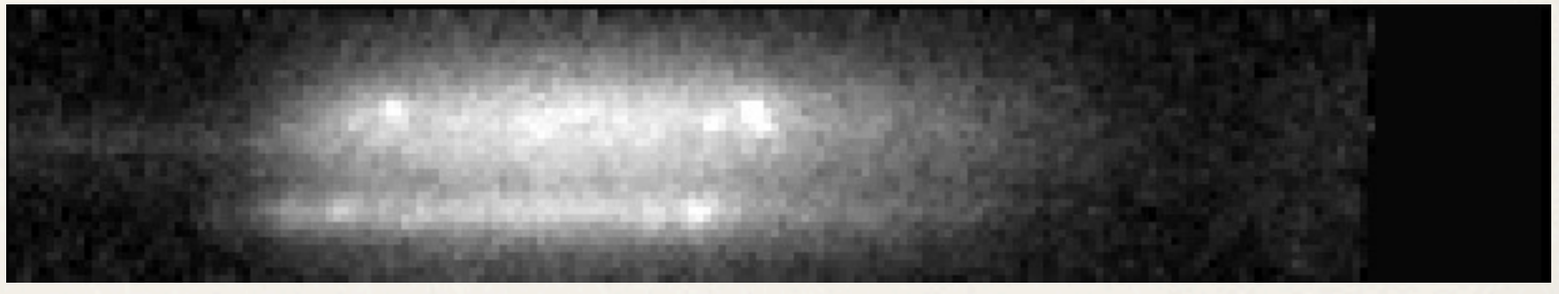
Direct images



PA1



PA2



PA3

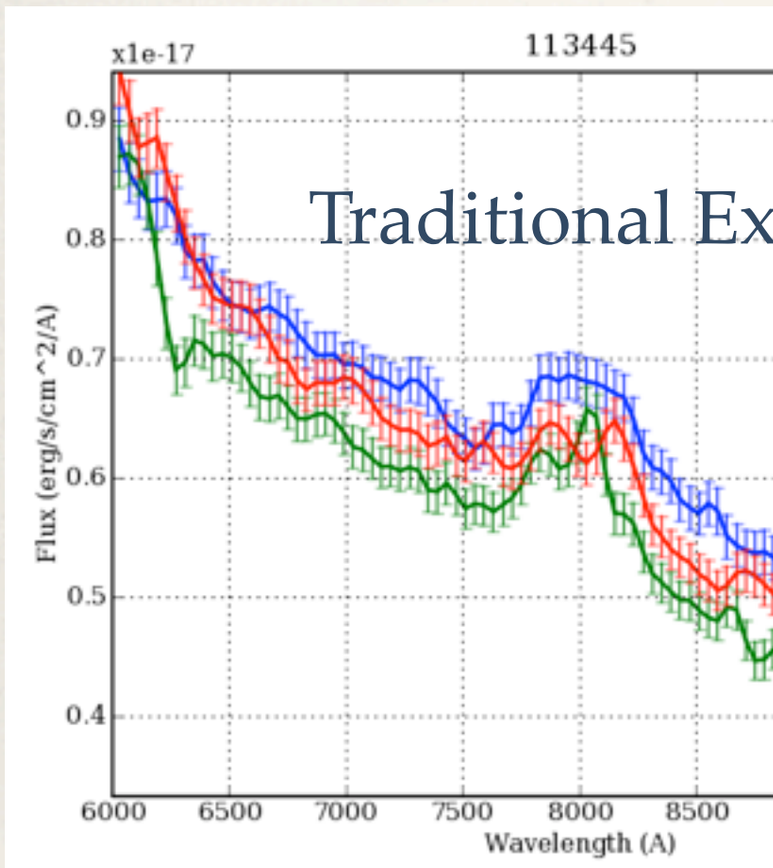
Grism Observations

PEARS 2D: Ex[illegible]

z=0.2

Hα 7x10^{-17} erg/s/cm^2

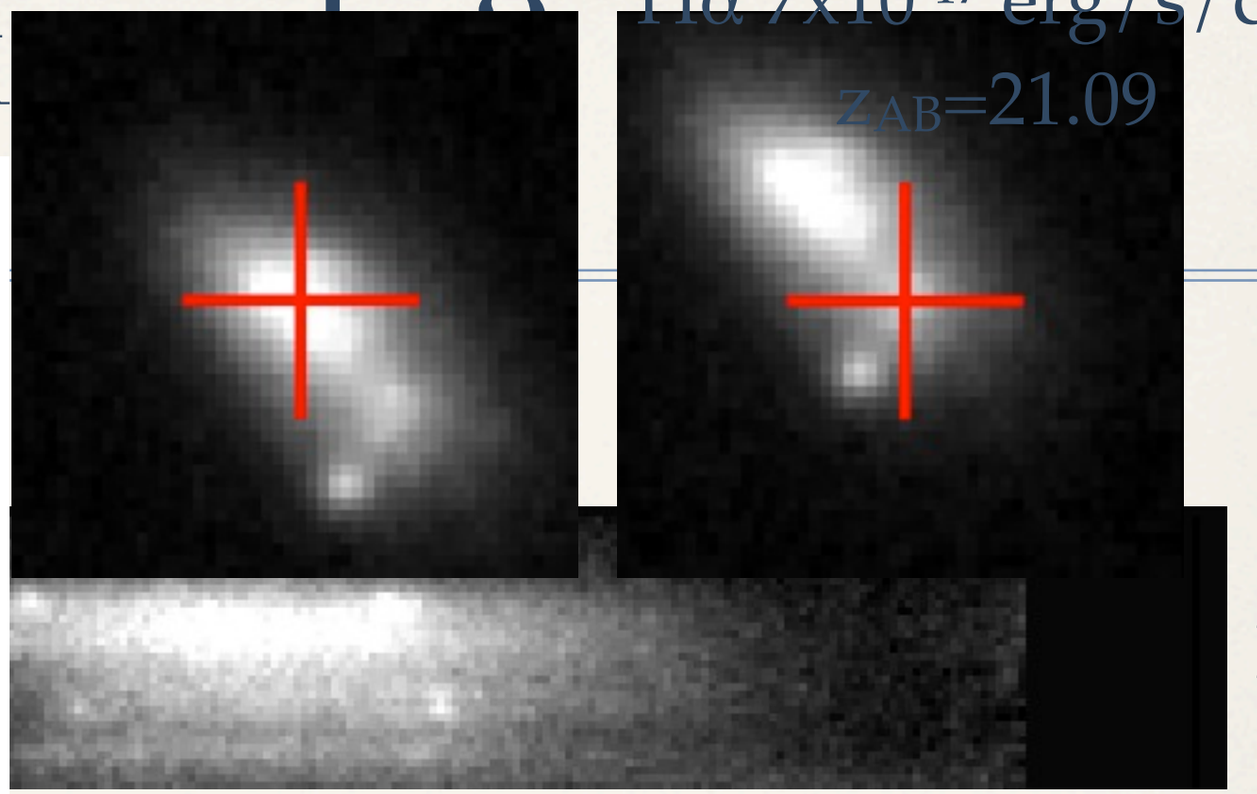
z_{AB}=21.09



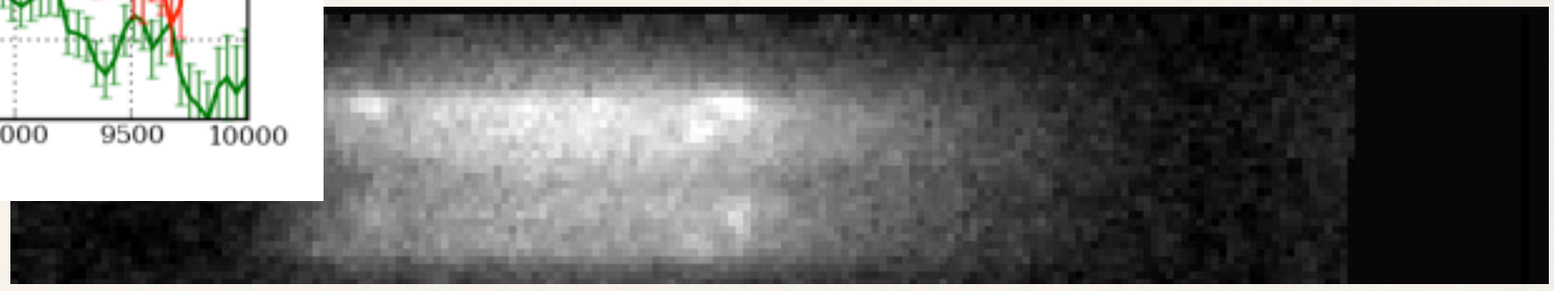
i

z

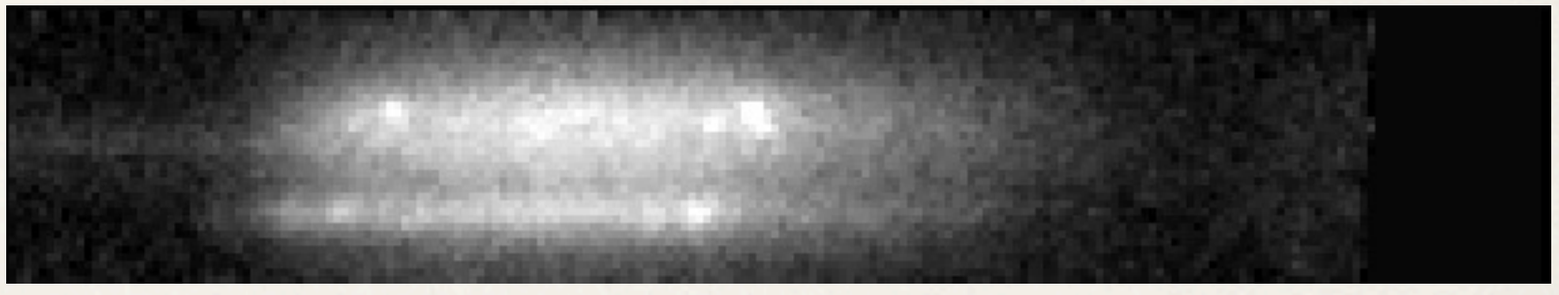
Direct images



PA1



PA2



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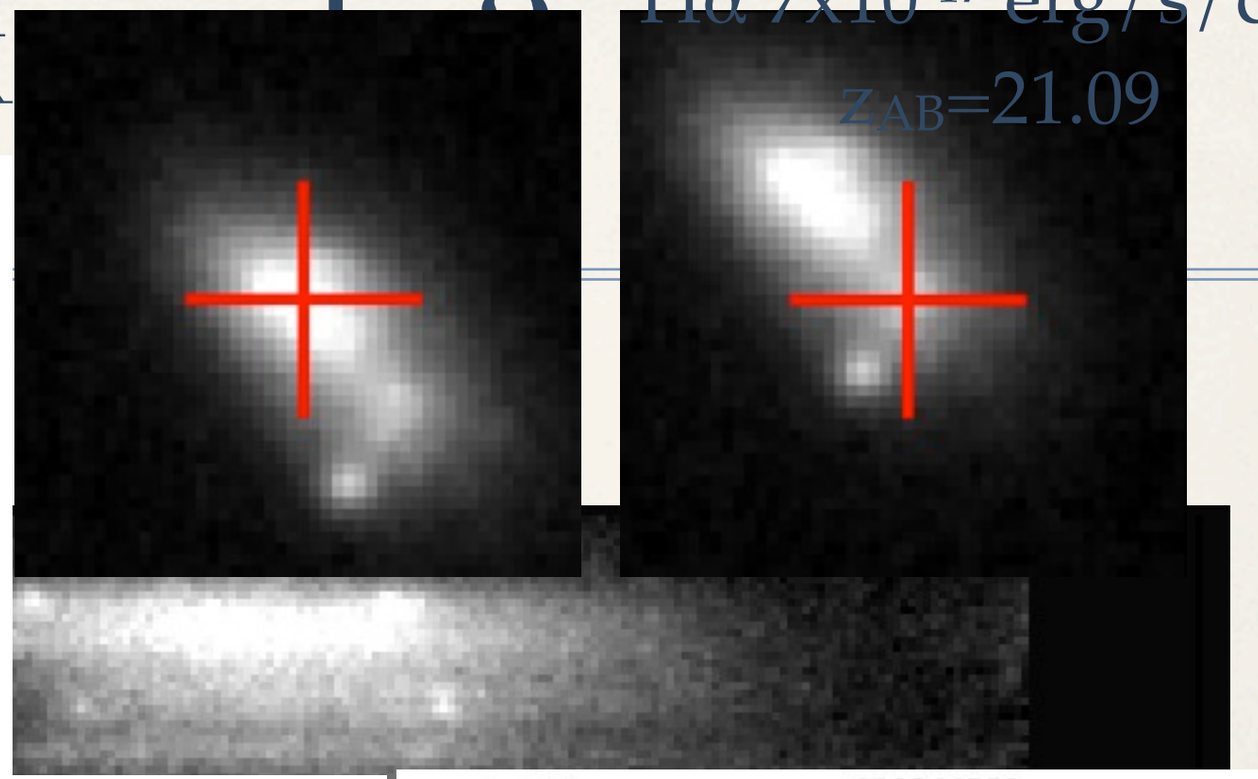
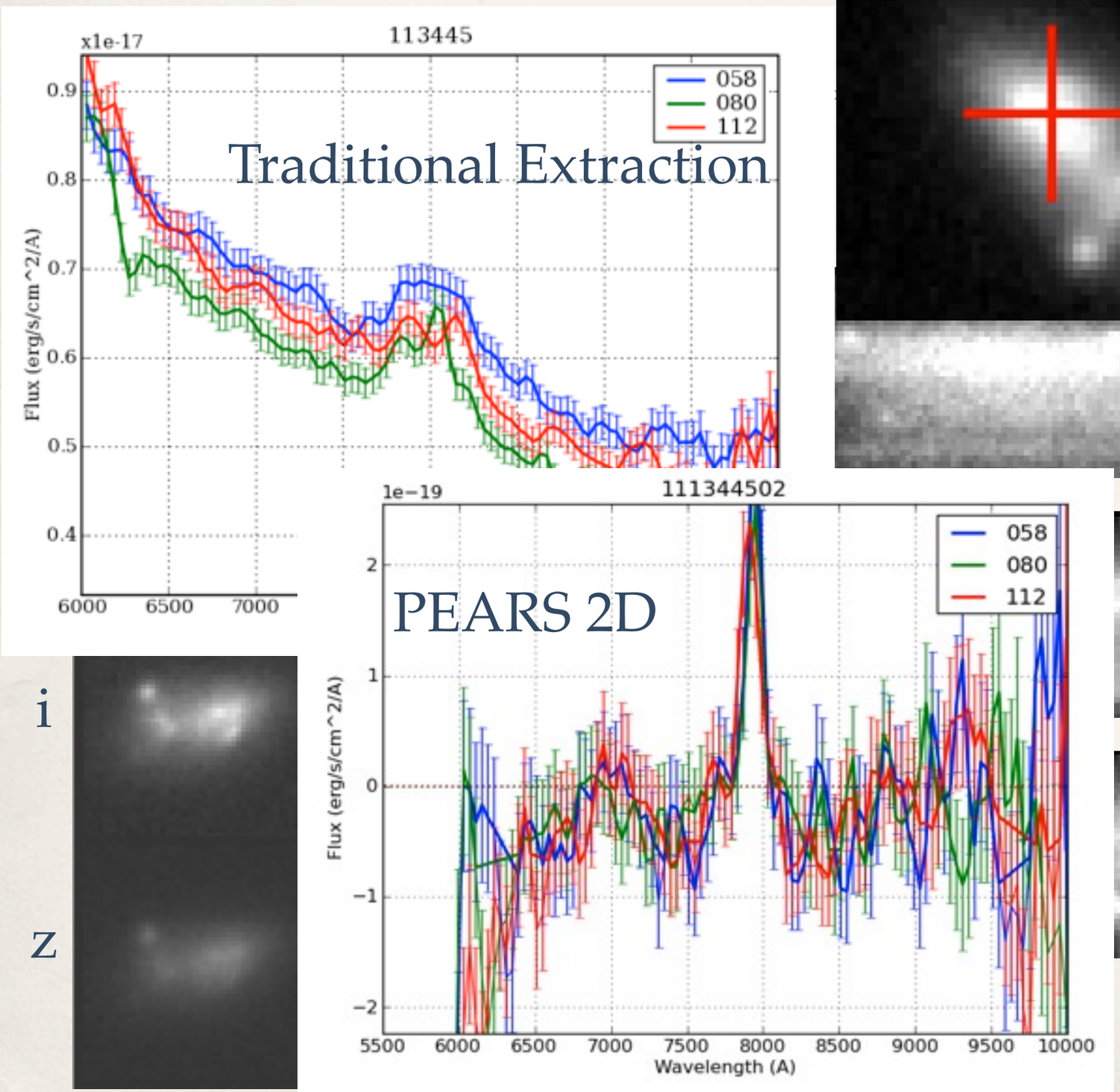
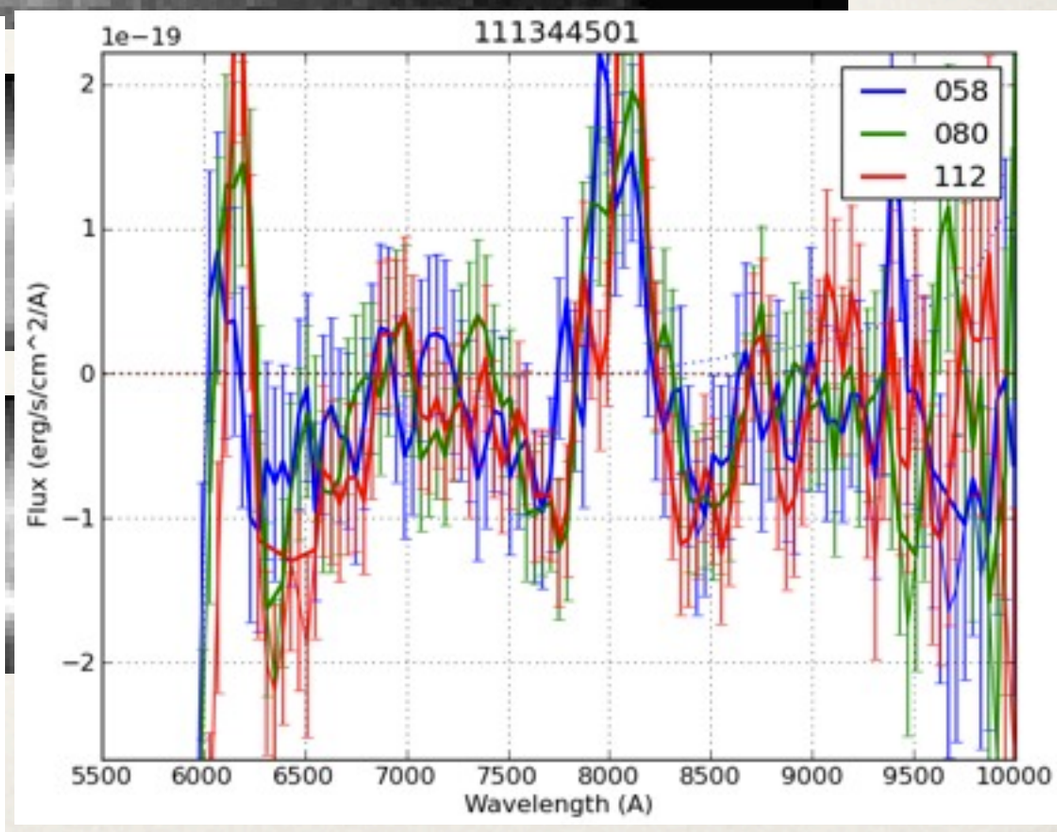


PA1





i

z

Direct images

Grism Observations

PEARS 2D: Example 1

$z=0.1$

$H\alpha$ $1x10^{-17}$ erg/s/cm^2

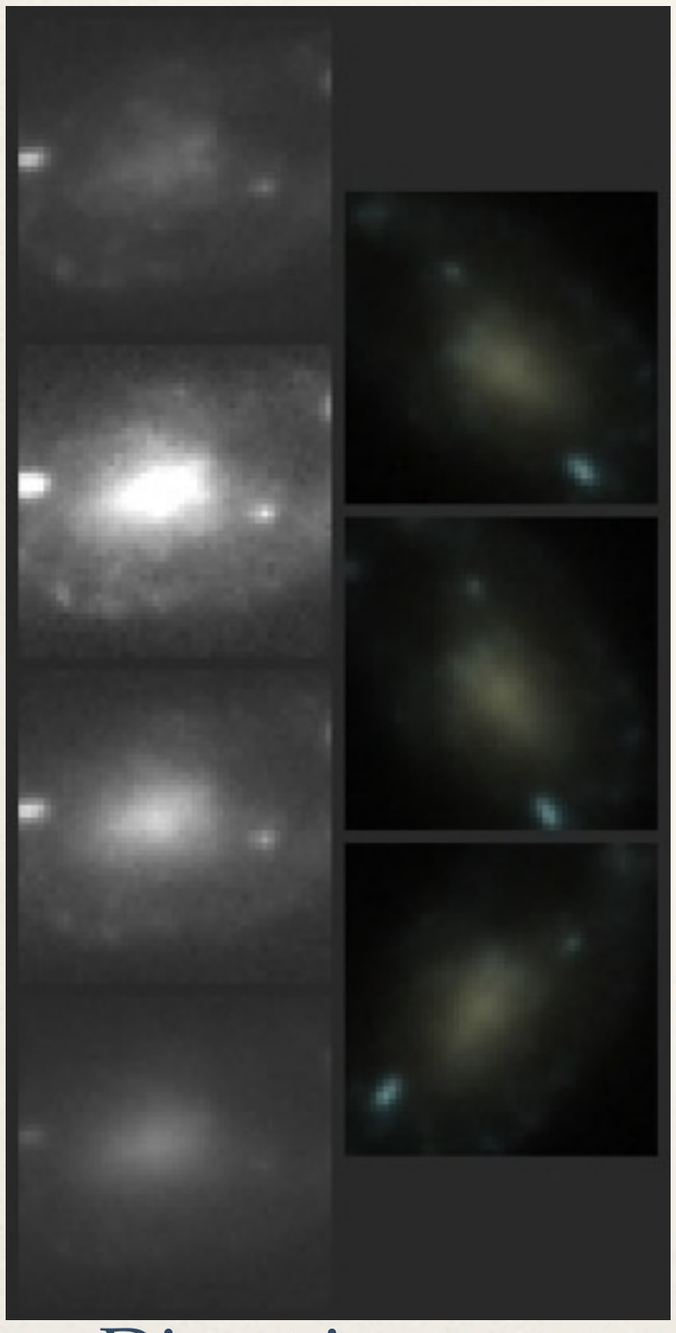
$z_{AB}=19.77$

B

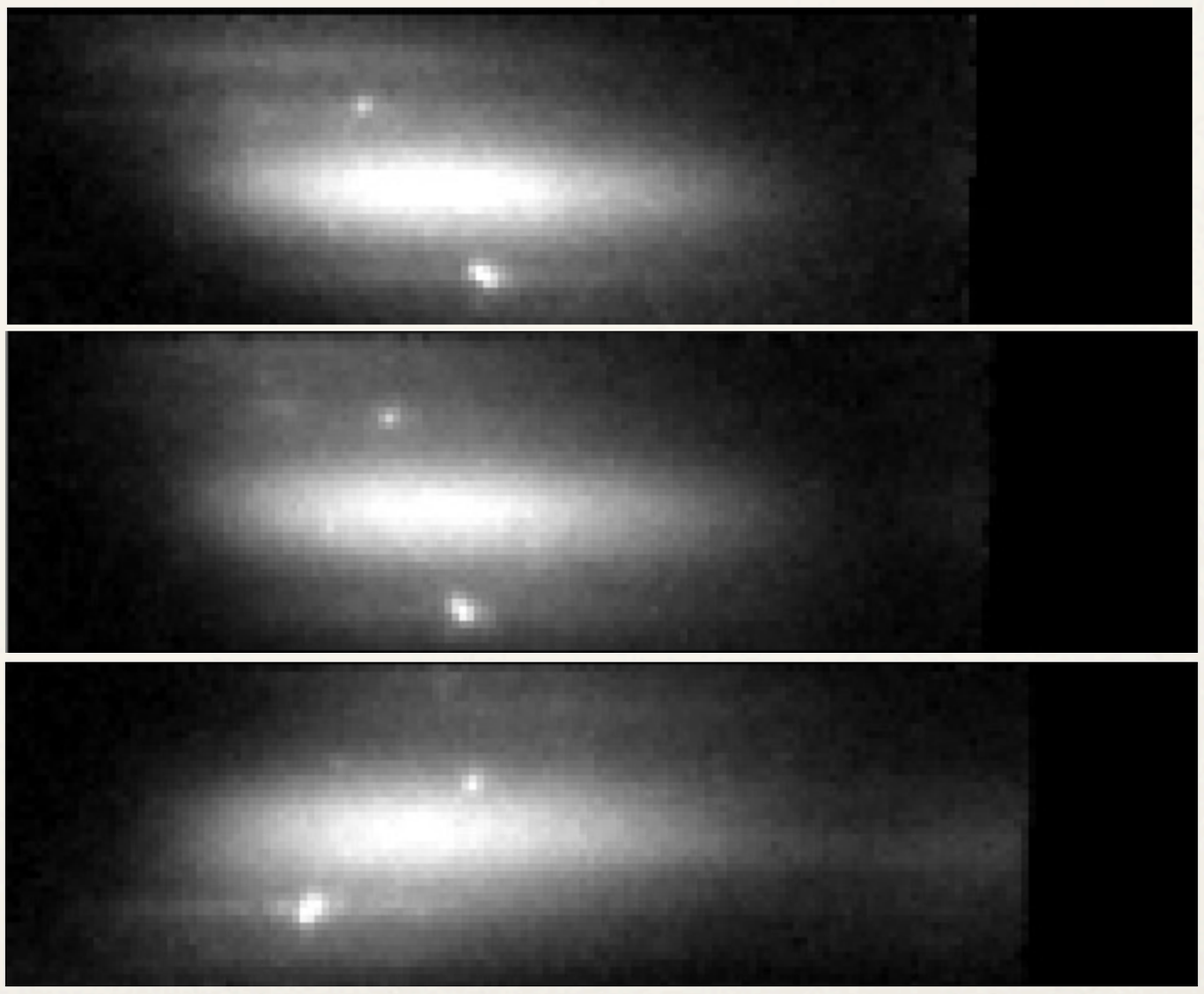
V

i

z



Direct images



PA1

PA2

PA3

Grism Observations

ample 1

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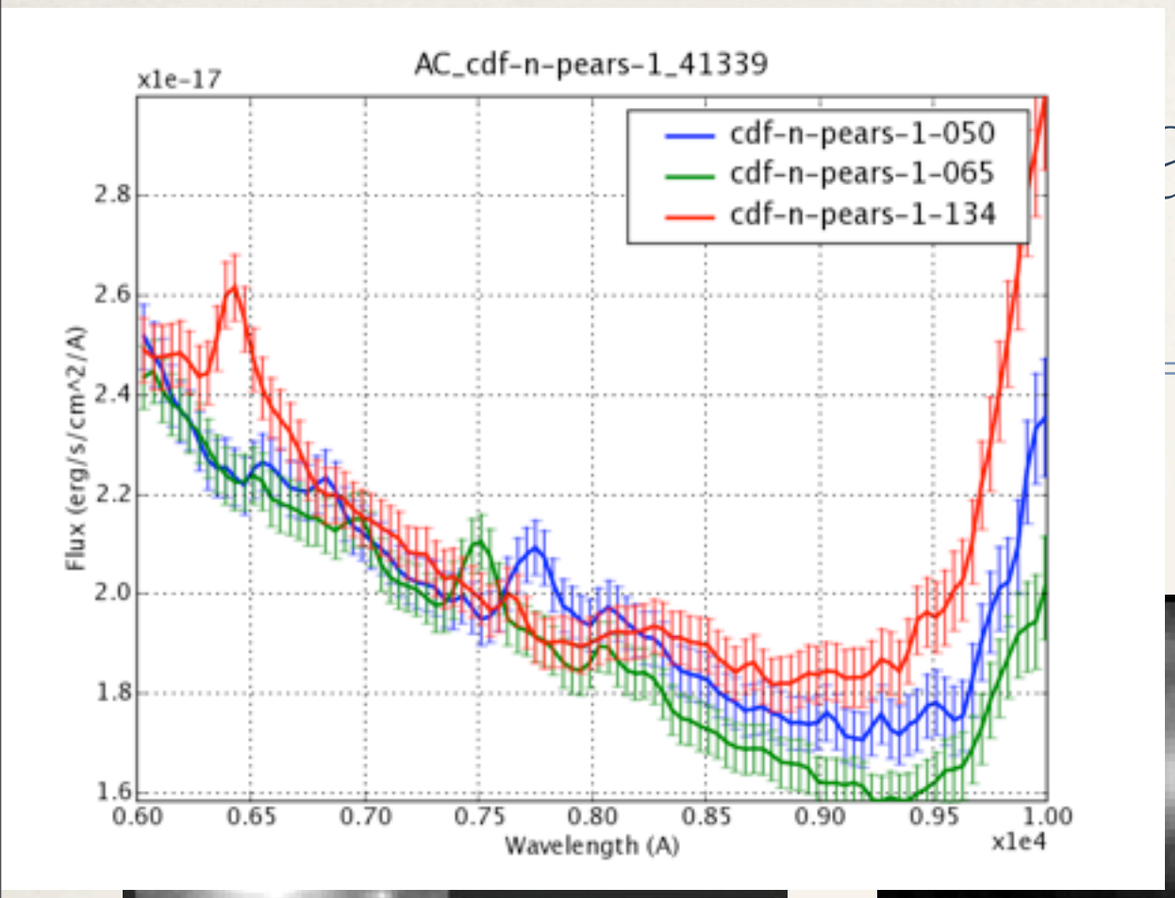
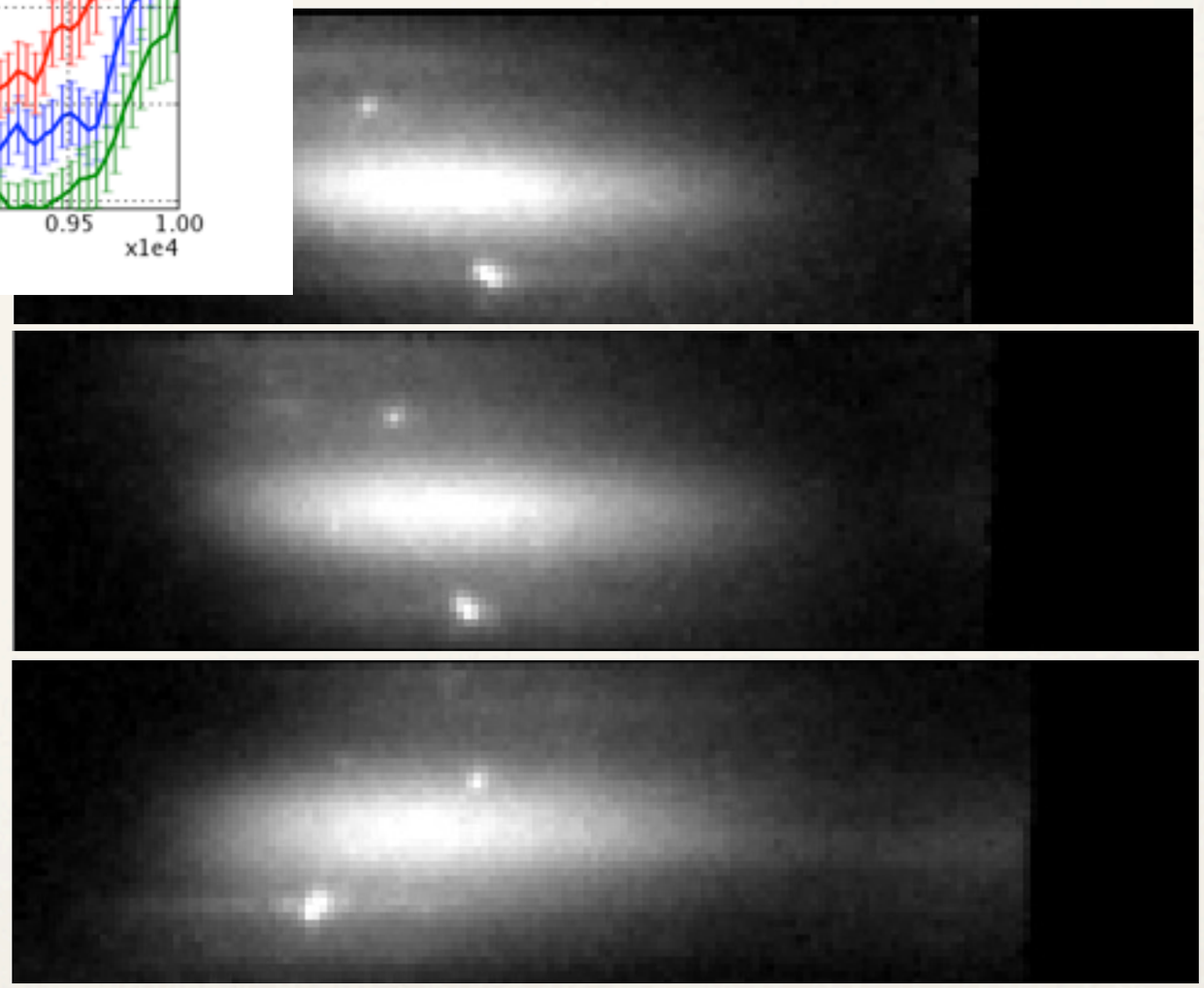


i

z

Direct images



PA1

PA2

PA3

Grism Observations

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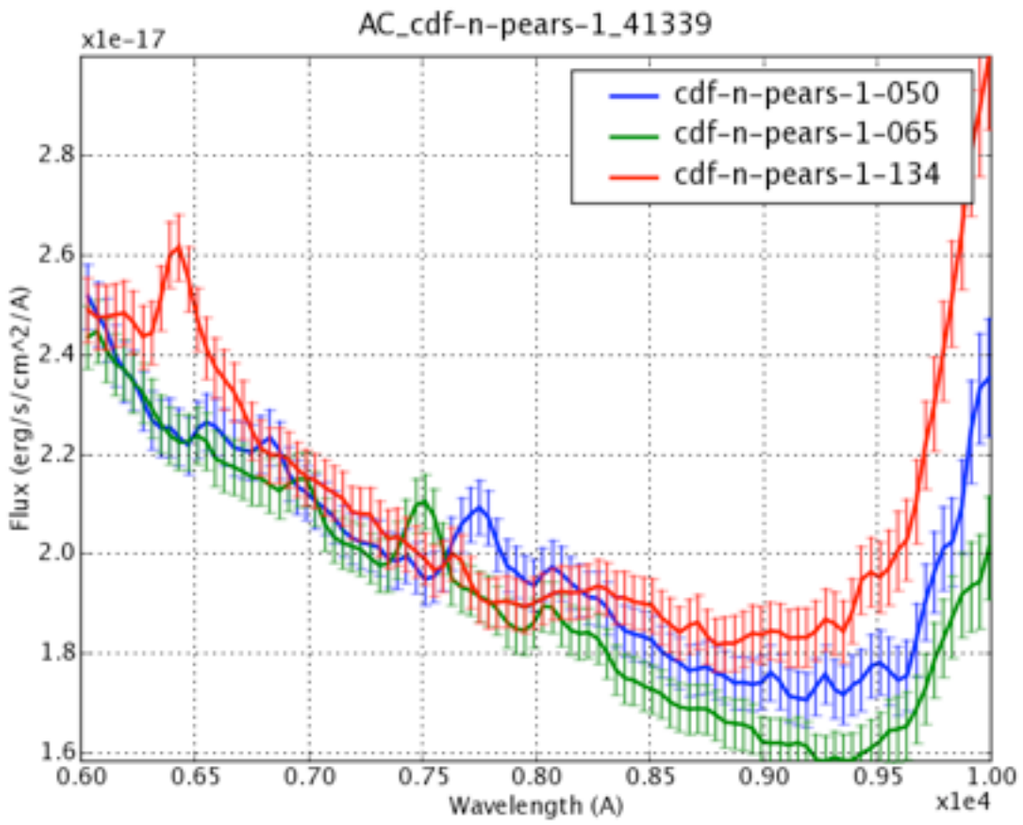
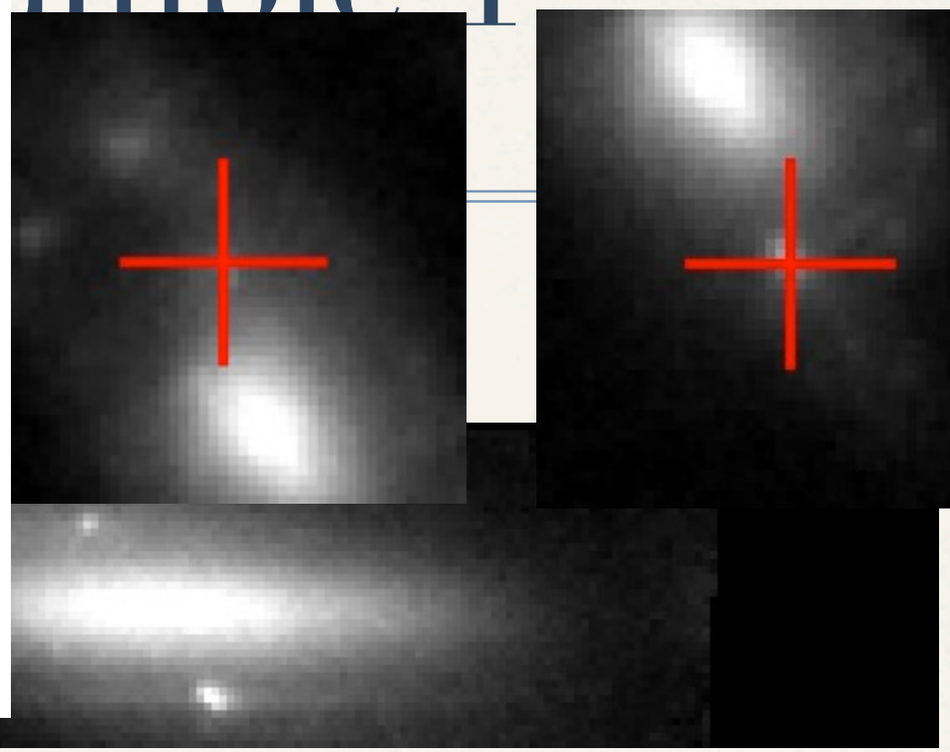
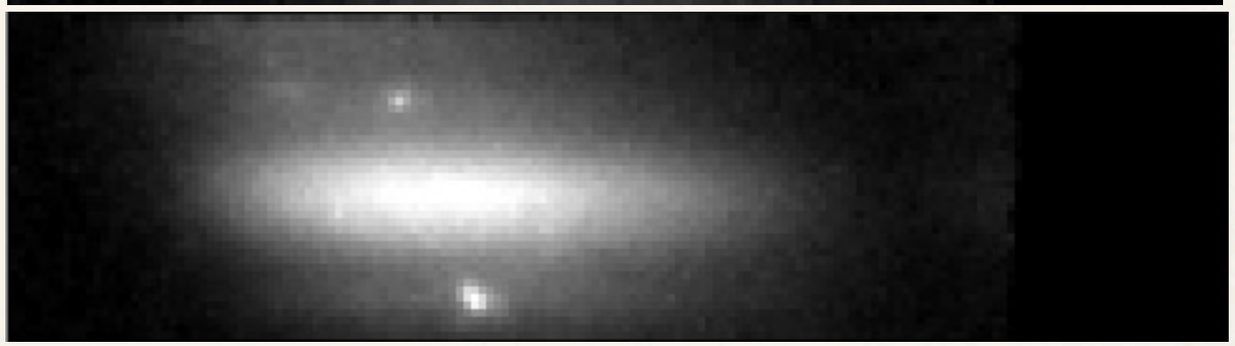
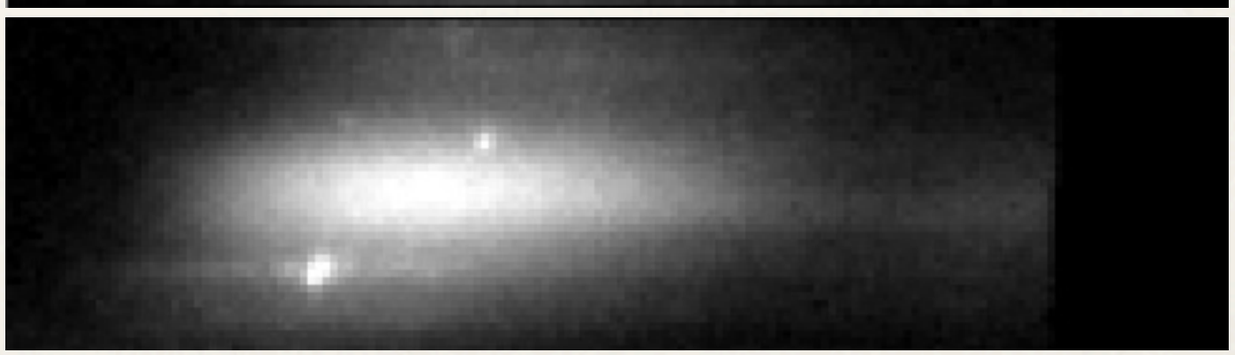








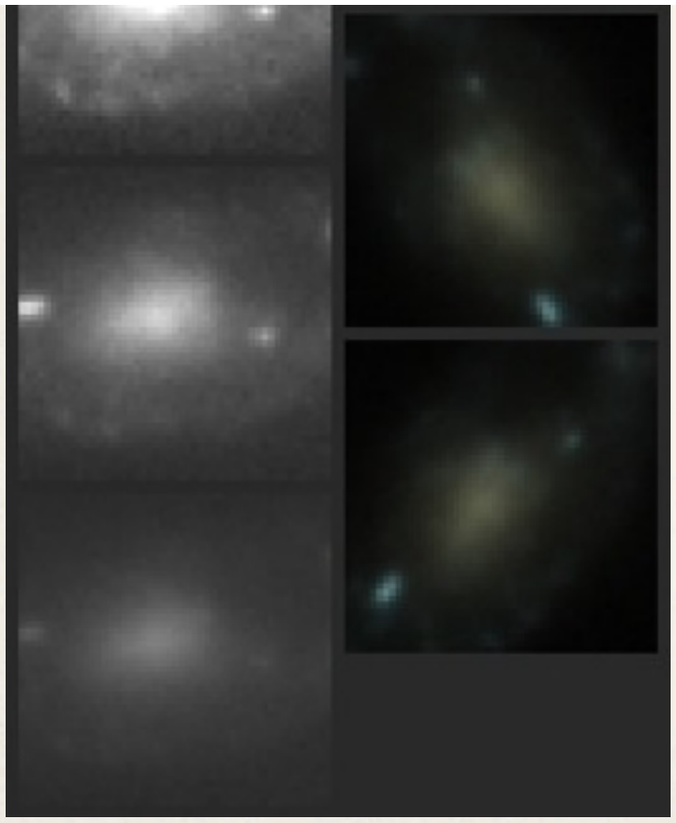
PA1

PA2

PA3

i

z



Direct images

Grism Observations

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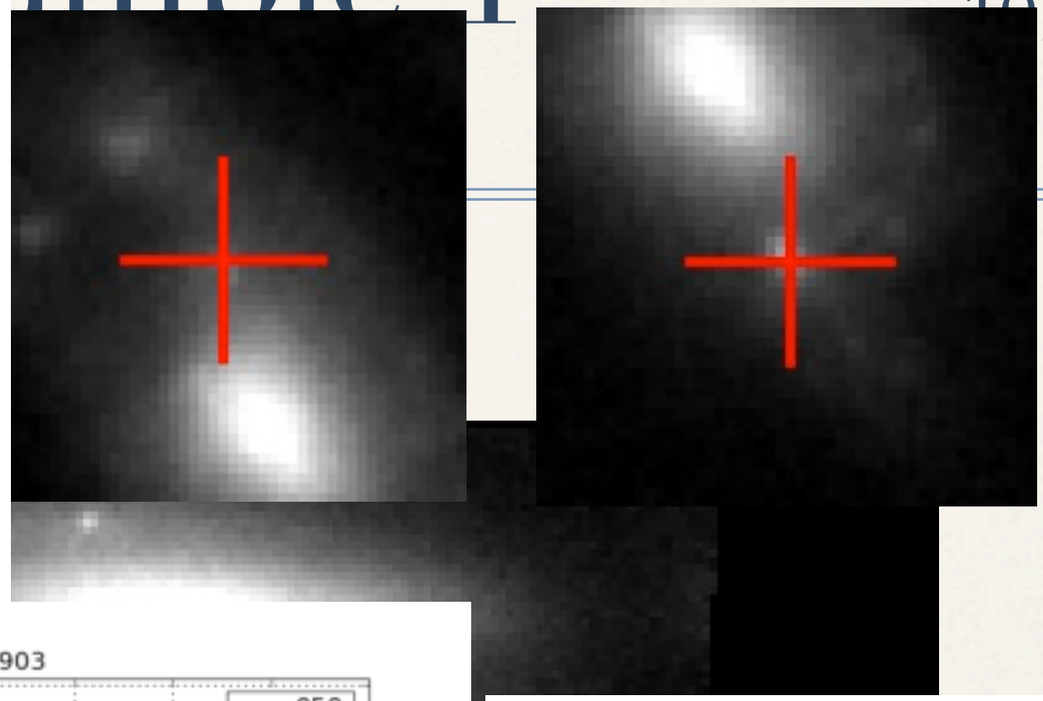
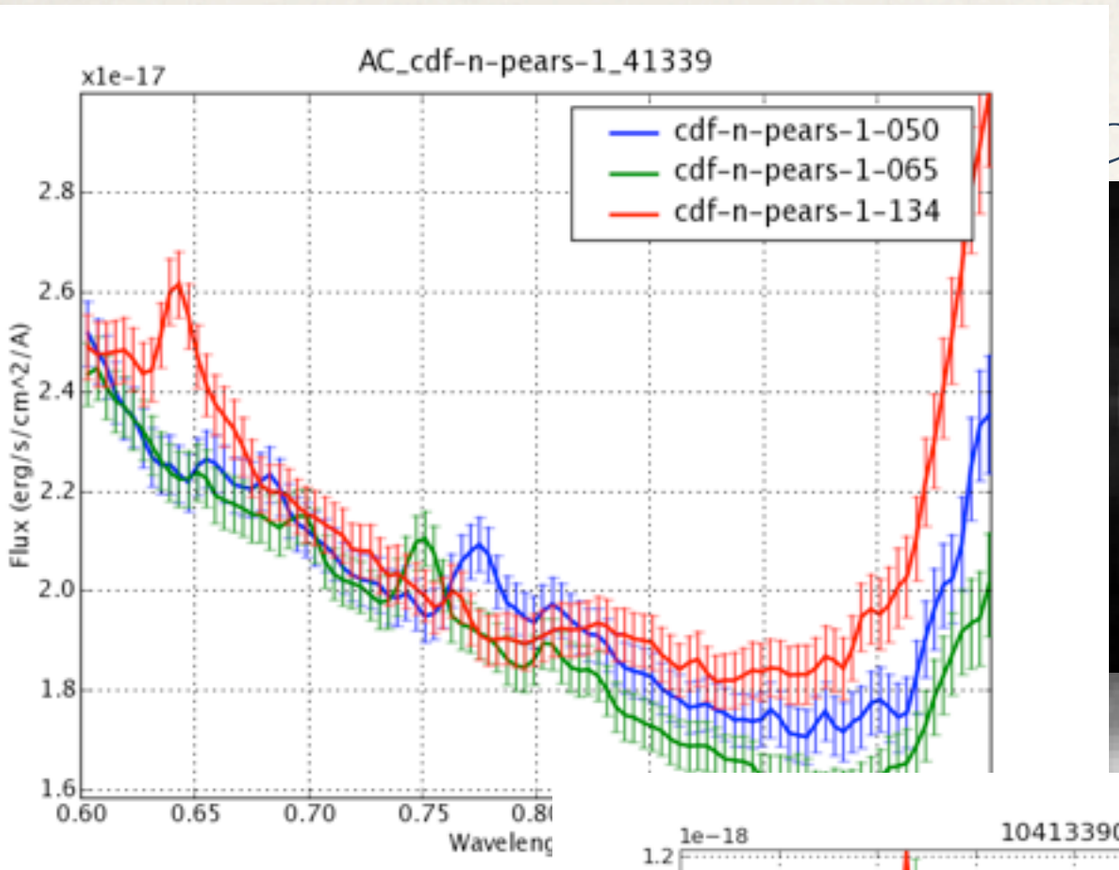
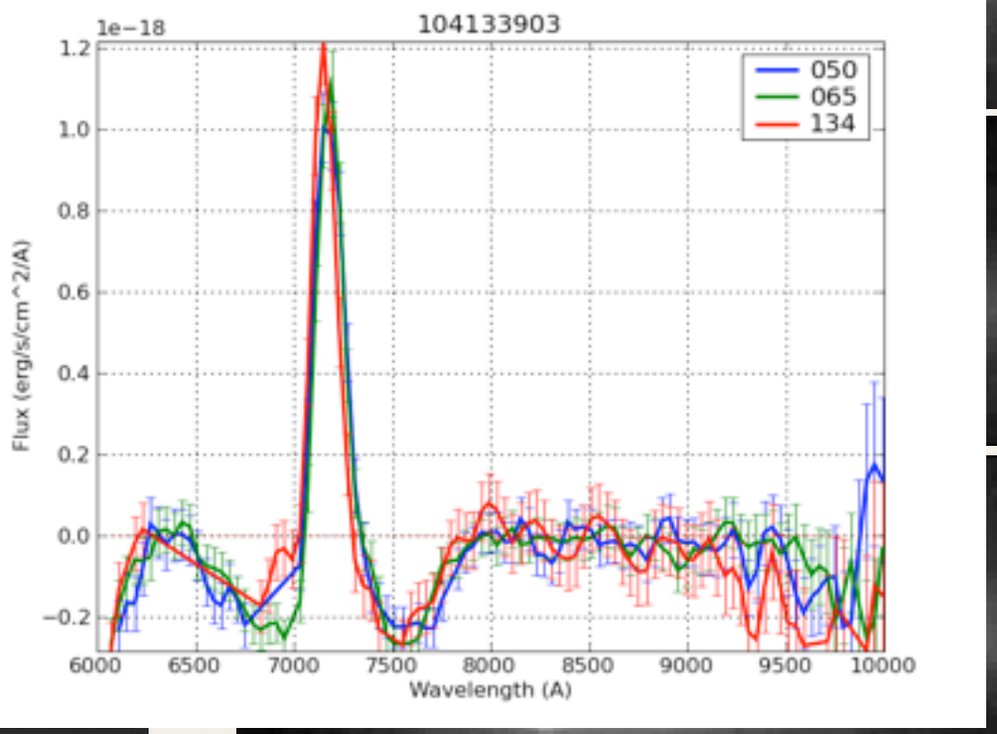
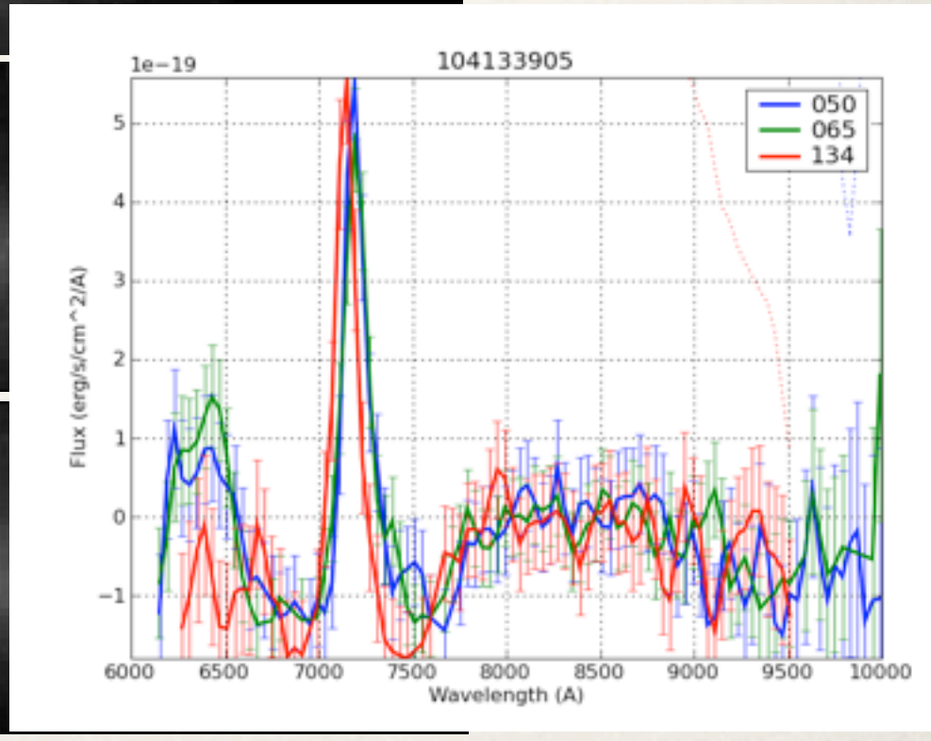
.77



PA1

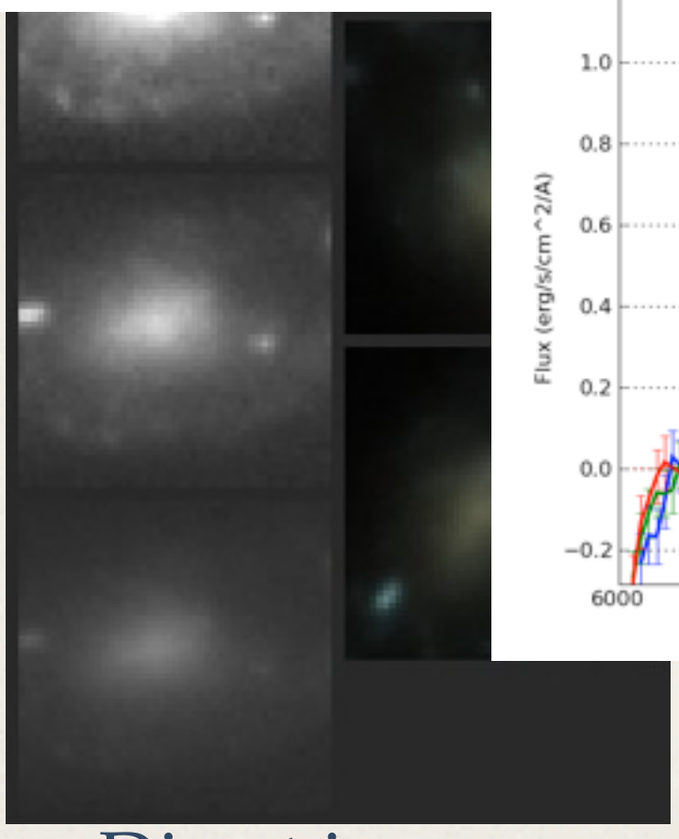






i

z



Direct images

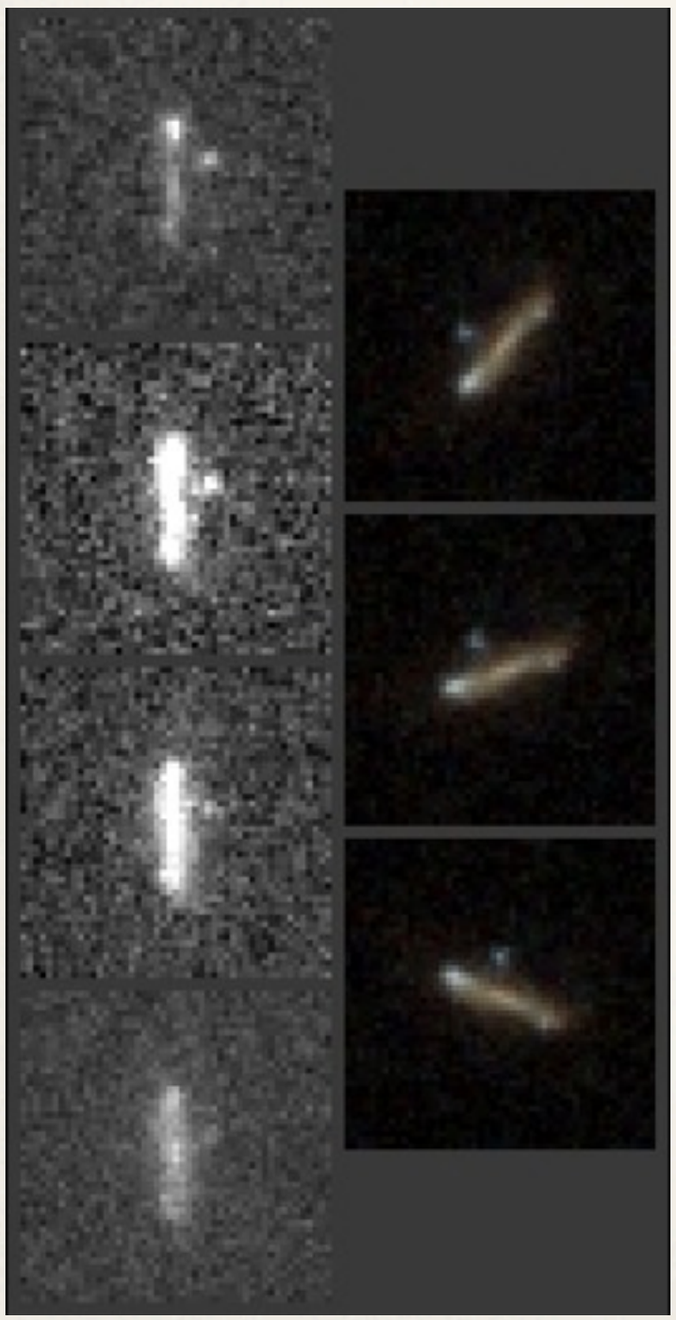
Grism Observations

PEARS 2D: Example 3

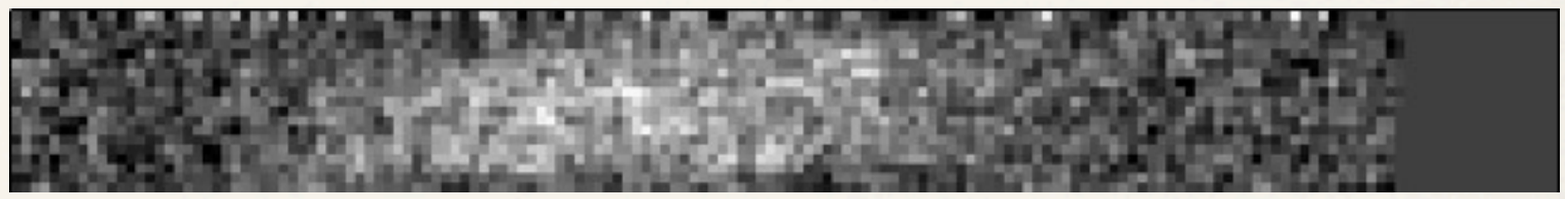
z=0.3

Hα 1.5×10^{-17} erg/s/cm²

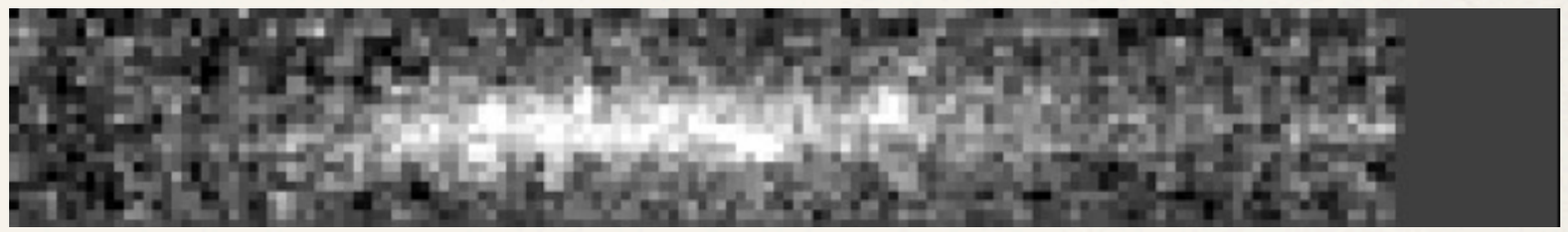
z_{AB}=23.86



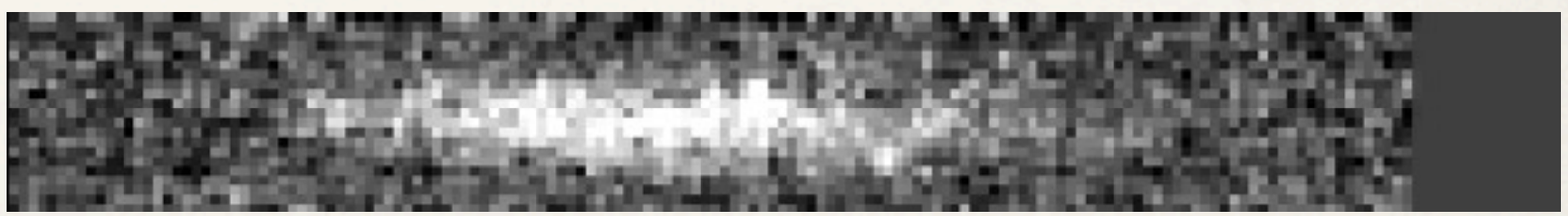
Direct images



PA1



PA2



PA3

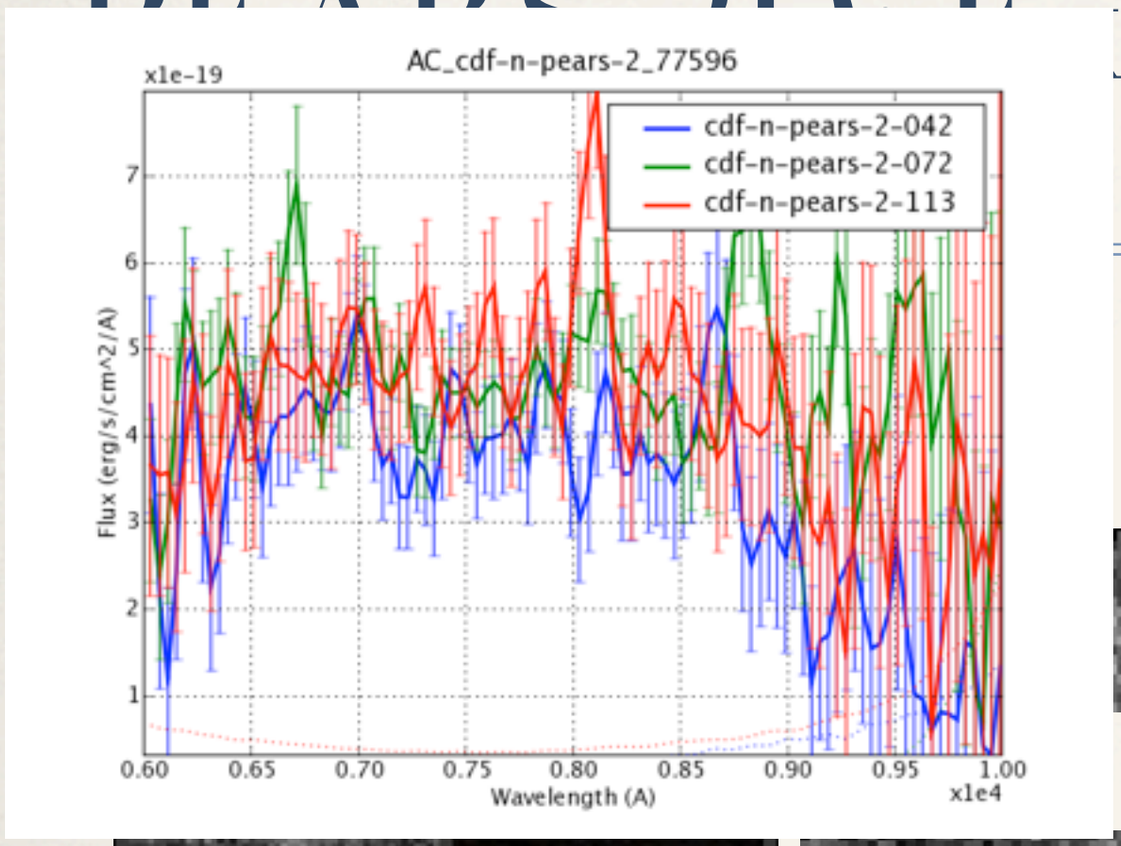
Grism Observations

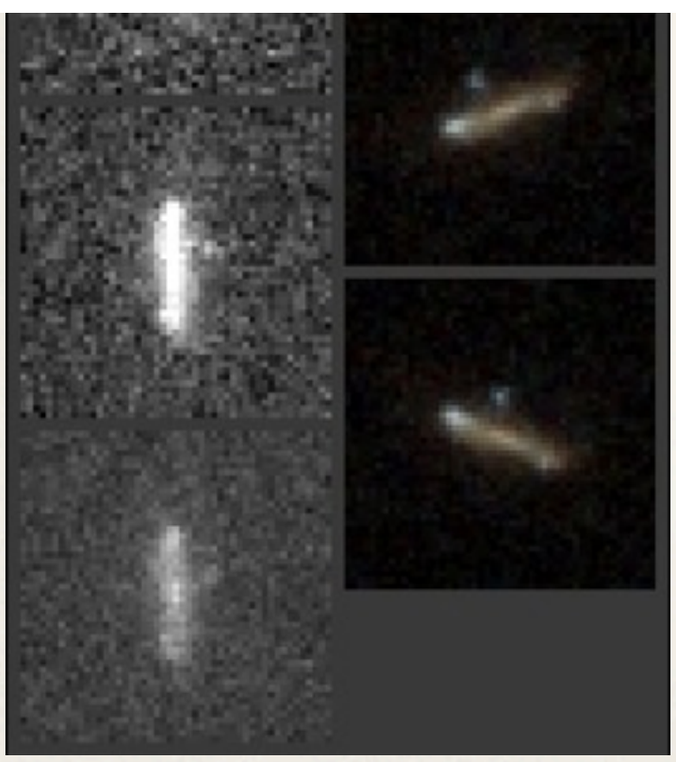
PEARS 2D: Example 3

z=0.3

Hα 1.5×10^{-17} erg/s/cm²

z_{AB}=23.86

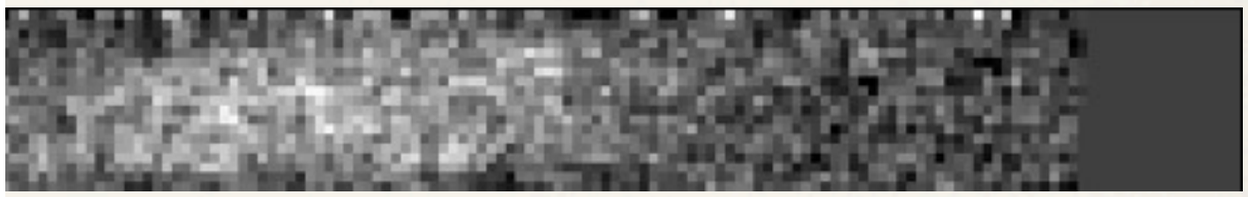




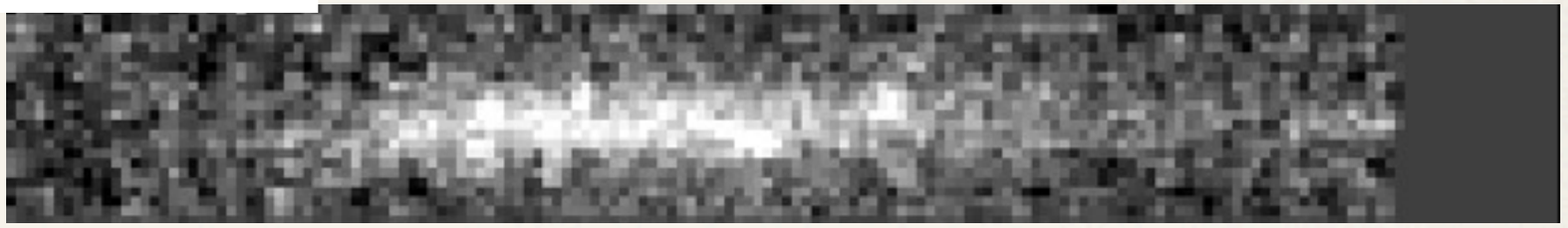
i

z

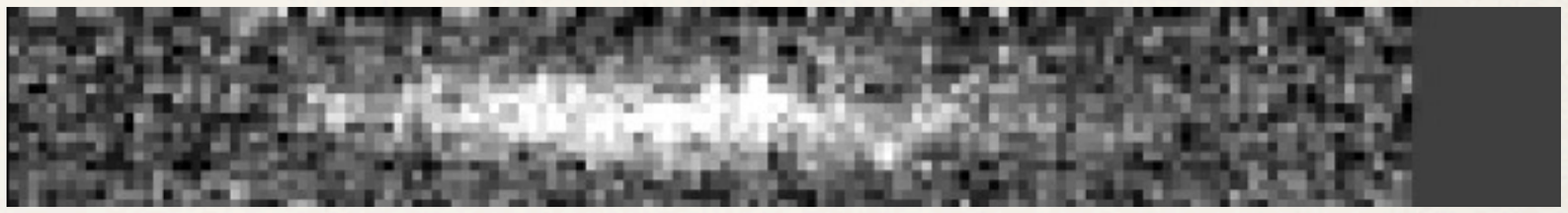
Direct images



PA1



PA2



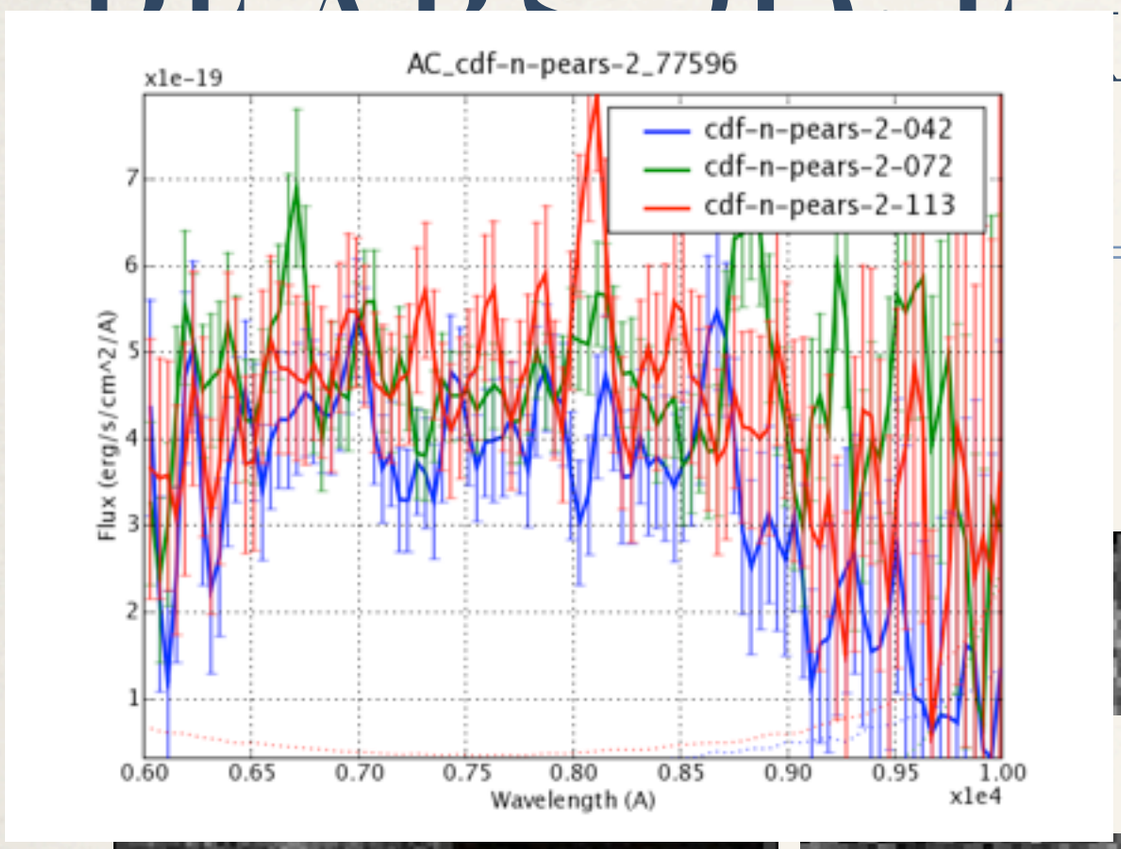
PA3

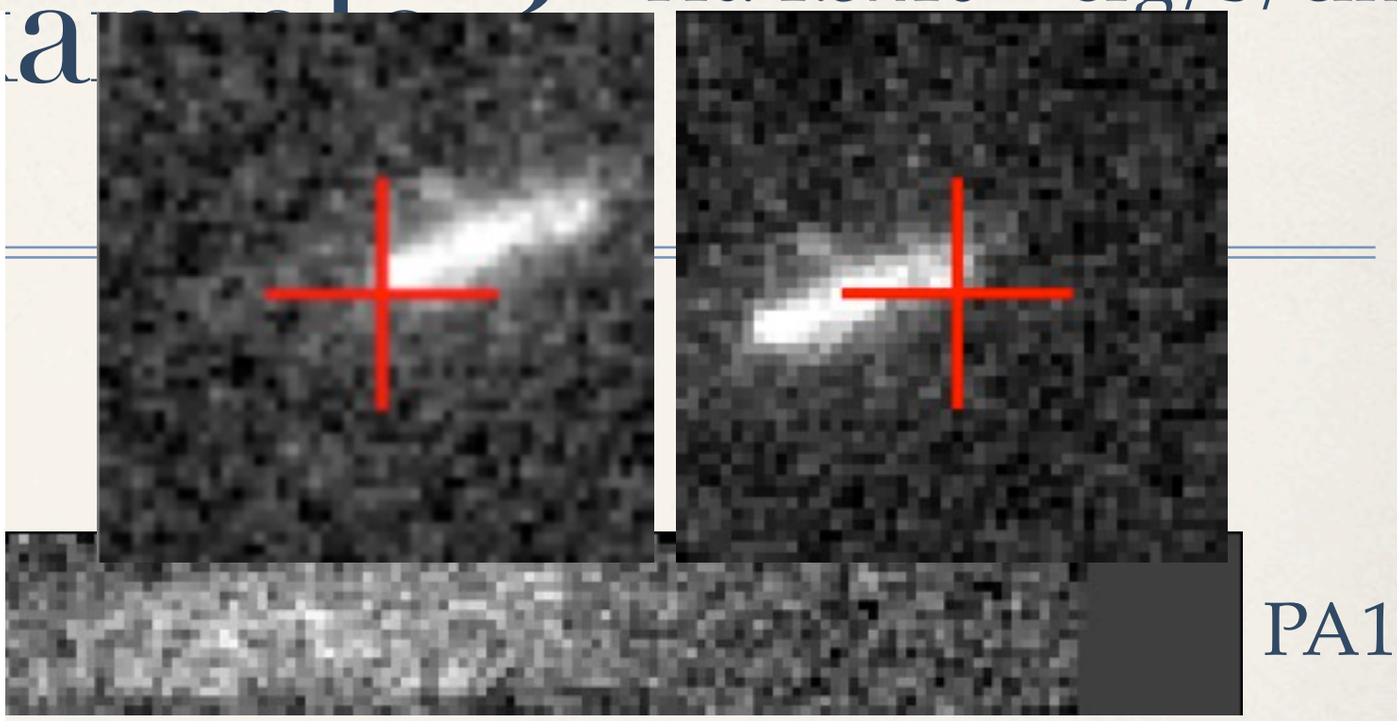
Grism Observations

PEARS 2D Example 2

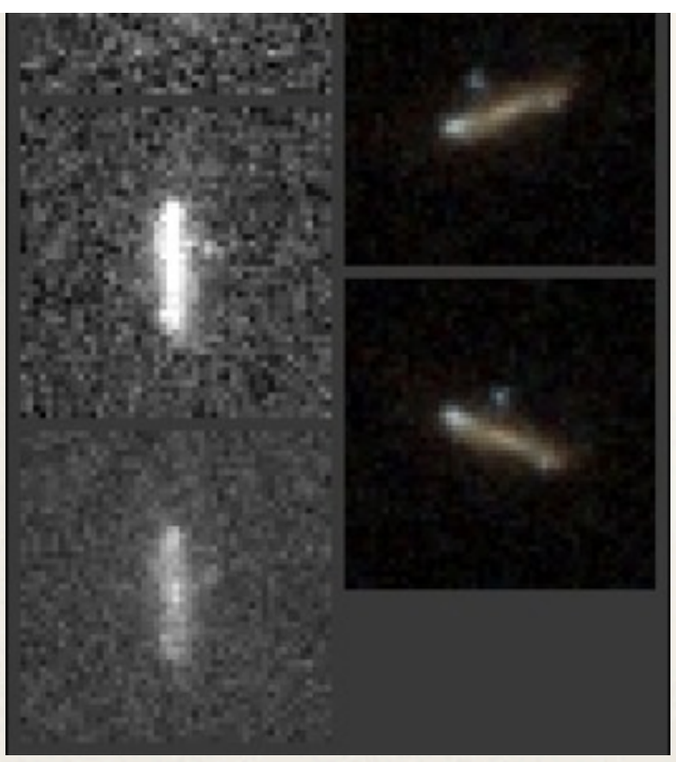
z=0.3

Hα 1.5×10^{-17} erg/s/cm²



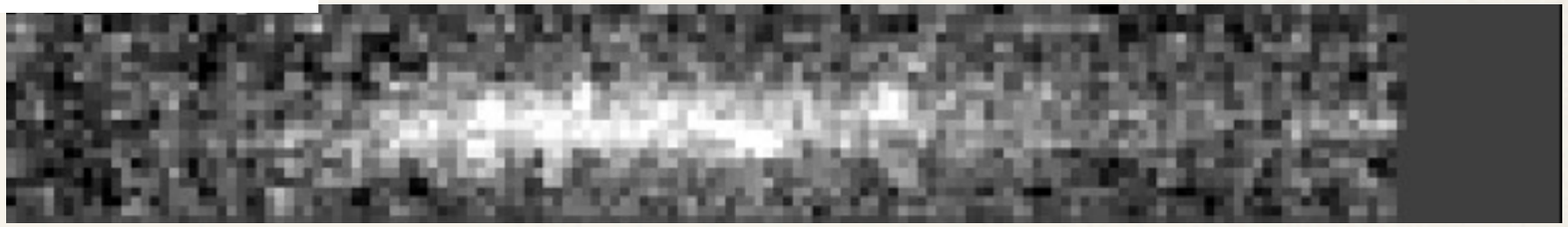


PA1

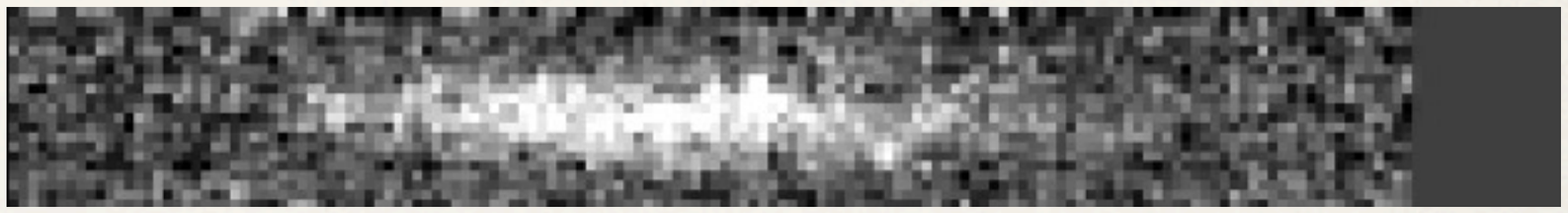


i

z



PA2



PA3

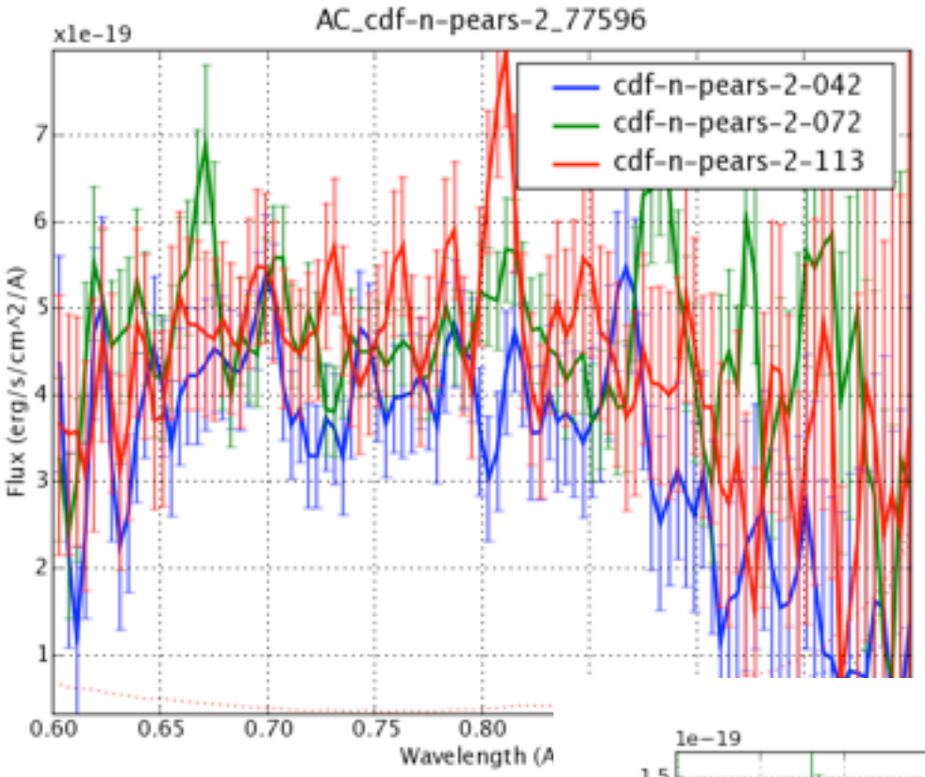
Direct images

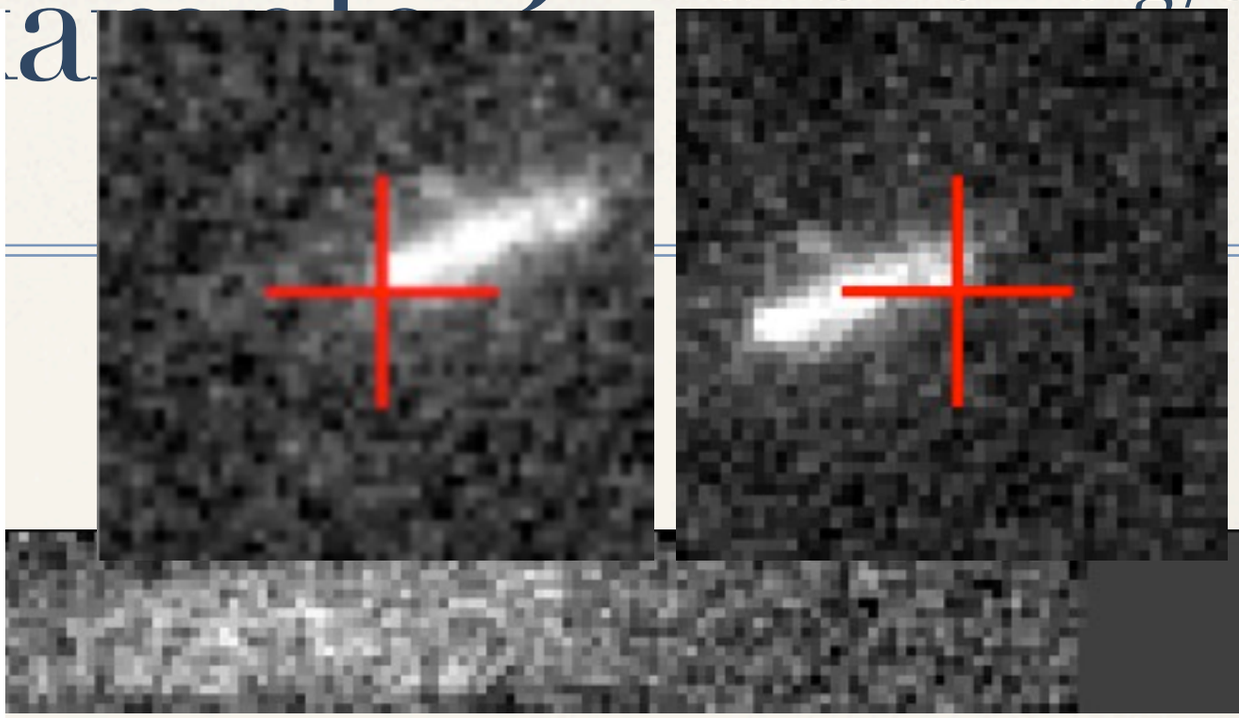
Grism Observations

PEARS 2D Example 2

z=0.3

Hα 1.5x10^{-17} erg/s/cm^2

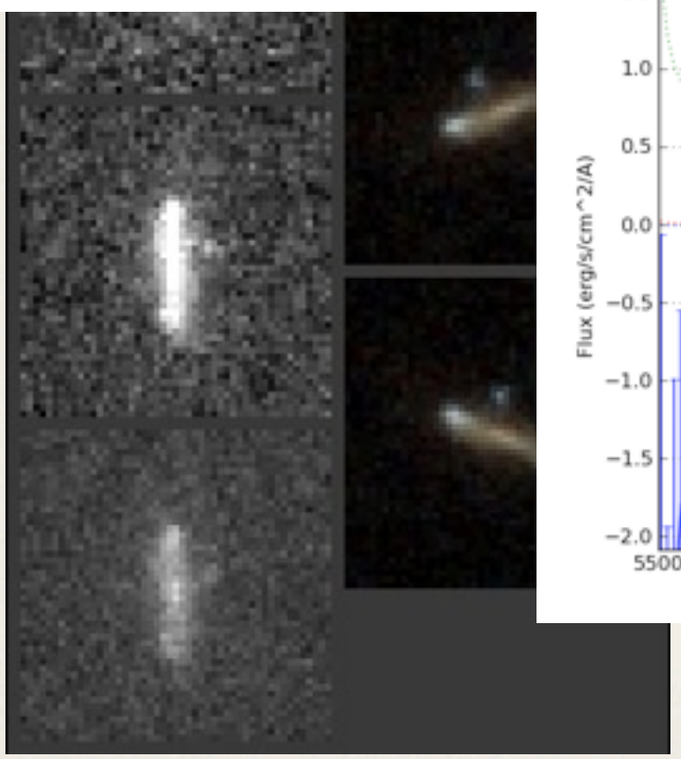


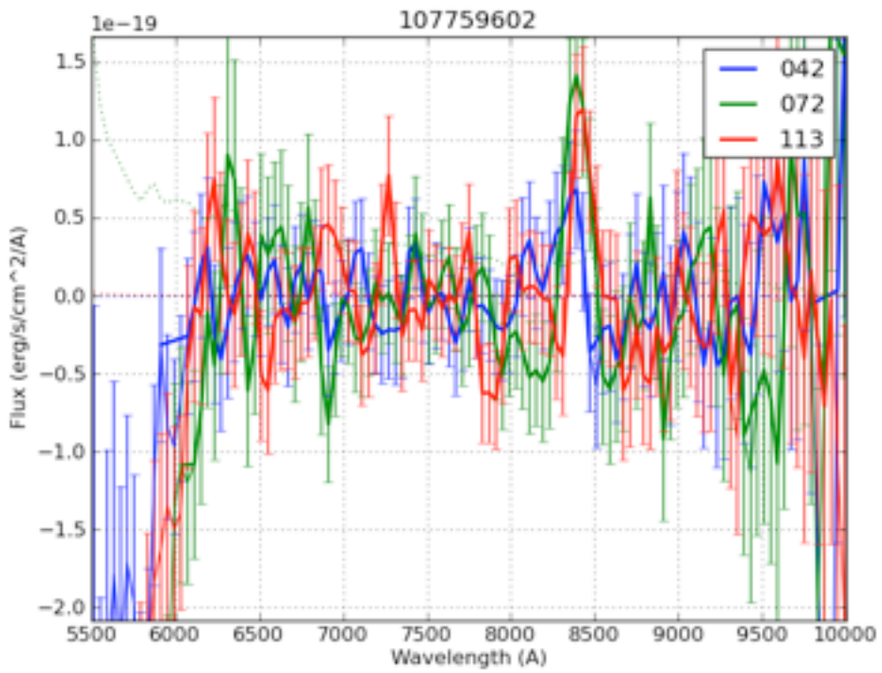


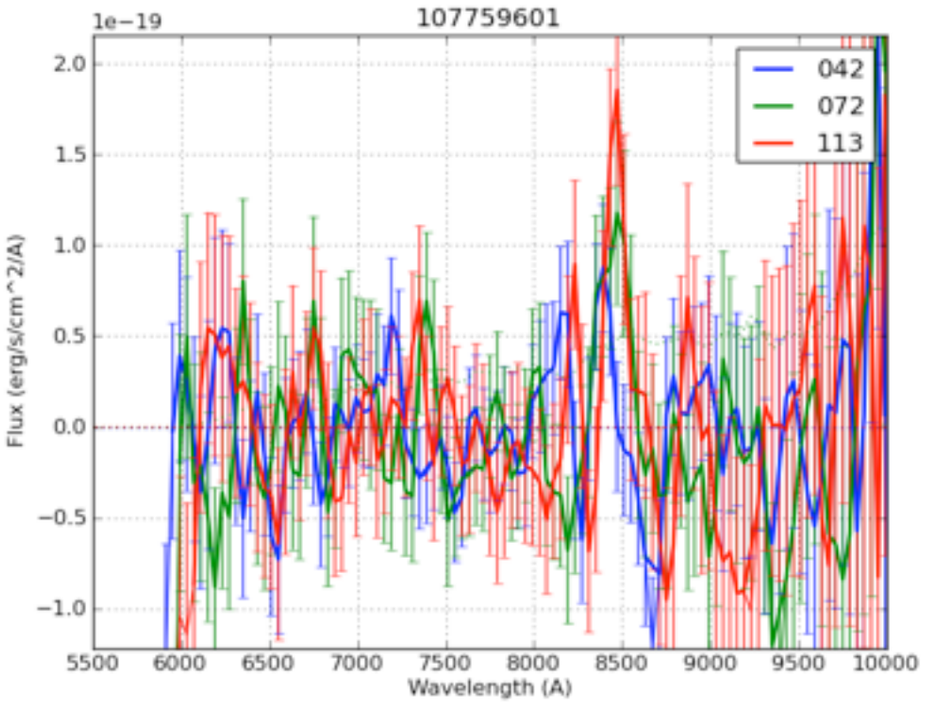
PA1

i

z





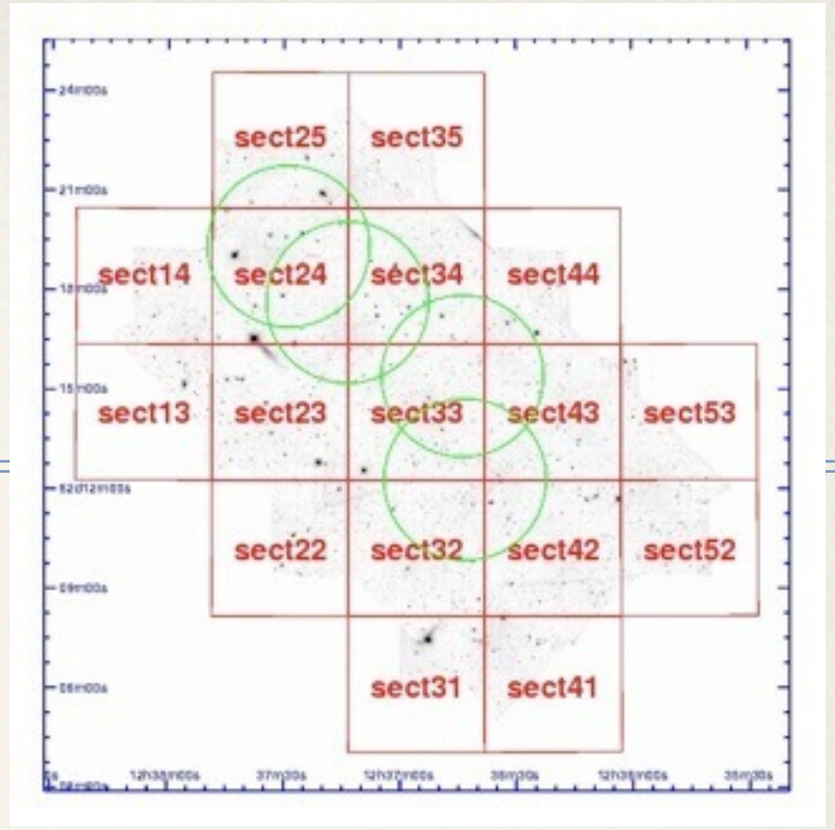


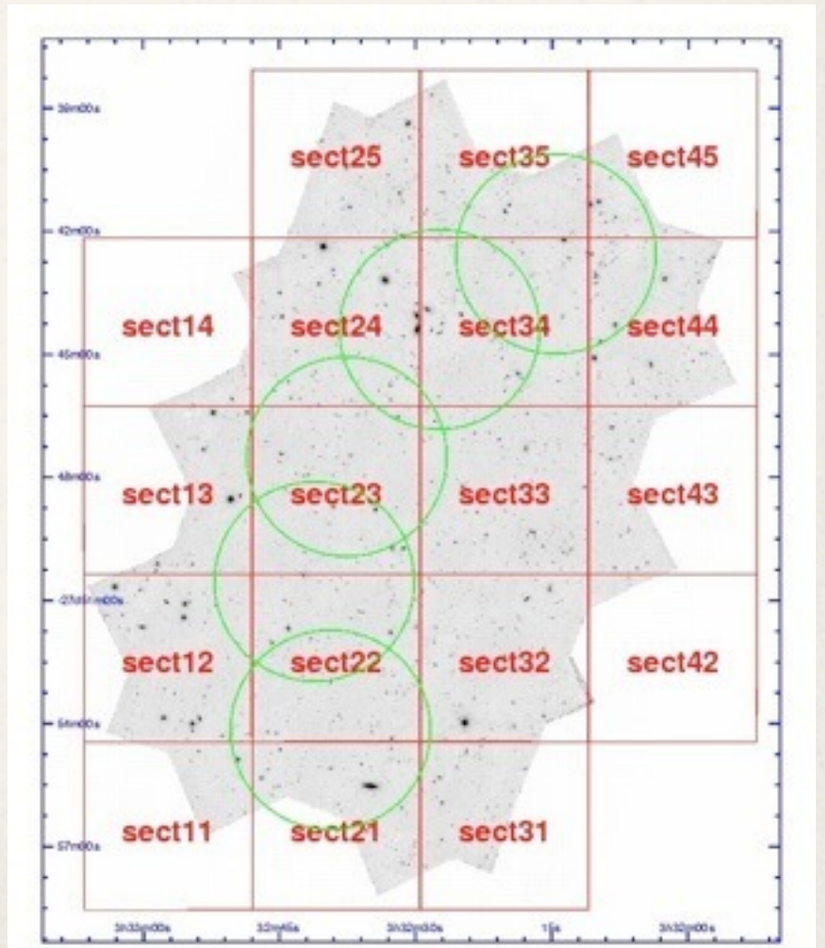
Direct images

Grism Observations

PEARS

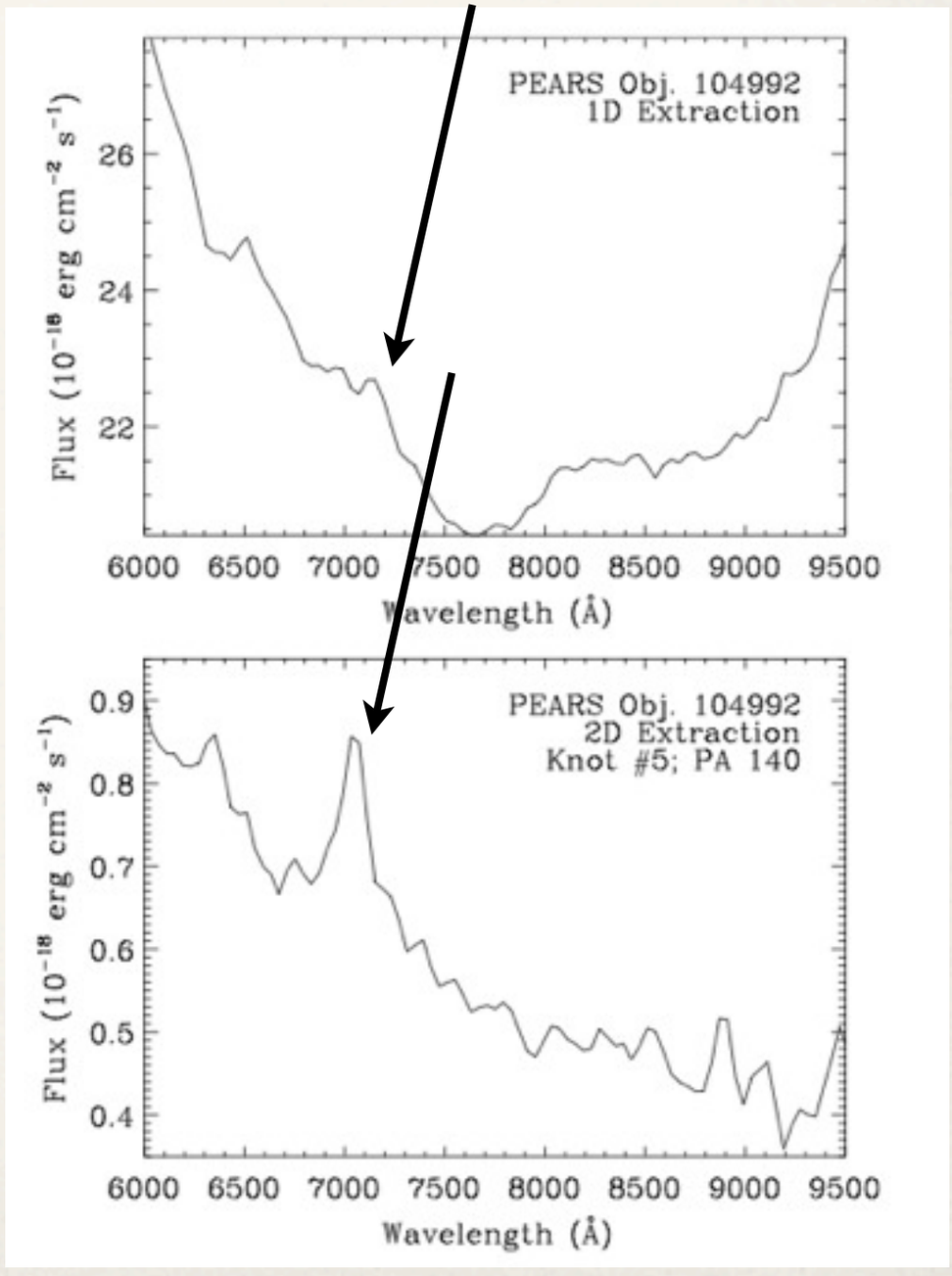
- "Probing Evolution And Reionization Spectroscopically"
- 9 fields, 4 in GOODS-N, 5 in GOODS-S
- 20 orbits/field
- 100 arcmin^2
- > 10,000 spectra extracted "normally"
- Object-based extraction available at http://archive.stsci.edu/prepds/pears/



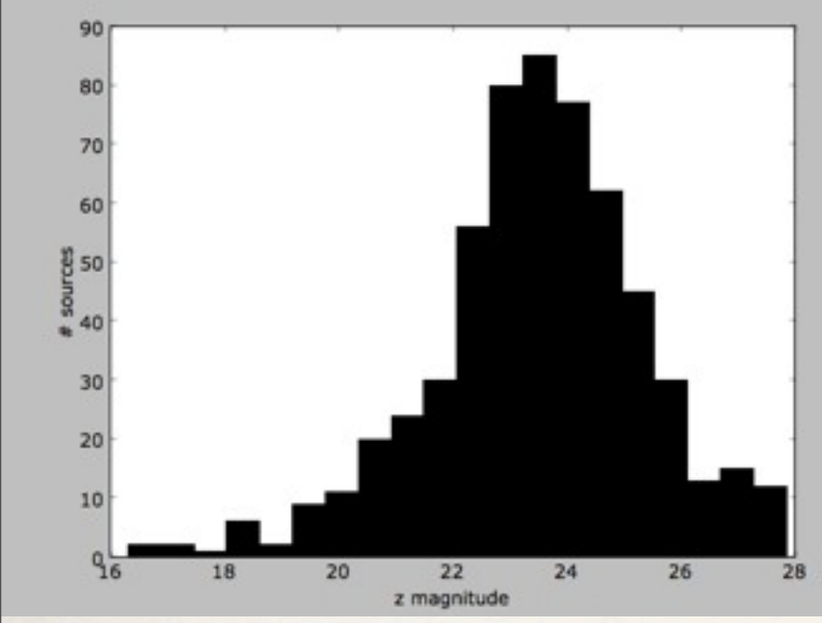


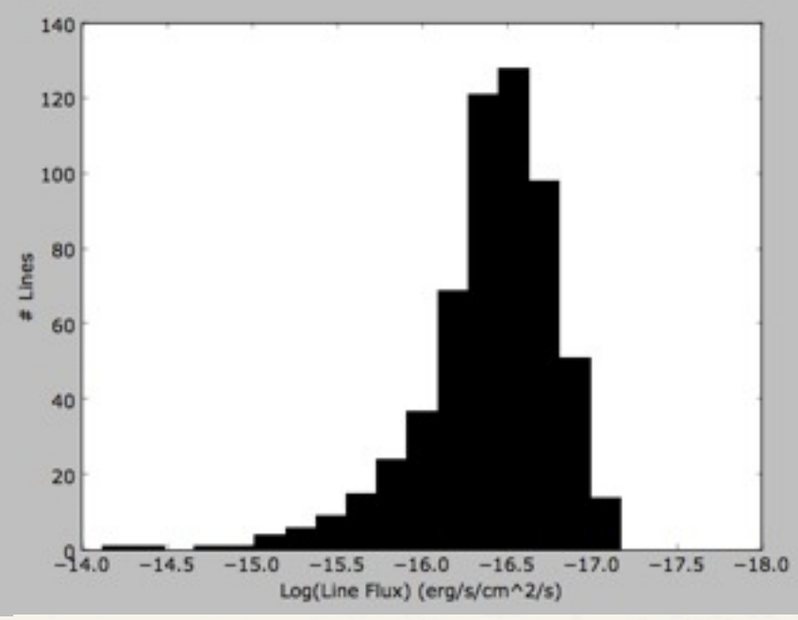
PEARS 2D Emission Lines

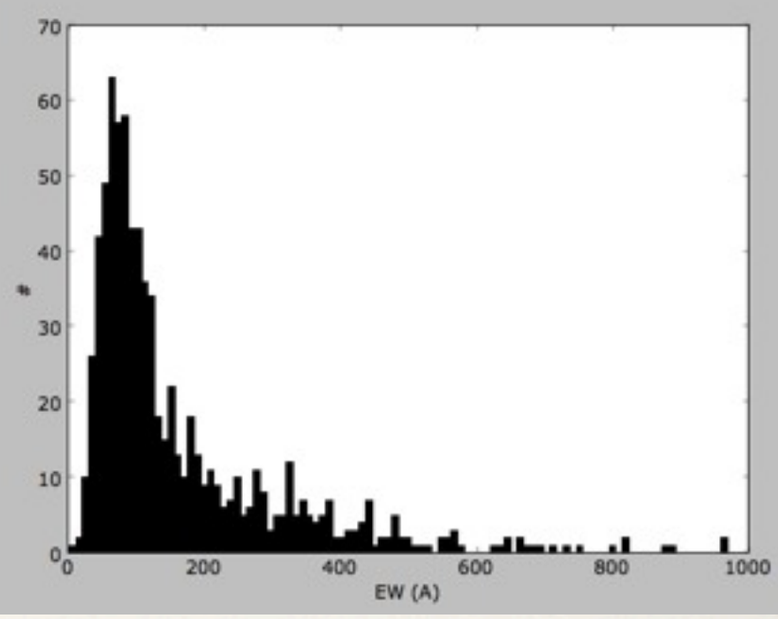
- Hα detected in objects as faint as $z_{AB} = 27.1$
- Lines with fluxes as faint as 5 10^{-18} erg/s/cm^2 are found
- 793 emission lines, ~1.5x 1D method
  - 213 Ha (S: 109, N:104) 0<z<0.5
  - 297 OIII (S:166, N:131) 0.2<z<1.0
  - 196 OII (S:101, N:95) 0.6<z<1.7
  - 74 Hg (S:44,N:30) 0.4<z<1.3
  - 13 Lya (S:10,N:3) 3.9<z<7.2



PEARS 2D Emission Lines







Host sources down to z_{AB}~28

Lines down to ~2×10^{-17} erg/s/cm^2

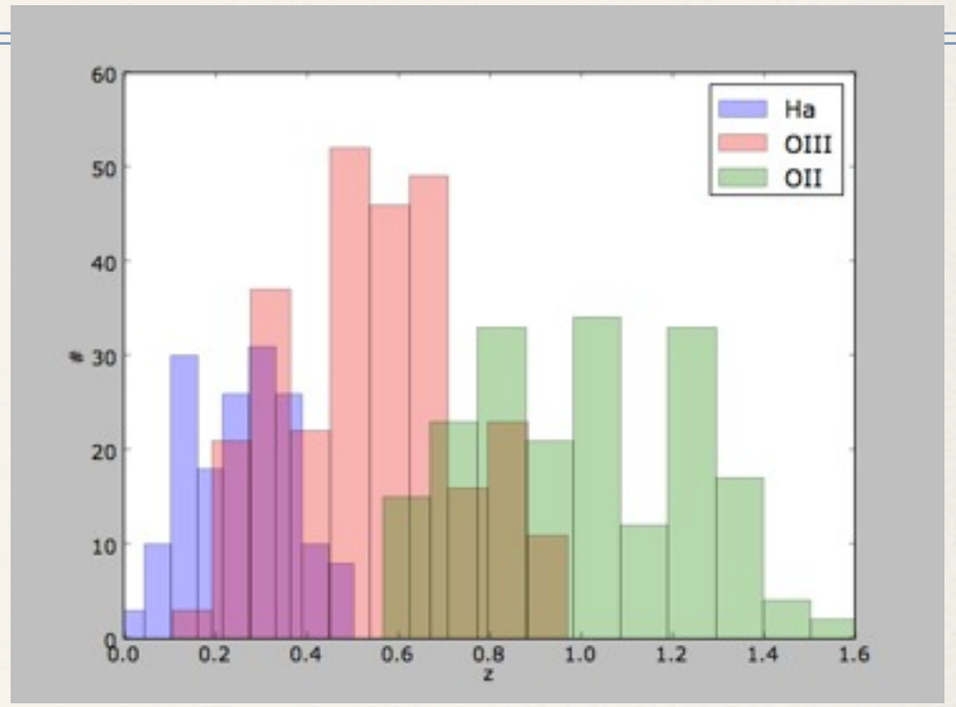
But, average EW_o>~50 Å cutoff

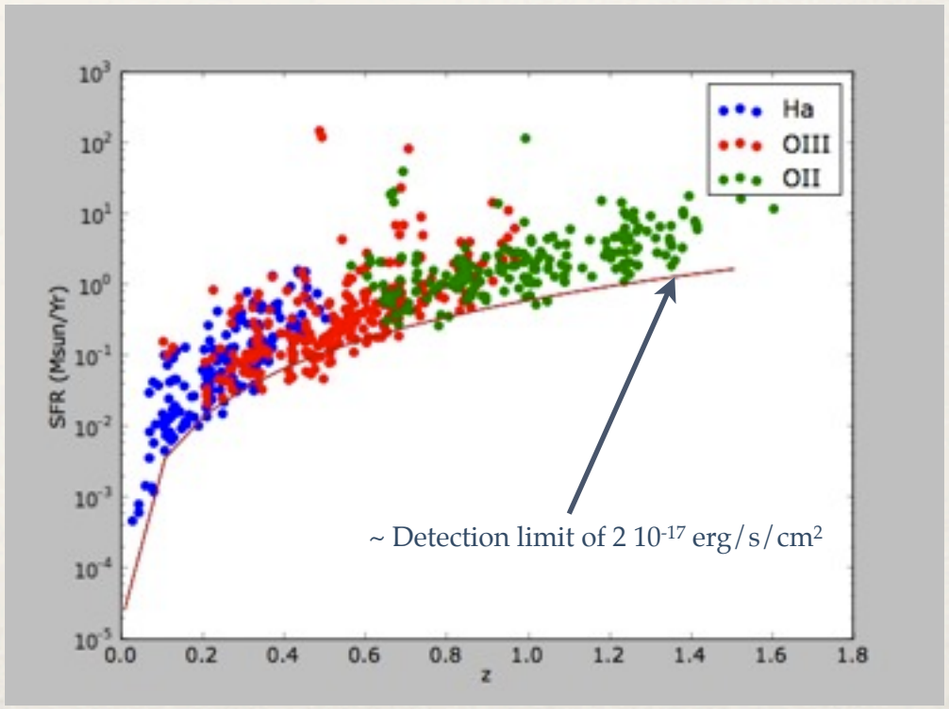
PEARS 2D Emission Lines Objects vs. Knots

- 793 lines in total:
  - 582 objects:
    - 446 single knots, 125 double knots, 9 triple knots, 2 quadruple knots
- 647 knots:
  - 510 single line, 128 double (OII+OIII or OIII+Hα), 9 triple (OII +Hγ+OIII)

PEARS 2D Emission: Lines Line Identifications

- When more than one line is present, identifying the lines is relatively straight forward
- Single emission line rely on spec-z probabilities to determine the most likely candidate
- We limit ourselves to the common lines of Lyα, **Hα**, Hγ, **OII**, and **OIII**





PEARS 2D Emission: Sanity Checks

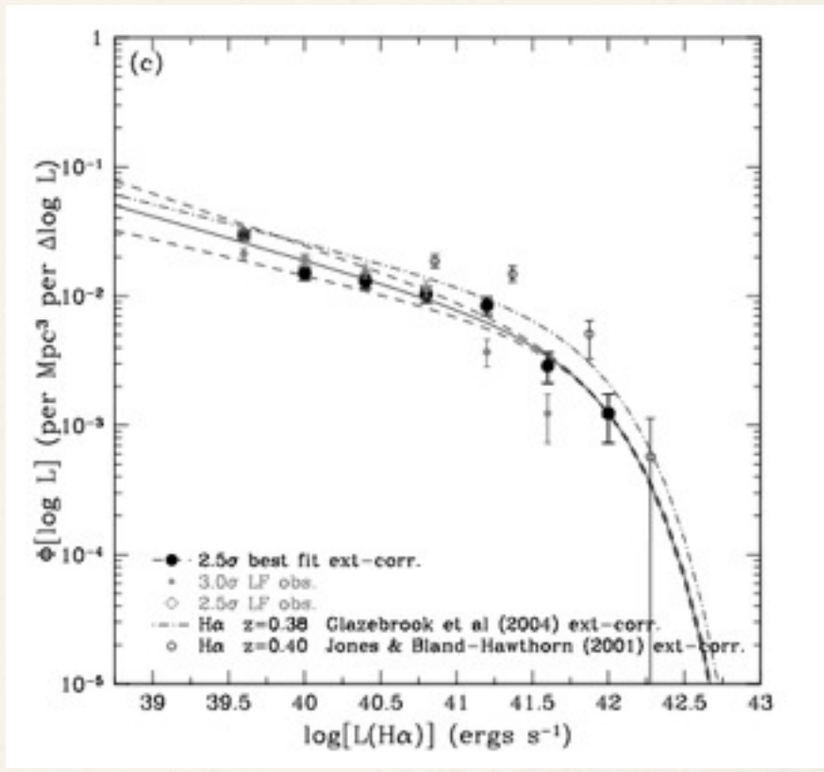
- We have objects that were observed more than once
- We have objects with more than one star forming region
- How consistent are our line identifications and redshifts?:
  - Good self consistency:
    - Object with multiple knots: dz=0.01
    - Objects observed in two PEARS fields:
    - δz=0.002
    - δflux ~< 10%
    - δlam < 20 Å
    - δpix knot position < 1 pixel (0.030″)

PEARS 2D Emission: Luminosity Functions

- Examine luminosity functions over continuous ranges of redshift

- 1/Vmax (somewhat bin size sensitive)

- Maximum likelihood method (e.g. STY, ϕ^* not constrained)



$$\Phi(\log L_i) = \frac{1}{\Delta \log L} \sum_j \frac{1}{V_i}$$

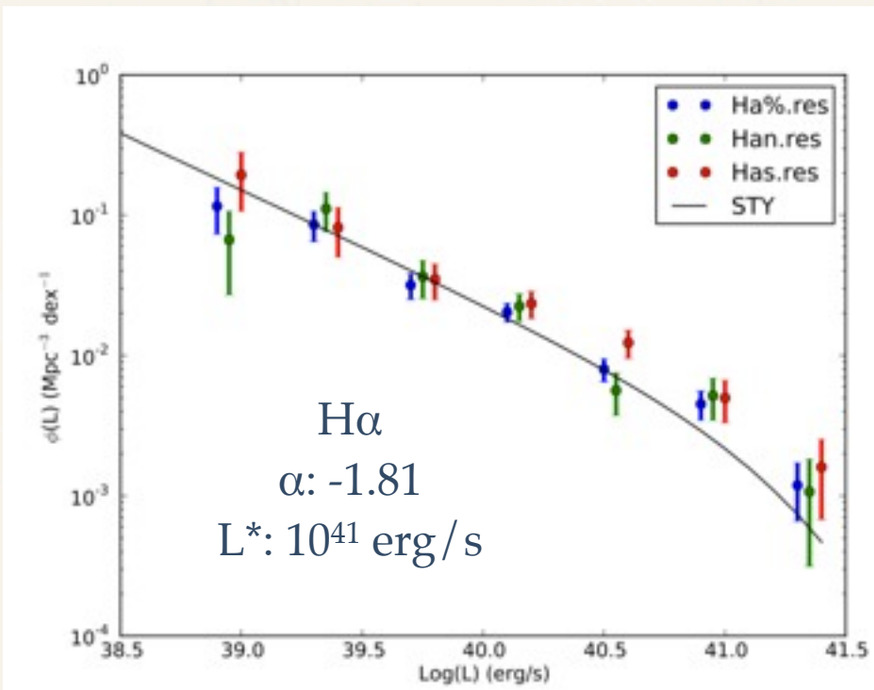
V_i : maximum volume over which object would be detected

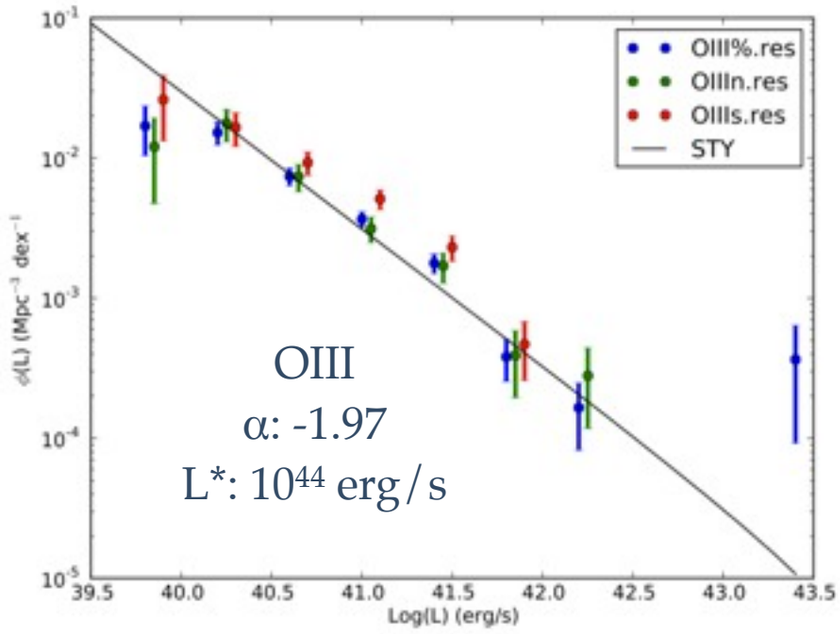
$$\Phi(L)dL = \phi_\star \left(\frac{L}{L_\star}\right)^\alpha \exp\left(-\frac{L}{L_\star}\right)\frac{dL}{L_\star} \qquad \alpha < 0$$

L<<L*: power law

L>>L*: exponentially decaying

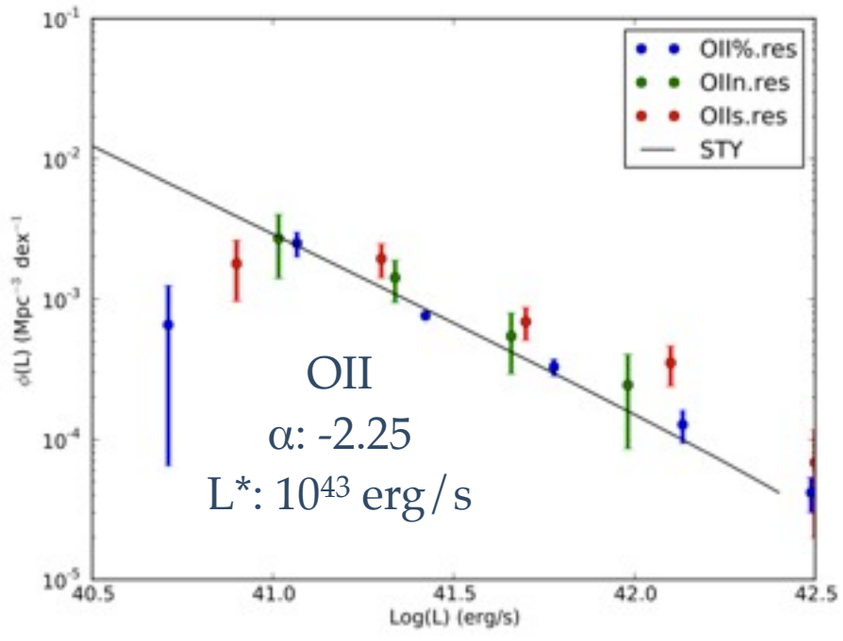
PEARS 2D ϕ(L): North vs. South



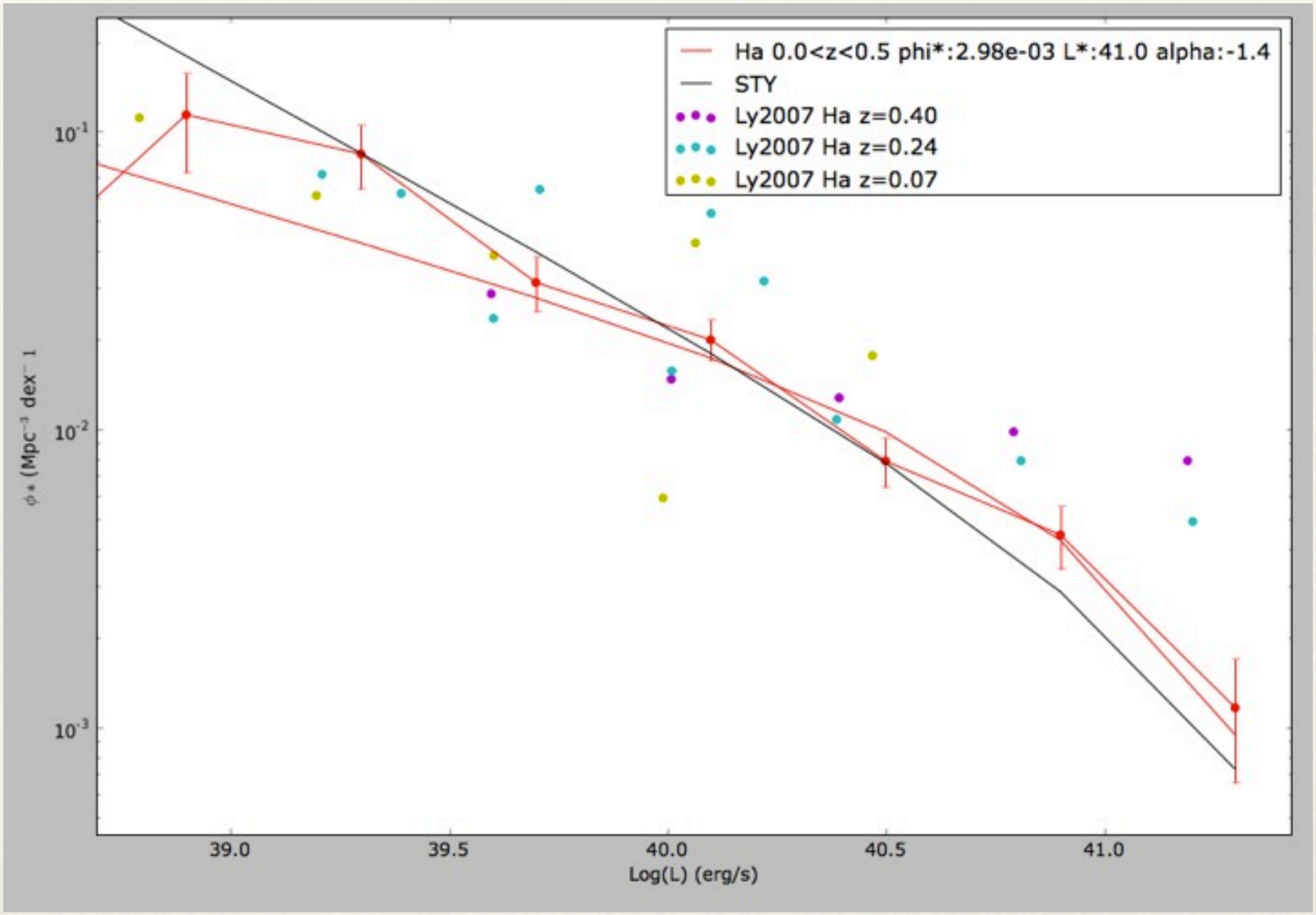


- PEARS-N vs. PEARS-S:
  No major comic variance despite the small field sizes

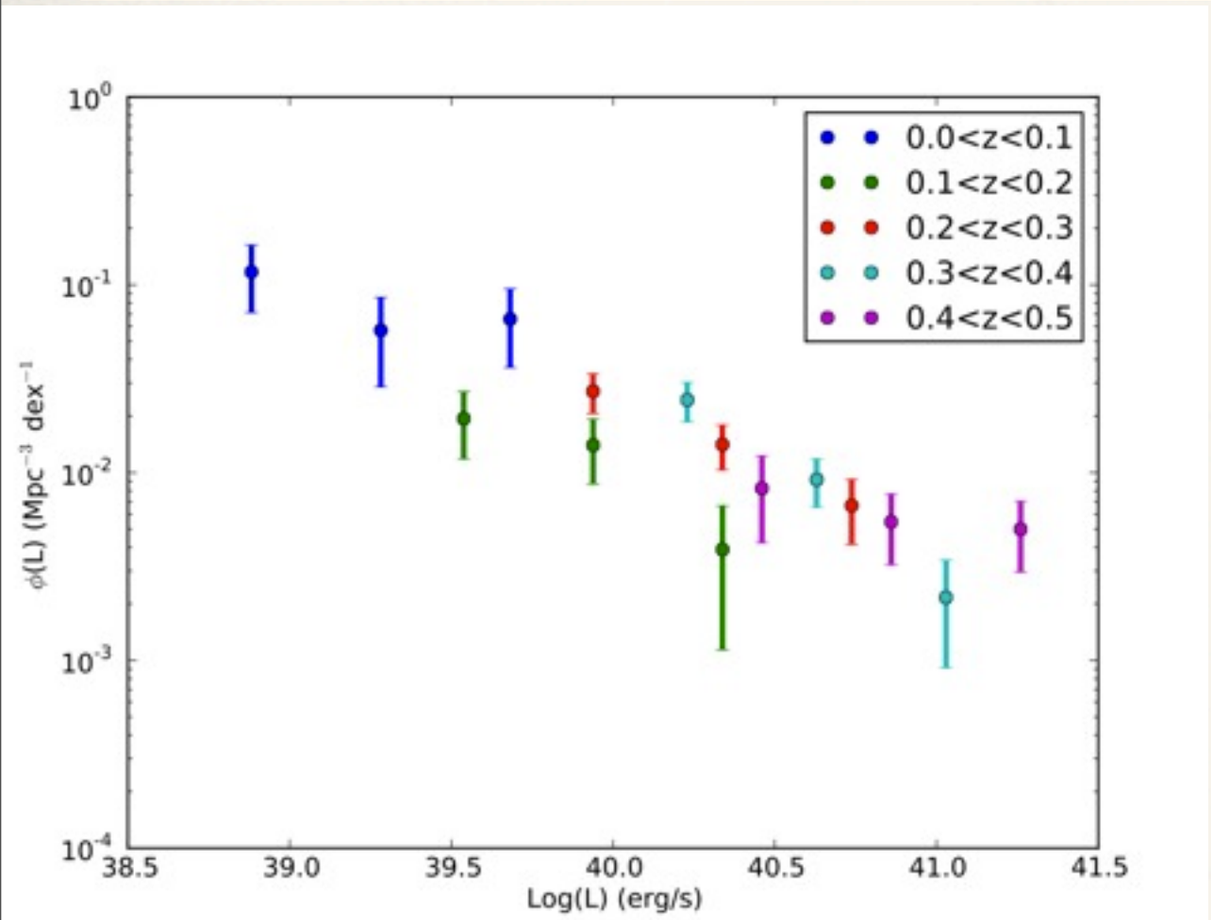
- We do not constrain the “knee” of the LF (L*)



PEARS 2D: Hα ϕ(L) 0<z<0.5

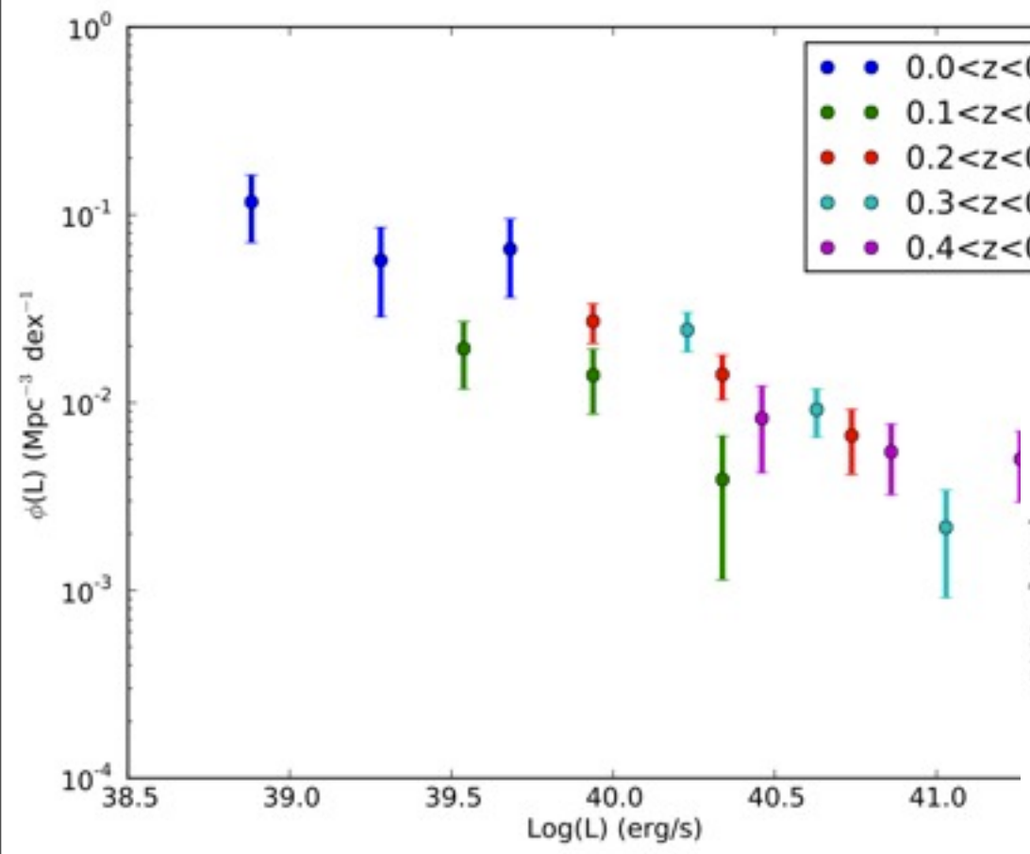


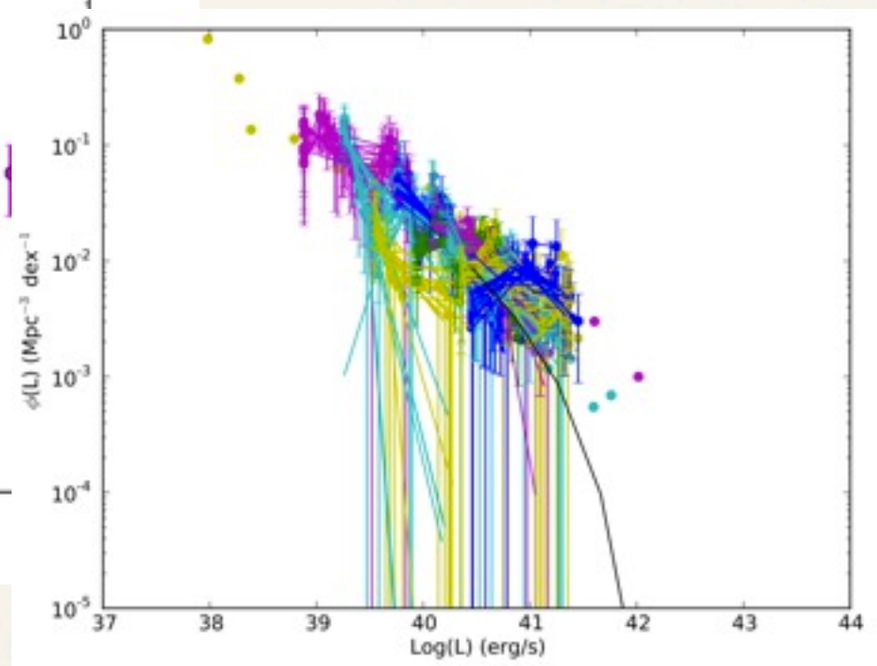
PEARS 2D ϕ $_{H\alpha}$(L): z evolution



- Fit a Schechter function fit in increasing redshift bins
- Tentative steepening of the luminosity function from z=0 to z=.5?

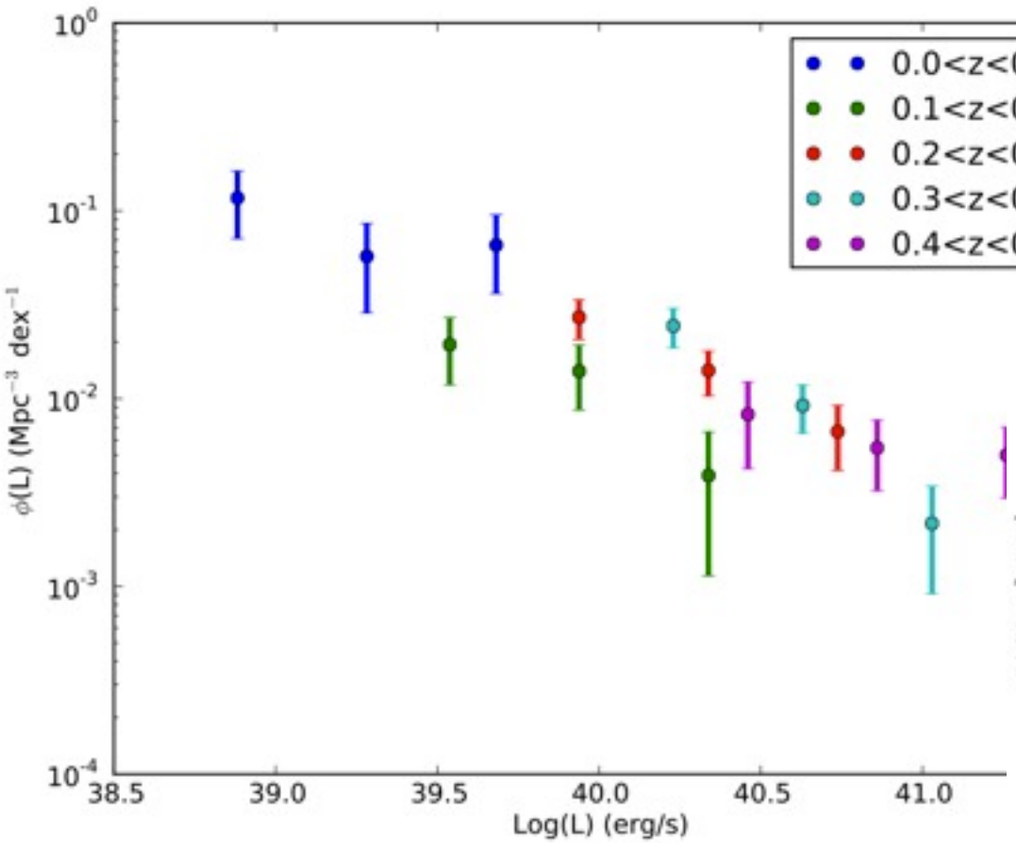
PEARS 2D ϕ $_{H\alpha}$(L): z evolution

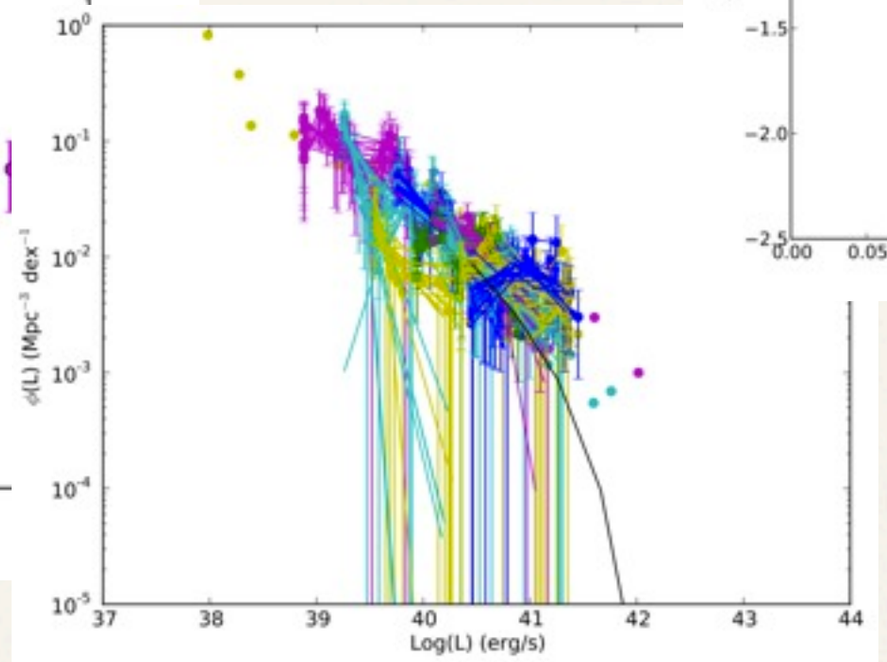


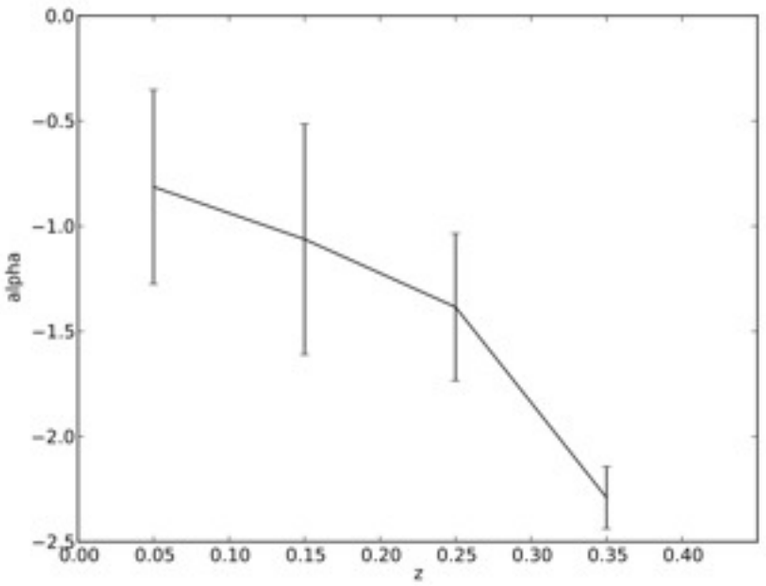


- Fit a Schechter function fit in increasing redshift bins
- Tentative steepening of the luminosity function from z=0 to z=.5?

PEARS 2D ϕ $_{H\alpha}$(L): z evolution







- Fit a Schechter function fit in increasing redshift bins
- Tentative steepening of the luminosity function from z=0 to z=.5?

Conclusion

- Object-independent identification of emission line “knots” and galaxies
- Allows to individually extract the spectra of star forming regions in resolved objects
- Reaches down to very faint line fluxes with moderate efforts (few x 10^{-18} erg/s/cm^2)
- Constraints the faint end of the lum. fct. for Hα, OII and OIII
- Luminosity functions for Hα over continuum redshift range of $0<z<0.5$ over 100 arcmin^2
- Confirm the possible steepening of the lum. fct as a function of z