Wide-field Slitless Spectroscopy from Space: Unique Constraints on Galaxy Evolution from Cosmic Dusk to Dawn

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z~1.3

z~1.4

z=0

z=11.1!

z~0.3

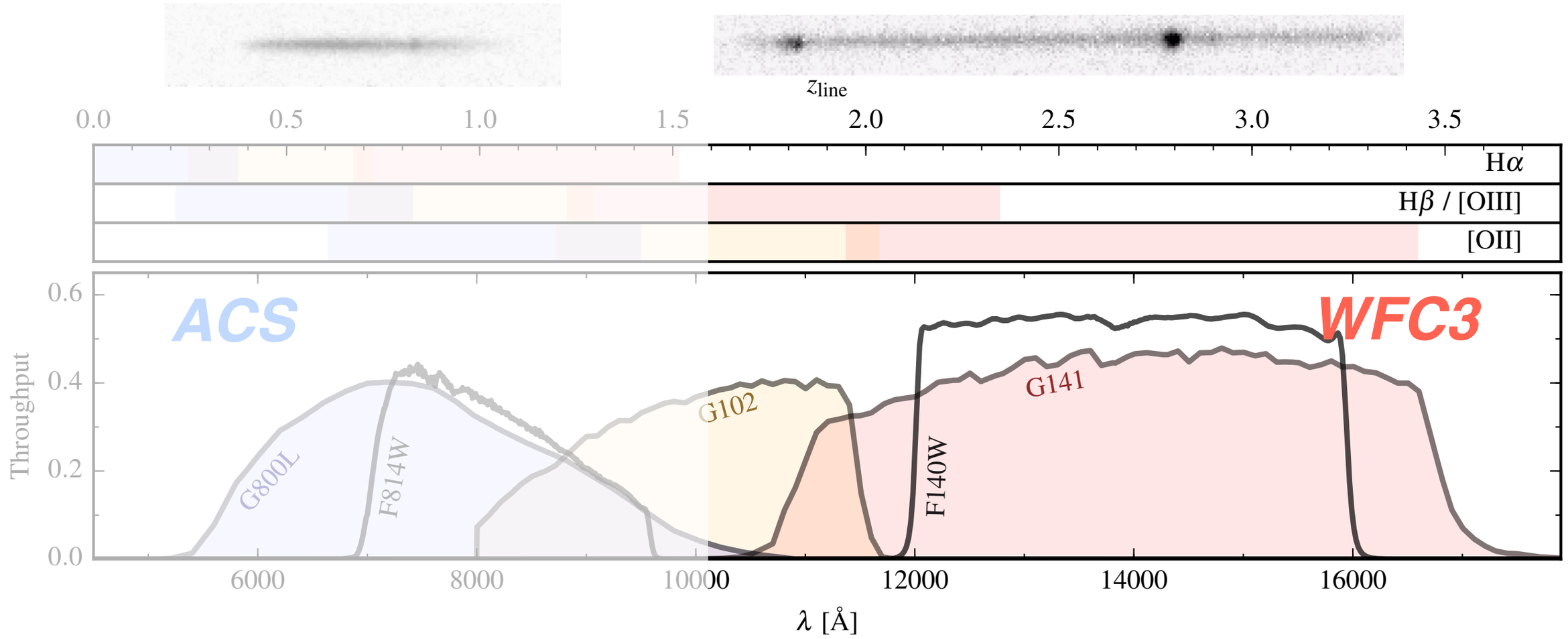
z~2

z~1.4

GO-13871 - G141/WFC3

Why slitless spectroscopy?

- Wide-field slitless surveys at z=1-2:
  - Large, uniform, ~unbiased samples
  - Spatially-resolved line diagnostics @ HST resolution
    - Δ z/(1+z) ~ 0.003: large scale structure & stacking
- Spectroscopic constraints at cosmic dawn
- Promising future prospects



ACS specs:

- *2-4 orbit coverage*
- *0.55 to 1.0 um*
- *40 A/pix*

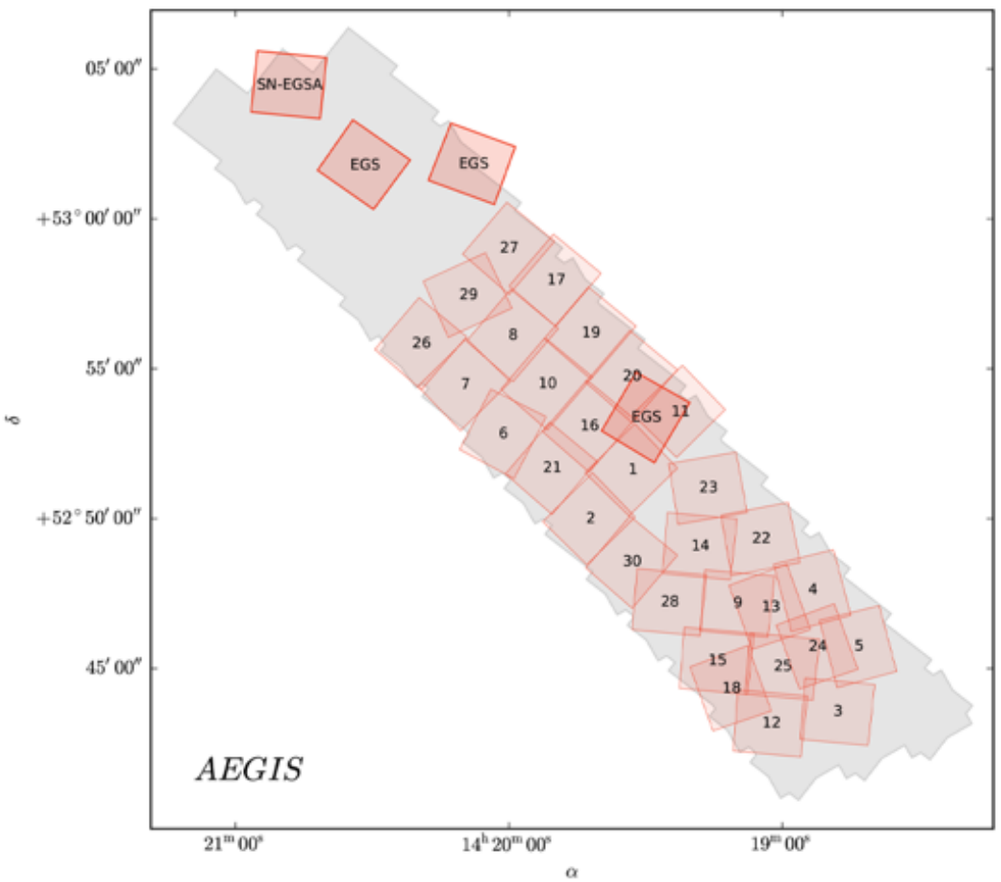
WFC3 specs

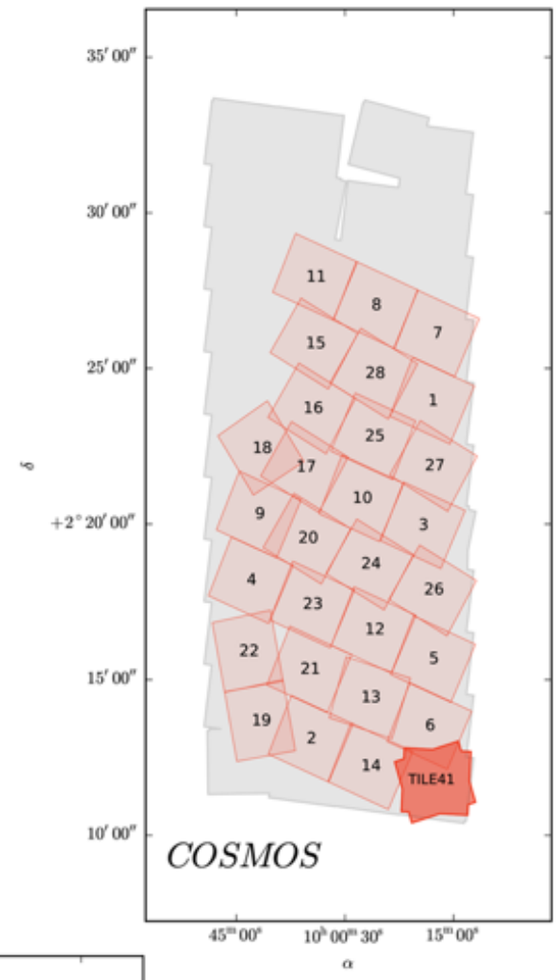
- *2 orbit coverage*
- *1.1 to 1.65 um*
- *46.5 A/pix*

Brammer et al., 2012

NEAR-INFRARED SPECTROSCOPIC SURVEY WITH THE HUBBLE SPACE TELESCOPE

3D-HST


SN-EGSA
EGS
EGS
EGS
AEGIS
05′ 00″
+53° 00′ 00″
55′ 00″
+52° 50′ 00″
45′ 00″
δ
21ᵐ 00ˢ
14ʰ 20ᵐ 00ˢ
19ᵐ 00ˢ
α


TILE41
COSMOS
35′ 00″
30′ 00″
25′ 00″
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15ᵐ 00ˢ
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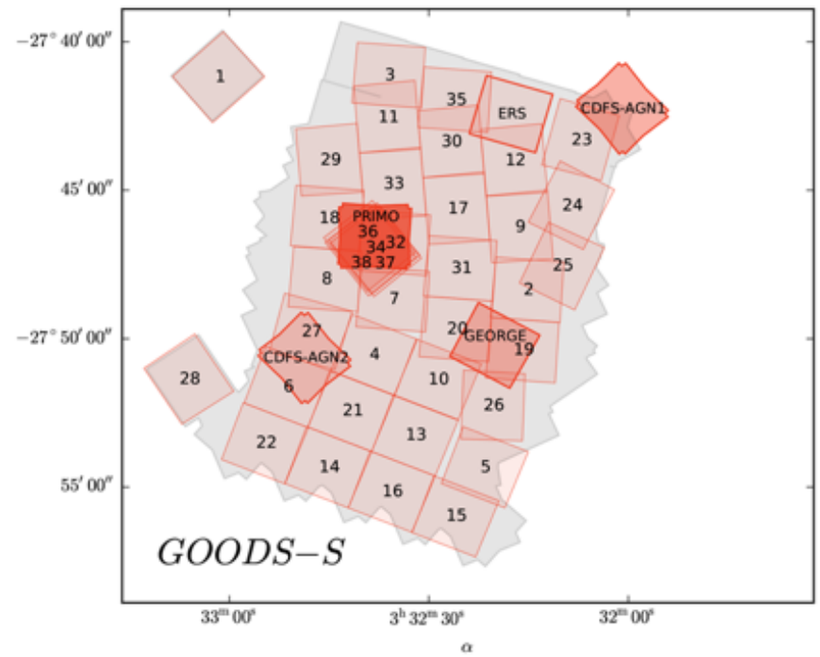
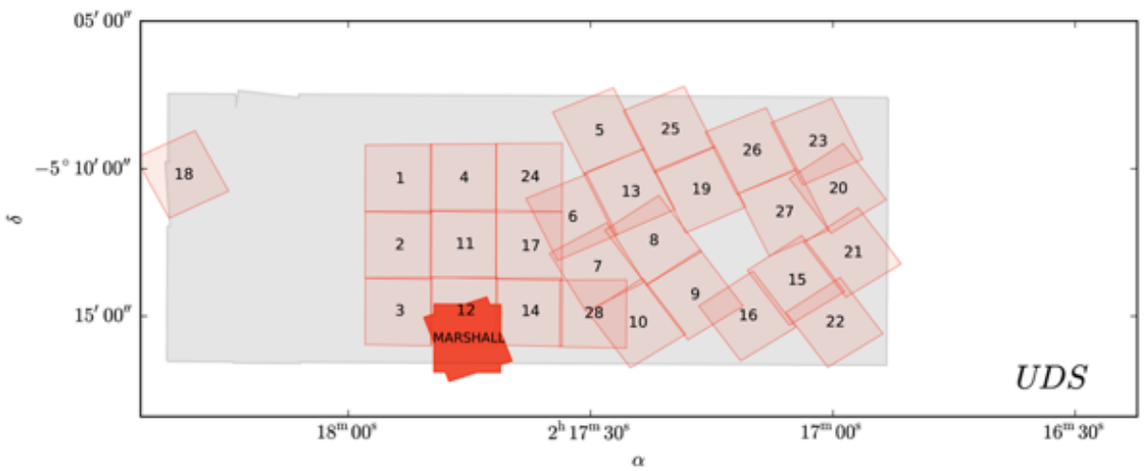

CDFS-AGN1
ERS
PRIMO
GEORGE
CDFS-AGN2
GOODS−S
−27° 40′ 00″
45′ 00″
−27° 50′ 00″
55′ 00″
33ᵐ 00ˢ
3ʰ 32ᵐ 30ˢ
32ᵐ 00ˢ
α


MARSHALL
UDS
05′ 00″
−5° 10′ 00″
15′ 00″
δ
18ᵐ 00ˢ
2ʰ 17ᵐ 30ˢ
17ᵐ 00ˢ
16ᵐ 30ˢ
α

AEGIS

COSMOS

GOODS-S

UDS

GOODS-N*

mosaics: F140W 3D-HST

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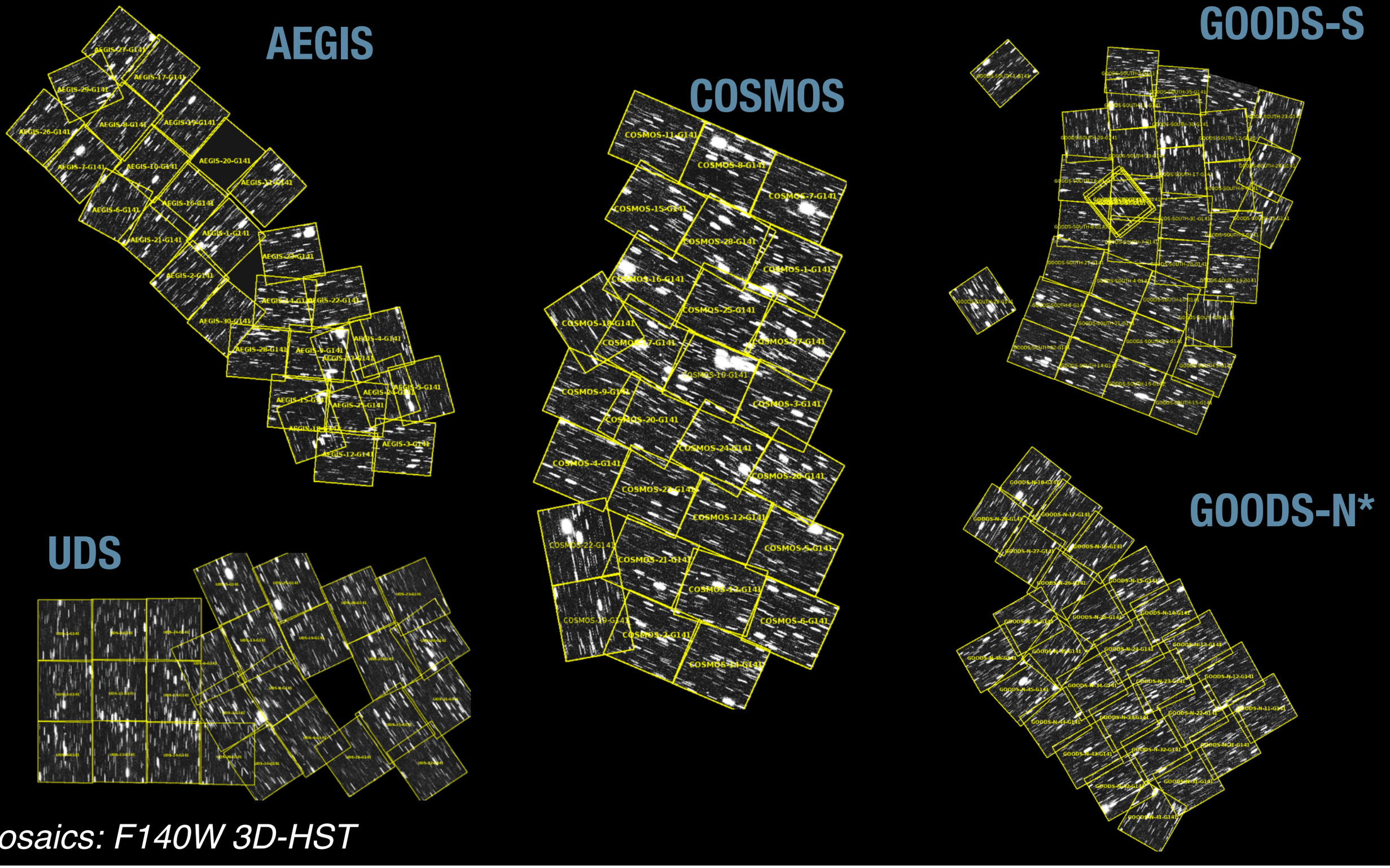
3D-HST



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AEGIS

COSMOS

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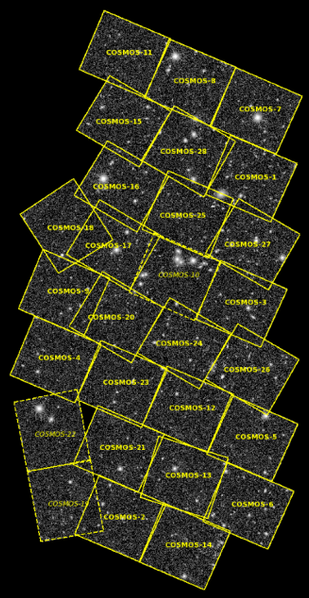
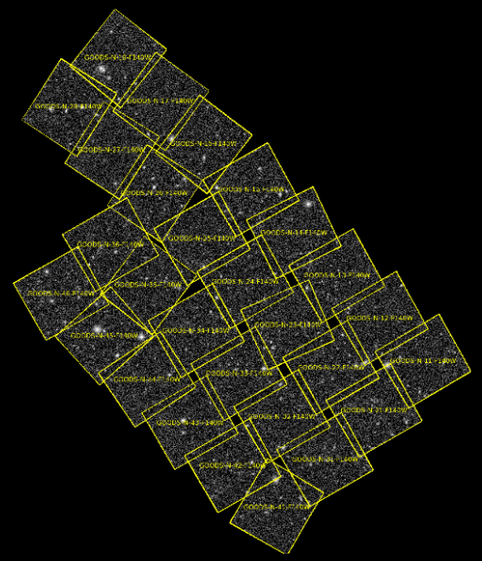
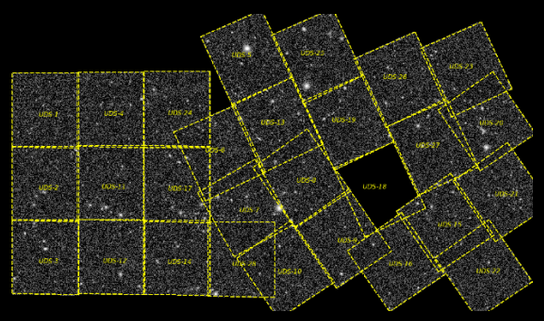
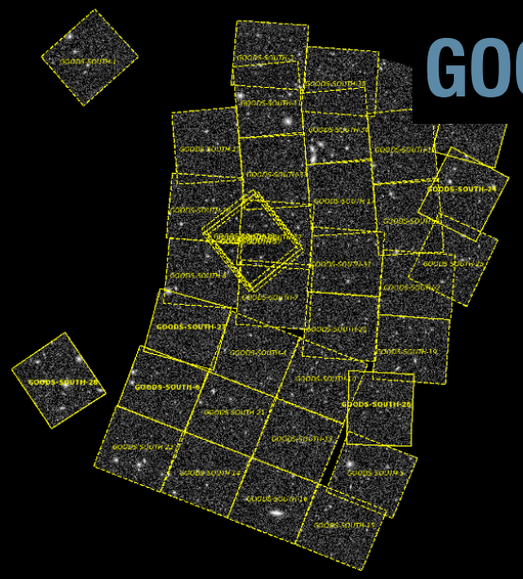




UDS



GOODS-N*



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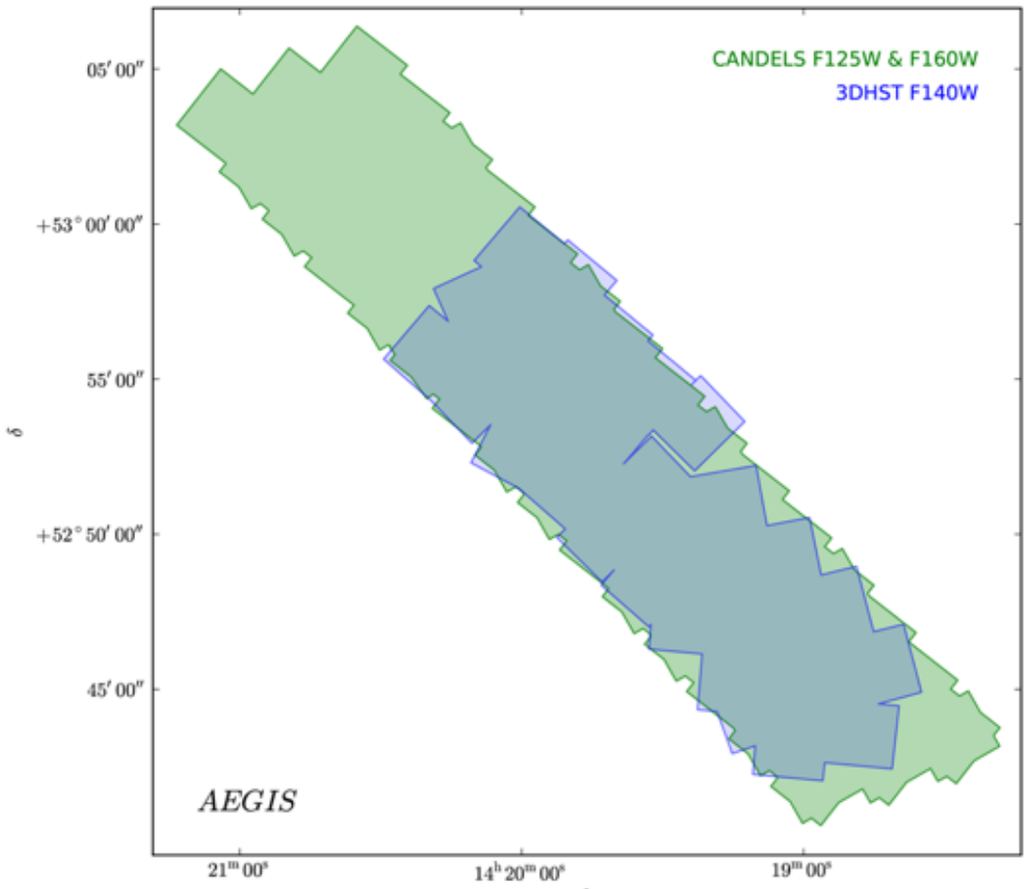
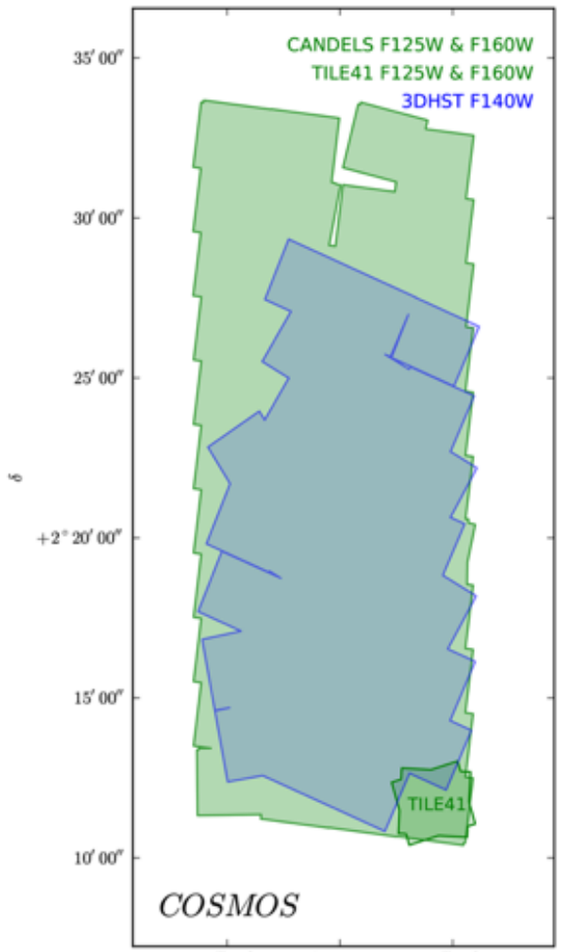
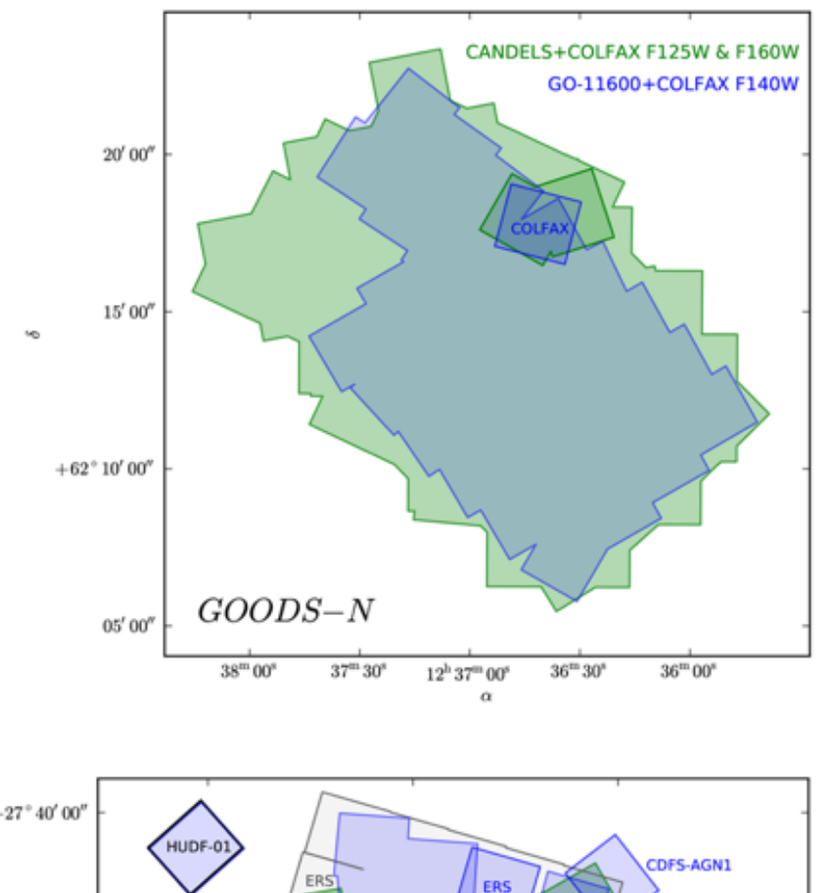
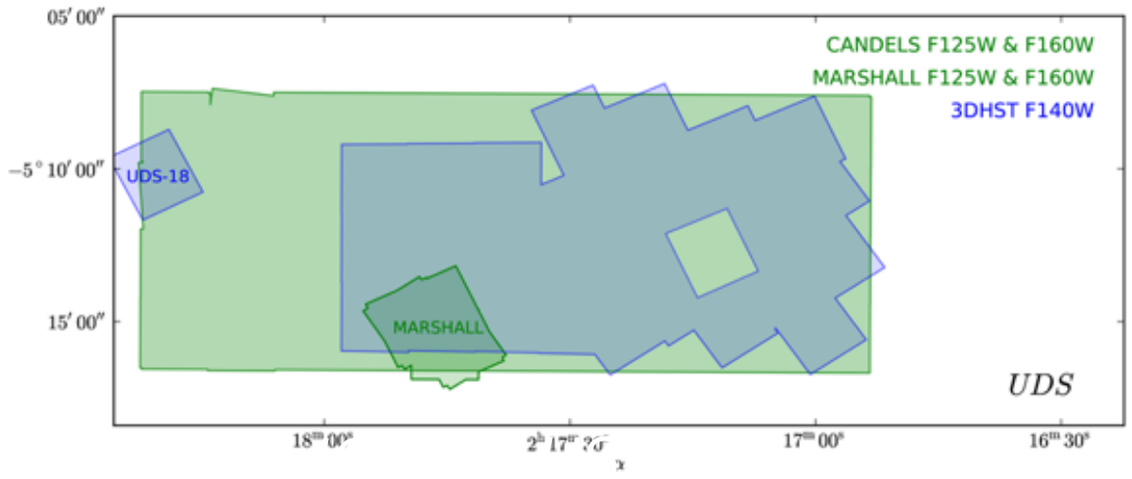
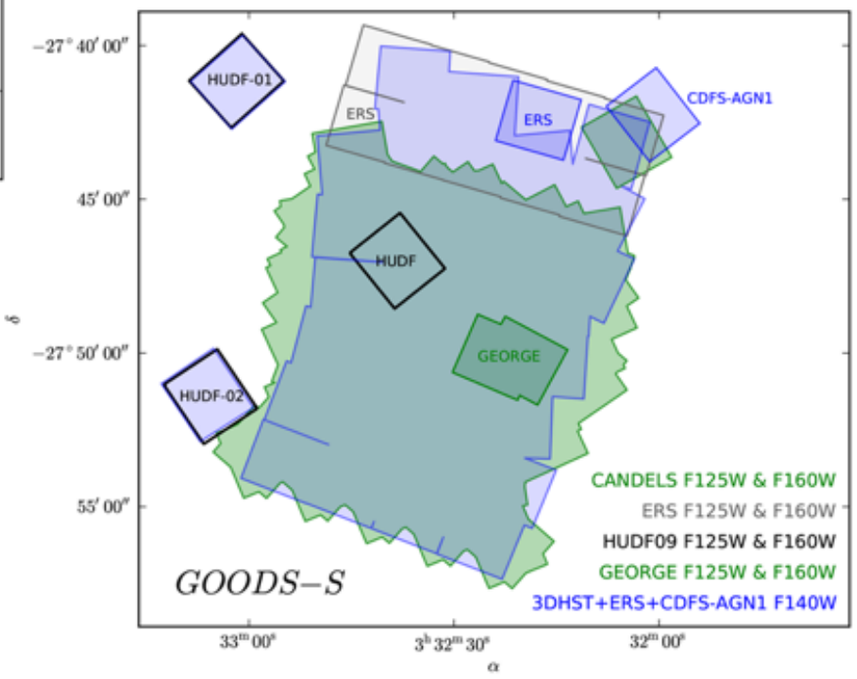








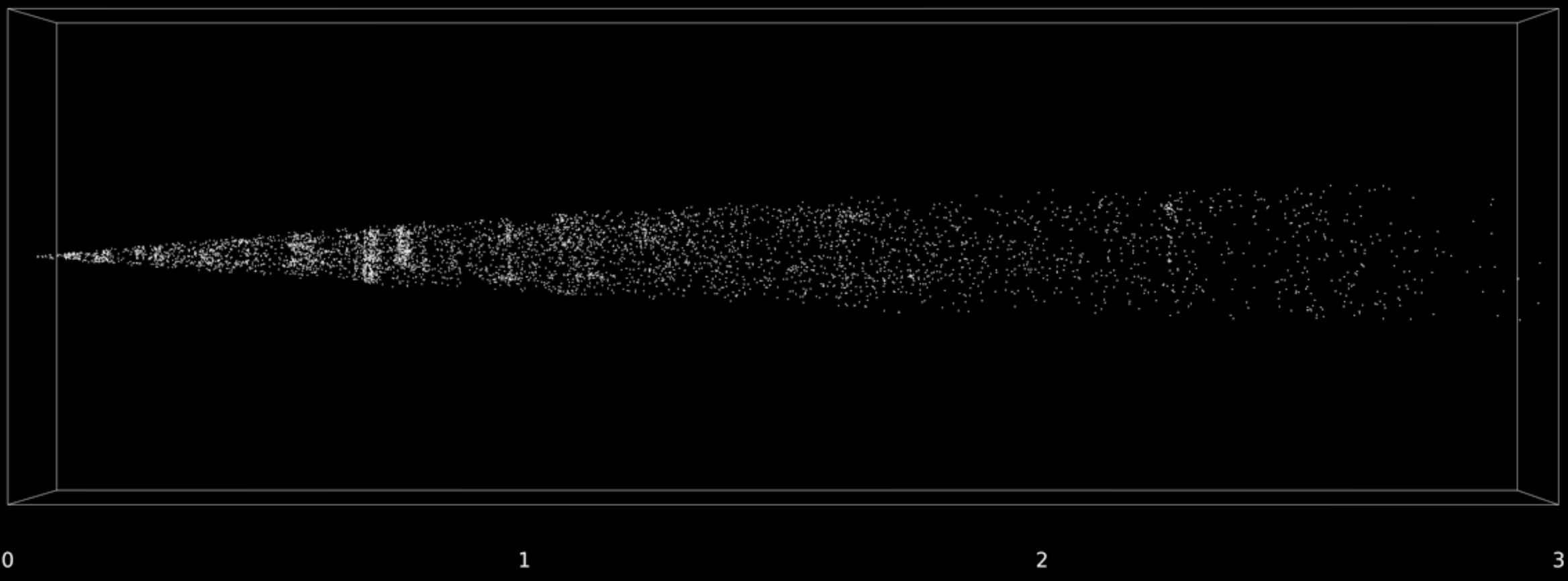


NEAR-INFRARED SPECTROSCOPIC SURVEY WITH THE HUBBLE SPACE TELESCOPE

3D-HST

GOODS-S catalog, photometric redshifts, F140W < 24.

N ~ 5,000 objects



Skelton et al., 2014

Redshift

GOODS-S catalog, grism+photometry redshifts,
F140W < 24.

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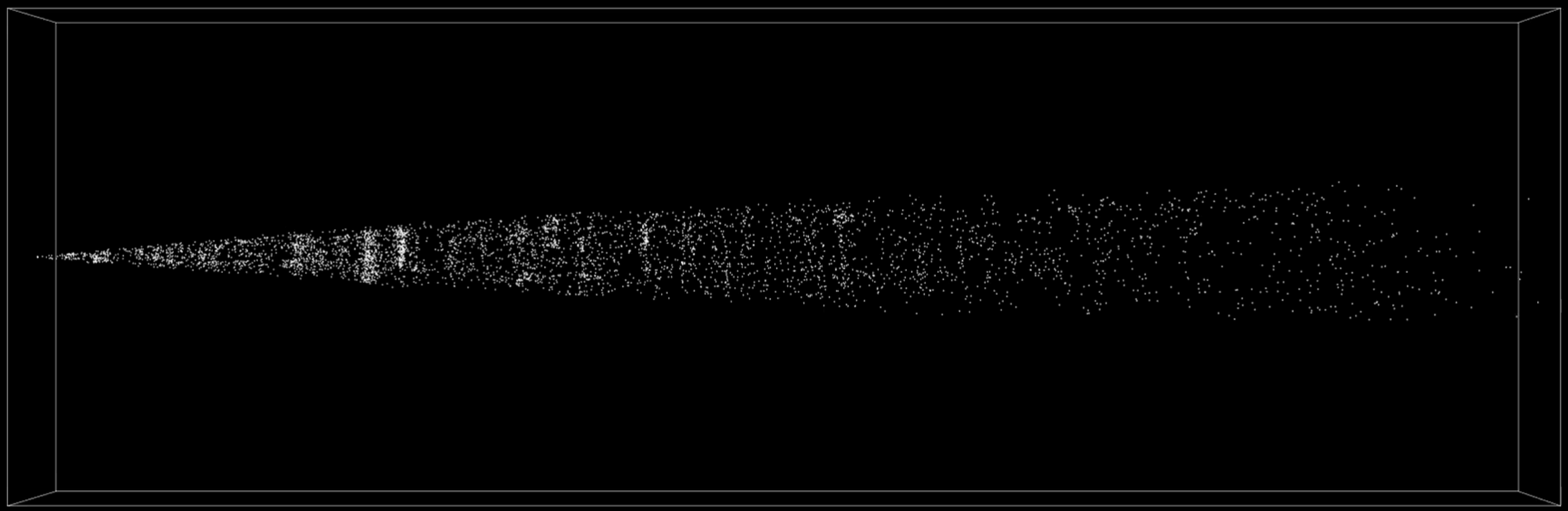

Momcheva et al., 2015

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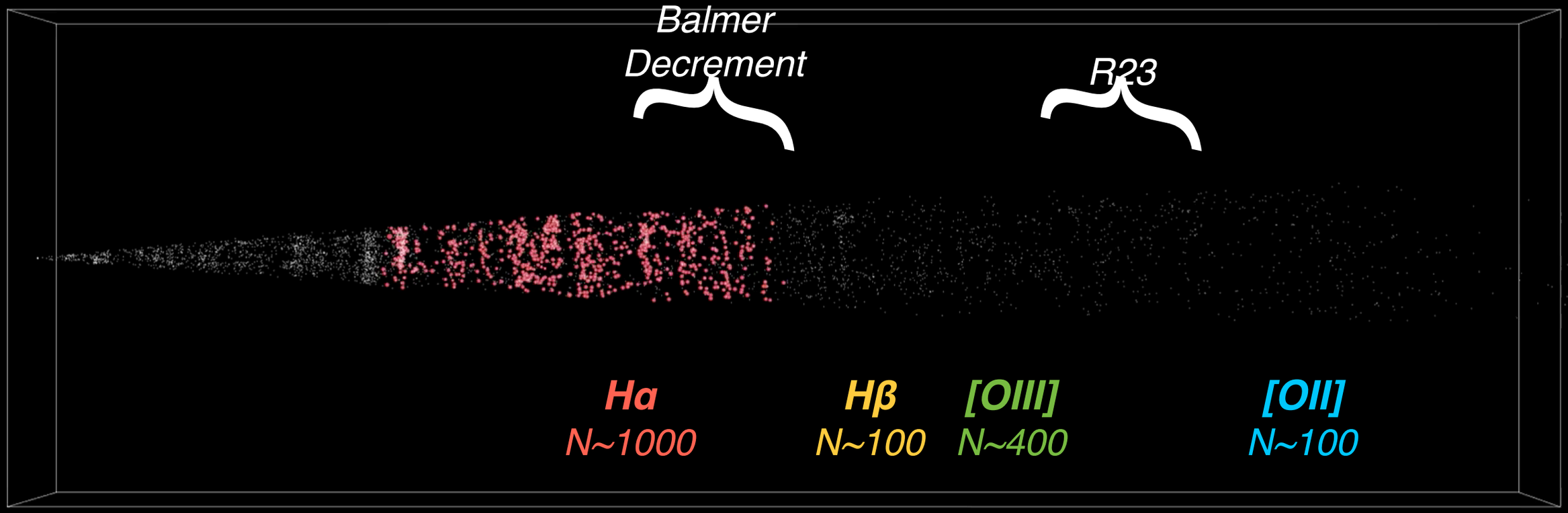
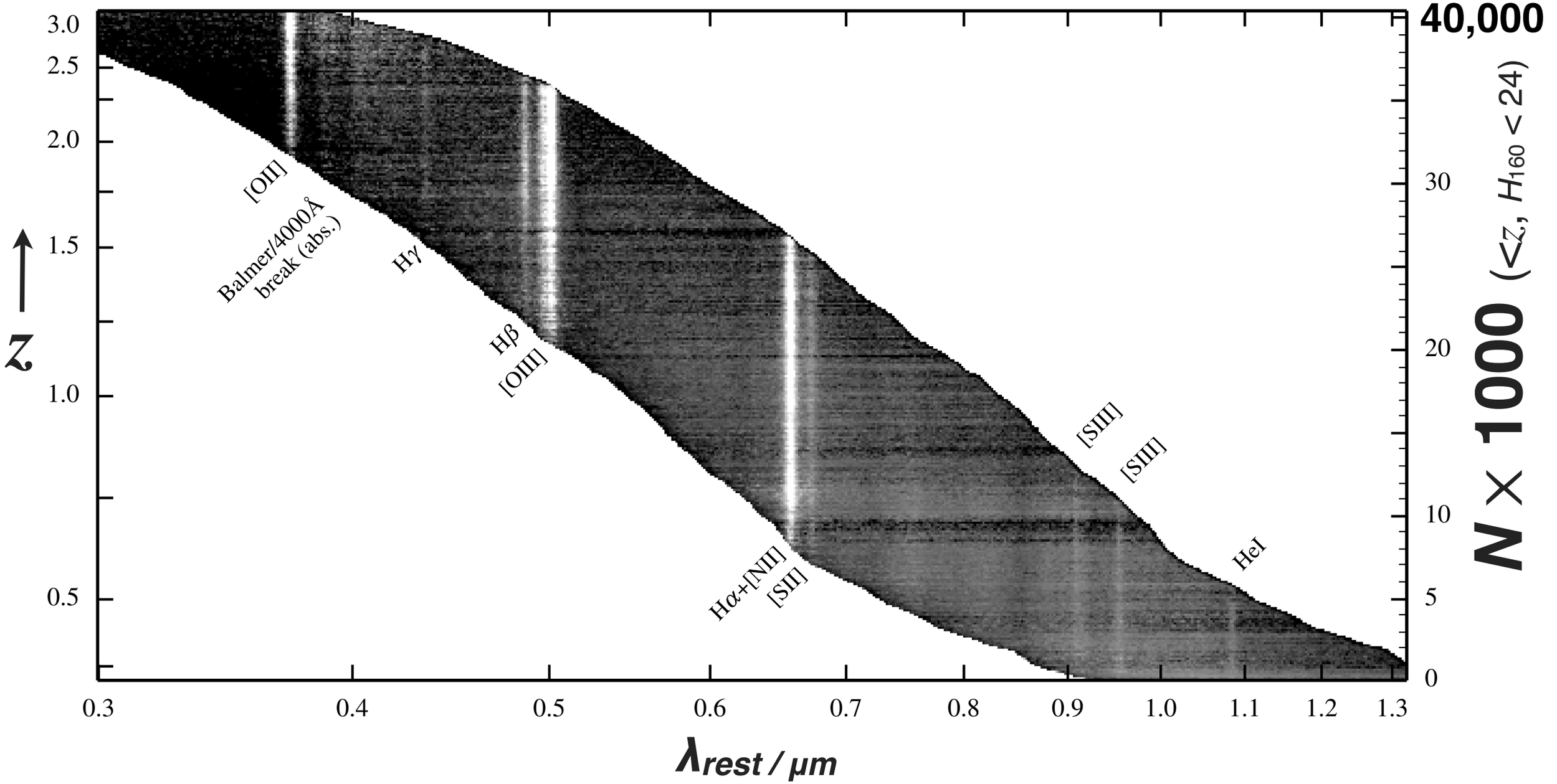
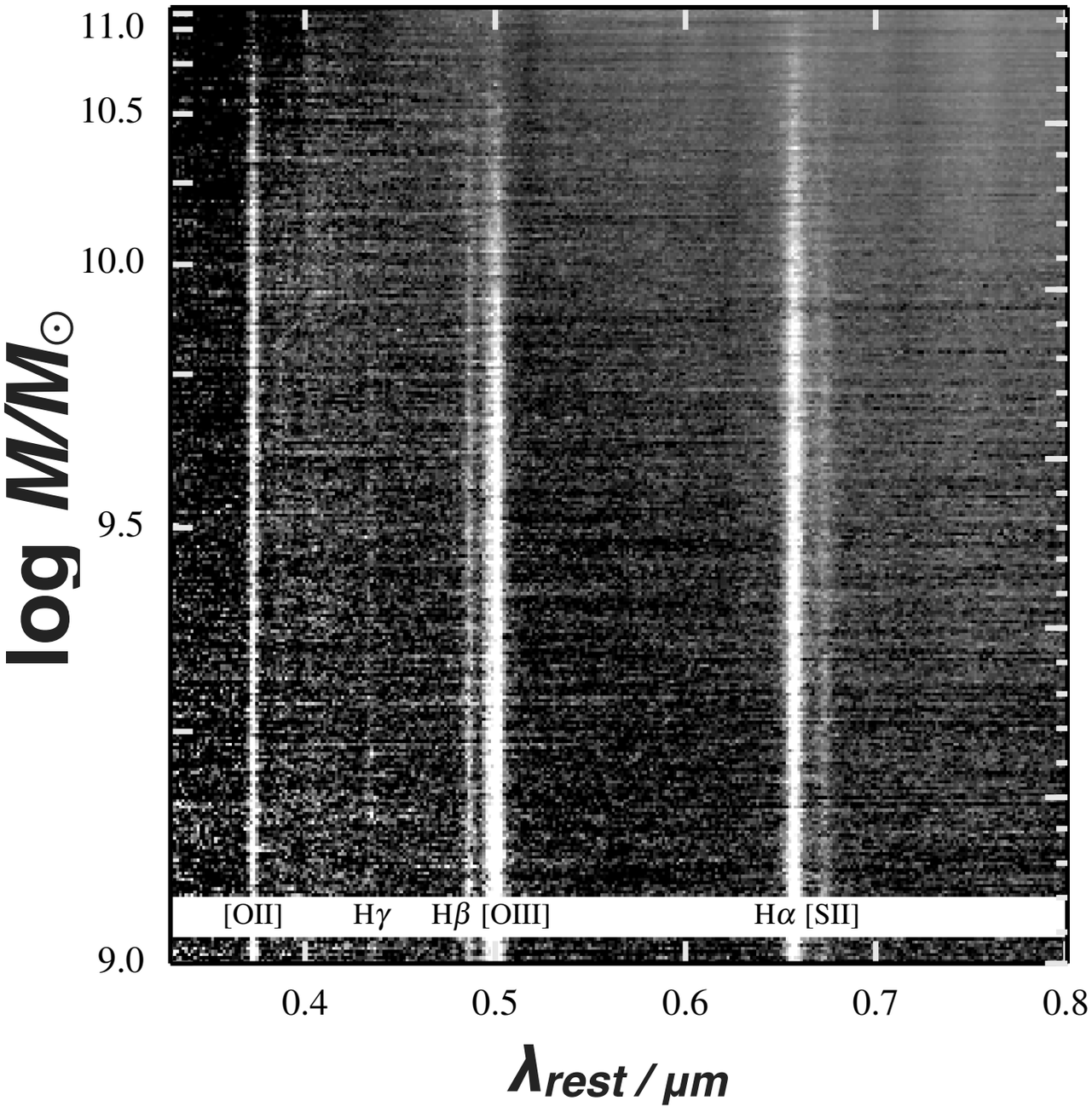


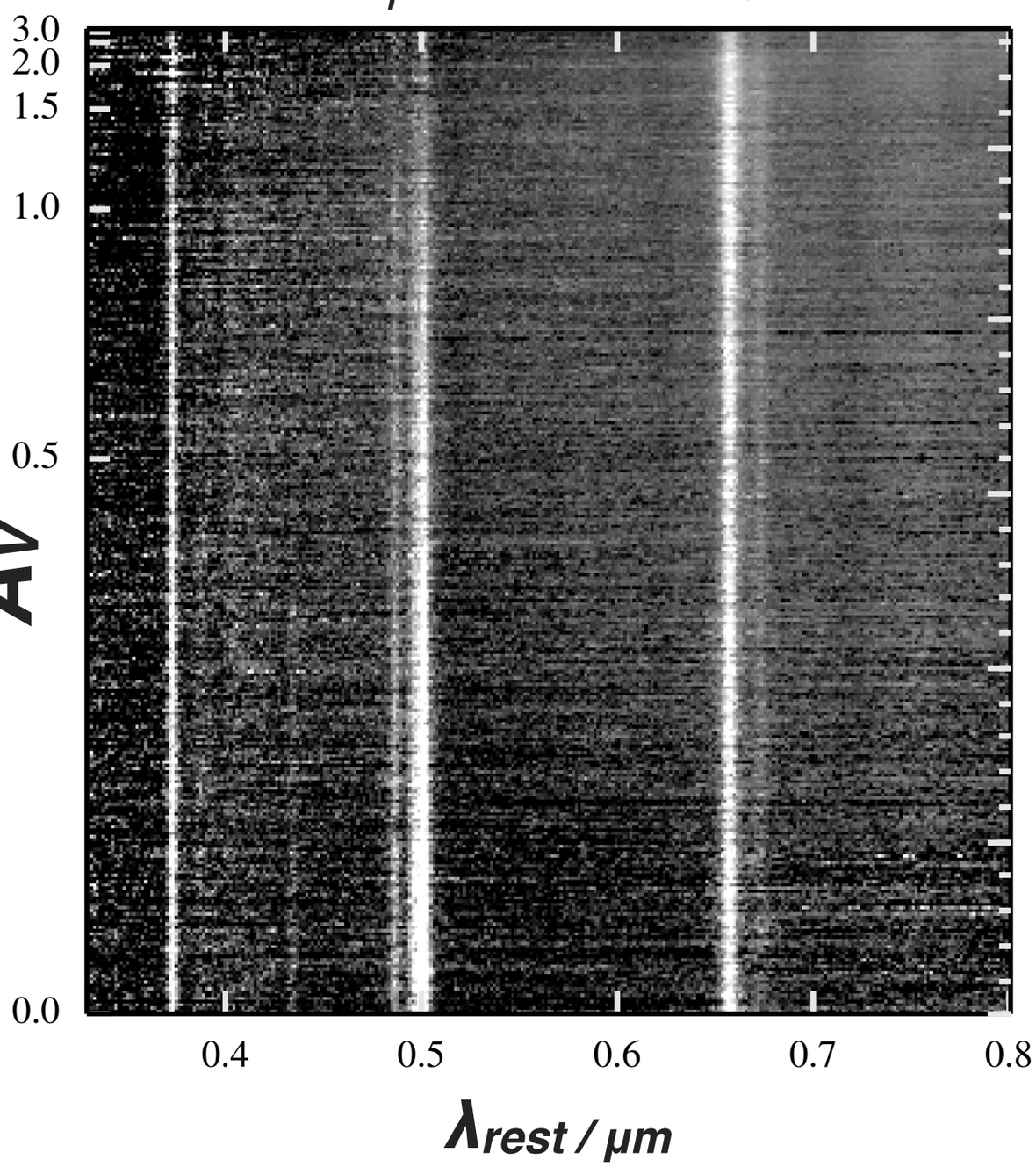
Momcheva et al., 2015



Automated extraction enables robust quantitative measurements for **10s of thousands of galaxies**

Momcheva+2015





Highly complete spectroscopic coverage allows detailed study of correlation and evolution of galaxy properties

Momcheva+2015

CANDELS+3D-HST: High-z SDSS

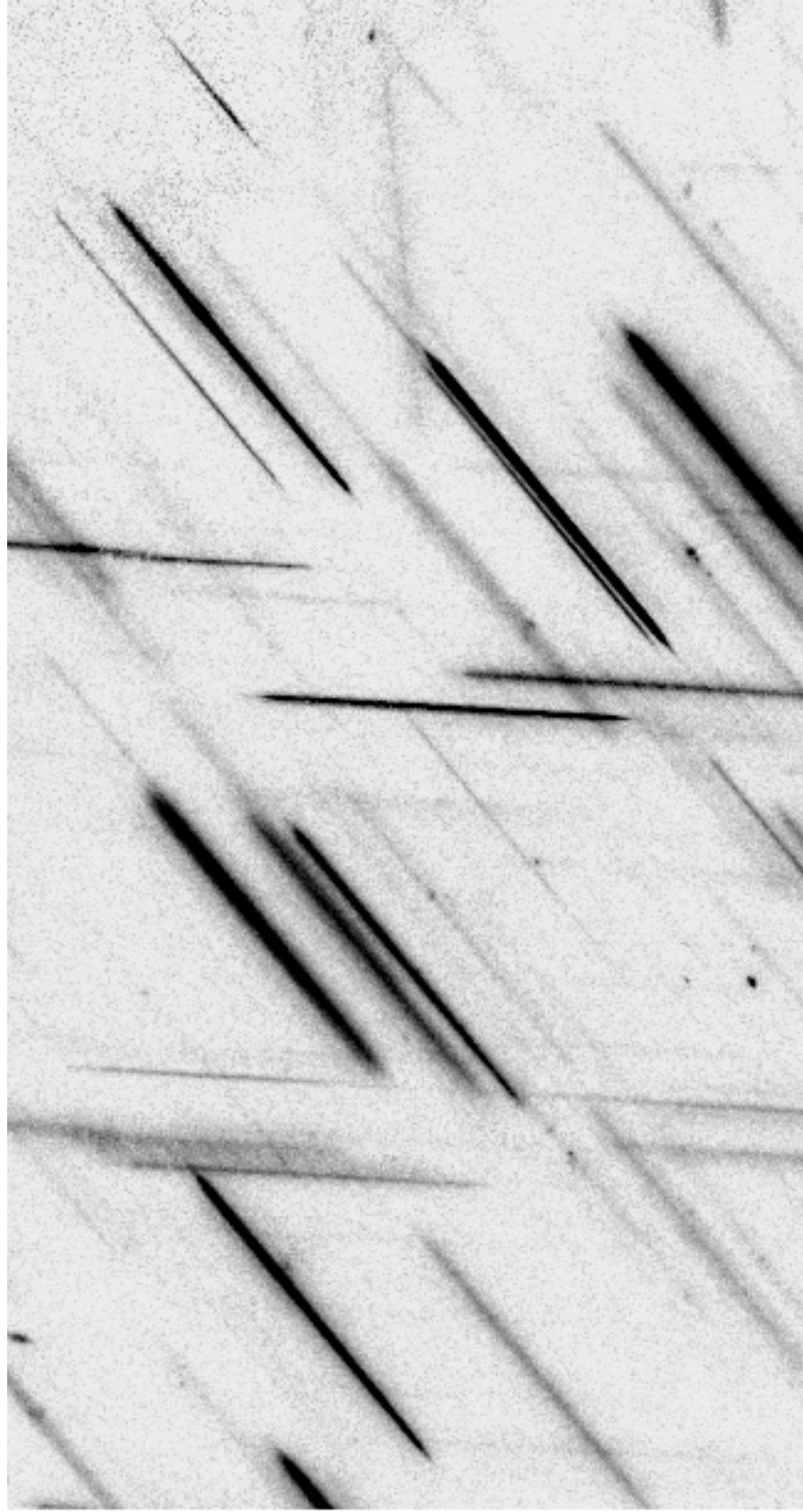
- >200,000 catalog entries
- 147 different bands, including available medium and narrow bands
- few % phot_z's
- EAZY photometric z's
- FAST SFR, M*, sSFR, Av, tau, age
- Morphological parameters
- Rest-frame colors

Skelton et al., 2014

- Grism spectra for ~20,000 objects to F140W<24. (~10^5 to F140W<26.)
- Grism + photometry redshifts, dz/(1+z) ~0.003
- Emission line fluxes, EQW

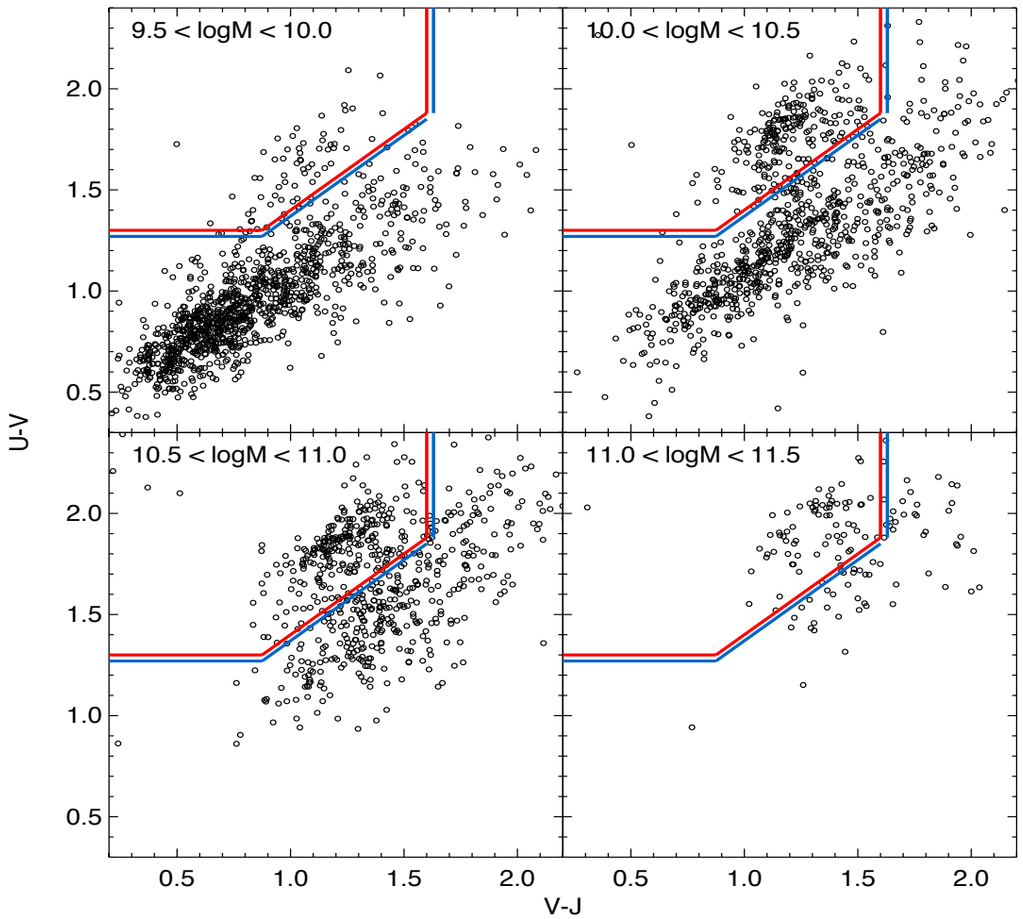
Momcheva et al., 2015

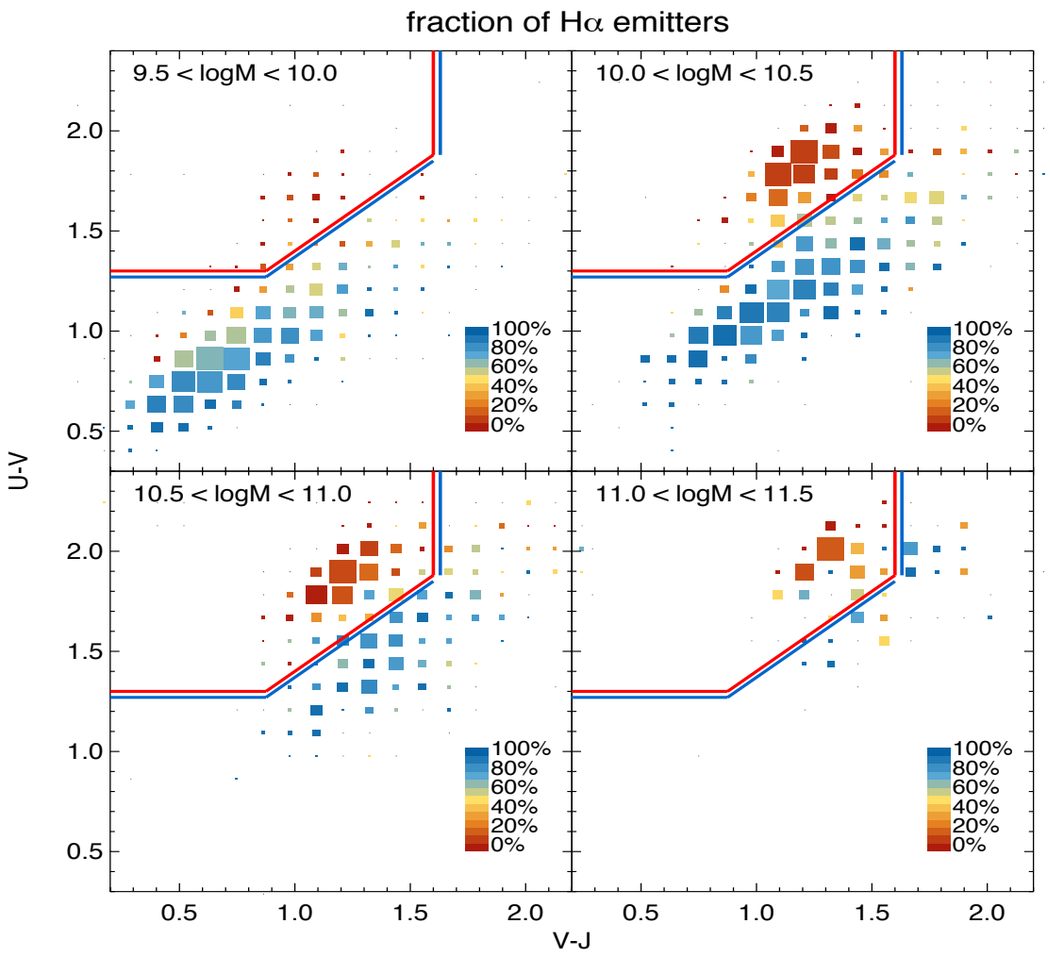
http://3dhst.astro.yale.edu
https://archive.stsci.edu/prepds/3d-hst/



Science Highlights

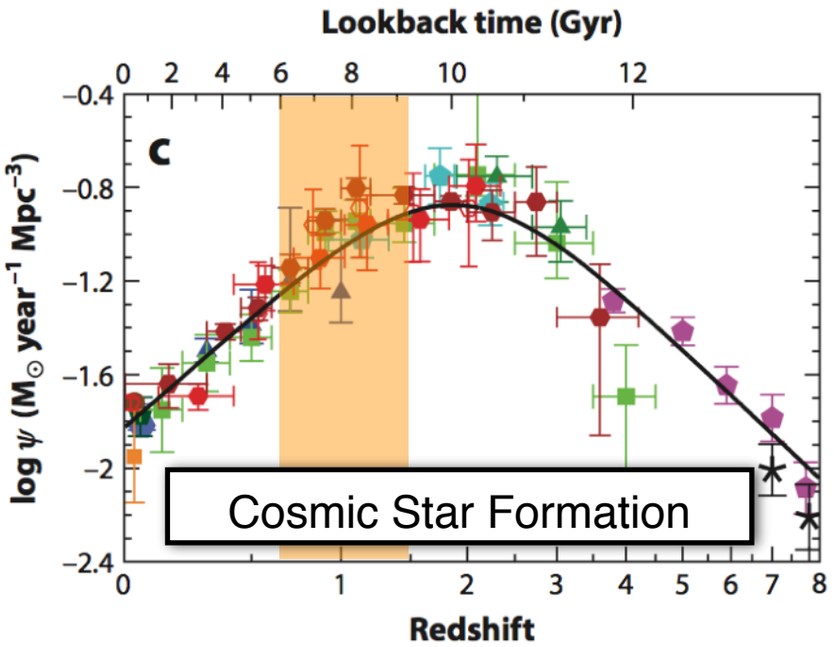
The Bimodality of Galaxy Populations



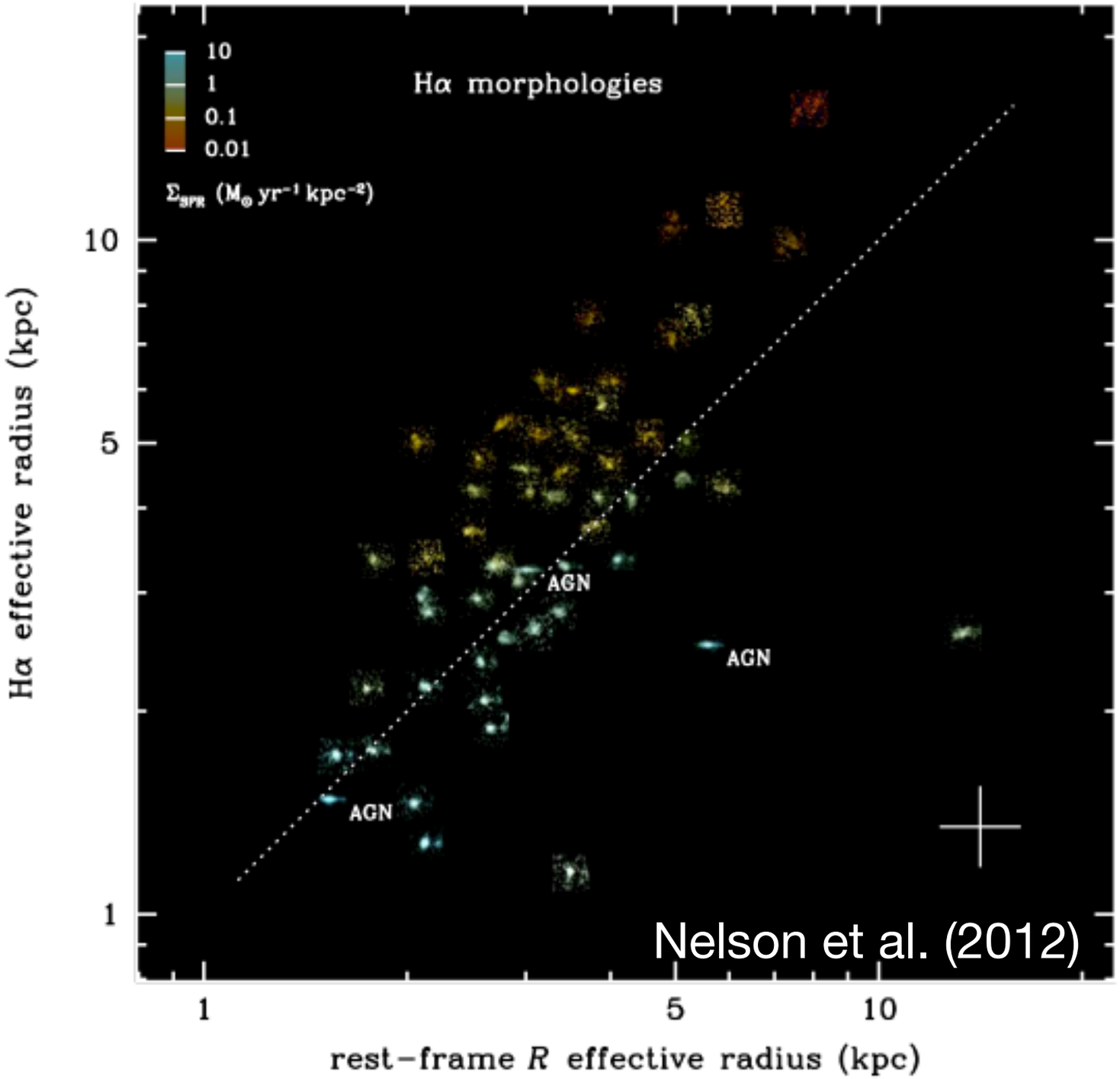


Fumagalli et al., in prep.

Where do stars form?



0.7<z<1.5: ~33% of all cosmic star formation



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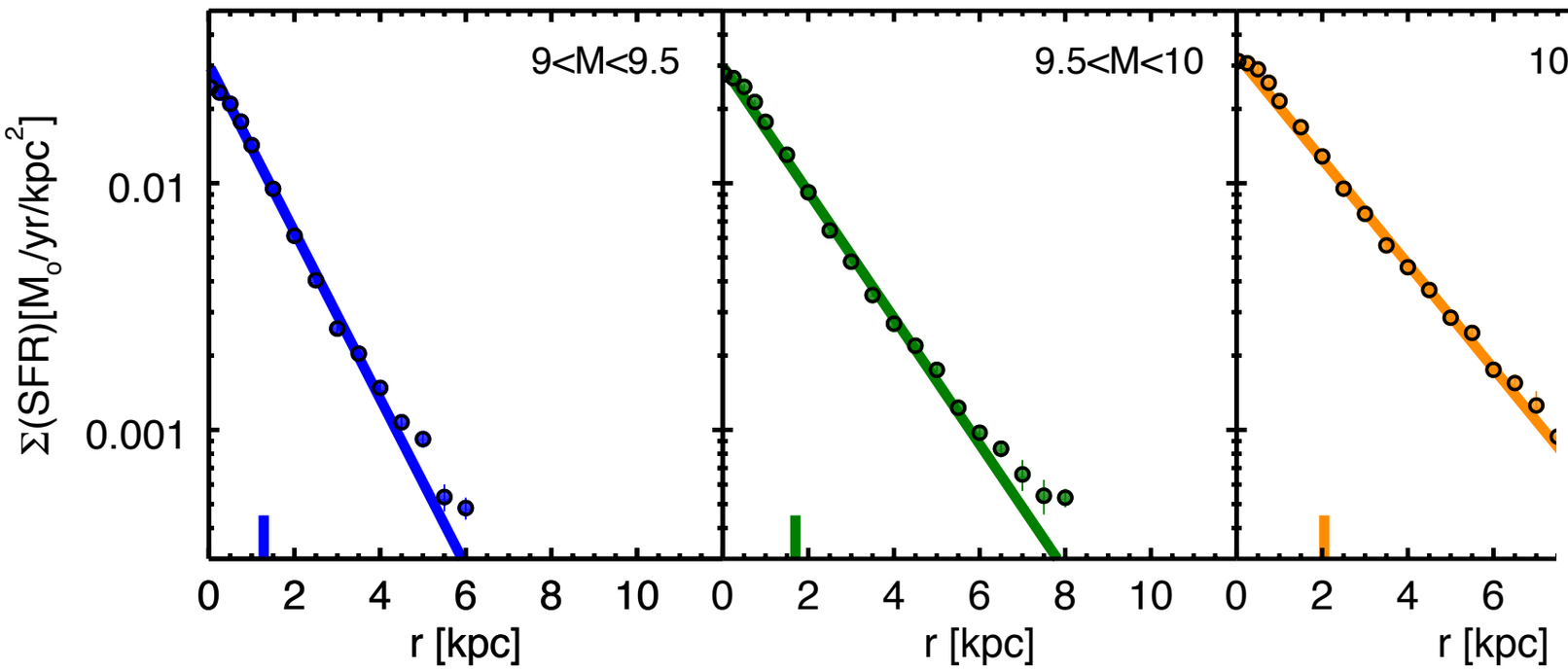
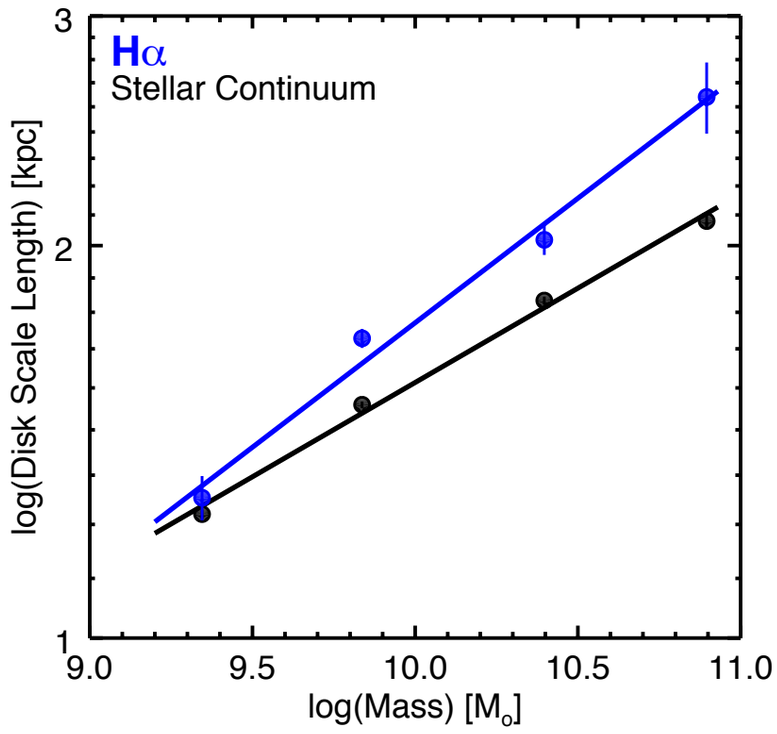
Nelson et al., 2015





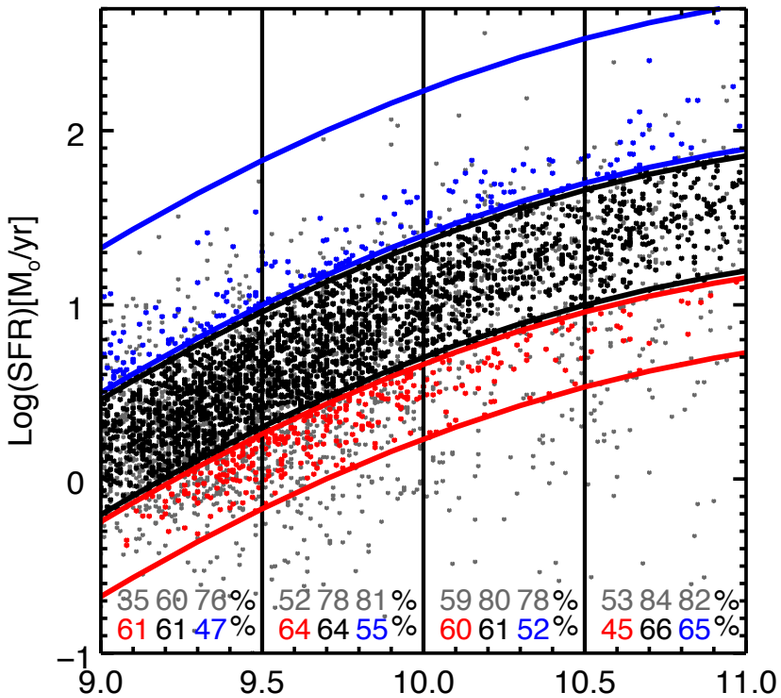
0.7<z<1.5:

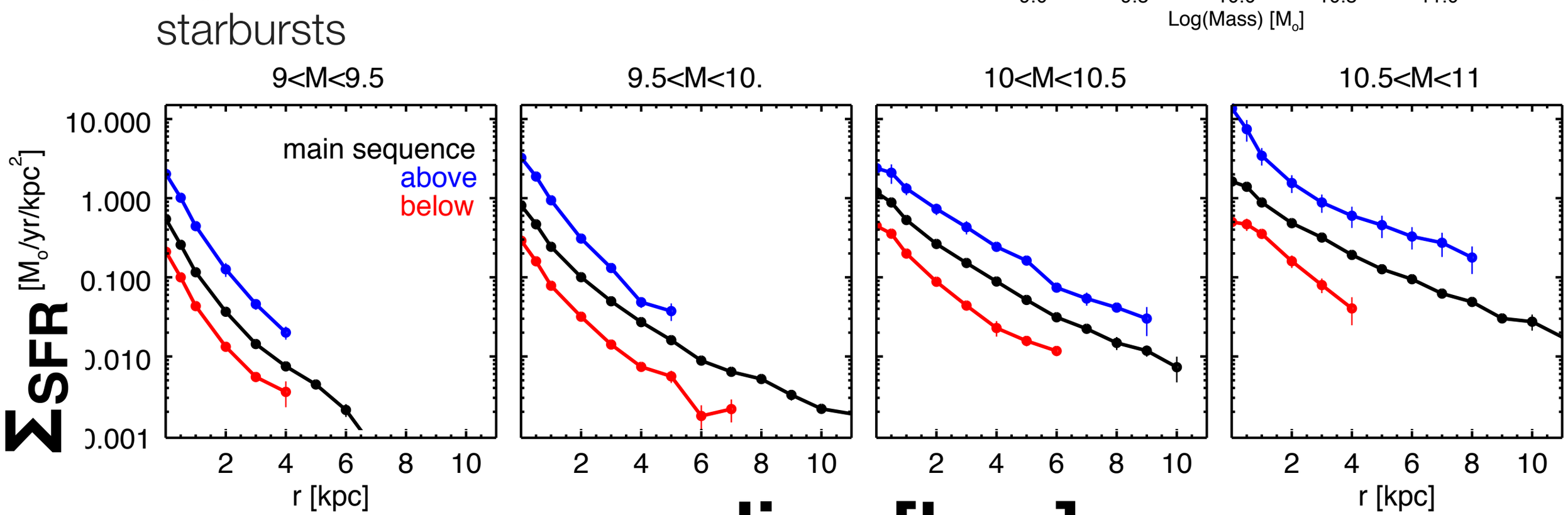
- star formation occurs in disks
- disks are building inside out

Where do stars form?

- Look at stacks on, above and below the star-forming sequence
- Elevated (suppressed) at all radii above (below) the SF sequence
  - e.g., no evidence for central starbursts

Nelson et al., 2015





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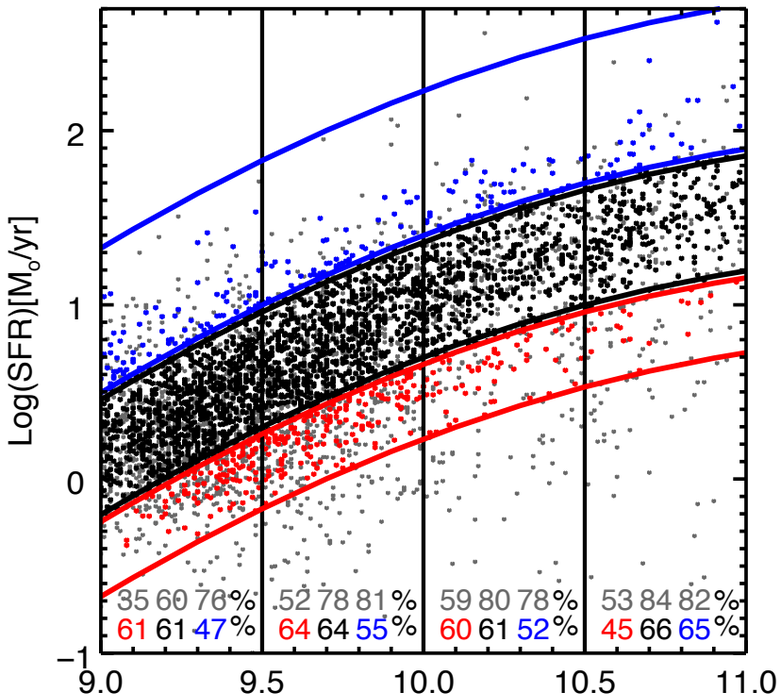

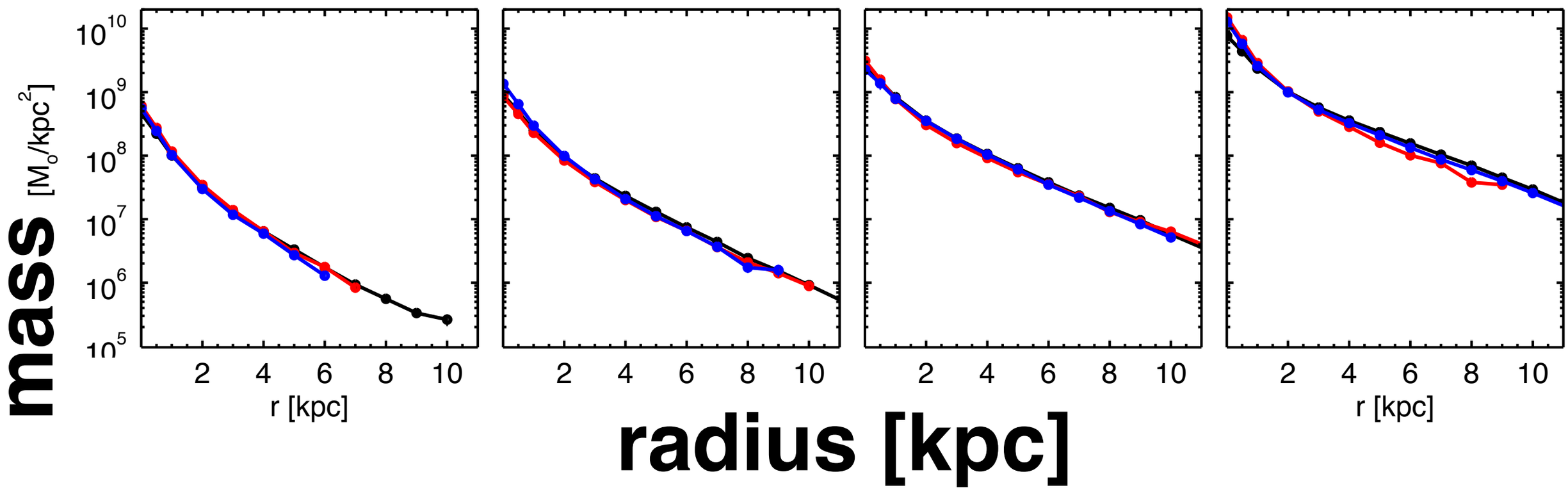

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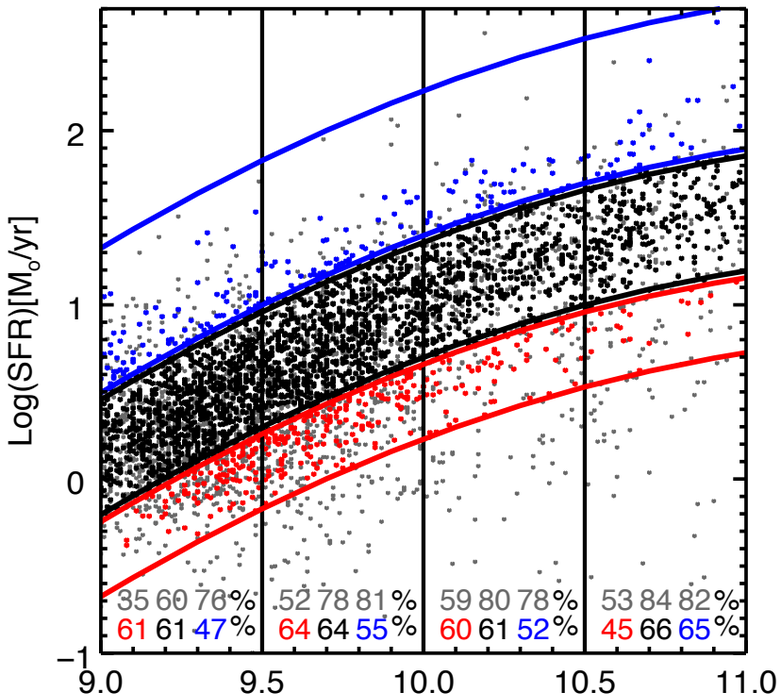
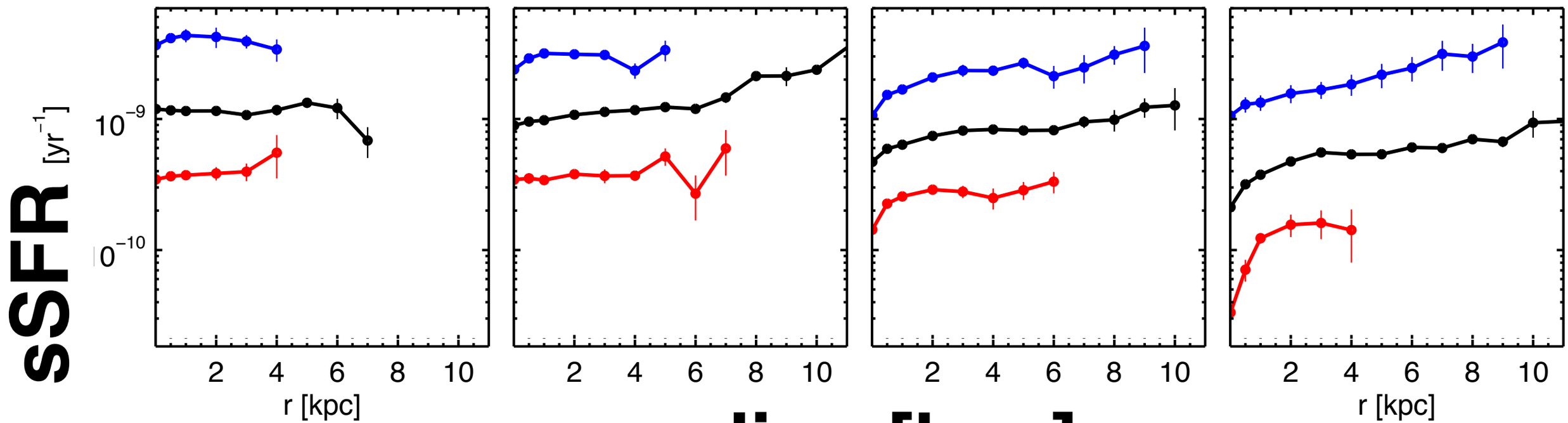
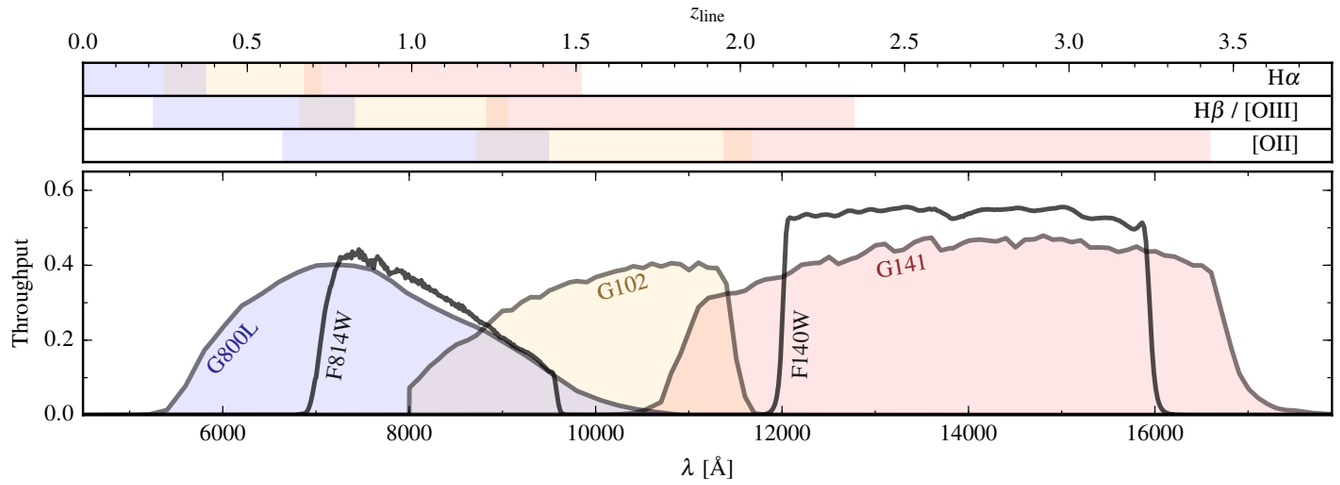


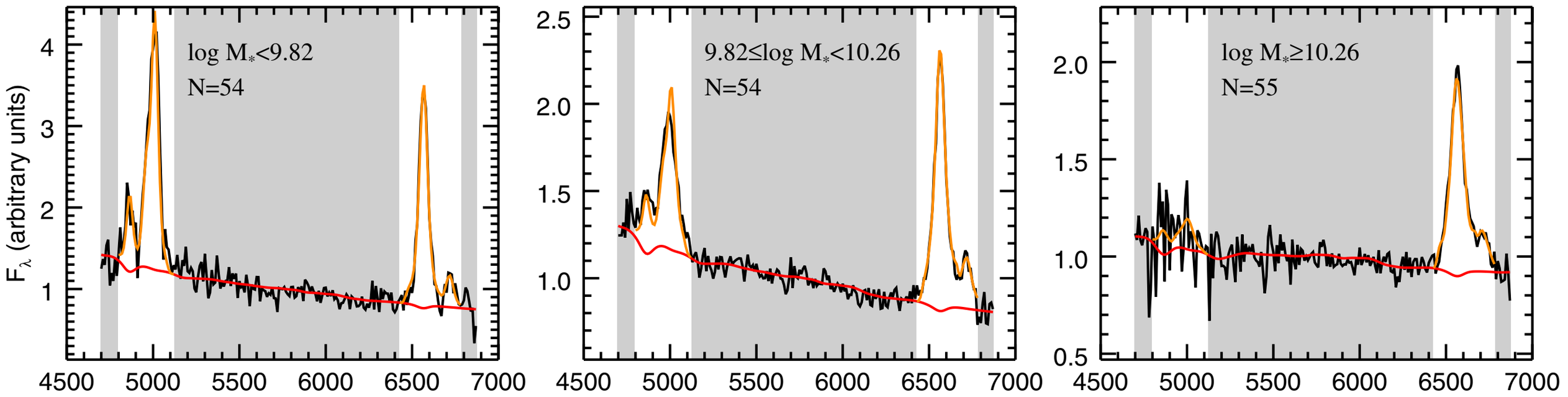


(Aside: Balmer Decrements)

- Get Hα + Hβ in a narrow redshift slice around z~1.3

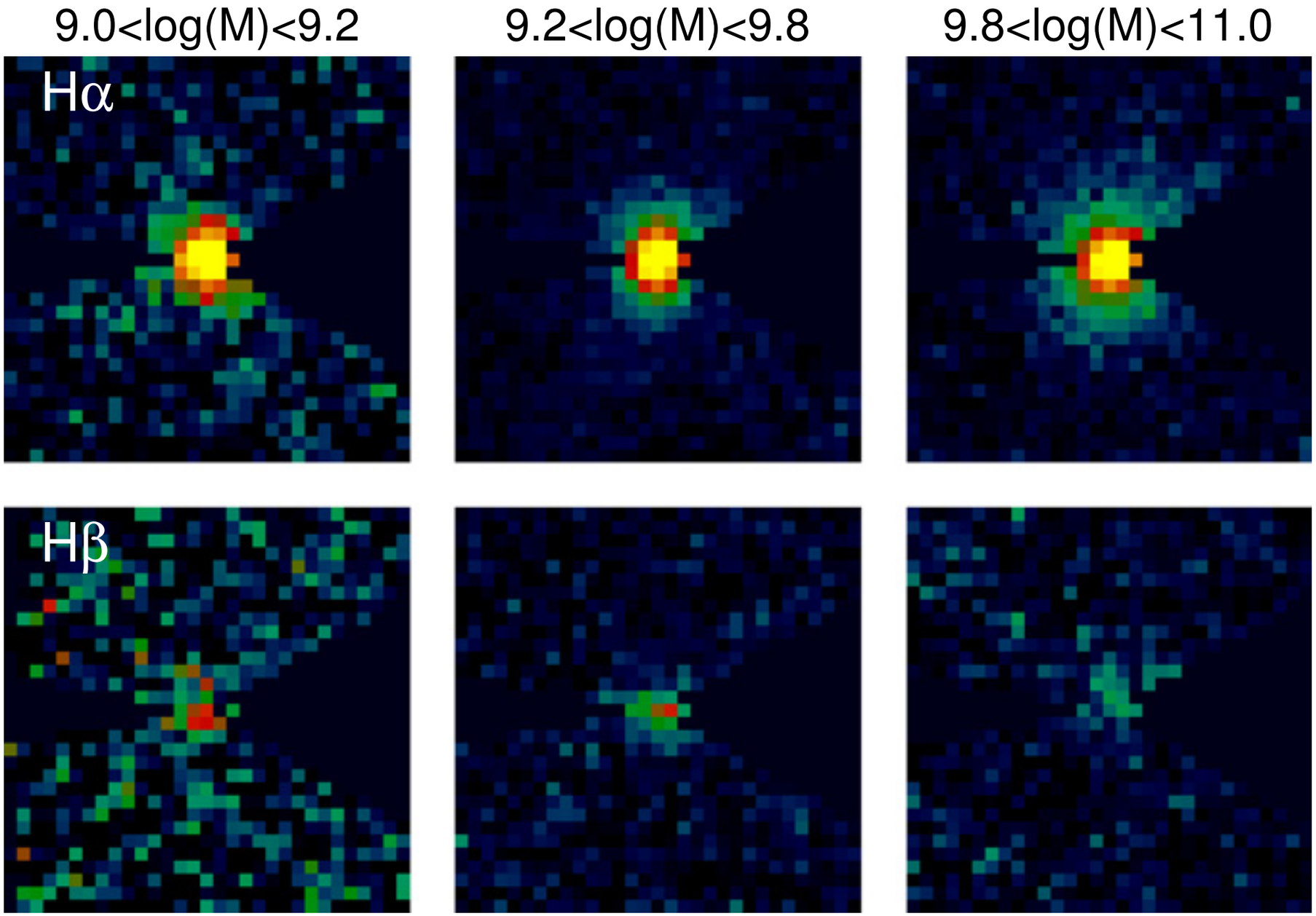


Price+2014



Where do stars form?

Nelson+2016



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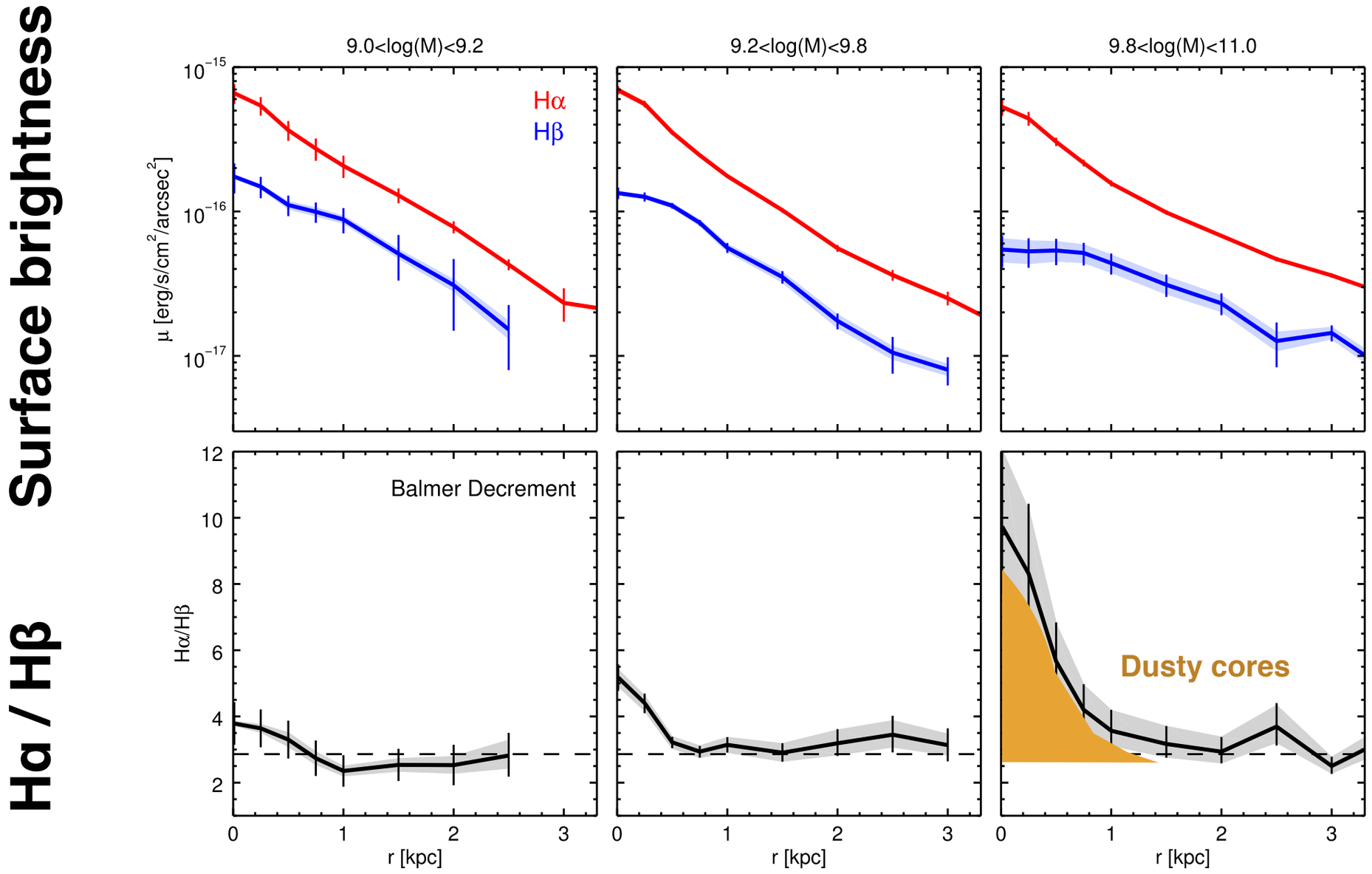

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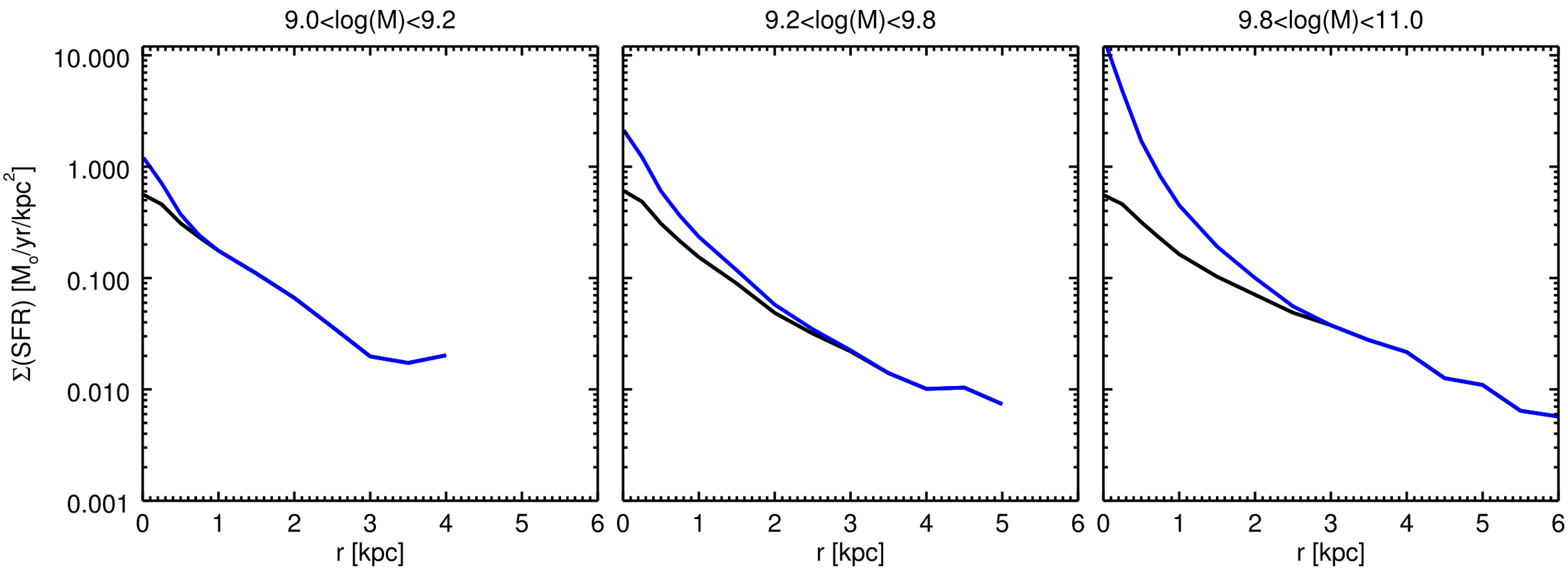
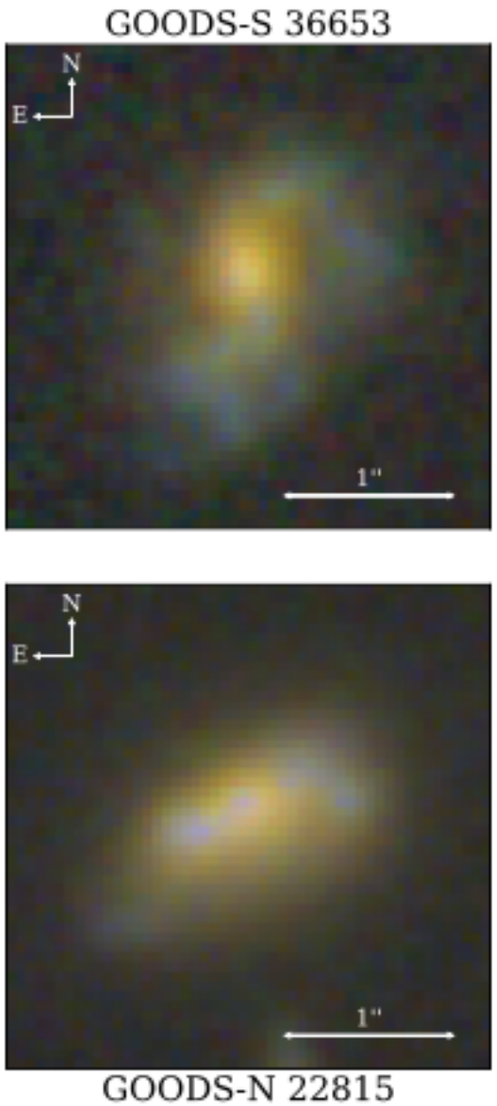
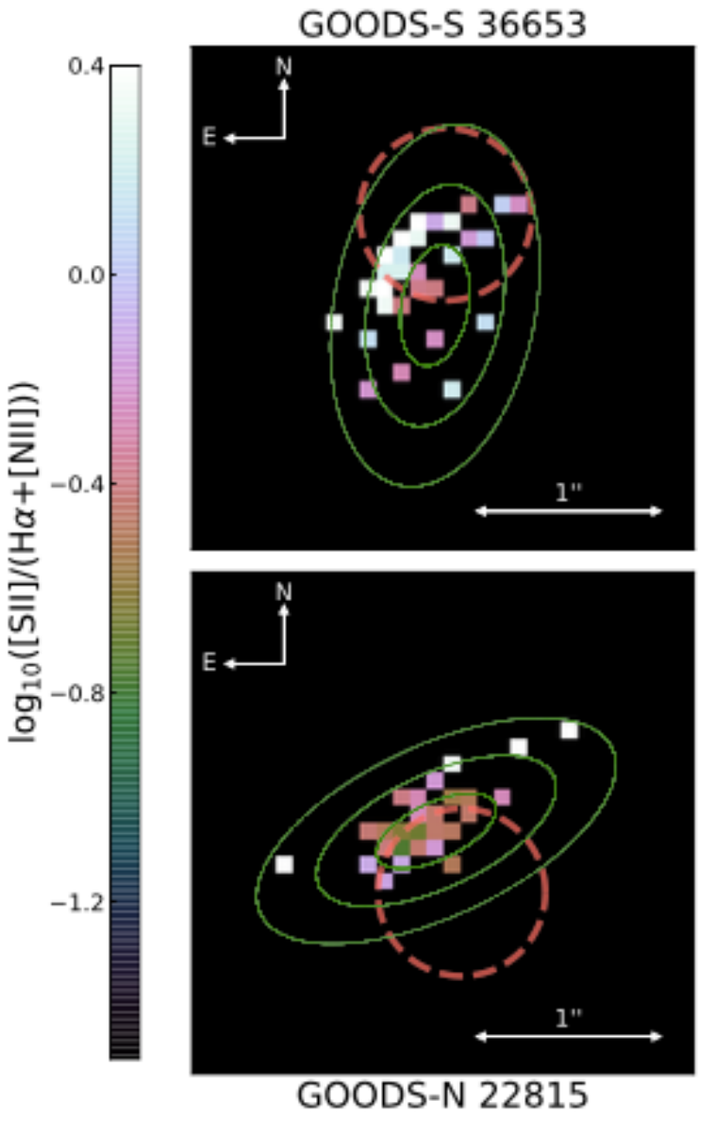


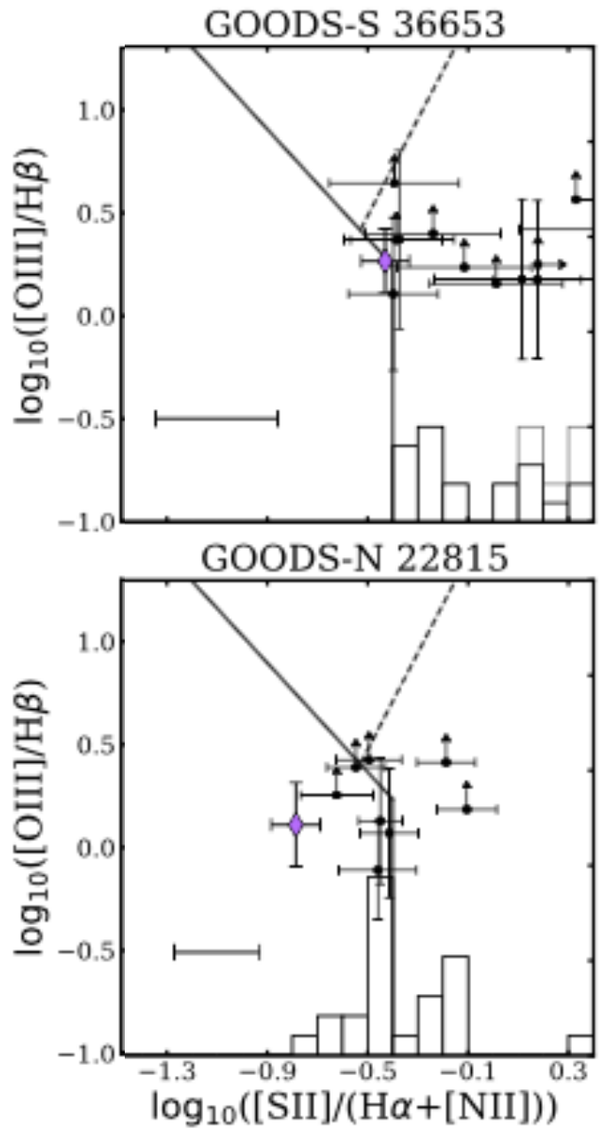
- Now see more of an **enhancement** in (massive) galaxy centers: building bulges with in-situ star formation?

Extended Low Ionization Emission-Line Regions at z~0.9

- Spatially-resolved emission line diagnostics
- First evidence of LIERs at high z





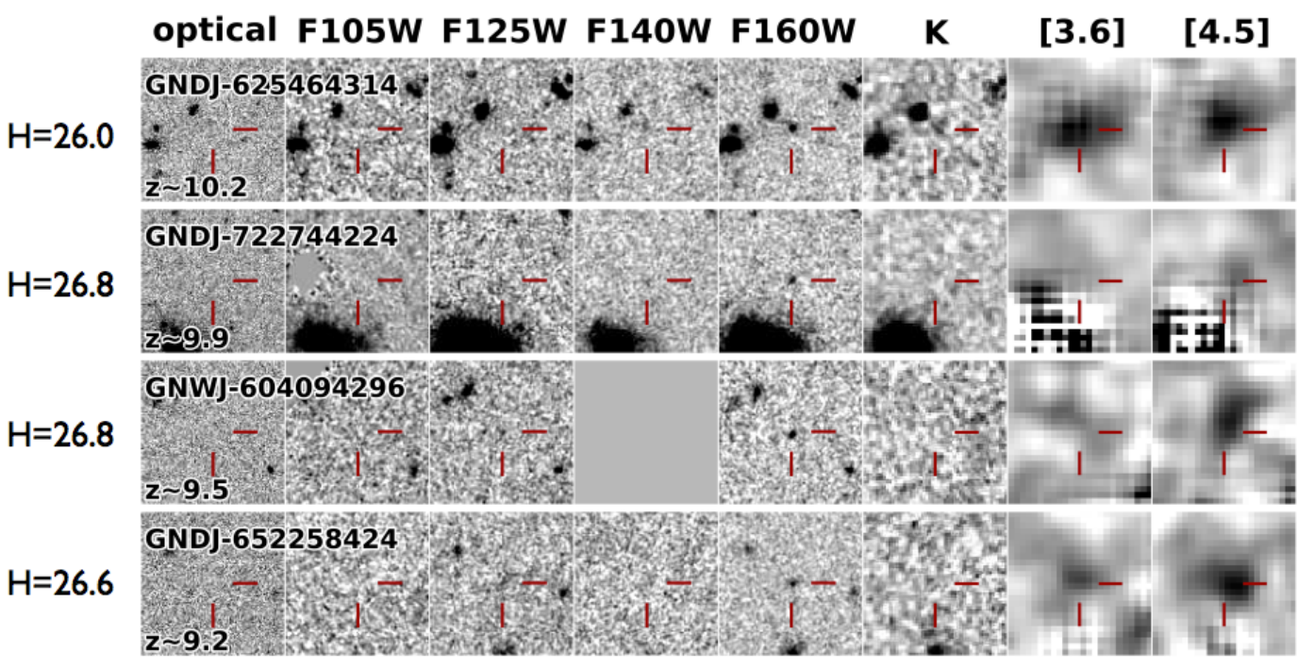


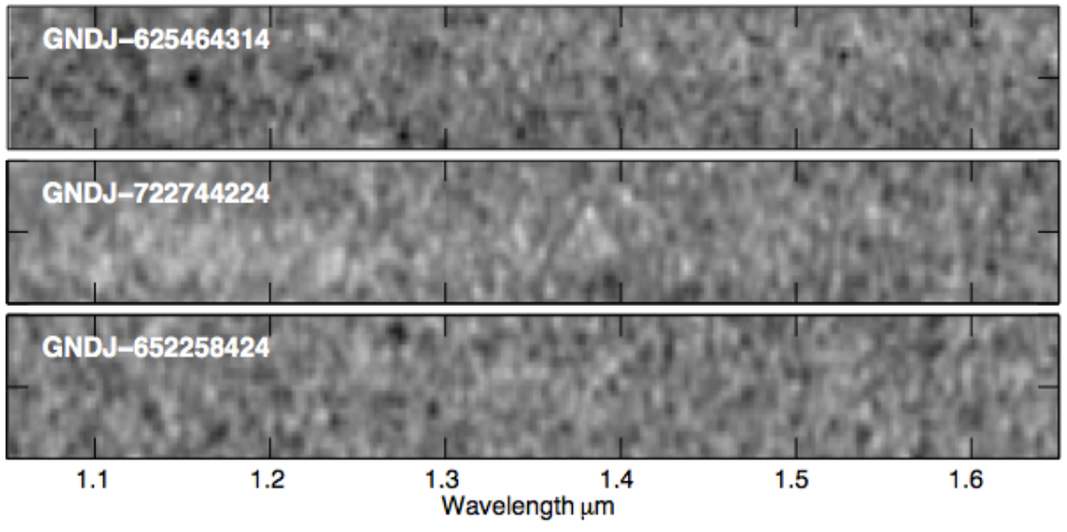
Hviding et al., in prep.

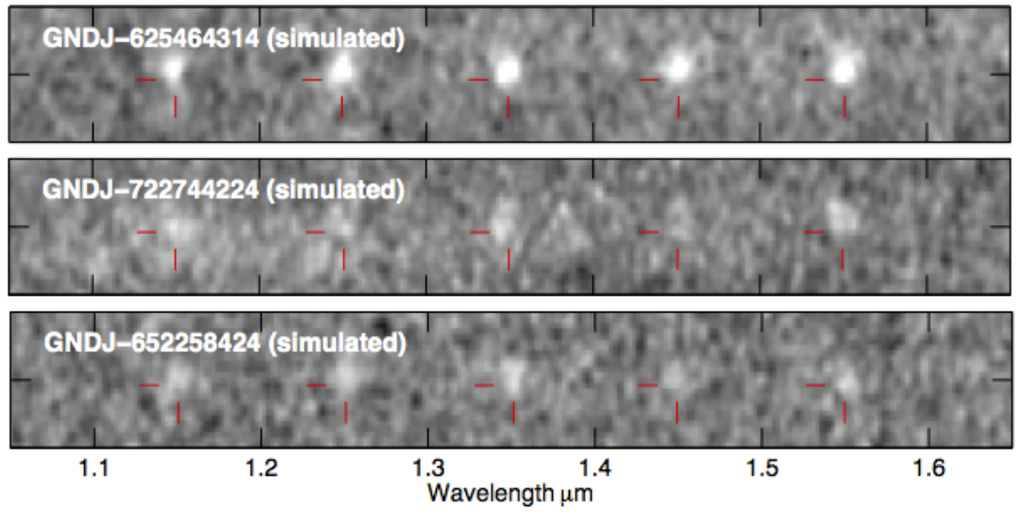
Cosmic Dawn

Cosmic Dawn

- Place constraints on emission line strength for GOODS-N z~10 candidates (Oesch+2014, 2016)

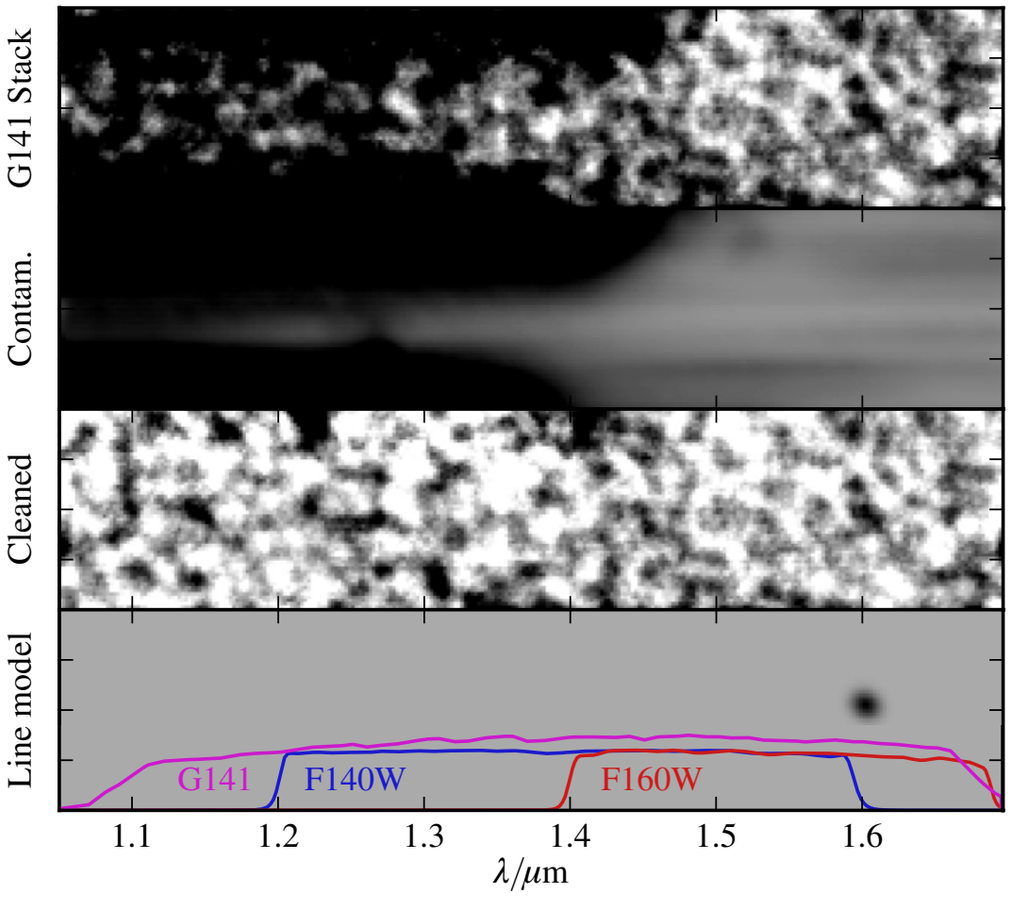


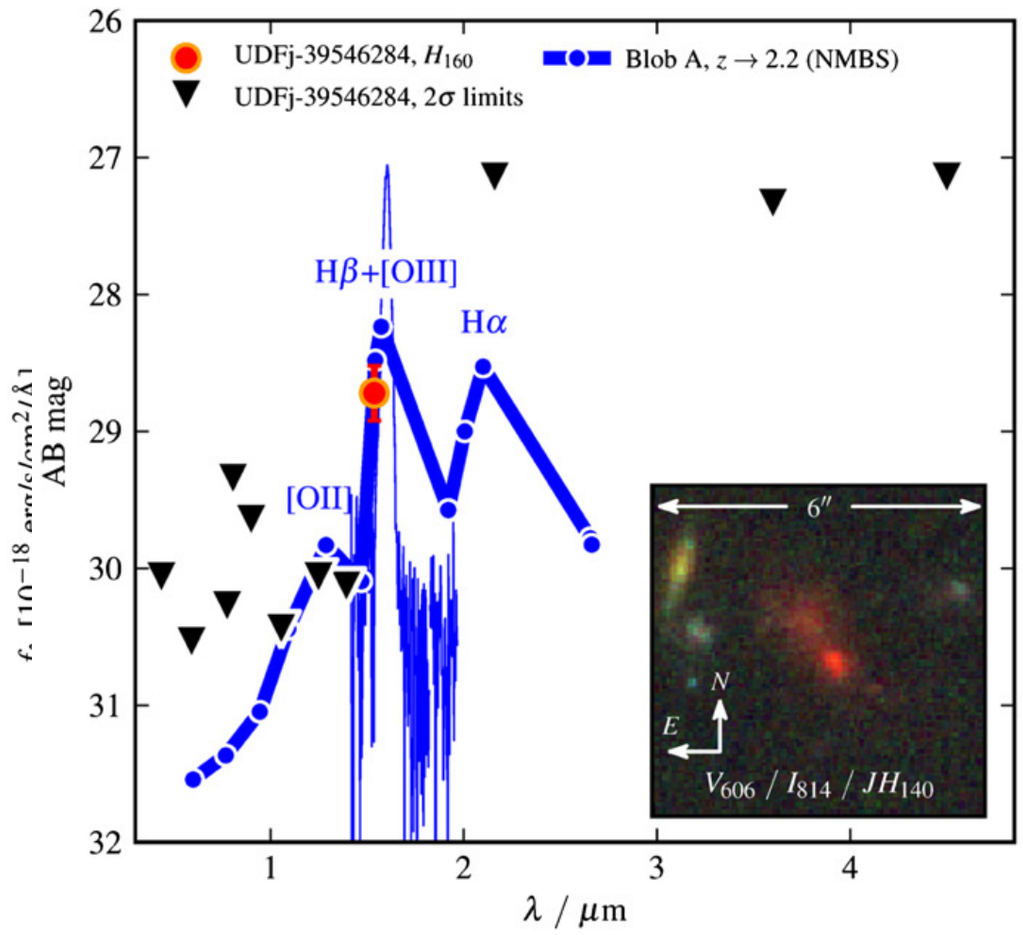




Cosmic Dawn

- Deep grism spectra of the $z\approx12$ candidate UDFj-39546284 revealed a faint emission line that could explain all of its broad-band flux in H_{160} -> more likely $z\approx2.2$ (Brammer+2013)





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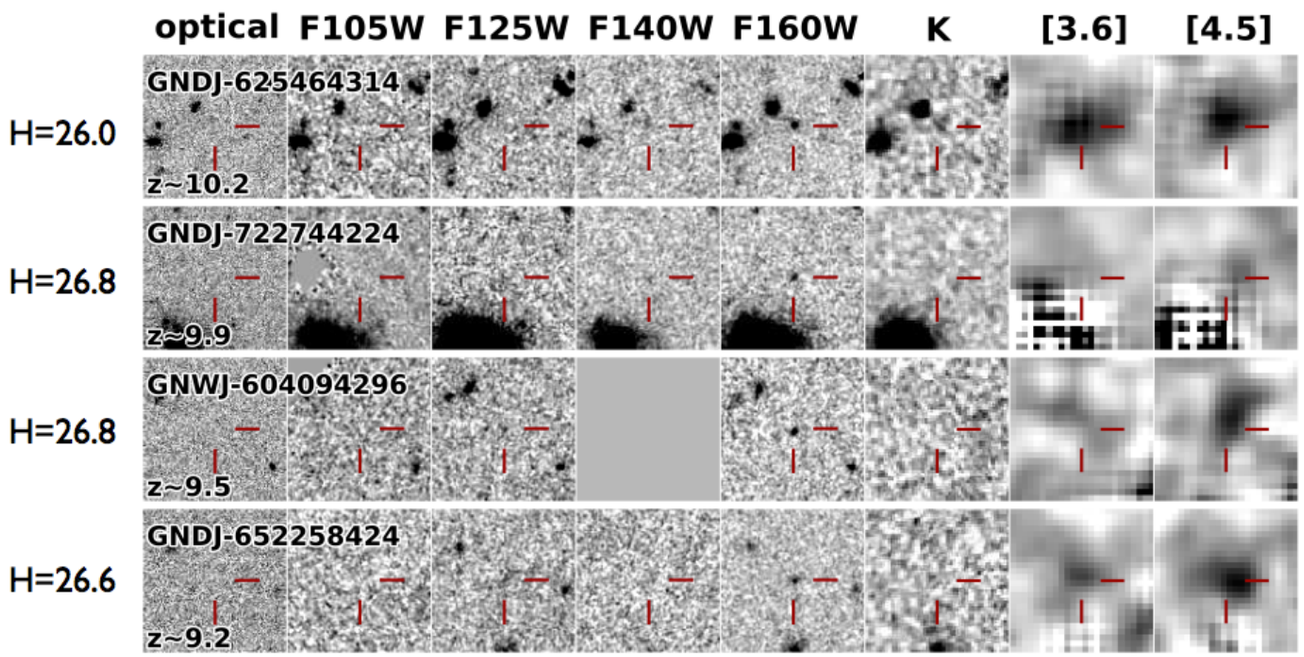
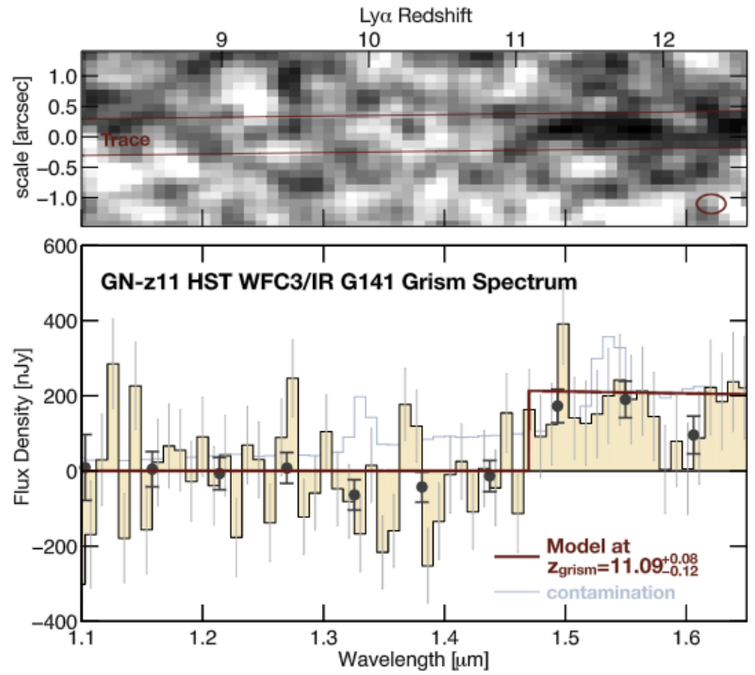
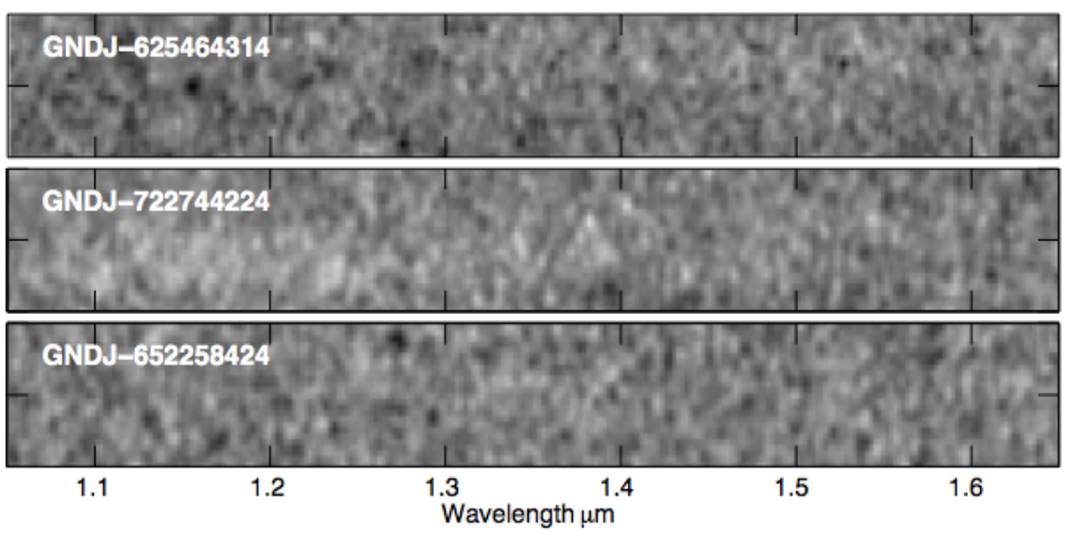
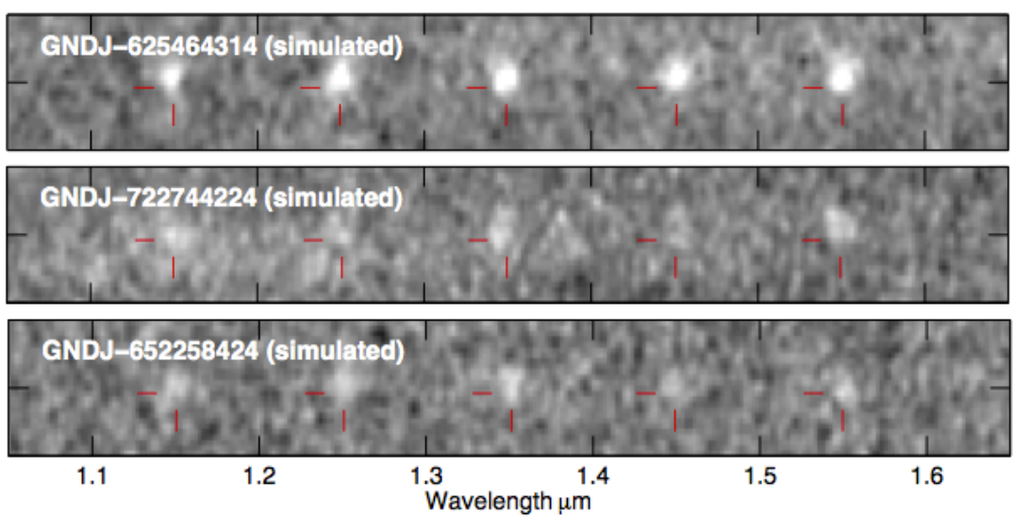
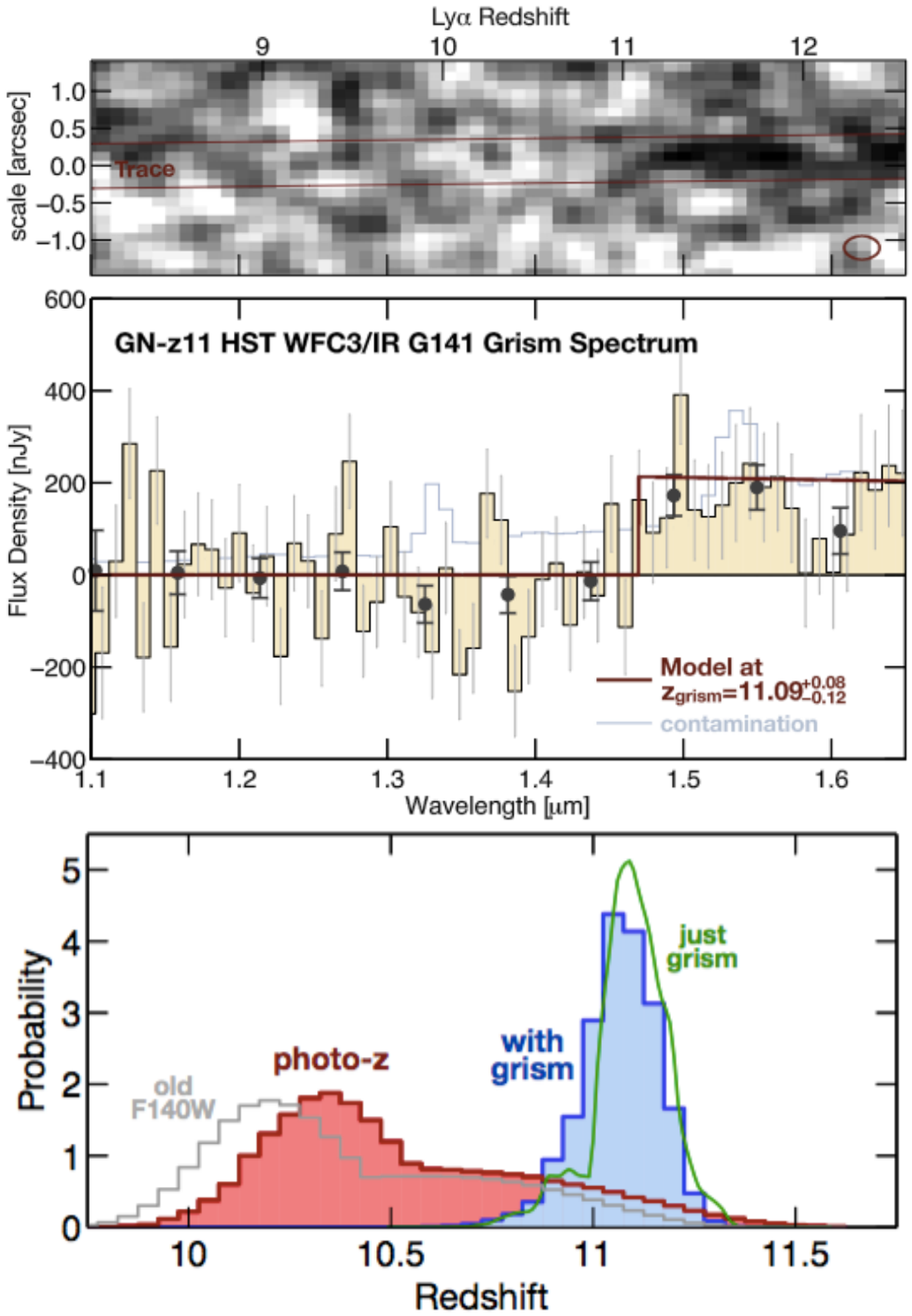








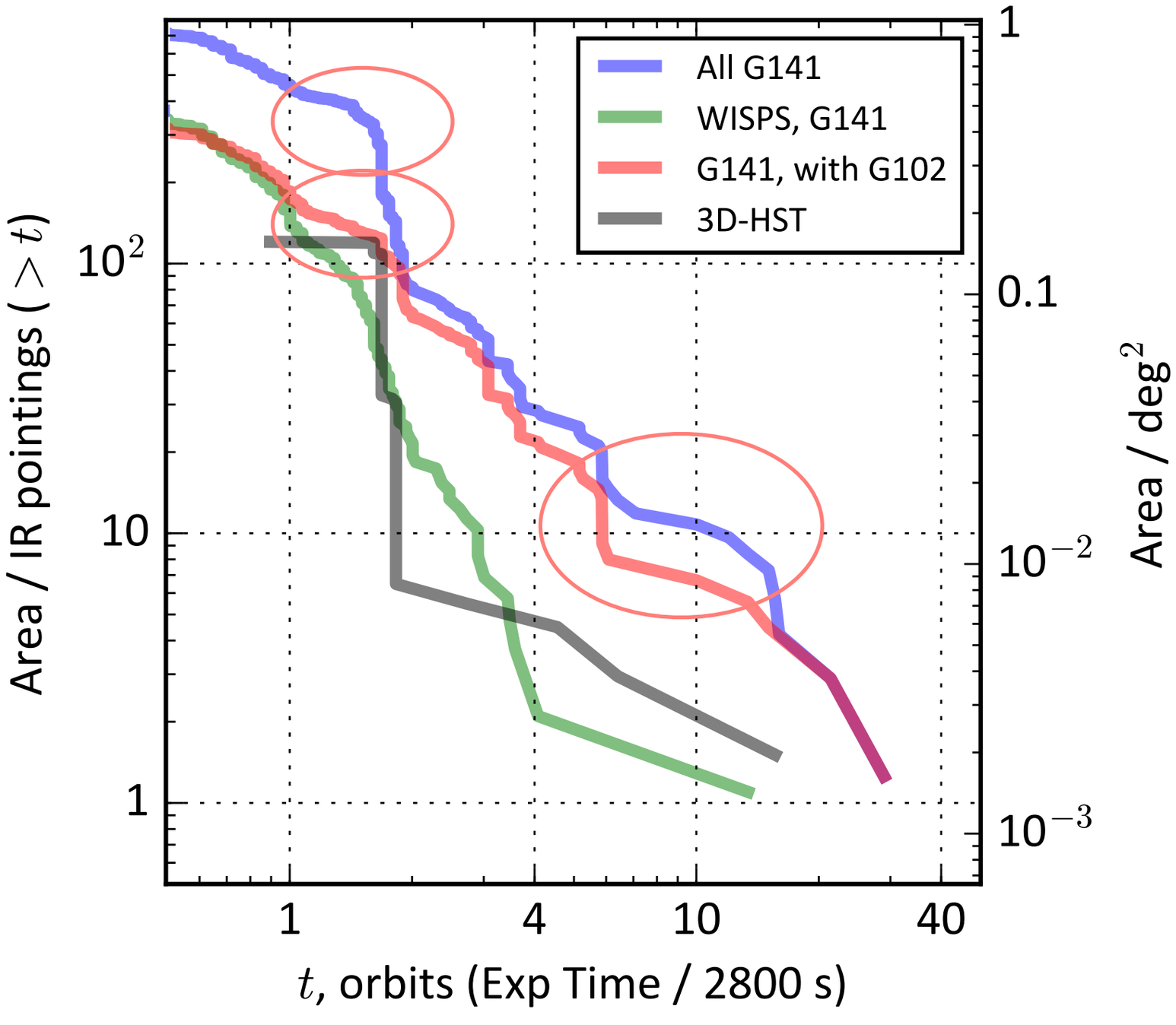
Cosmic Dawn



- Overall 5.5σ at λ > 1.47 μm
- Break factor of >3.1 (2σ, 500Å)
  - (Maximally old BC03 model at *z*=2.7 a factor of <2.7 defined the same way)
- Best-fit redshift of *combined* spectra + photometry: *z*=11.1 ±0.1

Future Prospects

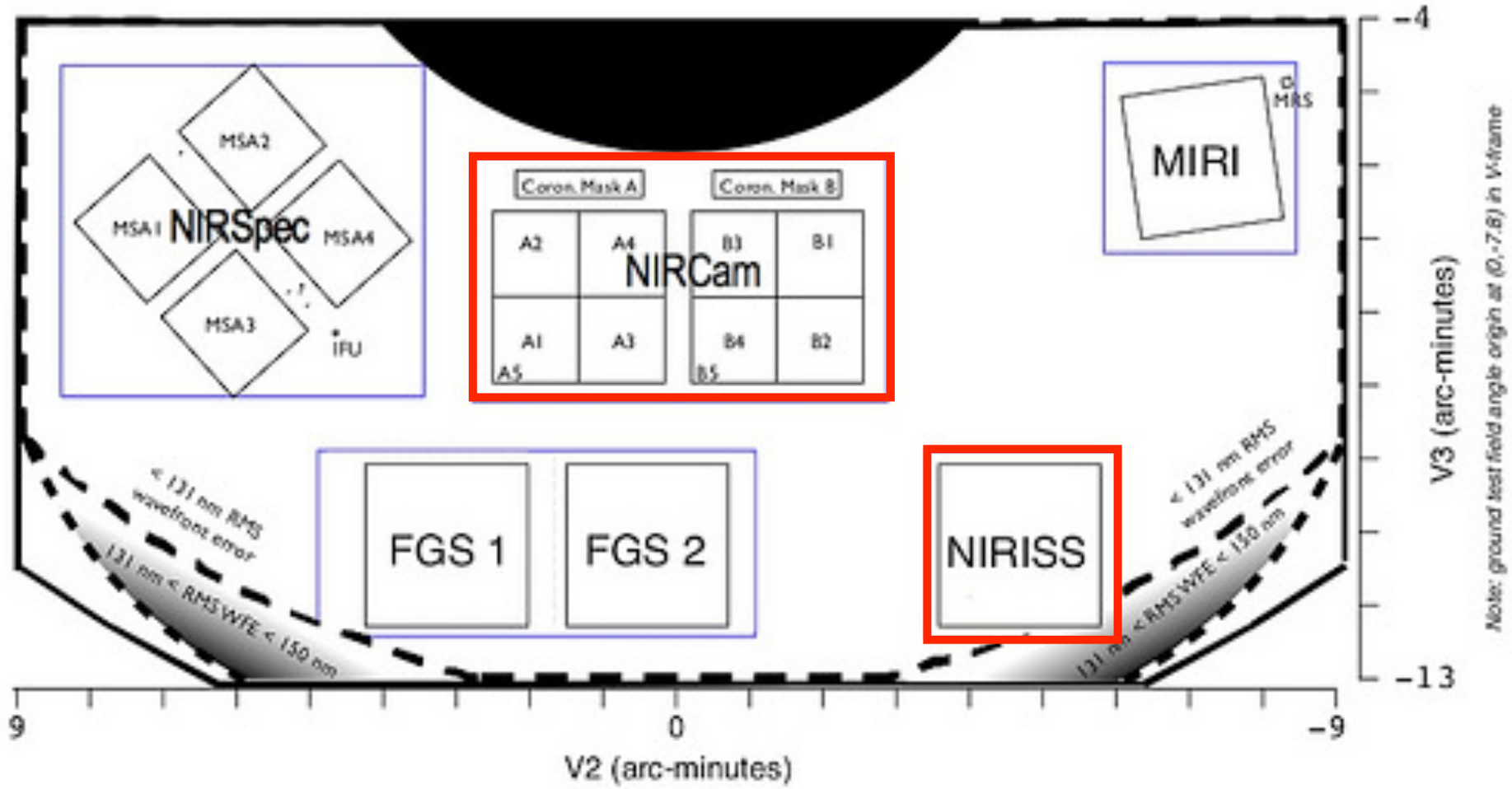
New capabilities with slitless spectroscopy: archival work



- 4x G141 area
- Joint G102+G141
- Deep pointings at multiple angles
- Heterogeneous supporting data (but always WFC3 imaging)
- Standardized analysis
- Cycle 24 Legacy Archival Program (AR-14553)

Grizli

New capabilities with slitless spectroscopy: JWST

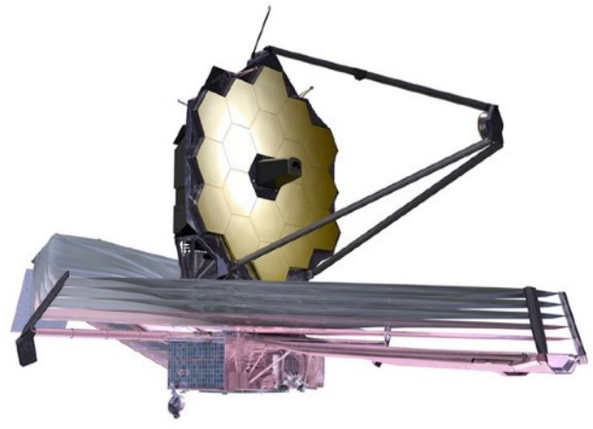


Capabilities science capabilities with dramatic improvements in:

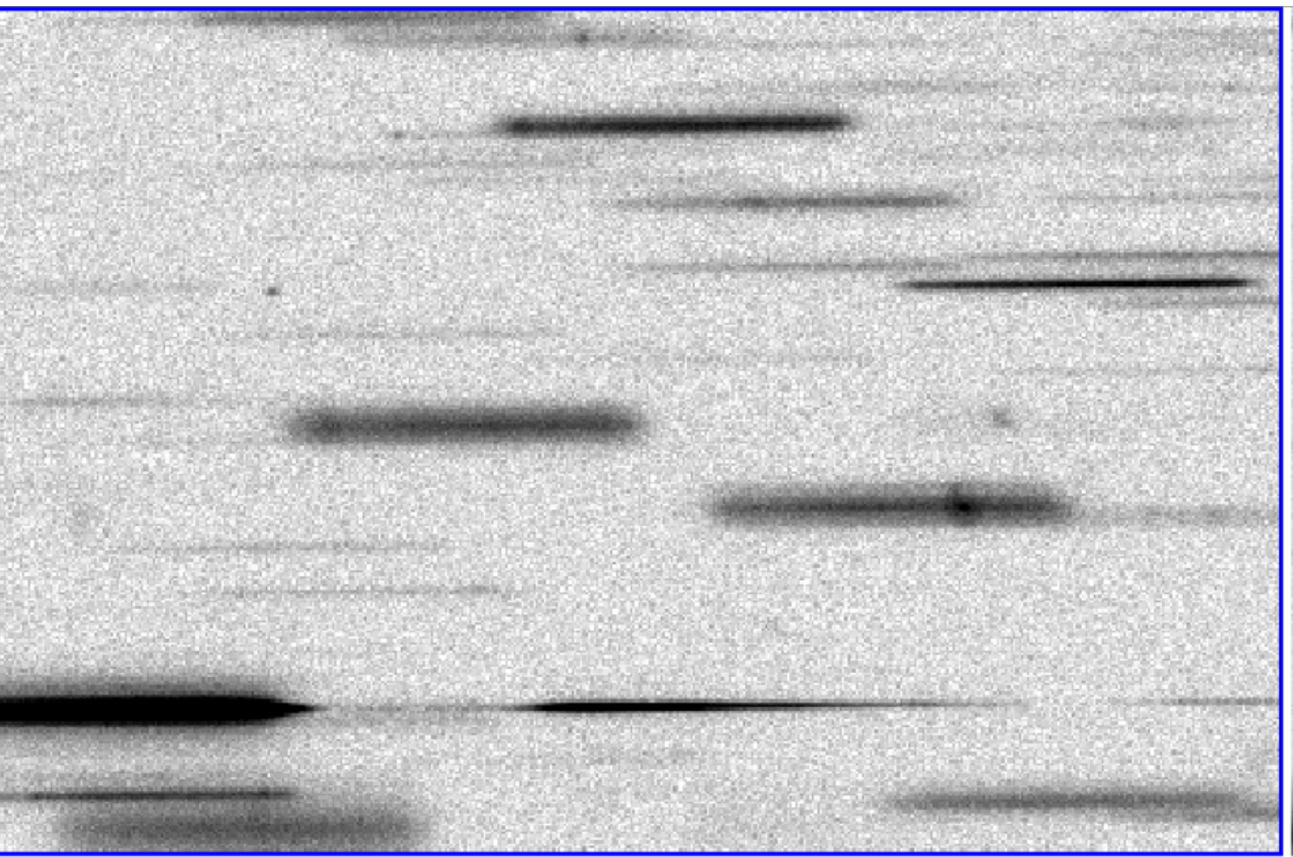
- Sensitivity
- Resolution
- Bandpass

New capabilities with slitless spectroscopy: JWST

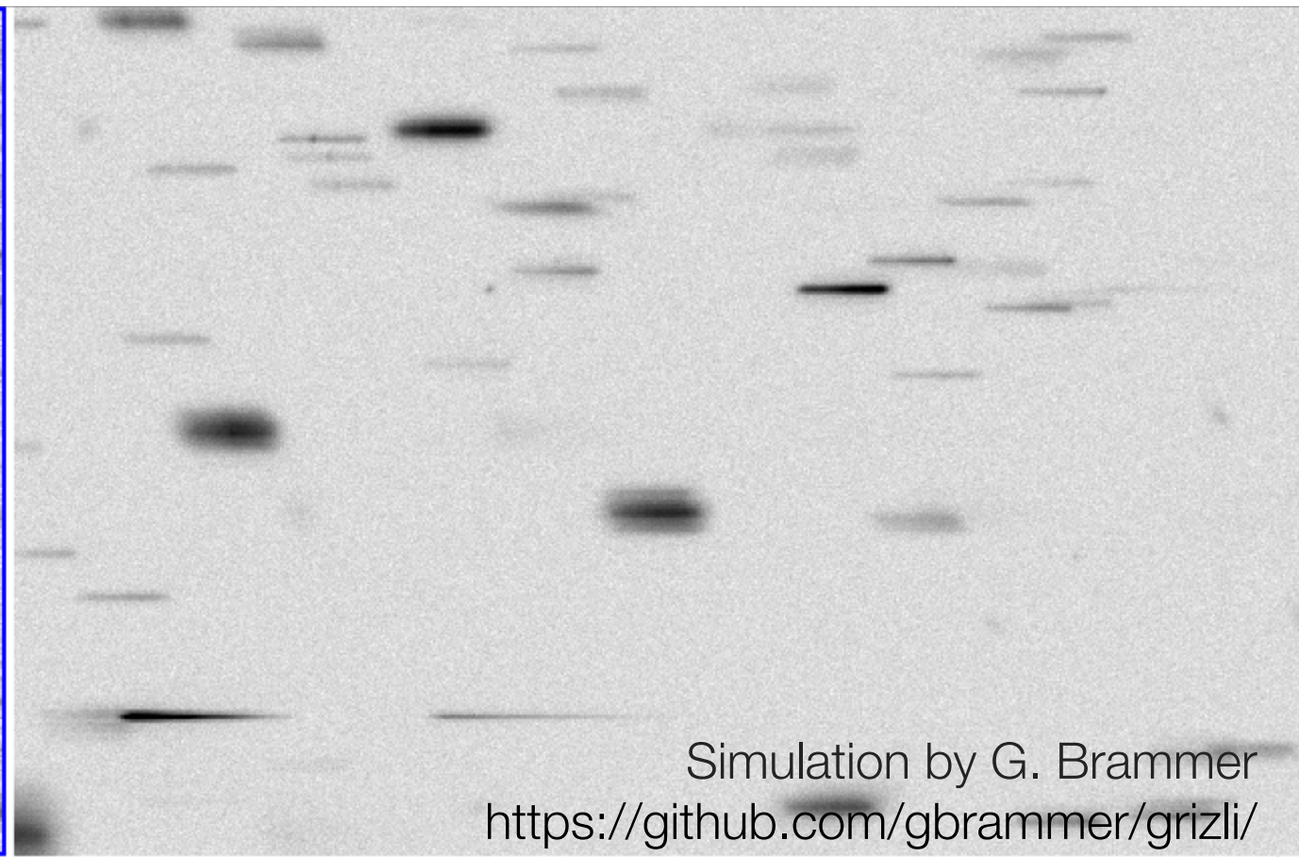
- **JWST NIRISS+FGS**
  - Big telescope! 0.065” pixels, ~WFC3/IR FOV
  - Two grisms rotated by 90°, *R*=150 (like WFC3/G141)
  - Bandpass limiting by crossed filters, **0.9 – 2.2 μm**



WFC3/G141



NIRISS, G150C + F115W



Simulation by G. Brammer
https://github.com/gbrammer/grizli/

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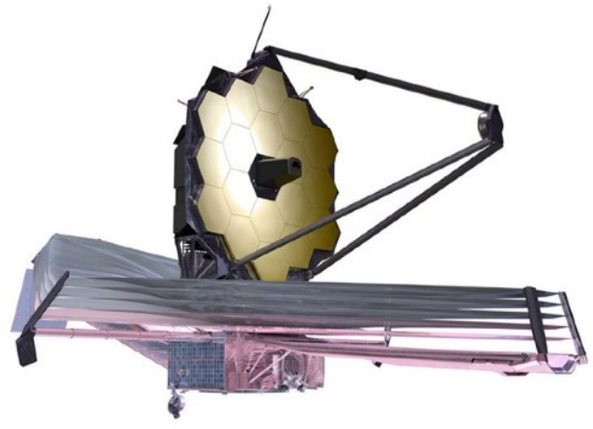
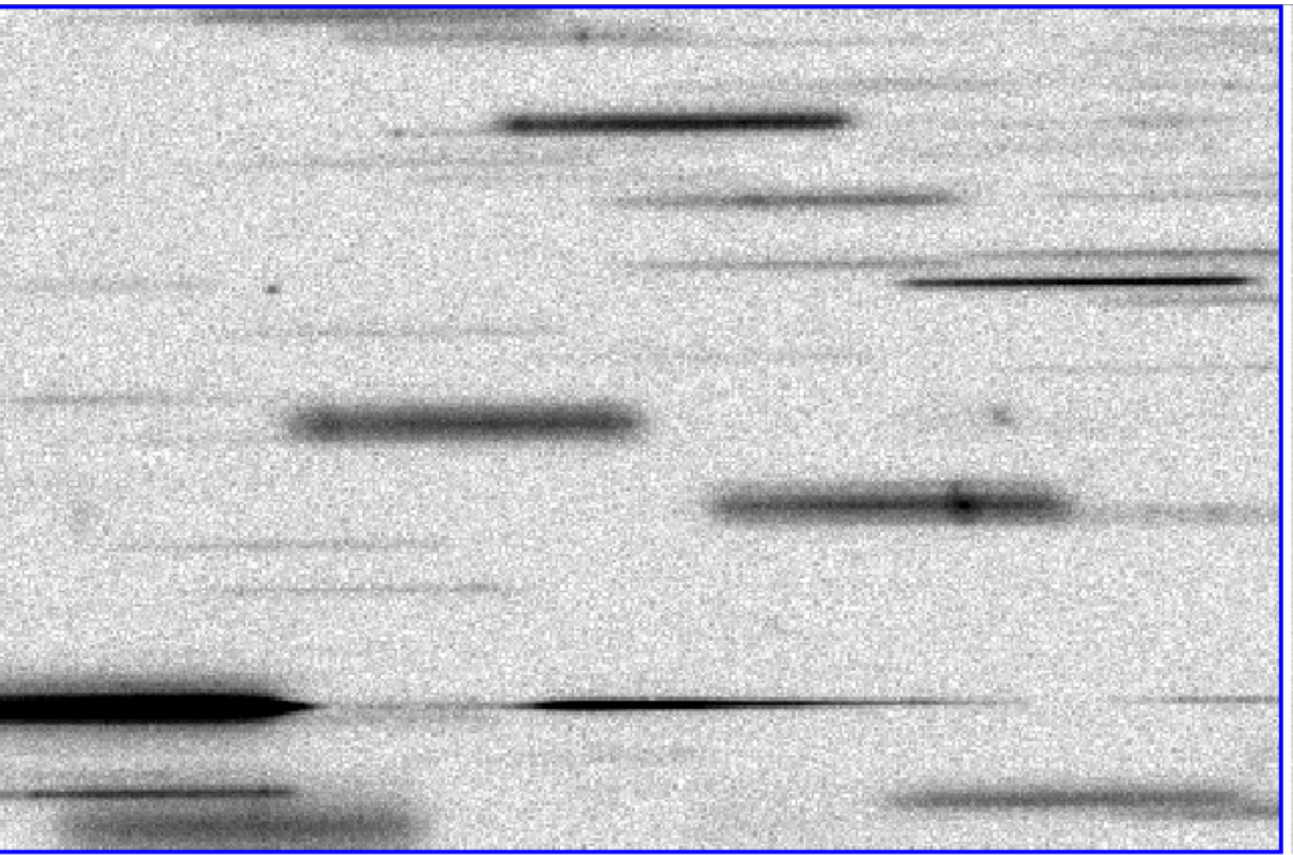
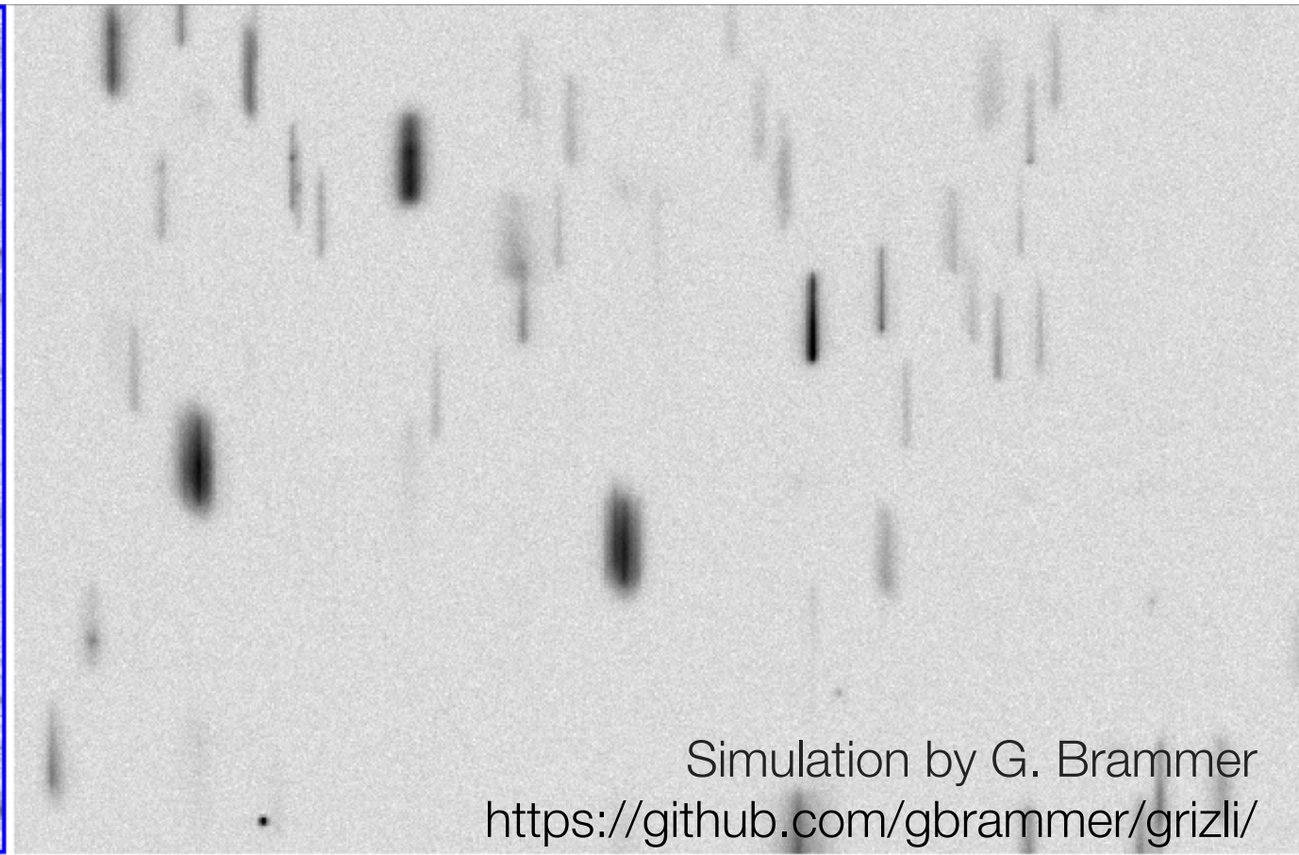


WFC3/G141



NIRISS, G150R + F115W



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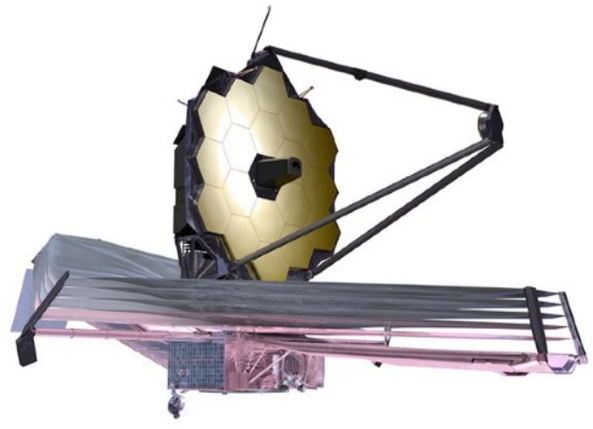
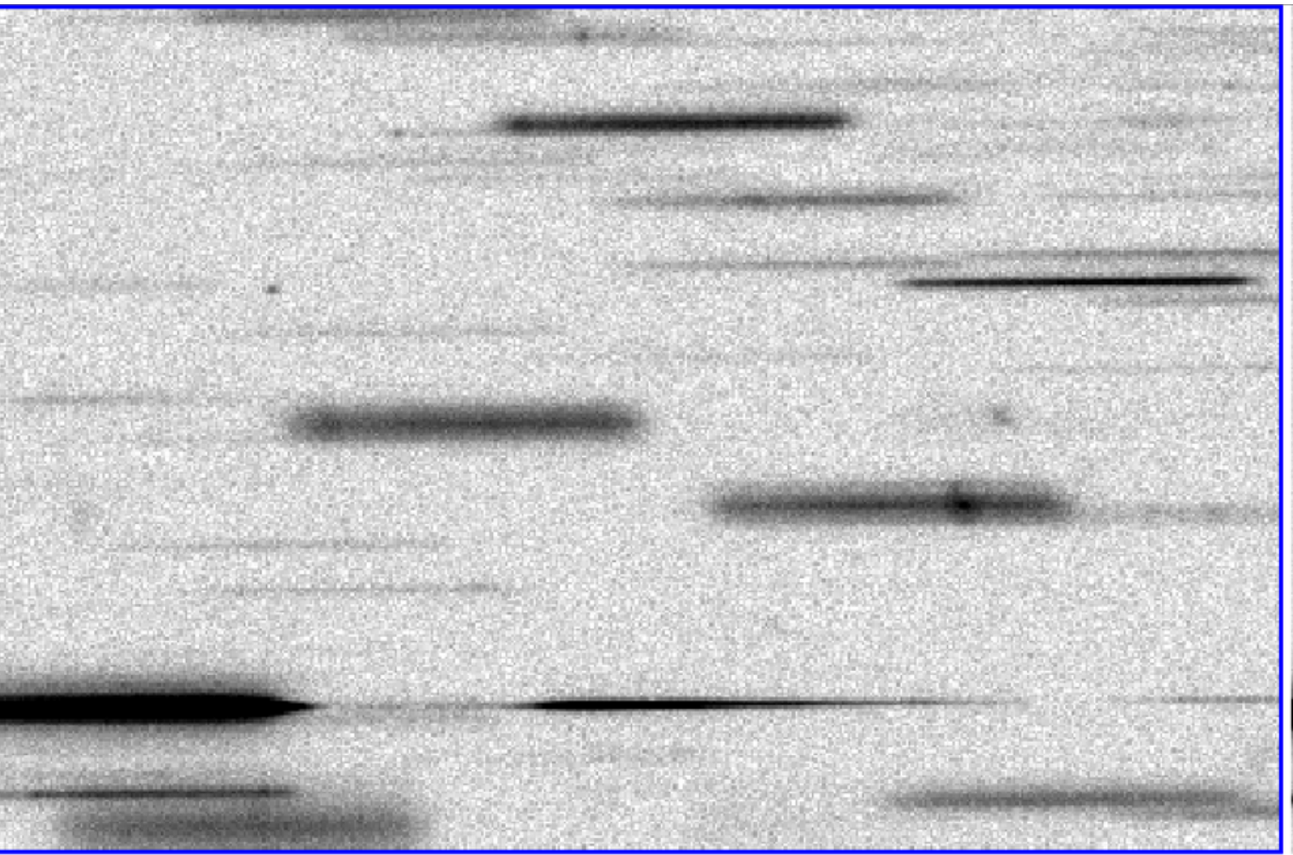
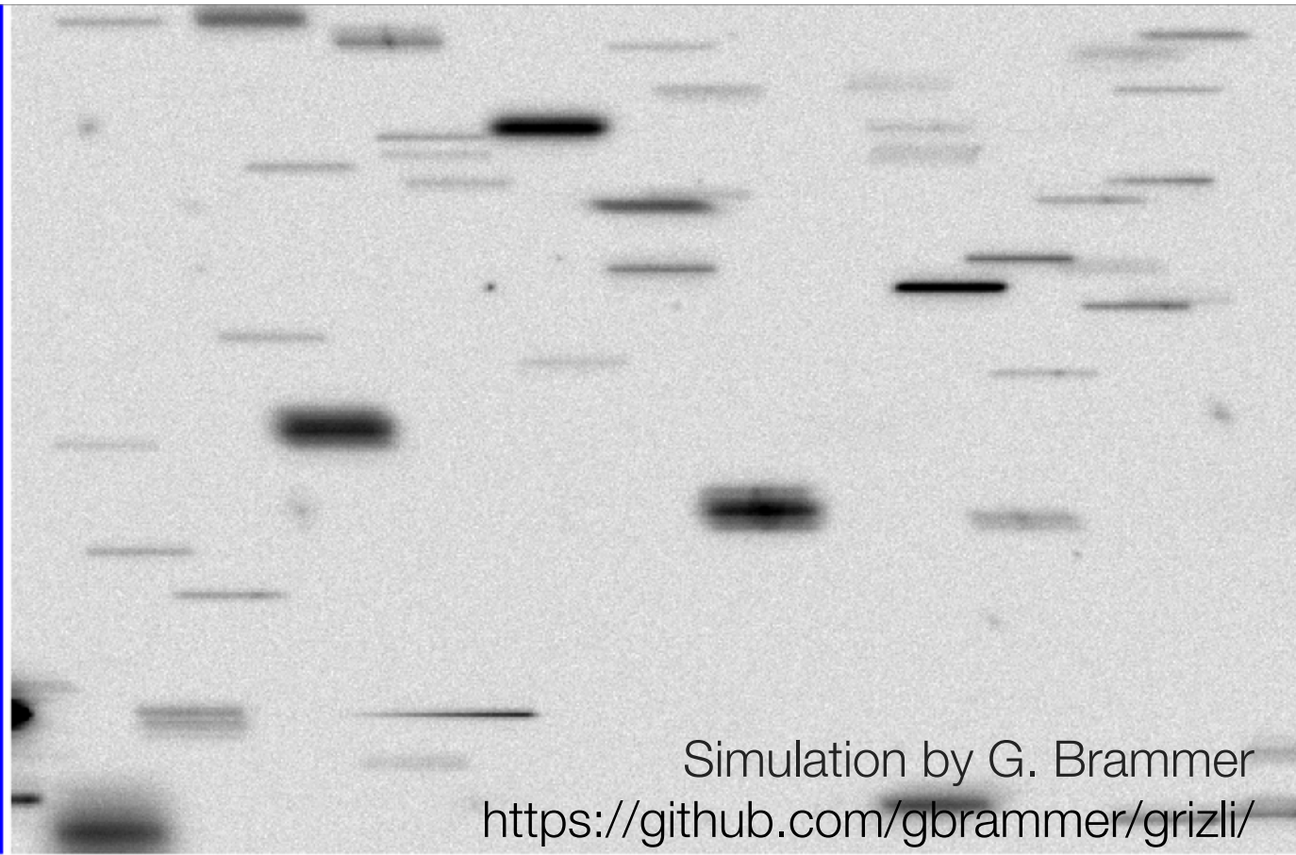


WFC3/G141



NIRISS, G150R + F150W



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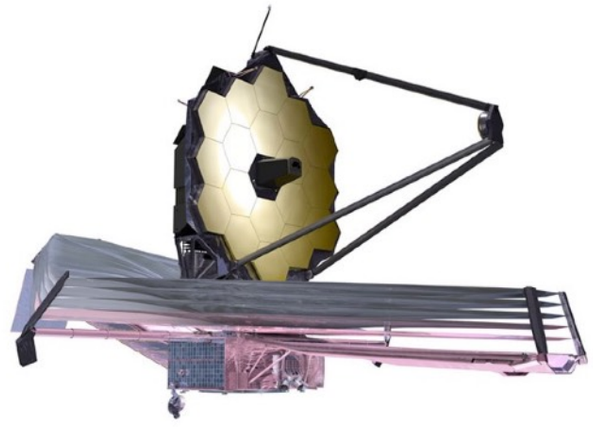
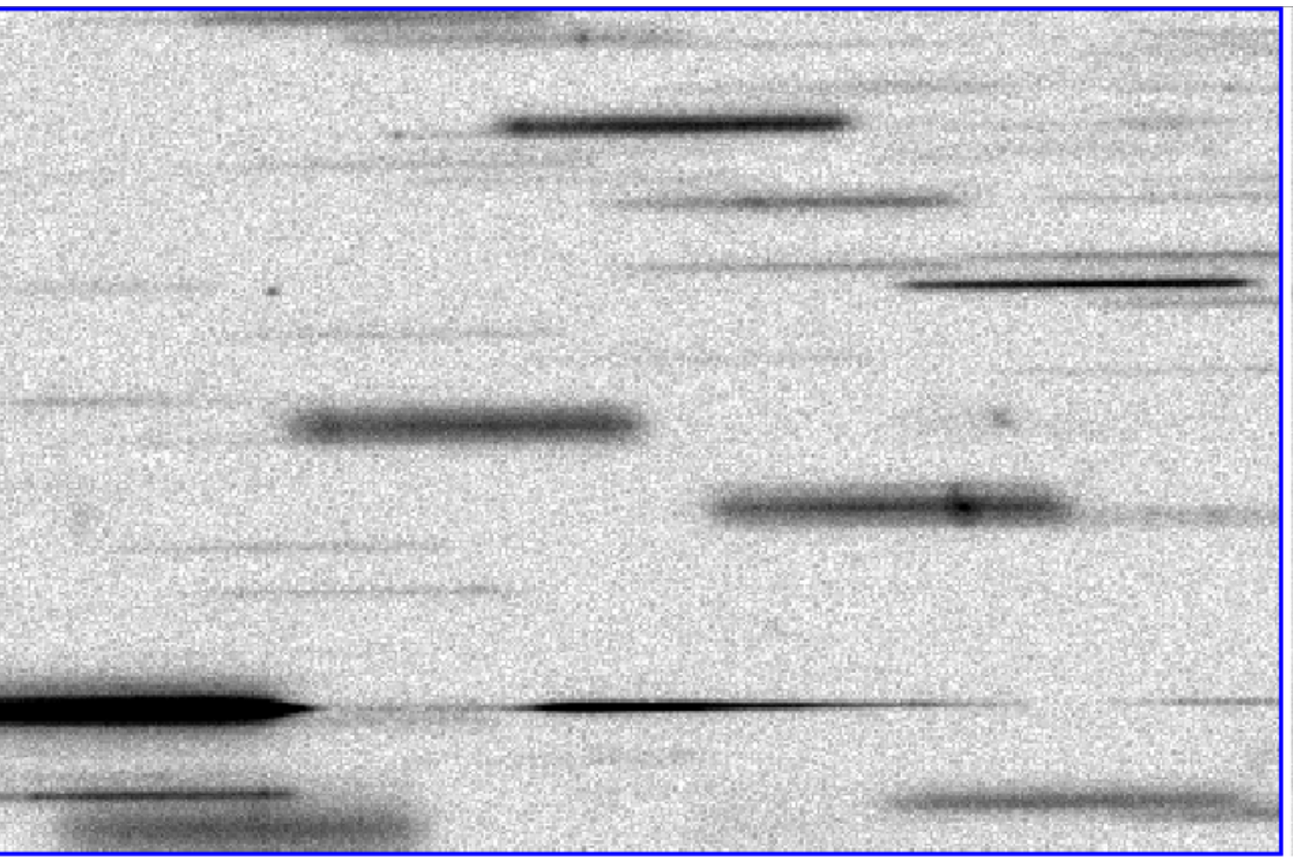
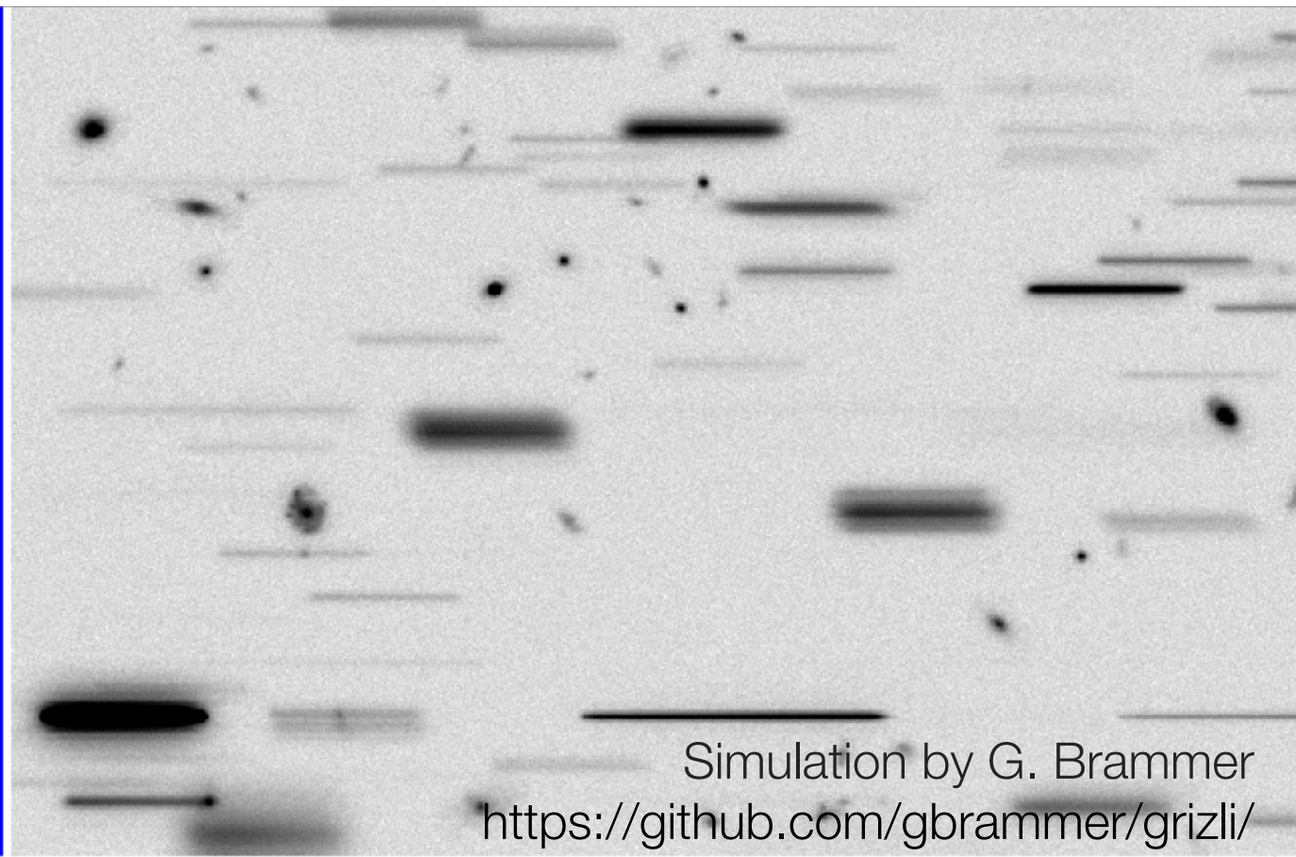


WFC3/G141

NIRISS, G150R + F200W





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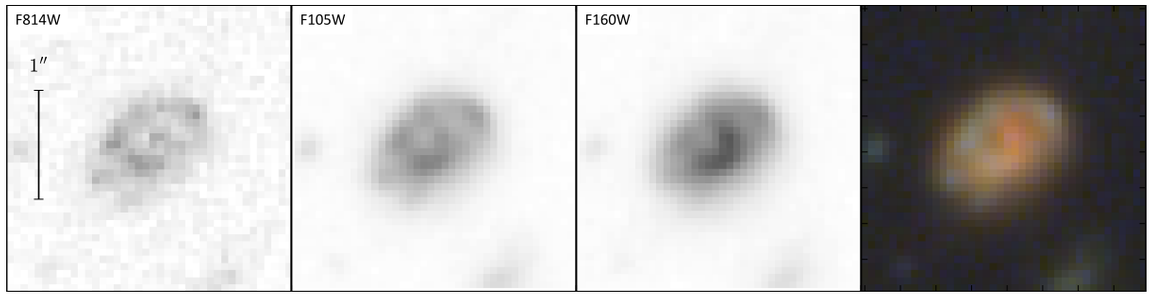

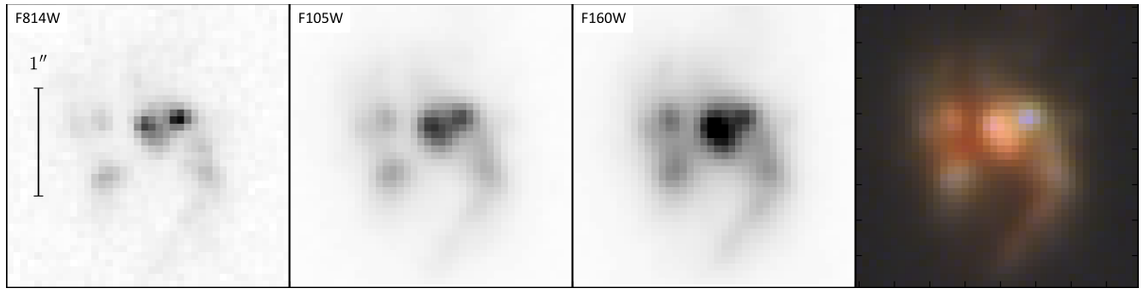

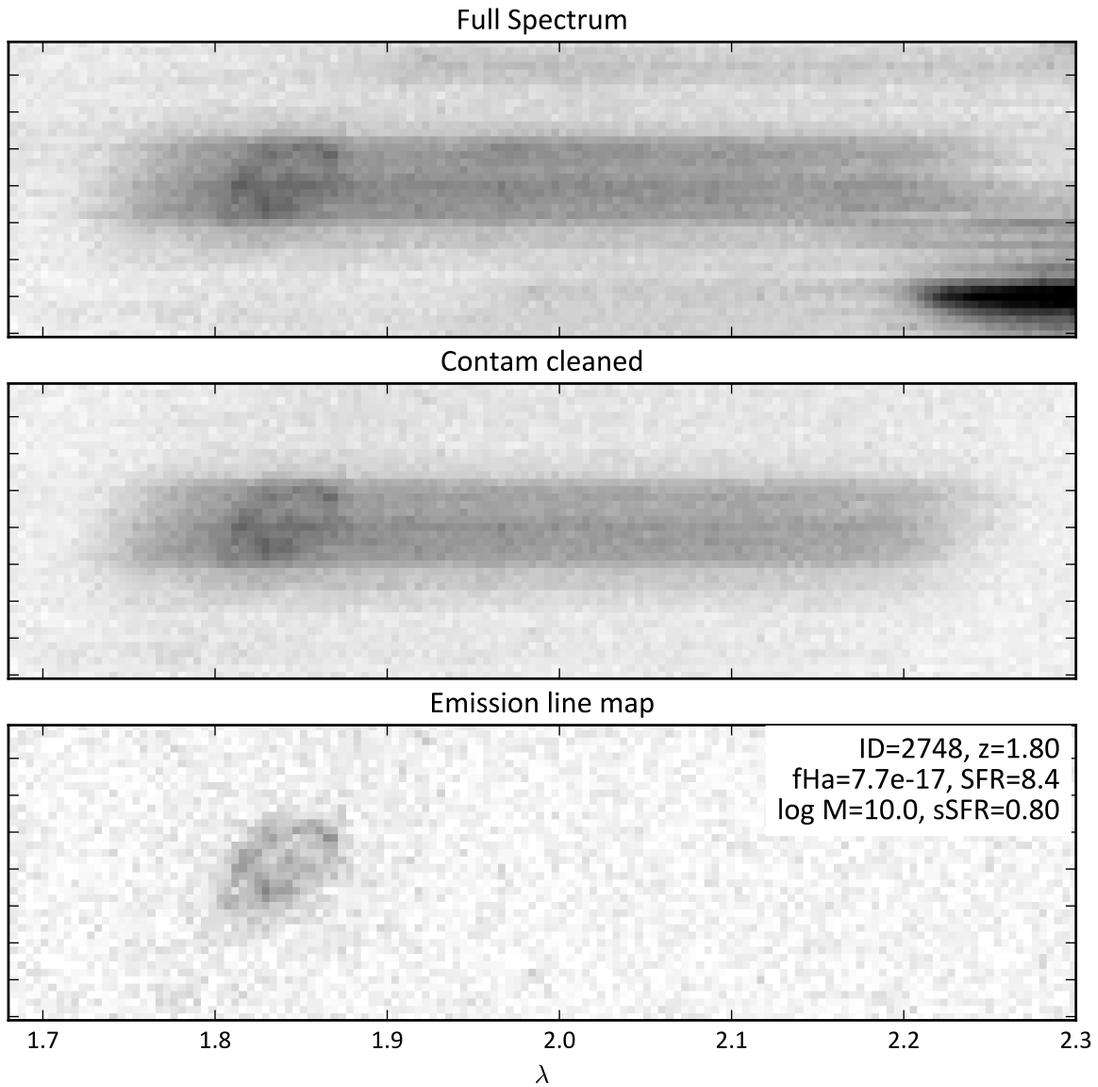

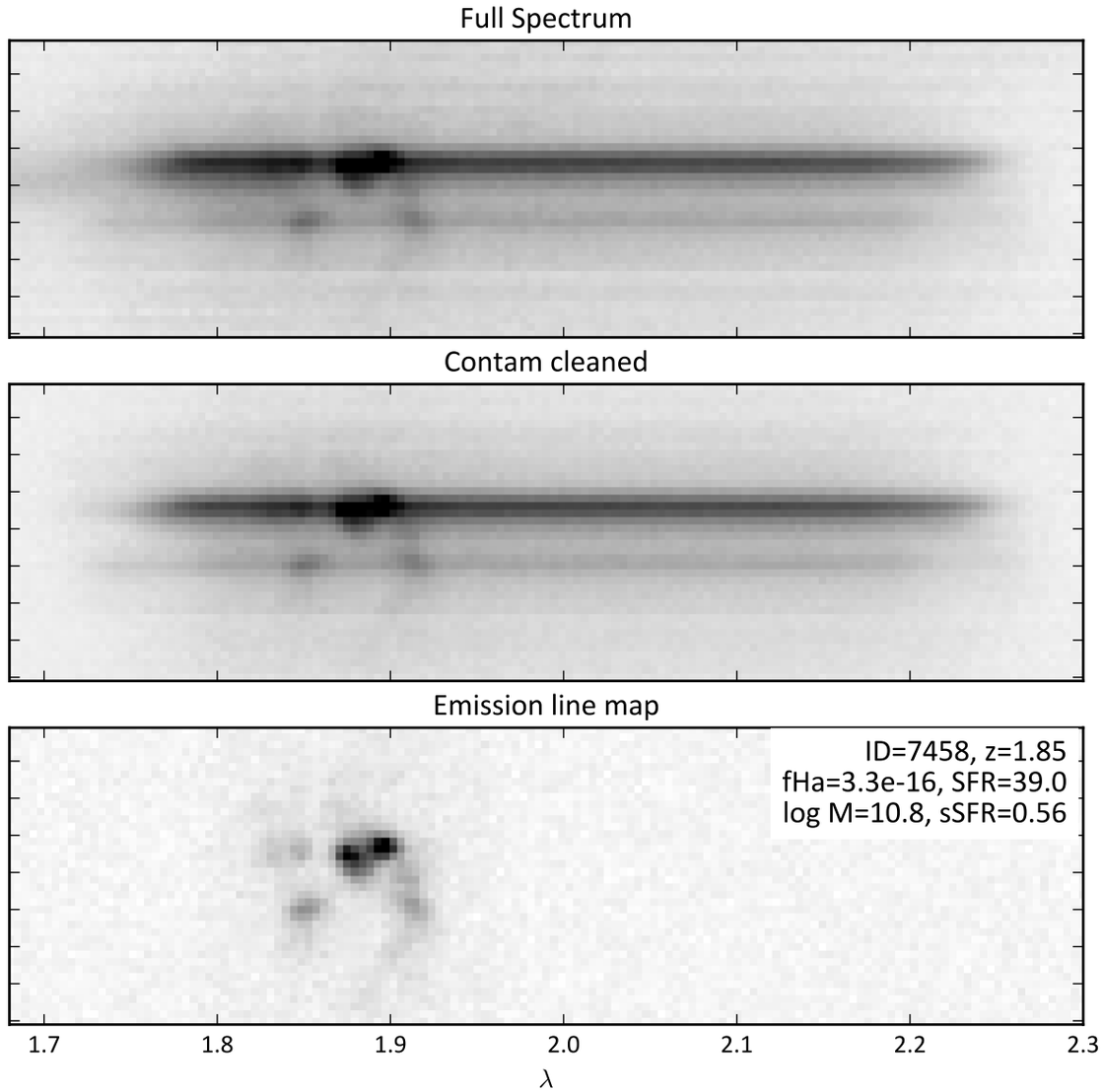

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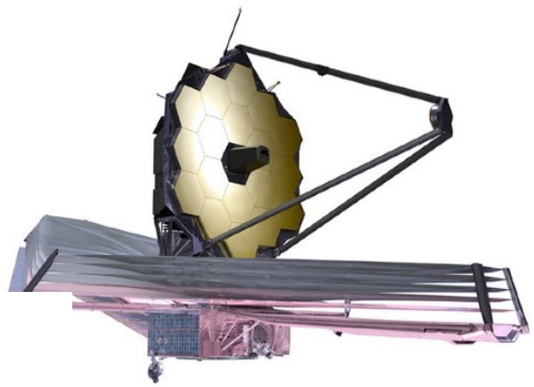
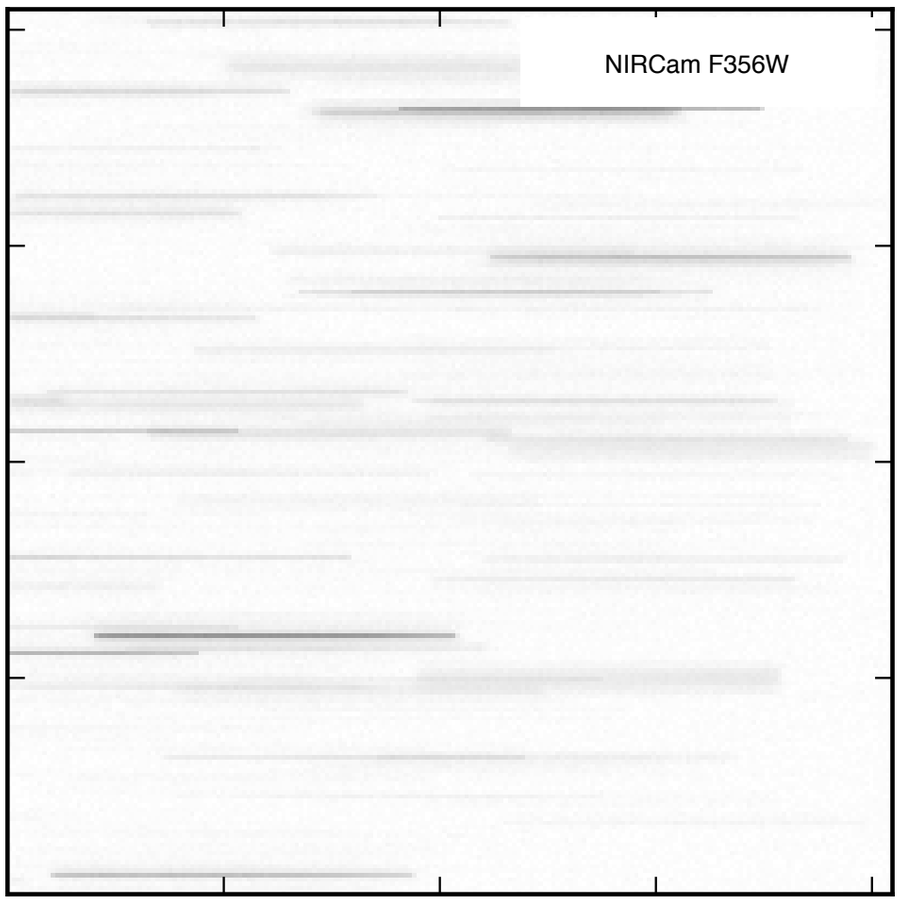
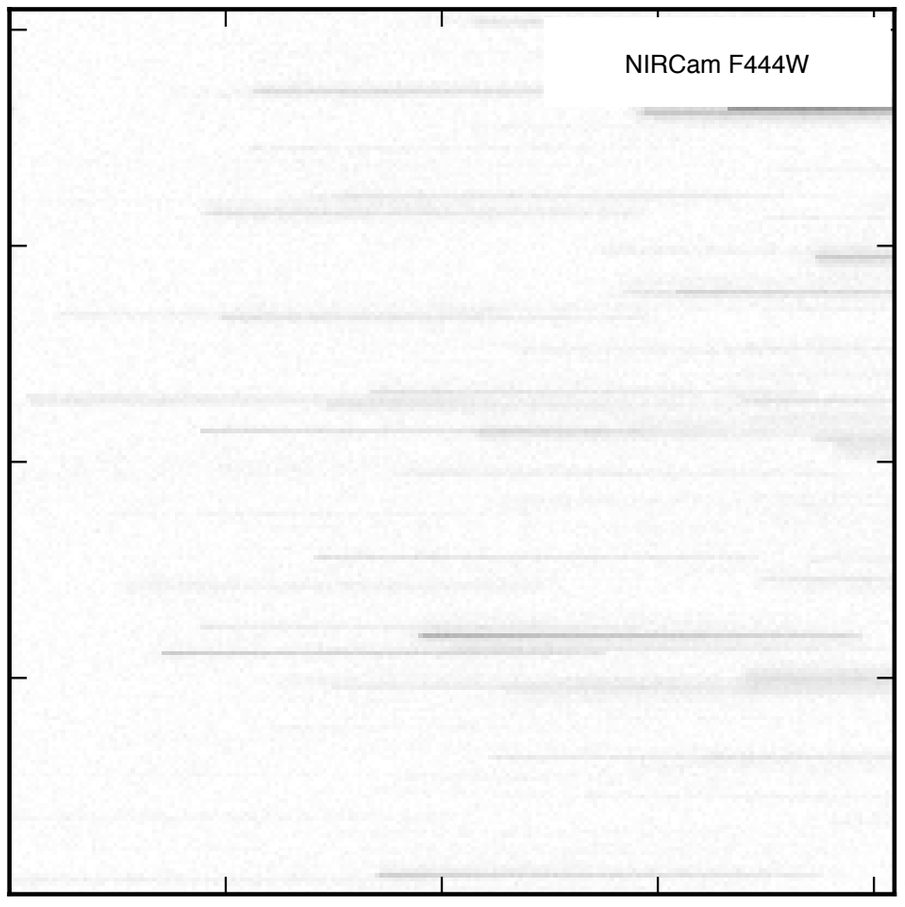
  - Bandpass limiting by crossed filters, **2.4 - 5.0 μm**







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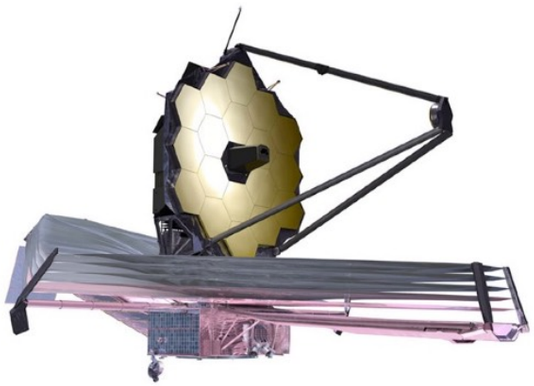
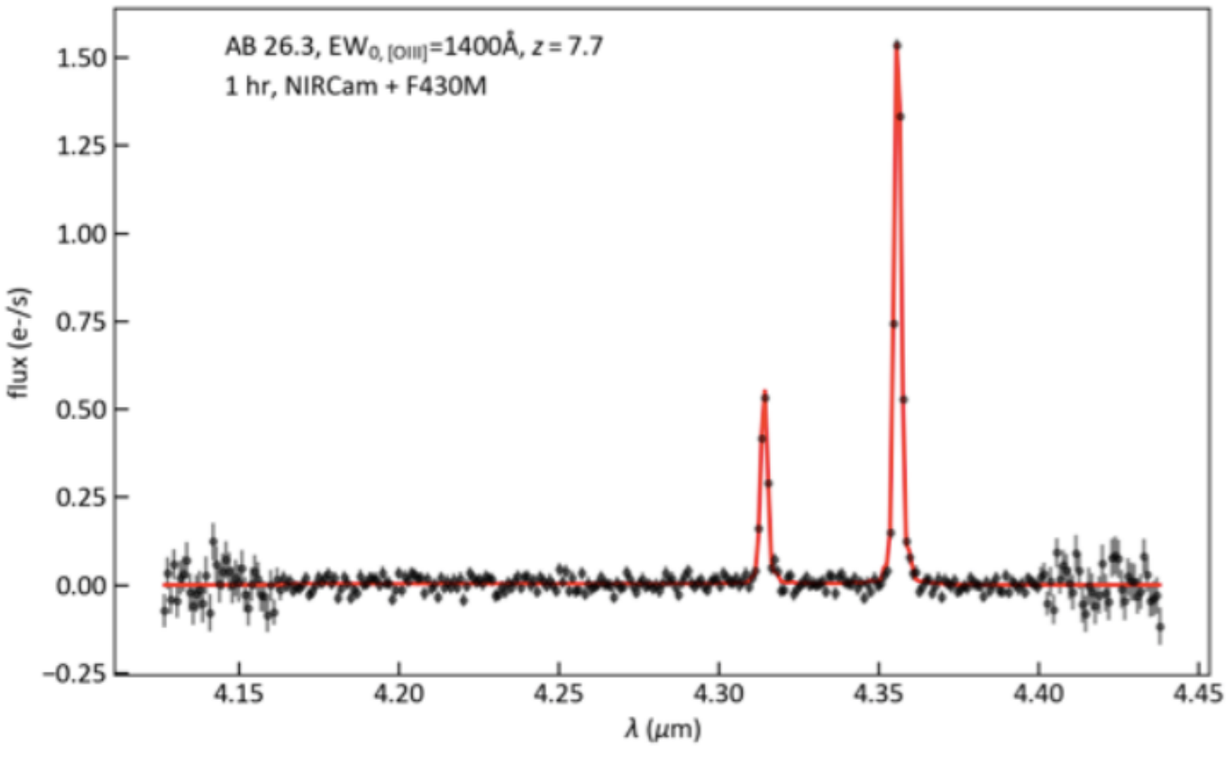
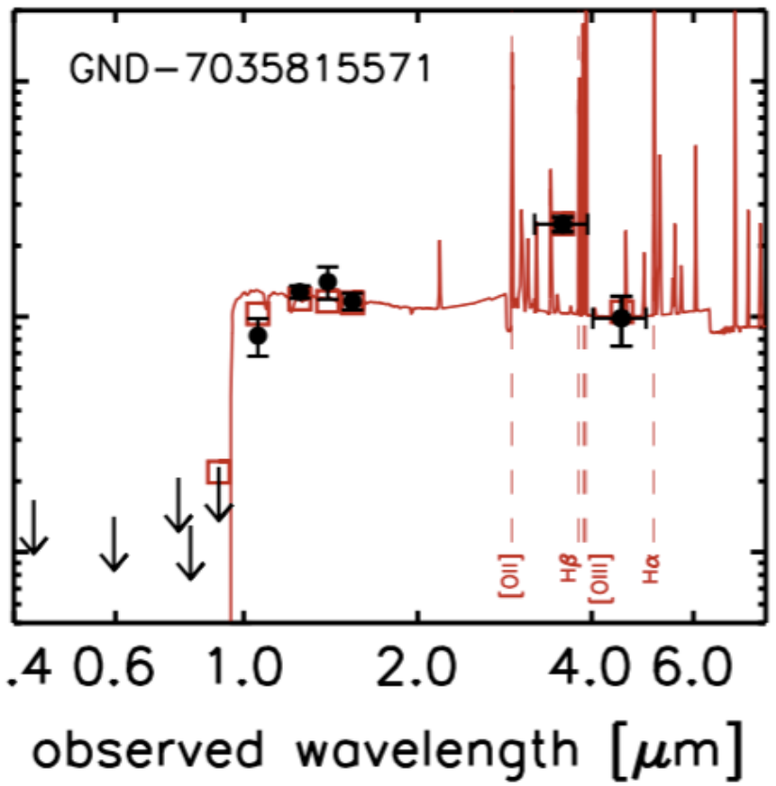




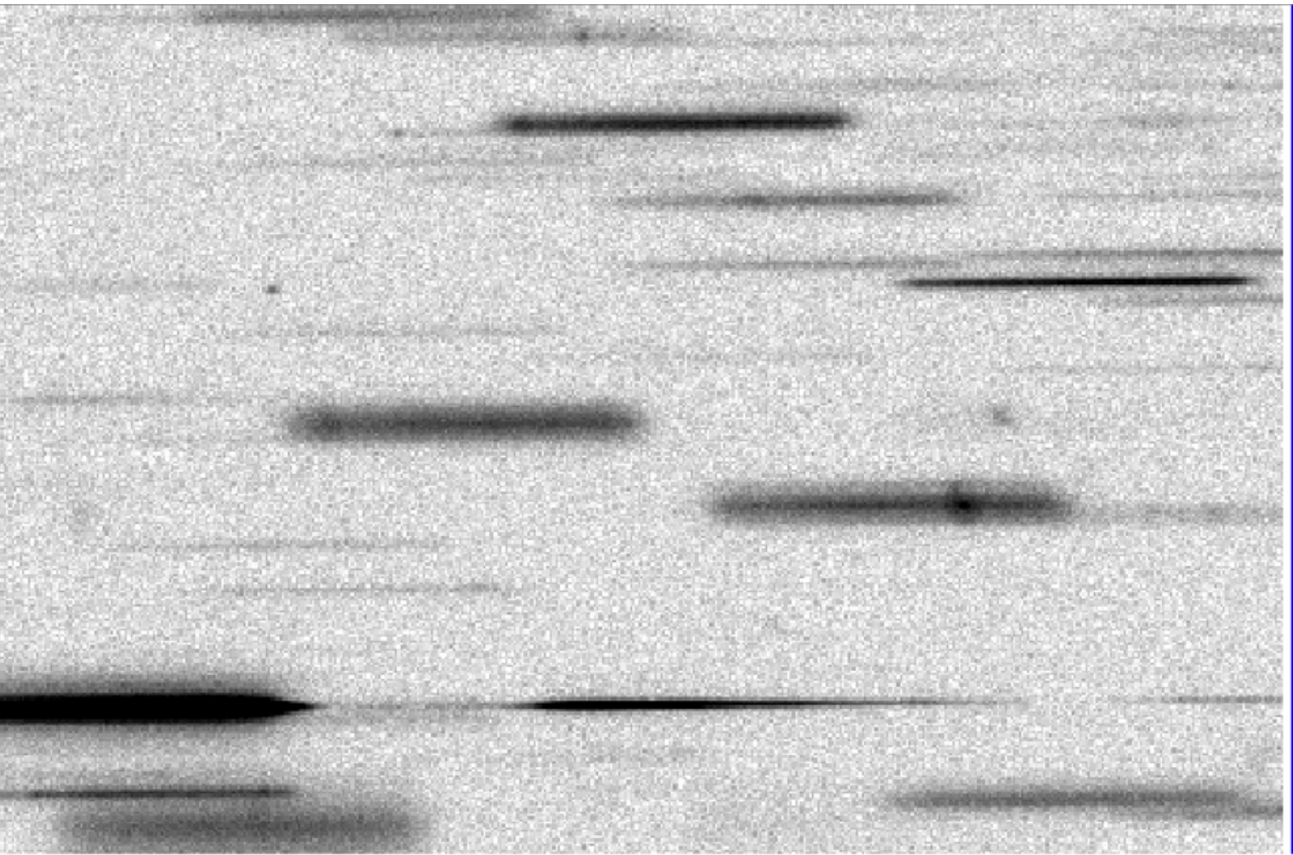
Smit+2015



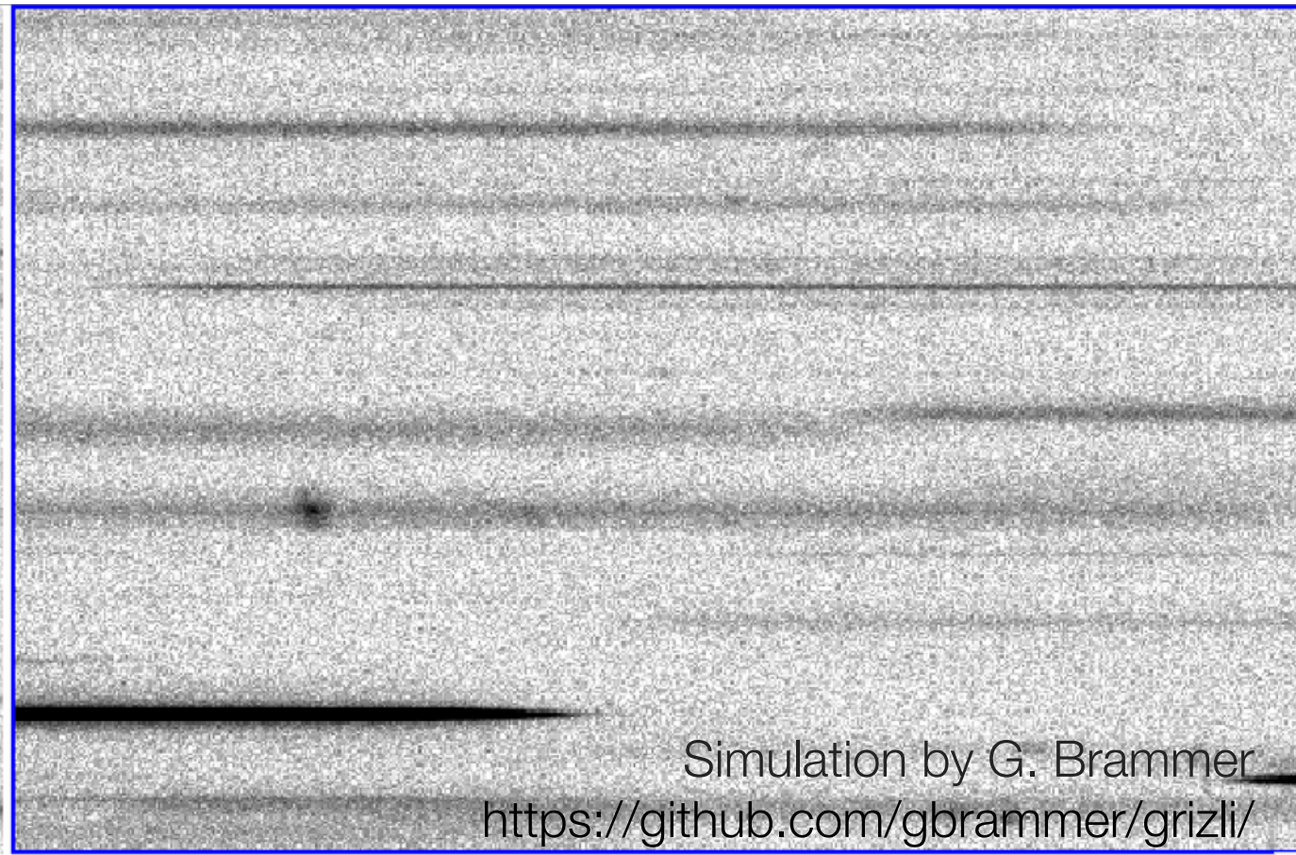
New capabilities with slitless spectroscopy: **WFIRST**

- **WFIRST GRS grism**
  - 0.28 deg^2 at a shot, 2400 deg^2 (!) High Latitude Survey (z for BAO, RSD, public survey)
  - 2.4m telescope (≈HST)
  - 1.3–1.9 μm, R = 4 x G141 (e.g., just resolves Hα, [NII])

WFC3/G141



WFIRST GRS grism



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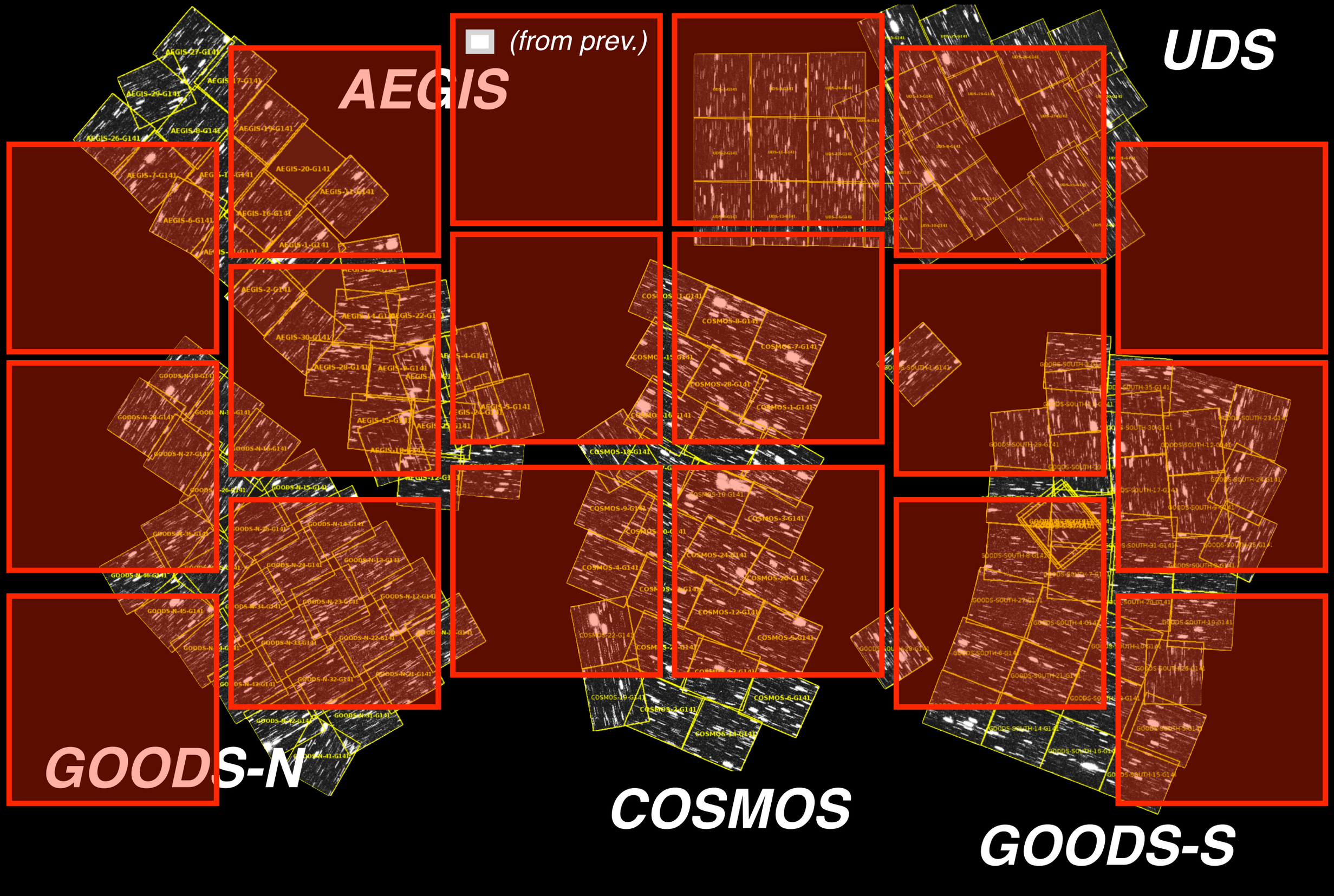
WFIRST: 0.28 deg^2 / pointing, 2400 deg^2 total



New capabilities with slitless spectroscopy

WFC3/IR

Hα
Hβ, [OIII]
[OII]

JWST
NIRISS, NIRCam

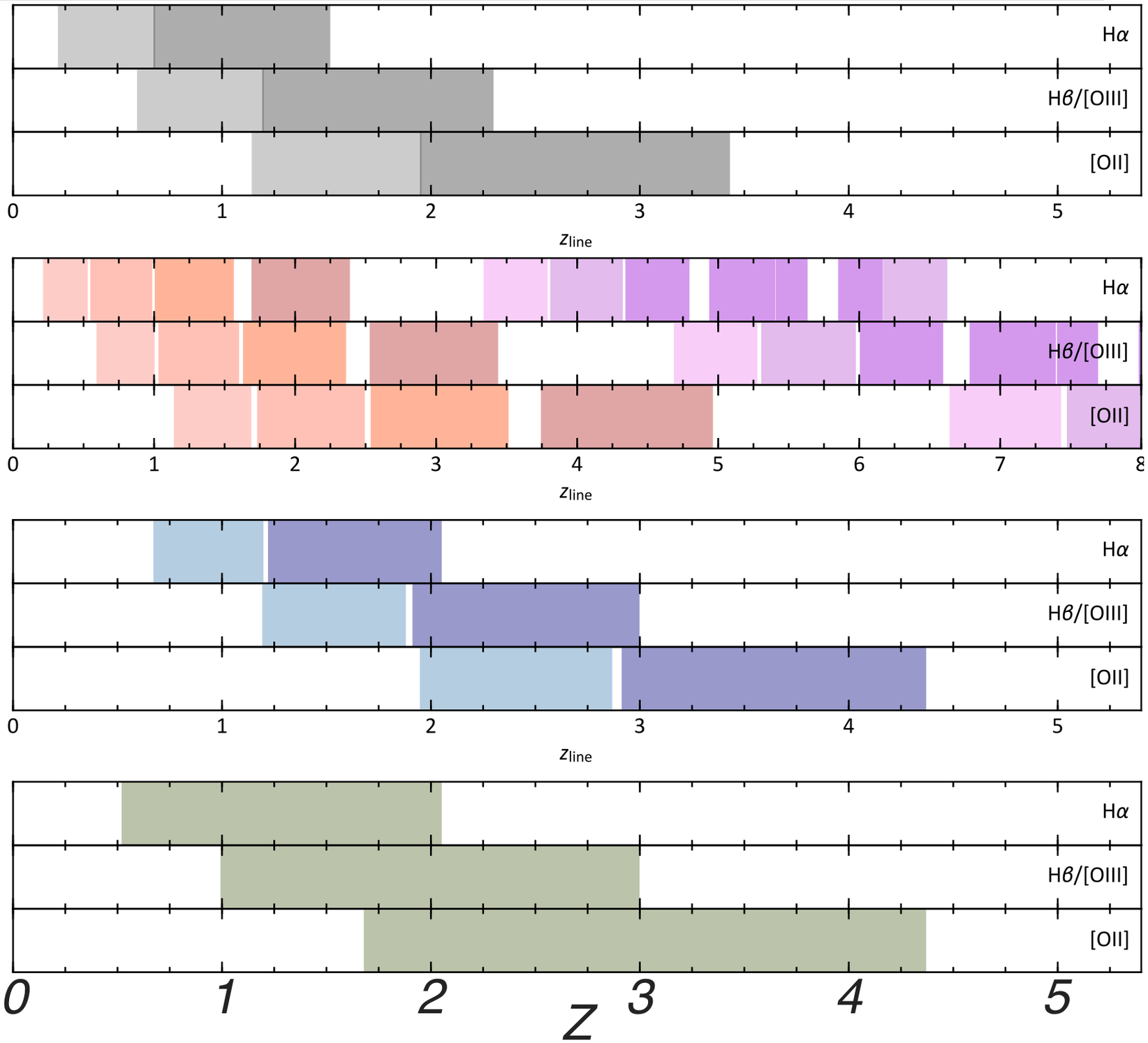
Deep, Hα z>5, [OIII] z>6

Euclid

Shallow, 10^4 deg^2

WFIRST

≈3D-HST, 2K deg^2



Conclusions

- Slitless grism surveys offer highly complete spectroscopic resource for galaxy evolution studies
- Slitless nature of the spectra presents data analysis challenges, but with significant benefits (e.g., continuum depth, completeness, spatial resolution)
- Lessons, science, and targets from current *HST* grism programs will help pave the way for upcoming space missions (JWST, EUCLID, WFIRST)