# Optical and Near-Infrared Spectroscopy with MMT Binospec & MMIRS

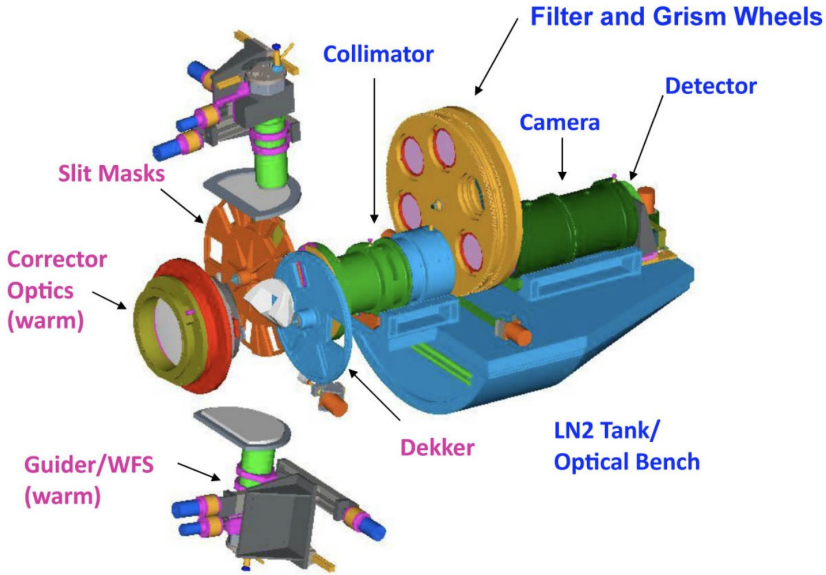
Mengtao Tang

EURECA Nov 22, 2024

Credit: https://www.mmto.org/

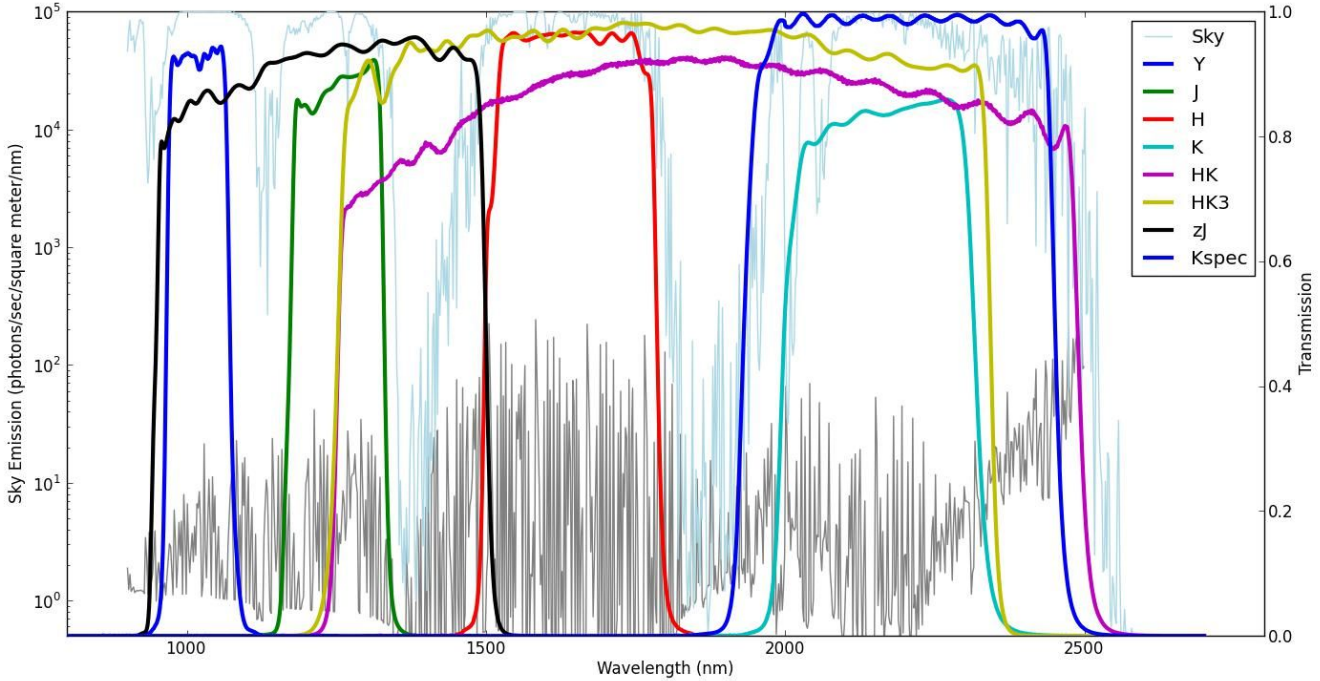
# MMIRS: MMT and Magellan InfraRed Spectrograph

- A near-infrared (0.9 - 2.4 μm) imager and multi-object spectrograph, PI: Brian McLeod at CfA
- https://lweb.cfa.harvard.edu/mmti/mmirs.html
- FoV: 4 arcmin x 6.9 arcmin
- Long-slit spectroscopy
  - Slit size 0.2”, 0.4”, 0.6”, 0.8”, 1.0”, 1.2”, 2.4” x 420”
- Multi-object spectroscopy
  - Slit size: 7” long & >= 0.4” width (I usually use 1” width for point source given the seeing conditions)




Credit: MMIRS Observers Manual

- Grism-filter sets supported by pipeline (resolution in 0.4” width):
  - J-zJ (0.94 - 1.51 μm, R ~ 2400)
  - H3000-H (1.50 - 1.79 μm, R ~ 3000)
  - K3000-Kspec (1.95 - 2.45 μm, R ~ 3000)
  - HK-HK3 (1.25 - 2.34 μm, R ~ 1400)



| Grism Modes | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Grism | Order | Filter | Wavelength range (um) | Spectrum dispersed over (pix) | Resolution (0.4" slit) | Field for complete spectra (arcmin)* | Grism Efficiency over band | Notes |
| Recommended modes fully supported by pipeline | | | | | | | | |
| H3000 (VPH) | 1 | H | 1.50-1.79 | 1000 | 3000 | -1.0 to +1.0(plot) | 80% | This grism gives slightly higher throughput and higher resolution than the original H grism |
| K3000 (VPH) | 1 | Kspec | 1.95-2.45 | 1000 | 3000 | -0.5 to +0.5 (plot) | 80% | This grism gives significantly higher throughput over the full K-band than does the HK grism. |
| HK | 1 | HK3 | 1.25-2.34 | 1800 | 1400 | -0.5 to +0.5 (plot) | 70% | Though offering both H and K simultaneously, the significantly lower throughput at K, and the lower resolution at H both compromise signal to noise. S/N in H-band for faint sources is dominated by the presence of OH lines. The higher the resolution, the larger the fraction of the spectrum that is uncontaminated by OH. Consider the H3000 and K3000 grisms instead. |
| J | 1 | zJ | 0.94-1.51 | 2600 | 2400 | n/a (plot) | 50% | |
| Unsupported modes | | | | | | | | |
| HK | 1 | HK | 1.25-2.45 | 1800 | 1400 | -0.5 to +0.5 (plot) | 70% | Use this grism+filter combination only if you need to go out to 2.45 microns. Consider the H3000 and K3000 grisms instead. |
| HK | 1 | K | 1.98-2.32 | 550 | 1700 | -2.0 to +1.2 (plot) | 70% | |
| HK | 1 | H | 1.50-1.79 | 450 | 1300 | -1.7 to +2.0 (plot) | 80% | |
| HK | 2 | Y | 0.96-1.07 | 360 | 1600 | -2.0 to +2.0 (plot) | 60% | |
| HK | 1+2 | zJ | 0.95-1.5 | var | 800,1600 | n/a (plot1, plot2) | var | |
| J | 1 | J | 1.17-1.33 | 720 | 2800 | -2.0 to +2.0 (plot) | 65% | This filter has lower throughput than zJ, but since the bandpass is restricted to the high throughput part of the J grism curve, it appears higher. |
| J | 1 | Y | 0.96-1.07 | 520 | 2400 | -0.5 to +2.0 (plot) | 33% | - |
| H | 1 | H | 1.50-1.79 | 800 | 2400 | -1.0 to +2.0 (plot) | 75% | |
| H | 2 | Y | 0.96-1.07 | 670 | 3000 | -2.0 to -0.3 | 40% | |

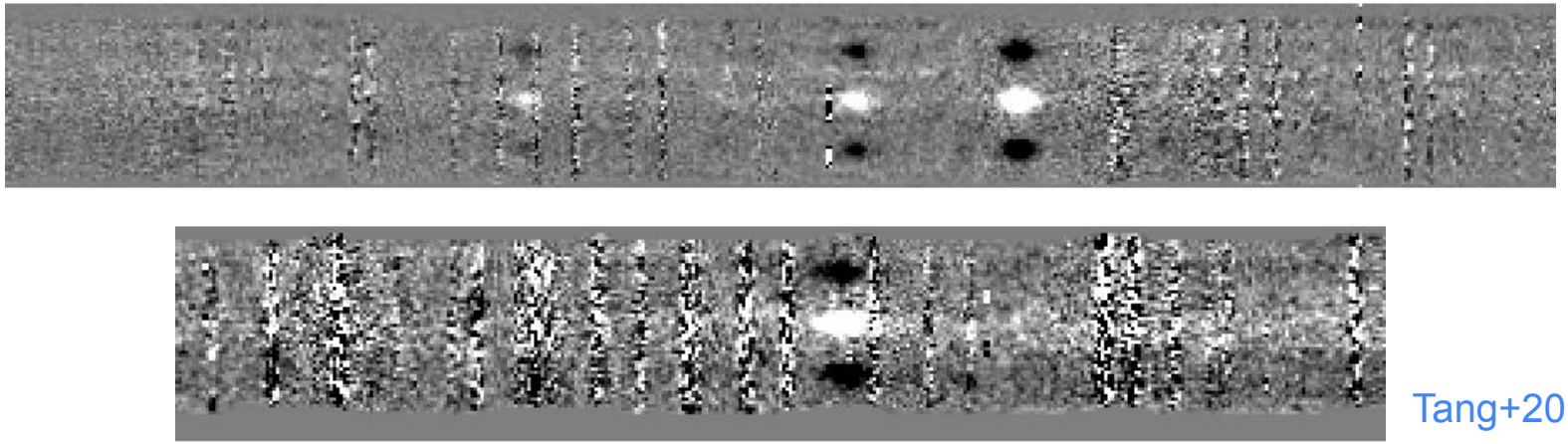
# MMIRS Observation and Data Reduction

- MMIRS mask design software: https://scheduler.mmto.arizona.edu/MMIRSMask/
- Queue observation: prioritize targets into three categories (1 = highest, 3 = lowest)
- Data reduction run by SAO with auto pipeline
- Or run your own reduction: data reduction pipeline (IDL based) available at https://bitbucket.org/chil_sai/mmirs-pipeline/, by Igor Chilingarian at CfA
- A Python based data reduction pipeline PypeIt: https://pypeit.readthedocs.io/

# Science with MMIRS

- Rest-frame optical spectra of galaxies at Cosmic Noon

Hβ, [OIII] (J-zJ), and Hα (H3000-H) of a star-forming galaxy at z = 1.52



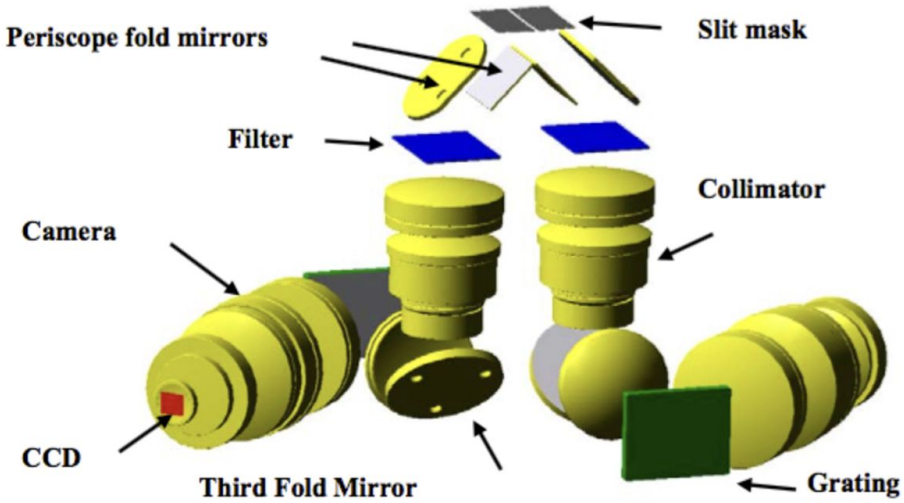
Tang+2019

# Science with MMIRS

- Rest-frame optical spectra of galaxies at Cosmic Noon
- Full suite of rest-optical emission lines ([OII], [NeIII], Hγ, Hβ, [OIII], Hα, [NII], [SII]) at z ~ 2:
  - Ionizing source (star formation vs. AGN; [OIII]/Hβ vs. [NII]/Hα or [OIII]/Hβ vs. [SII]/Hα BPT diagram)
  - Gas properties (metallicity; ionization parameter; [OIII]/[OII], [NeIII]/[OII])
  - Dust attenuation via Balmer decrement (Hα/Hβ)
  - Outflows (broad optical lines)

# Binospec

- An optical spectrograph, PI: Daniel Fabricant at SAO
- https://lweb.cfa.harvard.edu/mmti/binospec.html
- Large FoV: two 8 arcmin x 15 arcmin masks (gap 3.2 arcmin)
- Long-slit spectroscopy:
  - Slit width 0.75”, 1.0”, 1.25”, 1.5”, and 5”
- Multi-object spectroscopy:
  - Can place up to ~ 100 - 150 slits per mask



# Binospec Spectroscopy Mode

- Three gratings (resolution in 1” width):
  - 270 lines/mm (3900 - 9240 A, R ~ 1340)
  - 600 lines/mm (4500 - 6960, 6000 - 8480, 7255 - 9750 A, R ~ 2740 - 4360)
  - 1000 lines/mm (3900 - 5400 A, R ~ 3900)

| Grating lines/mm | Order | Blaze angle | Angle of incidence | Anamorph Demag. | Coverage (A) | Dispersion (A/pixel) | Pixels per 1'' slit | Resolution in 1'' slit |
|---|---|---|---|---|---|---|---|---|
| 270 | 1 | 5.5 | 28.0 | 1.08 | 3900-9240 | 1.30 | 3.75 | 1340 |
| 600 | 1 | 16.0 | 33.2 | 1.17 | 4500-6960 | 0.60 | 3.47 | 2740 |
| 600 | 1 | 16.0 | 36.1 | 1.22 | 6000-8480 | 0.61 | 3.32 | 3590 |
| 600 | 1 | 16.0 | 38.5 | 1.27 | 7255-9750 | 0.61 | 3.20 | 4360 |
| 1000 | 1 | 13.75 | 37.1 | 1.24 | 3900-5400 | 0.36 | 3.27 | 3900 |

| Grating lines/mm | Allowable central wavelengths |
|---|---|
| 270 | 5501 - 7838 A (approx 6560 A for full wavelength coverage) |
| 600 | 5146 - 8783 A |
| 1000 | 4108-4683, 5181-7273, 7363-7967, 8153-8772, 8897-9279 |
| | Ghosts may be troublesome with 1000 gpm grating at central wavelengths 5600-8500 A, worst near 7100 A.<br>Throughput of 1000 gpm grating will be low in the red. |

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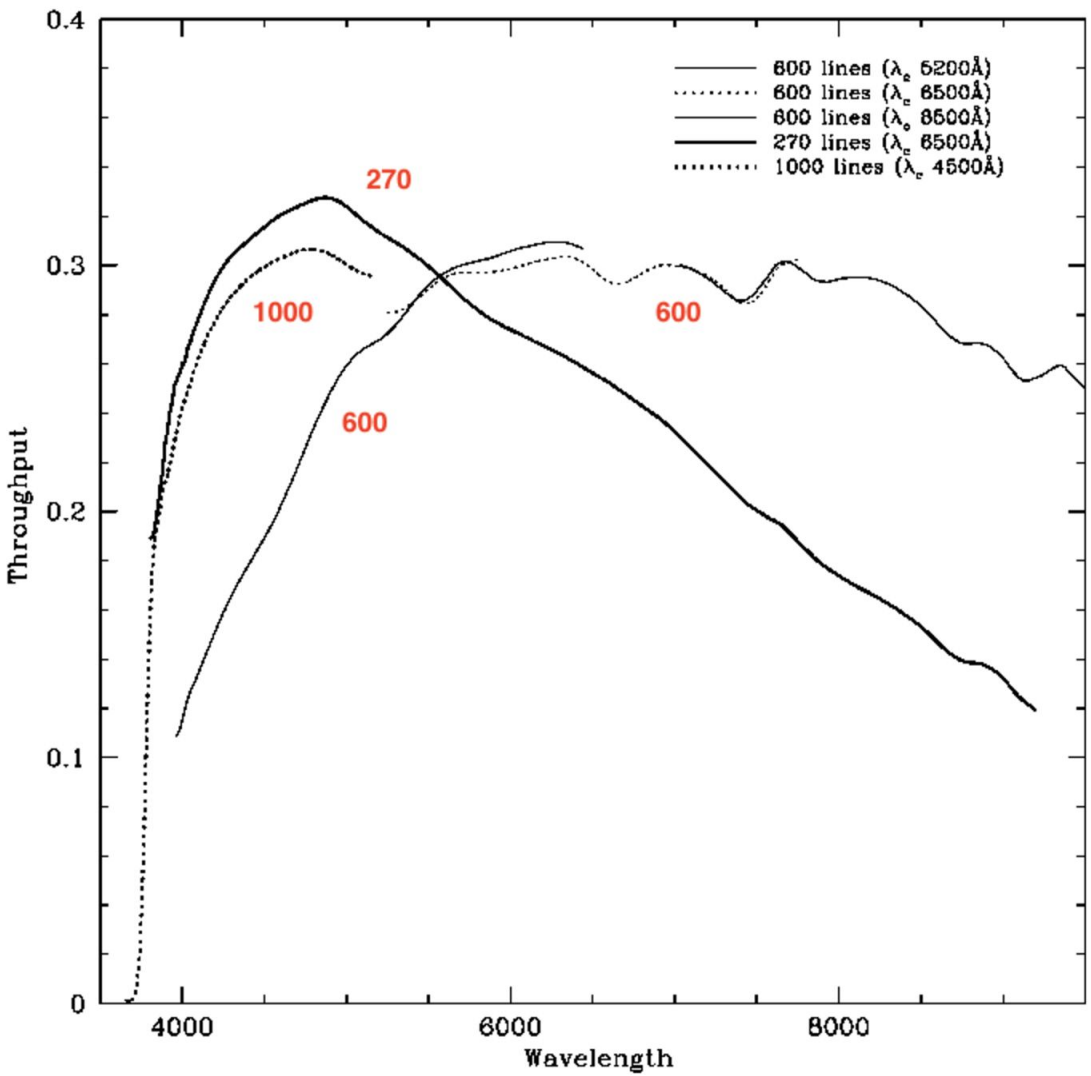
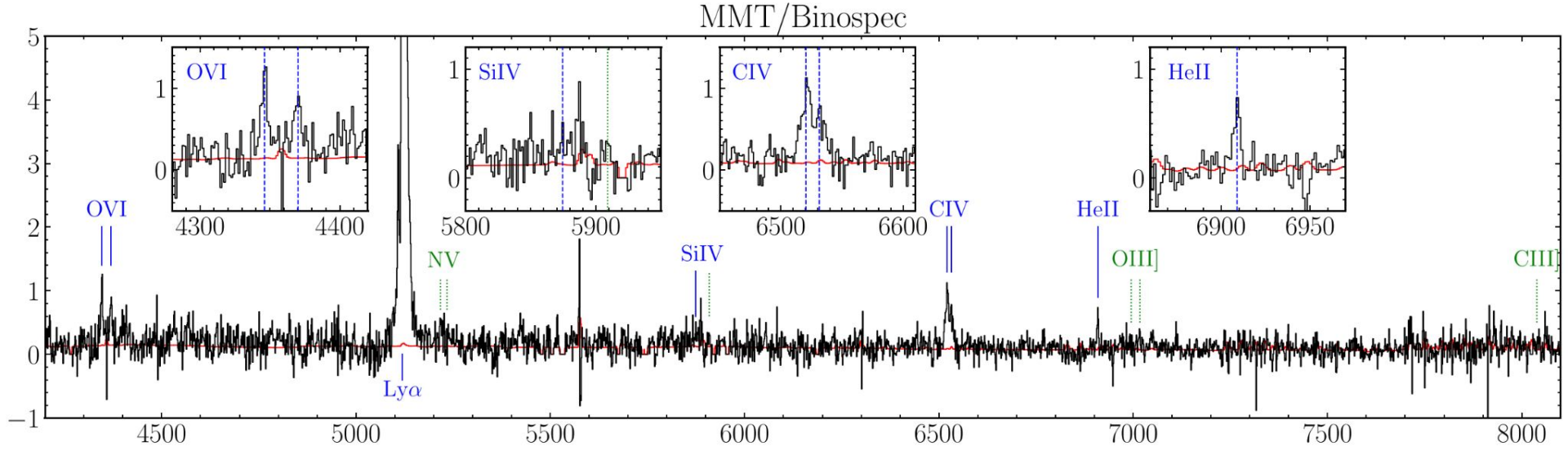


# Binospec Observation and Data Reduction

- Mask design software: https://scheduler.mmto.arizona.edu/BinoMask/
- Queue observing mode
- Data will be reduced by SAO after observation
- Data reduction pipeline: https://bitbucket.org/chil_sai/binospec/

# Science with Binospec

- Optical spectroscopy of z ~ 0 galaxies
- Rest-frame UV spectroscopy of z ~ 2 - 4 galaxies

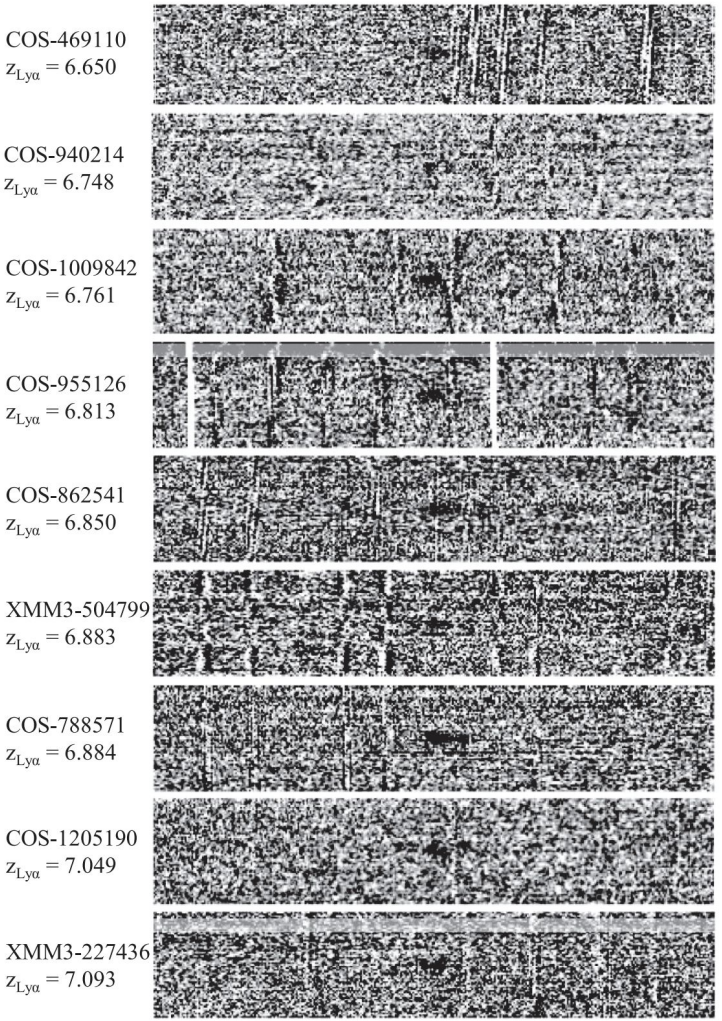



An AGN at z = 3.2

Tang+2022

# Science with Binospec

- Optical spectroscopy of z ~ 0 galaxies
- Rest-frame UV spectroscopy of z ~ 2 - 4 galaxies
- Lyα spectroscopy of z ~ 2 - 7 galaxies




Lyα emitters at z ~ 7

Endsley+2021