

Search for Broad H α Emitters
in the nearby universe ($z < 1$) with Subaru PFS

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bHAEs

Discovered by JWST in the $z \sim 5$ universe
Emits **broad** hydrogen **Balmer** series lines
(FWHM > 1000 km/s) (H α : 6560Å, H β : 4860Å, ...)

→ bHAEs = AGN?

bHAEs lack many AGN signatures

- No MIR emission from dust torus
- Faint in X-ray
- No other broad lines (CIV, MgII, HeII)
- No luminosity variability

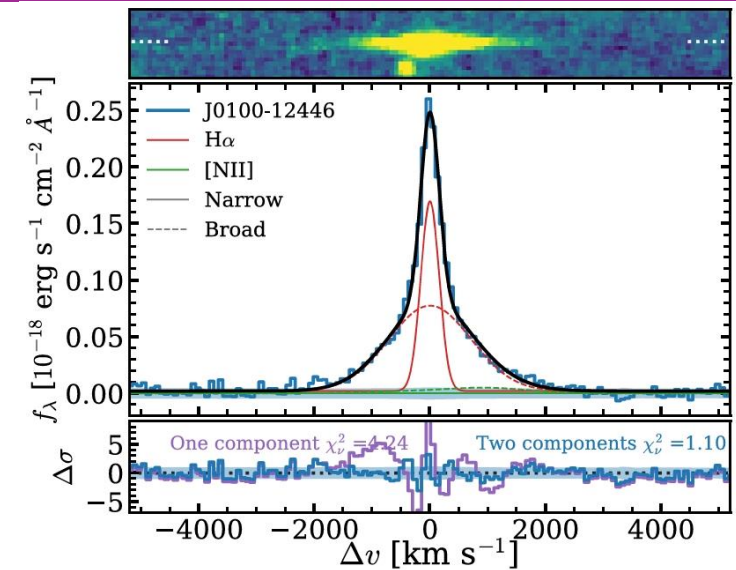
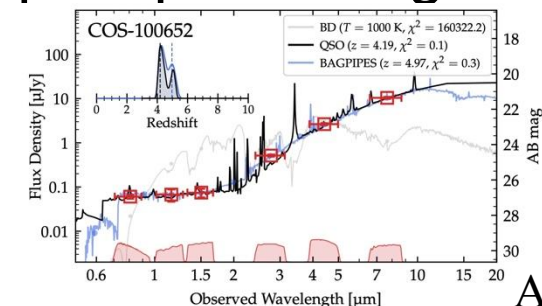
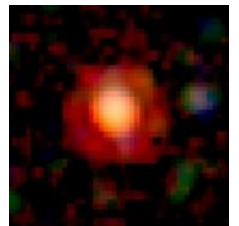


Fig: Broad H α emission line of bHAEs
(Matthee et al. 2024)

Little Red Dots (LRDs)

10–20% of bHAEs

Unique spectral signature



No systematic investigation

→ Number density of bHAEs is unknown in the nearby universe ($z < 1$)

Problem:
Could the high density of bHAEs also hold in the nearby universe?

Previous observations:

Optical only, low spectral resolution ($R < 1000$)

PFS observations:

Optical+NIR, high spectral resolution ($R \sim 3000$), high S/N,
Systematic spectroscopy possible (2400 fibers)

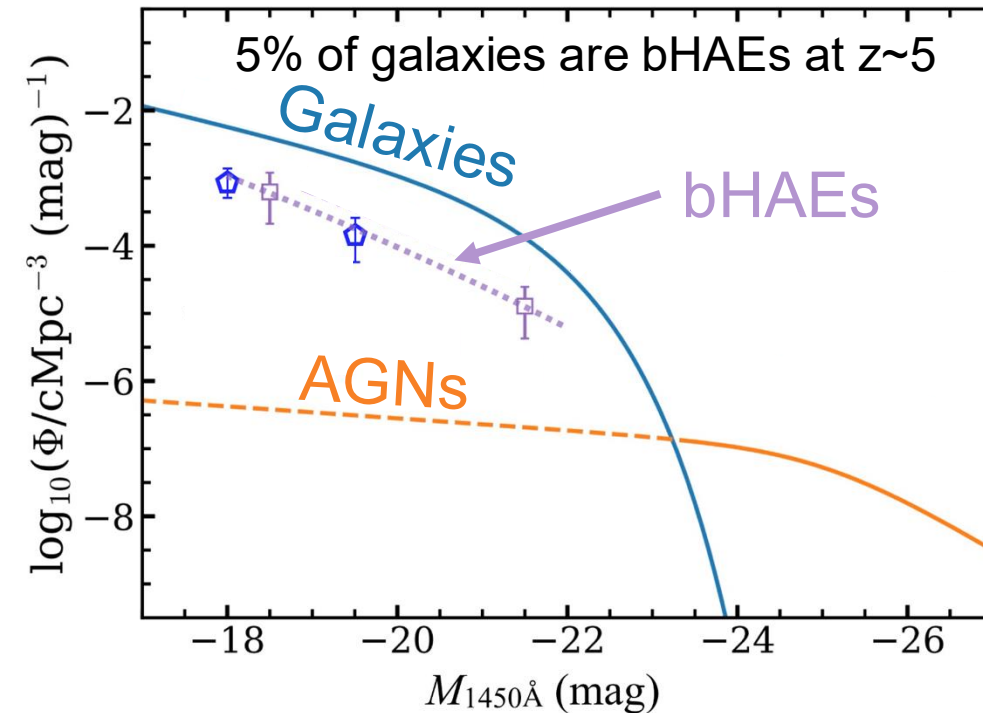


Fig: LF of galaxies, bHAEs, AGNs at $z \sim 5$
(Matthee et al. 2024)

Determine the Luminosity Function (LF) of bHAEs in the nearby universe ($z < 1$)

Assumed that 5% of galaxies are bHAEs

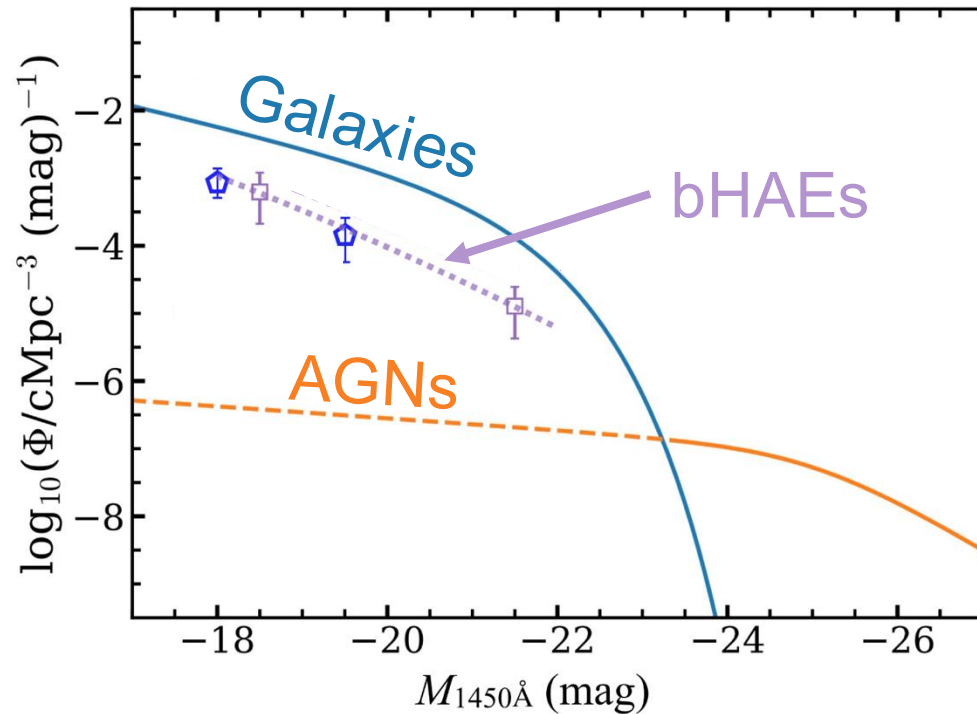


Fig: LF of galaxies, bHAEs, AGNs at $z \sim 5$ (Matthee et al., 2024)

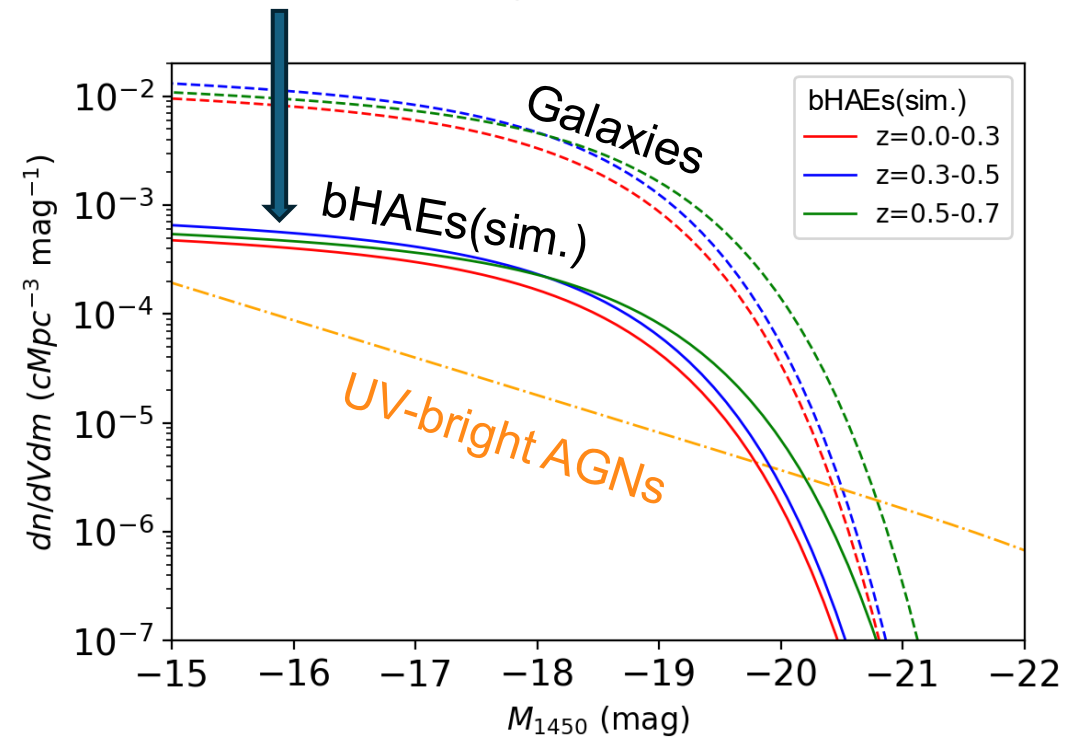


Fig: LF of galaxies, bHAEs(sim.), AGNs at $z < 1$

Target selection

Subaru/PFS OpenUse S25A-099

Observation region: COSMOS

- Observed multiple wavelengths
from radio to X-ray

Target selections criteria:

- Identified as galaxies
- X-ray non-detection
- Redshift $z = 0 - 0.7$
- Magnitude $I_{AB} (6870-9220\text{\AA}) < 22.5 \text{ mag}$

About 15,000 objects were observed (80% complete).

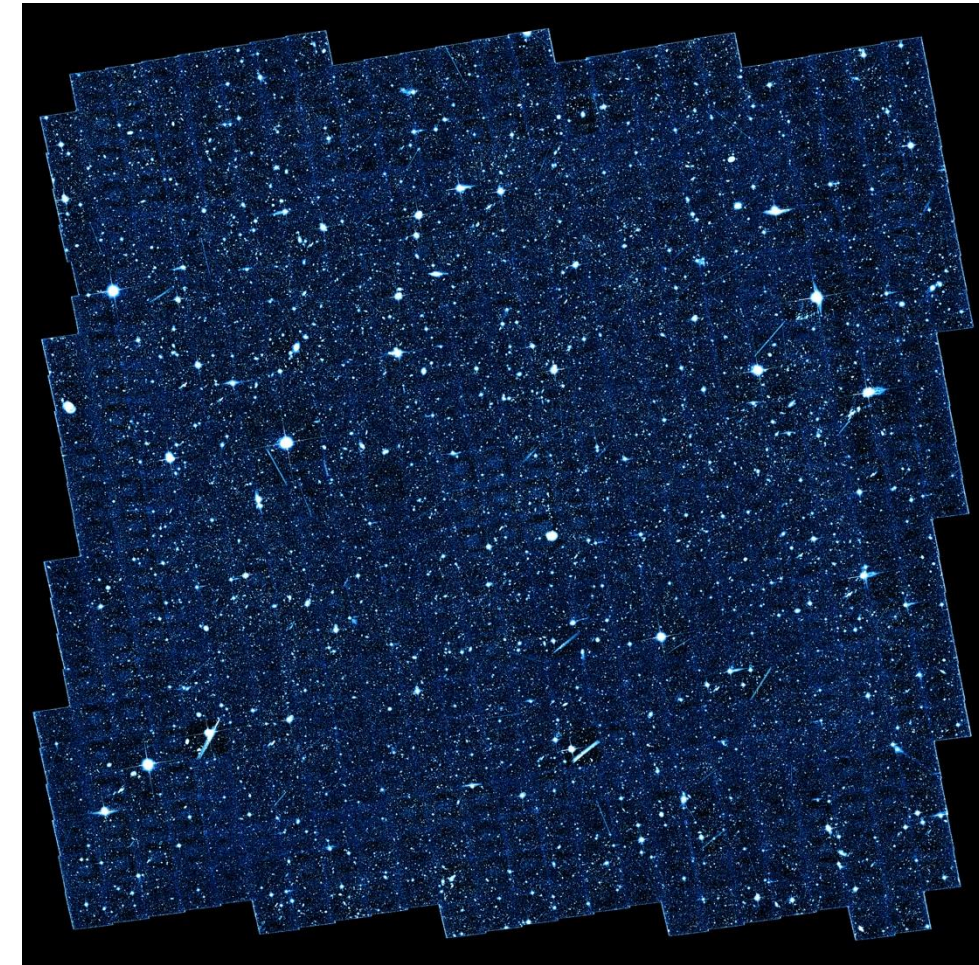
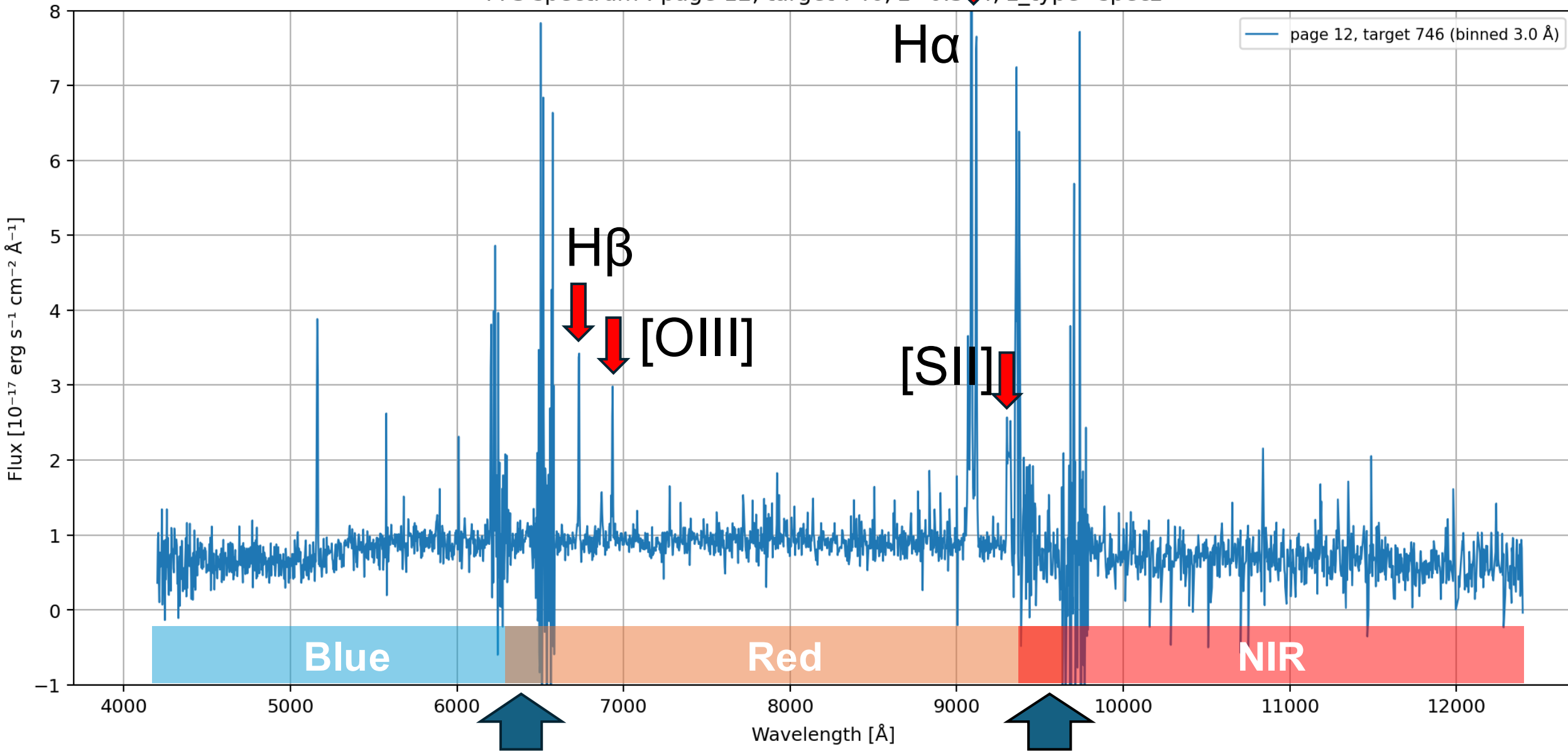


Fig: Image of the COSMOS (HST/ACS)

PFS Spectrum

PFS spectrum : page 12, target 746, z=0.34, z_type=spezc



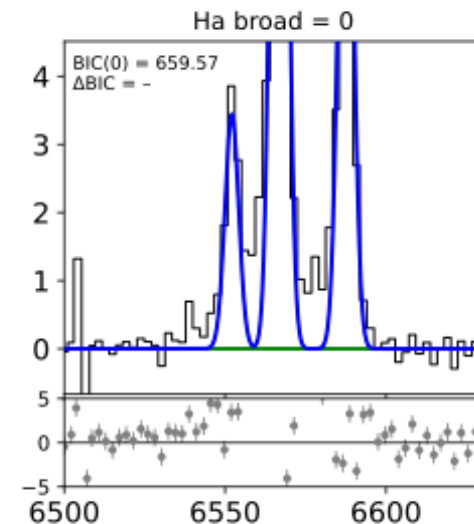
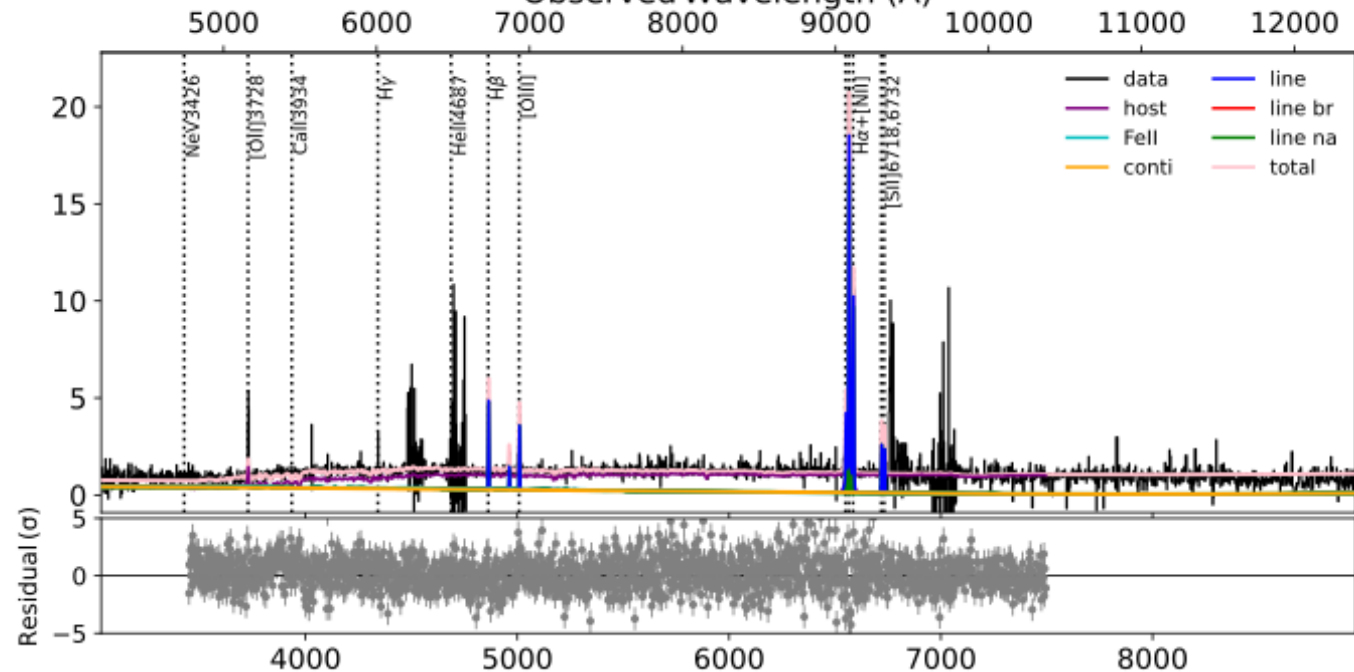
Fitting result



(Guo et al., 2018,
<https://github.com/legolason/PyQSOFit>)

page 12, target 746, z=0.38400

Observed Wavelength (Å)



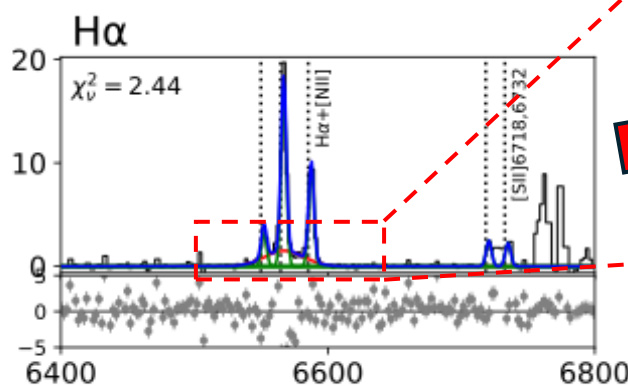
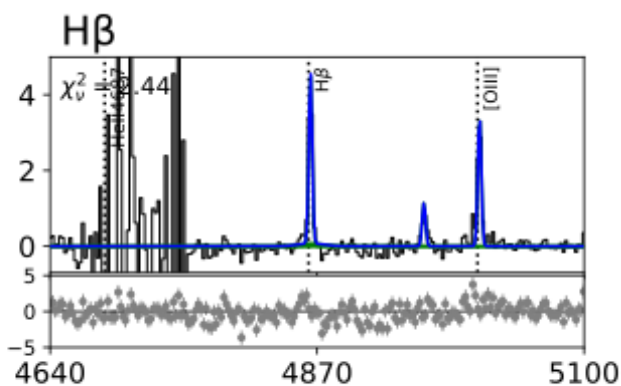
BIC=660

Δ BIC=268

Statistically significant

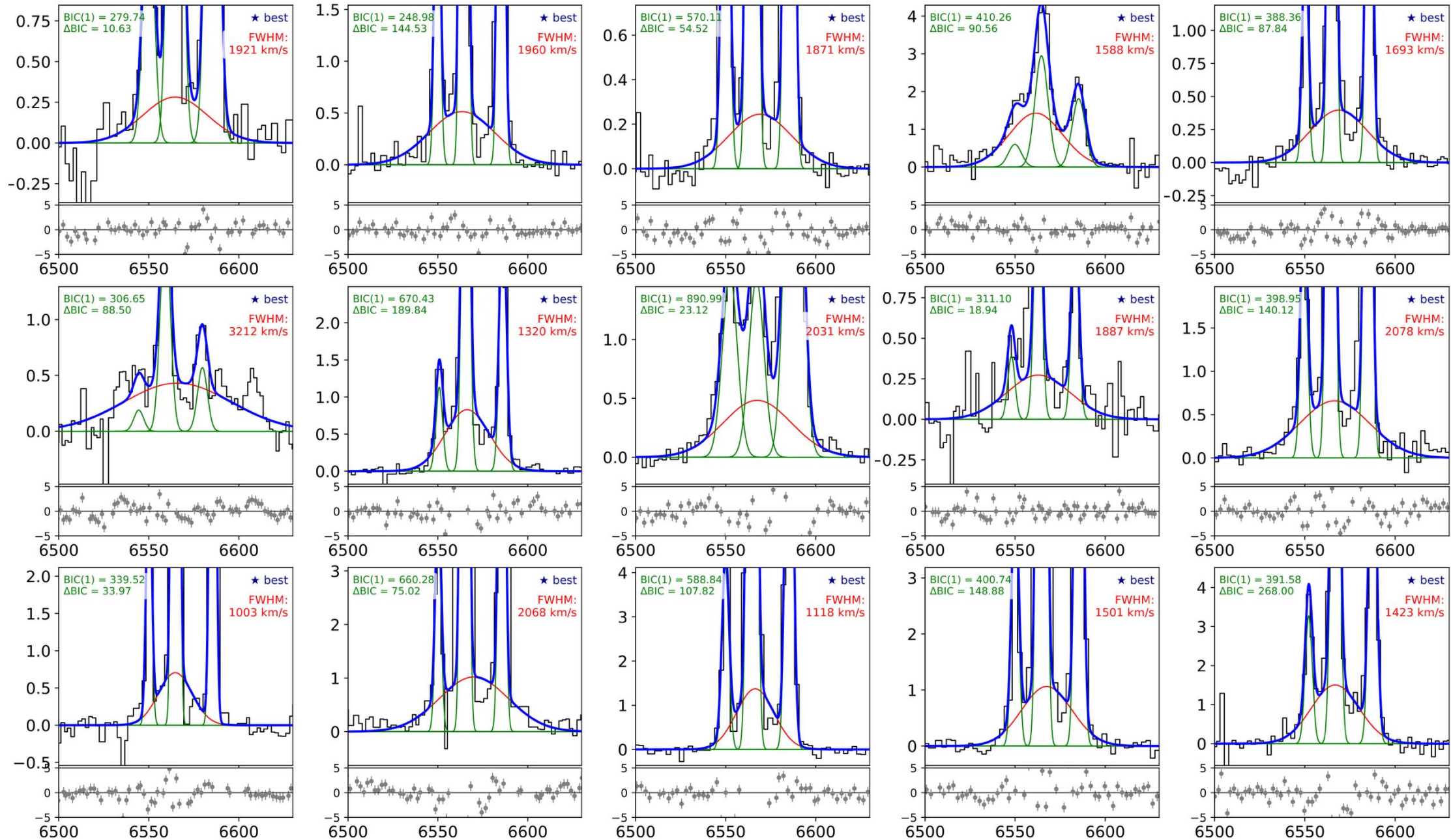
BIC=392

f_{λ} [10^{-17} erg s $^{-1}$ cm $^{-2}$ Å $^{-1}$]



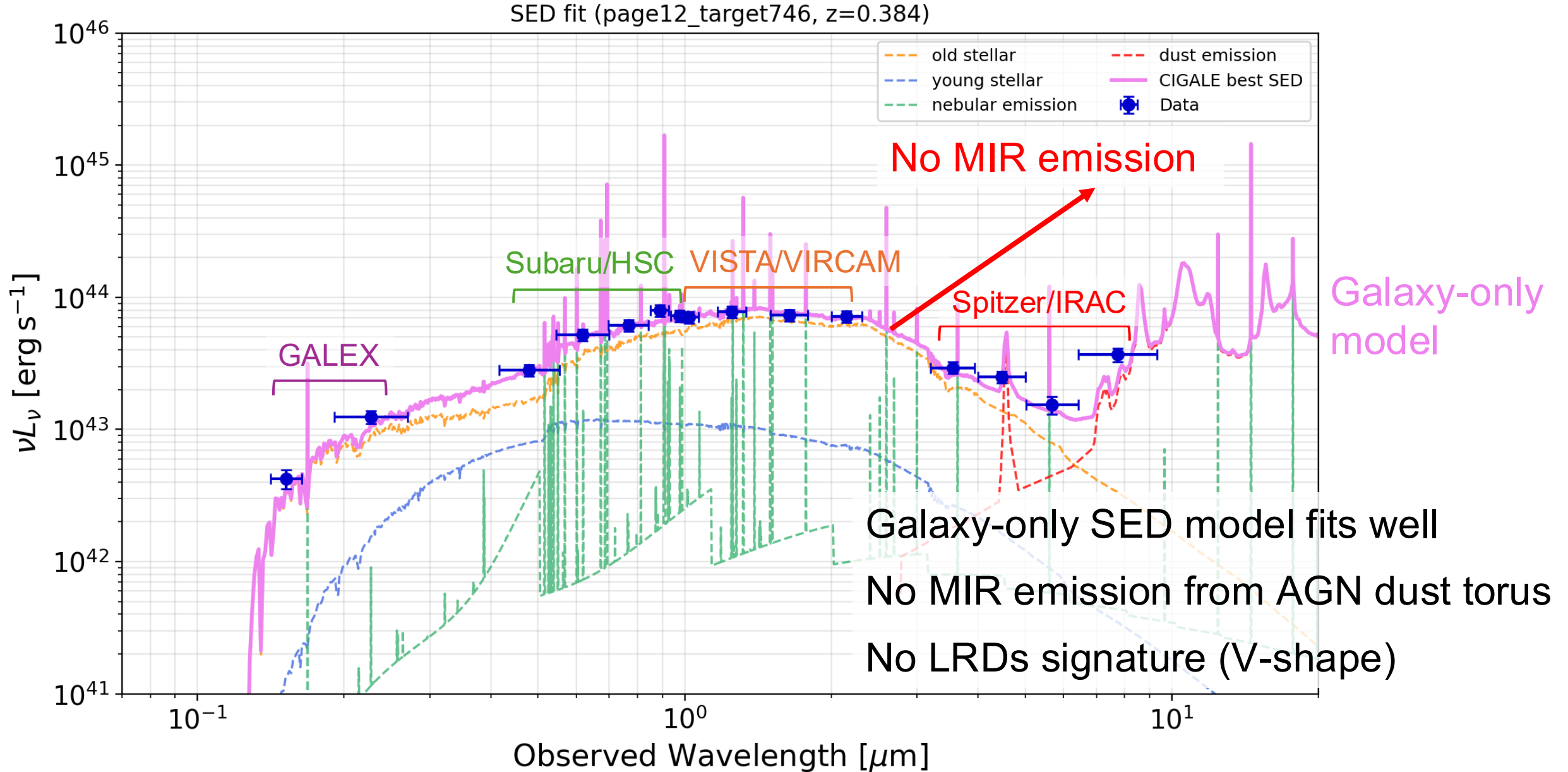
Rest wavelength [Å]

f_λ [10^{-17} erg s $^{-1}$ cm $^{-2}$ Å $^{-1}$]

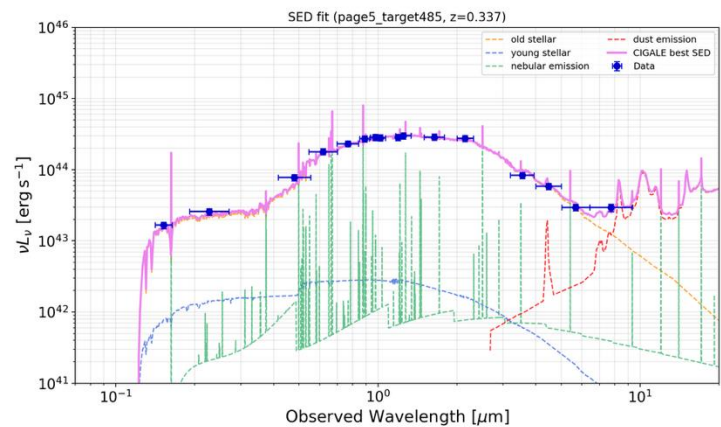
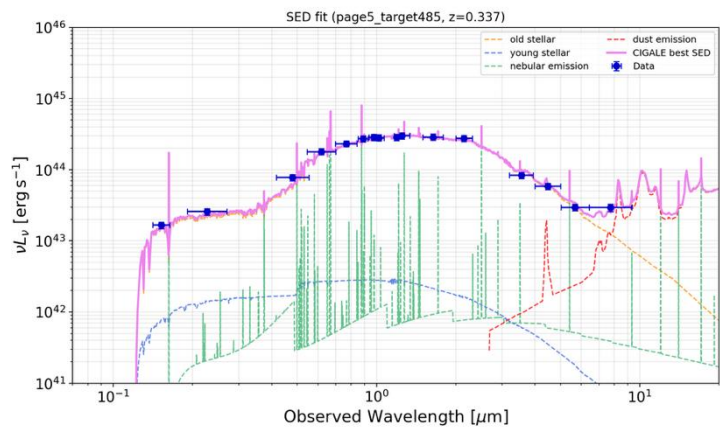
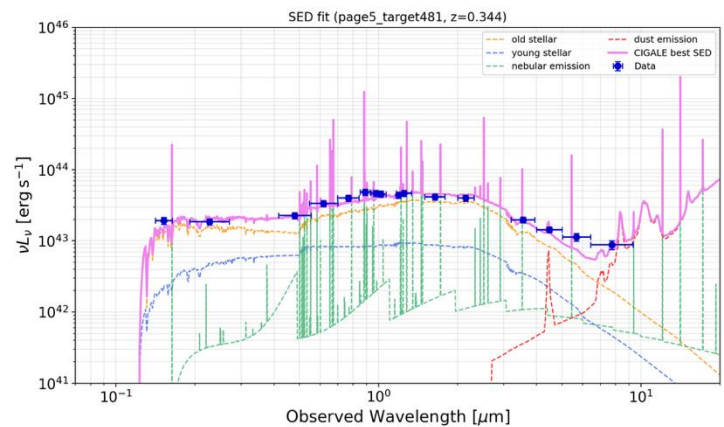
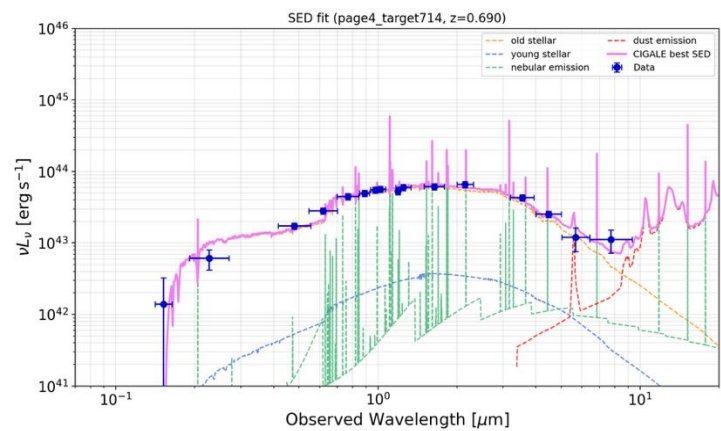
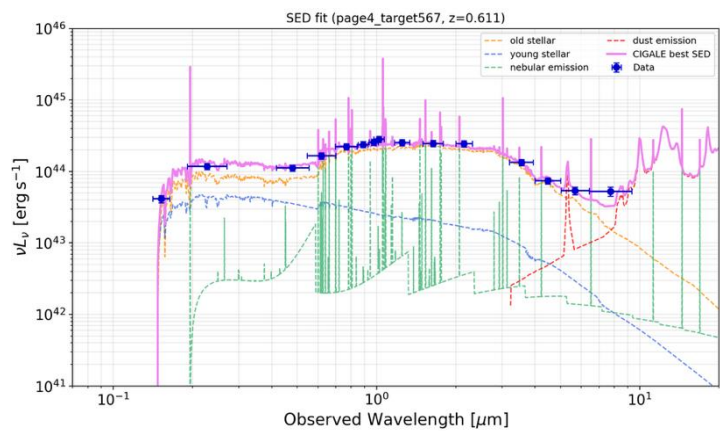
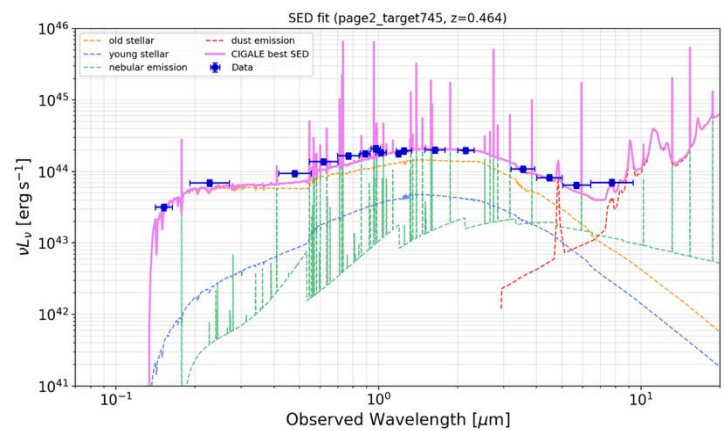
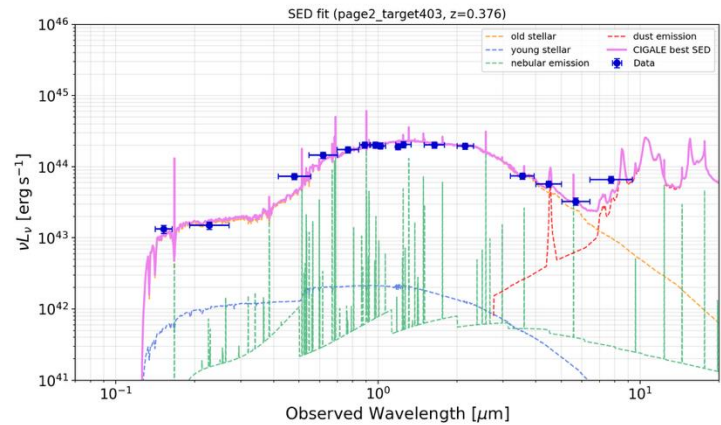
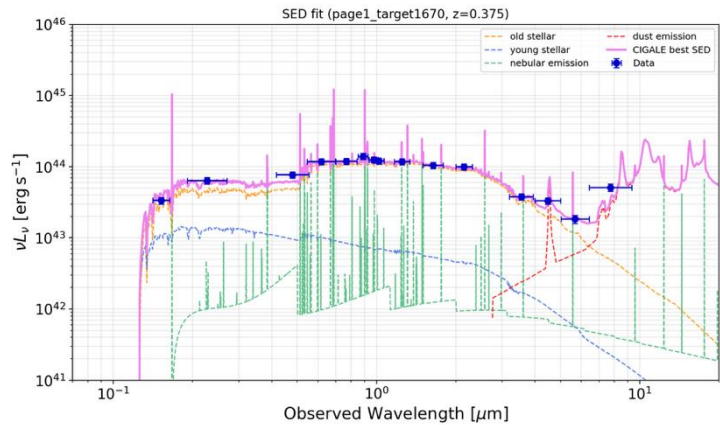
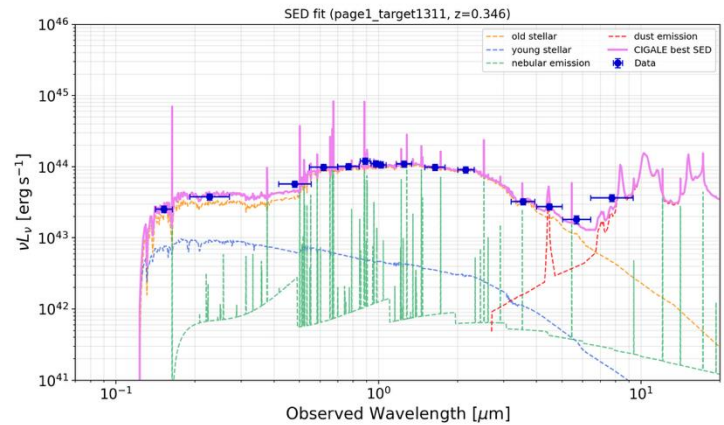


Rest wavelength [Å]

Check the SED

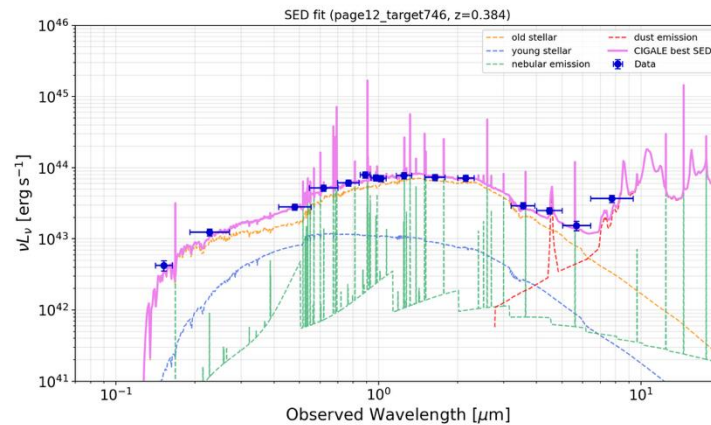
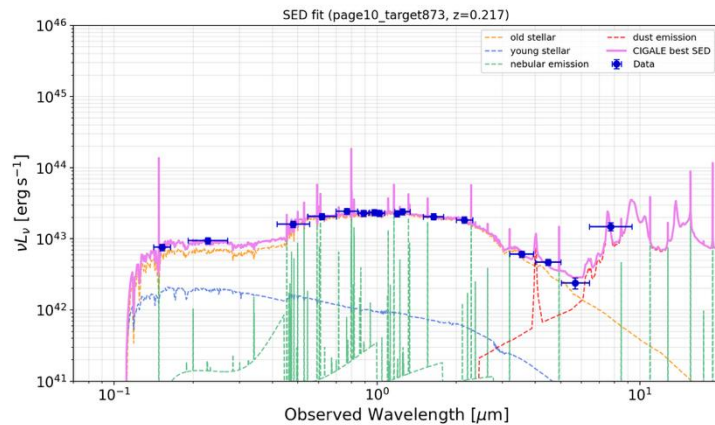
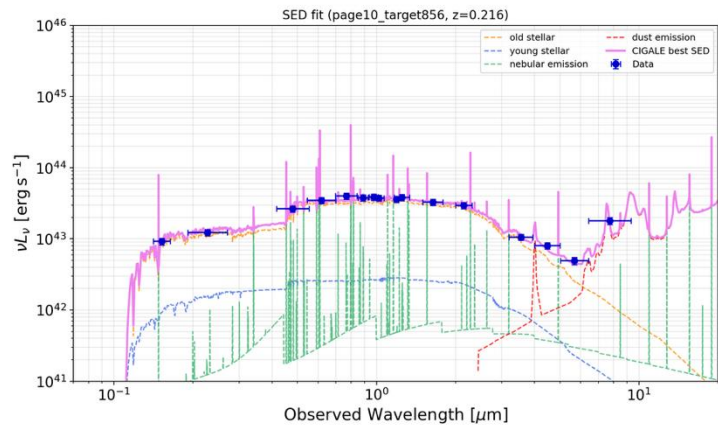
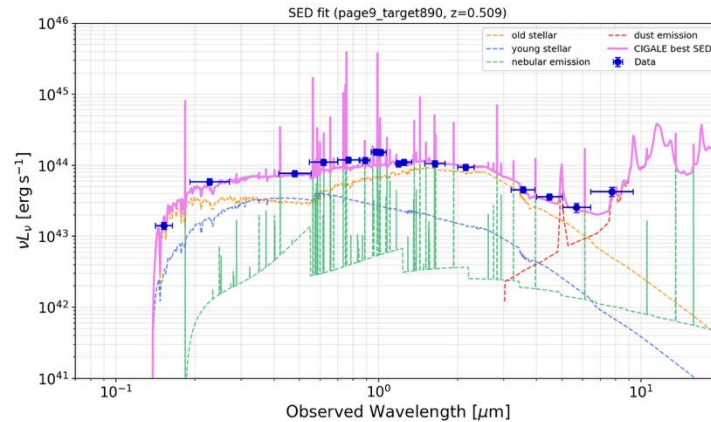
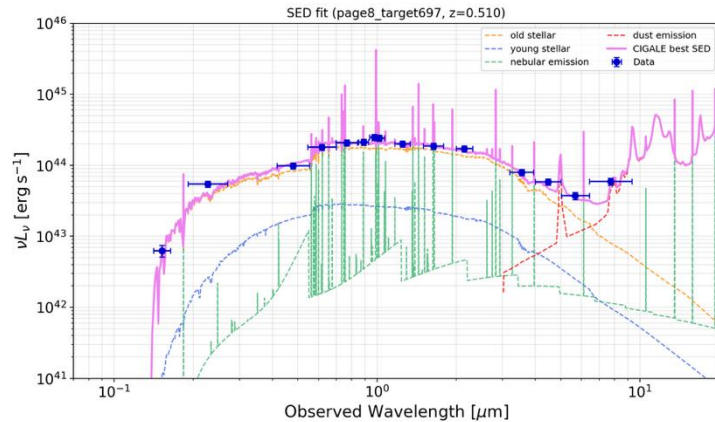
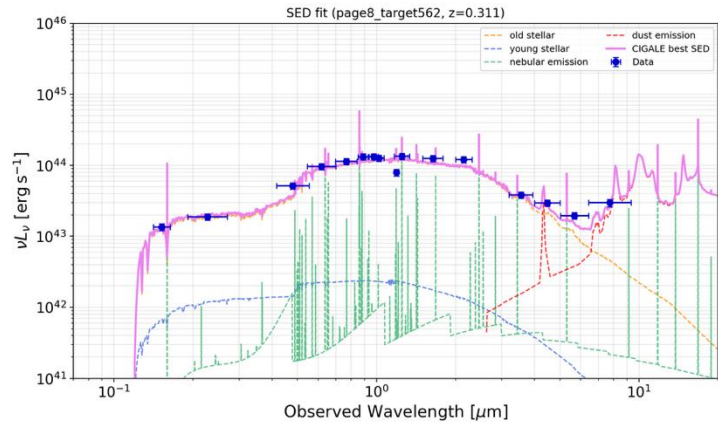


νL_{ν} [erg s⁻¹]



Observed Wavelength [μ m]

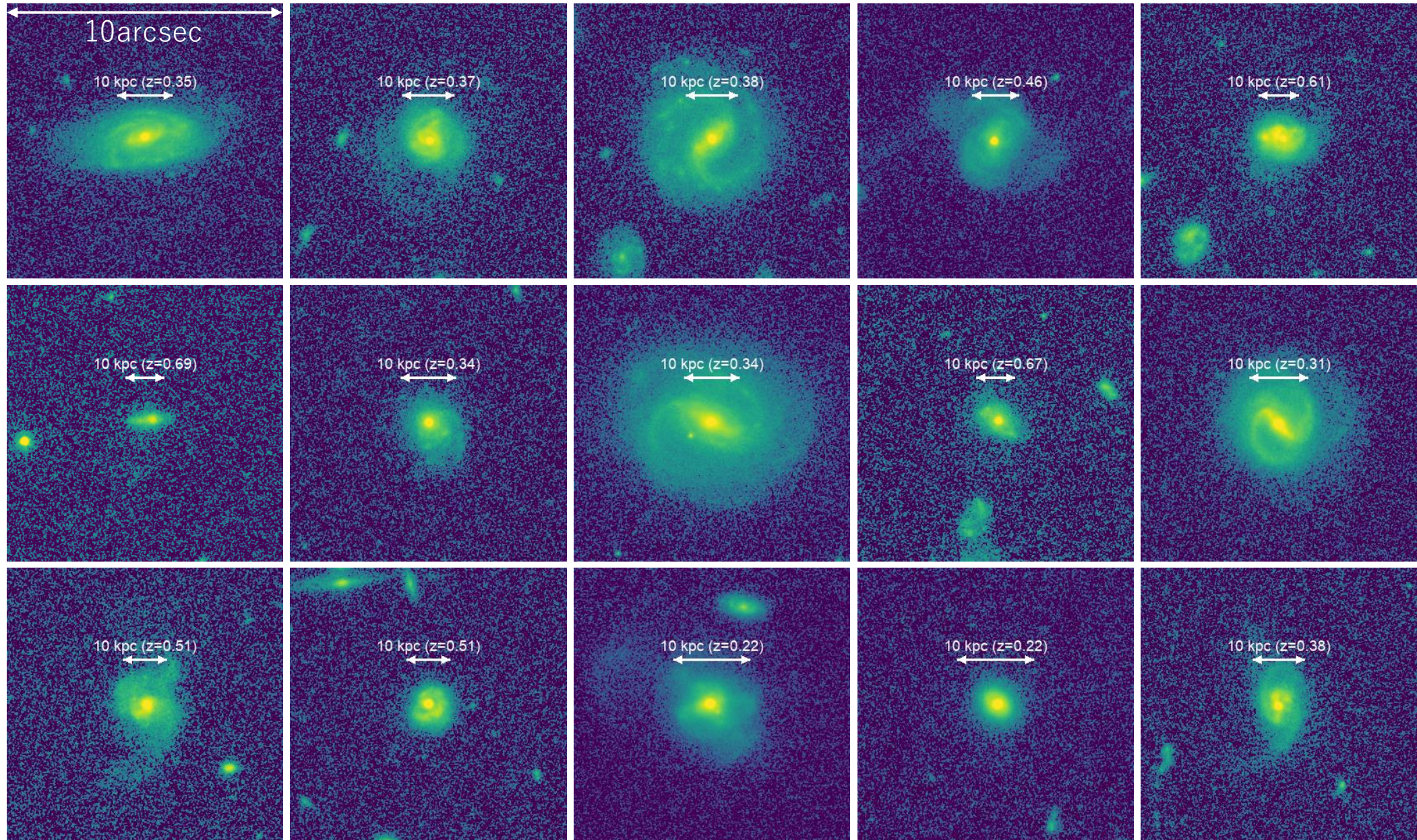
νL_{ν} [erg s⁻¹]



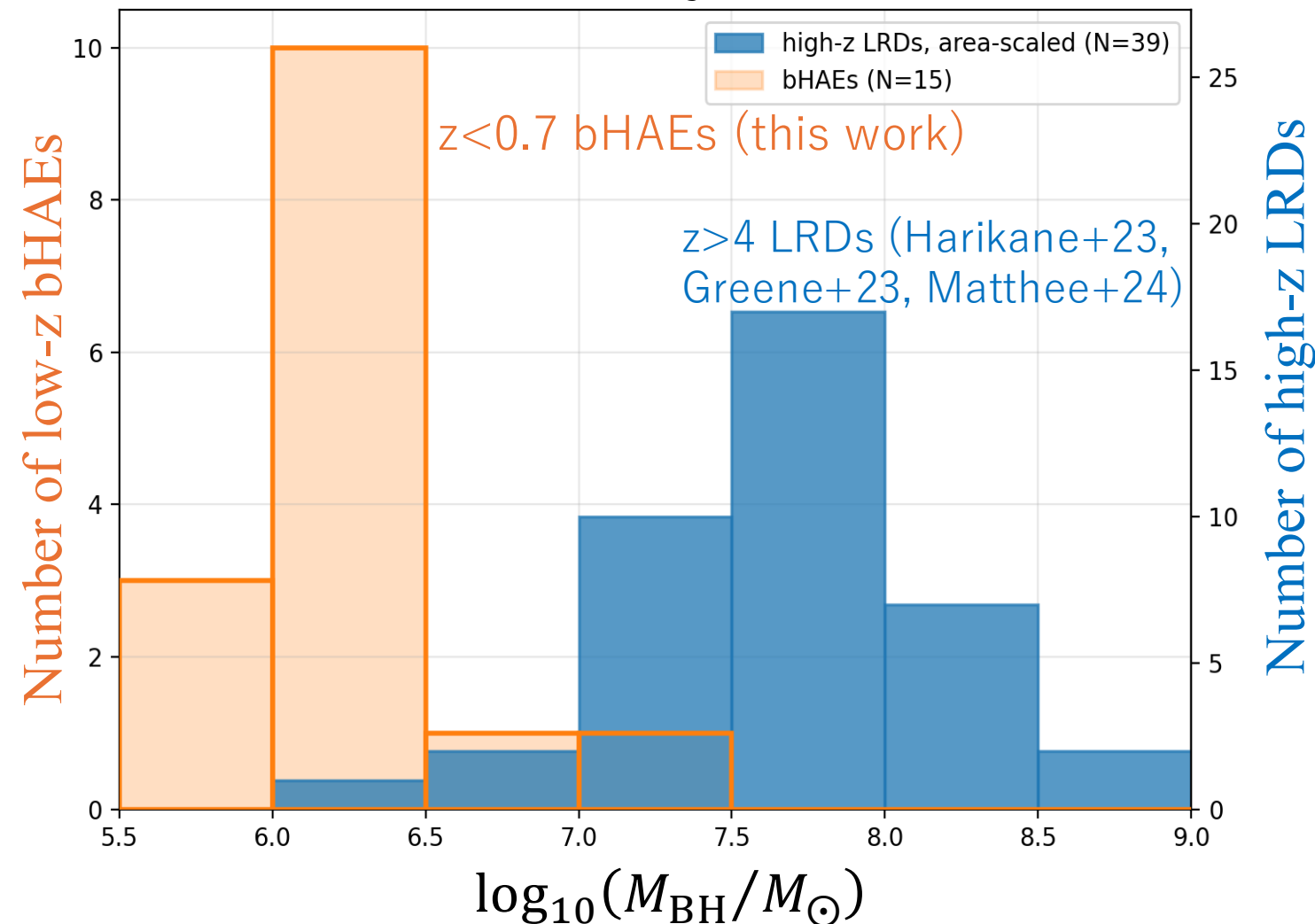
Observed Wavelength [μm]

HST/ACS images

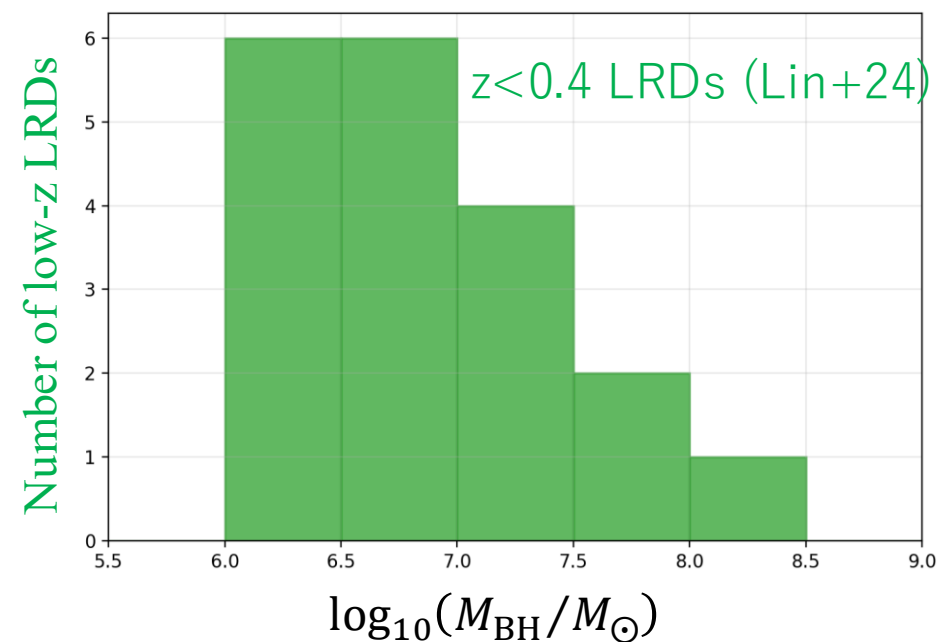
11/15

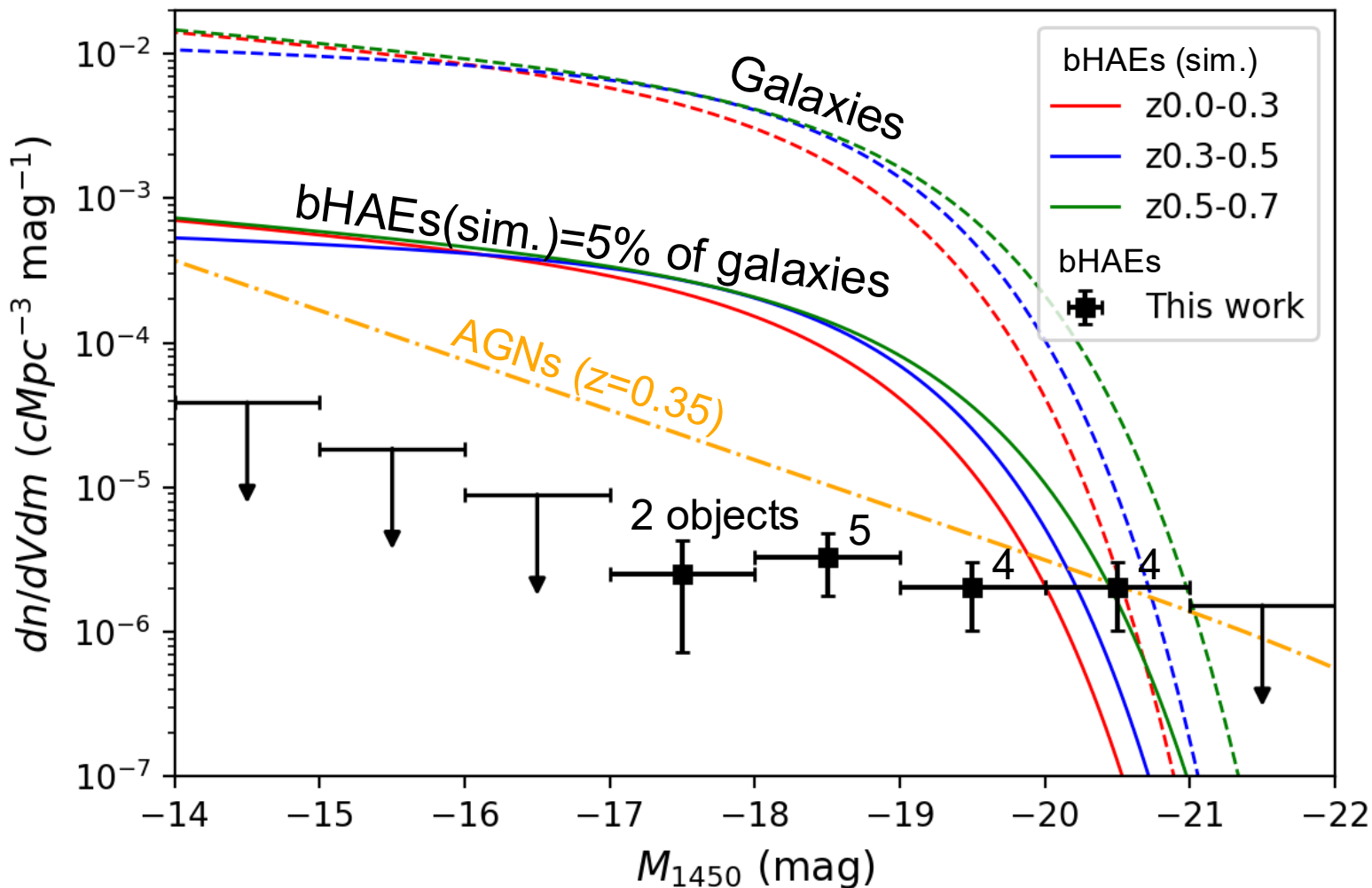


$$M_{\text{BH}} = 2.0_{-0.3}^{+0.4} \times 10^6 \left(\frac{L_{\text{H}\alpha}}{10^{42} \text{ erg/s}} \right)^{0.55 \pm 0.02} \left(\frac{\text{FWHM}_{\text{H}\alpha}}{10^3 \text{ km/s}} \right)^{2.06 \pm 0.06} M_{\odot} \quad (\text{Greene \& Ho, 2005})$$



M_{BH} distribution:
 low-z bHAEs < low-z LRDs
 < high-z LRDs

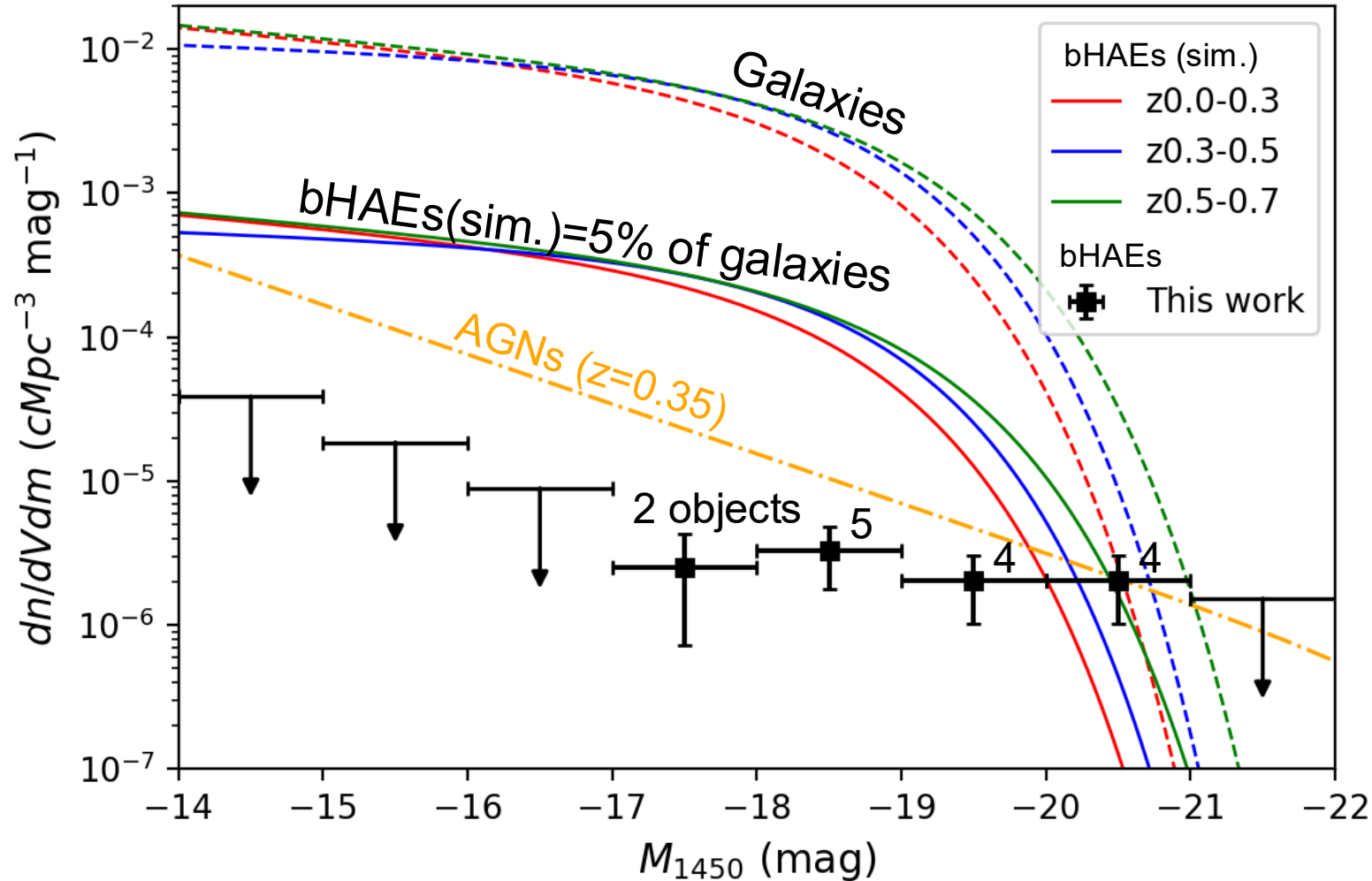




In nearby universe ($z < 1$):

- Number density of bHAEs is significantly lower than that at high redshift.

- bHAEs are rare objects, but they have not completely disappeared.



First large-scale survey in nearby universe

→ Number density is much lower than at $z \sim 5$

bHAEs/LRDs phase:

- Maintains only a short time
- Requires **special** conditions



Common in early universe ($z \sim 5$)
Rarer in nearby universe ($z < 1$)

- Searched for broad H α emitters (bHAEs) in the nearby universe ($z < 1$) using Subaru PFS.
- Using spectral fitting and statistical model selection, identified 15 bHAEs candidates.
- Their galaxy-like SEDs confirm that they show the known characteristics of bHAEs.
- The derived luminosity function indicates that bHAEs are much rarer in the nearby universe ($z < 1$) than at $z \sim 5$.

Future Work : Detailed follow-up observations of the broad H α line (longer exposure times)

Future works

- Detailed follow-up observations of the broad H α line (longer exposure times)
- Separate the host galaxy region from the central region in JWST and HST images, and estimate the host galaxy's stellar mass and star formation rate using SED fitting for comparison with high-redshift bHAEs.
- Search for bHAEs using a larger PFS-SSP galaxy sample ($\sim 100,000$ objects).

Special conditions

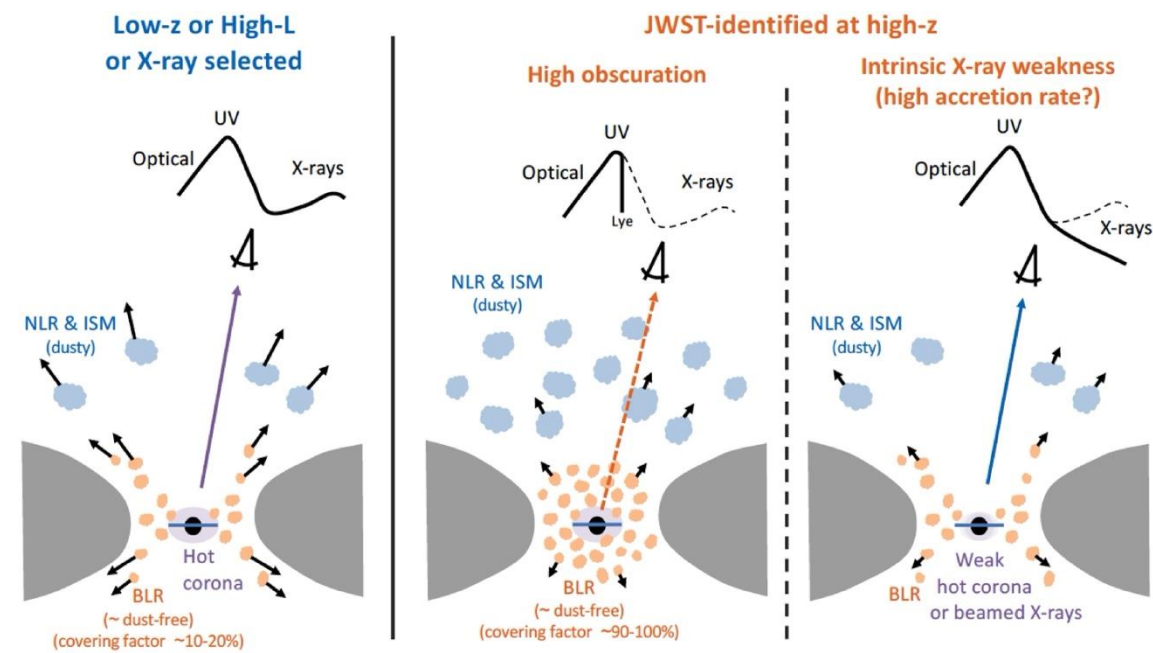
Most high-redshift objects with AGN-like properties, including bHAEs, are not detected in X-ray. The upper limits are 1–2 orders of magnitude lower than expected from a standard AGN SED.

- X-ray absorption by Compton-thick, dust-poor clouds
- Weak outflows → dense gas can more easily remain in the nuclear region
- High accretion rates (possibly super-Eddington accretion)
→ Weak X-ray emitting corona

- Transient events such as supernovae may coincidentally occur within galaxies and produce weak broad emission lines.

*Non-AGN scenario

[Maiolino et al. 2025]



Special conditions

The AGN accretion-disk continuum shows little intrinsic variability.

- Stable luminosity due to some non-standard accretion-disk state

- Accretion-disk continuum is heavily obscured

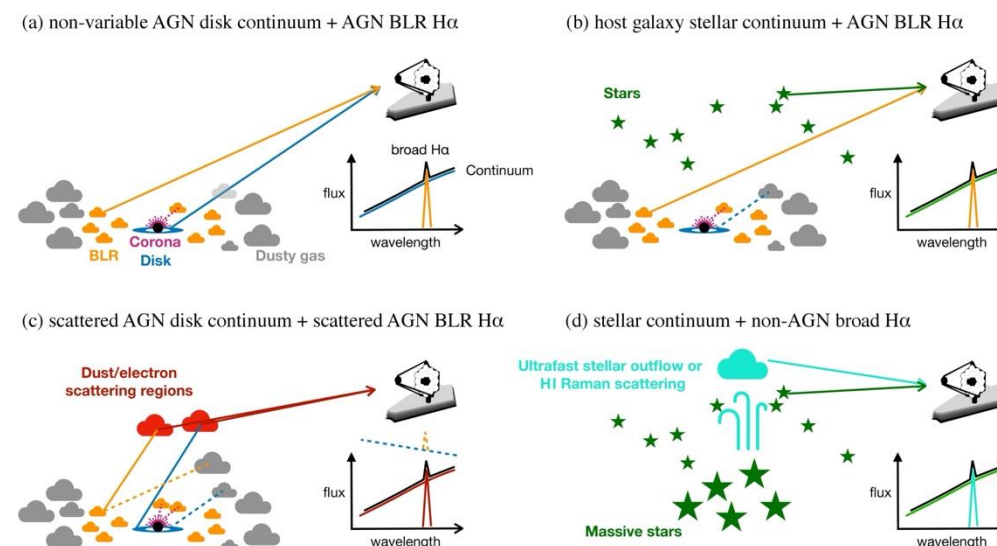
 - Observed continuum is dominated by the host galaxy

 - Variability is not seen

- Observed accretion-disk continuum is scattered light (not direct light)

 - Variability is averaged out and not observed

[Kokubo & Harikane 2025]



Special conditions

High-redshift LRDs rarely show high-ionization emission lines (both broad and narrow).

- Softer ionizing spectrum (fewer UV ionizing photons)
- Emitting region is covered by dense neutral gas and/or dust (fewer UV ionizing photons escape)

[Tang et al. 2025]

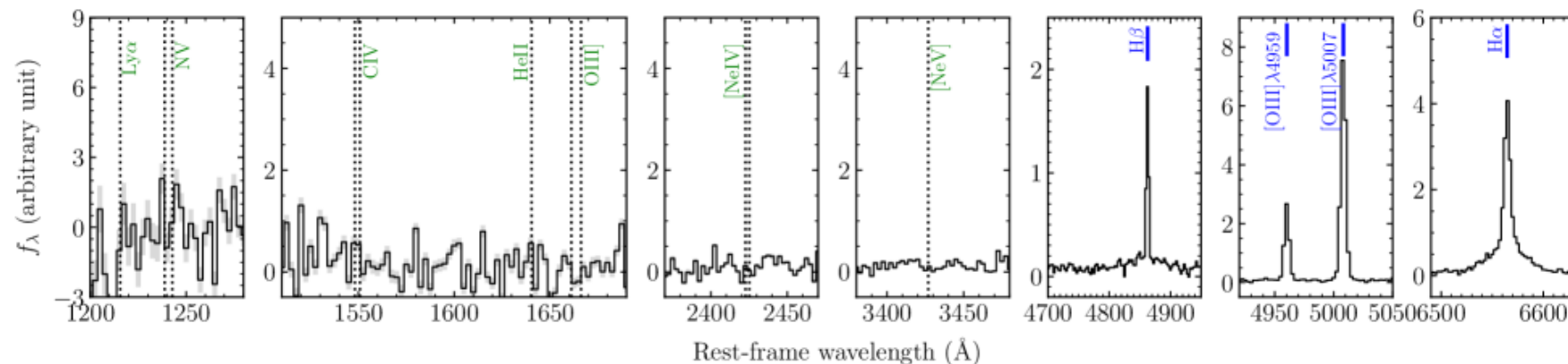
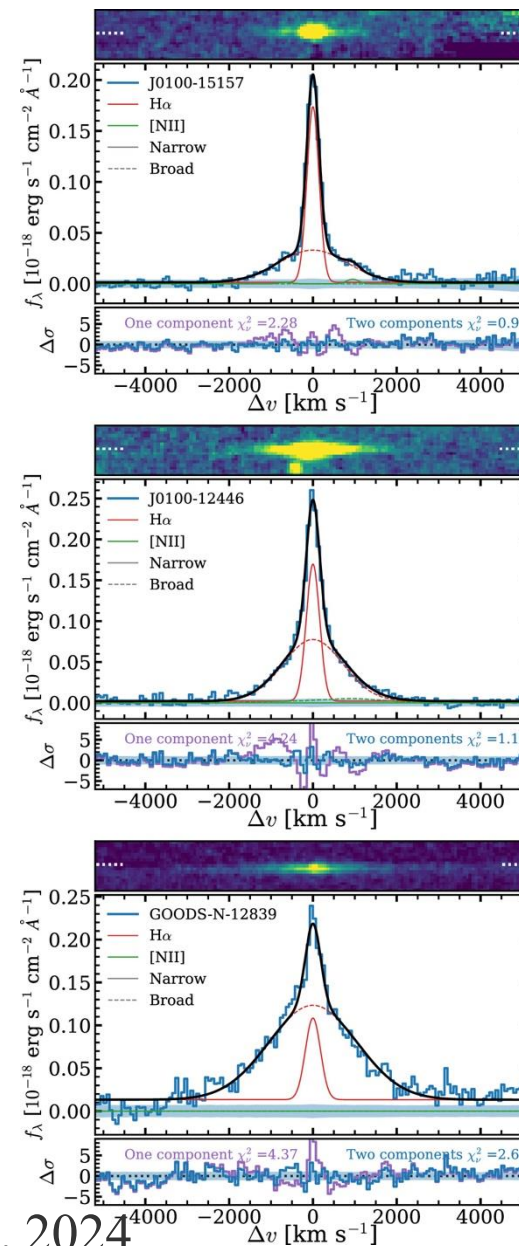
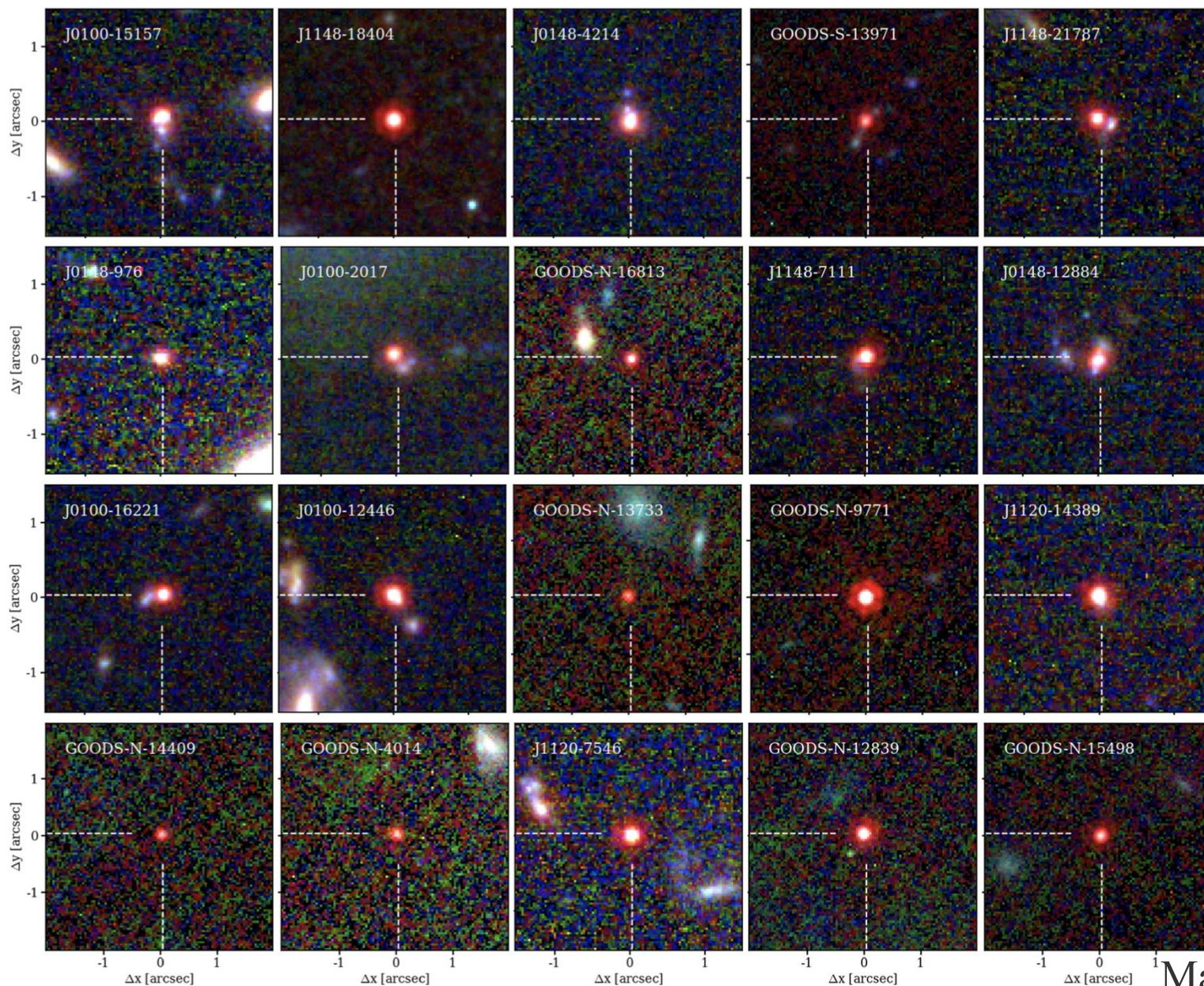


Fig: Stacked spectrum of 18 LRDs at $z > 4$

High-ionization lines (N V, C IV, He II, [Ne IV], [Ne V]) are not detected

JWST LRDs



Matthee et al., 2024

LRDs \Leftrightarrow “normal” bHAEs

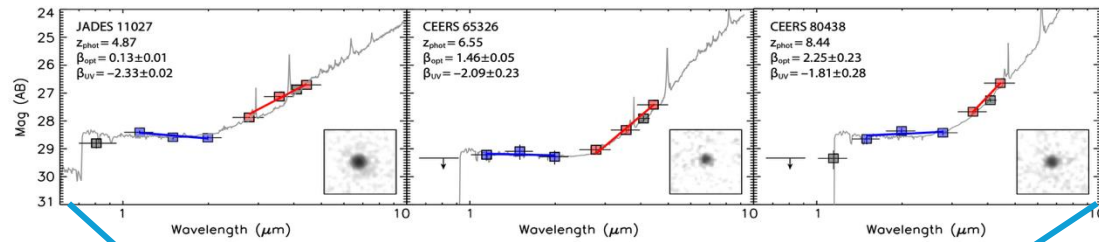
Central (nuclear) SED \gg host-galaxy SED \rightarrow LRDs

Central (nuclear) SED \ll host-galaxy SED \rightarrow “normal” bHAEs

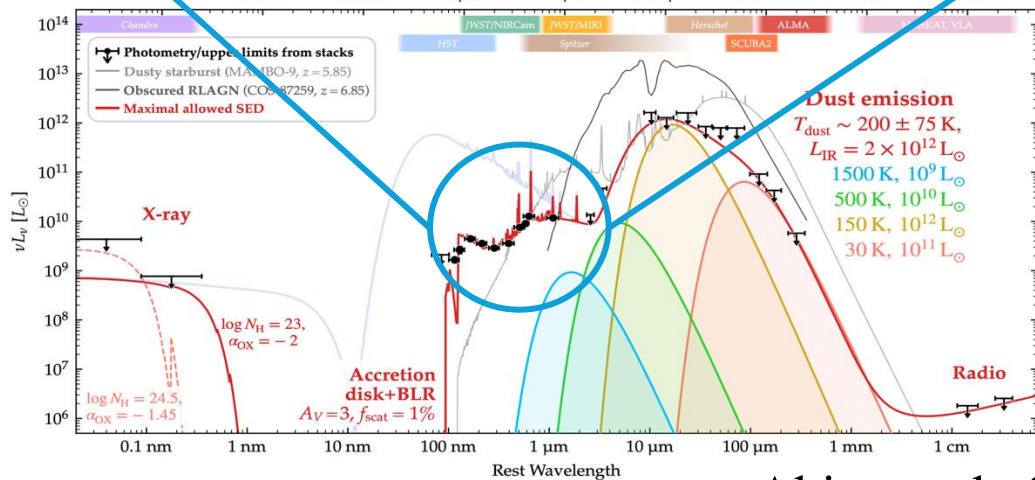
“normal” bHAEs (our 15 objects)

= broad-line emitters hosted by relatively evolved (more grown) galaxies (?)

[Sun et al. 2026]

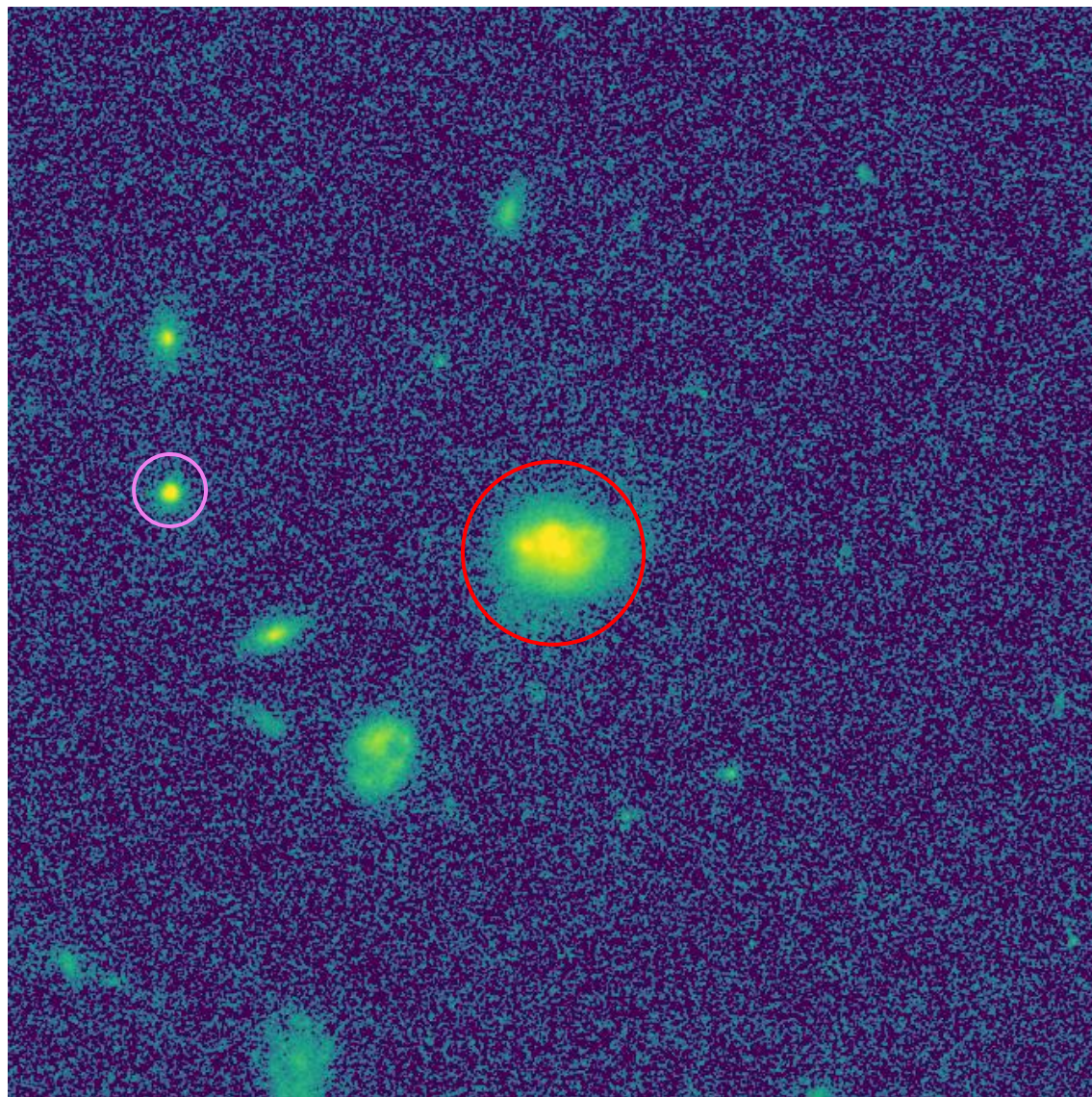


blue UV + red optical SED

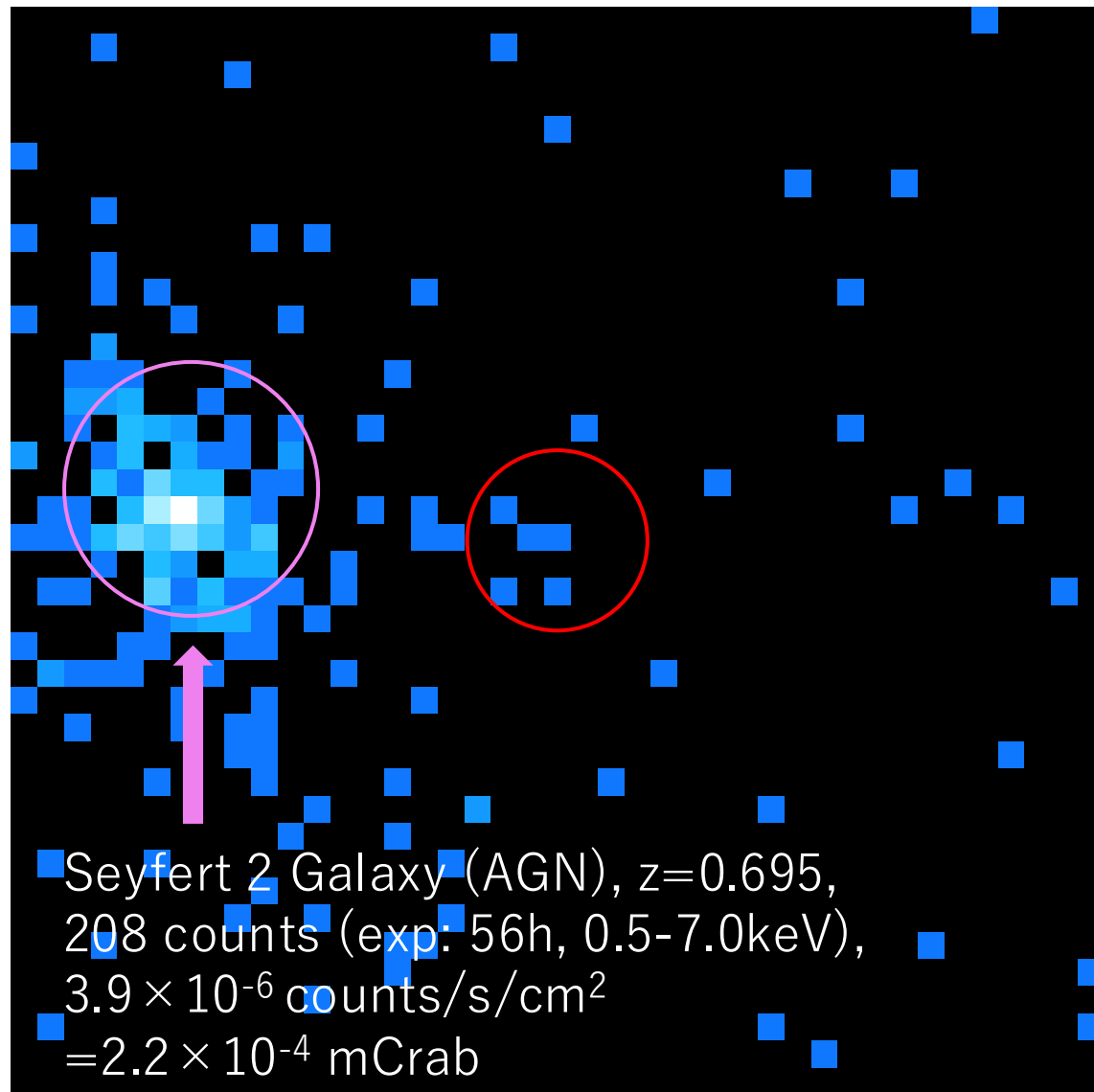


Akins et al., 2024

Optical and X-ray comparison



HST/ACS

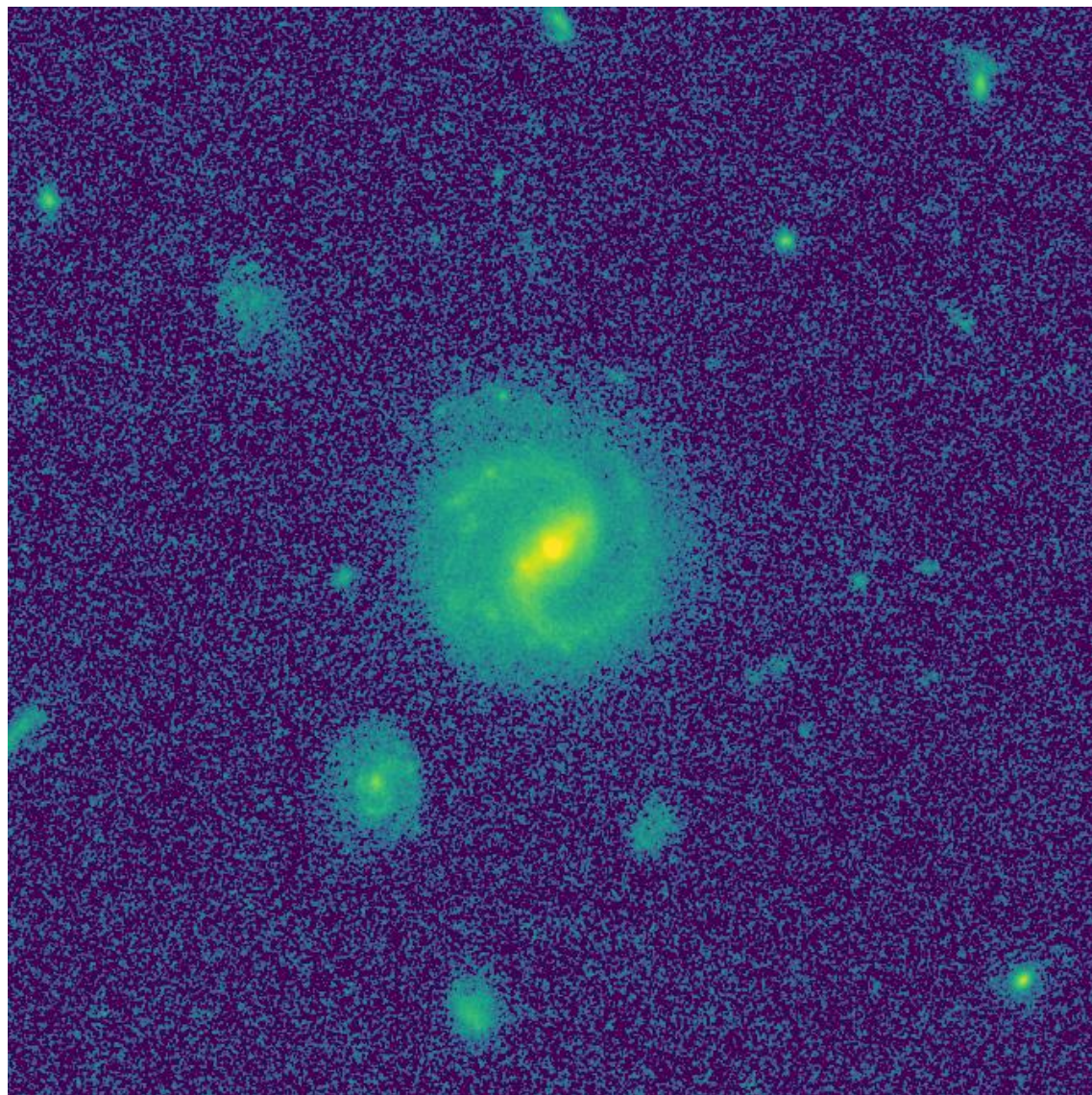


Seyfert 2 Galaxy (AGN), $z=0.695$,
208 counts (exp: 56h, 0.5-7.0keV),
 3.9×10^{-6} counts/s/cm²
 $=2.2 \times 10^{-4}$ mCrab

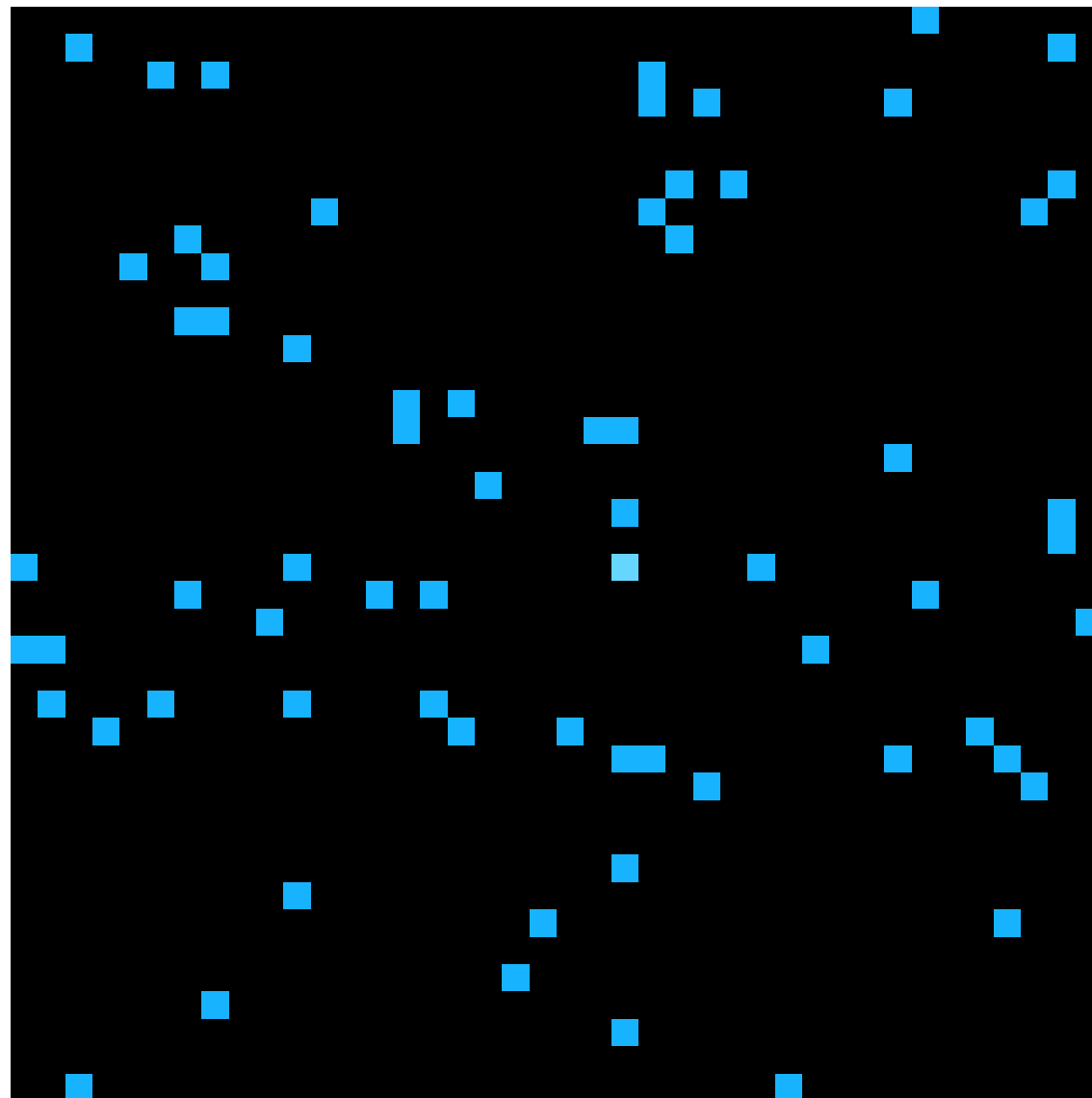
Same FOV

Chandra

Optical and X-ray comparison



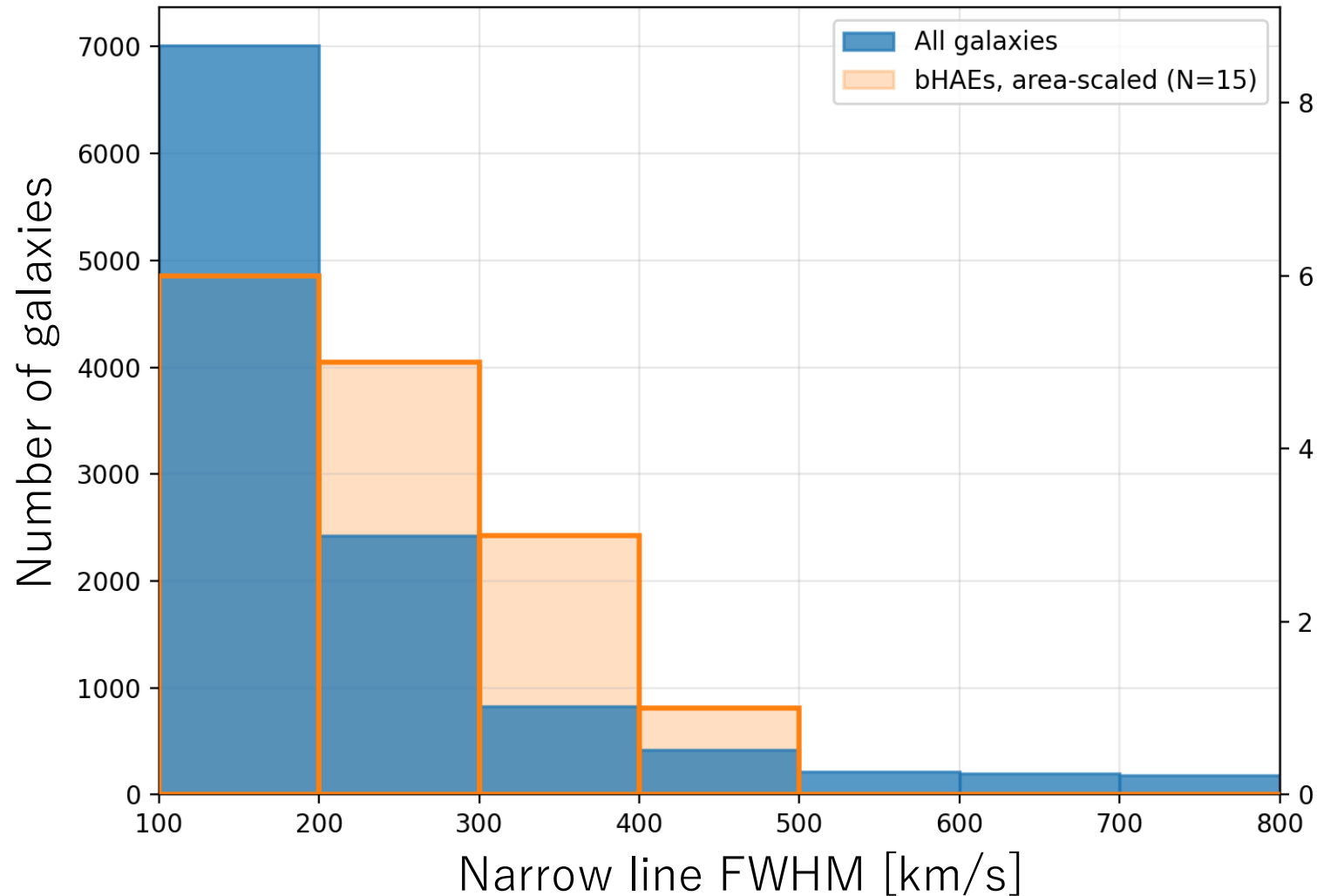
HST/ACS



Same FOV

Chandra

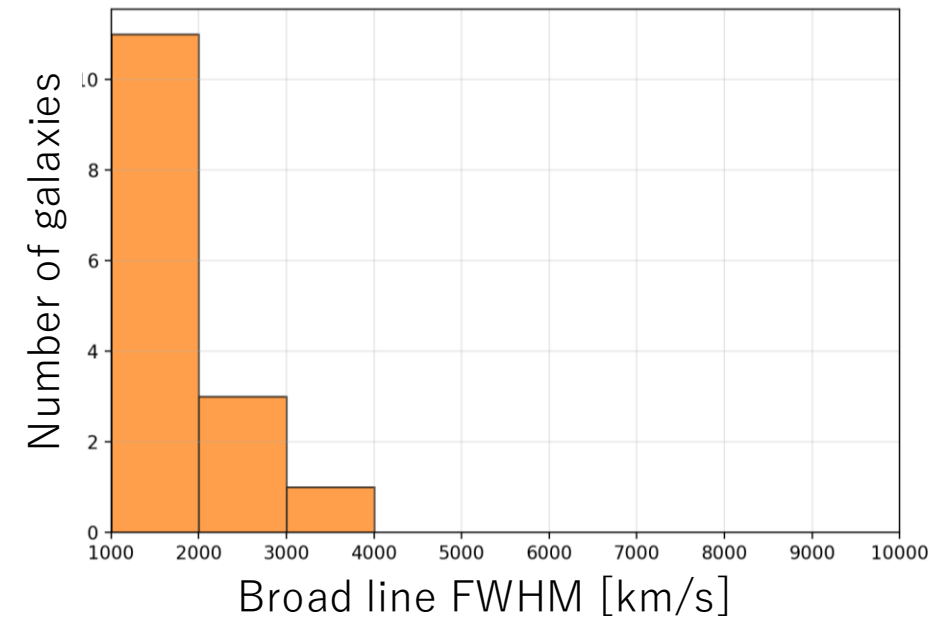
Narrow line FWHM



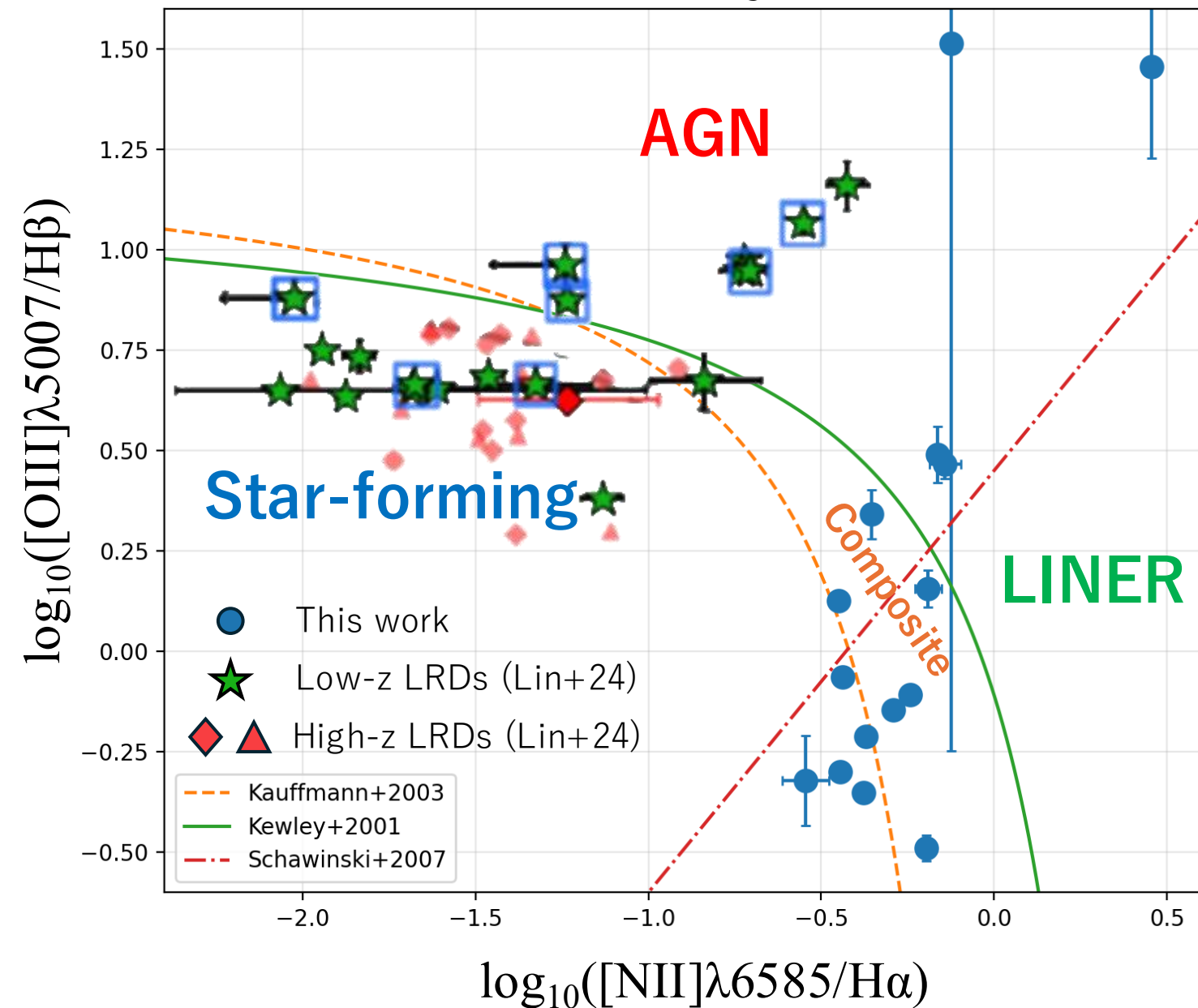
Narrow line: 100-500km/s

Broad line: 1000-4000km/s

→ Distinct components



BPT diagram



AGN: 3

Composite: 6

Star-forming: 5

(Not clear: 1)

comparing low-z bHAEs (●)
with low-z LRDs (★)

→ bHAEs have higher [NII]
luminosities than LRDs

Morphology

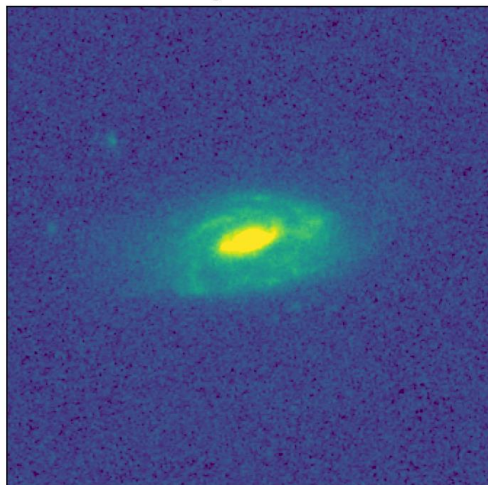


statmorph

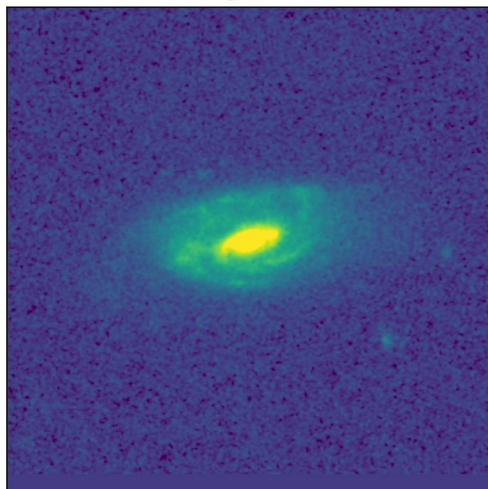
CAS (Concentration, Asymmetry, Smoothness) parameters
→ Characterize the shape of objects

page1_target1311_ACS.fits C=3.425, A=0.175, S=0.030, flag=0
z=0.3456, rCAS=2.74" =13.43 kpc, D=26.86 kpc

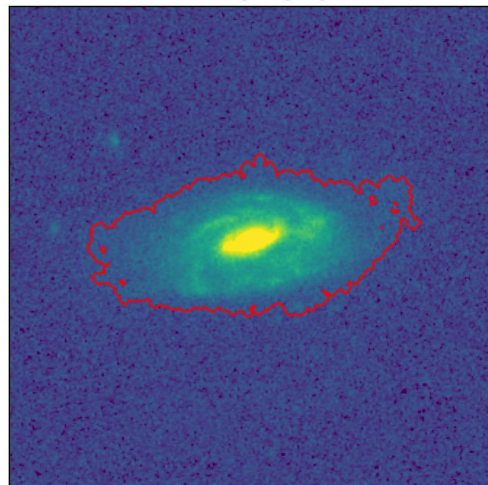
Original cutout



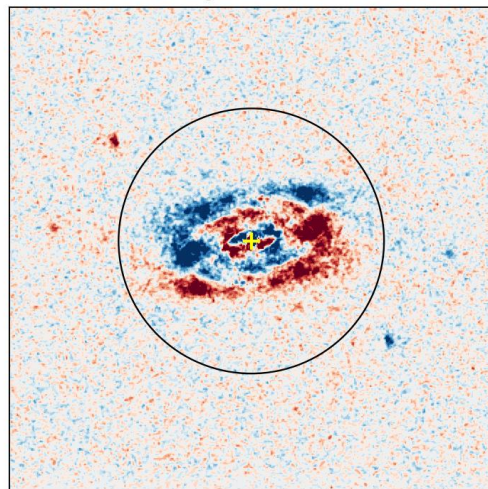
180-degree rotated



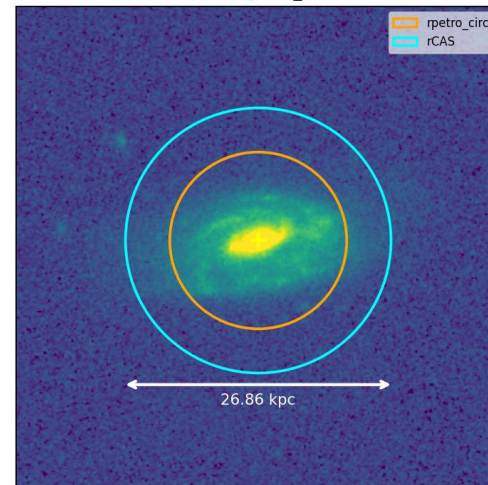
Estimated galaxy region



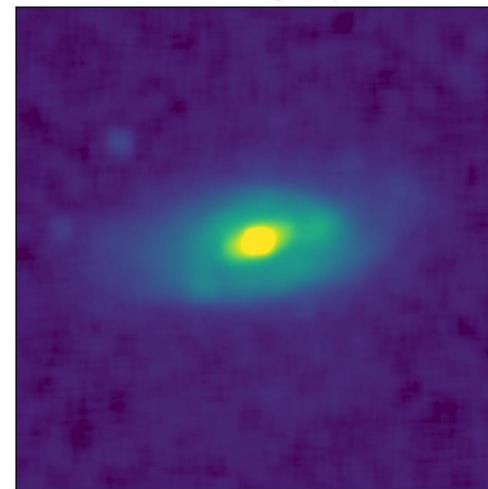
Original - rotated



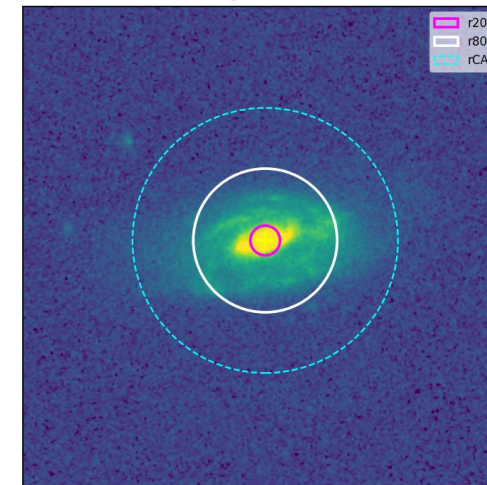
rCAS / rpetro_circ



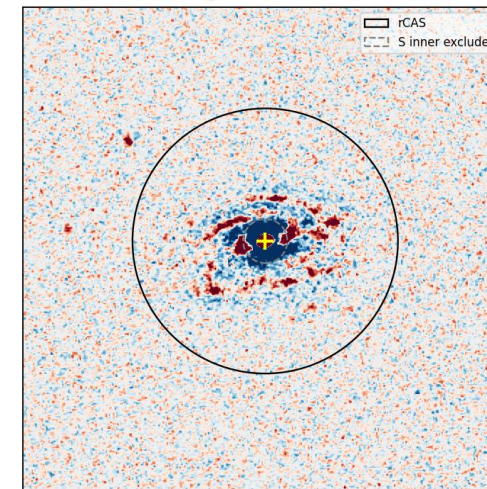
Smoothed image (15 pix)



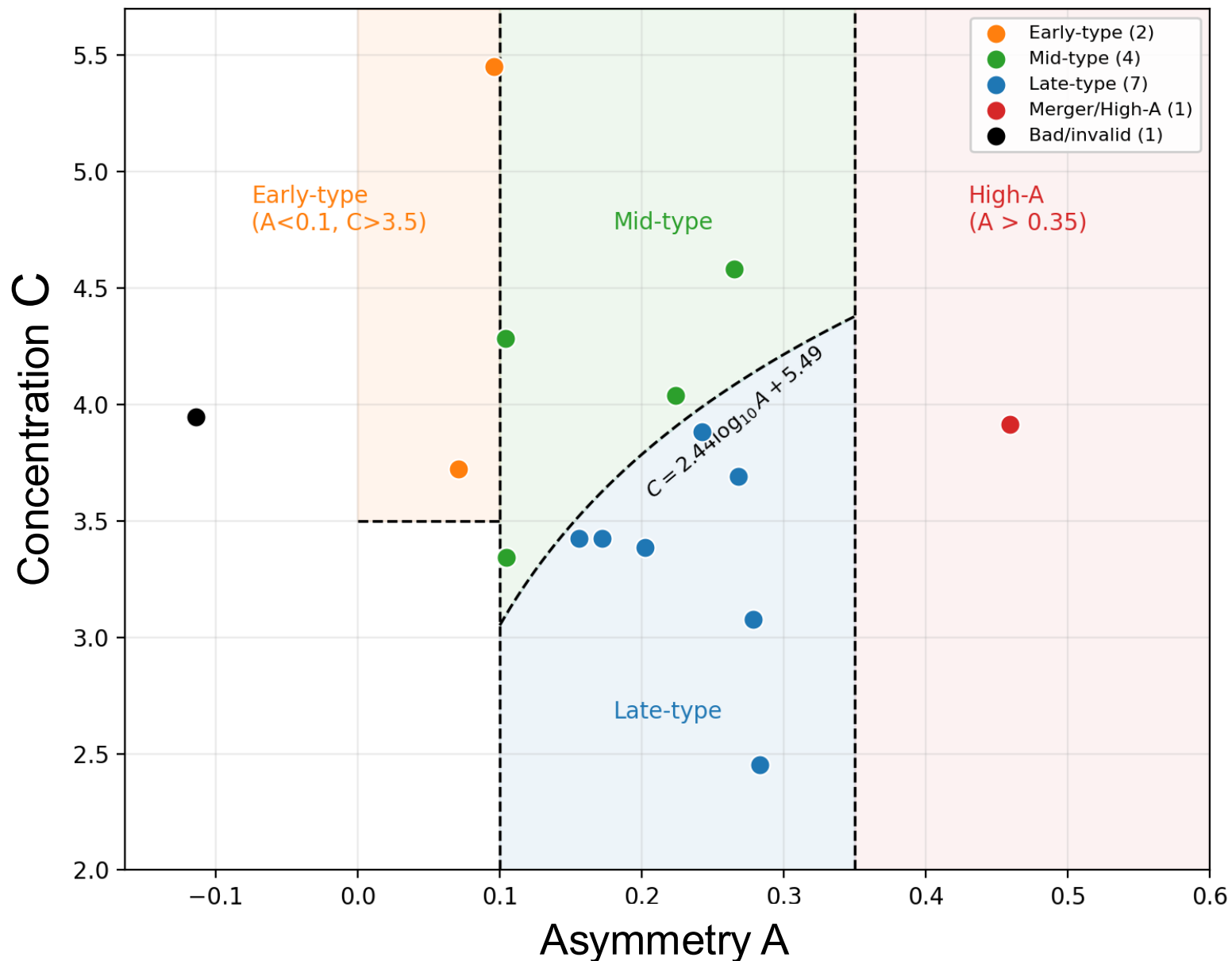
Flux regions: r20 / r80



Original - smoothed



Morphology



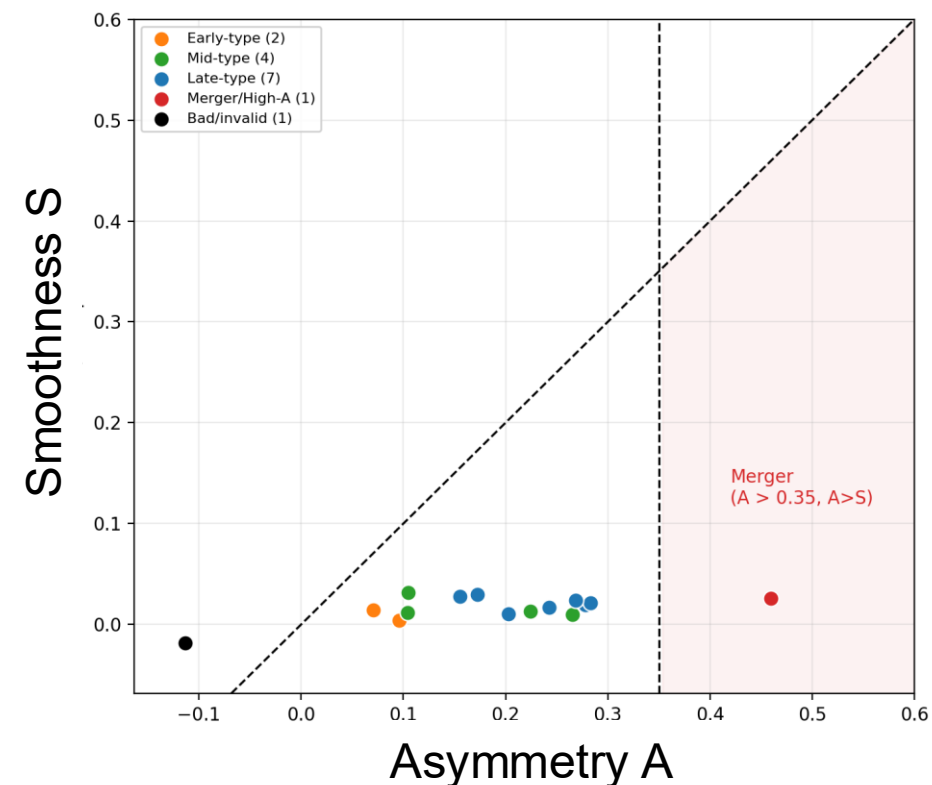
Early-type (E-S0): 2

Mid-type (Sa-Sc): 4

Late-type (Sd-Irr): 7

Merger: 1

→ Little or no correlation between bHAEs phase and morphology



Broad line detecting

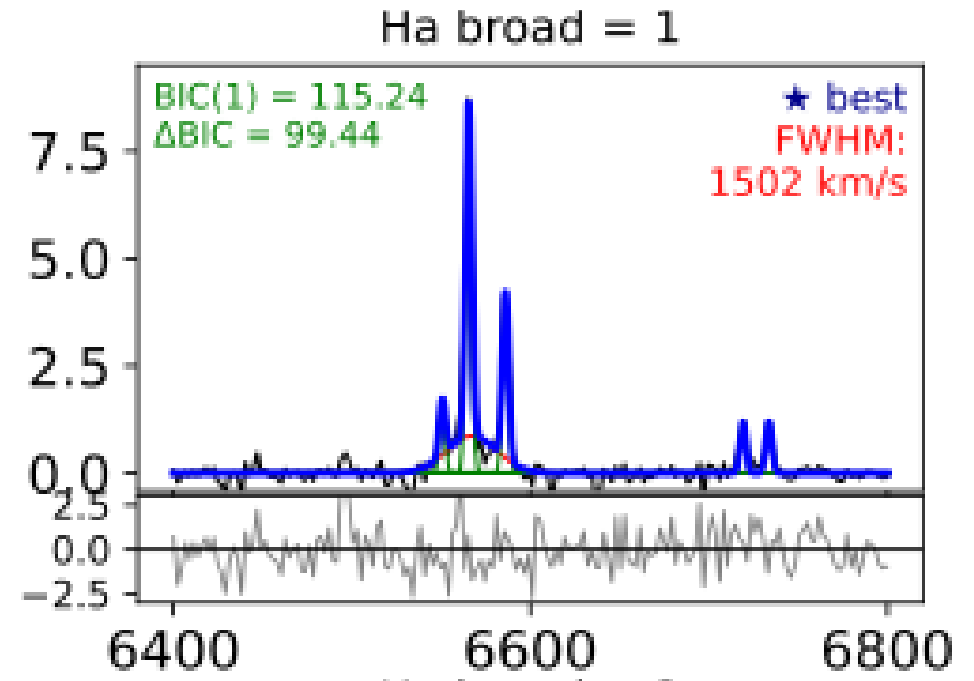
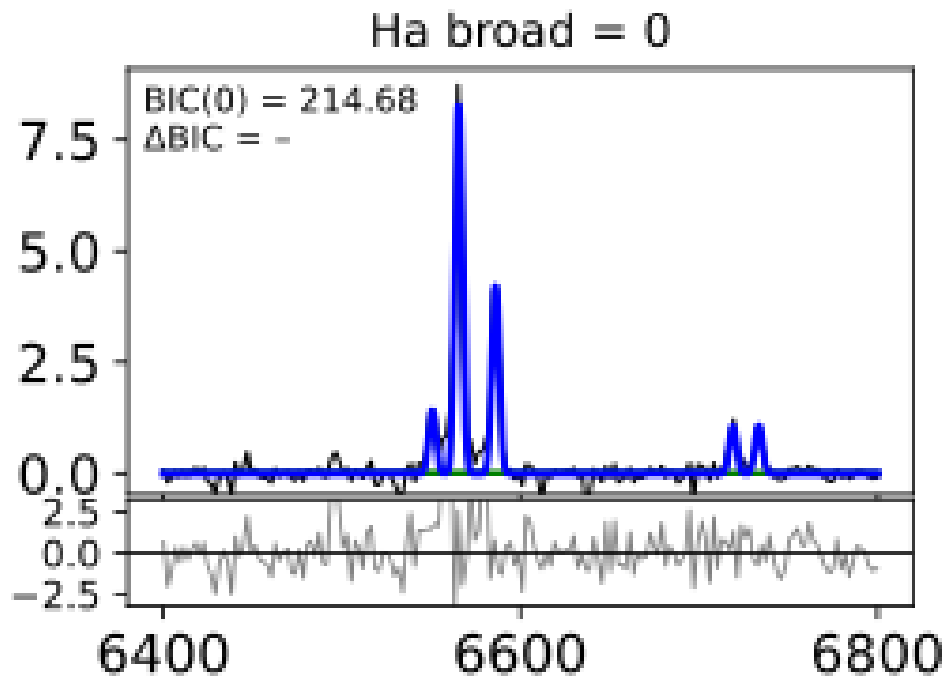
$$\text{BIC} = \chi^2 + k \ln n$$

k : Number of parameters

n : Number of data points

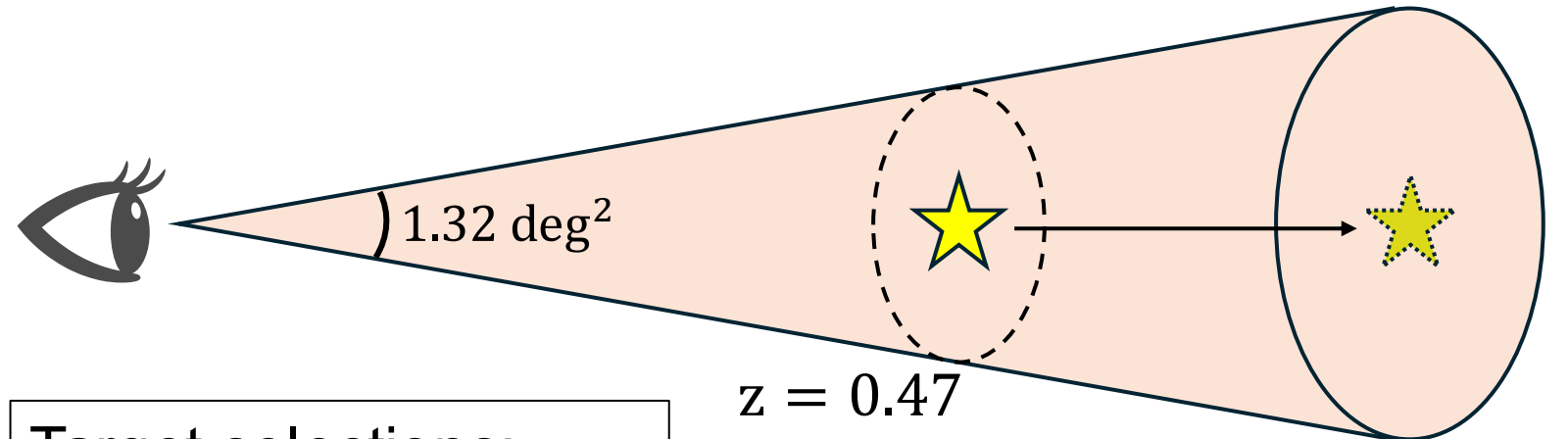
Broad line exists statistically significantly:
(Geris et al., 2025)

$$\Delta\text{BIC} = \text{BIC}_{\text{only narrow}} - \text{BIC}_{\text{narrow+broad}} > 10$$

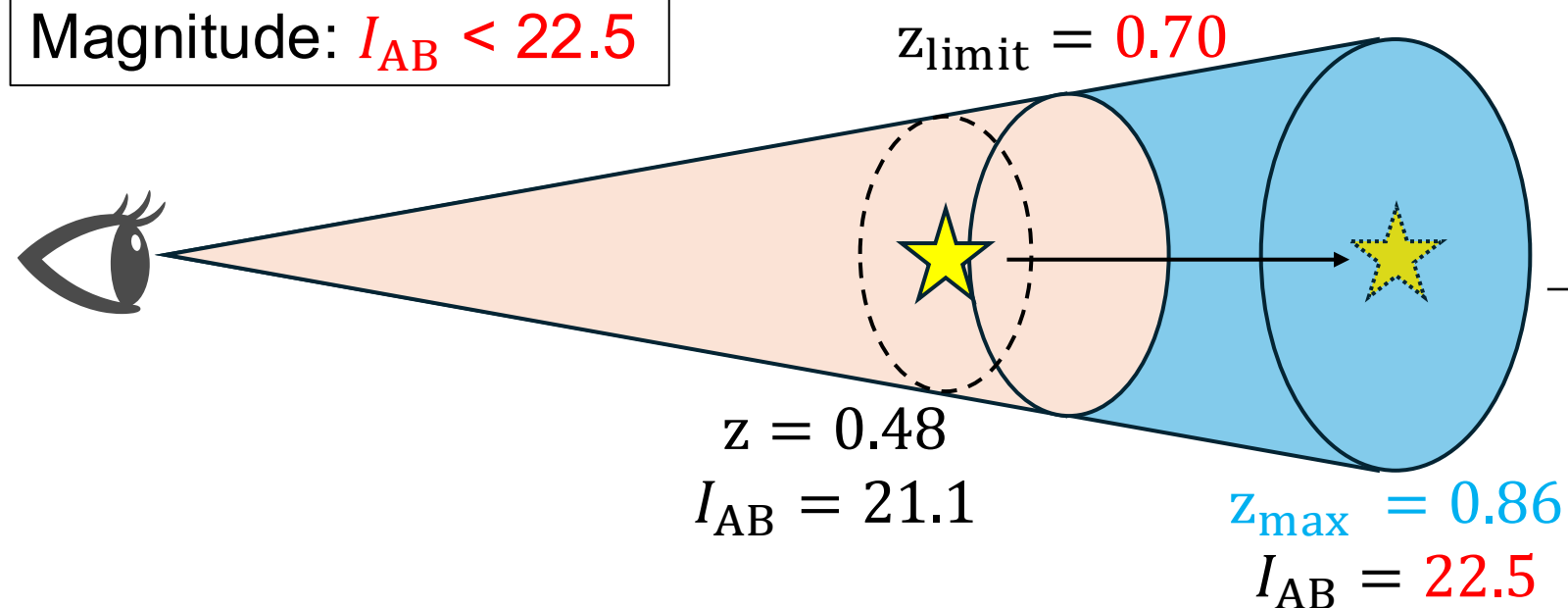


$$\text{BIC}_{\text{only narrow}} = 215 \xrightarrow{\Delta\text{BIC} = 99} \text{BIC}_{\text{narrow+broad}} = 115$$

LF calculate



Target selections:
 Redshift: $z = 0 - 0.7$
 Magnitude: $I_{AB} < 22.5$



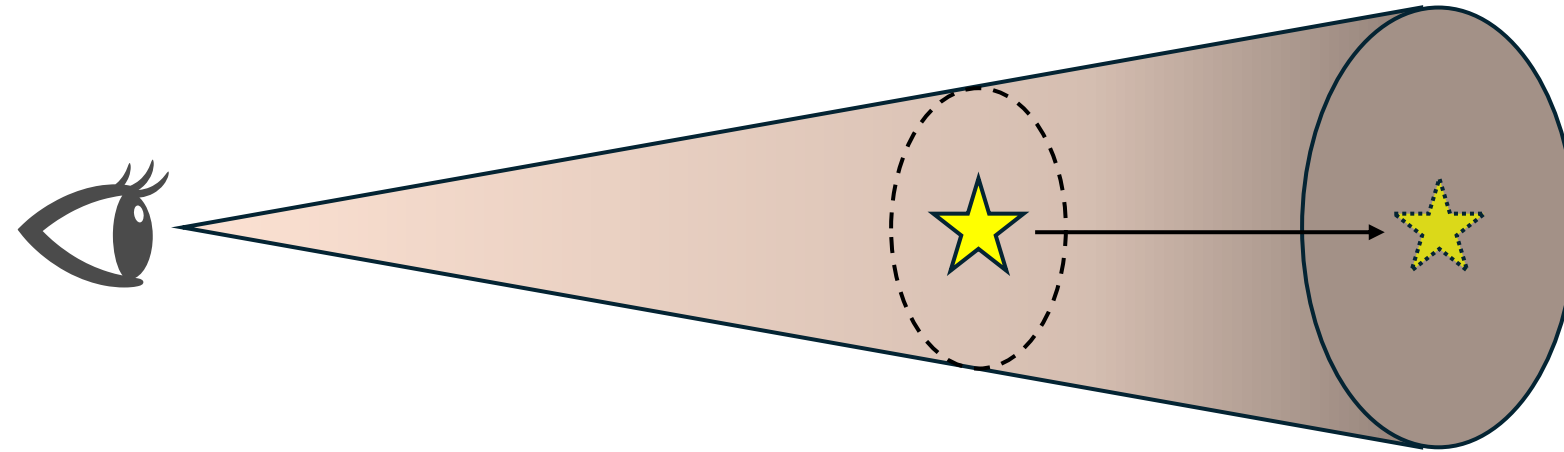
Vmax method

$$V_{\max} = \Omega \int_0^{z_{\max}} \frac{dV}{dz d\Omega} (z) dz$$

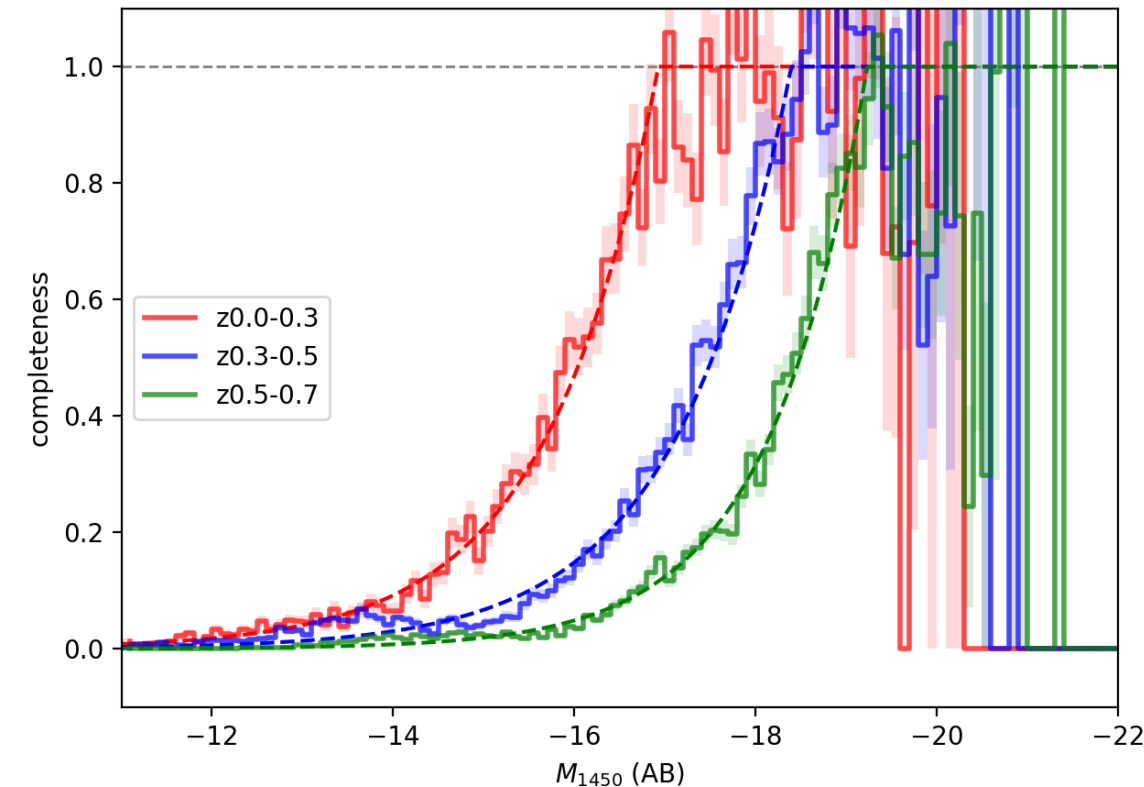
$$\Phi = \sum \frac{1}{V_{\max}}$$

$$V_{\max} = \Omega \int_0^{0.7} \dots dz$$

LF calculate



Completeness decrease
- Lower absolute magnitude
- Greater distance



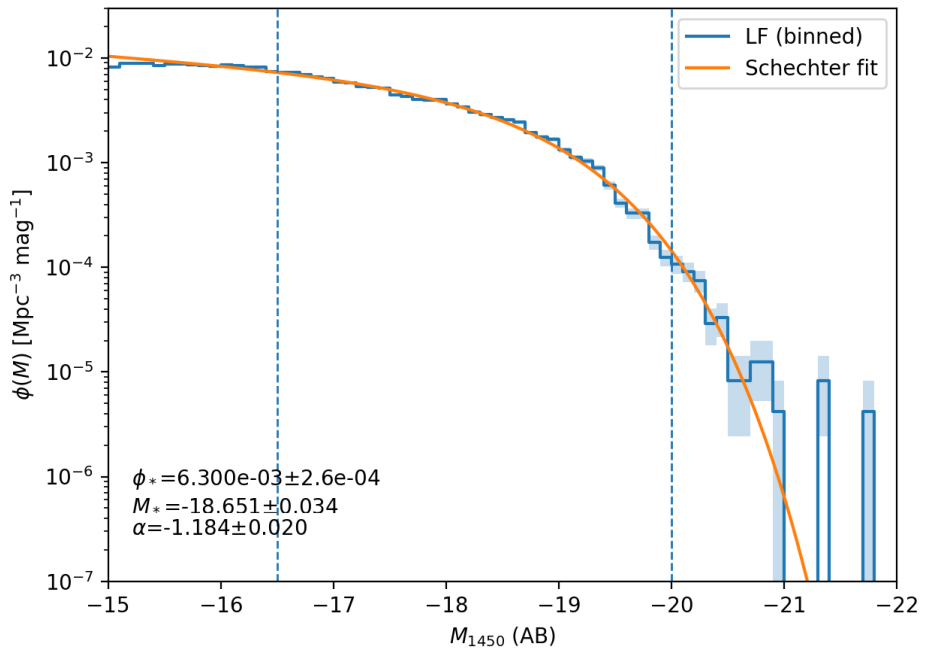
Completeness: $C(z, L)$

$$V_{\max} = \Omega \int_0^{z_{\max}} C(z, L) \frac{dV}{dzd\Omega}(z) dz$$

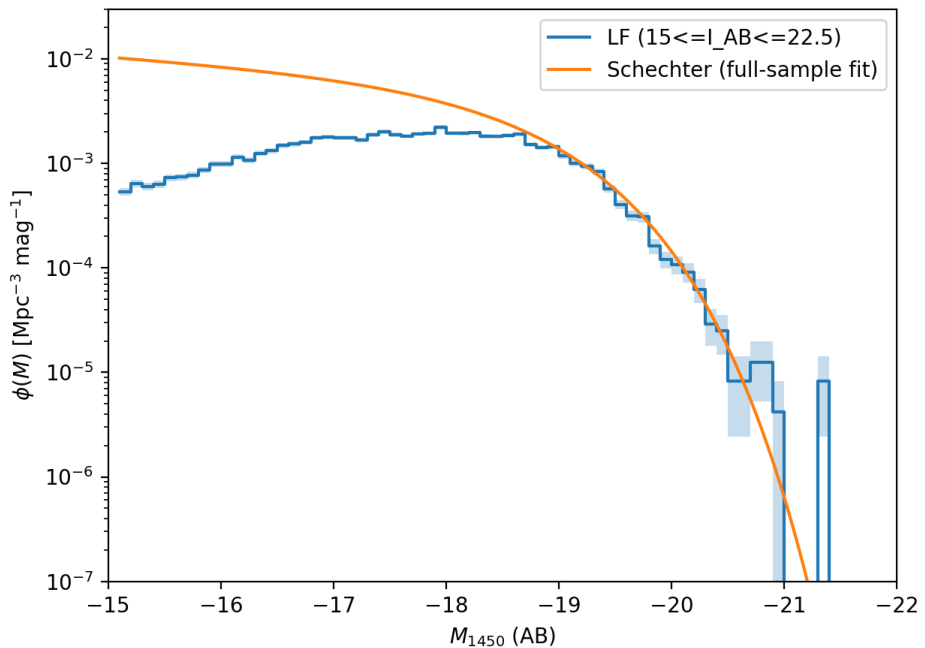
Fig: Relation between absolute magnitude and completeness for different redshift bins

Completeness

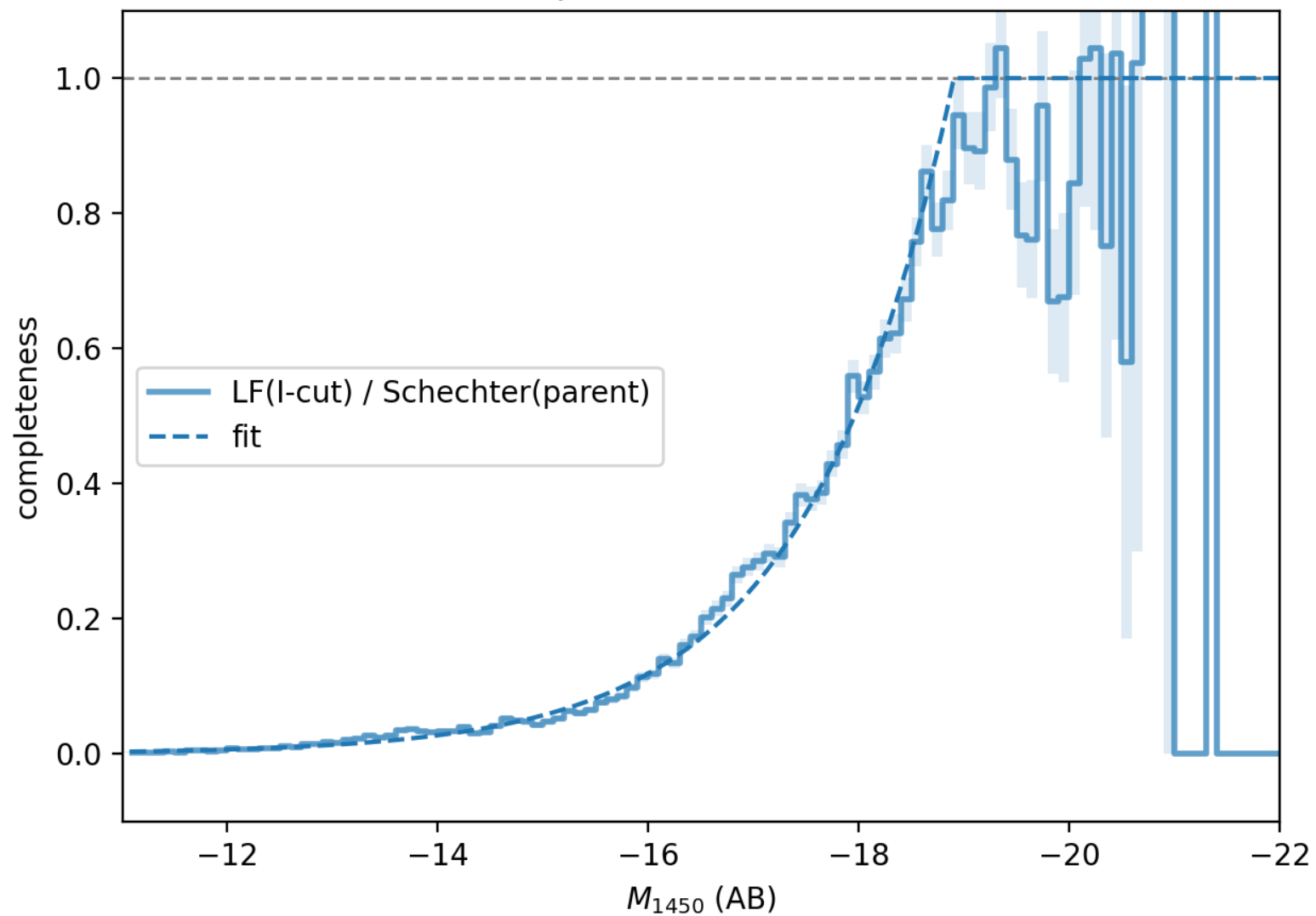
LF in z0.0-0.7



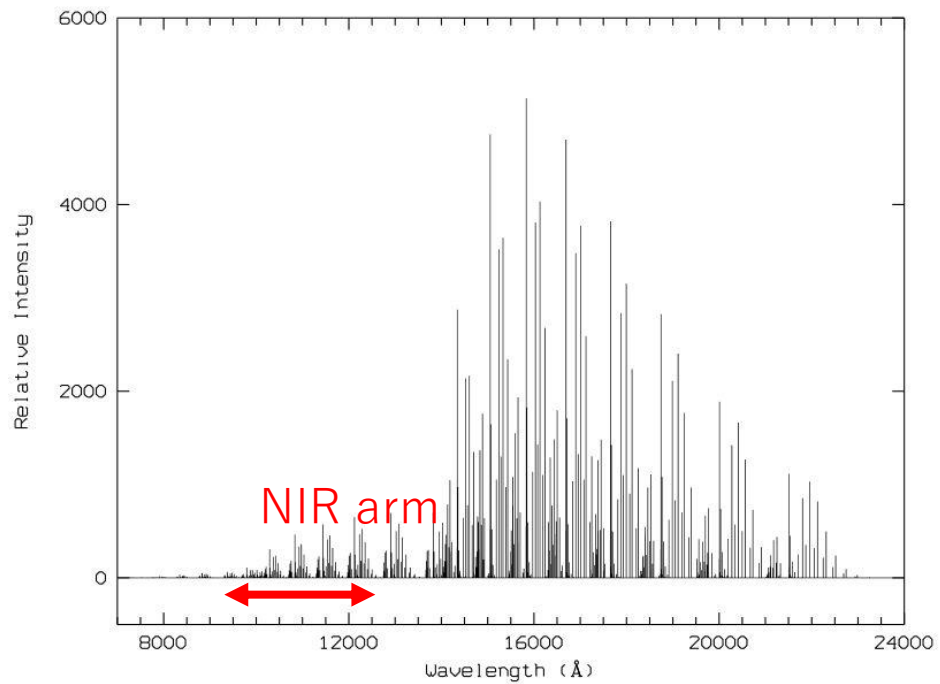
LF vs Schechter in z0.0-0.7



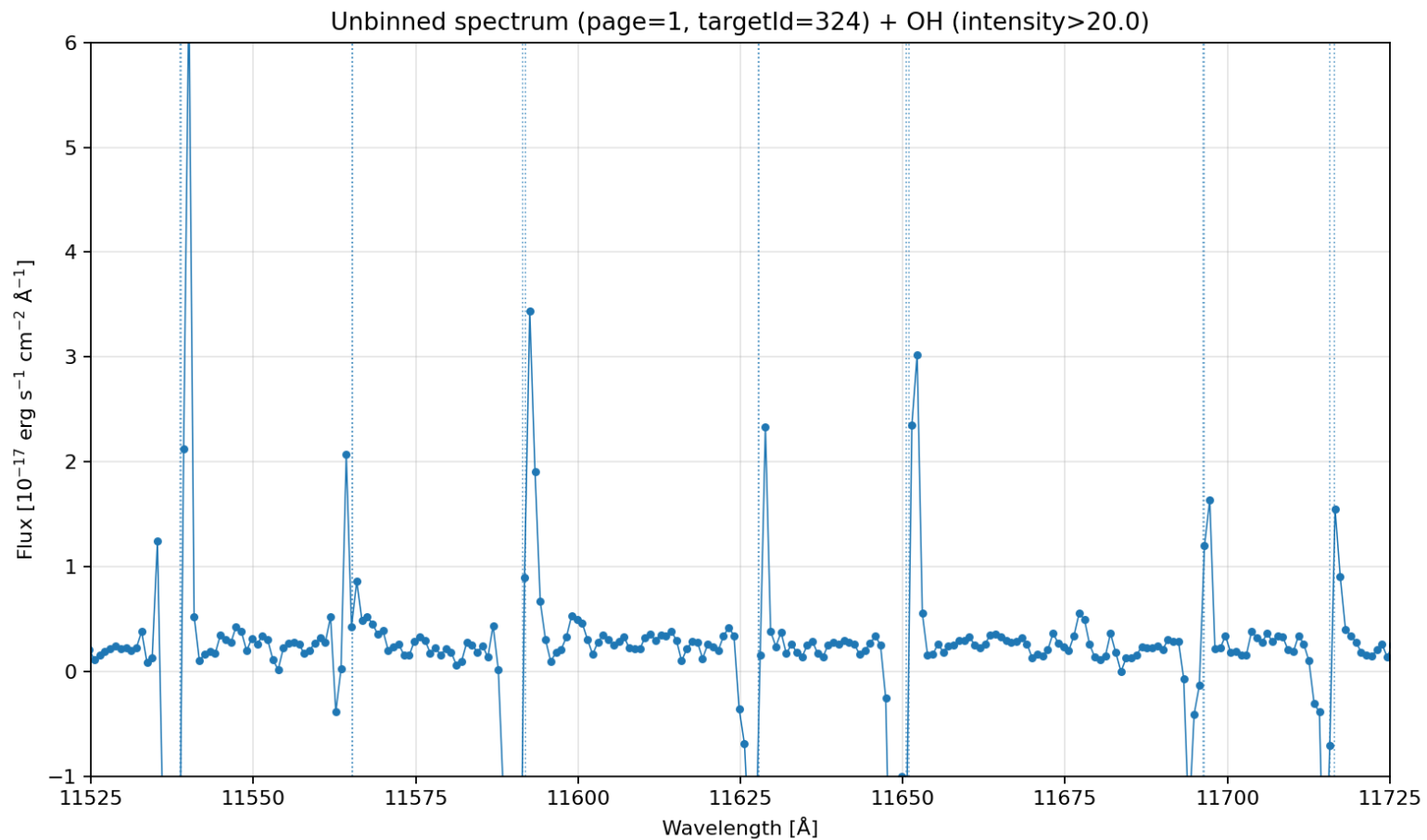
Completeness in z0.0-0.7



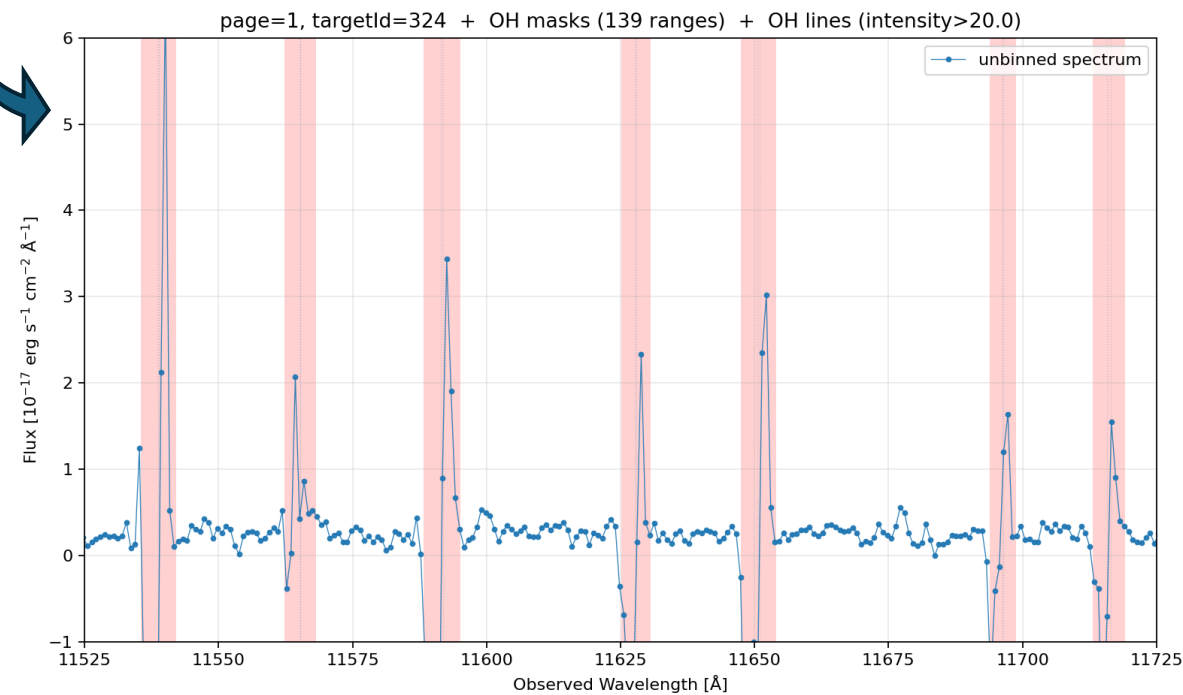
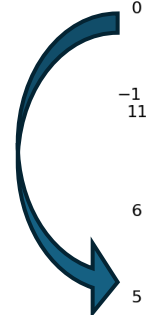
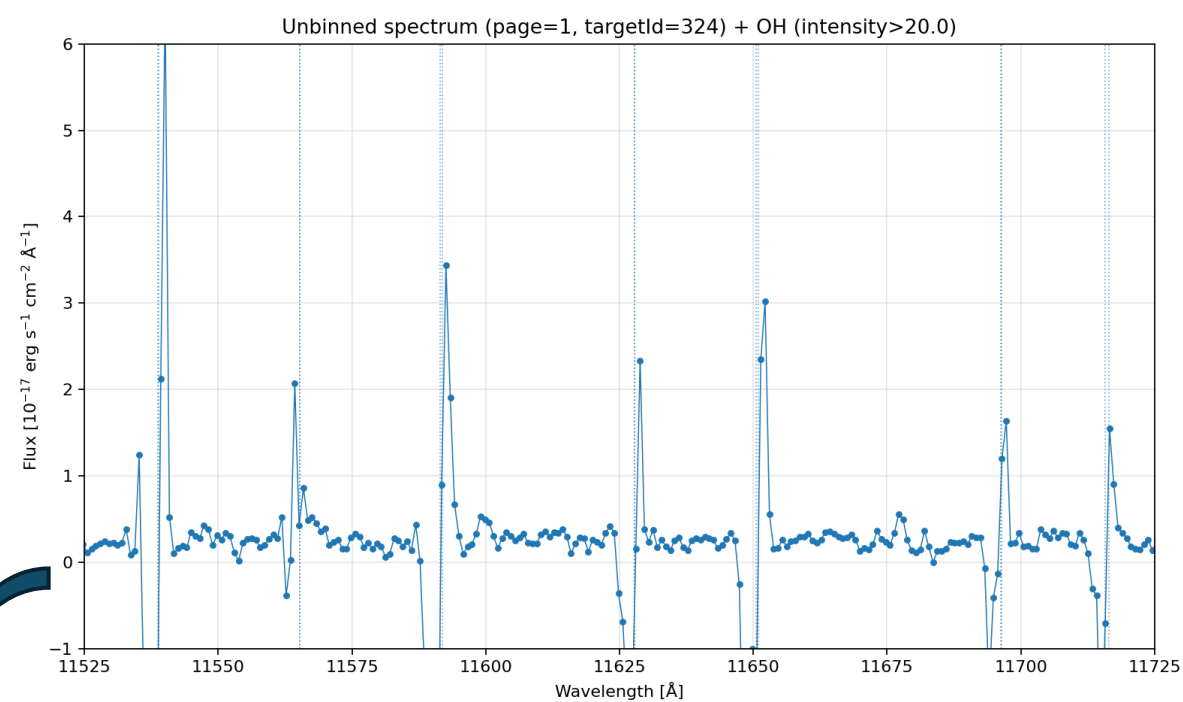
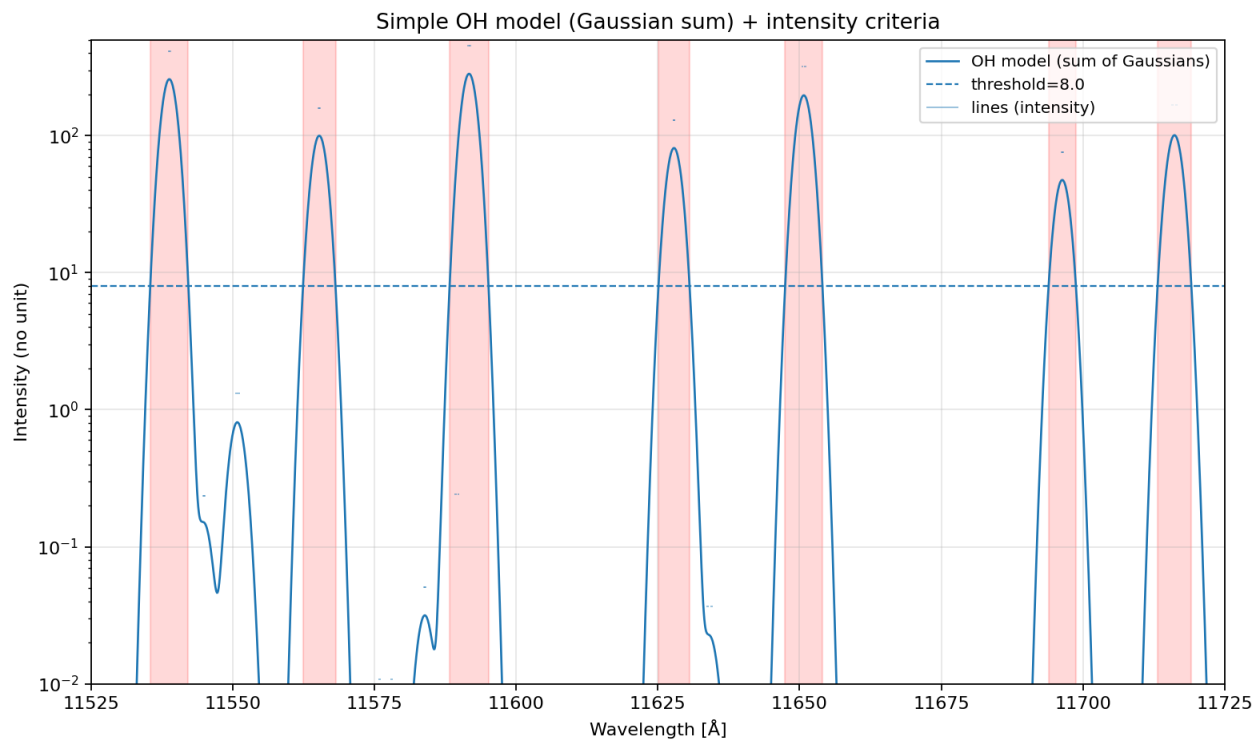
OH airglow



Rousselot et al. 2000



OH airglow



Active Galactic Nuclei (AGN)

Supermassive black holes (SMBH)

Mass = $10^6 \sim 10^9 M_{\odot}$

Location : galactic center

AGN

Extremely luminous SMBH
energy of mass accretion

Broad line region

Emits **broad** emission lines
(FWHM: $>1000\text{km/s}$)

→ Typical features of AGN

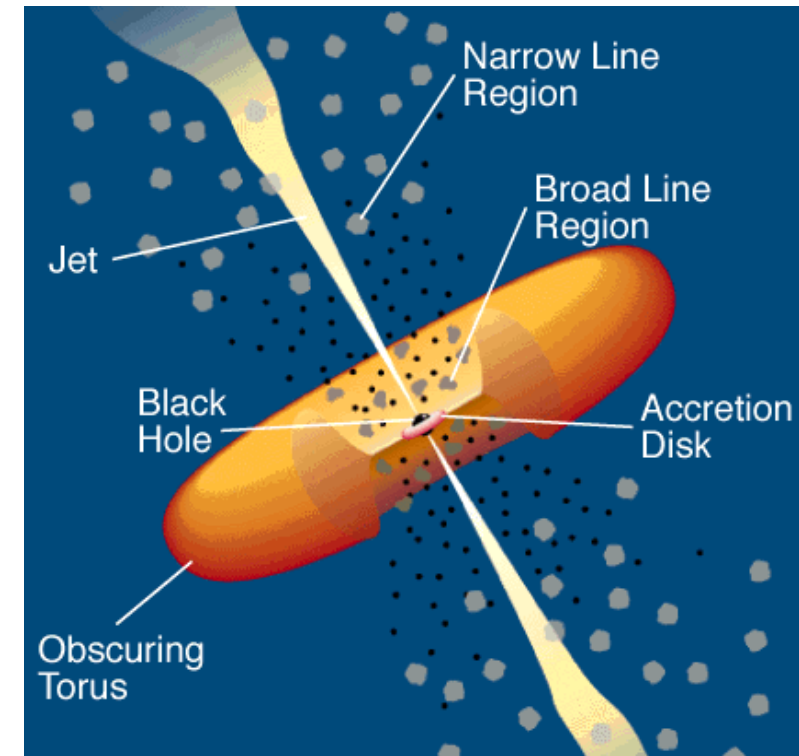


Fig: The structure of AGN
(Urry & Padovani, 1995)

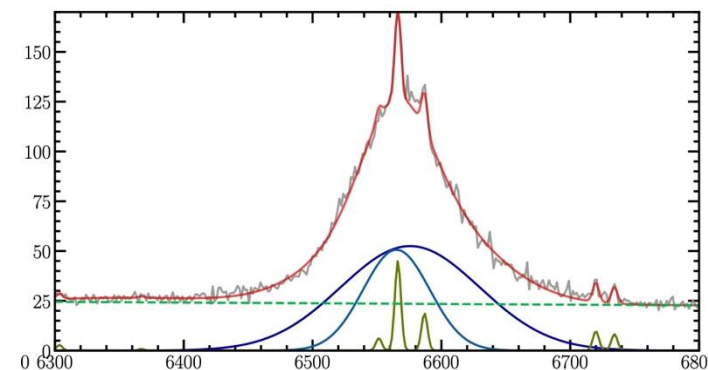


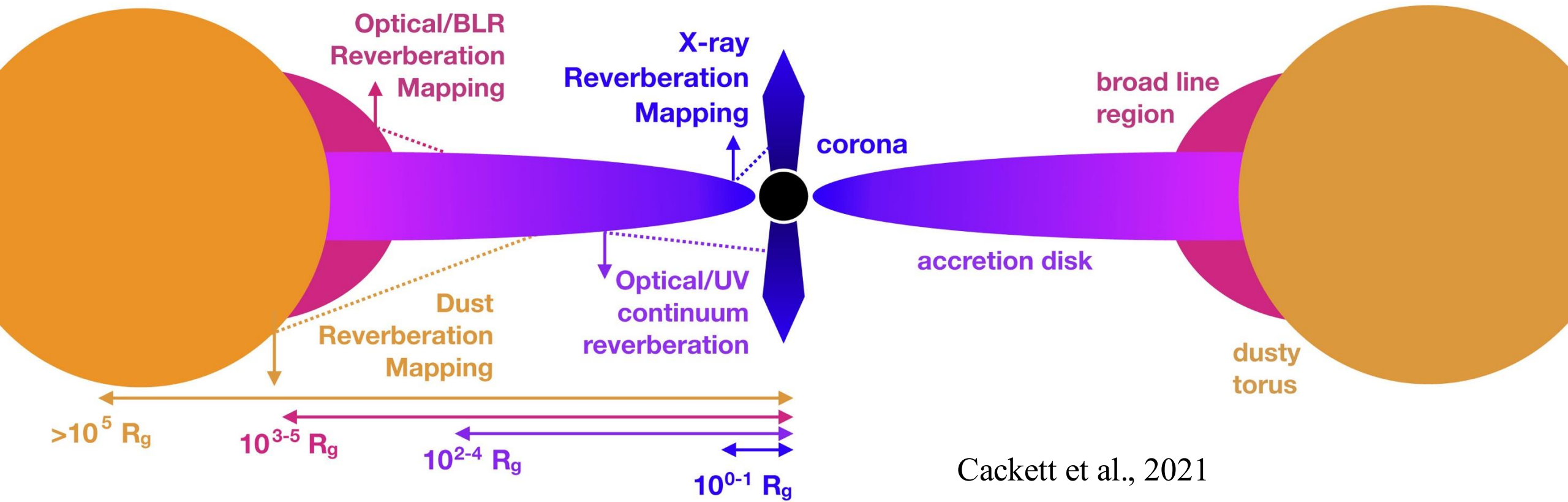
Fig: Broad H α line
of a type-1 AGN
(Rakić, 2022)

AGN emission

Optical/UV: Blackbody emission from the accretion disk, which is optically thick and geometrically thin

X-ray: The Optical/UV photons are scattered to higher energies through inverse Compton scattering by mildly relativistic electrons in the corona

IR: The optical/UV emission heats the dust torus, producing thermal radiation



Prime Focus Spectrograph (PFS)

New multi-object fiber spectrograph

First official observations: March 2025

Advantages:

- Wavelength range: $3800\text{\AA} - 12600\text{\AA}$
($H\alpha$ line: 6563\AA)
- Spectral resolution: $R \sim 3000$
(Sufficient to detect $\text{FWHM} \sim 1000 \text{ km/s}$)
- Deeper, high S/N observation

