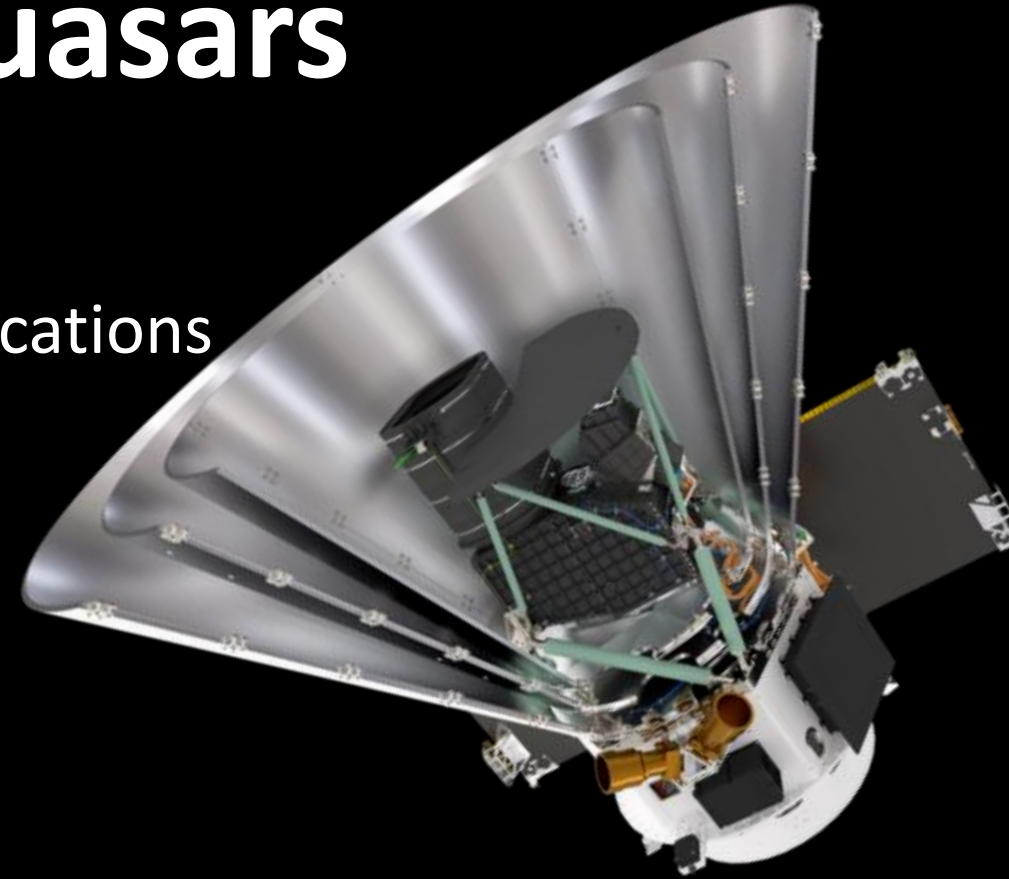


Probing High Redshift Quasars with SPHEREx

Rest Frame Optical Properties and Physical Implications

The 9th KAIST – KASI Network Meeting



Minjae Kim

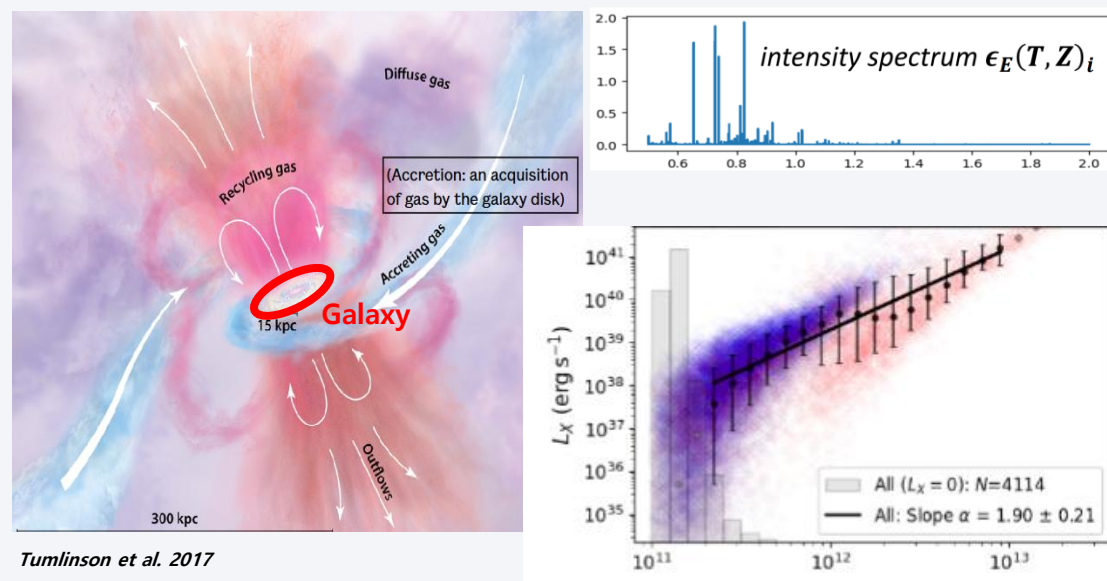
- Undergraduate Student, Department of Physics, KAIST
- Supervised by Junhan Kim (KAIST; ObsCAL) & **Bomee Lee (KASI; SPHEREx)**



Research Overview

Interest: Galaxy Formation and Evolution

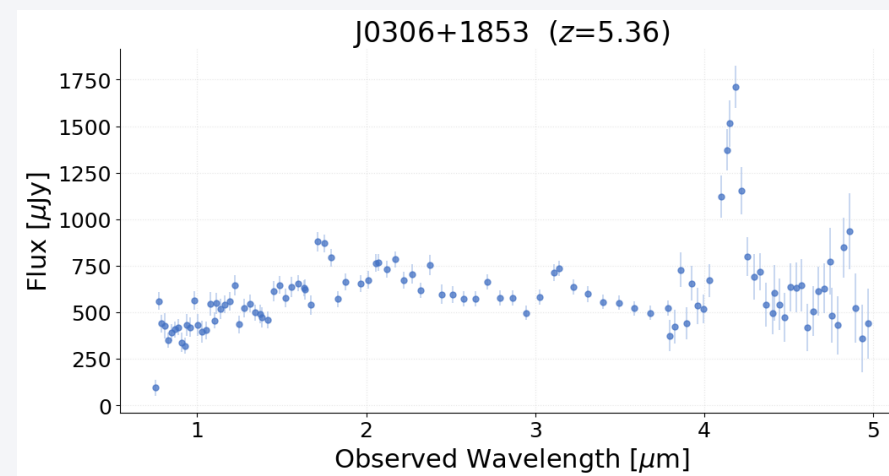
Intrinsic Soft X-ray Emission from the Hot Circumgalactic Medium in IllustrisTNG



24.09 - present

KAIST

SPHEREx Near-Infrared Spectrophotometric View of Luminous Quasars at $z > 5$



26.01 - present

KAIST 한국천문연구원
Korea Astronomy & Space Science Institute

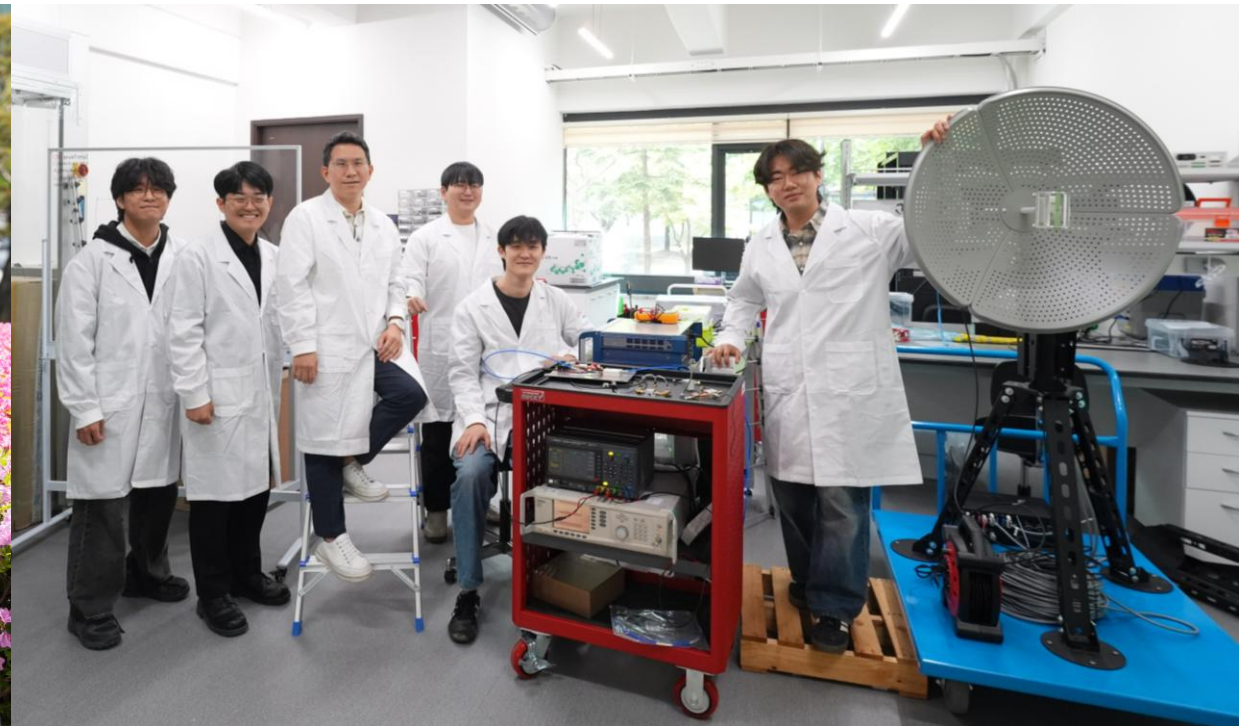
From Simulation to Observation

Simulation-based CGM research sparked a growing interest in observational data analysis



2026-08-26

ObsCAL group photo

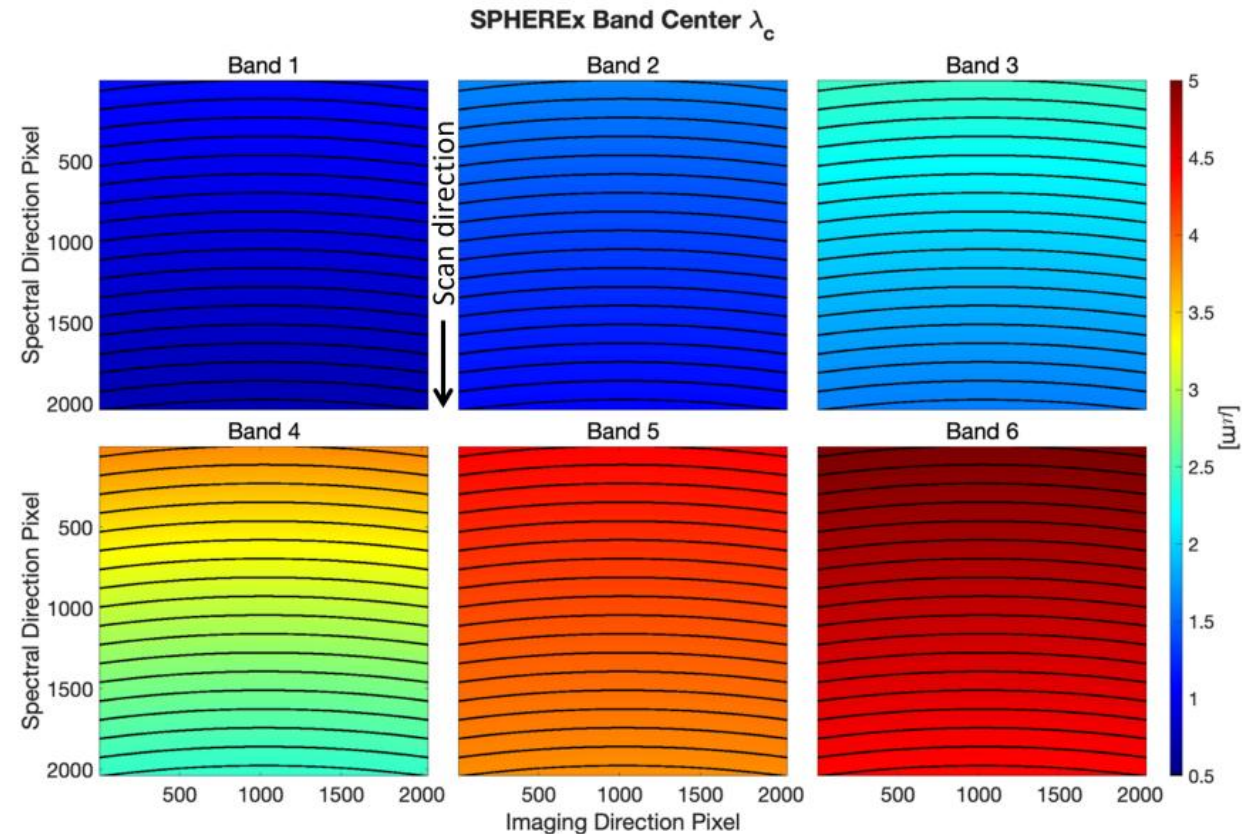


The 9th KAIST – KASI Network Meeting

Motivation: Why High-z Quasars with SPHEREx?

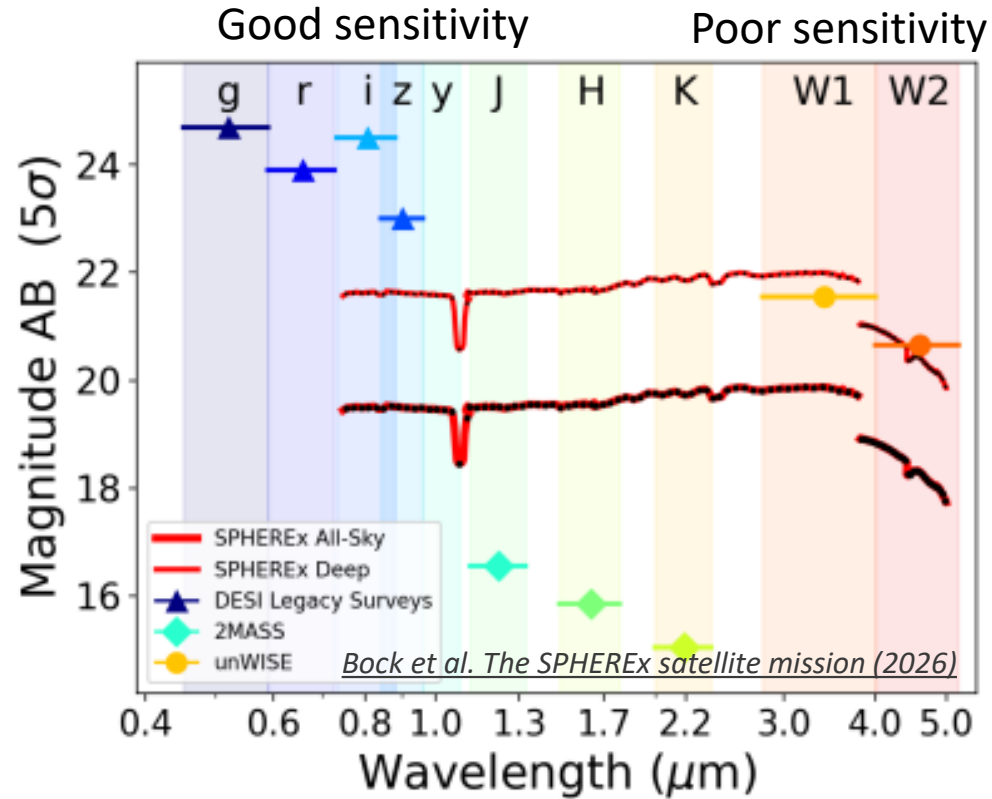
SPHEREx: all-sky spectrophotometric survey

- Low spectral resolution but very wide wavelength coverage (0.75–5 μm)
- Linear Variable Filter (LVF) scans all-sky enabling spectro-photometry
- Large-sample spectral studies beyond traditional spectrographs

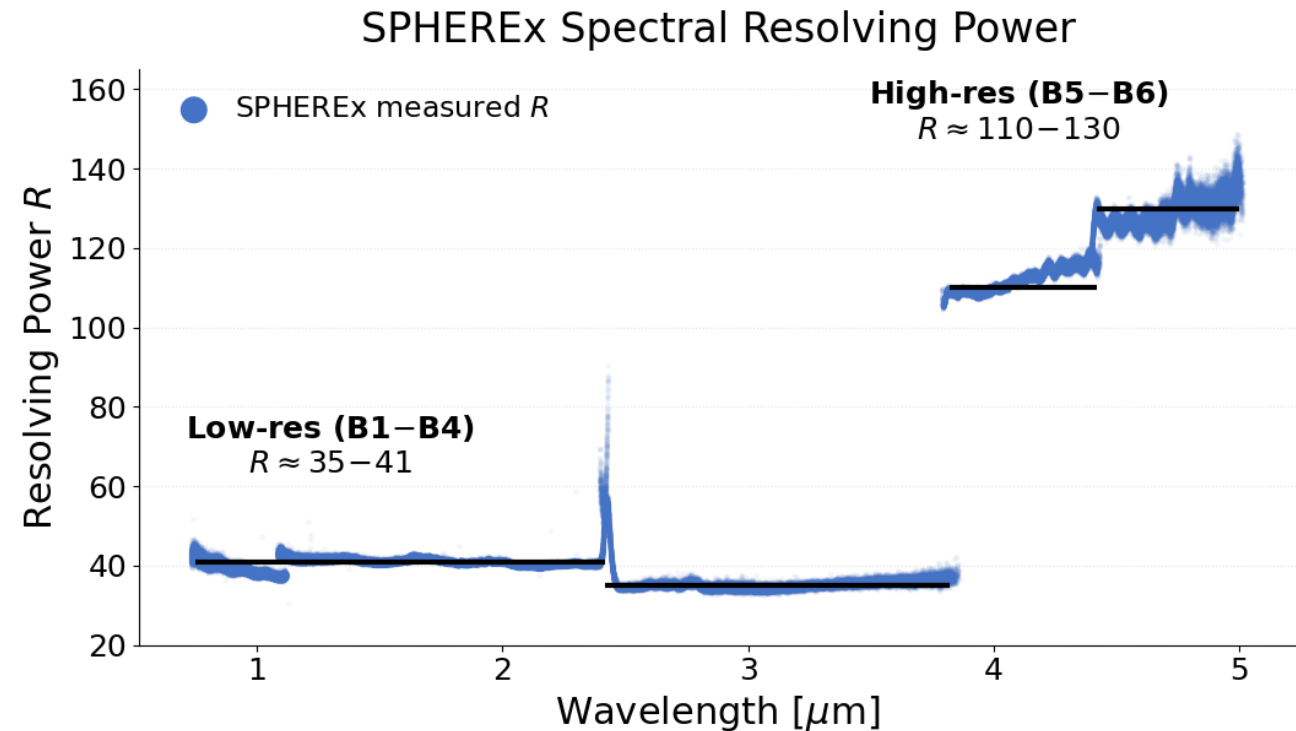


Bock et al. (2026) The SPHEREx satellite mission

Motivation: Why High- z Quasars with SPHEREx?



All-sky and deep field point source sensitivity



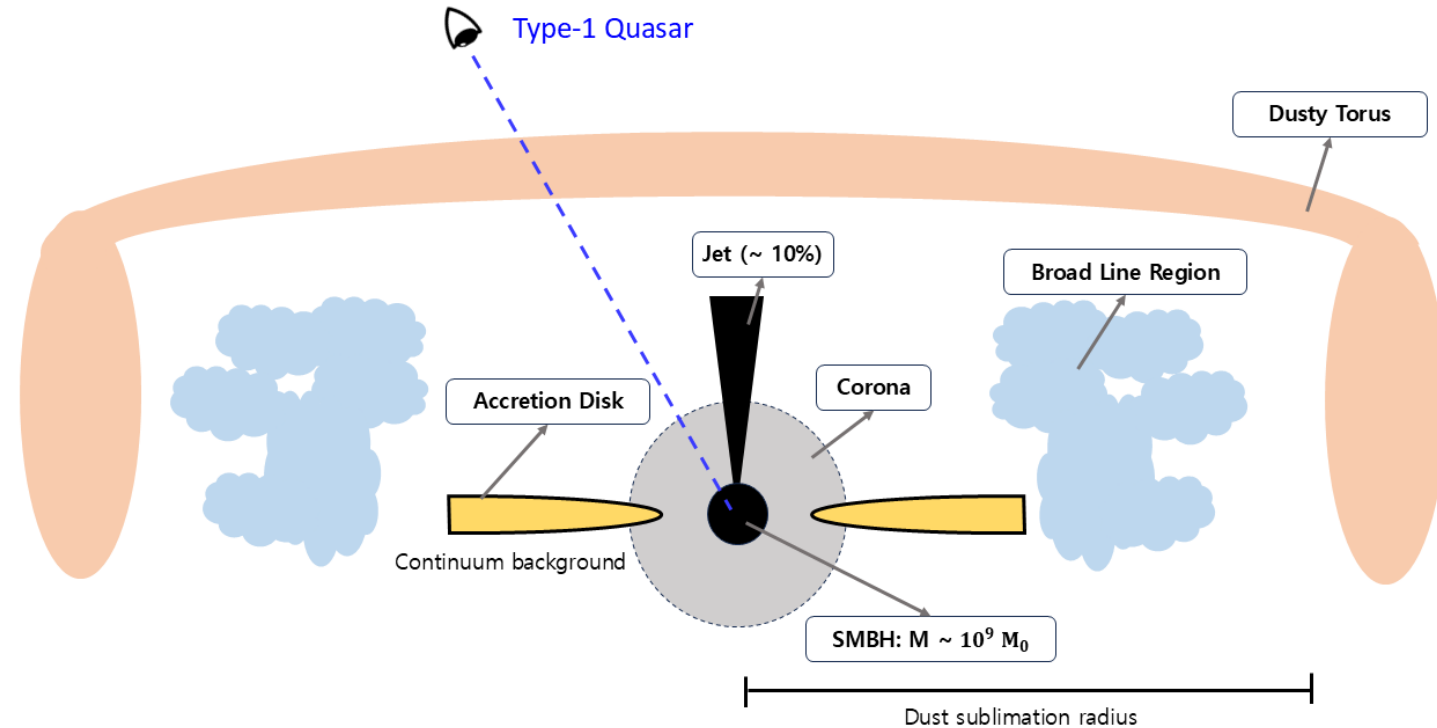
Spectral resolving power R at each wavelength

At B5 & B6, its spectral resolving power is relatively good despite its poor sensitivity.

Motivation: Why High-z Quasars with SPHEREx?

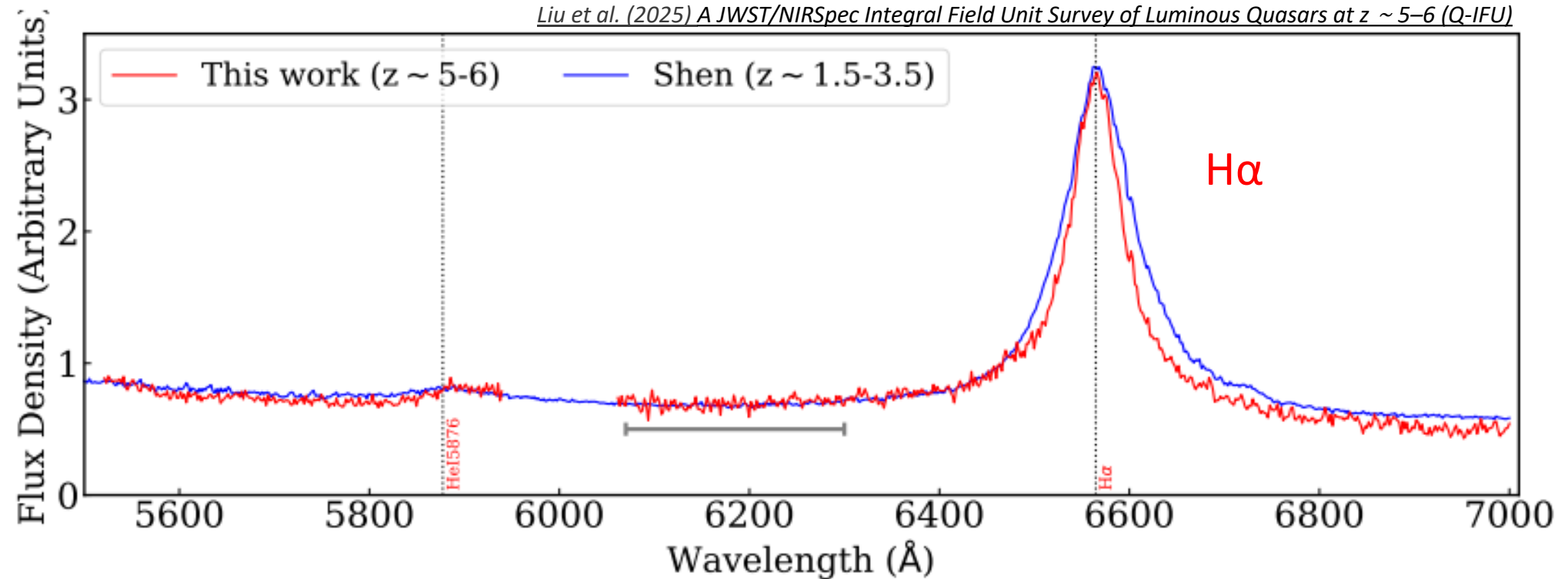
For luminous high-z quasars, SPHEREx can probe the $H\alpha$ signature with better spectral resolving power.

We estimated rest-frame optical properties to get physical implications.



$H\alpha$ (and $H\beta$) is crucial for identifying central blackhole characteristics.

Motivation: Why High-z Quasars with SPHEREx?



Composite spectrum of $z \sim 5 - 6$ quasars through JWST

If $5.0 < z < 6.5$, H α lies in B5 – B6 of SPHEREx where its resolving power is relatively better.

Sample Selection

Ross and Cross (2020)

<https://arxiv.org/pdf/1906.06974>

Fan et al. (2023)

<https://arxiv.org/pdf/2212.06907>

Liu et al. (2025)

<https://arxiv.org/pdf/2511.06085v1>

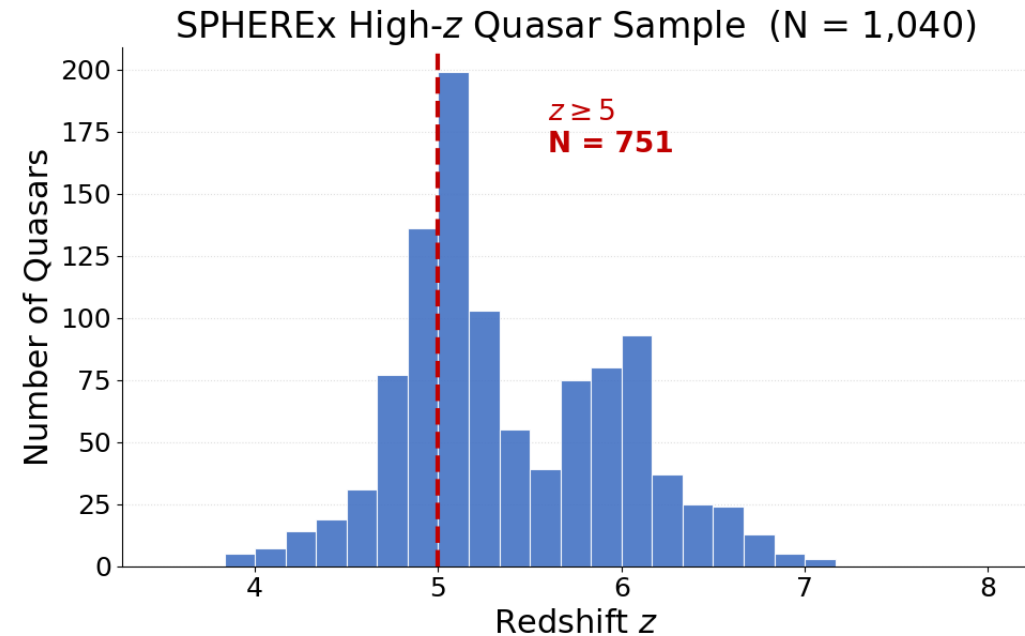
Yang et al. (2024)

<https://arxiv.org/pdf/2302.01777>

Davies et al. (2026)

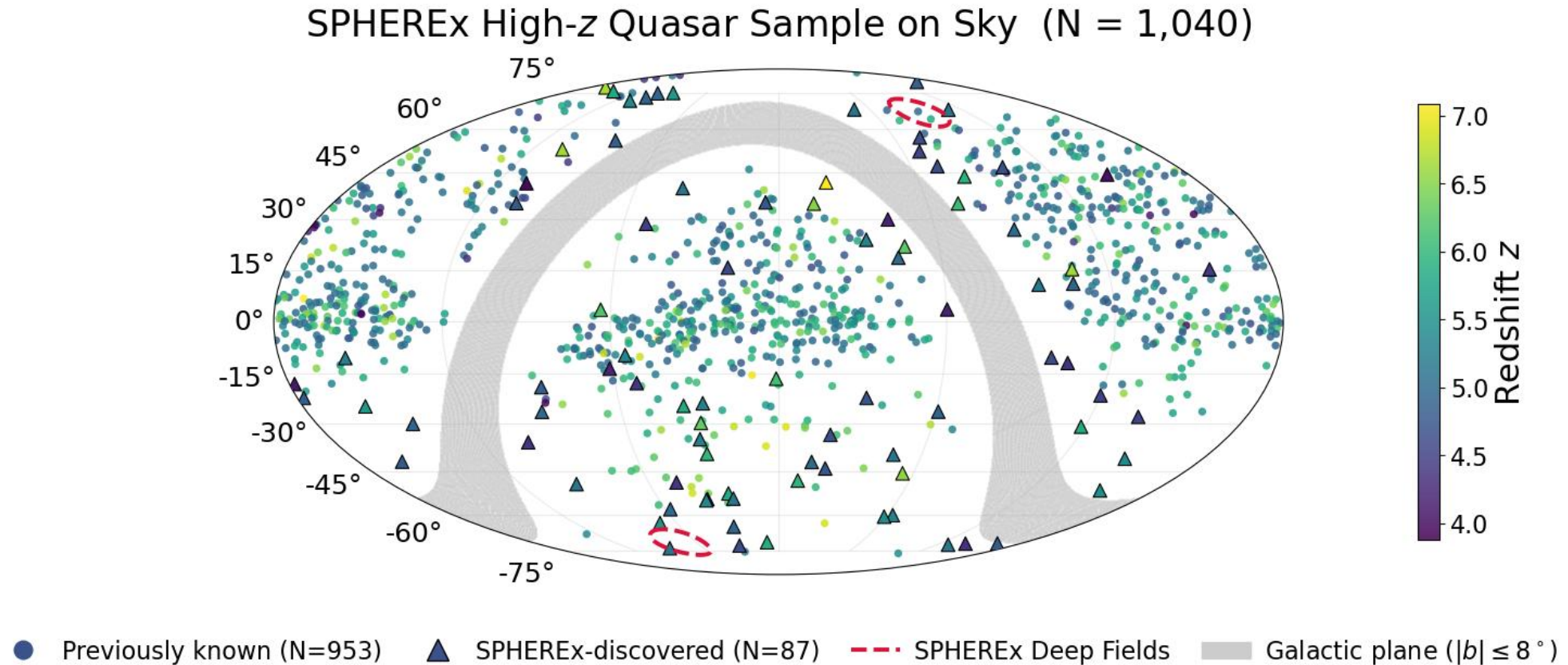
<https://arxiv.org/pdf/2603.10135>

Samples are matched to **SPHEREx** according to its **coordinates & redshift**.



Spectroscopic redshift distribution of sample quasars.
Two peaks are visible at $z \approx 4.8-5.4$ and $z \approx 5.6-6.2$.

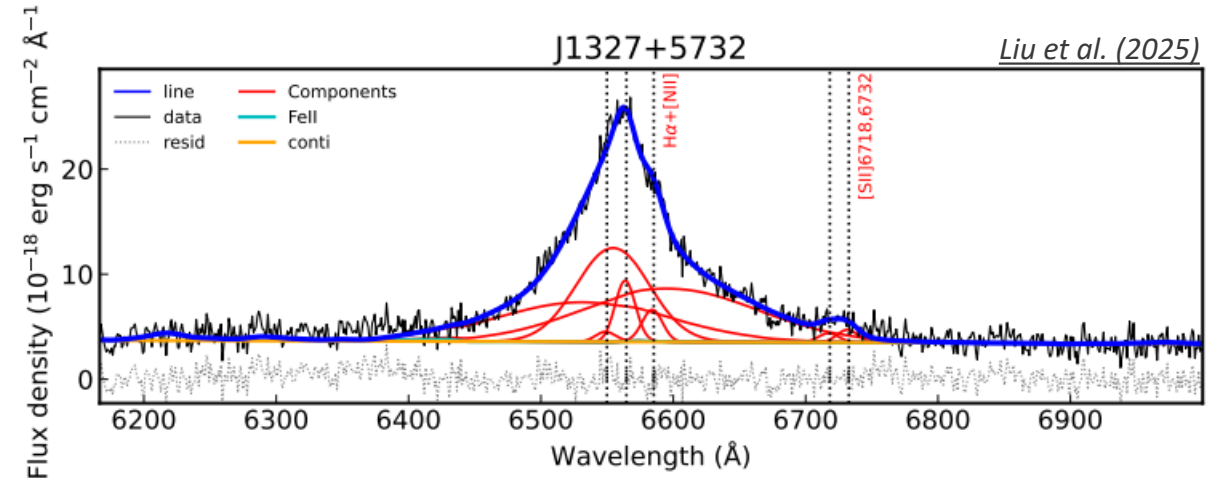
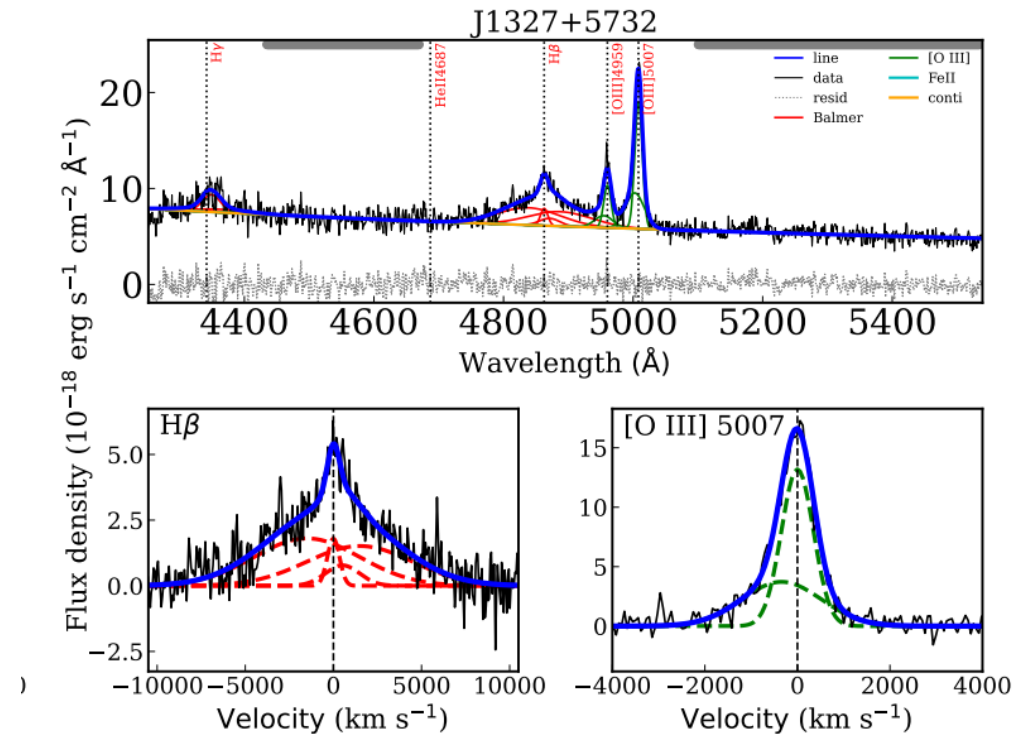
Sample Selection



Mollweide equal-area projection of all N = 1,040 quasars with successful SPHEREx spectral extractions. The gray band indicates the Galactic plane, where quasar detections are sparse due to high dust extinction.

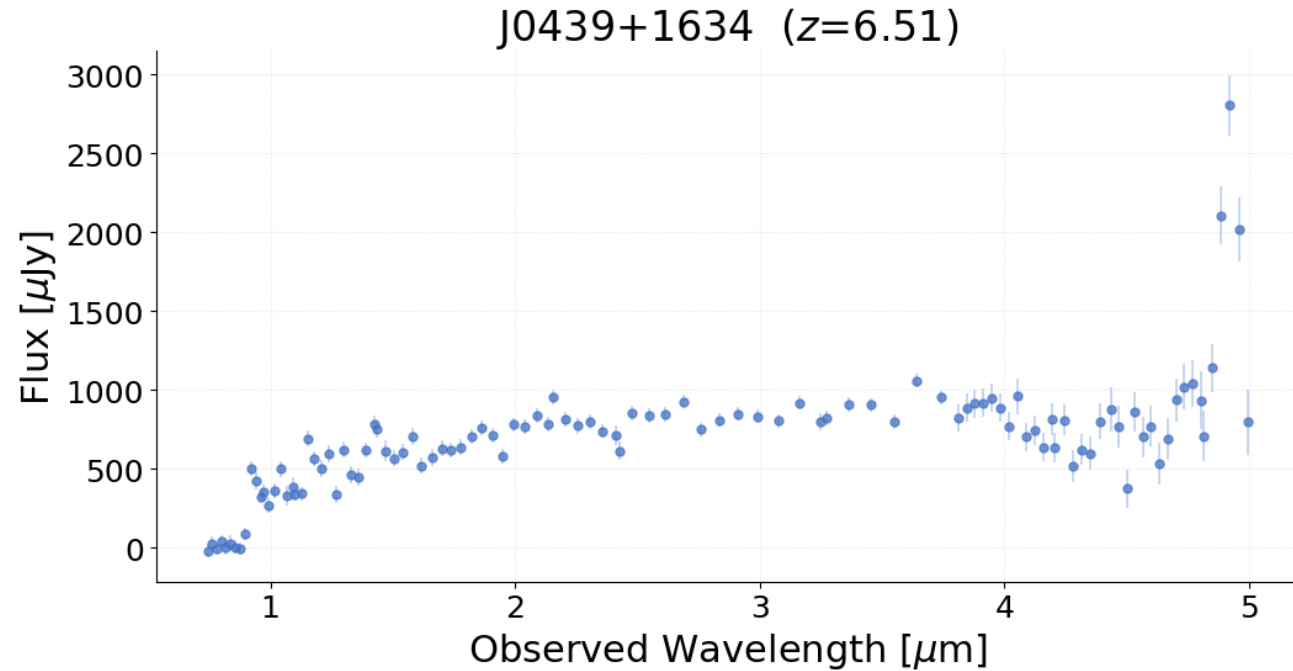
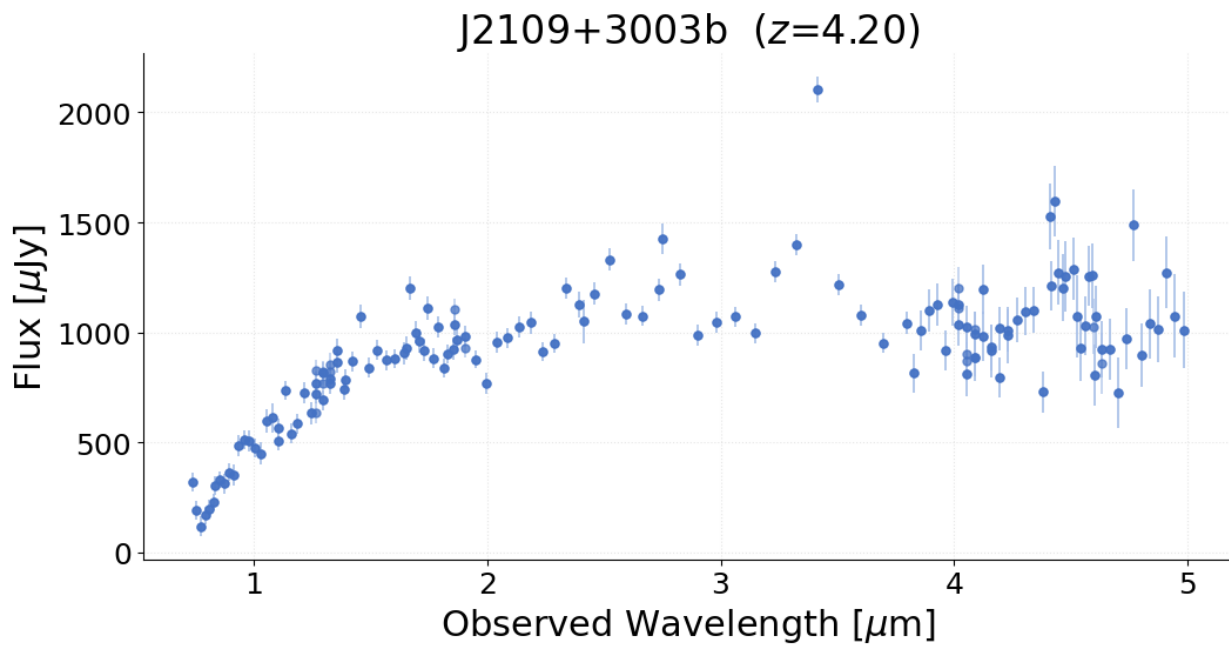
Methodology: Continuum + Single Gaussian

Originally, modeling spectral energy distribution (SED) of quasars encompasses complex compositions. (e.g. Fe II pseudo-continuum, [O III] doublets, [N II] doublets.)



Spectral decomposition of high-z quasar nearby H β (left) and H α (right)

Spectrum Data: Example



Methodology: Continuum + Single Gaussian

Due to its low spectral resolution, we used **single gaussian** to model **H α** and **simple power law** to model **continuum**.

- To avoid overfitting.
- But, our fitting should be uncertain because of our low spectral resolving power.
- How to evaluate uncertainty of fitting? Noise – injection MC approach!

Goal: Estimation of **physical properties** of **central BH**

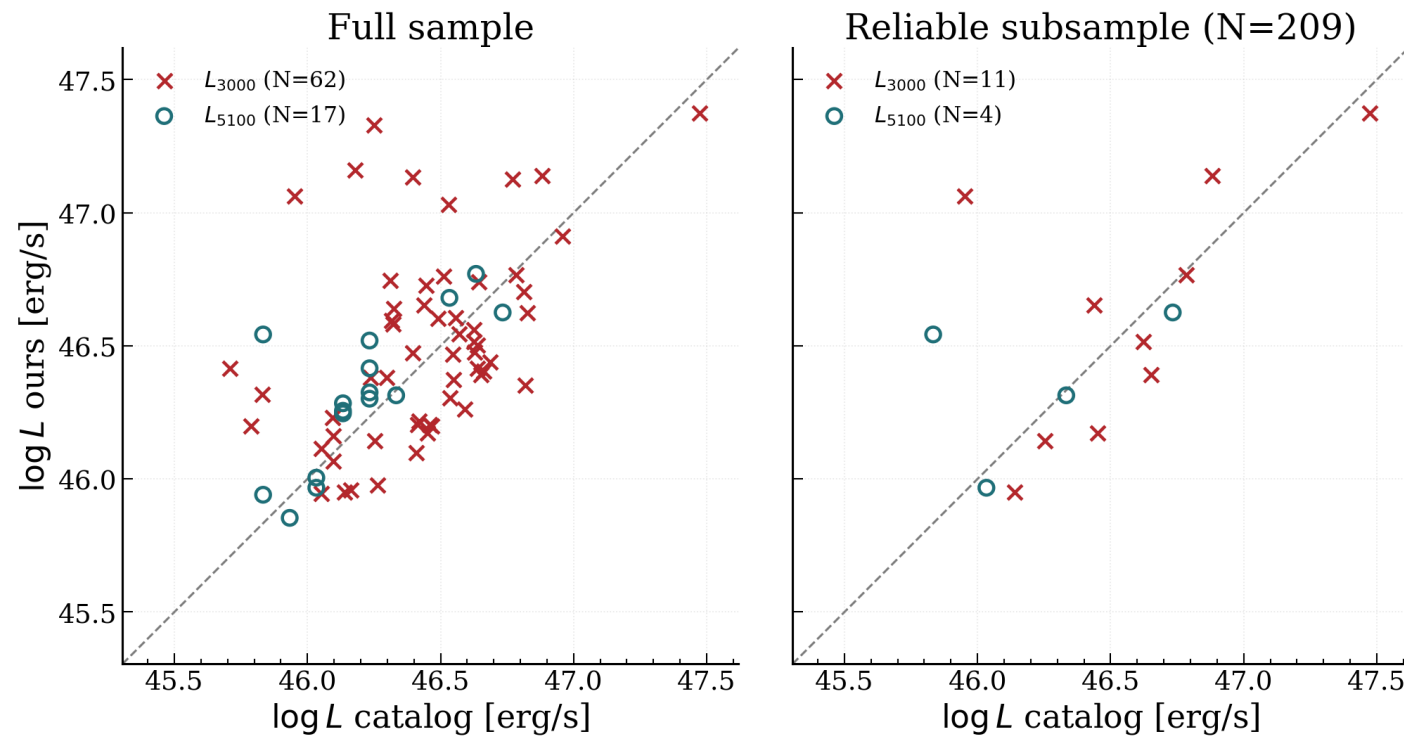
Validation Check with cross-matching

With $N = 14$ samples with the $H\alpha$ (or $H\beta$) catalog value, we cross-matched to validate our fitting method*. Here, we didn't care the data quality that much. Just to evaluate our fitting method*

Validation Check: Continuum

L_{5100} is estimated in our fitting, but inferred from $L_{5100} = L_{\text{bol}}/9.26$ in catalog, L_{3000} is inferred from extrapolation in our fitting to compare L_{3000} in catalog.

Reliable subsample refers to the fitted results that satisfied quality check criteria.

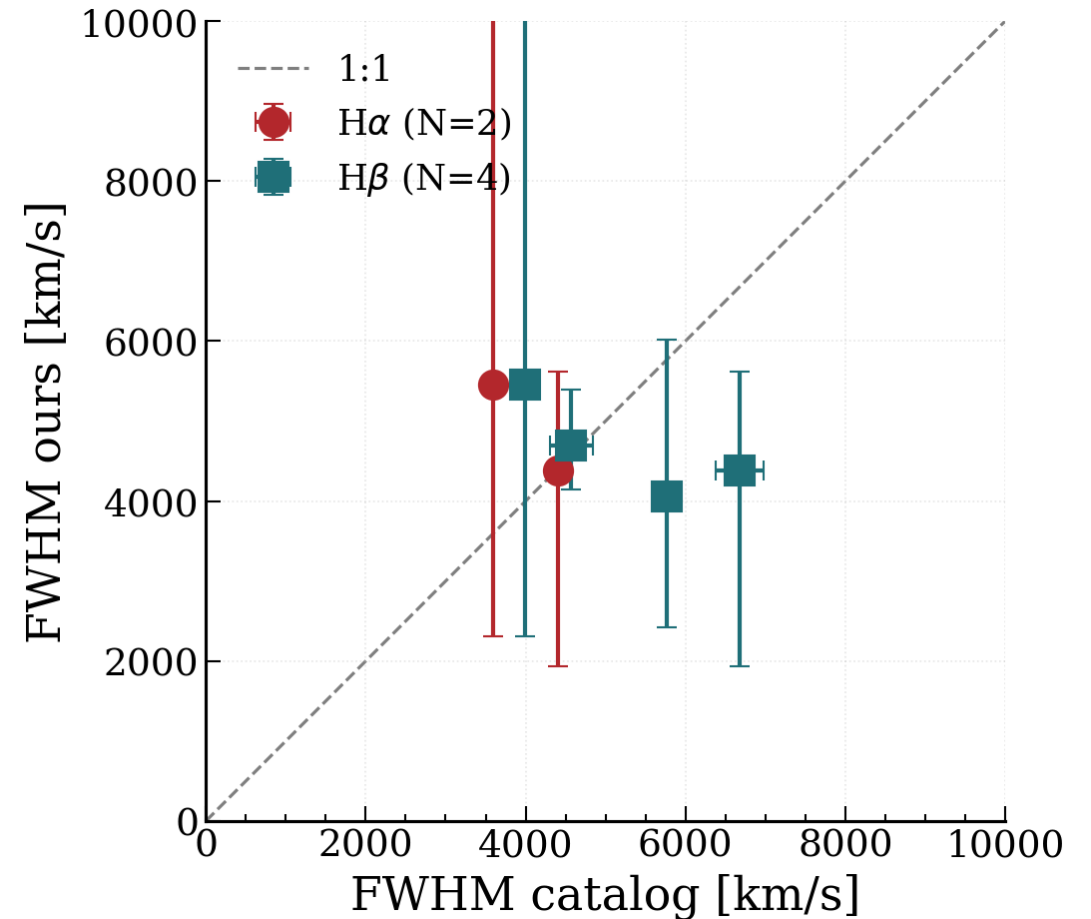


Comparison of L_{5100} and L_{3000} with the catalog value.

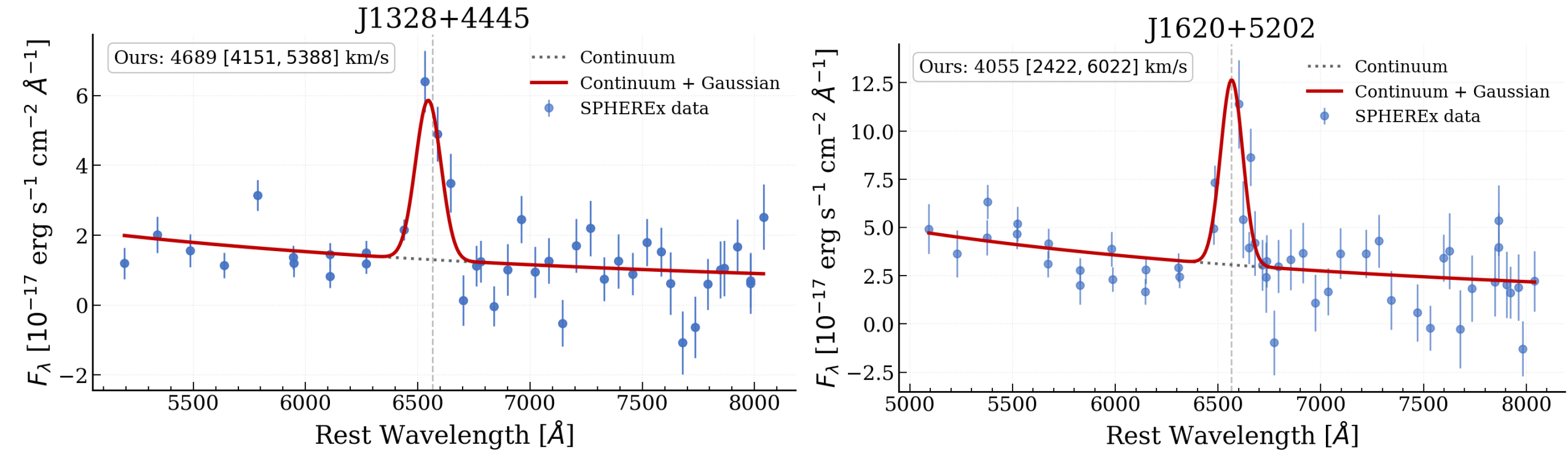
Validation Check: $H\alpha$ Gaussian

Our estimated FWHM of $H\alpha$ is broadly consistent with catalog value from JWST.

- Huge uncertainty due to its low data quality of matched sample

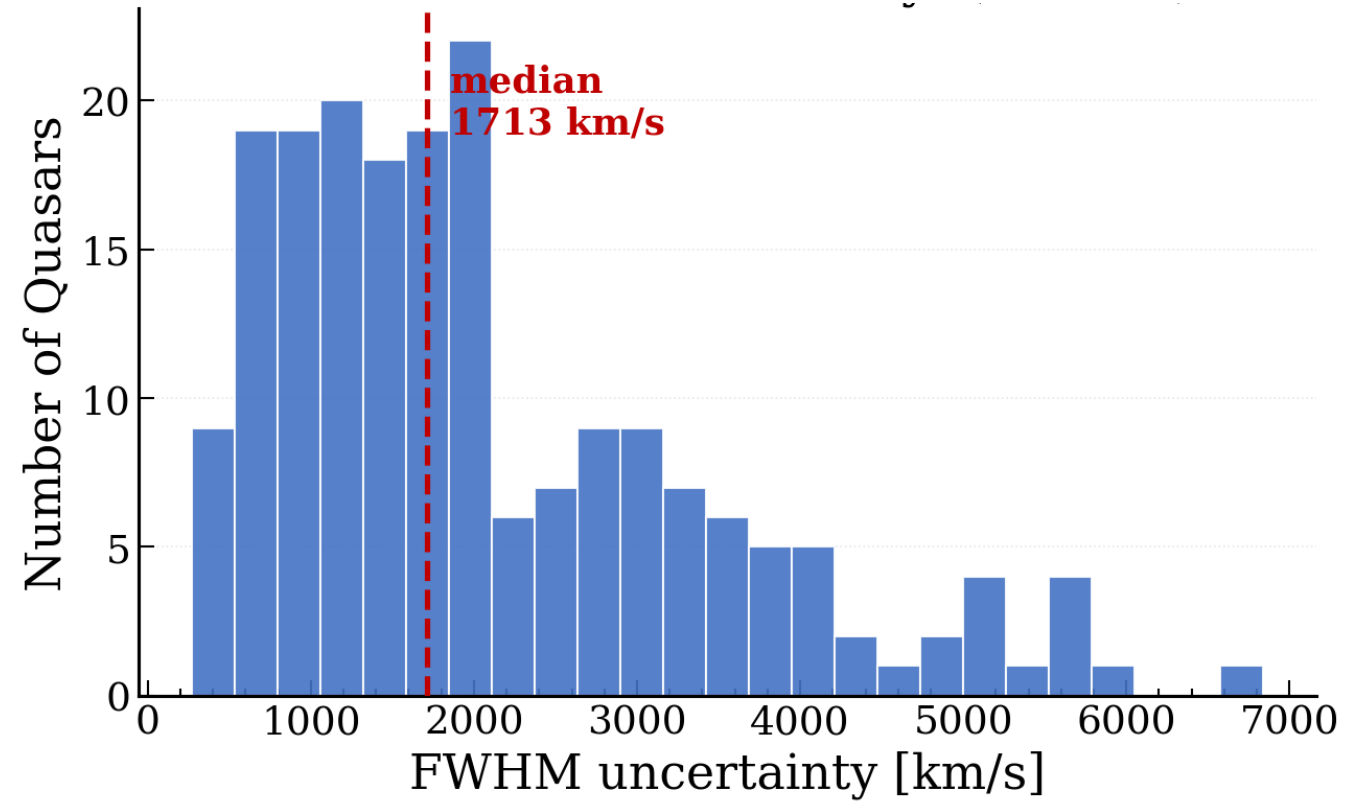
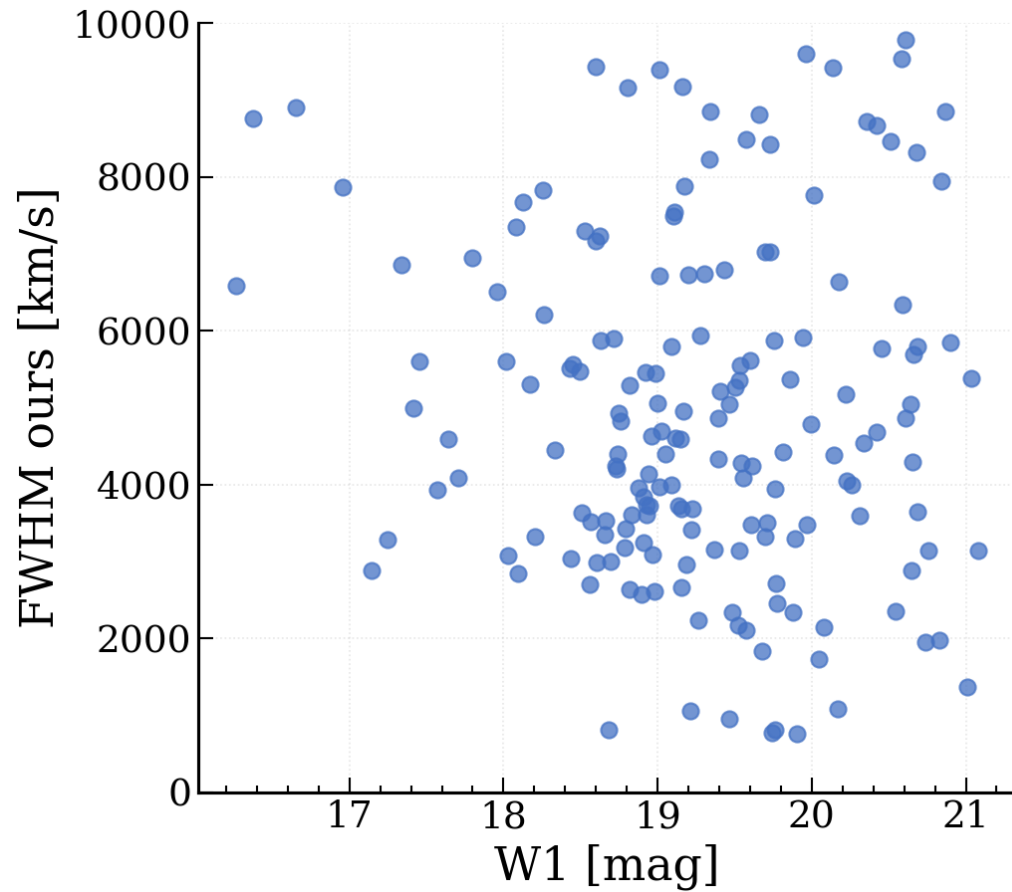


Validation Check: $H\alpha$ Gaussian



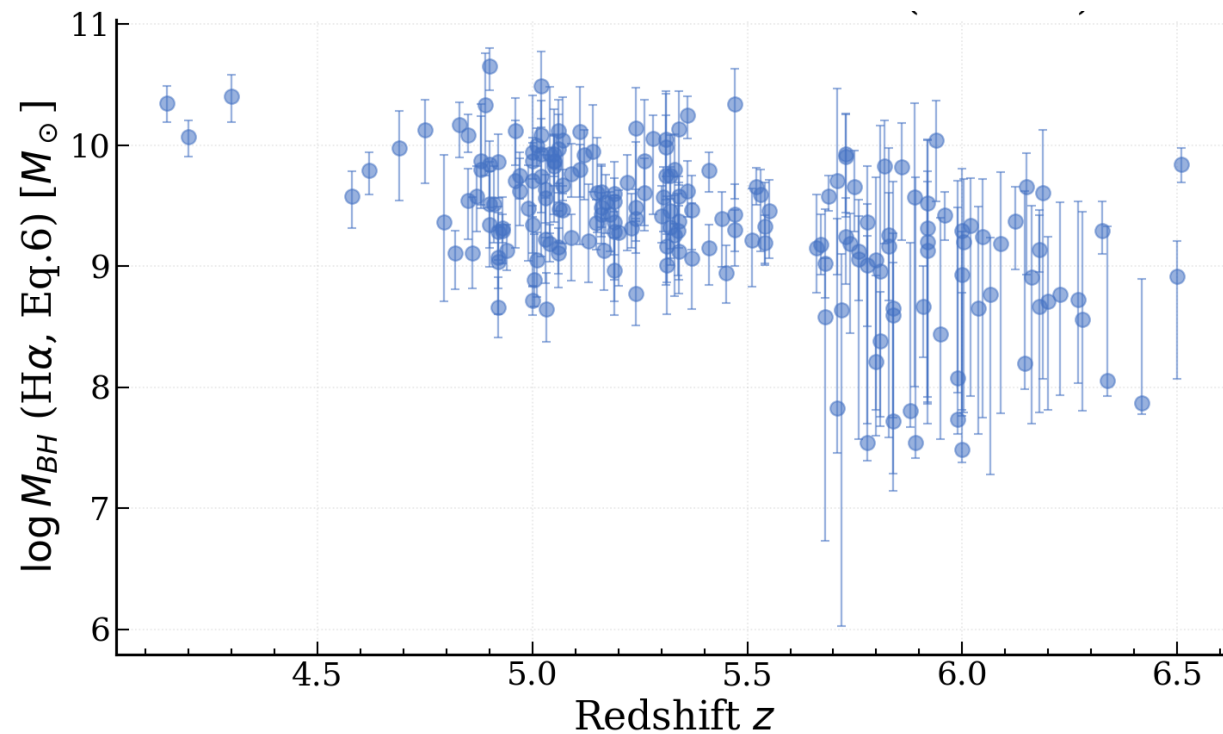
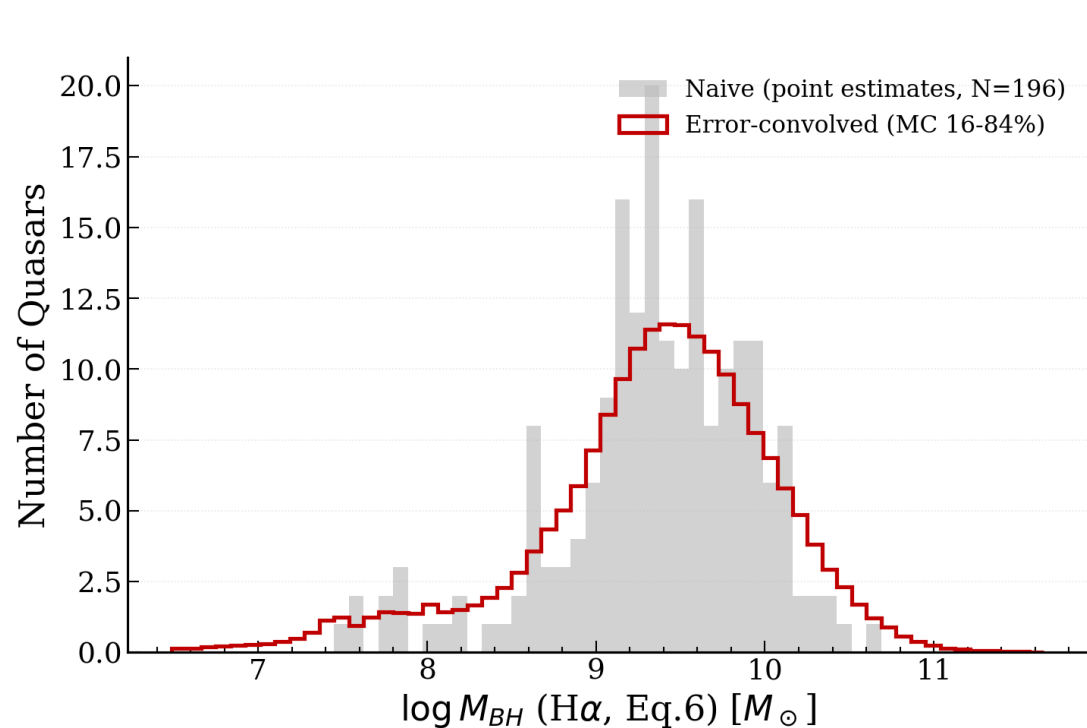
Spectrum fitting examples of cross-matched samples with Liu et al. (2025)

Preliminary Results: FWHM and BH Mass



FWHM vs magnitude (left) & FWHM uncertainty (Right)

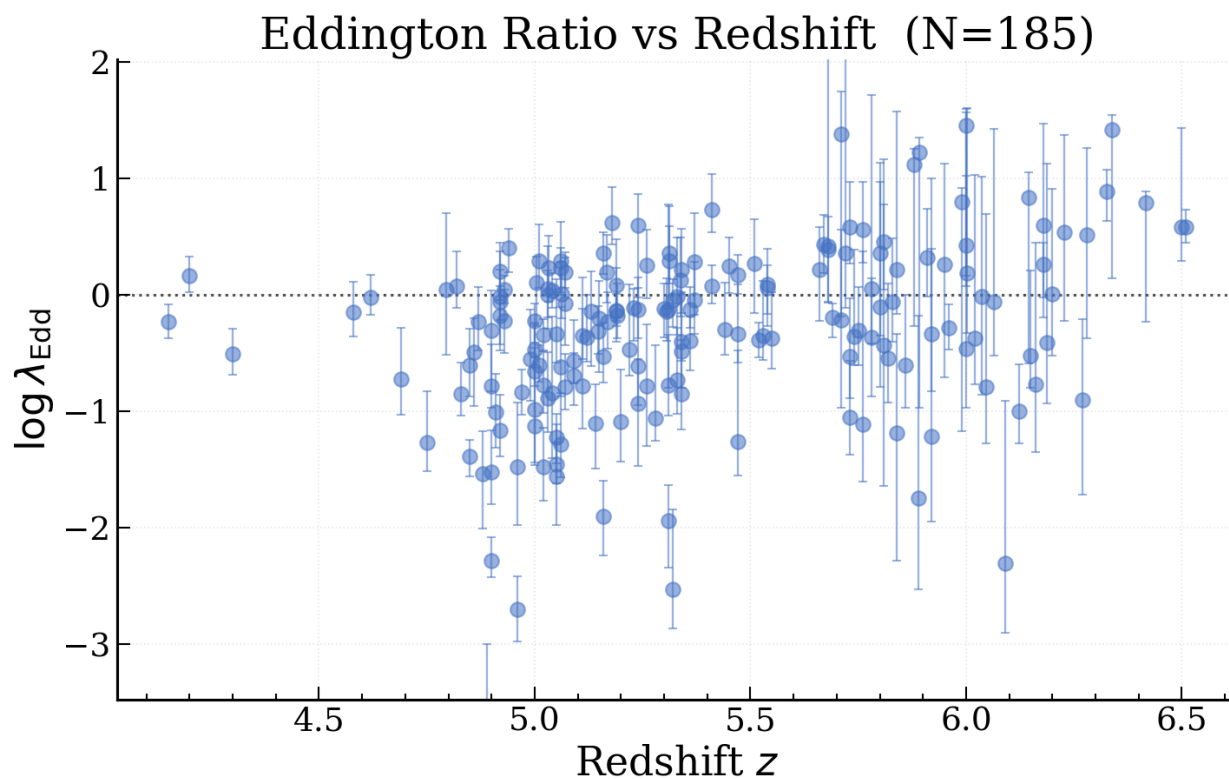
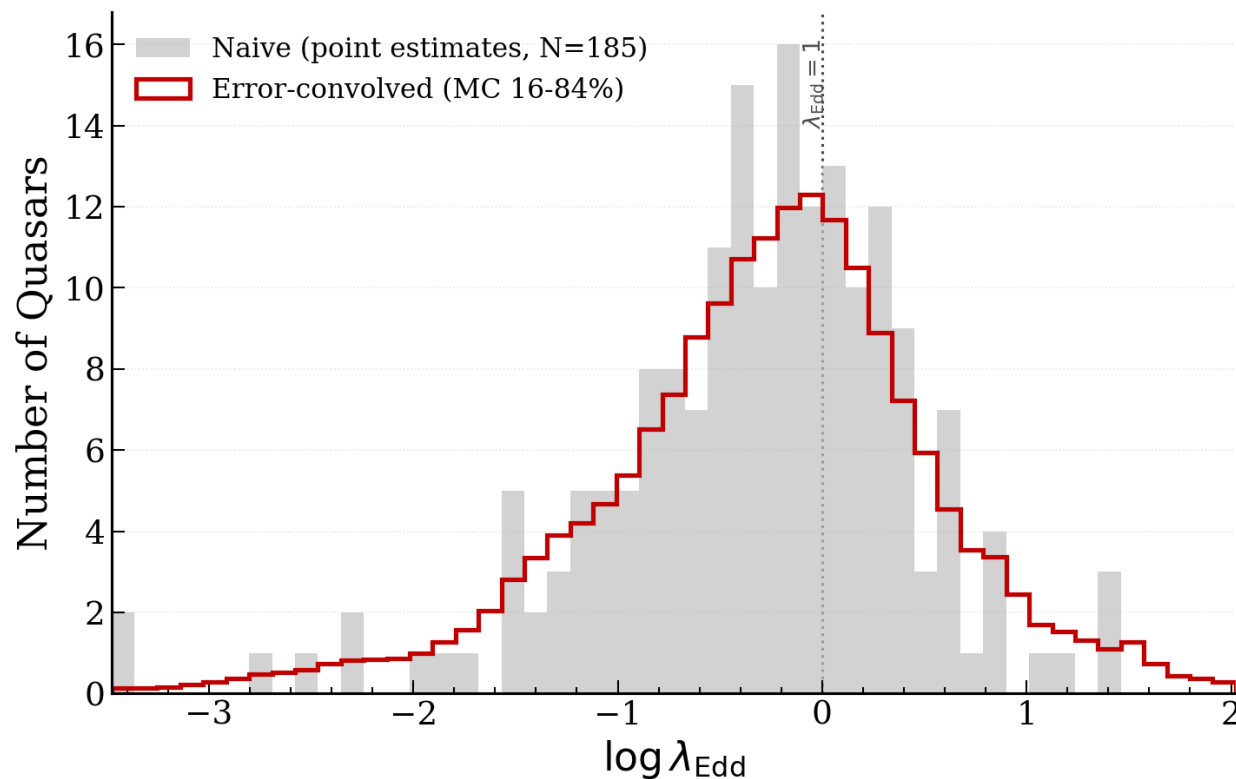
Preliminary Results: FWHM and BH Mass



BH mass estimation (left) and comparison with redshift (right)

Preliminary Results: Eddington ratio

Eddington ratio $\equiv L_{\text{bol}}/L_{\text{Edd}}$ — luminosity relative to the radiation-pressure/gravity balance limit; a proxy for relative accretion rate



Eddington ratio estimation (left) and comparison with redshift (right)

Conclusion & Future Works

1. We demonstrate that SPHEREx can probe rest-frame optical spectral features of high-redshift quasars.
2. This enables estimates of key physical parameters — BH mass and Eddington ratio — offering insight into the early growth of supermassive black holes.

Future Work

- Refine quality-check criteria for the fitting method
- Expand the sample and compare with previous studies for more statistically robust conclusions

Key References

1. Ross, N. P. & Cross, N. J. G. (2020), The Near and Mid-infrared Photometric Properties of Known Redshift $z \geq 5$ Quasars, MNRAS, 494, 789
2. Fan, X., Bañados, E., & Simcoe, R. A. (2023), Quasars and the Intergalactic Medium at Cosmic Dawn, ARA&A, 61, 373
3. Liu, W. et al. (2025), A JWST/NIRSpec Integral Field Unit Survey of Luminous Quasars at $z \sim 5-6$ (Q-IFU): Rest-frame Optical Nuclear Properties and Extended Nebulae
4. Yang, J., Fan, X. et al. (2024), DESI $z \gtrsim 5$ Quasar Survey I. A First Sample of 400 New Quasars at $z \sim 4.7-6.6$
5. Davies, F. B. et al. (2026), Three Hundred Quasars from the Couch: A First Look at High-redshift Quasar Discovery with SPHEREx
6. Bock, J. et al. (2026), The SPHEREx Satellite Mission
7. Greene, J. E. & Ho, L. C. (2005), Estimating Black Hole Masses in Active Galaxies Using the H α Emission Line, ApJ, 630, 122
8. Richards, G. T. et al. (2006), Spectral Energy Distributions and Multiwavelength Selection of Type 1 Quasars, ApJS, 166, 470

Appendix: Current Fitting Rule

Rule: chi-square minimization with constraint

- Bound: $\sigma \leq 10000 \text{ km/s}$, $|z - z_{\text{sys}}| \leq 0.1$
- 50 noise-injected MC to find best-fit model
- Corrected instrumental broadening from weak spectral resolving power
- Evaluate fitting mechanism cross-matching with values from JWST study (Liu 2025)
- Key parameter: **FWHM** of **H α** , **L₅₁₀₀** from **continuum model**

Appendix: How to Estimate Physical Implications

