SPHEREx Near-Infrared Spectrophotometric View of Luminous Quasars at z > 5: Rest-Frame Optical Properties and Physical Implications

UST-KASI Internship Final Presentation

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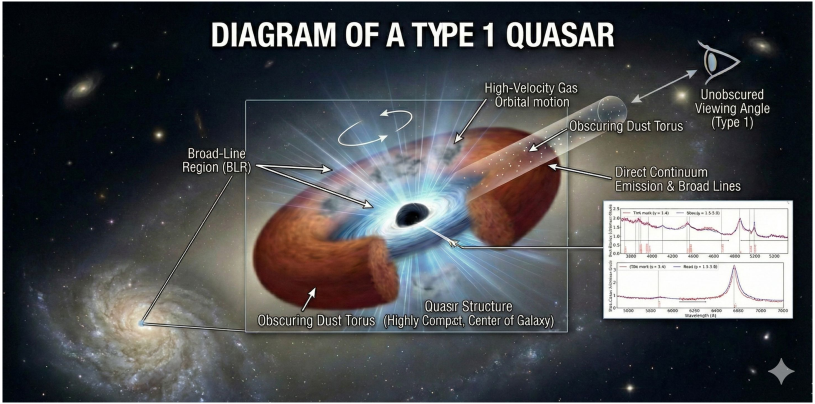
Outline

1. Introduction
2. Data and Sample Selection
3. Methodology
4. Preliminary Results
5. Summary & Future Work

Scientific Importance : Very High-redshift ($z \gtrsim 5$) Quasars (VHzQs)



Conceptual schematic of a quasar. From here on, we focus on Type-1 quasars
AI-generated image created with Google Gemini on 2026-02-03.

- Probes for early supermassive black hole (SMBH) growth ($M_{\rm BH} \gtrsim 10^9 M_\odot$).
- Key tracers of the Intergalactic Medium (IGM) during the Epoch of Reionization.

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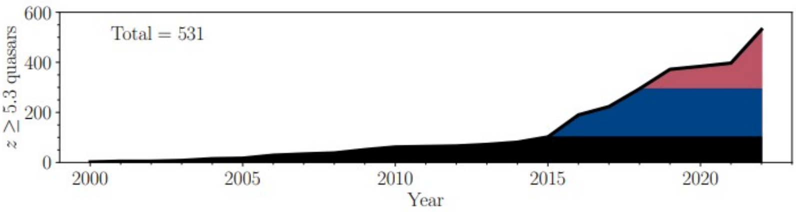
Current Limitations of the VHzQs Study



Cumulative number of known VHzQs ($z > 5.3$) (Fan 2023).

- Mostly identified via optical/NIR color selection ("dropouts").
- High contamination from M/L/T dwarfs and dusty galaxies.
- Key optical lines (Hβ, Hα) shift to $\lambda \gtrsim 3\mu$m.

Implication: These motivate that observing and studying VHzQs in the IR becomes increasingly important.

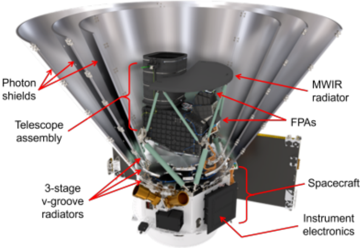
SPHEREx Mission Overview

SPHEREx at a glance

- All-sky near-IR spectrophotometric survey with a 6-month cadence.
- Wavelength coverage: 0.75–5 μm (**Linear Variable Filter(LVF) spectroscopy**).
- Low Spectral resolution: $R \sim 35$–130.
- Key deliverable: uniform spectra/SEDs for hundreds of millions of sources.

Three main scientific goals

- Inflationary Cosmology
- History of Galaxy Formation
- Interstellar Ices



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SPHEREx

Why SPHEREx? Comparison with JWST

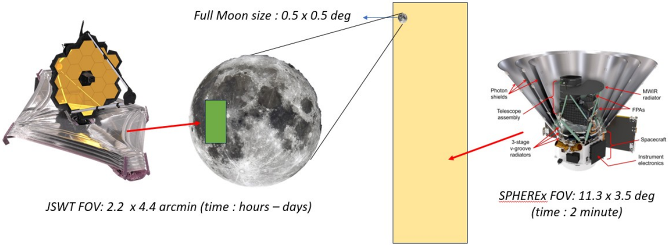
Similarity: Both observe in the IR, enabling access to rest-frame optical diagnostics at high z.

JWST (Pros/Cons)

- High spectral resolution ($R \sim 2200$).
- Small Field of View (FOV).
- Scheduling constraints.

SPHEREx (Pros/Cons)

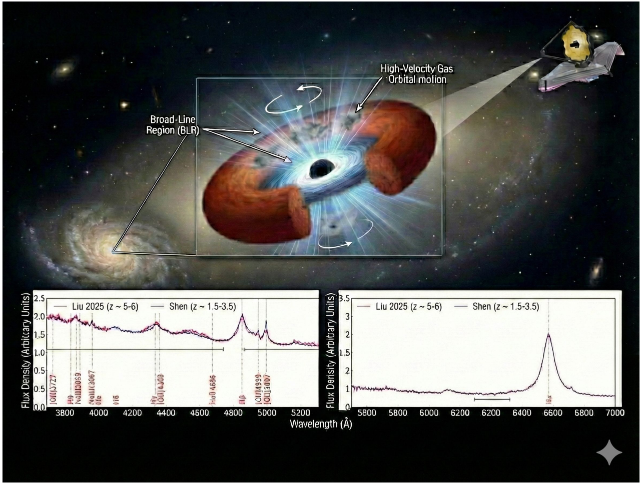
- Wide FOV ($3.5^\circ \times 11.5^\circ$) & all-sky survey (6-month cadence).
- Spectrophotometry from LVF (0.75–5 μm).
- Enables homogeneous, wide-area selection and population studies.
- **Cons:** Low spectral resolution ($R \sim 35$–130).



FOV comparison: JWST vs SPHEREx

Takeaway: Narrow & deep (JWST) vs Broad & shallow (SPHEREx)

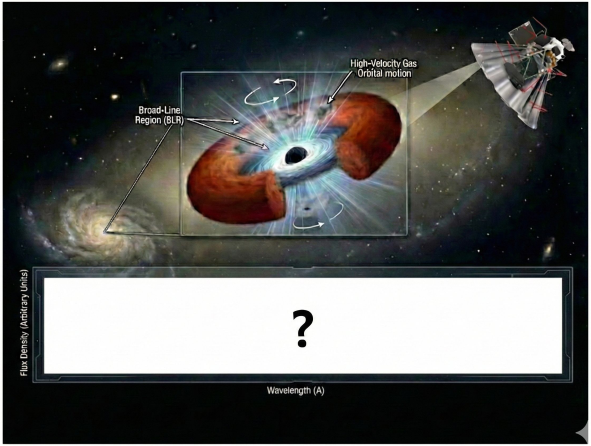
Former JWST study (Liu et al. 2025)



AI-generated image created with Google Gemini on 2026-02-03.

High spectroscopy quality, but limited sample size.

Goal of this Study: SPHEREx



AI-generated image created with Google Gemini on 2026-02-03.

Use SPHEREx with statistical approach to analyze spectral signatures (Hα, Hβ) and estimate physical parameters of VHzQs.

Data Compilation

1. **Catalog Integration ($N = 1182$)**
   - Sources: Ross et al. (2020), Yang et al. (2023, DESI), etc. ([3, 5, 6, 8])
   - Removed duplicates (matching RA, Dec, z).

2. **SPHEREx Matching ($N = 887$)**
   - Matched with SPHEREx Reference Catalog & Successful spectrum measurement.
   - **Dust Extinction Correction:**
     - Used Corrected SFD (CSFD) map ($R_V = 3.1$).
     - Equation: $A_V = R_V \times 0.86 \times E(B - V)$. ([2] and [4])
     - Created an integrated catalog (.parquet) including SPHEREx observation results.

3. **Final Bright Subsample ($N = 457$)**
   - Selection Criteria: $W1 < 20$ OR $z < 21$ (supplementary).

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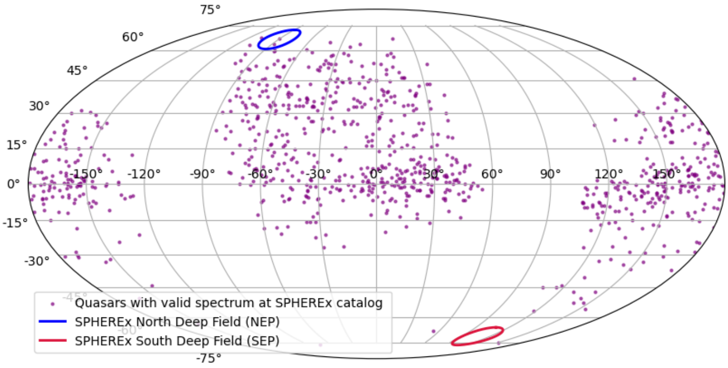
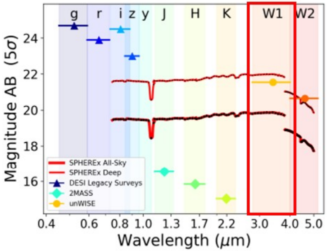


Integrated catalog sky distribution .



SPHEREx sensitivity (Bock et al. 2025)

These plots summarize (i) the sky distribution of our compiled VHzQ sample and (ii) the survey depth that governs detectability.

Sample Distribution (cont.)

* Note the relative deficit between $z \approx 5.4$ and 5.6, likely due to selection incompleteness in previous surveys.

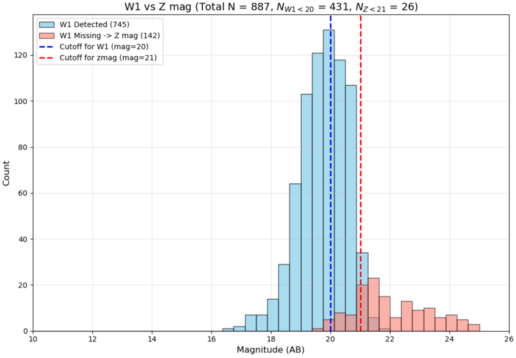


Figure: Photometry ($W1$ vs $zmag$)

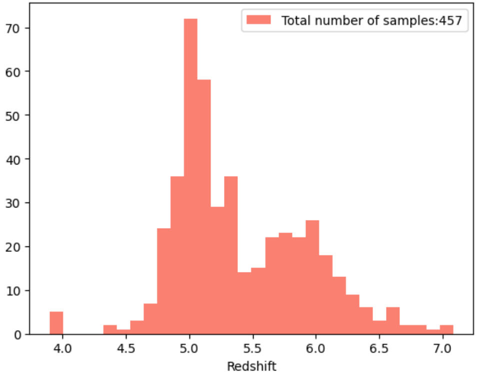


Figure: Redshift Distribution

Spectral Fitting Strategy : Hα Broad Line Region (BLR) emission

Target Wavelengths

- **Band B5** (3.82–4.42 μm, $R = 110$) & **Band B6** (4.42–5.00 μm, $R = 130$).
- Mainly targeting redshifted Hα. For Hβ, R $\sim$ 35, which makes it's hard to fit.

Modeling Components

1. **Continuum:** Single power-law fit.
2. **Redshift Uncertainty:** Allowed to vary within ± 0.05 based on Table 3 in [5]
3. **Emission Lines: The most challenging part**
   - Single Gaussian fits tend to overestimate width.
   - Current remedy: 1–3 Broad Gaussian components.
   - Approsimate scale : FWHM $= 220$ Å $\leftrightarrow \sigma_v = 1.0 \times 10^4$ km/s.

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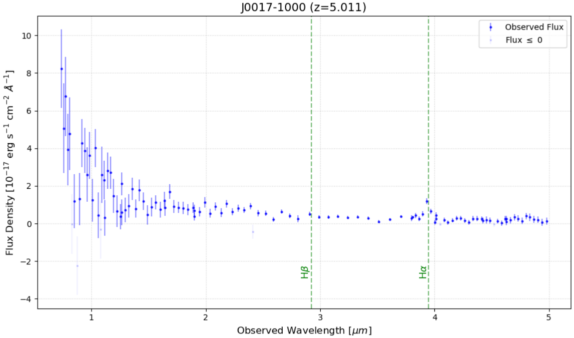
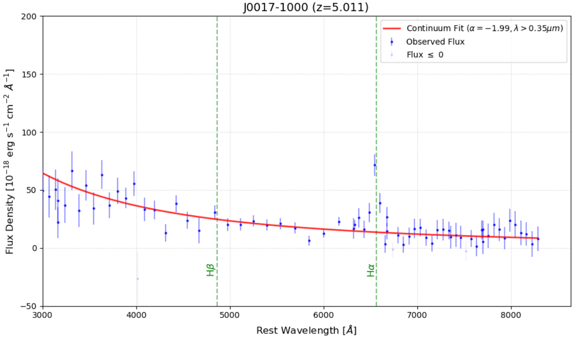
Spectral Energy Distribution: Hα BLR Emission



Observed-frame



Rest-frame

Observations

- Successful detection of broad Hα from the BLR in bright samples.
- **Challenge:** Blending with [N II] doublets due to SPHEREx resolution ($R \sim 130$).

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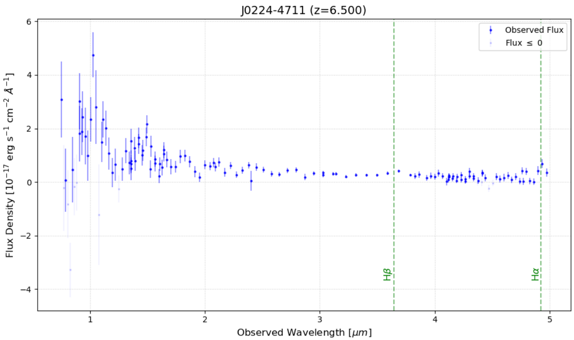
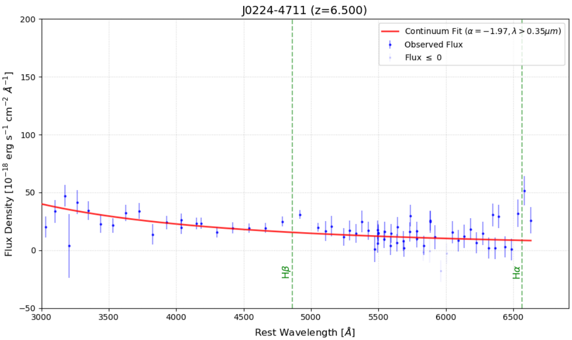
Spectral Energy Distribution: Hα BLR Emission





Observed-frame

Rest-frame

FWHM Estimation

- Currently treat FWHM estimates as **upper limits**.
- Plan to use [N II] $\lambda 6584/\mathrm{H}\alpha$ as priors based on the BPT diagram of the highest-redshift quasars to date.

Summary and Future Work

Summary

- Established data processing pipeline for VHzQs in SPHEREx including spectrum matching & dust correction
- Constructed the unified catalog of VHzQs for spectral fitting.
- Validated feasibility of detecting Hα despite resolution limits.

Future Work

- **De-blending:** Improve multi-component fitting to separate pure contribution of Hα from [N II] (and Hβ from [O III]).
- **Physics:** Calculate Black Hole Masses ($M_{\rm BH}$) and Eddington ratios through estimated FWHM and fitting.
- Plan to update future progress at Korean Astronomical Society(KAS) meeting (April, 2026)

References

[1] James J. Bock et al., "The SPHEREx Satellite Mission".

[2] Chiang, Yi-Kuan, "Corrected SFD: A More Accurate Galactic Dust Map with Minimal Extragalactic Contamination".

[3] Xiaohui Fan et al., "Quasars and the Intergalactic Medium at Cosmic Dawn".

[4] Karl D. Gordon et al., "One Relation for All Wavelengths: The Far-ultraviolet to Mid-infrared Milky Way Spectroscopic R(V)-dependent Dust Extinction Relationship".

[5] Weizhe Liu et al., "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".

[6] Nicholas P. Ross et al., "The Near and Mid-infrared photometric properties of known redshift $z \geq 5$ Quasars".

[7] Edward F. Schlafly et al., "Measuring Reddening with Sloan Digital Sky Survey Stellar Spectra and Recalibrating SFD".

[8] Jinyi Yang et al., "DESI $z \gtrsim 5$ Quasar Survey. I. A First Sample of 400 New Quasars at $z \sim 4.7$–6.6".

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Thank You

Acknowledgments

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