ULTIMATE-Subaru: Sensitivity Performance of the Wide-Field Imaging Camera with Ground-Layer AO

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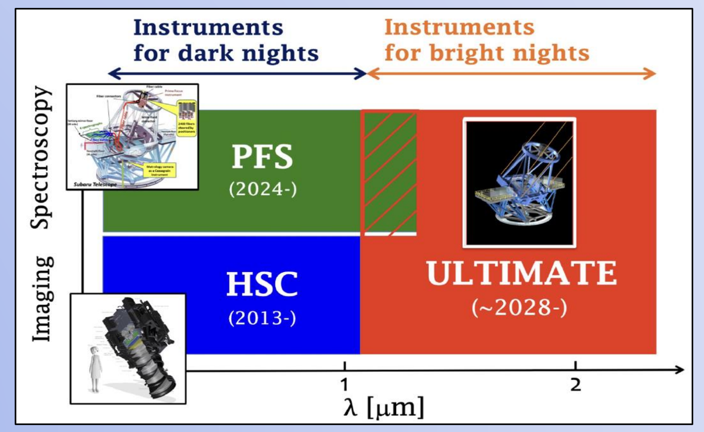
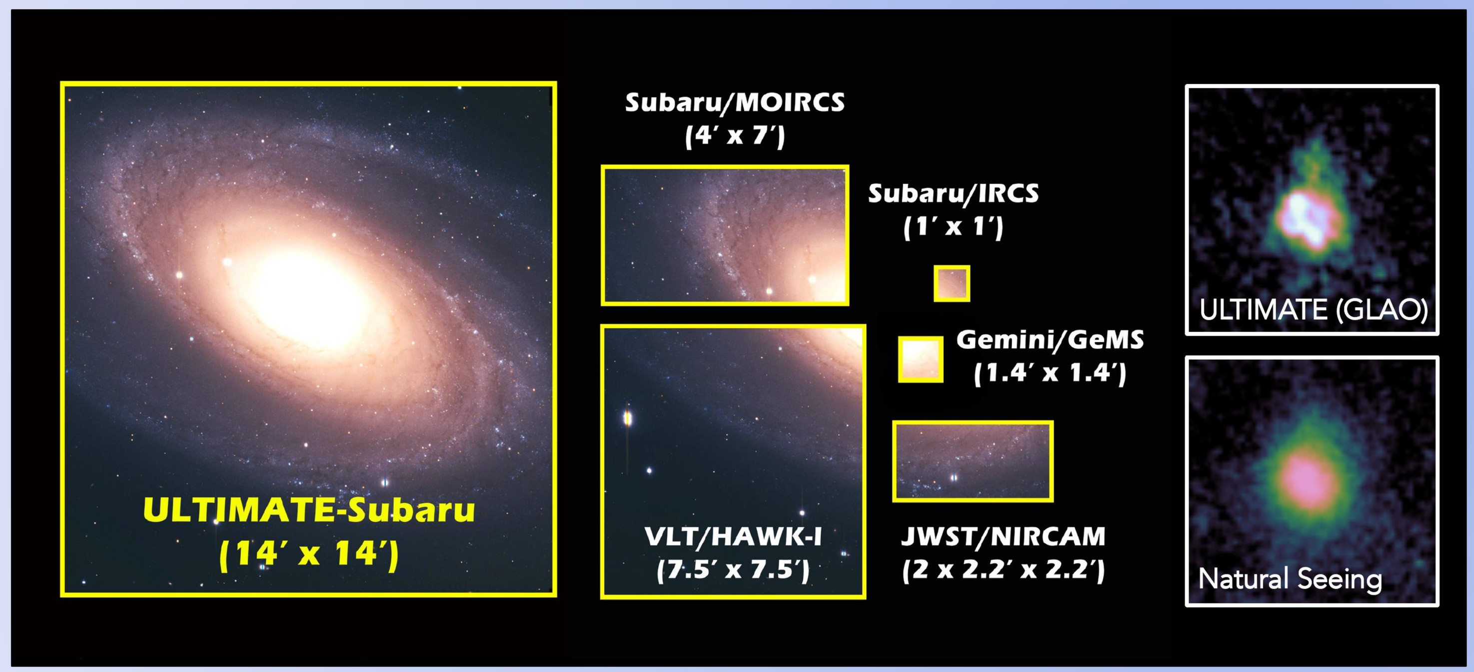
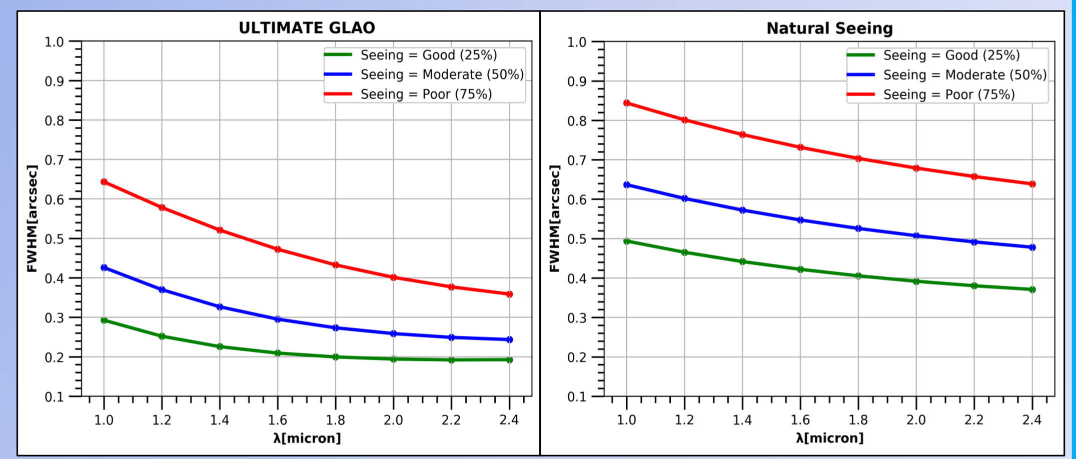
Ultra-wide Laser Tomographic Imager & MOS with AO for Transcendent Exploration

ULTIMATE-Subaru is a project to develop a near-infrared wide-field ground layer adaptive optics (GLAO) system and wide-field imager (WFI) for the Subaru telescope. It will achieve high-resolution imaging (K-band FWHM of 0.2") over a 14'x14' field of view – the widest AO-assisted imaging observations in the world and will become the NIR imager with the largest field of view of all 8-10m class telescopes [1].





Comparison of ULTIMATE-Subaru field of view with current instruments at Subaru, VLT, Gemini and JWST.

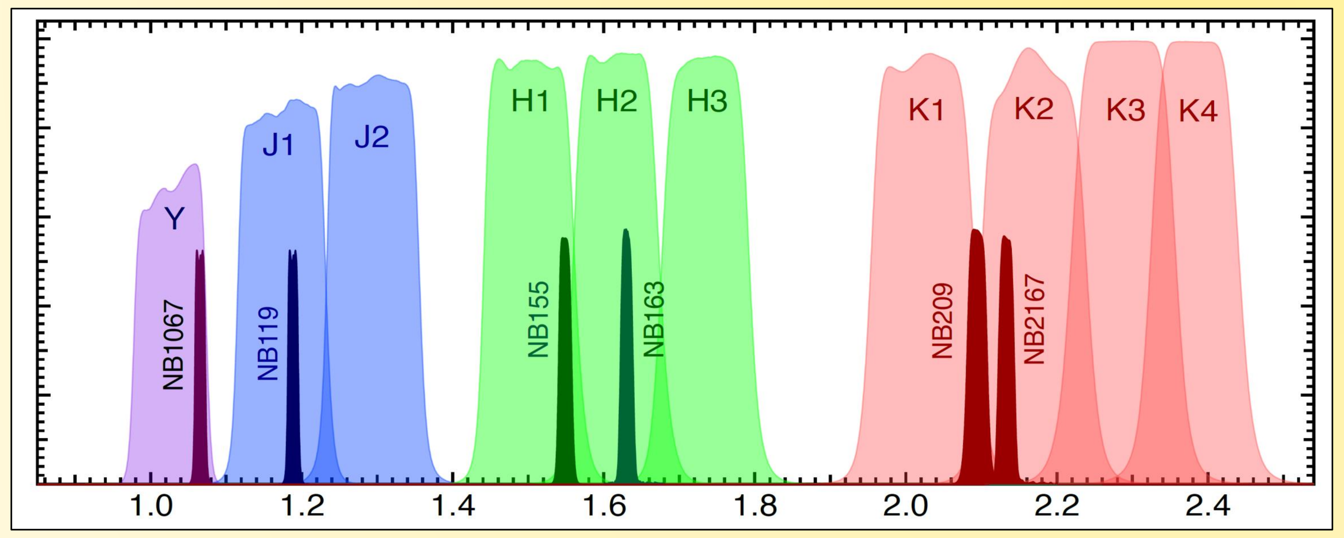


GLAO vs Natural Seeing FWHM at 60° elevation for good (25%), moderate (50%) and poor (75%) seeing. GLAO will offer close to a 2x improvement at longer wavelengths.

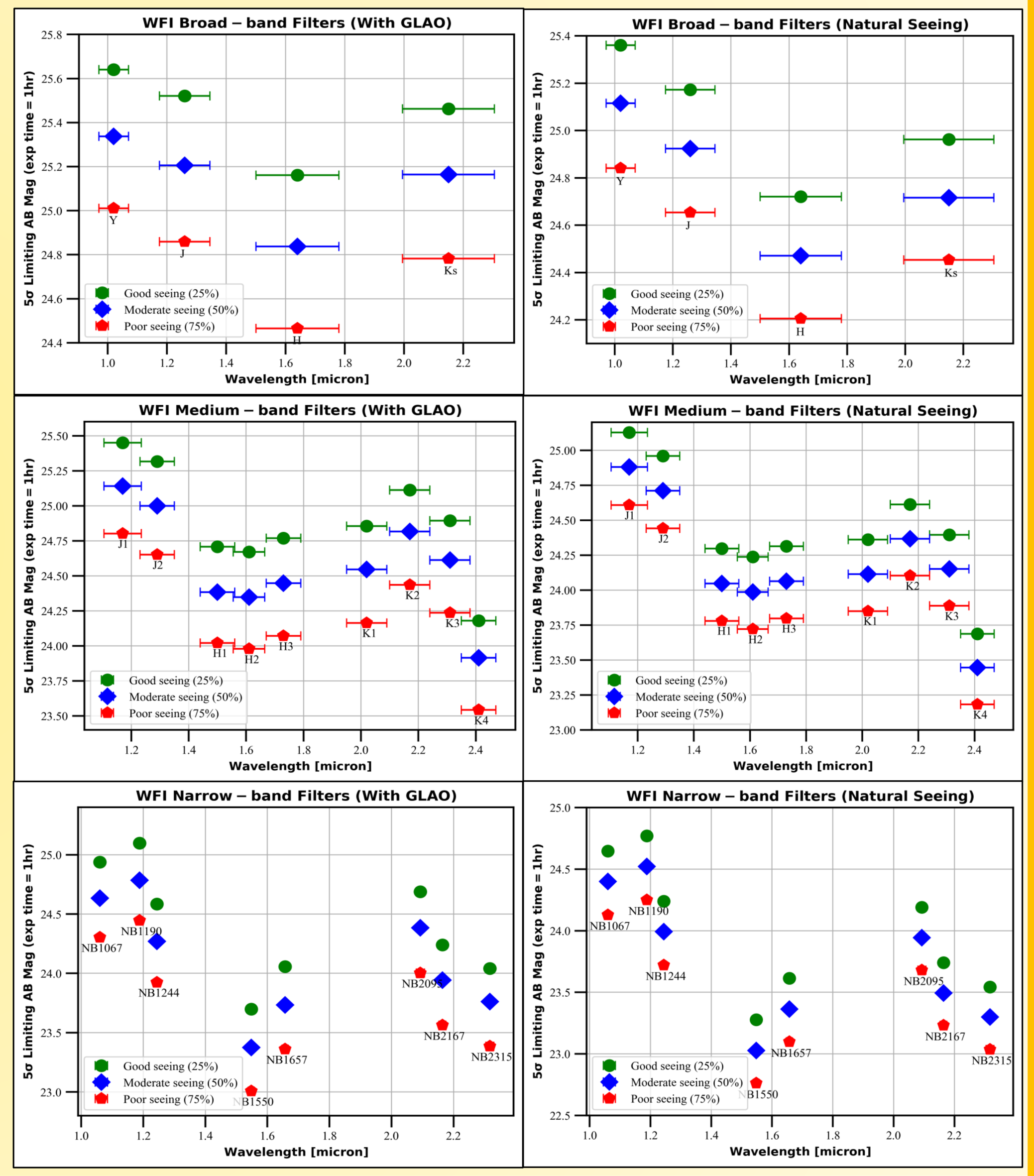
Sensitivity Performance in Broad, Medium and Narrow-band filters

A set of broad/medium/narrow-band filter transmission curves for ULTIMATE-Subaru have been created by combining existing MOIRCS and SWIMS filters (shown below). The exact specifications and filters are to be determined. The limiting magnitude sensitivity calculations were performed in these filters (shown on the right), while assuming the following parameters:

- Exposure time of 1 hour.
- Signal-to-noise of 5.
- Both with GLAO and natural seeing.
- Instrument temperature of 273K.
- Read Noise of 16 e-/rms
- Pixel scale of 0.1"/pixel
- Airmass of 1.0.
- Water vapor of 1.6 mm.



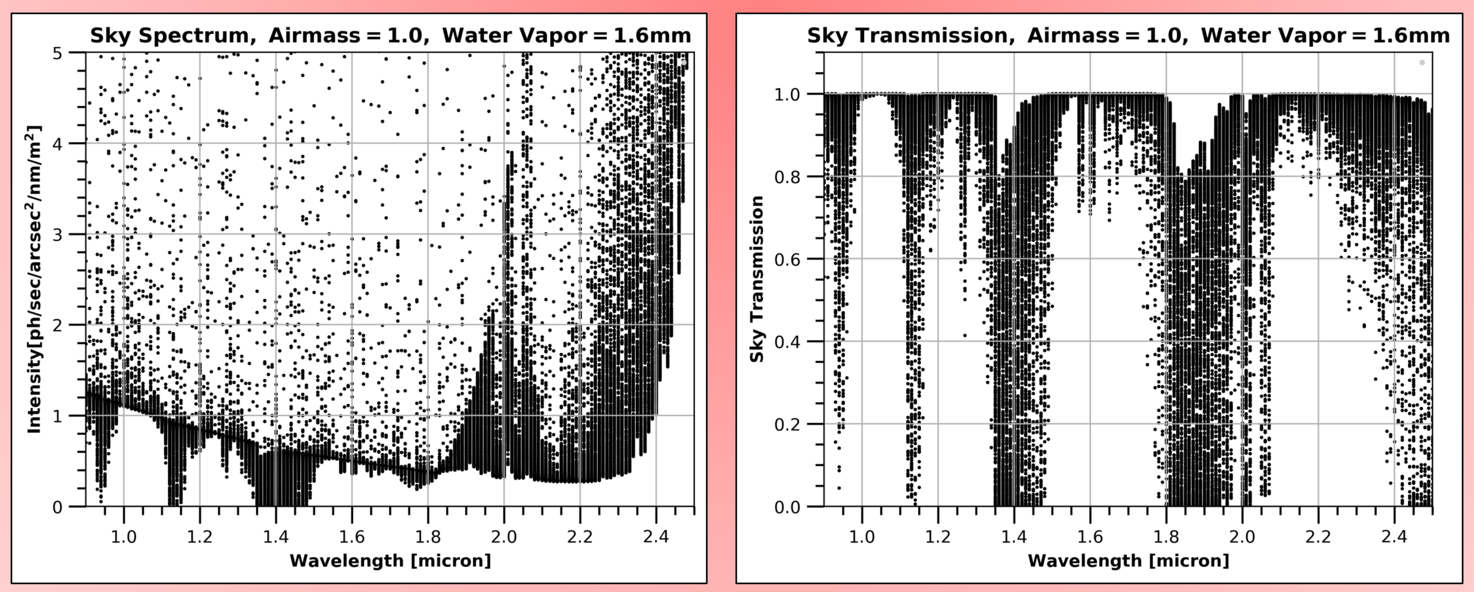
Proposed potential filters for ULTIMATE-WFI. Exact filterset and specifications are TBD.



Near-infrared Noise Sources

The main sources of background noise as incorporated in our calculations are as follows:

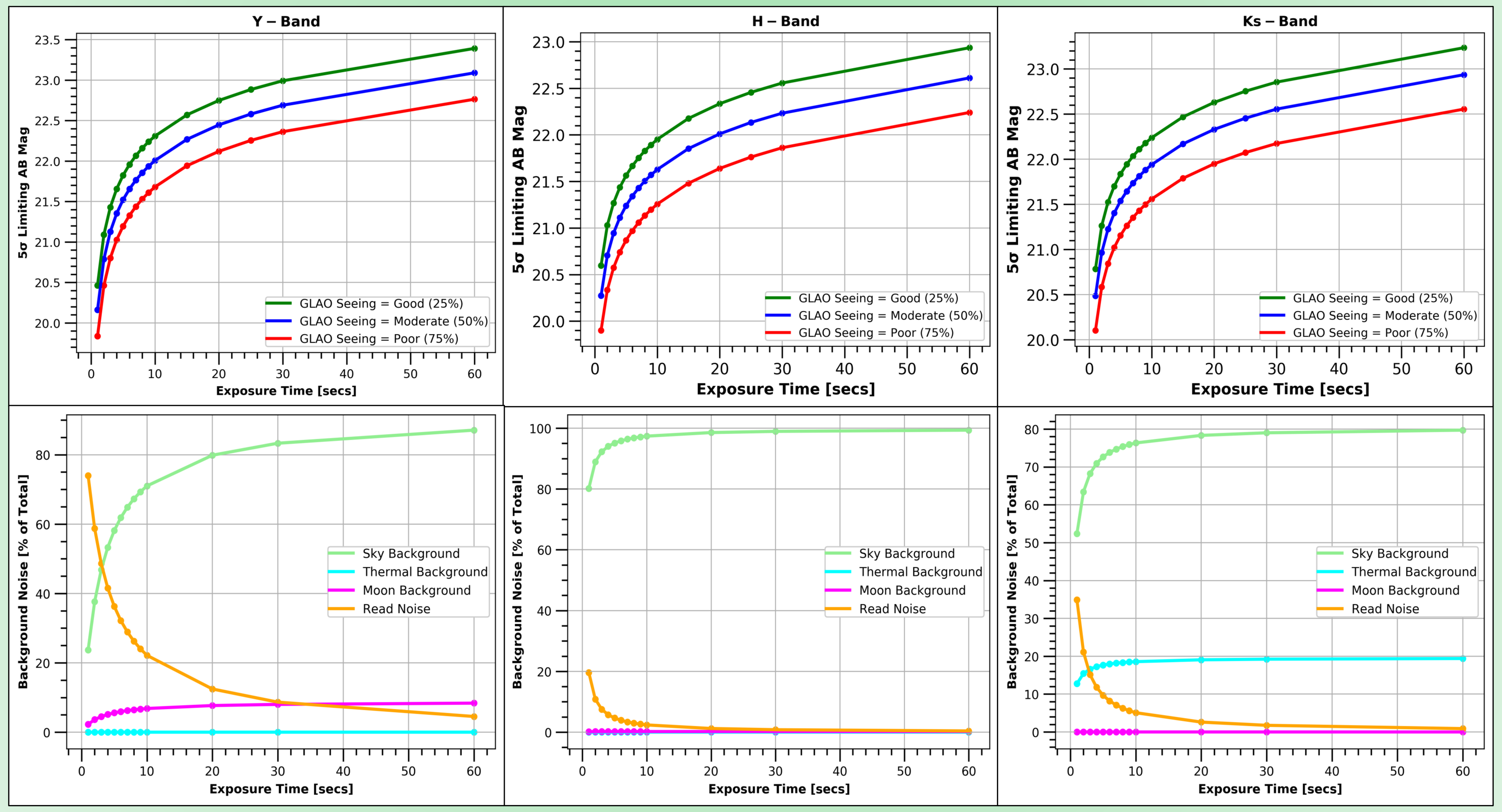
- **Sky background**: Computed from the Gemini sky background spectrum (consisting of zodiacal continuum emission, superimposed with sky spectral lines) and the sky transmission spectrum [2,3]. This is the dominant source of noise in most bands.
- **Thermal background**: Modelled as a blackbody representing the telescope and instrument's thermal emission. The thermal noise mostly affects K-band filters.
- **Moon background**: Incorporated using the moon's NIR spectrum [4]. Only affects the Y-band, and only marginally at low moon distance.
- **Read noise**: The H4RG detector readout noise is fixed to 16 e-/rms. It is negligible other than in extremely short (few seconds) and mostly NB exposures, where observations can be read-noise limited.



The Gemini near-infrared sky background and transmission spectra.

Sensitivity vs. Exposure Time

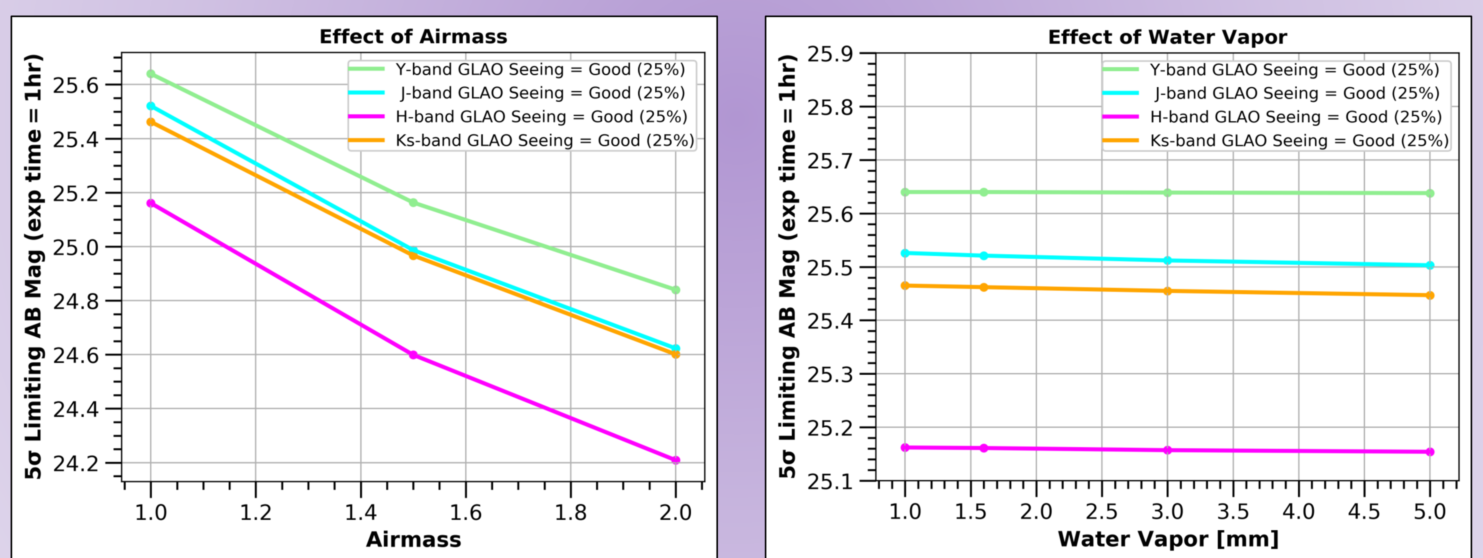
Below we show the change in sensitivity in Y, H and Ks filters for short (<1 minute) exposures and the fractional contribution to the overall background from each noise source described on the left.



Effect of Airmass & Water Vapor on Sensitivity

We calculated the change in sensitivity in the broadband filters with increasing airmass and atmospheric water vapor. We find that:

- The airmass can have a significant impact on the limiting magnitude at all wavelengths.
- The effect of water vapor is found to be relatively small in the near-infrared wavelengths and only becomes significant in the mid-infrared.
- It should be noted that the spectral lines in the NIR can vary significantly throughout the night, on a timescale of 5-15 minutes – leading to potential variability in the sensitivity of observations.



References

[1] Koyama Y. et al. 2024, PASJ, In Prep. [3] Tokunaga A. T. et al. 2002, PASJ, 114, 180
[2] Lord S. D. 1992, NASA Memorandum 103957 [4] Jones A. et al., 2019, A&A, 624, 16

The ULTIMATE-WFI sensitivity calculator can be found at the following link:
https://github.com/sali131/ULTIMATE-Subaru-Sensitivity-Calculator