Verification of Sky Brightness Models with Observed Data

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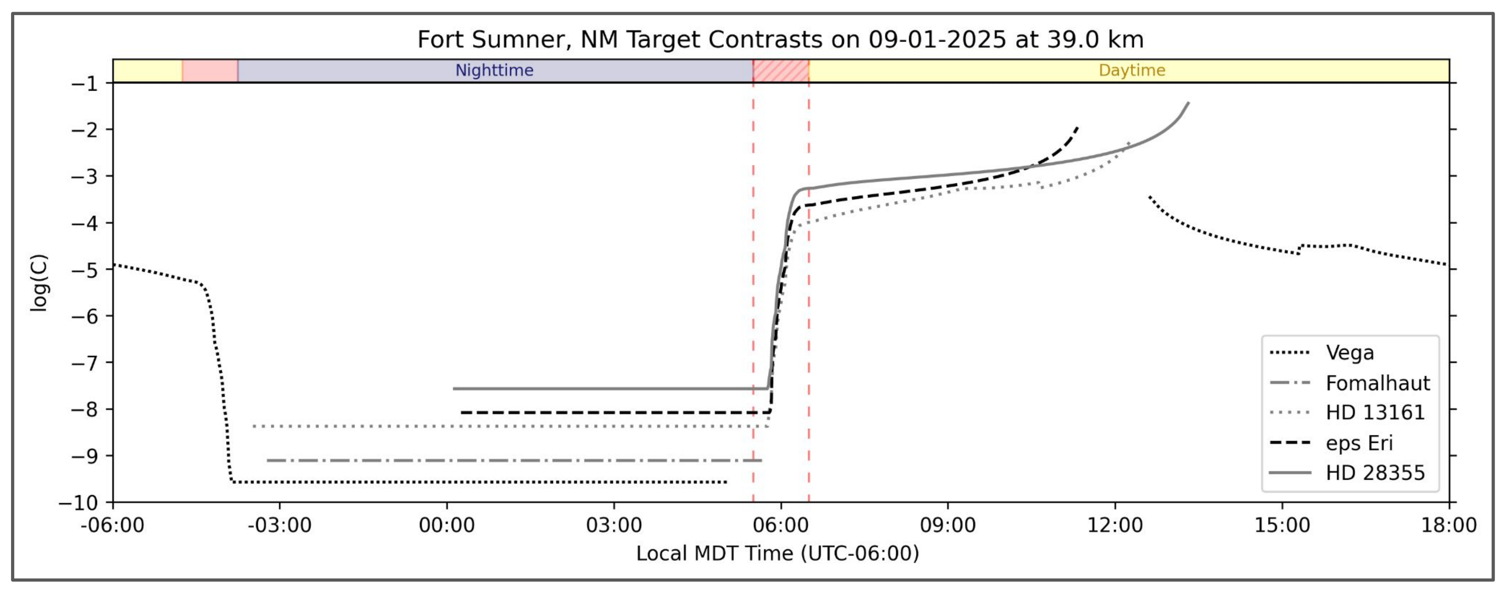
PICTURE in flight, note the nearly black sky background

Background

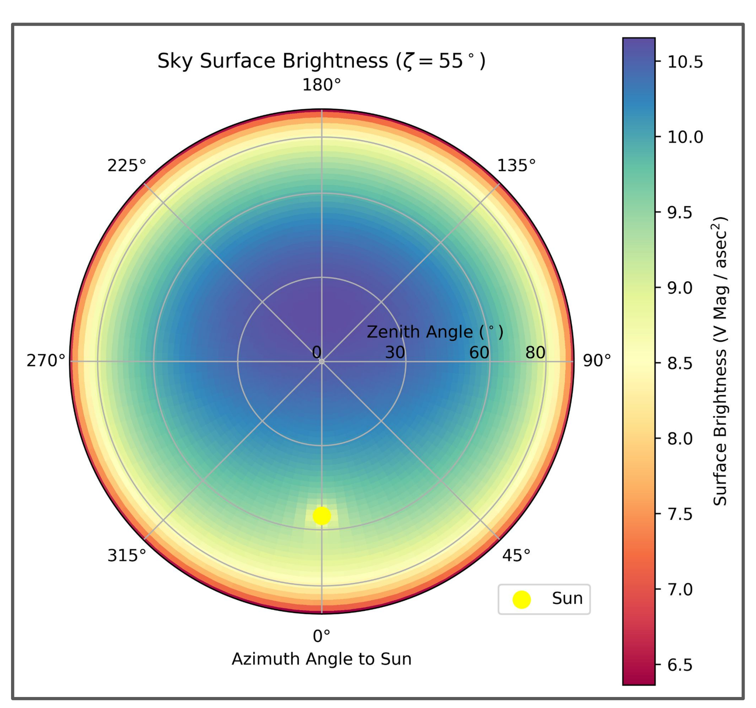
PICTURE-D is a stratospheric balloon-borne telescope used to image debris disks around other stars. Half of the flight is during the day, but most observations are at night, as the daytime sky reduces image contrast. Observations may still be possible during the day, so the sky brightness must be better understood.



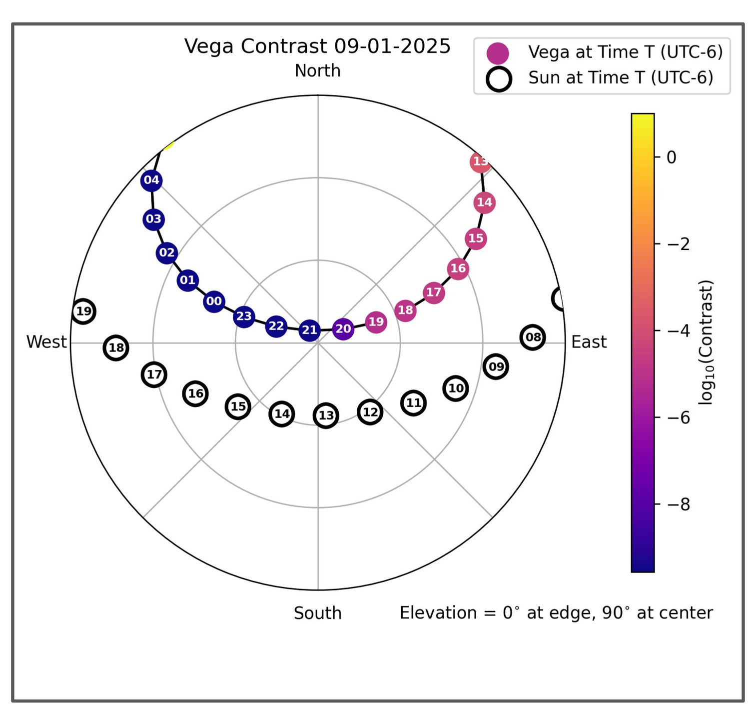
Predicted contrast values for various stars while in flight above Fort Sumner, NM

Previous Work

Last year, I used MODTRAN to quantify the sky brightness at high altitudes and compared it with various stars to calculate contrast. One star Vega had a predicted sky contrast of 10^{-4}-10^{-5}. On October 1st, 2025, PICTURE-D conducted various observations of stars such as Vega, and the sky when rotating between them.



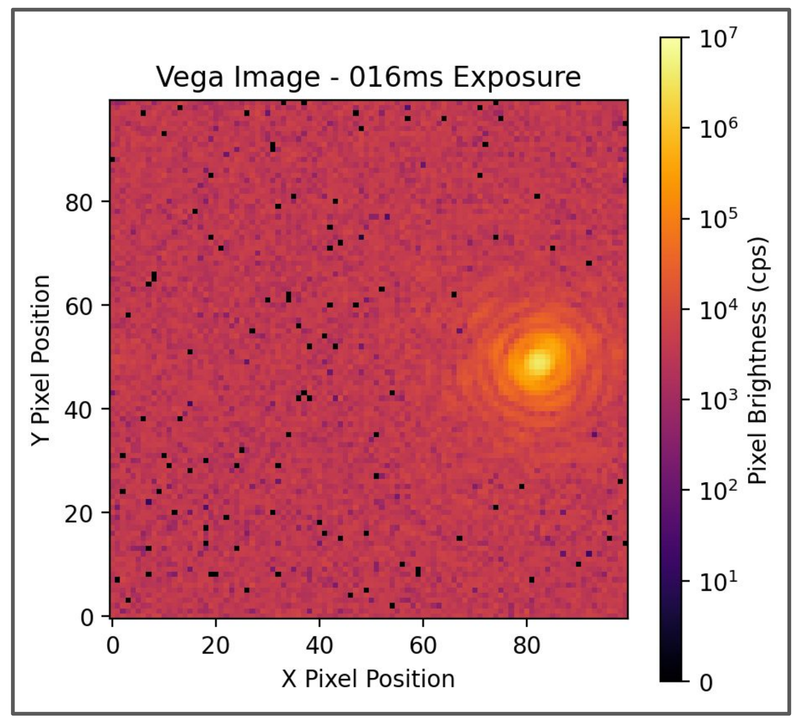
Example sky brightness map



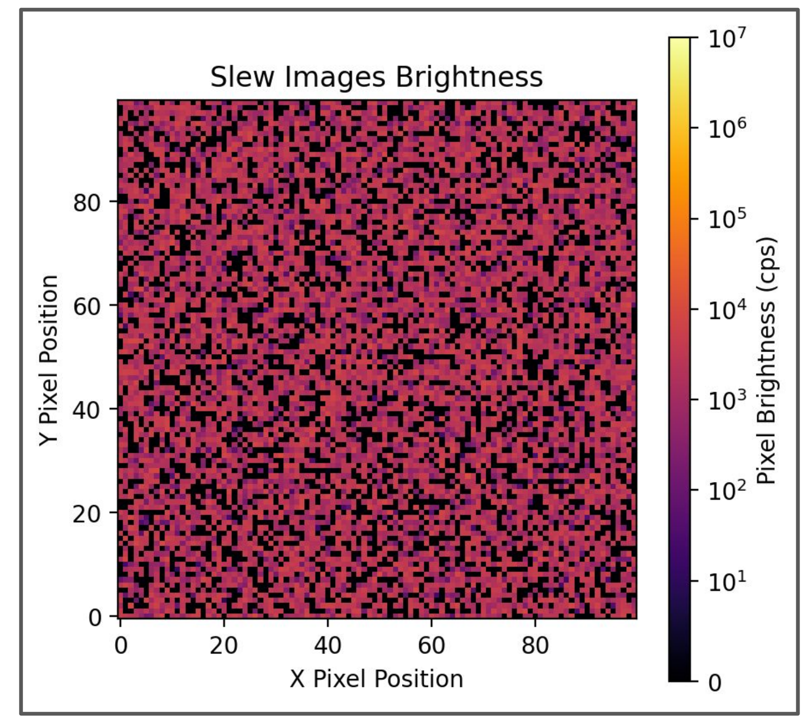
Example Vega contrast track across sky

Observations

PICTURE-D has a small FOV about 2 thousandths of a degree across. During the flight in October, the telescope imaged a few stars and the intervening sky between them. Telemetry data recorded during the flight tracks the location and view direction of the instrument. Utilizing the telemetry data, MODTRAN simulations can be run to predict the observed sky background.



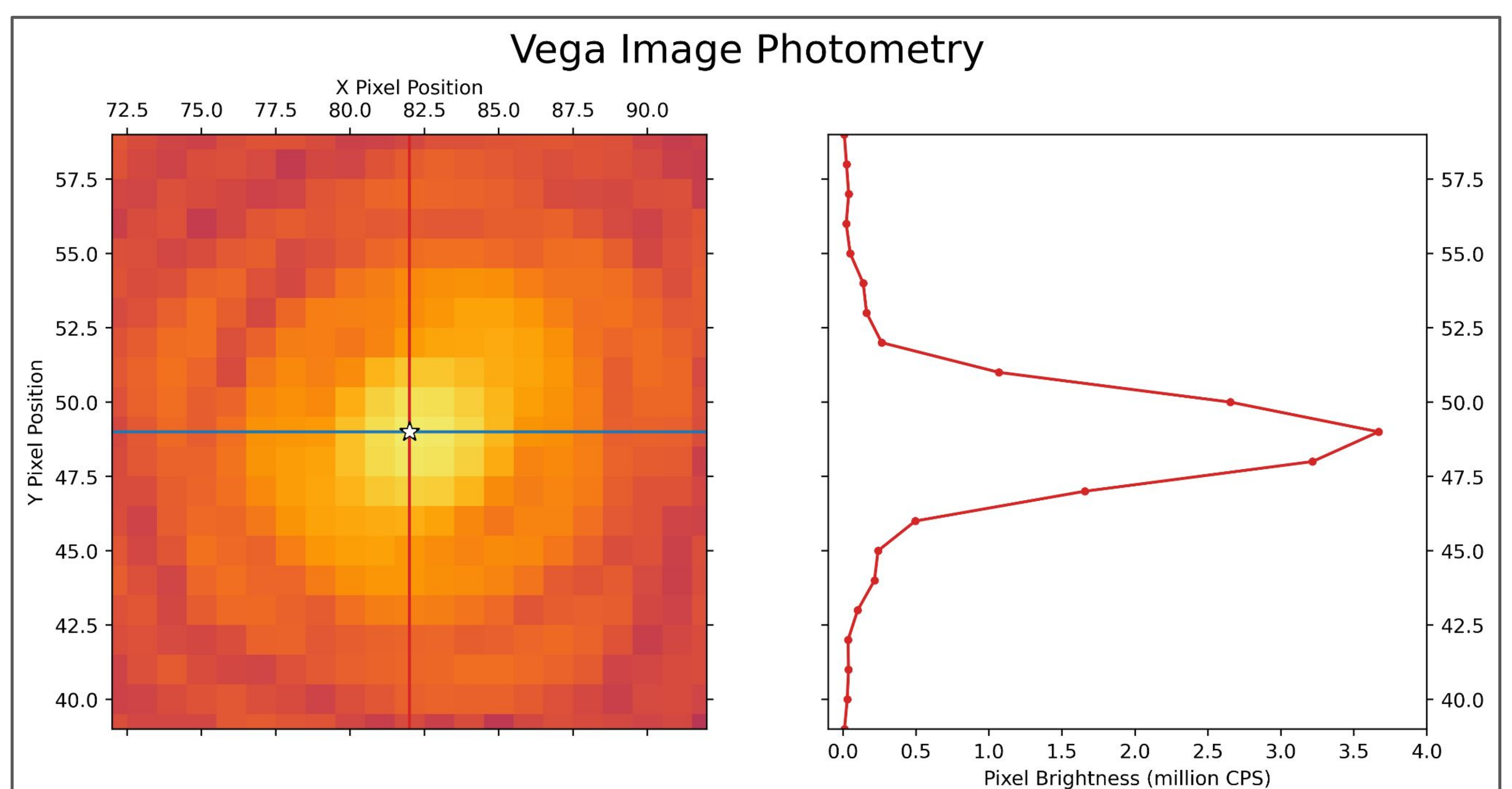
PICTURE-D off-axis Vega image

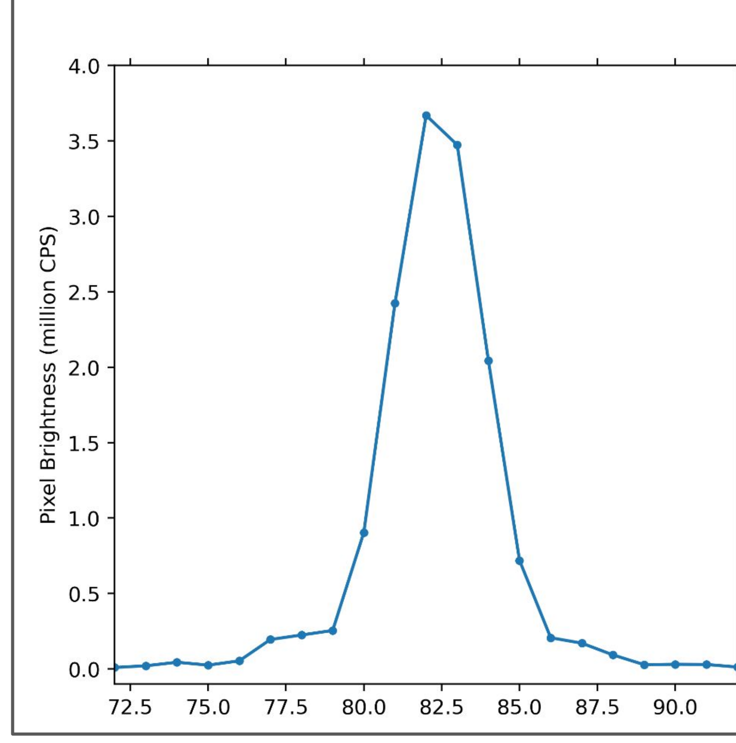


PICTURE-D sky background image

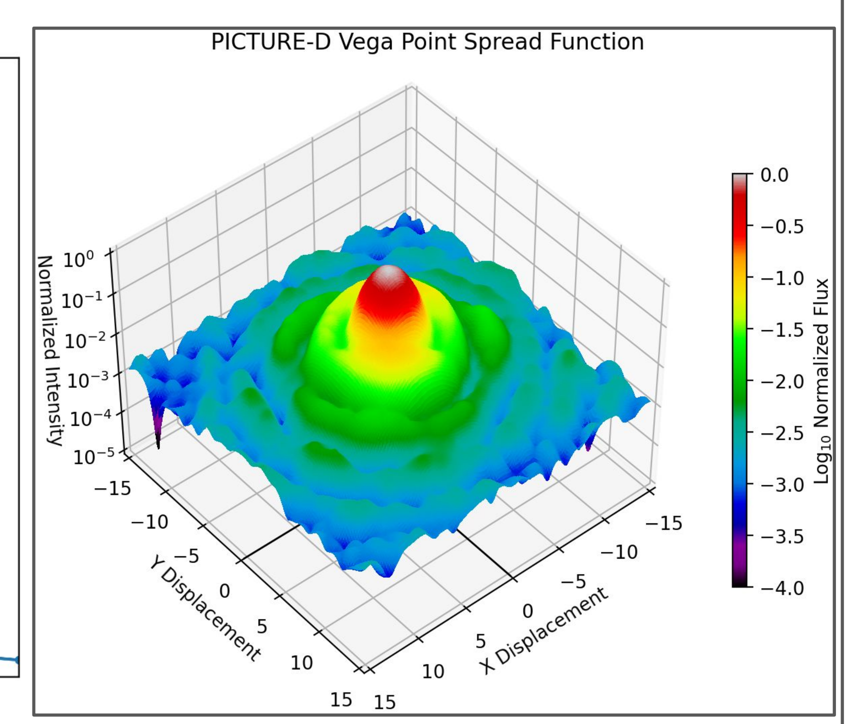
Image Photometry

To accurately compare the two datasets, a reference brightness is required for contrast values. The standard star for this is Vega, which we imaged during flight. To correctly measure its brightness as seen by PICTURE-D, a point-spread function (PSF) is fit to each frame. The PSF then provides the total brightness of the star, which can then be compared to the sky images.





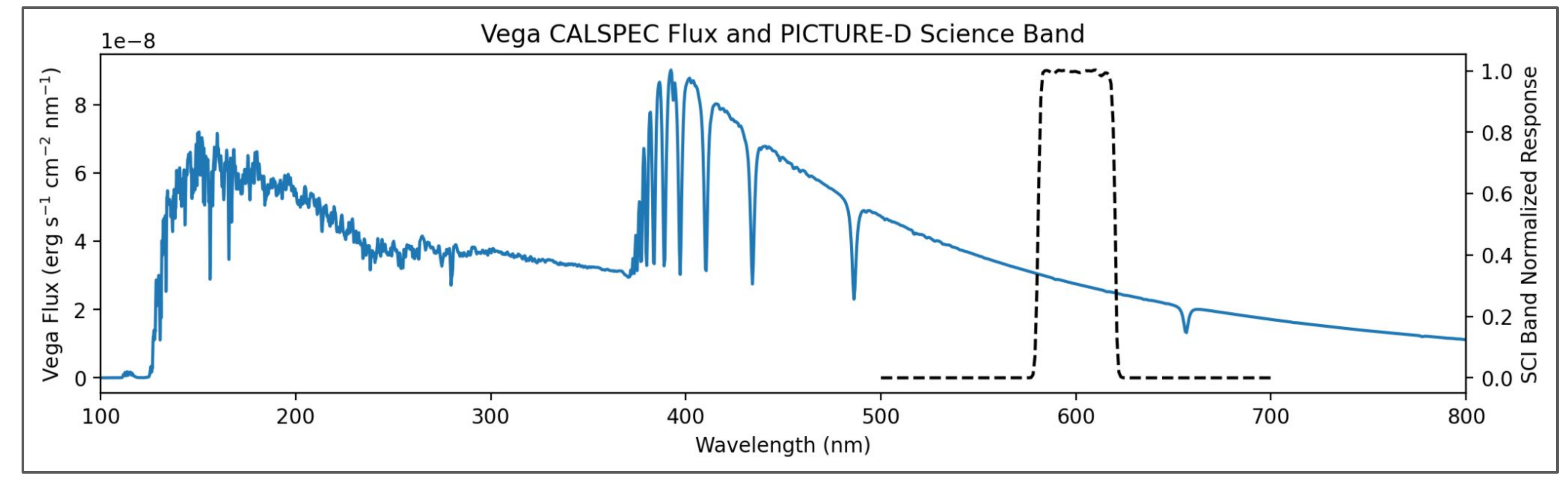
Pixel brightness distribution of Vega image



Average PICTURE-D PSF for Vega Images

Vega Flux Prediction

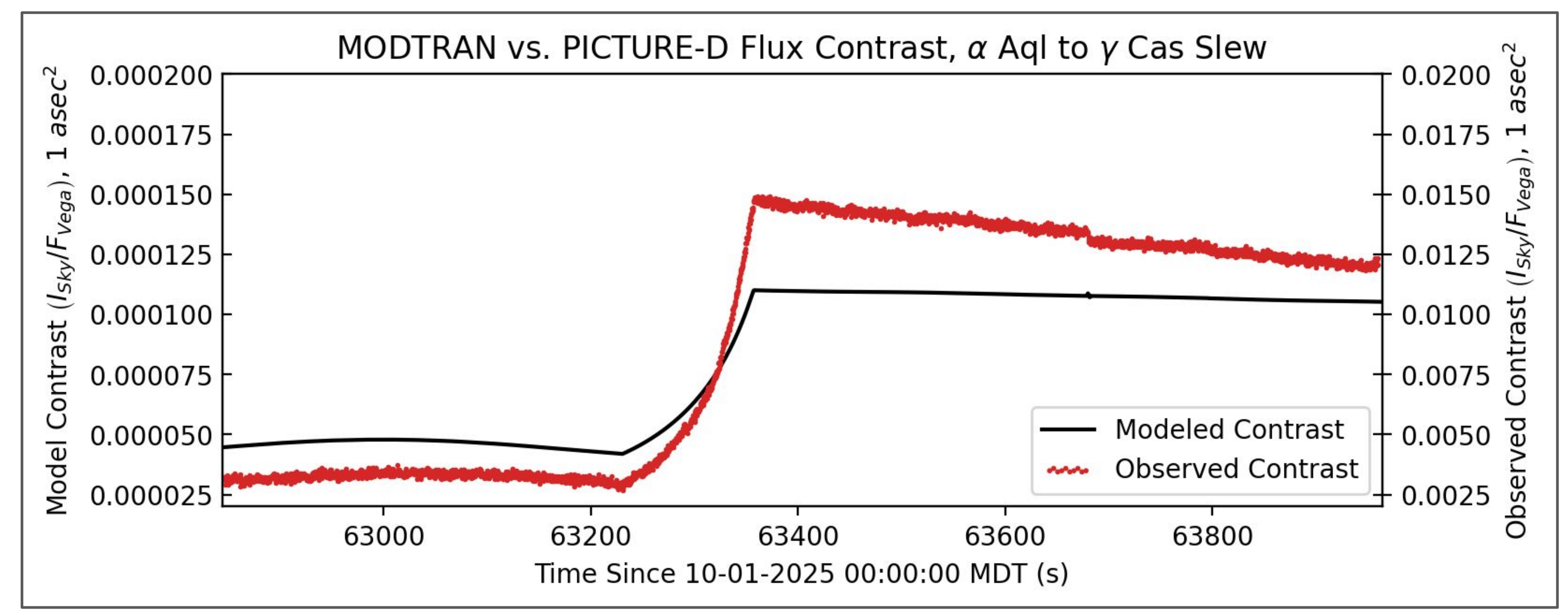
Vega is a standard star for flux calibration, so complete spectra are readily available. The spectrum can then be used with the bandpass of PICTURE-D to predict the amount of incident light from Vega. This value can then be compared to the sky brightnesses predicted by MODTRAN, providing a predicted contrast value.



CALSPEC Vega spectrum in blue with PICTURE-D science camera bandpass in black

Comparison

When the contrast values from the observations and simulations were compared, a drastic difference was found. The observed contrast was 175 times worse than predicted by simulations. The geometry of the curves is very similar, but when the minima and maxima of each are compared, the difference is a factor of 6 for the observations and a factor of 4 in the models, indicating another discrepancy.



Comparison of predicted (black) and observed (red) contrast, model contrast is on the right axis, measured on the left

Conclusions & Further Work

The large discrepancy has persisted despite numerous different methods to remove it or identify a problem in the formulas, so there is likely an unaccounted factor significantly brightening the sky images. It is uncertain what could cause this brightening, so more work is needed analyzing the state of the telescope during flight and how the optical systems may have been affected. While slewing, the optics are not aligned precisely, which may introduce errors with comparison.

References

1. Mendillo, C. B., Hewawasam, K., Martel, J., et al. 2023, in Techniques and Instrumentation for Detection of Exoplanets XI, ed. G. J. Ruane, Vol. 12680, International Society for Optics and Photonics (SPIE), 126800F, doi: 10.1117/12.2677518777
2. Stuchlik, D. 2017, in AIAA Balloon Systems Conference, doi: 10.2514/6.2017-3609800
3. Berk, A., Conforti, P., Kennett, R., et al. 2014, in Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XX, ed. M. Velez-Reyes & F. A. Kruse, Vol. 9088, International Society for Optics and Photonics (SPIE), 90880H, doi: 10.1117/12.2050433
4. Astropy Collaboration, Price-Whelan, A. M., Lim, P. L., et al. 2022, ApJ, 935, 167, doi: 10.3847/1538-4357/ac7c74
5. Chandrasekhar, S. 1960, Radiative transfer (Dover Publications)
6. Bohlin, R. C., Hubeny, I., & Rauch, T. 2020, AJ, 160, 21, doi: 10.3847/1538-3881/ab94b4

Acknowledgements

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