Transit Observations with SOFIA

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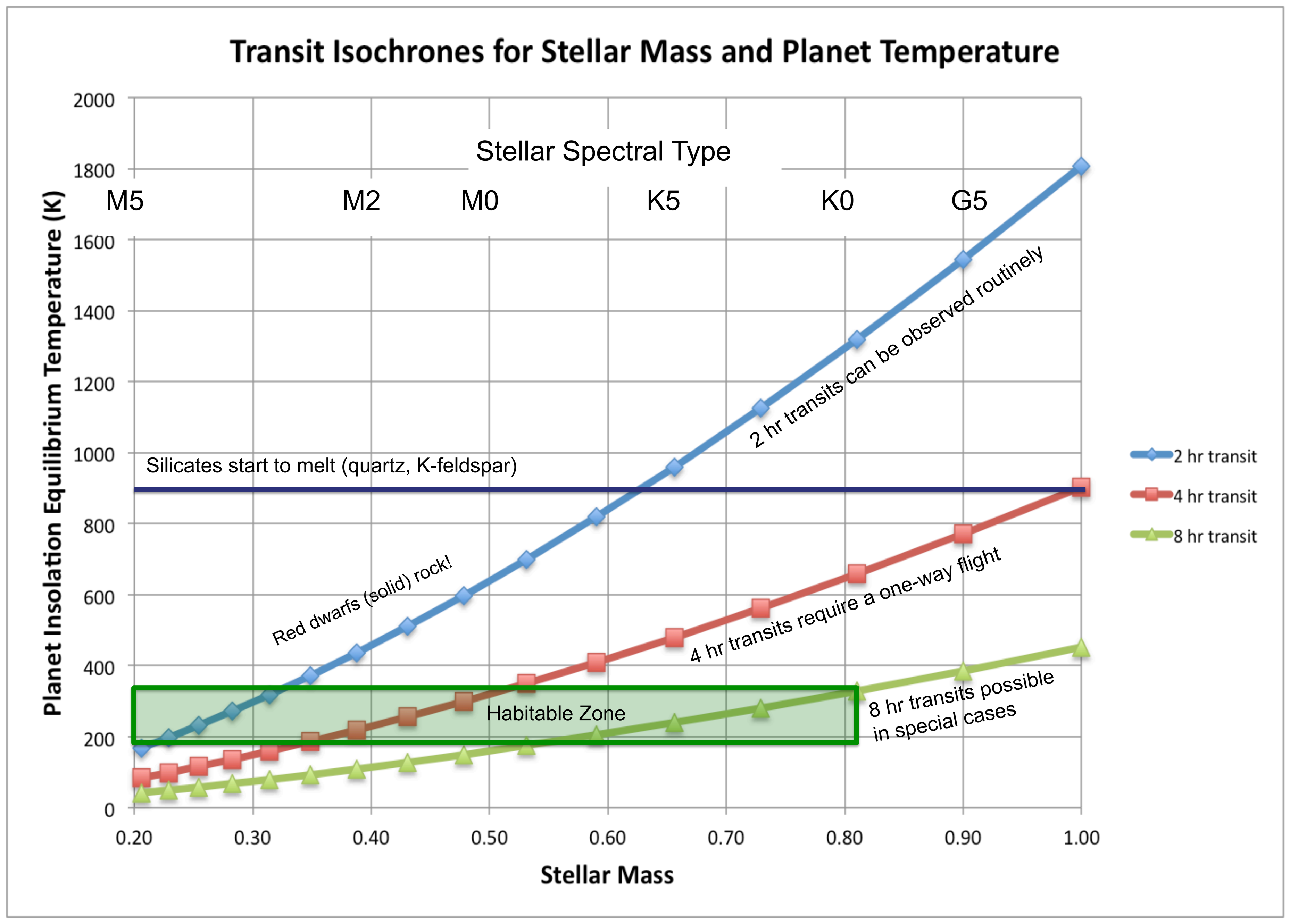
Introduction

Observing transits from SOFIA's airborne vantage point provides many advantages:
- Ability to observe wavelengths obscured from ground-based observatories
- Mobility allows wider selection of transits and observing circumstances
- Freedom from clouds, generally low extinction, and exceptionally low scintillation noise
- Two instruments of interest for exoplanet transit work are available and can be co-mounted
  - FLITECAM – IR imager and grism spectrometer covering 1-5 micron range, developed at UCLA
  - HIPO – Optical 2-channel imaging photometer covering 0.3-1.0 micron range, developed at Lowell
    - The co-mounted instrument configuration is known as FLIPO
  - In addition the focal plane imager (FPI) is capable of observations at a third optical wavelength
- New instruments can be developed in response to planned new instrument proposal calls

SOFIA also suffers certain drawbacks:
- Limited observing time, typically 2-4 hours. (Durations up to 10 hours are possible in special cases)
- SOFIA's unvignetted field diameter is 8'; the FLIPO field is about 6' square
- Variability in flight environment (Mach number, temperature, altitude, pointing jitter, focus variation)
  - These may cause PSF variations affecting photometry at levels of concern for exoplanet transit work
- Variable extinction can also be important in some cases:
  - Rayleigh scattering, ozone and episodic volcanic aerosols at optical wavelengths
  - Residual water vapor in water-sensitive IR bands.

SOFIA's position in mass/temperature phase space, with emphasis on low-mass parent stars and short transit durations, is illustrated in the figure to the right. Observation of transits by Neptune-size planets orbiting M stars is one application of interest to a possible *Kepler-2* mission with stabilization using only two reaction wheels.

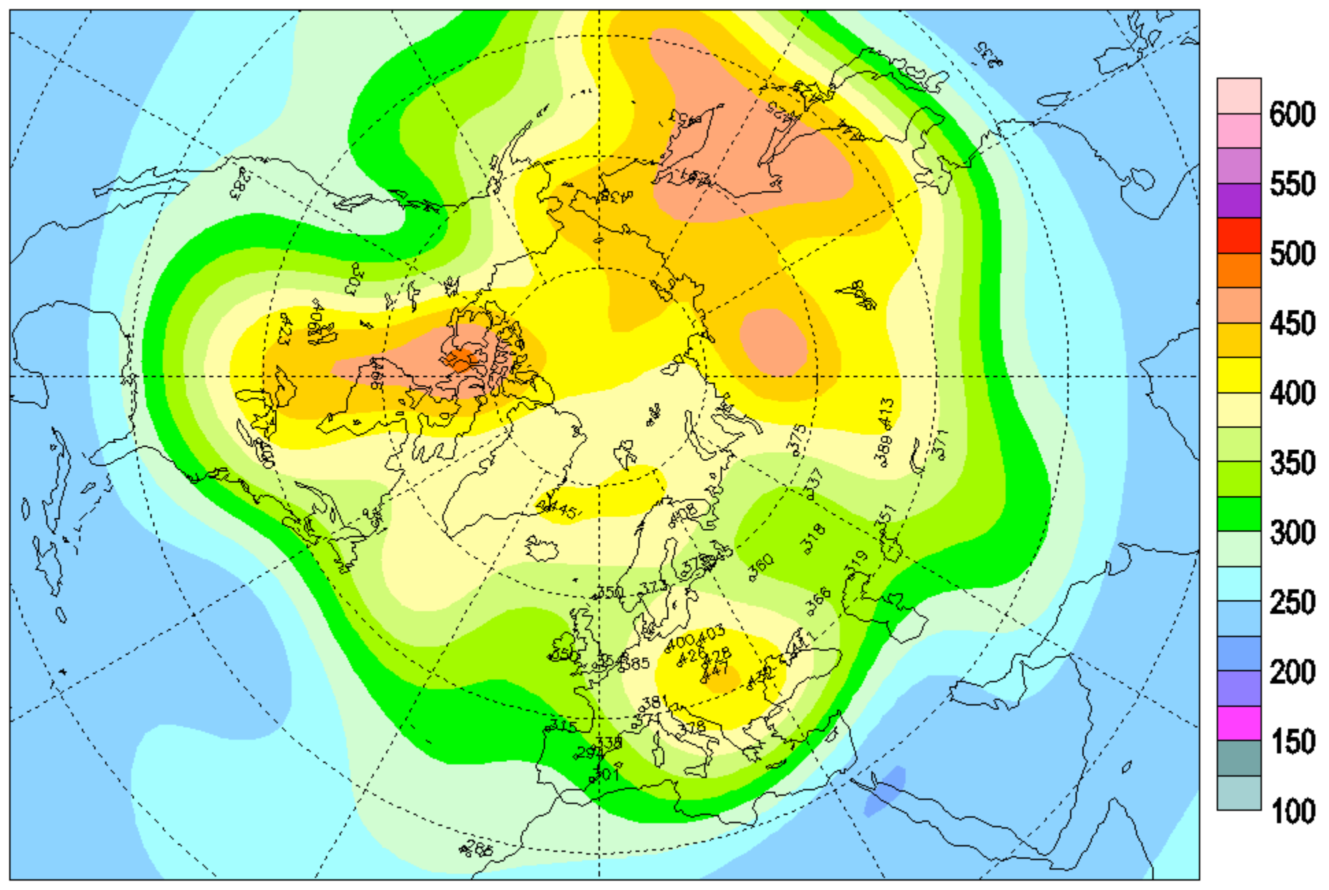
The transit SNR achievable varies strongly with stellar brightness and spectral type, wavelength, and filter bandpass. We focus here on the limiting photometric systematics as far as we know them now. Unfortunately we have had very little flight experience with FLITECAM so far.

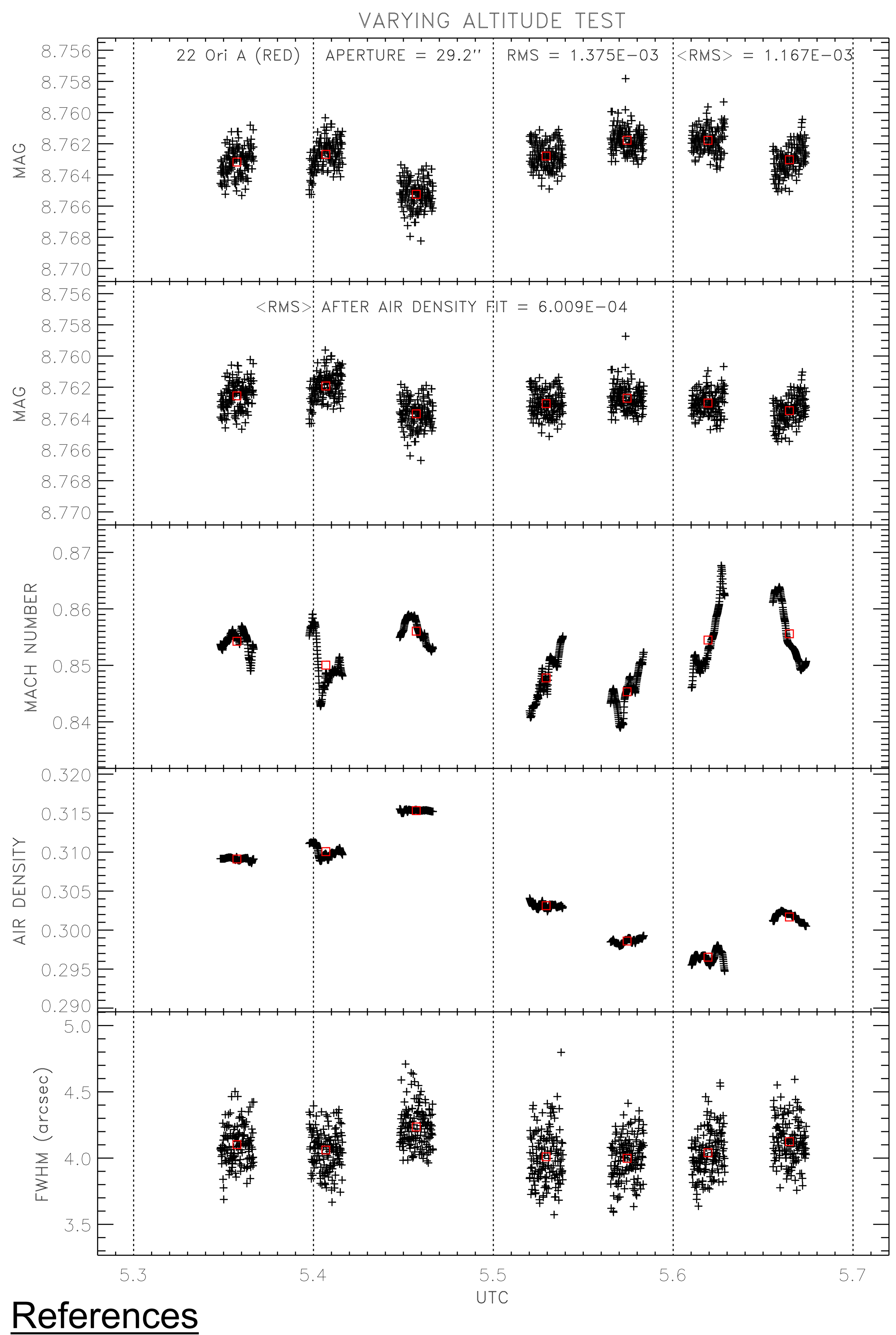


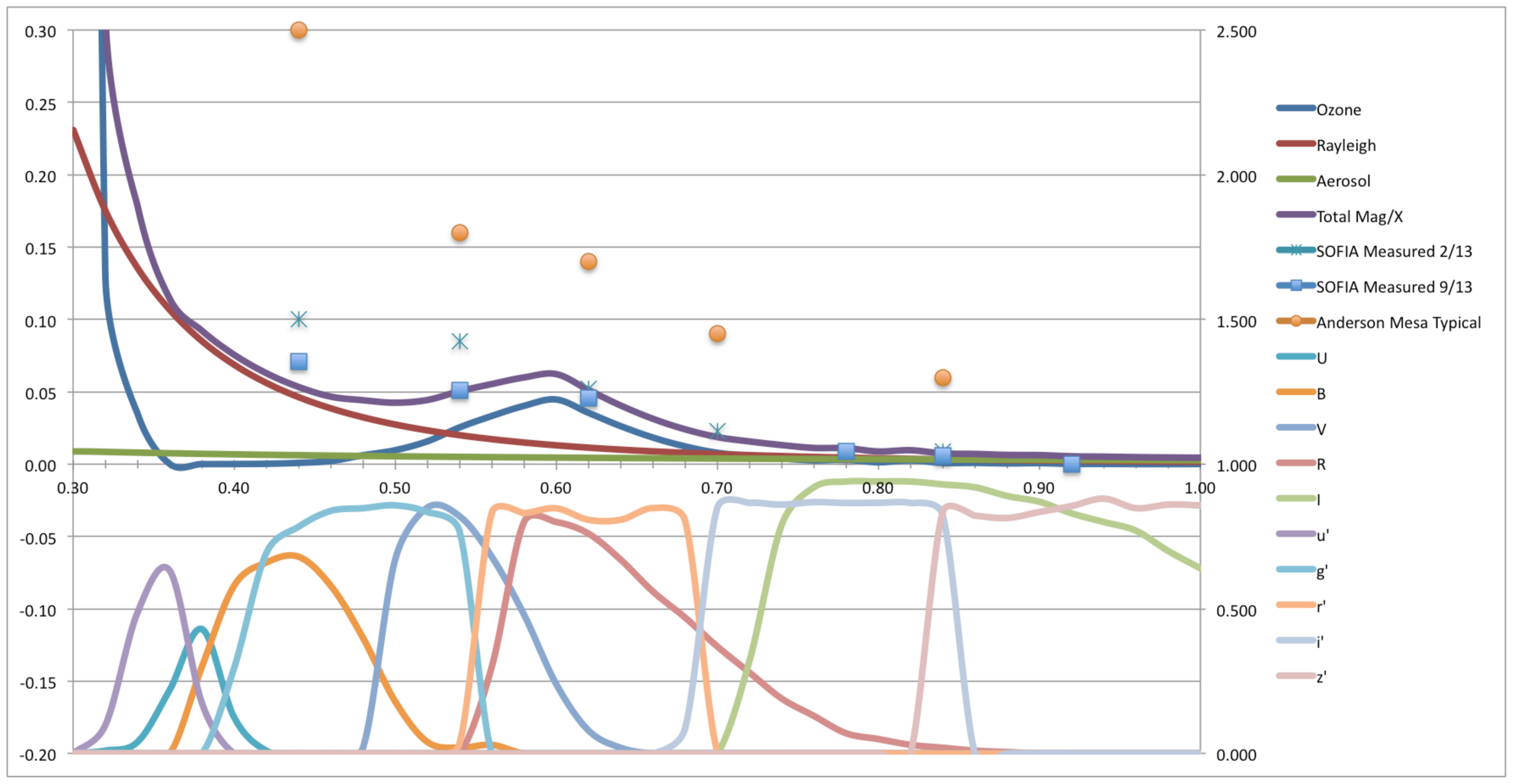
Systematics in Airborne Photometry

In our limited precise photometry test opportunities we have found:
- The well-known smooth, broad optical airborne PSF[1,2] formed by the turbulent shear layer requires large apertures to obtain good photometry
- Large apertures also reduce sensitivity to focus errors and image jitter
- Primary noise contributions are at periods from 5-20 minutes
- Differential photometry reduces, but doesn't eliminate systematics
  - Limited field of view reduces applicability of differential photometry
- Ozone absorption in the Chappuis bands must either be avoided by filter selection or corrected by some means (see below and immediate right)
  - ~5% extinction and ~2x change in total ozone demands correction!
  - This does not impact FLITECAM
- At optical wavelengths airborne photometry depends on mean air density
  - See top two panels of figure at far right
  - We expect a weaker dependence for FLITECAM
  - Optical photometry is surprisingly independent of Mach number.
- Flat field corrections are critical for FLITECAM, less so for HIPO
- Residual position sensitivity remains in flat-fielded images
- We routinely see HIPO precision of ~10^{-3} with only extinction correction
  - 5×10^{-4} can be achieved with density correction

Total ozone (DU) / Ozone total (UD), 2013/02/15







Conclusions

- Primary systematics for HIPO are ozone absorption and mean density variation.
- Flat-field variations and water vapor extinction are expected to be the worst problems for FLITECAM.
- We hope to reach photometric precision of 3×10^{-4} with HIPO by means of further correction of systematics.
- FLITECAM limiting precision is not well understood yet.
- The bright targets that will be found by TESS will be ideal SOFIA targets
- M dwarf targets found by a possible 2-wheel *Kepler* mission would also be good SOFIA targets.

References

1. Dunham, E.W. and J.L. Elliot, "Optical Photometry with the Kuiper Airborne Observatory", PASP 95, 325-331, (1983).
2. Elliot, J.L., et al., "Image Quality on the Kuiper Airborne Observatory, I. Results of the First Flight Series", PASP 101, 737-764, (1989).