MRD 140- Thermal excess-removed reflectance spectra

Overview The OVIRS instrument on board of OSIRIS-REx will measure spectra that cover the wavelength range between ~0.4 and 4.3µm. Within this wavelength range, beyond approximately 2 microns, the black-body thermal emission of Bennu may contribute to the total radiance measured. We sometimes call this "thermal excess" because we are trying to measure reflectance only, and we sometimes call it the "thermal tail" because it is the low-energy end of the thermal emission function. Early in the processing of OVIRS data, this energy must be removed from OVIRS spectra because subsequent analyses require that the data be in terms of reflectance units. Within the thermal tail, spectral features such as the ~3-µm phyllosillicate bands, the ~3.4-µm and 3.5-µm organic bands, and the ~3.8-µm and 3.9-µm carbonate bands are attenuated. Removing the thermal excess is an important task in the calculation of spectral indices that are developed by the SAWG, especially those spectral indices that measure the band depth of spectral features in reflectance units for comparison with laboratory measurements in reflectance units.

Thermal Excess

The measured OVIRS spectra of asteroid Bennu may exhibit a steep increase of apparent reflectance longward of ~2 µm, especially for the hottest surface regions, attributed to thermal radiation from the asteroid's surface (e.g., Fig.1 Clark et al. 2011).

Example: 101955 Bennu

In **Figure 1** we show the Asteroid (101955) Bennu composite spectrum (from Clark et al. 2011), using visible wavelength measurements from the McDonald Observatory and near-infrared wavelength measurements from the NASA Infrared Telescope Facility (black curve). The blue curve has been thermally corrected using nominal values of geometric albedo (pv) and beaming parameter (η) (the effective subsolar surface temperature is calculated from pv and η). The red curve shows removal using a low temperature model with values that are 3σ "cooler" than nominal, and the green curve shows removal using a high temperature model with values that are 3σ "warmer" than nominal. The nominal curve thus assumes a sub-solar point temperature of 355 K. This temperature is within the range of predicted surface temperatures that OVIRS will observe during proximity operations at the asteroid.

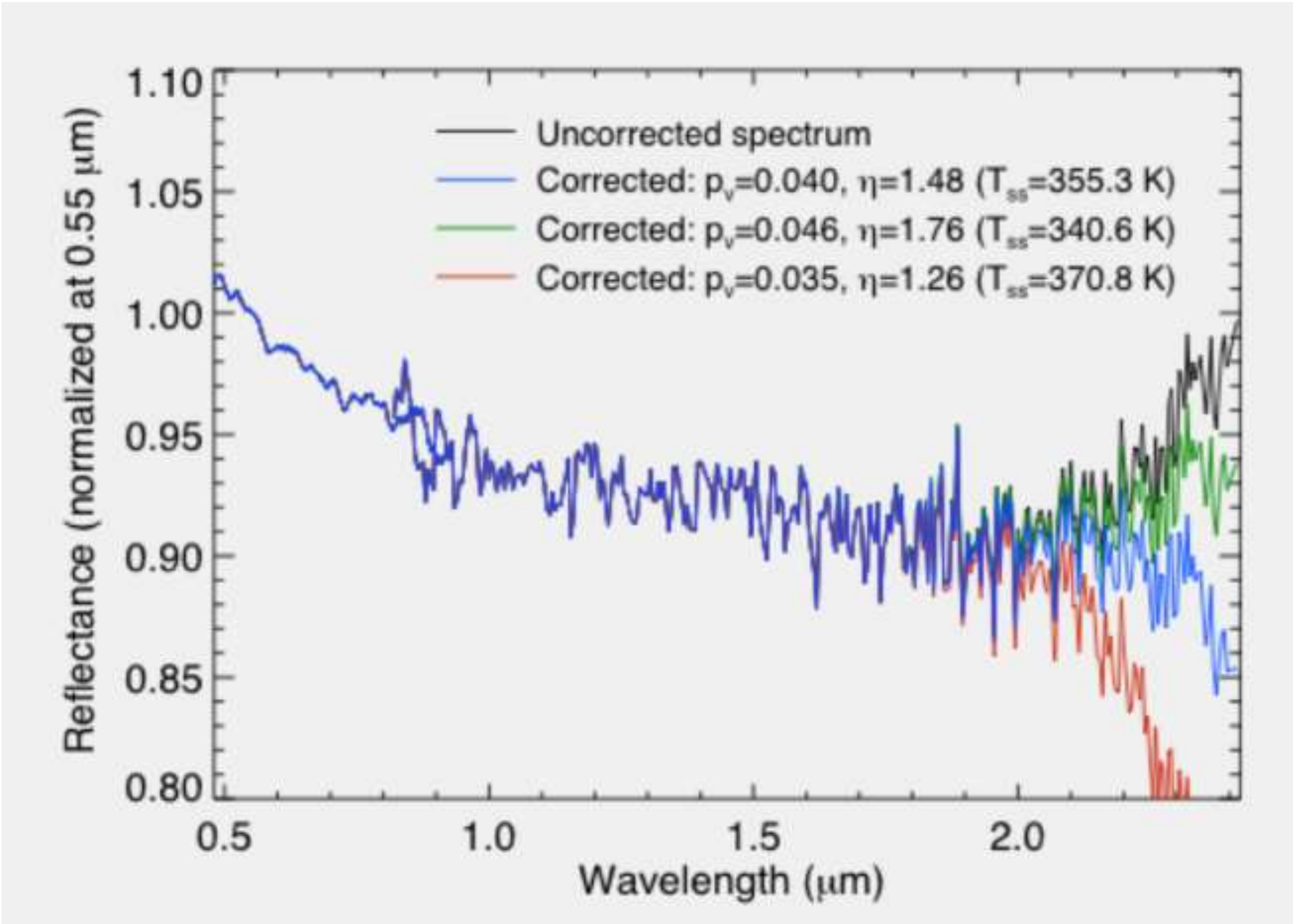


Figure 1: Observations of asteroid Bennu from the ground show thermal excess onset at about 2 microns.

The total amount of thermal excess energy and the onset wavelength at which it becomes apparent depend on surface temperature, which is a function of solar distance and several surface properties, such as albedo, roughness, and thermal inertia.

Example: 10 Hygiea

In the example shown in **Figure 2** for the asteroid Hygeia, the thermal excess was removed using the methodology described in Rivkin et al. (2005) and Takir and Emery (2012). The thermal excess $\gamma\lambda$, which is a measure of the thermal flux contribution at a given wavelength, is defined by:

$$\gamma\lambda = (R\lambda + T\lambda \,/\, R\lambda\,) - 1$$

where $R\lambda$ represents the reflected flux at a wavelength λ, $T\lambda$ represents the thermal flux at wavelength λ, and the quantity $R\lambda + T\lambda$ represents the measured relative spectrum (i.e., the black curve in Fig. 1 and the red curve in Fig 2).

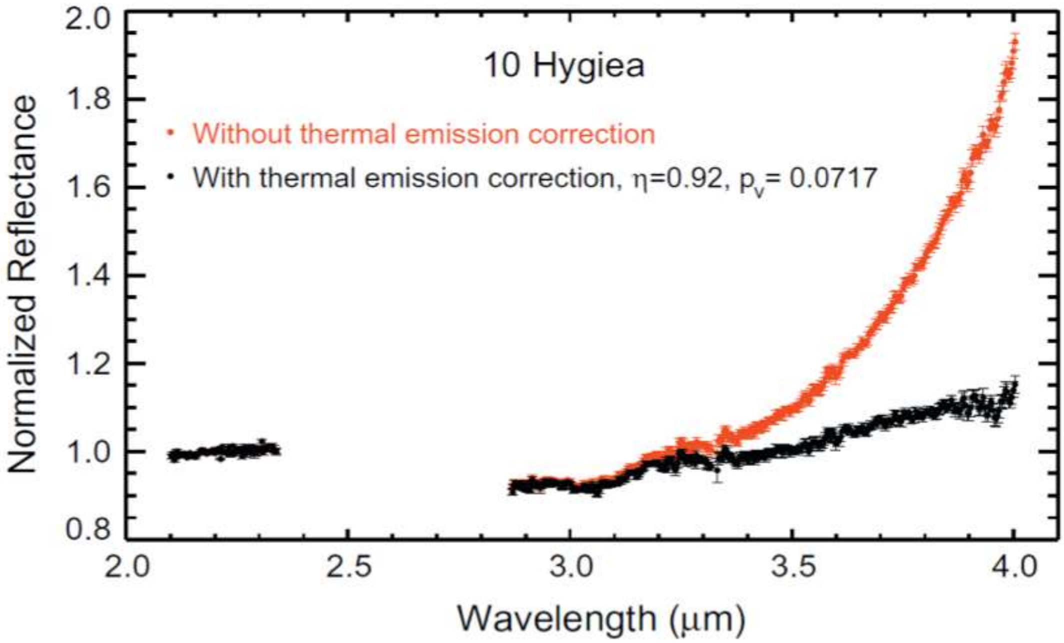


Fig. 2. Spectrum of 10 Hygiea uncorrected and corrected, using thermal model of a beaming parameter $\eta = 0.92$.

The task is more straightforward for disk-resolved observations of Bennu. OTES will provide measurements of the thermal flux from ~6 to 50 µm nearly simultaneously with OVIRS observations. The OTES temperature-emissivity separation algorithm will provide accurate temperature estimates for each spot.

Inputs to the Thermal Excess Calculation

For input to this calculation, the temperature of the OVIRS spot will be obtained from near-simultaneous OTES measurements. In the event that near-simultaneous OTES spots are not available (e.g., OTES observing the internal cal flag), we will use the OTES spot that is closest spatially to the OVIRS spot. OTES oversamples Bennu by a factor of ~2.5 during Detailed Survey, and the OTES spot is about twices as big as the OVIRS spot, so it is anticipated that every OVIRS spot will be covered by an OTES spot. The Planck function is then used to calculate the emitted intensity. The only required input is the OTES derived temperature. The model thermal flux is subtracted from the OVIRS spectra, spot by spot.

Output of the Thermal Excess Calculation

After the OVIRS spectra are corrected for thermal excess, the spectra will be in units of W cm-2 µm-1 across the entire wavelength range from 0.4 to 4.3 microns. Subsequent division by the solar spectrum will result in spectral radiance factor (RADF), or (I/F).

Test Data

Simulated OVIRS test data will be used to generate relevant OVIRS spectra that will include randomized thermal excess contributions at various temperatures within the range of 300 to 450 K. Spectral footprints will be generated at Detailed Survey-relevant spatial resolution for testing the process of thermal excess removal. Calibrations of the additional errors imparted to the data due to inaccuracies in thermal excess removal will carry through (along with the accuracy errors in photometric modeling) to subsequent OVIRS spectral index calculation.

Observation Requirements

The thermal tail subtraction will be applied to any OVIRS observation of the target (Bennu) with a simultaneous OTES observation of the target.* The expectation, described on the emissivity data product page, is that emissivity will be produced from all target (Bennu) spectra because the associated temperature is a required input to thermal models. For the resulting data to meet the expected areal coverage and spatial resolution requirements, the spacecraft must be within the stated delivery uncertainty of the range, latitude, and longitude for each mission phase.

(*In the event that OTES data are unavailable, a contingency approach for estimating the thermal contribution directly from the OVIRS data will be available.)

References

Clark, B.E., Binzel, R.P., Howell, E.S., Cloutis, E.A., Ockert-Bell, M., Christensen, P., Barucci, M.A., DeMeo, F., Lauretta, D.S., Connolly, H., Soderberg, A., Hergenrother, C., Lim, L., Emery, J., Mueller, M., 2011. Asteroid (101955) 1999 RQ36: spectroscopy from 0.4 to 2.4 µm and meteorite analogs. Icarus 216, 462–475.

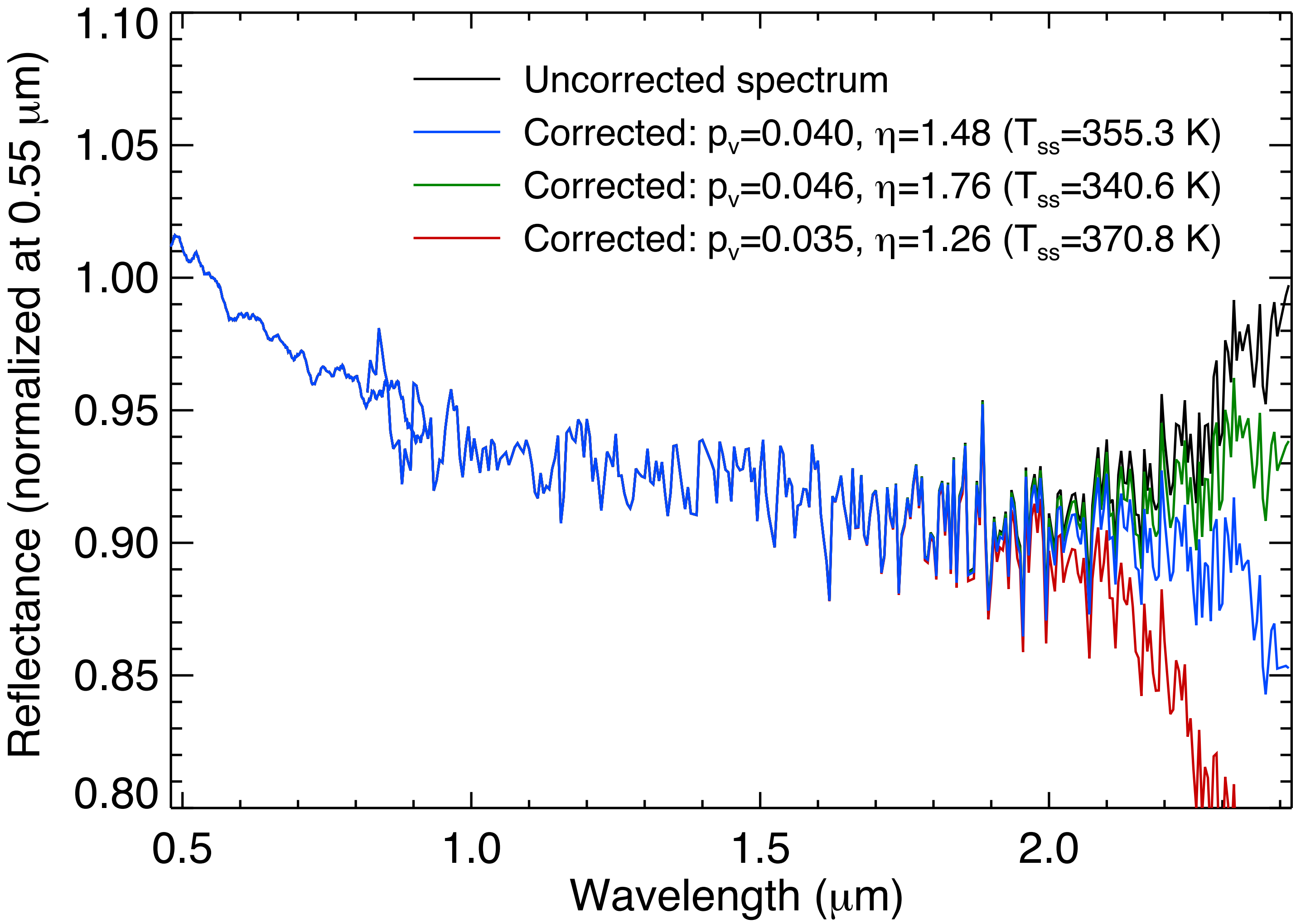
Rivkin, A.S., Binzel, R.P., Bus, S.J., 2005. Constraining near-Earth object albedos using near-infrared spectroscopy. Icarus 175, 175–180.

Takir, D. and Emery, J.P. Outer Main Belt asteroids: Identification and distribution of four 3-µm spectral groups. 2009. Icarus 219, 641-654.

Work to go regarding the Thermal Excess Removal from OVIRS Spectra:

- Include Thermal Excess Removal in SPOC: architecture, requirements, and data flow
- Write Algorithm Description (Josh Emery-lead, Beth Clark, and Vicky Hamilton - with approval by TAWG and SAWG)

- Assign software development and software testing tasks
- Address SPOC DPD template items
- Assist with development of appropriate test data



Uncorrected spectrum
Corrected: p_v=0.040, η=1.48 (T_ss=355.3 K)
Corrected: p_v=0.046, η=1.76 (T_ss=340.6 K)
Corrected: p_v=0.035, η=1.26 (T_ss=370.8 K)
Reflectance (normalized at 0.55 μm)
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.5
1.0
1.5
2.0
Wavelength (μm)