

Since its fall and recovery, the analysis of the Winchcombe meteorite has been a national endeavour. Of the material recovered, we were able to obtain two particulate samples to measure the visible to mid-infrared spectra of the meteorite, and one particulate sample to investigate the bidirectional reflectance distribution function. All samples were then passed along for further analysis. Here we present the measured spectra, analysis, and derived values for comparison with other meteorites and planetary surfaces from [1&2].

Methods:

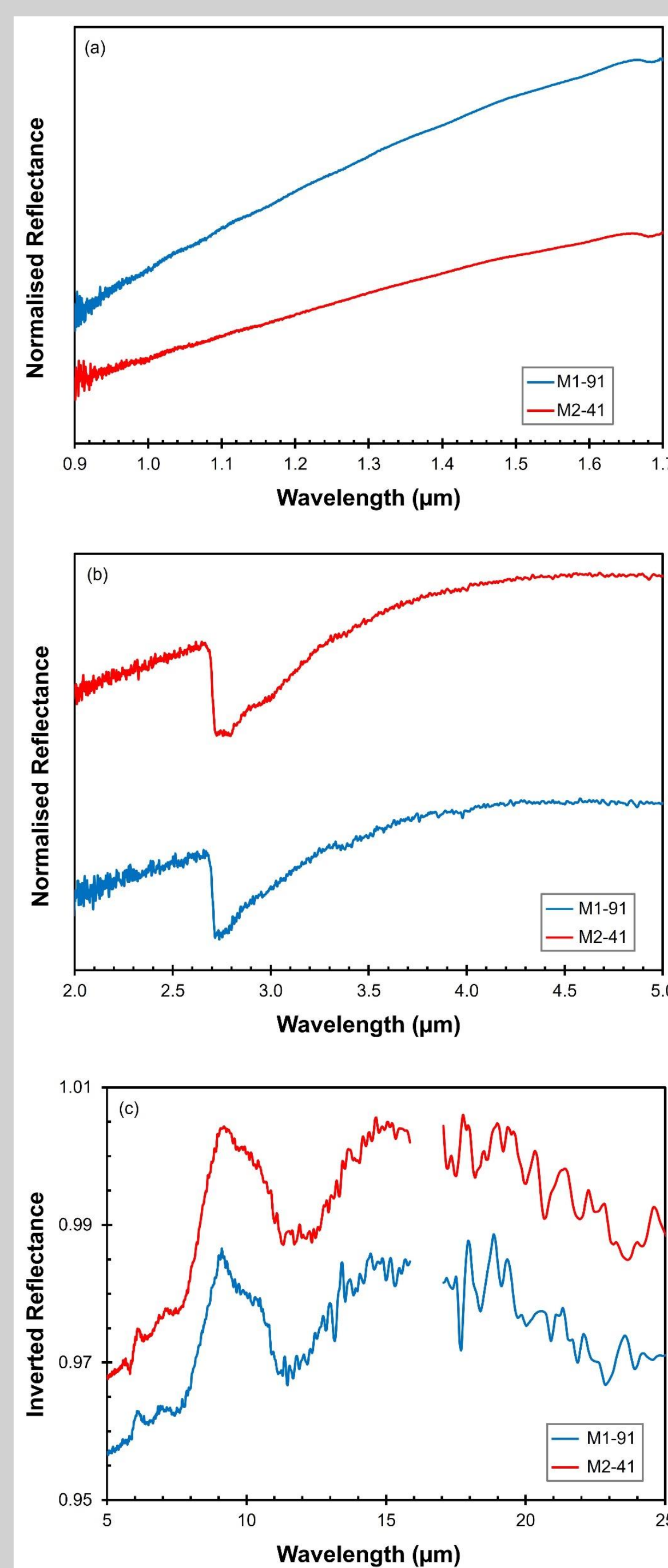
- We measured the diffuse reflectance of two fine-particulate samples of Winchcombe, BM.2022,M1-91 & BM.2022,M2-41.
- Measurements were taken using a Bruker VERTEX 70v Fourier Transform Infrared spectrometer under vacuum at 4 cm⁻¹ resolution calibrated to a diffuse gold target.
- Important spectral features were fit using polynomials to define their shape and position (Table 1).
- The BRDF of sample BM.2022,M1-22 (Fig 2) was measured using the Visible Oxford Space Environment Goniometer [3] (Fig 3) across 0-70° reflectance angles (in steps of 5°), 15-60° incidence angles (in steps of 15°), and at 0°, 90° and 180° azimuthal angles (Fig 4).

	BM.2022,M1-91	BM.2022,M2-41
OH-stretching feature (μm)	2.76 ± 0.01	2.74 ± 0.01
Christiansen feature (μm)	9.21 ± 0.02	9.13 ± 0.01
Transparency feature (μm)	11.83 ± 0.03	11.48 ± 0.01

Table 1. The positions of major features for the two samples.

Infrared Reflectance Spectroscopy

Figure 1. The spectra of the two samples normalized and split into different wavelength regions for clarity.



Results/Discussion:

The slope of the spectra in Fig 1a is likely attributed to compositional differences between the two samples which show a phyllosilicate content of 88 & 93 vol%.

The feature near 2.75 μm is attributed to OH⁻ stretching and indicates aqueously altered mineralogy. We calculated an estimated water content for M1-91 and M2-41 of 6.0 and 5.61 wt% using the methods of [4] and 10.5 and 9.5 wt% using the methods of [5]. These are both lower estimates than the values of 12.4 and 13.3 wt% measured through thermogravimetric analysis [2].

The mid-infrared region (Fig 1c) shows a Christiansen feature position near 9 μm consistent with a less polymerized bulk silicate mineralogy. The slight variation in the position is likely due to a higher olivine content in M1-91 [1]. The band-depth and shape of the transparency feature is indicative of fine particulate materials (<35 μm) and similarly shifts in position with composition.

Overall, the spectra show Winchcombe to be consistent with other highly aqueously altered CM chondrites, and further analysis highlights subtle composition and alteration variability within the meteorite also seen in the modal mineralogy of each sample.

Bidirectional Reflectance Distribution Function (BRDF)



Figure 2. The finely grained Winchcombe BM.2022,M1-22 sample used in the BRDF study.

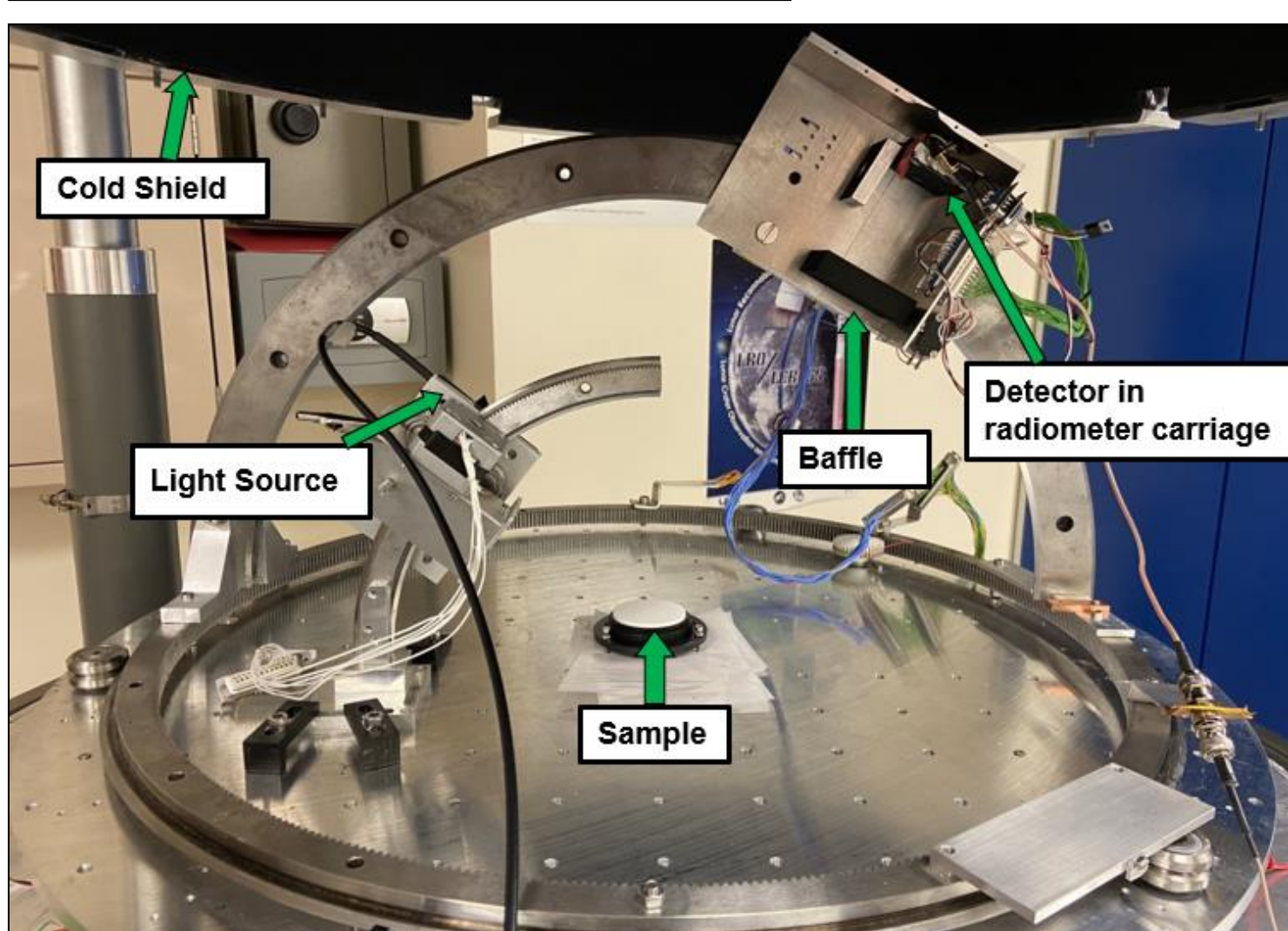


Figure 3. The Visible Oxford Space Environment Goniometer (VOSEG) with major parts labelled [3].

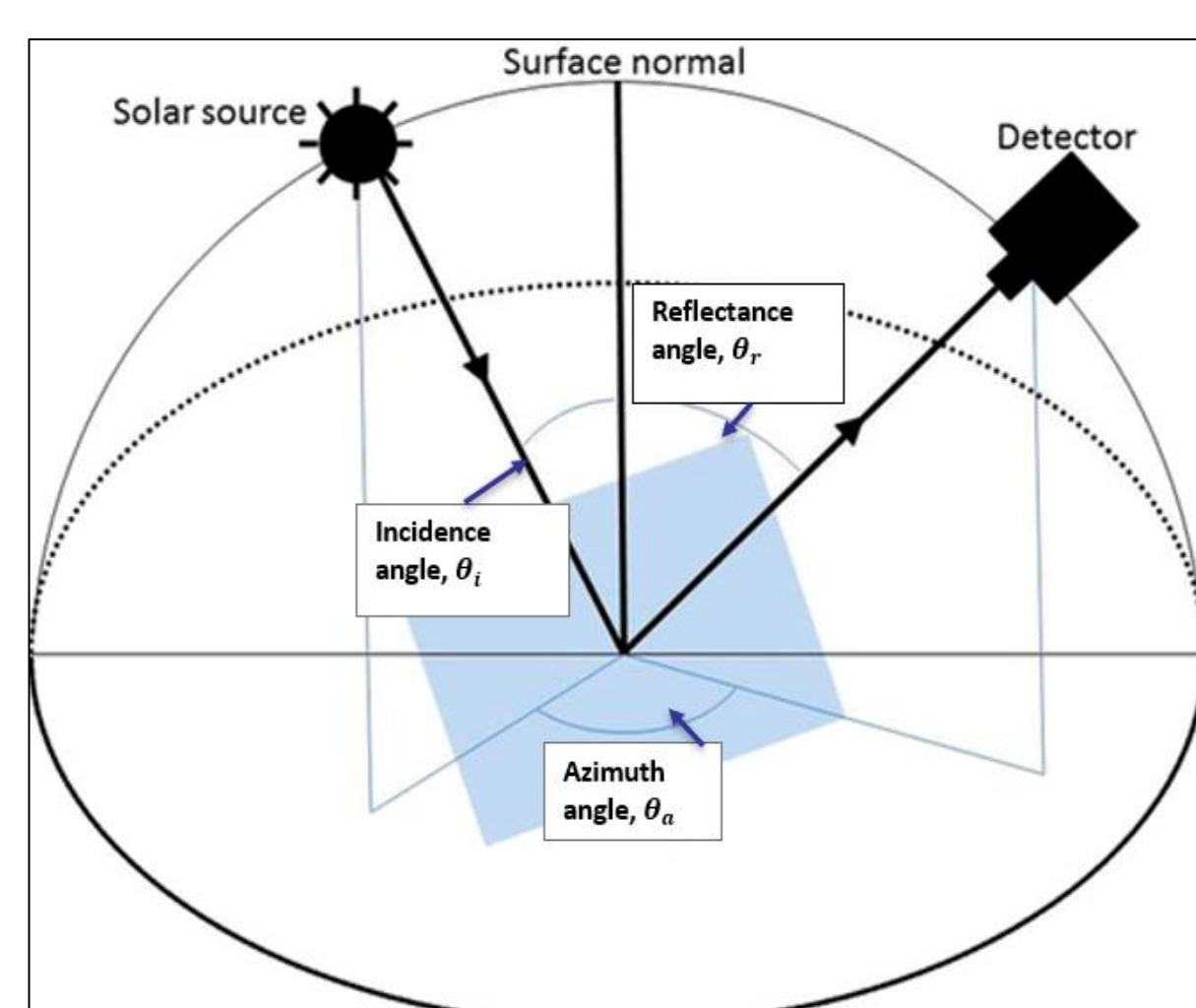


Figure 4. Angular definitions used in the BRDF study.

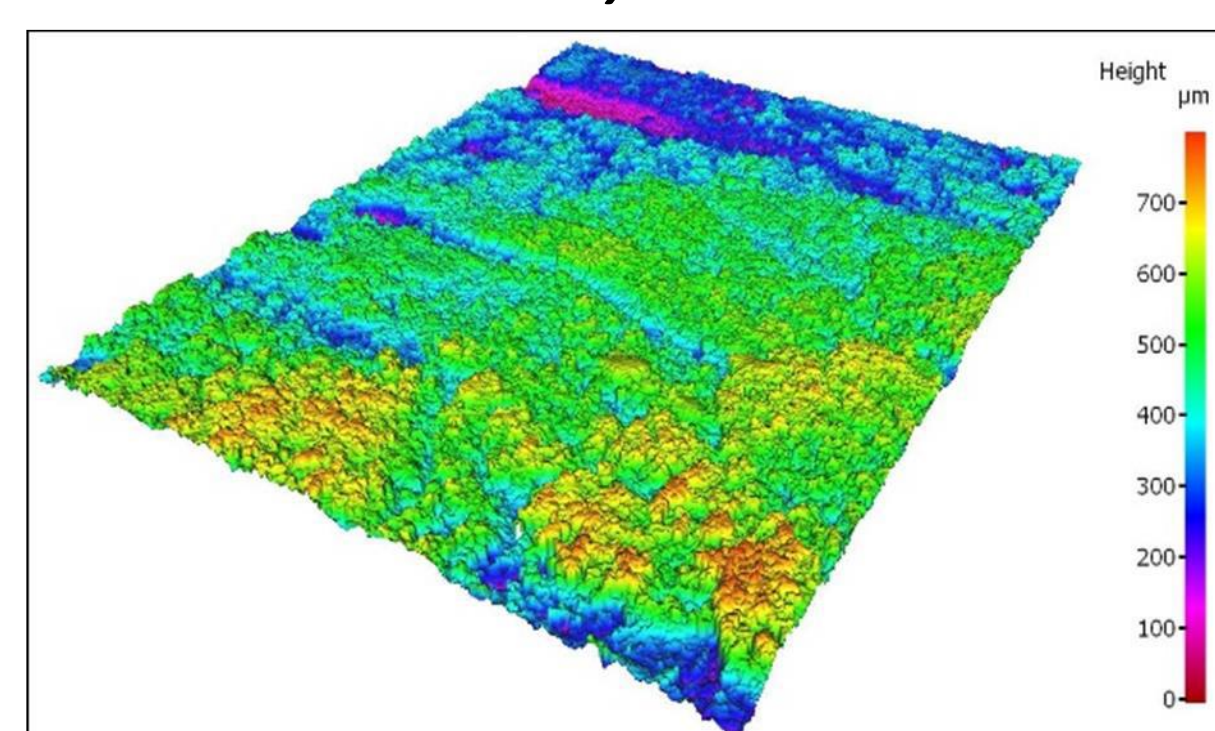


Figure 5. Winchcombe surface profile taken using an Alicona 3D.

- The BRDF data was fitted using the Hapke BRDF Model (with surface roughness included via the shadowing function) [8].
- The sample's surface profile was characterized using an Alicona 3D non-contact surface profiler (Fig 5).
- Therefore, two of the free parameters within the Hapke BRDF model – the filling factor, φ ; and the RMS slope angle, ϑ – could be set, as $\varphi = 0.65 \pm 0.02$ and $\vartheta = 16.11^\circ$. This enabled w (volume average single scattering albedo), b (Henyey-Greenstein forward scattering parameter) and h_5 (width of the opposition effect) to be set as three open parameters within a Hapke BRDF model Least-Squares Levenberg-Marquardt fitting function. The best fit Hapke parameters were determined to be $w = 0.152 \pm 0.030$, $b = 0.633 \pm 0.064$ and $h_5 = 0.016 \pm 0.008$.

The BRDF was measured for a powdered sample, which was characterized in terms of porosity and surface roughness, and this dataset was used to determine the broadband albedo (0.35-1.25 μm) of Winchcombe to be $4.09 \pm 0.18 \%$.

Summary:

- VNIR and MIR spectroscopy are highly effective tools used in planetary remote sensing to determine the composition and physical properties of rocks and minerals.
- The laboratory measured Winchcombe BRDF provides a reference photometric dataset for use in remote sensing studies of similar airless bodies.
- By combining the IR spectra of pristine Winchcombe material with other compositional measurements, we can better understand and interpret data from Solar System objects and learn more about their origins and evolution.