SIGNIFICANCE OF THERMAL EMISSION OF S-TYPE NEAR-EARTH ASTEROIDS AND THEIR MINERALOGICAL SIMILARITIES TO THE MOON. M. Schaal[1]. V. Reddy[2]. M. Gaffey[3]. [1]Department of Physics, Box 7129, University of North Dakota, Grand Forks, North Dakota 58202, [2]Department of Earth System Science and Policy, Box 9011, University of North Dakota, Grand Forks, North Dakota 58202, [3]Department of Space Studies, Box 9008, University of North Dakota, Grand Forks, North Dakota 58202, meagan.schaal@und.edu

Introduction: Solar System bodies are heated by the absorption of sunlight and the absorbed energy is reradiated off as thermal emission. Asteroids as well as other planetary bodies such as the moon, exhibit this phenomenon. The thermal emission on asteroids depends on the heliocentric distance, phase angle, beaming factor, emissivity, and most importantly the geometric albedo. All of these parameters are significant factors that determine the intensity of the thermal emission.

During the 2007 LPSC conference, Pieters (pers. comm.) raised the issue that thermal emission affects band parameters (band centers and band area ratio or BAR) of S-type near-Earth asteroids (NEAs) and that this could lead to misinterpretation of the asteroid's mineralogy. The rationale behind this suggestion was that such effects were observed and quantified on near-IR spectra of lunar basalts. In order to test this suggestion, we conducted a series of modeling experiments using possible meteorite analogs of S-type asteroids and lunar basalts. The results presented here are preliminary and we encourage others to conduct their own independent investigations.

Background: NEAs are generally only observable from ground-based telescopes during a close flyby of the Earth. Near 1.0 AU, most low-albedo NEA spectra display a sharp rise in apparent reflectance beyond ~2.0-µm. This effect was first noted by Abell [1] and later by Rivkin et al. [16]. However, near 1 AU, asteroids with albedos >20% do not show a detectable thermal excess in near-IR wavelengths. Gaffey et al. [6] identified no less than seven different possible meteorite analogs for S-type asteroids. This suggests a wide range of possible albedos and surface thermal properties for S-type NEAs.

In contrast, the moon's surface is primarily composed of several basaltic mineralogies that differ significantly from the basalts on Earth. Due to the moon's regolith surface, the lunar thermal emission is usually higher than that of other terrestrial basaltic surfaces. The reason for the emission difference can be explained by thermal inertia, a measure of the resistance to the change in surface temperature. When there is a low thermal inertia, fast heating and cooling occurs and higher peak temperatures are attained. When there is a high thermal inertia, slow heating and cooling occurs. The moon's thermal inertia is approximately 50, considerably lower than a typical NEA, which has a thermal inertia of about 250 [9]. Since thermal inertia affects the conductivity of heat, thermal emission would thus be affected by such variation. These distinctions would explain differences in the thermal emission on different surfaces.

Several of an asteroid's physical properties or its observing circumstances can influence the spectral reflectance and thereby the thermal emission of its surface. Geometric albedo, a ratio of visual brightness, is one of these parameters. An asteroid with low albedo has a higher surface temperature as it absorbs more energy [14]. The phase angle is defined as the angle between the incident and the reflected components of an object. At different phase angles, the distribution of surface temperature across the asteroid's surface varies altering the thermal emission from the asteroid. At angles close to zero, an opposition effect or visual brightening of the surface occurs. At such angles, the thermal emission is also maximized. The moon displays this effect quite often because of texture of its surface regolith. Another important parameter is the beaming factor, which modifies the effective surface temperature and the angular distribution of the emitted infrared flux [10]. The beaming factor is usually set to 1 for any phase angle greater than 10 degrees. For angles less than 10 degrees, a smaller value can be used, but is not necessary [2]. The emissivity of an object is a ratio of irradiative energy. A value of 0.90 is a standard value that is used for the spectral analysis of asteroids [7].

Methodology: Thermal curves were generated for two possible S-type meteorite analogs (Ordinary Chondrites [3], HEDs [11]) and lunar basalts [6]) using THERMFLX, a thermal modeling program developed by Gaffey based on the Standard Thermal Model [10]. The meteorite spectra were from lab samples and the lunar spectra were from ground-based telescopic data. By using the parameters designated in Table 1, distinct thermal emission curves were generated for each of the materials.

Parameters	Values
Heliocentric Distance	1 AU
Phase Angle	30°
Beaming Factor (Asteroid, Moon)	1.0, 0.83
Emissivity (Asteroid, Moon)	0.90, 0.80
Geometric Albedo	Varies

Table 1. Parameters used to generate thermal curves.

Once the thermal curves were generated, band parameters (Band centers, BAR) were first measured for the raw meteorite/lunar spectra. The next step involved adding the computed thermal flux curves to the reflected flux curves for the meteorite spectra. Since the lunar spectra were telescopic data (which already contained the thermal component), the thermal flux curve was subtracted to find the reflected component. The band parameters have the following errors: Band I: ±0.01 µm, Band II: ±0.1 µm, BAR: ±0.1. The raw and thermally-affected band parameters were compared to see any systematic trends or variations.

Results:

Table 2. Band parameters for meteorite/lunar spectra.

A. H-Chondrites Spectra		
Object/Albedo	**Raw BAR**	**Thermal BAR**
Tieschitz 14%	0.74	0.74
Castalia 13%	0.12	0.11

B. Basaltic Achondrites Spectra		
Object/Albedo	**Raw BAR**	**Thermal BAR**
Juvinas (Eucrite) 17%	1.85	1.85
Bereba (Eucrite) 26%	1.80	1.81
Pavlovka (Howardite) 27%	2.15	2.14
Shalka (Diogenite) 23%	2.33	2.32

C. Lunar Spectra		
Object/Albedo	**Raw BAR**	**Thermal BAR**
Apollo 16 12%	2.90	2.38
Aristarchus 12%	0.74	0.73
Mare Serenitatis 12%	1.81	1.98

D. (BAR Object) - (BAR Object +Thermal)	
Object	**Change in BAR**
Tieschitz	-0.0076
Castalia	0.0049
Juvinas	0.0029
Bereba	-0.0075
Pavlovka	0.0019
Shalka	0.0043
Apollo 16 Landing Site	-0.5180
Aristarchus	-0.0040
Mare Serenitatis	0.1750

As shown above, the BAR of H-Chondrites and Basaltic Achondrites are not significantly affected by thermal emission. Thermally-affected BAR to raw data decreases in the lunar samples except for the Mare Serenitatis, which is primarily composed of a basaltic mineralogy. However, only one of the lunar spectra falls within the ± 0.1 limit for BAR. Data from the other two lunar sites are not close to the limit and are significantly affected. The change in thermal emission, involving the Apollo 16 landing site and Mare Serenitatis, could be due space weathering, which reduces the overall albedo. An adequate amount of weathering occurs on the moon and not on asteroids [14]. Another possible explanation would be the mineralogy of the region. The Apollo 16 landing site contains various mineralogical features, which would alter the amount of radiation absorbed, ultimately affecting the thermal emission produced [12]. A more complex investigation of the specific mineralogy of these regions needs to be conducted to explain the differences in thermal emission.

The second parameter that was examined was band center. Within the error bars (Band I: ±0.01 µm, Band II: ±0.1 µm) reported for asteroid data, no significant changes in both Band I & II centers were noted between the raw and thermally-affected data for all samples. The maximum change in a band center in these samples was 0.003 µm (Band I) and 0.011 µm (Band II). The results for the lunar spectra were formulated using a simplistic thermal flux curve model. A spherical surface was used to calculate the thermal curves of the lunar samples. When considering telescopic lunar data, a flat surface might be a more appropriate fit. Further investigation and a more complex thermal model will be used to refine the results.

Conclusion: The results of our limited sample size modeling effort suggests that band parameters are not significantly affected by thermal emission for S-type NEAs with moderate-high albedos. A comprehensive test would be to conduct simultaneous near-IR and thermal observations of an S-type NEA at two different heliocentric distances and to quantify the differences in band parameters. This would serve as a validation for the results presented here. Limitations of the STM should also be taken into account when interpreting the results presented here. The validity of the application of STM to model lunar thermal properties needs to be further investigated.

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