A SPECTRAL LIBRARY OF EMISSIVITY MEASUREMENTS FOR ASTEROID ANALOGS. A. Maturilli[1], J. Helbert[1], M. D'Amore[1], S. Ferrari[1], R. Saladino[2], [1]Institute for Planetary Research, German Aerospace Center DLR, Rutherfordstr. 2, 12489 Berlin, Germany, [2]Department of Agrobiology and Agrochemistry, University of Viterbo, Italy.

Introduction: In the following years 3 space agencies plan sending spacecrafts to study three different asteroids and return sample. NASA's OSIRIS-REx mission will launch in September 2016 to explore the carbonaceous asteroid Bennu [1]. The exploration plan foreseen 505 days of remote observations of the target. As part of the payload, the Thermal Emission Spectrometer OTES will provide global mineralogical and thermal inertia maps and local spectral information of candidate sample sites, by collecting thermal infrared data between 4 and 50 µm. At least 60 grams of pristine surface will be collected and brought back to Earth, with a landing foreseen 7 years after launch.

After the success of the first ever asteroid sample return mission Hayabusa, JAXA is preparing a follow-up mission to collect a sample from an asteroid and bring it back to Earth [2]. Hayabusa-2 will also visit a C-type asteroid (current target 1999 JU3). This class of asteroids is thought to contain more organics and water, linking them closely to the question of habitability. The launch of Hayabusa-2 is foreseen for end of 2014, return of the sample to Earth follows 6 years later. A mid-infrared imager will observe the asteroid surface, with an IR filter covering the 7 to 12 µm spectral region. The MASCOT lander will carry the MARA instrument, a radiometer with 4 spectral channels allowing basic mineralogical classification [3].

MarcoPolo-R is a candidate mission for the ESA's Cosmic Vision program. The aim of the mission is to collect a pristine sample (~ 100g) from a primitive near-Earth asteroid - the current target is the C-type asteroid 2008 EV5 - and return it to Earth for in-depth investigation in laboratories. Launch is targeted between December 2022 and December 2024, with a cruise phase of 4.5 to 6 years. Among the five selected science instruments, a mid-IR thermal mapper (THERMAP) will map the asteroid surface in emissivity in the spectral region from 8 to 14 µm [4].

At the Planetary Emissivity Laboratory (PEL) of DLR in Berlin we are adding spectral measurements of several meteorites and other analogs for asteroid surfaces to the Berlin Emissity database [5].

The PEL instrumental set-up: Currently two spectrometers at PEL are equipped with external chambers to measure emissivity. The Bruker VERTEX 80V Fourier Transform Infrared-Spectrometer (FTIR) can be operated under vacuum to remove atmospheric features from the spectra. An external evacuable chamber is used to measure emissivity: it contains a motor-driven carousel for up to 12 samples in the same working session, thermal sensors for each sample and a webcam for monitoring the activities inside the chamber. Induction heating system allows to heat up the samples (in stainless steel cups) from 50°C to higher than 800°C. Bruker A513 accessory is used to obtain biconical reflectance with variable incidence angle *i* and emission angle *e* between 13° and 85° at room temperature, under purge or vacuum conditions, in the 1 to 100 µm spectral range.

Bruker IFS 88 FTIR spectrometer has an attached emissivity chamber for measurements at low to moderate temperatures [5, 6], that can be cooled down to 0° C. Samples can be heated from room temperature to 150°C in a purging environment. A Harrick Seagull™ variable-angle reflection accessory allows measurement of the biconical reflectance at room temperature, under purging conditions in the extended spectral range from 0.4 to 55 µm, for *i* and *e* from 5° to 85°.

Asteroid analogs: We have measured the emissivity and reflectance spectra for a suite of relevant analogs for the targets of the three upcoming asteroid missions. The suite consists of ten samples - 3 meteorites and 7 synthetic or terrestrial analog materials. Meteorite Allende represents the CV group of the Carbonaceous Chondrites meteorites; Murchison meteorite stands for the CM group, while the meteorite Millbillillie is achondritic eucrite. Synthetic and terrestrial enstatite, synthetic L-Chondrite and H-Chondrite, graphite and two phyllosilicates (montmorillonite and serpentine) complete the set of analogs.

At PEL we measured bi-directional reflectance of samples in the 1 to 100 µm spectral range, using the evacuated (10^{-4} bar) Bruker Vertex 80V FTIR spectrometer and the A513 reflection unit. The same instrument, coupled with the external emissivity chamber, was used to measure emissivity of samples at 50°C from 1 to 100 µm, under the same vacuum conditions as for reflectance. Using the Bruker IFS88 FTIR spectrometer equipped with its external emissivity chamber we obtained measurements of emissivity in the 1 to 16 µm spectral range under purge gas.

For this study, when possible we measured the smaller available grain size separate (0-25 µm) and for emissivity measurements we kept the sample temperature as low as possible while still having a good signal-to-noise ratio. Figure 1 shows as an example the emissivity of meteorite Allende measured in vacuum and under purging; 1-R under purging is shown for comparison.

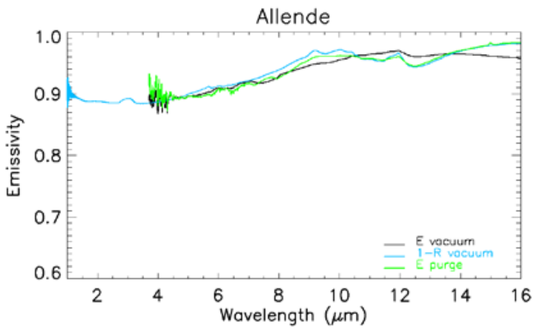

Figure 1. Emissivity and reflectance of meteorite Allende.

Sulfates, carbonates, and phyllosilicates: We present here new measurements on sulfates, carbonates, and phyllosilicates in various grain size ranges. The measurements where obtained in a configuration simulating the range of daytime temperatures encountered on the surface of the scientific target of the ESA Marco Polo-R mission asteroid 2008 EV5, during its revolution around the Sun.

The samples in vacuum (< 0.8 mbar) are measured at surface temperature around 70°C, then the same samples are heated to 220°C, and maintained at this temperature for one hour. Successively the sample temperature is reduced back again to 70°C and a second measurement is taken. Emissivity spectra before and after thermal processing are complemented with reflectance measurements on samples before and after thermal processing. Figure 2 shows as an example the results for an epsomite sample with grain size > 125 µm.

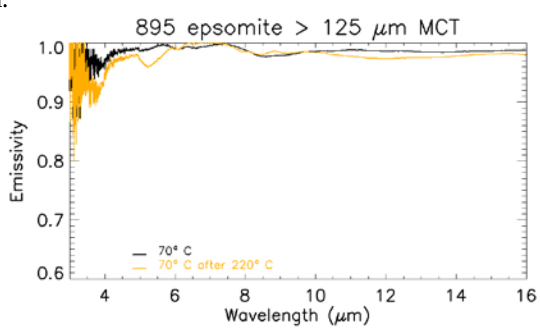

Figure 2. Emissivity spectra of epsomite > 125 µm.

This comparison shows us that for some minerals no spectral/structural changes appear, while others show signs of dehydration and among them some species show structural changes.

Formamide on meteorites: We set-up an experiment at PEL to investigate a key aspect in the prebiotic chemistry of formamide: the surface reactivity of minerals used as catalysts. Three meteorites, NWA2828 (PEL ID 00000887), Al Haggounia (PEL ID 00000888), and Dhofar959 (PEL ID 00000889), were used in this experiment. All the samples were reduced in the grain size fraction < 125 µm and stored in a desiccator before measuring. Each sample was poured in one from a set of identical stainless steel cups. Emissivity of the samples was measured with the Bruker Vertex 80V coupled to its emissivity chamber, both at P < 1 mbar.

The dry meteorites were measured in vacuum at 70°C, successively liquid formamide was vaporized on the samples surface, the cup was immediately transferred in the emissivity chamber, and evacuated. Each sample was measured at 70°, 100°, 140°, and 200°C. After cooling in vacuum each cup was put back in the desiccator, using a small amount of heated material to fill a cup for reflectance measurements.

When heating at 70°C we noticed in all the samples strong signatures attributable to liquid formamide, probably originating from a column of hot vaporized formamide lying above the sample surface. This effect vanished already at 100°C, due to the complete evaporation of the liquid formamide that was deposited on the meteorite sample surfaces. However, all the spectra measured at 100° and 140°C show signs of the presence of formamide, as we infer from comparing them with the 70° C dry measurement of the same samples.

Only when heating at 200°C for 2 out of 3 samples a new feature appears at 7.08 µm (1412 cm^{-1}). This band is very close to a similar band that liquid formamide has at 7.19 µm (1390 cm^{-1}), and that was even present in all the spectra of wet meteorites taken at 70°C. We interpret this band shift as a possible sign of interaction of formamide with the catalyst (the meteorite powder): the CH bend responsible for that is probably strengthening (see Figure 3).

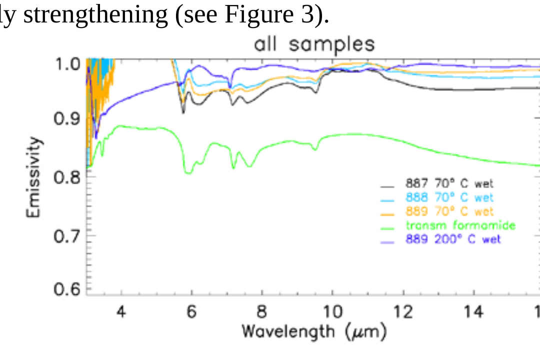

Figure 3. Meteoritic samples moisturized with formamide.

References: [1] Lauretta D. et al. (2012) *LPS XXXXIII*, Abstract #1659, [2] Abe M. et al. (2012) *LPI Contribution* No. 1667, [3] Grott M. et al. (2013) *LPS XXXXIV*, Abstract #1719, [4] Barucci M.A. et al. (2012) *Experimental Astronomy*, **33**, 645-684, [5] Maturilli A. et al. (2006) *PSS*, **54**, 1057-1064. [6] Maturilli A. et al. (2008) *PSS*, **56**, 420-425.