Imaging Spectrometry of Meteorite Samples Relevant to Vesta and the Moon. J.-Ph. Combe[1], S. Le Mouélic[2], P. Launeau[2], A. Irving[3] and T. B. McCord[1]. [1]Bear Fight Institute, Winthrop, WA, USA, jean-philippe_combe @ bearfightinstitute.com. [2]Laboratoire de Planétologie et Géodynamique, Nantes, France. [3]Department of Earth and Space Sciences, Seattle, WA, USA.

Introduction: The interpretation of remote reflectance spectra of planetary surfaces relies on reference spectra of known mineralogical composition, analogs, or samples when available. Some meteorites are also associated to rocky celestial bodies. The lunar origin of some meteorites has been proven by their equivalence to samples from the Moon. Howardite, eucrite and diogenites meteorites (HED) are assumed to come from Vesta because of similarities between their reflectance spectra. Meteorite samples are generally breccias of heterogeneous composition which full characterization implies either statistical analysis over many subsets, or imaging and mapping. Quantitative abundances are estimated at micrometric scales only, or by averaging. Imagery of samples is usually performed as a guide for microprobing. Recent developments of reflectance imaging spectrometry in the laboratory allow now for compositional mapping of thick samples, which is a non-destructive technique. The other advantage is the possibility of using the same technique on samples (in the laboratory or in-situ) and on planetary surfaces (from orbit or from ground-based observations}, therefore making comparative interpretation more direct and more reliable. Finally, this is an opportunity for developing and test methods of spectral analysis against composition derived from chemical analysis. Such cross-analyses are support for data processing of past and future missions. This study started in the context of the mission of the Moon Mineralogy Mapper (M^3) [1] onboard Chandrayaan-1, as well as future observations of Vesta by the Visible and Infrared spectrometer (VIR) onboard Dawn [2]. We present the first results of spectral mixture analysis on lunar meteorites and on HEDs.

Meteorite samples: Most of the meteorites come from North West Africa (NWA) and are part of the collection of Pr. Anthony Irving. Samples are opaque, thick sections (> 1 mm) with a smooth surface (non polished).

Lunar meteorites. These samples are all breccias. Both mare and highlands are represented, with gabbroic and troctolitic composition.

Potential Vestan meteorites. The suite of meteorites we have analyzed includes a large variety: Eucrite-polymict, Mesosiderite, Dunite , Eucrite (basaltic), Olivine diogenite, Diogenite, Diogenite-polymict and Eucrite-plutonic.

Spectral reflectance images:

Instrument characteristics. The HySpex imaging spectrometer is a push-broom system built by the NEO company. (Fig. 1) shows how it is setup at the LPGN in Nantes, France [3]. It is made of three two-dimensional detectors (one spatial dimension and one spectral dimension) covering the spectral range 0.4-1 µm (VNIR), 1-1.7 (SWIR-i), 1.4-2.6 µm (SWIR-m). Each image is acquired independently, line by line, by translating the stage that supports the samples.

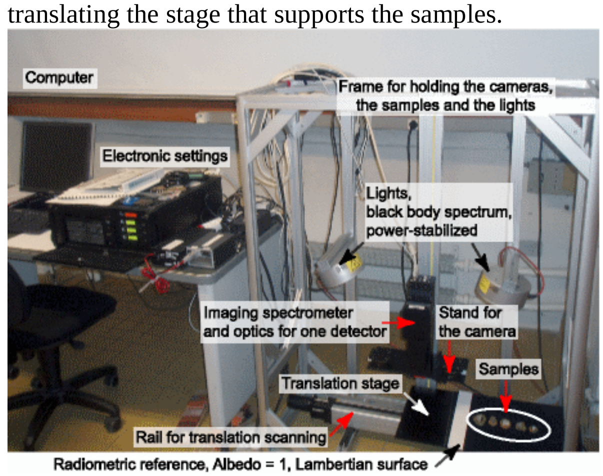

Figure 1: Imaging spectrometer facility at the LPGN, University of Nantes, France.

Image calibration and coregistration. Routine calibration steps such as flat field correction, electronic background subtraction and multiplication by the response function are computed routinely with customized software from NEO. The images are manually calibrated into reflectance: A white (reflectance = 1), diffusive surface (Lambertian) is observed with the samples as reference for radiometric calibration. Each pixel of the image is divided by an average of several pixels of the white reference recorded by the same detector element. The images are then spatially coregistered by taking reference control points on the visible image, then applying rotation, scaling and translation in order to correct for optical distorsion and misalignement of the cameras. A last radiometric adjustment between the detectors is performed by calculating an offset where the spectra overlap, and subsequently applying the offset to all the wavelengths of a given deetector.

Spectral analysis: The objective is to map the composition of each sample, which implies detection of the purest spectral components (spectral endmembers), calculation of their respective mixed contributions in the image (Spectral Mixture Analysis or SMA [4, 5]), and precise characterization of the composition of each spectral endmember.

Spectral endmember selection and SMA. 1) We use the strong linear correlation between reflectance values at all the wavelengths to automatically retrieve the darkest and the brightest spectral endmembers, which is equivalent of removing the first principal component, and therefore enhances the spectral contrast, such as a decorelation stratch. 2) Then a variant version of the SMA, the Multiple-Endmember Linear Spectral Unmixing Model (MELSUM, [6]) is calculated. Results are image fractions for each component and model residuals. 3) Manual analysis of the residuals helps identifying additional spectral endmembers. Steps 2) and 3) are performed iteratively until the addition of one more spectral endmember does not improve the residuals.

We have performed the SMA on meteorite sample NWA 5229, which is an ophitic-textured basaltic eucrite composed mainly of exsolved pigeonite and calcic plagioclase (probably ~An85) with accessory silica, ilmenite and troilite. As is typical, the pyroxene consists of high-Ca augite exsolution lamellae within orthopyroxene.

Spectral endmember characterization. Precise mineral composition can be derived from modeling the absorption bands. The Modified Gaussian Model (MGM [7]) is especially suited for identification of pyroxene types in a mixture and calculating modal compositions [8].

Preliminary results from the SMA: The spectral endmembers in Fig. 2 show mostly two absorption bands near 1 and 2 µm that are characteristic of pyroxenes. The position of the center of the absorption from long to short wavelengths translates compositions ranging from high-Ca to low-Ca. The absorption band near 1.2 µm is characteristic of Fe2+ electronic transitions in M2 sites of pyroxenes [10], which implies rapid cooling during crystallization, and therefore formation close to the surface. Variations in spectral slopes still have to be investigated. An additional component, such as the one represented by the red curve, is spectrally similar to an iron oxide, which could be explained by terrestrial alteration of the minerals in fractures of the samples (Fig. 3).

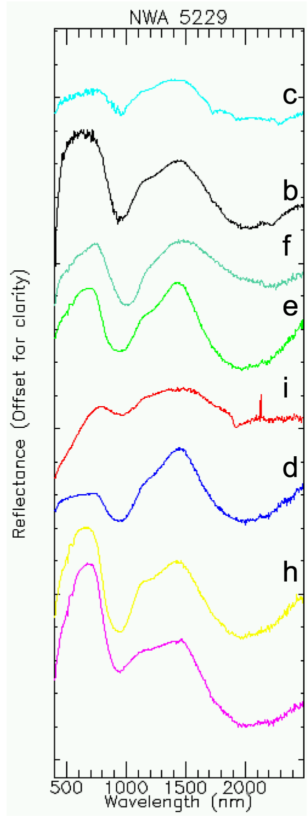

Figure 2: Spectral endmembers derived from MELSUM on sample NWA 5229. Labels correspond to image fractions in Fig. 3.

Perspectives:. Preliminary results indicate that imaging spectrometry in the laboratory make possible to map image fractions of representative spectral endmembers of meteorite samples, and to obtain interpretations that are consistent with information derived from microprobe chemical analysis. The objective is now to interpret the spectral components in more details, and to perform similar analysis on the other samples.

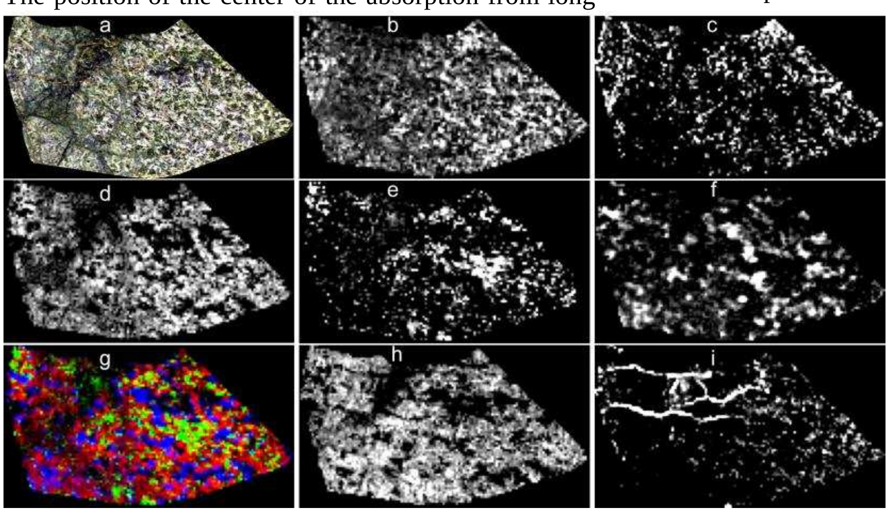

Figure 3: Eucrite-basaltic sample from NWA 5229 and image fractions from MELSUM. a – Visible color composite. b to i: Image fractions of spectral endmembers from Fig.2, except g: Color composite of d (red), e (green) and f (blue).

References:

[1] Pieters et al., Science 326, 2009. [2] Russell et al., EMP 101, 2007. [3] Le Mouelic et al., WHISPERS abstract, 2011. [4] Adams et al., JGR 91, 1986. [5] Adams and Gillespie, Cambridge University Press, 2006. [6] Combe et al., PSS 56, 2008.[7] Sunshine et al., JGR 95, 1990. [8] Sunshine and Pieters, JGR 98, 1993. [9] Klima et al., MPS 42, 2007. [10] Burns et al., Cambridge University Press, 1993.