Activity on the MATISSE tool

MATISSE is a web-tool allowing access and visualization of planetary data (from raw data to high-level products). The main advantage of this tool is the 3D visualization of the data on a shape model. Data are extracted from their own databases with metadata and can be selected by the user by means of several searching parameters, such as target, mission, instrument, latitude/longitude, illumination/viewing angles, wavelength. Moreover, MATISSE can read and visualize planetary data in several formats, e.g. PDS, FITS, ENVI. The tool is currently available at [http://tools.asdc.asi.it/matisse.jsp](http://tools.asdc.asi.it/matisse.jsp) and described in detail by Zinzi et al. (2016).

This report is divided in two sections. In the first one, we show the performed activity on the MATISSE tool itself, consisting in the implementation of new algorithms and functionalities, allowing a quicker and powerful analysis of asteroids data, which is one goal in the Small Bodies task of the JRA.

In the second section, we identify the basic requirements to interface MATISSE with VO tools and data services, i.e. VESPA interface, TOPCAT, CASSIS, ALADIN, 3Dview. In particular, we focus on the handling of planetary data in spectral cube format. As already stated before, contrarily to some VO tools MATISSE is able to access spectral cubes, therefore a link between the MATISSE tool and VESPA interface (in this case to use MATISSE as a plotting tool after the search interface) and tools (in this case to take advantage of further possibilities already implemented in existing tools) will give a strong support in the analysis of this kind of data.

Implementation of new functions on the MATISSE tool

Currently, the following functions have been developed and are currently used by the MATISSE tool for Vesta Dawn-VIR data (to be extended to Ceres data in a near future), but can be of wider use and interest (spectral cube of solid surfaces), simply by changing the instrument parameters in the source codes.

- **Akimov**

  **Application:** any minor bodies image taken in the visible/infrared spectral range, equipped with geometric information.

  **Description:** This function takes reflectance at a defined wavelength in input, as well as incidence, emission and phase angles, expressed in degrees. It gives in output the equigonal albedo (i.e. the reflectance corrected for topography effects, i.e. incidence and emission angle influence), obtained by applying the Akimov disk function (Shkuratov et al., 1999). The bidimensional input variables must have the same dimensions.

  An example of equigonal albedo image obtained by applying the Akimov function is shown in Figure 1.

![Figure 1. Equigonal albedo distribution at 1.2 mm, corresponding to a Dawn/VIR observation of Vesta, obtained by implementing the Akimov function of the MATISSE tool. The image is projected on the Vesta shape model](image)

- **Conversion**

  **Application:** In its current form, this function can work on hyperspectral data provided by imaging spectrometers, having the spectral resolution of VIR/Dawn, VIRTIS/VeX, VIRTIS/Rosetta. Minor changes would be needed to extend its application for other instruments.

  **Description:** This function converts a hyperspectral radiance image in a hyperspectral reflectance (specifically, radiance factor $\ell/F$) image. It takes in input a radiance cube (expressed in the format “bands, samples, lines”), a wavelength array (which must have the same size of the dimension “band” of the radiance cube) and the name of the file corresponding to the observation (expressed as string), giving the reflectance cube (in the format “bands, samples, lines”) as output.

  The relation used for conversion is shown in Filacchione and Ammannito (2014). The considered solar spectrum irradiance is obtained from the convolution of the Cebula+Kurucz spectrum with VIR spectrum resolution. The Cebula+Kurucz solar spectrum was obtained from the Renewable Resource Data Center of the National Renewable Energy Laboratory, and is an Air Mass Zero (AM0) spectrum derived from the combination of solar spectrum data from Kurucz et al. (1984) and Cebula et al. (1996).
In order to work correctly, the log file corresponding to the considered observation must label the spacecraft solar distance as "SPACECRAFT_SOLAR_DISTANCE", which is the used norm for Dawn/VIR, Rosetta/VIRTIS, VeX/VIRTIS observations.

The function needs two IDL/GDL auxiliary routines, i.e. rd_tfile.pro and str2arr.pro.

An example of a reflectance image, obtained by applying the Conversion function on a radiance image is shown in Figure 2.

![Figure 2](image)

Figure 2. Reflectance distribution at 1.2 mm, corresponding to a reflectance image, obtained by applying the Conversion function of the MATISSE tool on a Dawn/VIR radiance image of Vesta. The image is projected on the Vesta shape model.

- Vesta_nir_alb_ret and Vesta_vis_alb_ret

**Application:** These functions are an example of photometric correction by means of a semi-empirical approach. They are optimized for Vesta high and low resolution, but the extension to other bodies will be straightforward, because it would need only a change of coefficients of the phase function. The geometric information is essential.

**Description:** These function applies photometric correction on reflectance 2D images, by using the relations obtained by Longobardo et al. (2014). Input variables are reflectance, and incidence, emission and phase angles (expressed in degrees). The correction is optimized for Vesta at wavelengths between 1 and 1.8 um (Vesta_nir_alb_ret) and between 0.4 and 0.8 um (Vesta_vis_alb_ret).

The function will give in output three photometrically-corrected reflectance images, i.e.:

a) geometric albedo images, obtained by applying the "low resolution" photometric correction, optimized for Approach and Survey phases of the Dawn mission (Longobardo et al. 2014);

b) reflectance at 30° phase obtained by applying the “low resolution” photometric correction, optimized for Approach and Survey phases of the Dawn mission (Longobardo et al. 2014);

c) reflectance at 30° phase, obtained by applying the “high resolution” photometric correction, optimized for HAMO and LAMO phases of the Dawn mission (Longobardo et al. 2014);

This is the most general case since for other minor bodies, no difference between low and high resolution phase functions arise, therefore the extension to other minor bodies will be simpler because will provide in output less photometrically-corrected images.

**NOTE:** The input variable should be radiance factor and not equigonal albedo, since retrieval of equigonal albedo is already included in the function.

The following functions have been developed and are going to be implemented on the MATISSE tool.

- Hed_center1 and Hed_center2

**Application:** These functions can be applied to the bodies composed of HED (regardless of data format and instrument), i.e. Vesta and Vestoids. Hed_center2 works well for bodies composed of pyroxenes, too, e.g. S-type asteroids (Eros, Ida, Gaspra, Annefrank). The extension of Hed_center1 to S-type asteroids will require only a slight change of coefficients of the used relation. Temperature data are essential.

**Description:** These functions takes in input the band center of the HED 1 um (Hed_center1) and 2 um (Hed_center2) band (due to pyroxene absorption) and the temperature relative to the observation (expressed in Kelvin degrees), and removes the thermal effects on the band center, by giving the band center at a temperature of 300 K. The bidimensional input variables must have the same dimensions.

- Lambert

**Application:** any minor bodies image taken in the visible/infrared spectral range, equipped with geometric information.

**Description:** This function takes reflectance at a defined wavelength in input, as well as incidence angle, expressed in degrees. It gives in output the equigonal albedo (i.e. the reflectance corrected for topography effects, i.e. incidence and emission angle influence), obtained by applying the Lambert disk function. The bidimensional input variables must have the same dimensions.

- Lomsel
Application: any minor bodies image taken in the visible/infrared spectral range, equipped with geometric information.

Description: This function takes reflectance at a defined wavelength in input, as well as incidence and emission angles, expressed in degrees. It gives in output the equigonal albedo (i.e. the reflectance corrected for topography effects, i.e. incidence and emission angle influence), obtained by applying the Lommell-Seeleiger disk function. The bidimensional input variables must have the same dimensions.

- Pyro_corr_band1 and Pyro_corr_band2

Application: These functions are an example of photometric correction of pyroxene band depths, by means of a semi-empirical approach. They are optimized for Vesta high and low resolution, but the extension to other bodies will be straightforward, because it would need only a change of coefficients of the used relations. The geometric information is essential.

Description: This function applies the photometric correction on the 1 um (Pyro_corr_band1) and 2 um (Pyro_corr_band2) pyroxene band depth, by means of the relation obtained for Vesta (Longobardo et al., 2014). The input variables are a 1 um/2 um band depth image, a geometric albedo at 1.2 um (obtained from the function Vesta_nir_alb_ret see), the reflectance at 30° phase at 1.2 um (obtained from the function Vesta_nir_alb_ret see) and phase angle (expressed in degrees). The bidimensional input variables must have the same dimensions.

The function will give in output three photometrically-corrected band depth images, i.e.:

a) band depth corrected at 0° phase, obtained by applying the “low resolution” photometric correction, optimized for Approach and Survey phases of the Dawn mission (Longobardo et al. 2014);

b) band depth corrected at 30° phase, obtained by applying the “low resolution” photometric correction, optimized for Approach and Survey phases of the Dawn mission (Longobardo et al. 2014);

c) band depth corrected at 30° phase, obtained by applying the “high resolution” photometric correction, optimized for HAMO and LAMO phases of the Dawn mission (Longobardo et al. 2014).

This is a general case since for other minor bodies, no difference between low and high resolution phase functions arise, therefore the extension to other minor bodies will be simpler because will provide in output less photometrically-corrected images.

- Pyroxene_band_1_ um and Pyroxene_band_2_ um

Application: any minor body composed of pyroxenes, and hence showing the 1 mm and/or 2 mm absorption bands in their spectra.

Description: This function calculates the descriptors of the pyroxene 1 um (Pyroxene_band_1_ um) and 2 um (Pyroxene_band_2_ um) absorption bands. The input variables are a wavelength array and a reflectance hyperspectral image (in format "bands, samples, lines"). The output consists in a hyperspectral image of 12 absorption band descriptors: in other word, it is a variable of "12, samples, lines" elements. The twelve descriptors are: 1) band minimum; 2) band center; 3) band depth; 4) band area; 5) band slope; 6) band FWHM; 7) band HWHM; 8) reflectance at left shoulder wavelength; 9) reflectance at band minimum; 10) reflectance at right shoulder wavelength; 11) left shoulder wavelength; 12) right shoulder wavelength. Parameters are calculated by using the methodology of Longobardo et al. (2014), i.e.:

- Left shoulder is fitted by a 4th order polynomial between 0.55 and 0.80 um (Pyroxene_band_1_ um) or between 1.10 and 1.69 um (Pyroxene_band_2_ um), respectively. Left shoulder wavelength corresponds to the maximum fitted reflectance in this interval;
- Trough is fitted by a 4th order polynomial between 0.80 and 1.10 um (Pyroxene_band_1_ um) or by a 3rd order polynomial between 2.07 and 2.40 um (Pyroxene_band_2_ um). Band minimum is the wavelength corresponding to the minimum fitted reflectance in this interval;
- Right shoulder is fitted by a 4th order polynomial between 1.10 and 1.69 um (Pyroxene_band_1_ um) or by a 3rd order polynomial between 2.07 and 2.40 um (Pyroxene_band_2_ um);
- Continuum is a straight line, starting from left shoulder wavelength and tangent to right shoulder. The tangent point identified right shoulder wavelength (Pyroxene_band_1_ um);
- Continuum is a straight line, between left shoulder and fitted reflectance at 2.40 um (Pyroxene_band_2_ um);
- Band center is the band minimum after the continuum removal;
- Band depth is 1-Rc/Rcon, where Rc and Rcon are the measured reflectance and the calculated continuum reflectance at the band center;
- Band area is the sum of the differences between continuum and fitted band and each wavelength contained in the band;
- Band slope is the ratio between the differences of shoulders’ reflectances and shoulder’s wavelengths, respectively;
- FWHM is calculated on the band after continuum removal and is the difference between the two wavelengths having a reflectance value differing from the continuum of half band depth;
- HWHM is calculated on the band after continuum removal and is the difference between the band center wavelength and the wavelength, shortward of band center, having a reflectance value differing from the continuum of half band depth;
- Ref_extract

Application: Any hyperspectral image.

Description: This function extracts the reflectance at a wavelength defined by the user from a hyperspectral image. The input variables are a wavelength array, a hyperspectral image (in format "bands, samples, lines") and the wavelengths where reflectance should be extracted. According to the Longobardo et al. (2014) procedure, the reflectance is calculated by averaging in a wavelength interval 8 nm (for the visible) and 38 nm (for the infrared) wide and centered at the wavelength defined by user, in order to maximize the signal-to-noise ratio.

The following algorithms are going to be developed:

- Retrieval of descriptors of other absorption bands (e.g., water ice at 1.5 um and 2 um; phyllosilicates at 2.7 um, organic at 3.2 um, ammoniated at 3.05 um, carbonates at 3.4 um and 3.9 um)
- Retrieval of spectral slopes
- Retrieval of spectral indices for olivine retrieval
- Retrieval of wollastonite, ferrosilite and enstatite content
- Retrieval of dark and bright areas
Interfacing MATISSE with VO tools and data services

The MATISSE tool is particularly useful for the analysis of PDS-format spectral cubes, and hence its integration in the VESPA interface or with VO tools will give an added value to VESPA for the analysis of hyperspectral images.

The VVEX service on VESPA currently allows linking, visualization and download of the hyperspectral data, i.e. PDS cubes provided by the VIRTIS/Venus Express (VVEX) instrument.

The procedure to handle these cubes currently consists of the following steps:

1. The user selects an observation from the VESPA interface.
2. The user can handle PDS cubes by sending them to the APERICubes demonstrator tool by means of SAMP protocols.
3. APERICubes is linked via SAMP to other VESPA VO tools, allowing a more detailed analysis of images (ALADIN), tables (TOPCAT), spectra (CASSIS) and 3D images (3dview)

Schematically:

VESPA --> APERICubes --> VO tool (ALADIN, TOPCAT, CASSIS or 3dview)

We identified three options to interface MATISSE with VESPA service and tools. The difference among these three options is in the tool/service that will interface MATISSE:

- in the first option, MATISSE will be linked directly to the VESPA interface in step 2 (in place of APERICubes);
- in the second option, APERICubes will interface MATISSE in step 3;
- in the third one, an additional step will be added, corresponding to the interface between VO tools and MATISSE.

We describe in the following the requirements needed to apply the three options.

Option 1: VESPA --> MATISSE

MATISSE can be used as an alternative to APERICubes to handle PDS spectral cubes. The identified requirements to apply this option are the following:

a) SAMP protocols must be included in MATISSE. Moreover, MATISSE should be responsive to the same SAMP message (Mtype) as APERICubes. Then, we can decouple APERICubes from the search interface, so that it is not the launched by default. Both tools would receive the message and work if are launched;

b) VESPA must send to MATISSE not only the spectral cube, but also the corresponding geometric cube. This means that the geometric information must be available. In the case of VVEX, geometric cubes are already included in the service and the identification of the geometric cube relative to a specific observation is straightforward because part of the filename is the same. The use of the Datalink protocol from IVOA is under evaluation for this step. Alternatively, MATISSE could include a script to look for the geometric cube associated to the observation (see Option 3).

c) The wavelength vector is needed to apply the functions implemented on MATISSE. However, it would not be necessary to pass this information from VESPA to MATISSE. Since the wavelength vector is unique for any instrument this information can be stored in a standard location so that the tool can retrieve it. Alternatively, the wavelength vector included in calibrated files (e.g. case of VIRTIS) could be used.

Option 2: VESPA --> APERICubes --> MATISSE

In this case, MATISSE is one of the tools linked by APERICubes, like the other VESPA VO tools. The identified requirements to apply this option are the following:
a) SAMP protocols must be included in MATISSE;

b) VESPA should send the URL of the geometric cube (corresponding to the selected observation) to APERICubes, together with the PDS cube. APERICubes in turn should send the URL to MATISSE, which will use it to download the geometric cube. The use of Datalink protocol for this operation is under evaluation.

c) The wavelength vector will be passed to MATISSE, as specified in point c) of previous option.

**Option 3: VESPA -- APERICubes --> VO tool --> MATISSE**

The difficulty of this option is that in the transfer from APERICubes to the VO tool, we lose any information about the geometry, which is included in the VESPA interface. The triple transfer of the geometric cube URL from VESPA to APERICubes, then to VO tool and then to MATISSE would require to modify each VO tool, which is a non optimal solution.

The best solution would be that the users “order” MATISSE to download the geometric cubes. A general procedure could be the following:

a) The user selects the instrument/channel from an appropriate MATISSE menu. The selection will allow MATISSE to upload the corresponding wavelength vector and link the corresponding database;

b) Whatever the instrument, the instrument and the spectral cube names allow the identification of a unique geometric cube, which could be then uploaded to MATISSE.

The use of Java and Javascript libraries to access EPN-TAP services is under evaluation for this end.

In the following, the input/output format of each VO tool and MATISSE are compared:

**Option 3a: VESPA -- APERICubes --> ALADIN --> MATISSE**

ALADIN gives in output FITS images. MATISSE can read this kind of data and hence ALADIN output can be exported to MATISSE without criticalities. The inverse operation (from MATISSE to ALADIN) is also possible.

**Option 3b: VESPA -- APERICubes --> TOPCAT --> MATISSE**

The TOPCAT works with VO tables, which are among the possible MATISSE input formats. Therefore, the interface between TOPCAT and MATISSE is possible.

**Option 3c: VESPA -- APERICubes --> CASSIS --> MATISSE**

CASSIS works only on spectra, whereas MATISSE on images. An interface between the two tools would be needed.

**Option 3d: VESPA -- APERICubes --> 3dview --> MATISSE**

3dview does not allow download of data, and hence an interfacing with MATISSE is not considered.

A great part of the requirements necessary to link MATISSE with VESPA interface/tools could be implemented by introducing changes in the EPNcore data model. In this way, once the PDS spectral cube is passed to MATISSE following one of the three options described above, it would be straightforward for MATISSE to use the correct geometry and wavelength information. After this first analysis these aspects will be taken in consideration and carefully analyzed.