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Rosetta-Mars fly-by, February 25, 2007

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Abstract. On the 25 of February 2007, the ESA Rosetta mission approached planet Mars. This gravity assist gave the opportunity to the scientific community to get several sets of images through the use of OSIRIS instrument: Rosetta imaging camera. The entire surface of the Red Planet has been imaged as well as the atmosphere and the clouds which were partly covering it. The aim of this paper is to introduce and show the preliminary studies which have concentrated on three images sets obtained during Rosetta closest approach to Mars.

Key words. OSIRIS – NAC – Remote sensing – Mars – Spectrophotometry – Rosetta

1. Introduction

The Rosetta mission was launched on March, 2nd, 2004 from the European Spaceport of Kourou, French Guyana. Its main goal is to analyse the comet 67P/Churyumov-Gerasimenko orbiting for the first time around such a target before, during and after the perihelium approach to the Sun (Glassmeier *et al.* 2006).

This mission will allow to understand the alteration processes of the comet during a period of one year and the interaction between the solar wind and the outgassing comet as well as the processes on the surface layer of the nucleus and the inner coma.

Before reaching the target in 2014, after its eleven years journey, the space probe takes advantage of four gravitational assist manoeuvres (Earth-Mars-Earth-Earth) to get enough energy to reach the comet. On February, 25th, 2007 Rosetta approached the planet Mars at an average speed of 10 *km/s*. During this gravity assist most of scientific instrumentation was switched on and OSIRIS imaging system had the great opportunity to obtain scientific images of the surface, atmosphere and clouds of the Red Planet. Several useful data have been obtained in order to calibrate the Narrow Angle Camera, NAC and the Wide Angle Camera, WAC, the two OSIRIS eyes.

The instrument observation plan has provided the possibility to image the entire surface of the planet, specific parts of it, clouds, craters, and plains, together with the transit of the satellite Phobos and a close observation of it. The planet has been observed in the entire wavelength range allowed by NAC and WAC, *i.e.* from 240 up to 990 *nm*, see Fig. 1.

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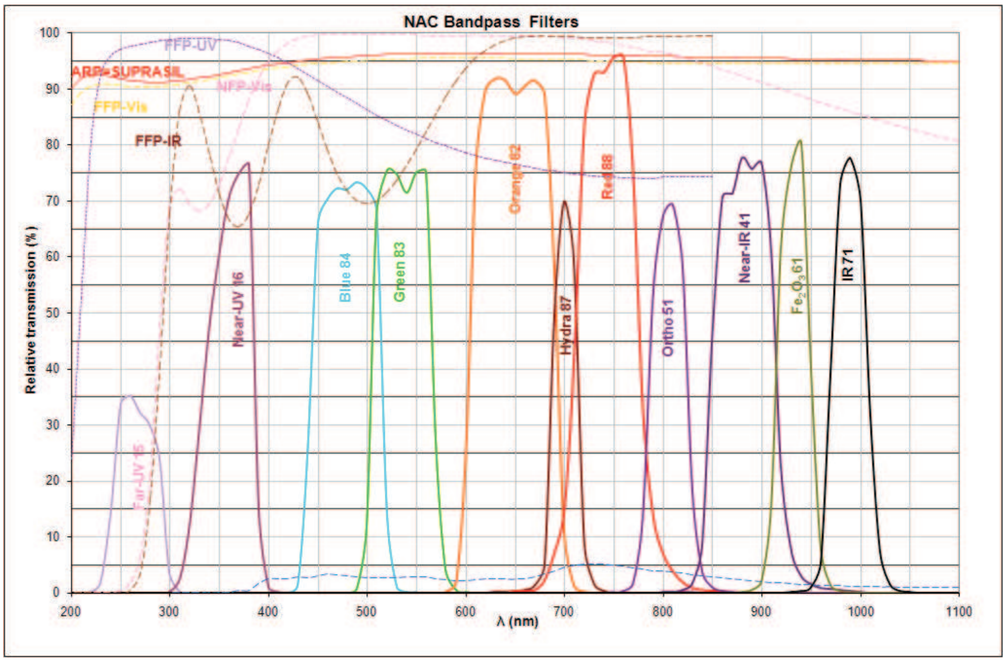

Fig. 1. NAC bandpass filters used during Rosetta Mars fly-by.

2. The NAC instrument

The Narrow Angle Camera has been realised to obtain images not only of 67P/Churyumov-Gerasimenko comet from distances that go from 500000 *km* to 1 *km* (Keller *et al.* 2006), but also of the asteroids 2867 Steins and 21 Lutetia visited during Rosetta interplanetary journey. This instrument has been switched on during Mars fly-by in order to image the planet through the entire set of its available filters in the range between 250 *nm* to 1000 *nm*. The set of filters used during Mars fly-by is showed in Fig. 1 and presented in Table 1.

Filter number	Filter name	Central λ *nm*	Bandwidth *nm*
F15	FFP-UV Far-UV	269.3	53.6
F16	FFP-UV Near-UV	360.0	51.1
F84	Neutral Blue	480.7	74.9
F83	Neutral Green	535.7	62.4
F82	Neutral Orange	649.2	84.5
F87	Neutral Hydra	701.2	22.1
F88	Neutral Red	743.7	64.1
F51	Ortho FFP-IR	805.3	40.5
F41	Near-IR FFP-IR	882.1	65.9
F61	Fe_2O_3 FFP-IR	931.9	34.9
F71	IR FFP-IR	989.3	38.2

Table 1. Filter number, name, central wavelength and bandwidth for each badpass NAC filter used during Mars fly-by.

3. OSIRIS Mars images

3.1. RGB Images

By observing through IR and Visible wavelengths to UV using RGB images obtained by OSIRIS, it is possible to see how the atmosphere of this planet interact with electromagnetic radiation (Figs. 2, 3 and 4).

Using as red, green and blue channel the filters 71, 61 and 41 respectively, that are IR wavelength range centered, all the clouds that covers the surface of the planet disappear. This is because CO_2, that mainly composes Martian atmosphere and clouds does not absorb photons with this three specific wavelengths, i.e. 989.3, 931.9 and 882.1 *nm*.

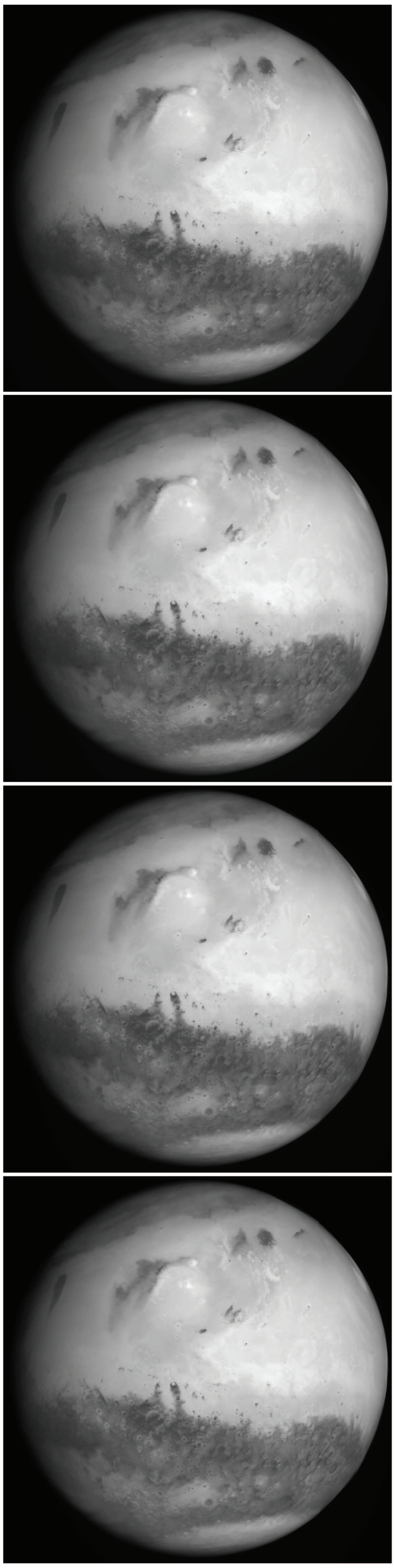

Fig. 2. Set of Mars images obtained by OSIRIS-NAC from a distance of 244000 *km*, with a resolution of 4600 *m/px*. The wavelengths are (from the top to the bottom): 989.3, 931.9, 882.1, 805.3 *nm*.

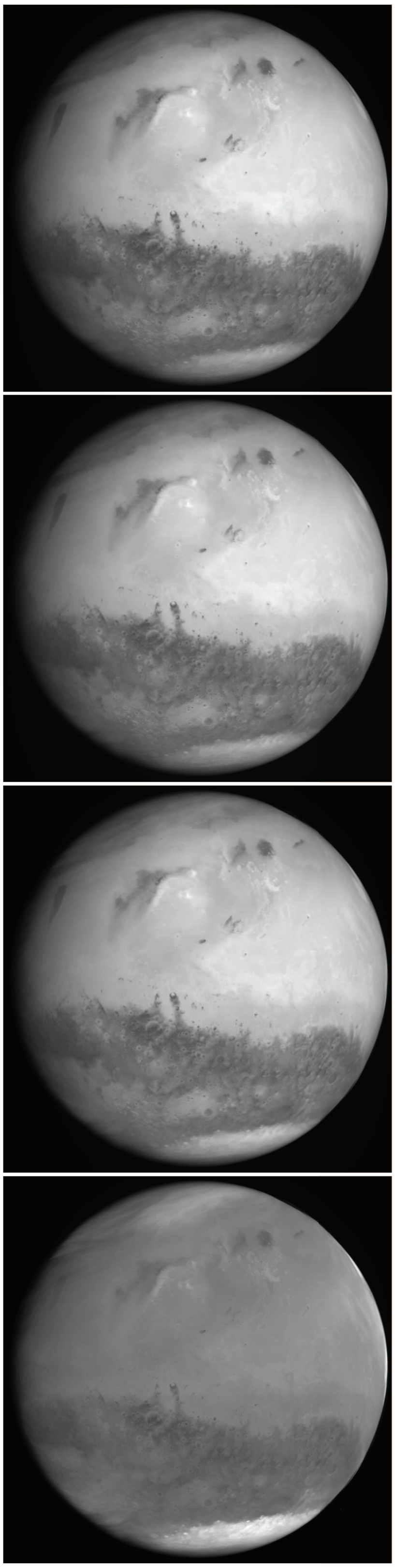

Fig. 3. Set of Mars images obtained by OSIRIS-NAC from a distance of 244000 *km*, with a resolution of 4600 *m/px*. The wavelengths are (from the top to the bottom): 743.7, 701.2, 649.2, 535.7 *nm*.

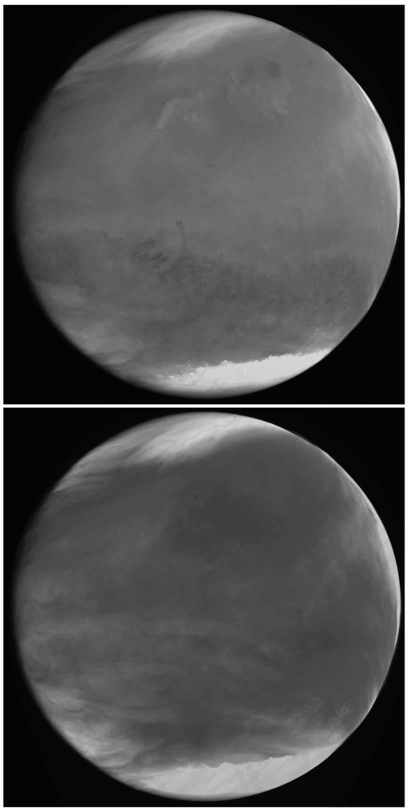

Fig. 4. Set of Mars images obtained by OSIRIS-NAC from a distance of 244000 *km*, with a resolution of 4600 *m/px*. The wavelengths are: 480.7, 360.0 *nm*.

Moving to shorter wavelengths and realising the RGB image with filters 82, 83, 84, i.e. 649.2, 535.7 and 480.7 *nm*, it is possible to see the characteristic red color of Mars, due to the surface dominant nanocrystalline reddish hematite Fe_2O_3 together with the extent low basins and polar white clouds. Another interesting triplet which is possible to use obtaining false color images is the one with filter 83, 535.7 *nm*, as red channel, 84, 480.7 *nm*, as green and the near UV filter 16, 360.0 *nm*, as the blue channel. Thanks to this false color image, see Fig. 5, it is possible to see clouds located not only at the polar caps, but also at equatorial latitudes where there are white veils surrounding Mars.

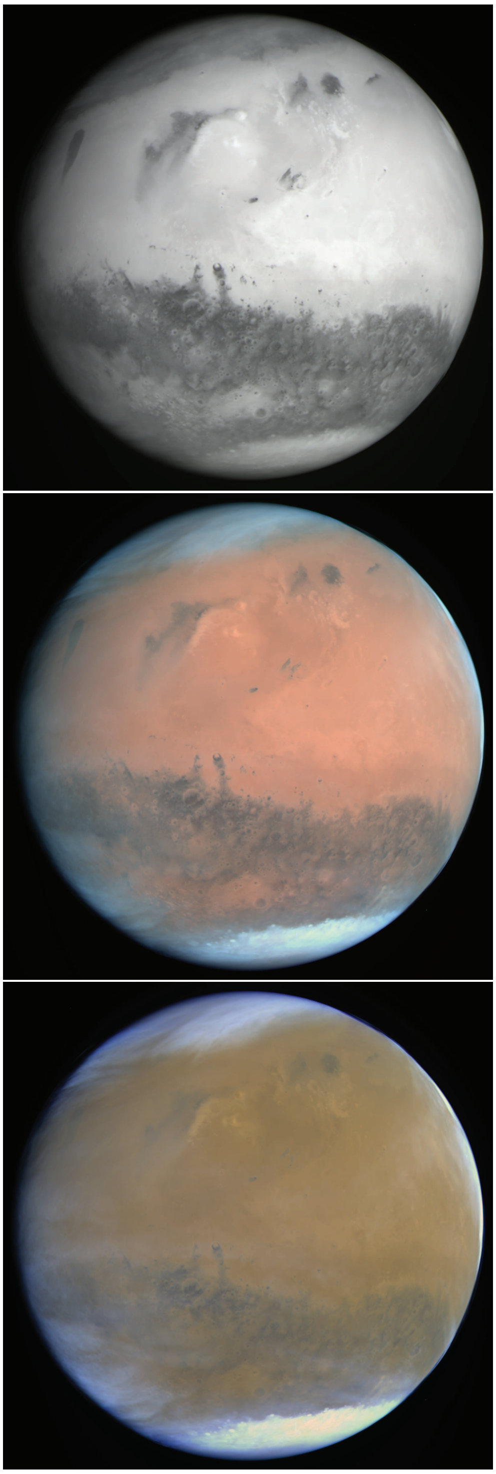

Fig. 5. RGB images realised with filters F71, 61 and 41 for the IR image, filters F82, F83 and F84 for the visible one and F83, F84, F16 for the UV centered. The resolution is 4600 *m/px*.

3.2. Altitude of Martian Clouds

During the Rosetta fly-by of Mars, OSIRIS-NAC instrument allowed to get several high resolution scientific images, not only of the surface of the planet, but also of the Martian limb. In all 2048 × 2048 and also 1024 × 1024 images it is possible to detect the different layers of clouds in the atmosphere.

The Martian clouds that have been studied are those that are located on the east limb of the imaged planet. This choice is due to the fact that the altitude of an object has to be always referred to a ground level and this is detectable only on the east limb of the planet. There, it is allowed to observe a complete section of the atmosphere, its cloud layers and the reference ground from which the derivation of their altitude is possible.

The bandpass filter, which has been chosen for the analyses of the altitude of clouds, is the NAC Orange filter 82, 649.2 *nm*. It has been preferred with respect to the others because it gives the best contrast and compromise to see the ground level of Mars and all the detectable layers of clouds.

The presence of atmosphere and the consequent scattering of the radiation have spread the decreasing values of flux over several CCD pixels giving a hard definition of limb; to solve this problem the Roberts edge enhancement operator for images has been introduced. Once the limb has been defined as the maximum value of the first absolute derivative of the image, *i.e.* where the variation between a pixel and its successive is maximum, a series of plots have been produced with on Y axis the flux value of each pixel that has been radially selected from the center of Mars, and on the X axis the distance in km from the ground level.

Every point plotted has a value of separation which is the resolution per pixel of the image, that depends on the distance of OSIRIS from Mars. The limb distance of the clouds in kilometres has been obtained from the focal length of the scientific instrument used, the detector pixel size and the distance of the space probe from Mars.

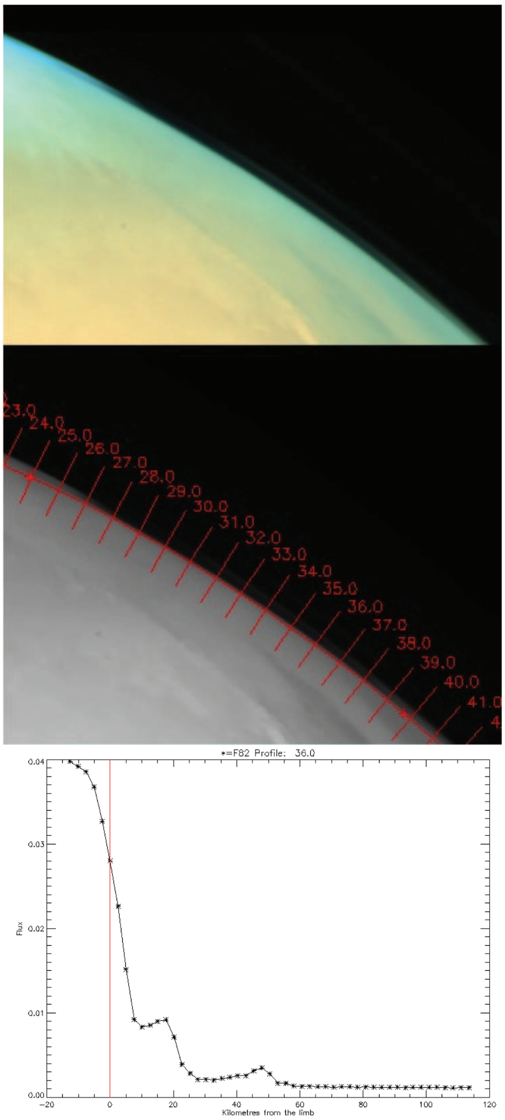

Fig. 6. Altitude of different cloud layers (profile number 36) observed by OSIRIS in the Martian atmosphere. This image is taken at a distance of 130400 *km* with a resolution of 2.5 *km/px*. It is possible to see two different layers at 17.2 and 46.7 *km*.

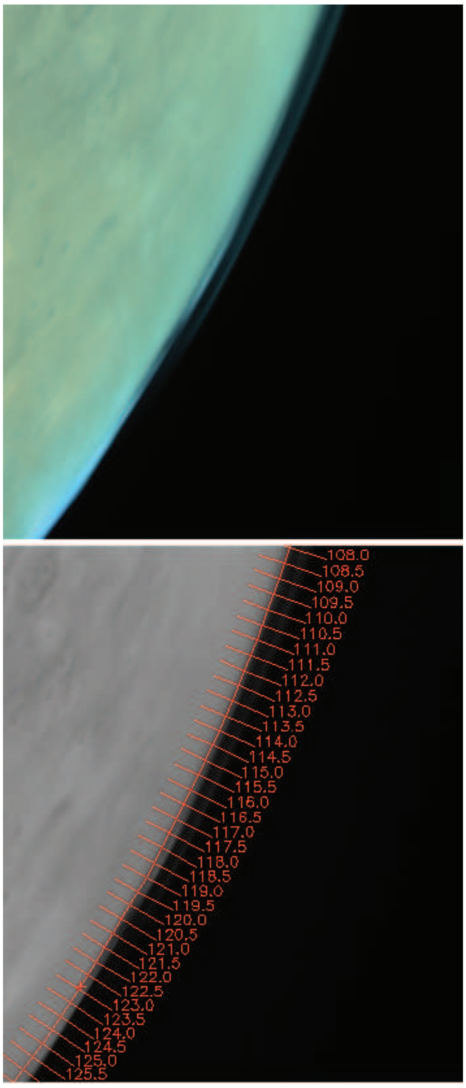

Fig. 7. Section of Martian limb presenting different cloud layers observed by OSIRIS on February 25th, 2007 . This image is taken at a distance of 111200 *km* with a resolution of 2.1 *km/px*.

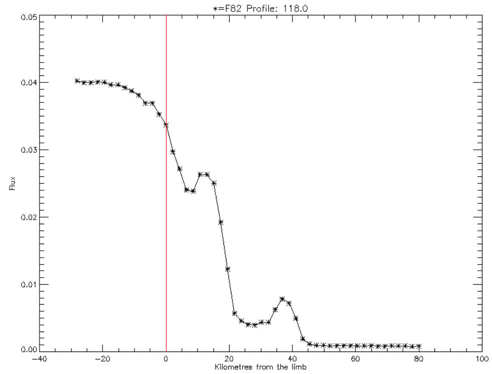

Fig. 8. Profile number 118 (see Fig. 7) presenting the altitude of two layers of clouds observed by OSIRIS in the Martian atmosphere. The resolution per pixel is 2.1 *km/px*, it is possible to see the two different layers at 10.5 and 34.6 *km*.

Due to perspective effects it is possible to see that each layer of clouds could present a specific width but this does not mean that this is the real width of the clouds, in fact it is just a superior limit of it.

The flux error of every point in all altitude plots is the 2.5% of the flux value and the altitude error of the cloud-layers resolution is the resolution per pixel of each image selected.

3.3. Low Resolution Spectra

After the proper superimposition of images belonging to the same set and realising consequently multiband datacubes, it has been possible to select the square area around a specific pixel selected on a reference image: the resulting value of reflectance is the mean reflectance between all pixels' values.

The first analysis has regarded an equatorial area located between -20° and +20° of latitude and 90° East and 140° East of longitude. The square dimension of the area selected is 5 × 5 pixels.

Scientific observations realised up to nowadays underline that the main surface component on Mars is hematite, the mineral form of iron(III) oxide (Fe_2O_3), one of several iron oxides.

Terrestrial hematite is typically a mineral that forms in aqueous environments, or by aqueous alteration; this detection consequently forced to target the second of the two NASA Mars Exploration Rovers, MER, Opportunity, to a site called *Meridiani Planum* where Fe_2O_3

Fig. 9. Set of eight 5×5 Martian areas selected to get the low resolution spectra through remote sensing. This image is taken from a distance of 130360 *km* from Martian surface with a resolution of 2.5 *km/px*.

was previously seen in abundance. This rover landed on Mars in January, 25th, 2004.

The multispectral imaging instrument PANCAM aboard Opportunity identified several units around the landing site which include bright and dark versions of soils, granules, rock clasts, and outcrop materials; the low resolution spectra provided constraints on the iron-bearing mineralogy of the materials exposed on the site.

Through the studies performed thanks to PANCAM multiband images, it has been observed that most dark sand, dark floor and *Meridiani* plains materials exhibit a ferric iron spectral signature together with evidence of crystalline ferrous or ferric iron bearing phases.

The studies performed at *Meridiani Planum* indicate that a stronger kink in the spectra near 530 *nm* and a shallow absorption band centered near 900 to 950 nm can be consistent with ferric iron bearing phases such as schwertmannite, ferrihydrite, and disordered goethite (Bell *et al.* 2004). Although the 900 to 950 *nm* band is not consistent with the presence of fine grained, cristalline hematite alone, the presence of that band and the kink at 530 *nm* may indicate a mixture of red hematite and a possible ferric iron bearing phase such as the hydroxide sulfate phase jarosite, or a ferric oxyhydroxide such as goethite, or a ferrous iron bearing volcanic phase such as pyroxene (Bell *et al.* 2004).

OSIRIS NAC filter 61 is centered at the wavelength of 931.9 *nm*, this filter has been introduced in the filters wheel in order to identify the possible presence on comet 67P/Churyumov-Gerasimenko and on the observed asteroids of minerals containing iron. It has then been used during Mars fly-by in order to calibrate it properly and to help the scientific analysis of the surface.

If we plot the eight OSIRIS spectra selected in Fig. 9 with respect to the USGS Spectroscopy Lab spectra of hematite and goethite, which is an iron oxyhydroxide FeO(OH), we can see that OSIRIS data seems to have found a good match between a mixture of these minerals on the surface of the specific selected areas of Mars. All OSIRIS spectra span between the brightest, N6, and the darkest, N8, spectrum and are presented together with Opportunity spectra obtained by the PANCAM camera.

The low resolution spectra of OSIRIS, reported in Fig. 10, are the brightest/reddest and the darkest/bluest obtained in the first set. All the left low resolution spectra span in the middle of these two extremities according with the spectra obtained by the PANCAM of Opportunity. The composition of the area selected on the surface of the planet can be then the same of the one present at *Meridiani Planum*, *i.e.* ferric iron bearing iron oxide like hematite.

All this evaluations are still at a first level, in fact this is a preliminary data analysis and work is still ongoing.

4. Conclusions

The analysis of Martian data have provided the possibility to underline the differences present in the atmosphere of this planet by realising false colours images, observing it from IR to UV wavelengths. Moving towards UV radiation (see Figs. 2, 3 and 4), several clouds fronts appear on the surface of the planet especially

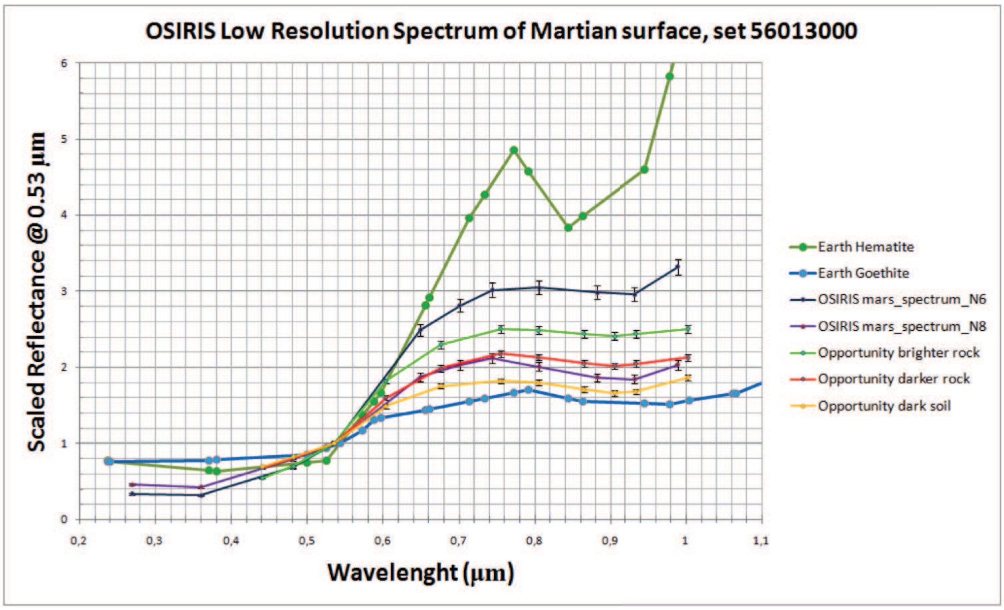

Fig. 10. The brightest, N6, and the darkest, N8, low resolution spectra of the selected areas of Martian surface observed by OSIRIS NAC. Earth Hematite and Goethite spectra are reported together with NASA Opportunity spectra obtained on *Sol 4* at *Meridiani Planum* (see Bell *et al.* (2004)).

over the great lowlands on the southern hemisphere like Hellas Planitia, but also on the two polar caps and over Mons Olympus. Several equatorial veils and limb clouds show that the atmosphere of Mars, even if thin, is present and active (see Fig. 5).

The limb observation of Mars performed by the NAC has allowed the identification of several layers of clouds, located at an altitude which varies from 10 *km* up to 50 *km* with a position error that goes from 4.6 *km* when the space probe is at a distance of 244000 *km* from the planet, to 2.1 *km* down at 111000 *km* from the surface (see Fig. 6, 7 and 8). These specific layers are all along the East observed side of the imaged planet. The following realisation of high spatial resolution multiband spectra across several areas (Fig. 9) on the observed side of the planet gives possible evidence of hematite on the surface of the target. The low resolution spectra regards specific dark and bright areas on Elysum Planitia and Hesperia Planum. These results have been then compared with those obtained by the PANCAM multispectral camera aboard NASA's Opportunity rover located on Meridiani Planum (see Fig. 10), showing the possible connection between the chemical composition of the areas analysed. The OSIRIS spectra seem to confirm the possible presence of the Iron-oxides observed by the rover on the opposite side of Mars.

This is a preliminary analysis of all data and still a lot of work can be and will be done on the data obtained.

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