USE OF UV RADIATION FOR DETECTING LIFE RELATED PHENOMENA IN PLANETARY ATMOSPHERES.

D. Gillotay, D.Moreau and C. Muller

Belgian Institute for Space Aeronomy, 3 Av. Circulaire, Brussels, Belgium, B-1180

e-mail : Christian.Muller@oma.be

phone : +32-2-3730372, fax : +32-2-3748423

ABSTRACT

The present remote sensing techniques in planetary atmospheres use well known transitions ranging from the microwave to the UV with large successes and due to Rayleigh scattering in dense atmospheres. Few environmental sensors are designed to operate below 280 nm. In the Mars atmosphere, however radiation down to 200 nm can certainly reach the surface and can be used as a source for gaseous composition observations Also, penetration of solar UV-B and C in planetary atmospheres is an important element in determining the sterile character of the surfaces and has to be simulated using atmospheric models demanding a knowledge of UV radiative transfer. An other use of UV radiation could be the in-situ spectrometry of gases, ices and minerals using specialized lamps allowing thus nighttime and subterranean observations The status of the UV spectroscopic data base is discussed.

Existing UV sensors on approved missions to Mars will be described with emphasis on their astrobiological implications.

INTRODUCTION: MARS ATMOSPHERE AND LIFE

The Martian atmosphere consists mainly of carbon dioxide *(95.32 %)* with trace quantities of N_2 *(2.7 %)*, *Ar (1.5 %)*, O_2 (*0.13 %*), CO (*0.07 %*) and less abundant species. However, minor constituents have been very rarely studied because of the difficulty of putting on Martian spacecrafts the complement of instruments now used in earth observations.
Additional trace species are important in understanding the behaviour of atmospheric and surface oxidants that have been usually accepted as making the Martian environment sterile. These are ozone and the water vapour which are good indicators of the odd hydrogen species (*H*, *OH*, HO_2). Dust is also suspended in the Mars atmosphere and its radiative and chemical properties are quite unknown. Also a surface or near surface oxidant has been stated to be the source of the absence of organic molecules observed by Viking, however, several claims have been made for the presence of methane and formaldehyde in the atmosphere since the Russian Phobos mission in 1989 (Korablev et al, 1993). All these elements require the knowledge of photochemically active UV in Mars atmosphere and on Mars surface.

UV AS A DRIVE FOR MARS LIFE STUDIES.

UV studies of the Martian environment can be considered from an orbital geometry as backscattered U.V, UV absorption spectrometry using natural sources: SPICAM and FUSE (Far Ultraviolet Spectrometric Explorer) are examples of these techniques .
UV active absorption spectrometry using lamps on the surface has not yet led to a practical proposal due to the necessity of developing new means of energy conditioning, they are however necessary for near surface gases which absorb only in the UV as the biologically important molecular hydrogen.
Finally, surface UV monitoring is now considered as part of the EXOMARS payload both as an environmental monitor and as a way to probe atmospheric composition.
A first example is give by the SPICAM instrument which in NADIR mode was able during a pointing test at more than 5.5 10^6 km to obtain on December 1 2003 a spectrum of the whole disk during a 0.64sec exposure time (fig.1).

Proc. of the III European Workshop on Exo-Astrobiology. Mars: The search for Life, Madrid, Spain, 18-20 November 2003.
(ESA SP-545, March 2004)

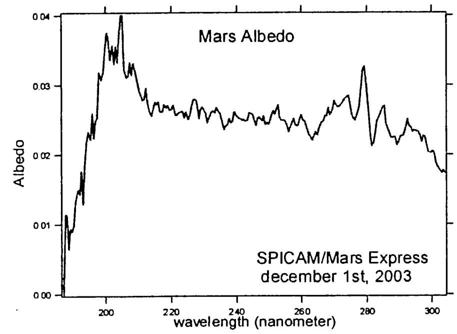

Fig.1: UV preliminary albedo of Mars deduced from the Bertaux et al (2003) observation of SPICAM on Mars-Express, this observation is obtained from more than 5.5 millions kilometres and show that globally CO2 below 200 nm appears to be the only significant UV filter.

This spectrum of the full disk appears to be pessimistic for the outcome of the search for life on Mars when compared with fig 2.

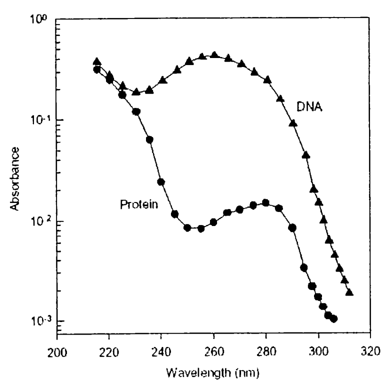

Fig. 2. : action spectra of UV radiation (Rettberg and Rothschild,2002).

However, the real situation is more complex, first the dust level was very low as exemplified by the analysis of the Mars Global Surveyor images obtained at the time of Beagle-2 landing and second the full disk has a major contribution from the equatorial regions where the ozone is so low that it will be a prime SPICAM mission to determine it accurately for the first time.

SPECTRAL DATA BASE

Both gases and aerosols data bases are in development at the present time. Gases are basically common to the earth and Mars and the knowledge of their absorption cross-sections has been important for the last sixty years for studies of penetration of dissociating radiation leading to the formation of atmospheric ions and active radicals. However, they were usually studied at low resolution in order to obtain effective parameterisations and not in order to assess actual penetration of radiation especially between lines unbroadened by predissociation. This issue is important for biological purposes as weak doses which would escape the spectral resolution of figure 1 are cumulative in terms of biological damage and cannot be neglected. In the CO2 case, new studies (Stark et al, 2002) reveal spectacular changes in the UV spectrum as low as 110 nm when resolution is increased indicating that the dissociation broadening limit is not reached by the present instrument. Theoretical line parameters allowing line by line computations would require the combination of both the electronic transitions involved and the rotation-vibration band structure. This task, even if it were achieved could not be checked as long as individual lines are not reached and identified and it is understandable that the highest priority is put to the precise measurement of high resolution spectra at various temperatures.

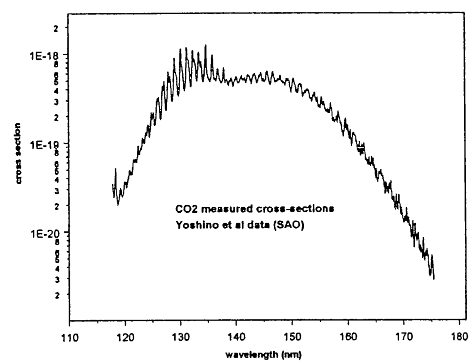

Fig. 3.: measured cross-sections of CO2 (Yoshino, 2003, Yoshino et al, 1996, Stark et al, 2002).

These cross-sections lead to the penetration curves of figure 4, confirming the observational result of figure 1: no radiation below 200 nm should reach the Martian surface, however, again, micro-windows could exist between lines at infinite spectral resolution. The present effort underway at the Smithsonian Astrophysical Observatory and other centres to measure accurate cross-sections at high resolution is thus still far from reaching its final objective . It should ideally complemented by actual high resolution observations from earth upper atmospheric platforms or later from the Mars surface.

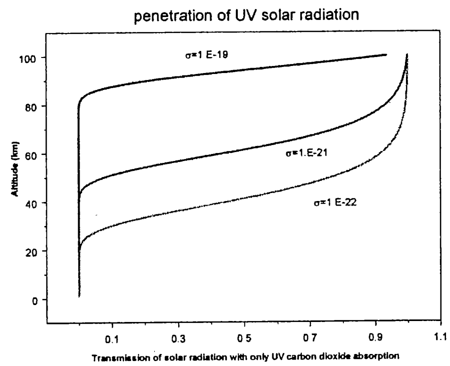

Fig. 4: penetration of UV solar radiation in the Martian atmosphere for three absorption cross section in the range of Fig. 3.

The dust case is more complex as the composition is largely unknown and variable as illustrated by albedo changes. In the estimates of UV penetration as measured by SPICAM, a dust model based on Libyan sand with 5% hematite was previously used (Muller et al, 2001) and showed that a tiny surface deposit could be an effective UV filter. Estimates of the magnetic properties of Martian dust during the Pathfinder magnet experiments lead to a much higher content of iron oxides in the dust (Merrisson et al, 2002). This would make suspended dust an extremely effective UV filter.

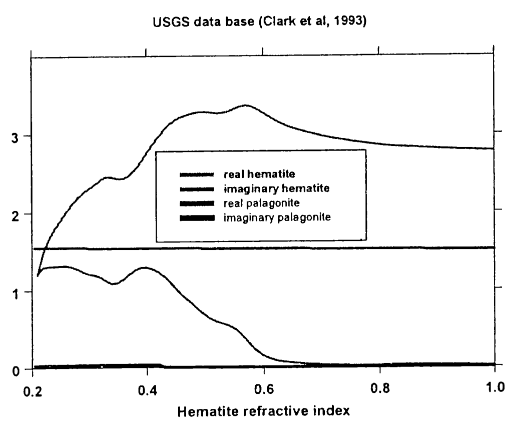

Fig. 5: Refractive indexes (real and imaginary) of hematite and palagonite as a function of wavelength. Palagonite as an optically neutral silicate is a realistic Martian soil analogue. Its absence of imaginary refractive index deprives it of absorption cross section in the Mie theory.

The geological data bases (Clark et al, 1993) unfortunately do not extend below 200 nm, they are of very low spectral resolution, but this last point fits well with the wide bands observed in solids.

DIRECT USE OF UV FOR BIOLOGICAL MOLECULAR SPECIES DETECTION.

In the Martian case, three biologically important molecules could be detected in the UV at surface level: NO, H2 and H2O2.

Hydrogen peroxide has cross-sections which peak between the ozone and carbon dioxide absorptions and thus would permit to a high quality UV instrument using the backscattered UV analysis to determine its presence as a total column. As H2O2 dissociates rapidly toward OH above the surface, this orbital measurement will be directly relevant to surface processes.

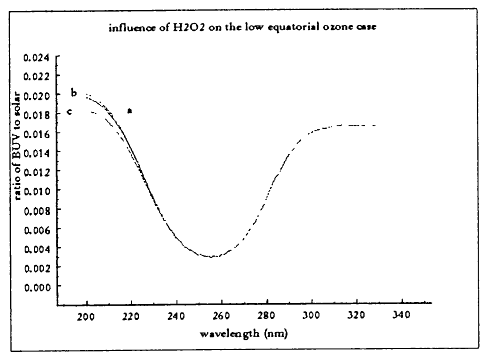

Fig. 6: ratio of backscattered UV to solar input showing the possibility to measure ozone from the orbit: the main curve and to distinguiish between three different H2O2 models. (Muller et al, 2002).

H2 and NO are unfortunately present in the entire atmosphere including the upper atmosphere where their observation gives major information on the exchanges between the planet and the interplanetary medium. Their UV absorption band are in spectral regions where the solar source is expected to be weak at the surface, so this measurement on the surface will thus require in situ lamps. The importance of H2 as both a product of biological activity and the most efficient fuel for life processes cannot be overstressed. This gas has been neglected in the earth's biosphere due to the challenge in its measurement, it is however observed in Mars upper atmosphere from the NASA FUSE satellite (Fig.7). NO is also life processes related both as a product and a primitive neurotransmitter, its infrared bands are weak and thus, in situ UV would also be the most efficient technique.

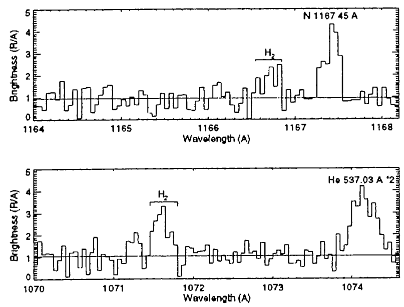

Fig 7.: FUSE spectrum of Mars showing molecular hydrogen emissions in the upper atmosphere. (Kranopolsky and Feldman, 2001).

FUTURE PROJECTS :

A recent development considered for an implementation in the EXOMARS project is a surface UV sensor. It will be a multiple channel radiometer covering the UV from Lyman α (121.6 nm) to UV-A and part of the visible (500 nm) with up to 14 channels some of them as narrow as a few nm. Optimally, the instrument should have a capability to monitor total irradiance, direct sun and diffuse irradiances as a function of time between sunrises and sunsets for an entire Martian year. In the case of deployment on a rover, this requires precise knowledge of position, time and attitude.
The instrument will address both UV climatology and gas detection.

ACKNOWLEDGMENTS

This work was made possible by the PRODEX programme managed by ESA for the Belgian Science Policy Service. The presented SPICAM Mars-Express preliminary result could not have been obtained without the excellent management of the cruise and commissioning phase by the ESA ESOC team.

REFERENCES

Bertaux, J.L. and the SPICAM team (S.A.France, IASB-BIRA Belgium and IKI Russia), SPICAM-Light study of the global structure and composition of the Martian atmosphere, first Martian light, 2003.

Clark, R .N., Gregg, A. ,Swayze[1], A., Gallagher J., Trude, V., King, V. and Calvin, W.M., 1993, Digital spectral library, U.S. Geological Survey, Open File Report 93-592.

Korablev, O.I., Ackerman, M., Krasnopolsky, V.A., Moroz, V.I., Muller, C., Rodin, A.V. and Atreya, S.K, .1993 Tentative identification of formaldehyde in the Martian atmosphere, Planet. Space Sci, **41**, 441-451.

Krasnopolsky, V.A. and Feldman, P.D.,2001, Detection of Molecular Hydrogen in the Atmosphere of Mars, *Science* , 1914-1917

Moreau, D., L.W. Esposito, and G. Brasseur, 1991. The chemical composition of the dust-free Martian atmosphere: preliminary results of a two-dimensional model, J.G.R., 96, 7933-7945

Moreau, D. and Fonteyn, D., 1999, Two-dimensional study of the atmospheric and surface oxidants on Mars, Proc. Fifth Int. Conf. On Mars, Lunar and Planetary Institute contribution 972, 6093.

Muller, C., Moreau, D. Fonteyn, D., Bertaux,J.L. and. Korablev,O., 2001, SPICAM-light on Mars-Express as a monitor of surface UV radiation and atmospheric oxidants, Planetary and Space Science ,49, 165-171.

Merrison, J.P., Gunnlaugsson, H.P., Mossin, L., Nielsen, J., Nørnberg, P., Rasmussen, K.R. and Uggerhøj, E. 2002: Capture of magnetic dust in a simulated Martian aerosol: the Importance of aerodynamics. Planetary and Space Science, 50, 371-374.

Rettberg, P. and Rothschild, L.J. ,2002. Ultraviolet radiation in planetary atmospheres and biological implications. In: G. Horneck & C. Baumstark-Khan (Eds.). *Astrobiology: The Quest for the Conditions of Life* (pp. 233-244). Heidelberg, Germany: Springer-Verlag.

Stark , G., Yoshino,K., Smith, P.L, Ito, K, 2002, Photoabsorption Cross Section Measurements of carbon Dioxide in the 106 to 120 nm Region, DPS 34th Meeting.

Yoshino, K., J.R. Esmond, W.H. Parkinson, K. Ito, and T. Matsui Absorption Cross Section Measurements of Carbon Dioxide in the Wavelength Region 118.7 nm - 175.5 nm and the Temperature Dependence, 1996, J. Quant. Spectrosc. Radiat. Transfer, 55, 53-60.

Yoshino, K., private communication, 2003.