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SWS spectroscopy of small grain features across the M17-Southwest photodissociation front *

L. Verstraete[1], **J.L. Puget**[1], **E. Falgarone**[2], **S. Drapatz**[3], **C.M. Wright**[3], **R. Timmermann**[3]

[1] Institut d'Astrophysique Spatiale, Université Paris-Sud, Bât.121, F-91405, Orsay, France
[2] Radioastronomie millimétrique, Ecole Normale Supérieure, 24 rue Lhomond - 75005 Paris - France
[3] Max Planck Institut für extraterristrische Physik - Postfach 1603, D-85740 Garching - Germany

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Abstract. We present SWS spectra taken across the M17-Southwest photodissociation front and discuss spectral properties of PAHs and VSGs. We report new features at 4.65, 6.35, 8.7 and 11μm which we interpret as PAHs and/or VSGs emission. From feature intensity ratios along the cut, we find PAHs are mainly ionized and almost fully hydrogenated.

Key words: ISM: molecules – ISM: dust – ISM: molecular cloud, HII region

1. Introduction

M17SW is a region where young, massive stars shine on a dense molecular complex. It is bright (total IR luminosity of 6 to 7 10^6 $L_\odot$, Wilson *et al.* 1979) and situated 2.2 kpc away from the sun (Chini *et al.* 1980). The photodissociation front has a fairly well defined edge-on geometry (Stutzki *et al.* 1988). Both the HII region and the molecular cloud have been recognized inhomogeneous (Felli *et al.* 1984, Stutzki & Güsten 1990). The $C^{18}O$ maps of Stutzki & Güsten (1990) show a steep density gradient towards the molecular cloud. This copiously irradiated ridge favours the excitation of molecular and dust emission features (Bregman *et al.* 1989, Giard *et al.* 1992). The present SWS observations have been planned to investigate the physics of small grains at such interfaces and we focus on their spectroscopic signatures ($\lambda/\delta\lambda \sim 30$).

The family of dust features at 3.3,6.2,7.7,8.6,11.3 and 12.7μm has been observed towards many bright interstellar sources over the past 15 years and polycyclic aromatic hydrocarbons (PAHs) have been proposed as the origin of this emission (see Léger *et al.* 1989, Allamandola *et al.* 1989a for reviews). Due to their small size, PAHs emit during temperature fluctuations after single photon absorption as opposed to classical big grains. In addition, a population of very small grains (VSGs) is required to explain the IRAS emission at 25 and 60μm (Désert *et al.* 1990) and so far the exact nature of VSGs is unclear. PAHs features are now known to be ubiquitous in the general interstellar medium (Giard *et al.* 1994, Ristorcelli *et al.* 1994 and Boulanger *et al.* , Mattila *et al.* 1996 this issue). In the PAH model, the 3.3,8.6 and 11.3-12.7μm features correspond to aromatic CH-stretch, in-plane and out-of-plane bending modes respectively. When there is no adjacent hydrogen atom on the aromatic ring the CH-out-of-plane mode falls at 11.3μm (solo mode); it shifts to around 12 (12.7)μm when there are 1 (2) adjacent hydrogen atoms (duo and trio modes, see above quoted reviews). The bands at 6.2 and 7.7μm involve skeleton CC-modes of PAHs.

2. Data reduction

The data presented here is part of the garanteed-time central program MPEWARM performed by the Short Wavelength Spectrometer (SWS) on board the ISO satellite (de Grauuw *et al.* , Kessler *et al.* 1996 this issue). SWS-AOT1 complete spectra (2.4-45μm, scanspeed 2) have been taken along a 3.5 arcminutes northeast-southwest cut (from RA=18h17m35.9s, Dec=-16°13'14" to RA=18h17m23.4s, Dec=-16°14'44", 1950 equinox) identical to that of Stutzki *et al.* (1988). In 10 equally spaced positions (labeled 1 to 10, first position in the HII region), one goes from the HII region towards the molecular cloud. Standard data reduction has been performed at MPE during 6 to 8th of May 1996. All the data presented here has been rebinned to a resolving power of 300. Mean relative error was around 30,20,10 and 5% in bands 1,2,3 and 4 respectively. At this rapid scanspeed narrow ($\lambda/\delta\lambda \geq 500$), bright lines were

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Send offprint requests to: L. Verstraete - verstra@ias.fr

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confused with glitches and removed: we retrieved them from the raw data. The 2c/3a-band match of continua was poor (fig.2a): between 12.5 and 14μm the 3a-band curves up with decreasing wavelength, lying above the 2c-band by less than 30%. While rebinning, however, the weight of the 3a-band around 12.5μm was low enough not to introduce any spurious feature. To increase the signal-to-noise ratio, we averaged data taken at positions which showed similar spectral behaviour: the "HII-region" and "Interface" spectra group 3 positions each (1-2-3 and 4-5-6 respectively), the "Molecular cloud" spectrum sums up the 4 last positions. In summary, small grain features are often seen with high signal-to-noise ratios in spectral regions where calibration errors are estimated to be less than 20% (Schaeidt *et al.* 1996, this issue).

3. Spectral analysis

Spectra are given in fig.1 & 2. In the HII region, recombination and fine structure lines dominate the spectrum. In the other spectra, dust features are prominent. Concentrating on small grain features, we restrict ourselves to the 2.4-14μm range; the analysis of the remaining data will be done in a forthcoming paper. The continuum could be uncertain by significant factors when signal is weak. These systematic effects are very clear in fig.1c below 4μm; yet they do not affect the intensity of dust features we are dealing with. In fig.1a, the continuum rises below 4μm as expected from emission of the ionized gas in the HII region. PAH features are present in the 3 spectra. The 3.3μm band extends to a plateau at longer wavelengths and the 3.4μm-feature is clearly visible in figs.1b&c. The latter has been assigned to the aliphatic CH-stretch of methyl side groups on PAHs (de Muizon *et al.* 1986, Shan *et al.* 1991, Joblin *et al.* 1996). The emission plateau may arise from hot bands, overtone and combination modes (Allamandola *et al.* 1989b, Geballe *et al.* 1989) or anharmonic vibrational progression (Talbi *et al.* 1993). In the HII region, the Pfδ[3.296μm] line falls within the 3.3μm-band (fig.1a): we subtracted it assuming its intensity is a tenth of the Brα[4.05μm] line (Hummer & Storey 1987). Other features are detected at 4.65, 5.25 and 5.65 μm at the interface with a signal-to-noise ratio of at least 15. The two latter bands have been ascribed to PAH combination modes (Allamandola *et al.* 1989b, Roche *et al.* 1996). The 4.65μm-band, very similar, is to our knowledge unreported so far and could have the same origin (it is also seen in the HII region with the Pfβ[4.654μm] and possibly a HeI recombination line superimposed).

The 8.6μm feature changes dramatically in the HII region: it broadens, gets stronger than the 7.7μm and shifts towards 8.7μm. In addition, the 6.2-7.7-8.7μm features sit on top of a broad continuum extending from 6 to 11μm. We also find two new features at 6.35μm (a red shoulder of the 6.2μm-band, note the superimposed [ArIII]6.37μm line) and 11μm in the HII region (the latter is also present in the other spectra). The 7.7μm-band has 2 peaks (figs.2c&d) at 7.6 and 7.8μm. Recent work (Langhoff 1996 and references therein) shows that the 6.2 and 7.7,11.3μm bands shifts to longer and shorter wavelengths respectively when PAHs are singly ionized. Hence, our spectra suggests that PAHs are mainly ionized. A similar modification of the PAH emission spectrum has been seen towards compact HII regions (Roelfsema *et al.* 1996, this issue). Away from the HII region, spectra exhibit a band at 12μm probably due to the duo CH-modes of PAHs (see also Cesarsky *et al.* 1996). The 12.7μm-feature would then correspond to the trio CH-mode (the NeII[12.81μm] is superimposed). Similar bands have been detected in the

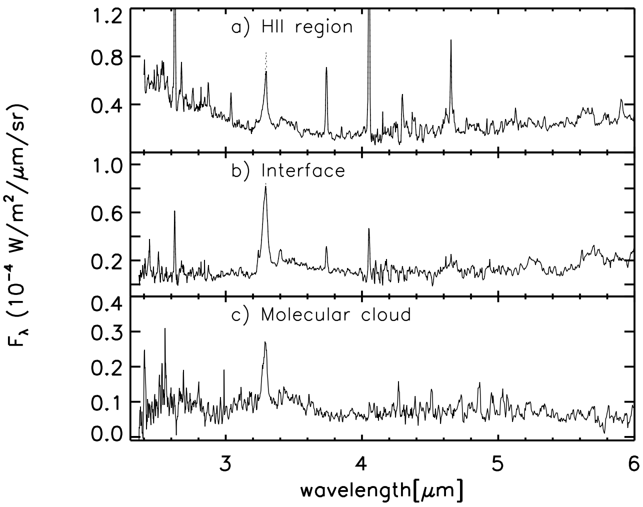

Fig. 1. SWS-AOT1 spectra in the 2.4-6μm range. In a) and b), the spectrum not corrected for the Pfδ line at 3.3μm is represented by the dotted line (see text).

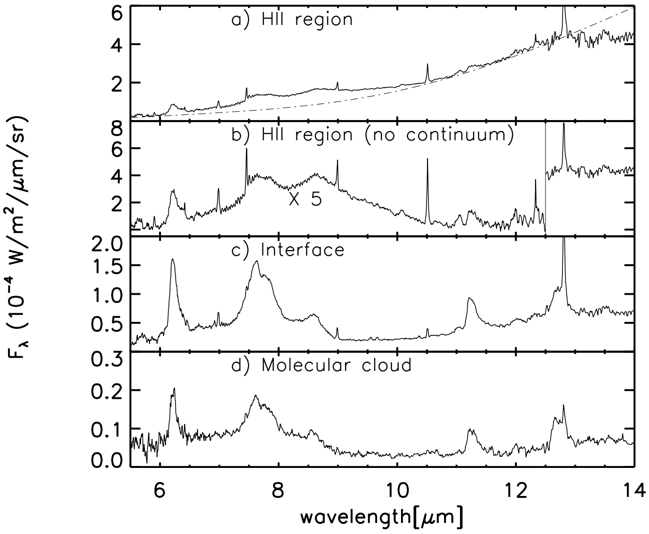

Fig. 2. Same as fig.1 for the 6-14μm range. In b), the HII region continuum (sum of two blackbodies at 120 and 280 K, see the dot-dashed line in fig.2a) has been subtracted and the spectrum multiplied by 5 at wavelengths below 12.5μm.

past at lower resolution (Roche *et al.* 1989, Cohen *et al.* 1985). Two more features at 13.1 and 13.5μm appear in all spectra (see §4).

4. The physical state of PAHs across the M17-photodissociation front

From our spectra we have derived band intensities at all positions by simply subtracting a straight baseline at the bottom of each band. Thus, continuum uncertainties (see §2&3) do not affect our band intensities. The 6.2,7.7 and 8.6μm bands sit on top of a broad plateau which may be related to PAHs (Bregman *et al.* 1989, Boulanger *et al.* 1996): we have, however, taken only the narrow bands and not this underlying broad feature to estimate intensities. In the HII region, systematic errors prohibited a reliable estimate of the 12.7μm intensity. At other positions, we estimate the error on the 12.7μm-band intensity due to the poor 2c/3a band match (see §2) to be within the error bar. All PAH feature profiles (fig.3) peak at the interface: such a limb brightening effect has been observed in other regions and can only be understood if the PAH abundance varies (see *e.g.*, Bregman *et al.* 1989, Bernard *et al.* 1993). Conversely, the 16μm-continuum decreases monotonously away from the second position. The 3.3, 11.3μm and the CC-modes profiles are very similar (our mean 6.2/7.7 ratio is 0.5). The 12 and 12.7μm profiles are slightly offset towards the molecular cloud with respect to the 11.3μm suggesting that PAHs rehydrogenate in shielded regions. The 6.35μm feature vanishes rapidly away from position 1. All these features are decorrelated from the 16μm- continuum, a behaviour characteristic of single photon heating which supports the PAH hypothesis. In the HII region, the 8.7 and 11μm intensities follow the 16μm-continuum suggesting they originate mainly from VSGs which dominate the continuum at these wavelengths (Désert *et al.* 1990). Towards the molecular cloud the 8.6 and 11μm emission, in excess of the 16μm-continuum , is mainly due to PAH cations (see below). The 13.1 and 13.5μm-bands correlate with the 16μm-continuum throughout the cut. Artefact arising from ill-calibrated data could produce such features and we plan to inquire again this spectral region. A comparable 13.5μm-feature appears in ISOCAM-CVF spectra (Cesarsky *et al.* 1996). If real these features, correlated to continuum, would again be the signature of VSGs emission.

At the interface and in the HII region, PAHs are exposed to a harder radiation field: they can be ionized, loose hydrogen atoms and/or disappear by photodissociation. We define below band ratios able to trace these events. The effect of single ionization (Szczepanski & Vala 1993, DeFrees *et al.* 1993, Hudgins & Allamandola 1995, Langhoff 1996) on the infrared modes of PAHs has recently been investigated. So far only small PAHs are involved whereas interstellar PAHs are probably larger (Désert *et al.* 1990): we assume the above results also hold for larger species. Clear trends appear when comparing the spectra of PAH cations with neutrals (Langhoff 1996). Ionization depresses the 3.3μm band by factors of 10 to 100 (the spread is large between laboratory measurements and also with theoretical results); conversely the 6.2, 7.7 and 8.6μm bands are larger in cations by at least a factor 10. These changes are best traced with band ratios. The ratio of in-plane CC to CH-out-of-plane modes (6.2 + 7.7)/(11 to 13) is about 0.4 for neutral PAHs vs 4 for cations, we note this ratio ION and use it as a tracer of PAH ionization.

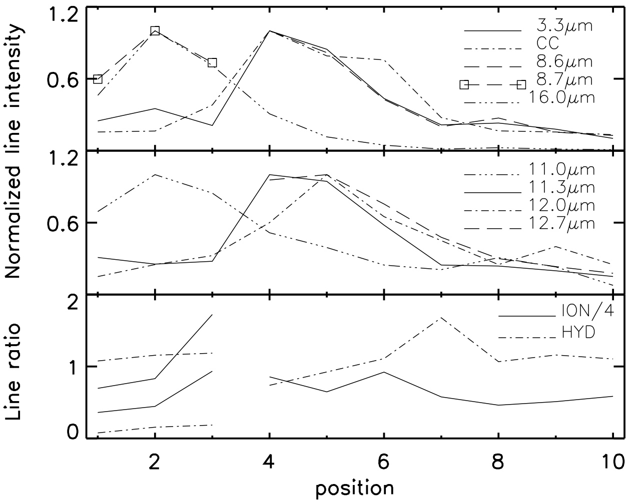

Fig. 3. Profiles across our M17SW cut. Abscissae are position numbers, the distance between 2 subsequent positions is 23.3 arcseconds. **Top and middle:** PAH band intensity profiles. Ordinates are normalized to peak values (in 10^{-6}W m^{-2} sr^{-1}): 4.9(3.3μm), 94(CC=6.2+7.7μm), 14(8.6μm), 13.6(8.7μm), 16(11.3μm), 1.9(12μm), 11.2(12.7μm) and 6.5 10^{-4} W m^{-2} μm^{-1} sr^{-1} (16μm-continuum). **Bottom:** band intensity ratios (see text). The ION ratio has been divided by 4. At the 3 first positions, only upper and lower limits to ION and HYD are given (see text).

The ION profile is shown on fig.3. At the 3 first positions, the 12.7μm- intensity was not available: we estimated an upper limit by taking the 12.7μm and 11.3μm intensities equal and a lower limit with the 12.7μm intensity set to zero. Our ION ratio varies between 2 (molecular cloud and lower limit in the HII region) and 3.3 (interface). Adopting the intrinsic band ratios quoted above, these values correspond to a PAH ionized fraction of 44 and 80% respectively. We have so far assumed that the same species emits in all the PAH features. However, in a given radiation field, an interstellar PAH emits at a color temperature fixed by its size and the smaller (larger) species dominate the emission at short (long) wavelengths. Using the Désert *et al.* (1990) model, we estimated this color variation effect to enhance ION by a factor 1.7 with respect to its value for a single PAH: this reduces our ionized fractions to 22 and 43%. The latter value is a lower limit: indeed, in the

HII region and at the interface the smallest PAHs are expected to be photodissociated (Allain *et al.* 1996) so that color temperature variations should be smaller because of the smaller size range. Final numbers will be obtained from detailed modelling of the complete infrared spectrum involving emissivities of PAH cations and taking into account PAH destruction. PAHs would thus be mainly ionized in the HII region and interface and mostly neutral in the molecular cloud. The 6.35μm-band, strongest in the HII region, could thus be due to large ionized PAHs which can survive in the strong radiation field. Dehydrogenation has a less dramatic influence than ionization (Pauzat *et al.* 1995). The CC-modes remain unchanged in the neutral and cation while the CH-out-of-plane modes vary proportionately to the hydrogen coverage. The 2 other modes (3.3 and 8.6) have opposite behaviour for the neutral and ion. To trace PAH dehydrogenation independently of ionization, we define the ratio HYD=(12+12.7)/11.3 which rises as PAH rehydrogenate (Schutte *et al.* 1993). From position 4 to 10 this ratio increases from 0.8 to 1.2 (fig.3). As for ION we calculated an upper and a lower limit for HYD in the HII region, they are 1.2 and 0.2 respectively. Assuming PAHs are fully hydrogenated in the molecular cloud, we find a degree of hydrogenation of 80% at the interface and of at least 40% in the HII region. Spectra of the Orion bar (Bregman *et al.* 1989, Roche *et al.* 1989) yield very similar values of ION and HYD. Finally, our mean 3.4/3.3 intensity ratio is about 0.1 implying a radiation field of 10^5 times standard (Joblin *et al.* 1996) consistent with earlier work (Stutzki *et al.* 1988, Giard *et al.* 1992). In the molecular region, the feature emission would thus occur in the unshielded outer parts of dense clumps.

5. Conclusions

We have studied the evolution of small grain dust features across the M17SW photodissociation region with SWS-AOT1 spectra. Intensity profiles of PAH features peak at the interface as expected in a picture where PAHs are destroyed in the HII region and condense in molecular regions. We have defined line ratios tracing the fraction of PAH cations as well as their degree of hydrogenation. PAHs are mainly ionized at the interface and in the HII region. PAHs probably have a high hydrogenation degree increasing towards the molecular cloud. We report new bands at 4.65, 6.35, 8.7, 11μm and confirm the presence of the 12μm duo CH-mode of PAHs. In the HII region the (broad) 8.7 and 11μm bands, correlated with the mid-infrared continuum, could be the signature of VSGs emission.

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