EVOLUTION OF NEAR UV HALLEY'S SPECTRUM IN THE INNER COMA

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Abstract

A direct way to observe the photodissociation of water vapor in a cometary coma consists to detect the OH prompt emission. This emission is shifted of $\delta\lambda=4$ nm with respect to the OH 309 nm fluorescence band. The extended data set obtained with the three-channel spectrometer on-board Vega 2 reveals at short distance of the nucleus (i.e. less than 600 km) an excess of emission on the right wing of the OH band which may be interpreted as being mainly due to prompt emission.

Introduction

The three-channel spectrometer embarked on Vega 2 transmitted approximately 3600 spectra during the encounter day on March 9, 1986.

The spectra cover the range 275 to 710 nm. They were obtained in a spectro-imagery mode, since the instrument scanned a rectangular field of view of 2x1.5°. During the last half-hour before encounter, this field was restricted to a 2° line scanned in a see-saw motion. Taking advantage of the zoom effect which results of the approach motion, monochromatic images of the inner coma were constructed at selected wavelengths (Clairemidi *et al.*; 1990 a,b). They show the progressive increase of the emissions when the projected distance nucleus-optical axis decreases from 38 000 to 420 km. The distance between the spacecraft and the nucleus decreases then from 516 000 to 8 030 km.

The measured spectrum consists of molecular fluorescence bands superposed on a solar dust-scattered continuum. This solar component is carefully subtracted from the measurement signal in adjusting an absolute solar spectrum, taken from Labs *et al*. (1987) convoluted with the instrument response function, which has a FWHM of 7 nm.

A careful study of the OH emission in the inner coma is of special interest to obtain a direct record of H_2O photolysis. When a water molecule escapes from the nucleus, it is rapidly photodissociated under the following mechanism:

$$H_2O + h\nu_1 \rightarrow H + OH(A^2\Sigma^+) \qquad (\lambda_1 < 136 \text{ nm})$$
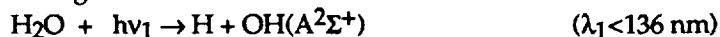
Then the electronically excited OH releases a photon:

$$OH(A^2\Sigma^+) \rightarrow OH(X^2\Pi_i) + h\nu_2 \qquad (\lambda_2 \approx 309 \text{ nm})$$
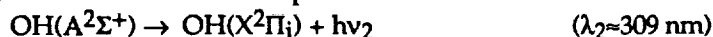
The emission of the photon called $h\nu_2$, at the scale of the inner coma, occurs at the same place as where the H_2O molecule is photolysed. The lifetime of $OH(A^2\Sigma^+)$ is estimated to 0.83×10^{-6} s and the ejection velocity of H_2O to 1 km.s^{-1} (probably higher than the ejection velocity of OH with respect to H_2O). As a consequence, the $h\nu_2$ photon is emitted within a distance of about 1 mm from the place where H_2O photodissociation occurs.

This means that the observation of $h\nu_2$ photons is a straightforward way to show evidence of H_2O photodissociation. Since the distance of the nucleus to the optical axis is as small as 400 km, the detection of the OH prompt emission in the three-channel spectra can reasonably be expected.

Theoretical spectrum calculation

A difficulty arises when trying to detect the OH prompt emission because the OH molecules emit fluorescence radiation between the same $X^2\Pi_i$ and $A^2\Sigma^+$ states (Budzien and Feldman, 1991). This emission is dominant in the near UV, especially at 309 nm, which corresponds to the (0,0) transition. The fluorescence emission is superposed on the prompt emission which makes its detection difficult. However, a small difference exists, which is due to a temperature difference of the rotational levels.

Let us consider both processes:

i) *H_2O photolysis and prompt emission (fig. 1)*: in the present calculation, we have taken into account the effect of the solar Ly α only, because this line is responsible for 86 to 93% of the water

vapor photodissociation, depending upon solar activity (Festou, 1981). The rotational quantum number of $OH(A^2\Sigma^+)$ can reach $J'=23$ in the $v'=0$ and $J'=19$ in the $v'=1$ states.

   ii)*Resonance fluorescence excitation (fig. 2)*: here we have used the rotational population calculated in full detail in Schleicher's thesis (1983) for the case when the heliocentric component of the velocity is equal to +24 $km.s^{-1}$. It may be noted that the only first four rotational levels of the $A^2\Sigma^+$, $v'=0$ and $v'=1$ states are significantly populated.
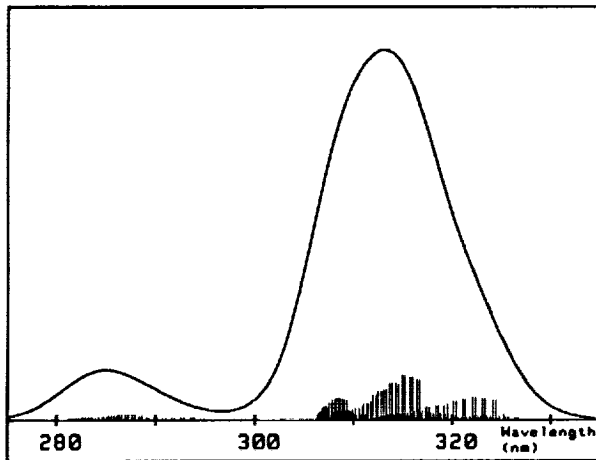

Fig. 1. Emission spectrum of OH $(A^2\Sigma^+ \rightarrow X^2\Pi_i)$ due to H_2O photolysis. This spectrum is calculated with the relative population distribution of the rotational levels given by Carrington (1964) for $v'=1$ and by Simons and Smith (1984) for $v'=0$. The branching ratio $P(v'=1)/P(v'=0)$ is taken in Okabe (1980), and the wavelengths and rotational-transition probabilities of the lines are taken in Dieke and Crosswhite (1962). The convolution is calculated with a FWHM of 7 nm.
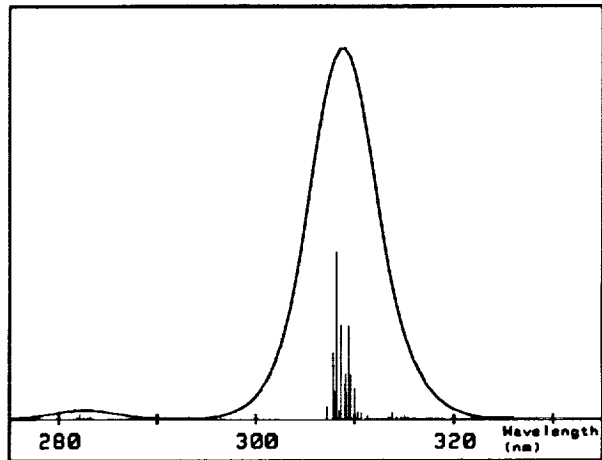
Fig. 2. Emission spectrum of OH $(A^2\Sigma^+ \rightarrow X^2\Pi_i)$ excited by resonance fluorescence. The relative population distribution of the rotational levels are taken in Schleicher (1983) for a radial velocity $v=+24$ $km.s^{-1}$. The wavelengths and rotational-transition probabilities of the lines are taken in Dieke and Crosswhite (1962). The convolution is calculated with a FWHM of 7 nm.

   A close examination of both figures shows a difference in the wavelengths of maximum intensity, even after convolution: about 313 nm for prompt emission, and 309 nm for fluorescence. In order to know whether OH prompt emission is detectable or not it is necessary to compute the intensity ratio ρ of the two types of emission. We use here the formulae given by Bertaux (1986):

$$\rho = \varepsilon(H_2O)/\varepsilon(OH) = (g(H_2O)/g(OH)) \ (n(H_2O)/n(OH))$$
(under optically thin conditions)

where: $g(H_2O)$ and $g(OH)$ are the excitation rates, in $photon.s^{-1}.molecule^{-1}$
         $n(H_2O)$ and $n(OH)$ are the number of molecules along the line of sight

$$g(H_2O) = q\tau^{-1}$$

   q and τ are, respectively, the fraction of OH radicals which are produced in the $A^2\Sigma^+$ state, and the lifetime of the water molecules against photodissociation by solar photons, both at the wavelength of Ly α.

   The following values are obtained:

   i) $\tau \approx 1.49 \times 10^5$ s at 0.83 AU (sun-comet distance on March 9, 1986), according to Lewis *et al.* (1983). Consequently, if we take q equal to 7.5%, the quantum efficiency is: $g(H_2O) \approx 5.5 \times 10^{-7}$ $photon.s^{-1}.molecule^{-1}$ at 0.83 AU (if Ly α is responsible for 90% of the process).

ii) $g(OH) \approx 1.67 \times 10^{-3}$ photon.s^{-1}.molecule^{-1} according to Schleicher (1983). In this calculation we suppose that $g(OH)$ is proportional to r^{-2}, where r is the distance nucleus-sun in AU.

Consequently we obtain: $\rho \approx 3.3 \times 10^{-4}$ (n(H$_2$O)/n(OH))

It is more difficult to estimate the ratio n(H$_2$O)/n(OH) with accuracy. However, since H$_2$O is the major source of OH molecules, we shall examine spectra taken as close as possible of the nucleus.

TKS Observations

Figure 3 shows two spectra obtained around 309 nm which show the (0,0) transition of OH ($A^2\Sigma^+ — X^2\Pi_i$) and the much weaker (1,1) transition. The intensities of these two emission bands are normalized, in order to compare their features. They correspond to impact parameters of, respectively, 538 and 3631 km.
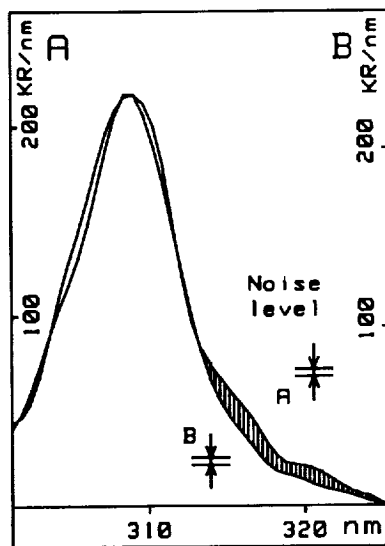

Fig. 3. Spectra obtained with TKS. The intensities are normalized in order to compare the features. The impact parameter ρ of the spectrum (A) is 538 km and of the spectrum (B) is 3631 km. Intensity units are KiloRayleighs/nm. The noise level, which is equal to about 4 KR/nm, is shown for A and B.
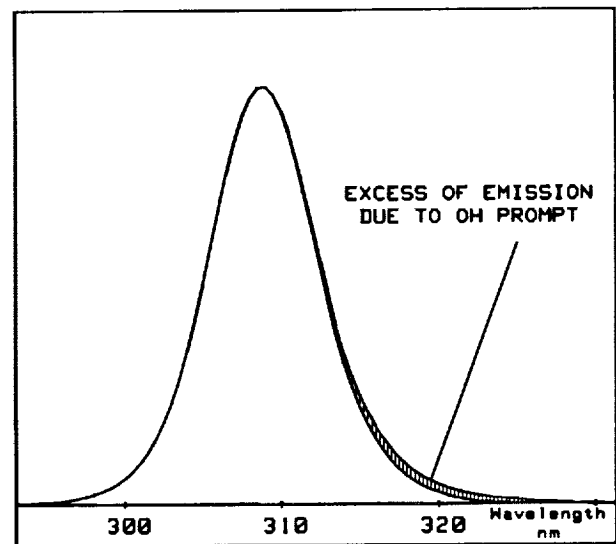
Fig. 4. Theoretical visualisation of OH prompt emission. The weaker spectrum is due only to a resonance fluorescence mechanism and the other is increased by 7.5 % of OH prompt emission. The intensities of the two spectra are normalized in order to compare their features. The convolutions are made with an instrument response function having a FWHM of 7 nm.

An excess of emission may clearly be seen on the right wing, which can be modelized (Fig. 4) with a spectrum of pure fluorescence and a spectrum mixed with 7.5% of prompt emission. This spectrum includes the (0,0) and (1,1) bands.

This modelization implies a ratio n(H$_2$O)/n(OH) of nearly 230. Effectively, we have:

$\rho \approx 0.075 = 3.3 \times 10^{-4}$(n(H$_2$O)/n(OH)) $\Rightarrow$ n(H$_2$O)/n(OH)$\approx$230 at 538 km of the nucleus

This ratio is appreciably higher than the value obtained with Haser's classical model (1950) which gives n(H$_2$O)/n(OH)$\approx$40-45. It may also be compared with the value of about 180 for comet IRAS-Araki-Alcock, that can be inferred from the calculation of Budzien and Feldman (1991, table II, exposure LWR 15914).

Therefore, the study of the radial distribution of OH radicals shows a slight decrease of the integrated intensity of this radical near the nucleus, which is not predicted by Haser's model (which overestimates appreciably the integrated OH quantity in this region). This decrease is may be due to an absorption of the solar photons by the inner coma (mainly the H$_2$O molecules).

The true ratio $n(H_2O)/n(OH)$ is consequently probably as high as 100-150, which gives the best agreement with the spectra obtained by TKS.

Conclusion

The spectra obtained with TKS in the inner coma of Halley's comet, on March 9, 1986, show that:

i) The intensity of the OH $(A^2\Sigma^+ \rightarrow X^2\Pi_i)$ emission bands stops to increase when the distance to the nucleus decreases, below 2000 km.

ii) The emission shows an excess of intensity on the right wing of the (0,0) band, only in the vicinity of the nucleus (i.e. within a few hundred km of the nucleus).

The emission excess on the right wing can be partially explained in introducing an OH prompt emission due to the photolysis of water.

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