THE FIRST IDENTIFICATION OF C_2^- EMISSION BANDS IN COMET SCORICHENKO-GEORGE (1989e$_1$) SPECTRUM

Churyumov K.I., Chorny G.F.

Astronomical Observatory of Kiev Shevchenko University,
Main Astronomical Observatory of Ukrainian Academy of Sciences

ABSTRACT

Wave lengths from 360 emissions within the spectral range $\lambda\lambda$ 3380-6290 Å in the spectrum of the comet Scorichenko-George, obtained with the help of the TV spectral scanner of a 6-meter reflector BTA (in Special AO) have been determined. The CN, C_2, C_3, $NH, CH, CO, Na, NH_2, N_2^+, CO^+, CH^+, CO_2^+, H_2O^+$, and C_2^- emissions have been identified. For the first time it has been shown that emissions of C_2^- (the transitions 0-0, 0-1 et al.) in the cometary spectrum possibly exist. Molecular ions C_2^- column density with cross-section 1 cm^2 is $N = 1.44 \cdot 10^{-12}$ cm^{-2} and their upper limit of gas C_2^- productivity is $Q(C_2^-) = 2 \cdot 10^{28}$ c^{-1}.

INTRODUCTION

The present paper was stimulated by the original spectral observations on the 6-m telescope BTA at Pastukhov's Mount (Northern Caucasus) and the calculations of radiative transition probabilities in C_2^- made by Rosmus and Werner (1984).

As early as 1963 it was noted that the low intensity of the Phillips emission bands from comets might be caused at least by one of two reasons. The first one: the C_2 molecules are formed initially in a triplet state and do not have any time to decay to the $X^1\Sigma_g^+$ state during the time when a comet is reasonably close to the Sun. The second one: the C_2 molecules are converted from the $X^1\Sigma_g^+$ state to the $a^3\Pi_u$ state by an optical pumping mechanism that involves solar radiation, the conversion from singlet to triplet occurring via the perturbed levels (Ballik and Ramsay, 1963).

Later on an important work has been done to verify the mechanism of this type of optical pumping (Krishna Swamy, 1986). Noted by Krishna Swamy (1986) some overpopulation of the lower vibrational levels in the low triplet $a^3\Pi_u$ state of the C_2 radical is connected with the optical pumping too.

There is, in principle, one more process which ideally promotes both the depopulation of the ground $X^1\Sigma_g^+$ state and the appearance of C_2 mainly in the lower vibrational levels of the $a^3\Pi_u$ state. The problem concerns the formation of the C_2^- anions

either by radiative attachment of electrons to the C_2 radicals or by dissociative attachment of electrons to the C_2H_2 molecules if C_2 is a granddaughter species of C_2H_2. The C_2^- ions are formed in the ground $X^2\Sigma_g^+$ state. Afterwards under the influence of solar radiation they can be excited into the bound $B^2\Sigma_u$ electronic state and either perform a spontaneous transition to the ground state (with emission in the optical range) or autodecay. As soon as the excited C_2^- ions occur on the vibrational levels $v' \geq 6$ the autodecay rate can be comparable with the spontaneous transition rate. In its turn this autodetachment rate in $C_2 a^3\Pi_u + e$ is about ten times more than it is in $C_2 X^1\Sigma_g^+ + e$ (Jones et al.,1980). Because the level $C_2^- B^2\Sigma_u^+ v'=6$ interferes with the $C_2 a^3\Pi_u v''=0$ and 1 levels, the autodetachment from the level $v'=6$ goes preferably to the levels $v''=0$ or 1 of the C_2 radical in the $a^3\Pi_u$ state.

Thus the process in question proceeds in the very direction the optical repumping process does. It may be true that both mechanisms of repumping coexist in cometary atmospheres. A quantitative study of the role of the C_2^- formation in the photochemical kinetics of cometary C_2 will be performed later. It is quite possible that the efficiency of this process (limited only by reagents abundances) is higher than the efficiency of the intercombination transitions $C_2 a^3\Pi_u \to C_2 X^1\Sigma_g^-$ and may be comparable with the efficiency of the $C_2 a^3\Pi_u v \geq 4 \to C_2 b^3\Sigma_g^- v' \to C_2 a^3\Pi_u v < 4$ transitions surveyed in (Krishna Swami,1986).

We have calculated g-factors of fluorescence efficiency in the $C_2^- B^2\Sigma_u^+ v' \to C_2^- X^2\Sigma_g^+ v''$ bands for a possible identification of emissions in the observed cometary spectra (Tab. I).We used the formula

$$g_{v'v''} r^2 / (\pi F_\odot) = 8.853 \cdot 10^{-6} \lambda_{v'v''}^2 f_{v'v''} \tilde{\omega}_{v'v''}$$

where r is the comet's heliocentric distance (AU), $\pi F_\odot$ - solar irradiance at r=1 AU (phot/(s nm cm^2)). For the meaning of the rest of the variables see e.g. (Lutz, 1987). Missing oscillator strength in the absorption have been calculated by the formula

$$f_{v'v''} = 3.04 \cdot 10^{-6} \tilde{\nu}_{v'v''} q_{v'v''} |\langle x|z|B \rangle|^2$$

using the momenta $\langle X|z|B \rangle$ from (Rosmus and Werner, 1984).

Note also that some evidence on the presence of the radiative attachment of electrons to the cometary C_2 molecules can be seen in the observed cometary spectrum in the range 3642.3-3679.1 Å where the onset of $C_2 X^1\Sigma_g^+ v =0 \to C_2^- X^2\Sigma_g^+ v = 0$ emissions lies (in accordance with the electron affinity value 3.370-3.404 eV (Nichols and Simons,1987)). The photoattachment cross-section for the $C_2 + e \to C_2^- + h\nu$ reaction is about 10^{-17} cm^2 (Feldman, 1970).

Table I. Oscillator strength $f_{v'v"}$ and g-factors of fluorescence efficiency for $B^2\Sigma_u^+v' \to X^2\Sigma_g^+v"$ bands of C_2^- anion.

v'v"	band a) onset $\lambda_{v'v"}$ (Å)	b) $q_{v'v"}$	$|<X|z|B>|^2$	$\tilde{\omega}_{v'v"}$	$f_{v'v"}\cdot(10^{-1})$	$\dfrac{r^2 g_{v'v"}}{\pi F_\Theta}$ (cm²nm)
0 0	5415.87	0.7	1.1100	1/3	0.436[c]	$3.7739\cdot10^{-16}$
0 1	5984.82	0.2	1.1100	1/3	0.113	$1.1944\cdot10^{-16}$
1 0	4902.02	0.3	0.7742	1/5	0.144[c]	$0.6127\cdot10^{-16}$
1 1	5363.26	0.3	0.7742	1/5	0.132	$0.6723\cdot10^{-16}$
1 2	5912.69	0.3	0.7742	1/5	0.119	$0.7366\cdot10^{-16}$

a)Herzberg and Lagerqvist (1968),   b)Jones et al.(1980),   c)Rosmus and Werner (1984).

POSSIBLE IDENTIFICATION OF C_2^- EMISSIONS IN COMETARY SPECTRUM

The spectra of the comet Scorichenko-George (1989e₁) were observed by V.L.Afanasiev, A.I.Shapovalova and K.I.Churyumov on Feb.26.7 UT,1990 at the Special Astrophysical Observatory of the USSR Academy of Sciences (Nizhny Arkhyz) with the help of the TV scanner located on a spectrograph in the Nasmith focus of a 6-meter reflector BTA. The spectrographic slit was observed with a mask that selects two regions of the comet that are separated from one another by the angular distance 20" (31000 km). This gave the opportunity during one exposition to accumulate in the computer memory two spectra, one of which is referred to the cometary nucleus, the other to the coma's region.The six spectra were recorded in three channels, which are characterized by the following spectral ranges: 1 - 3350-4450 Å, 2 - 4290 - 5390 Å, 3 - 5190 - 6290 Å. Spectral resolutions for each channel is 1.1 Å. The identification of the spectrum showed that it contains many typical cometary emissions (wave lengths of 360 emissions are measured with the precision up to ±0.5 Å). Among them are: $CN, C_2, C_3, CH, NH, NH_2, Na, CO, CO^+, N_2^+, CH^+, CO_2^+$, H_2O^+ and C_2^-. This spectrum for the first time has found out the emissions of the negative ions C_2^- (see λ_{obs} in the Table II):

Table II. Identification of C_2^- emissions in the comet's spectrum

$\lambda_{obs}\pm0.5$ Å	$\lambda_{v'v"}$ d)	v'v"	$\lambda_{obs}\pm0.5$ Å	$\lambda_{v'v"}$ d)	v'v"
5416.5	5415.9	0-0	4902.5	4902.0	1-0
5984.4	5984.8	0-1	5363.1	5363.3	1-1
			5913.1	5912.7	1-2

d) the theoretical $\lambda_{v'v"}$ from Table I

Comparison of the observable and theoretical data shows their

close coincidence within the measurement made. The sharp peaks in the spectrum are the transitions 0-0 and 0-1 (see Fig.a,b) that have the largest values of g-factors. The transitions 1-0, 1-1 and 1-2 have some emission peculiarities in the spectrum. The spectrum also contains the band in the wave length range 3642.3-3679.1 Å (the observed band is 3642.4-3678.7 Å), where lies the beginning of the transition $v'=0X^1\Sigma^+C \to v'=0X^2\Sigma_g^+C_2^-$ (Fig.c).
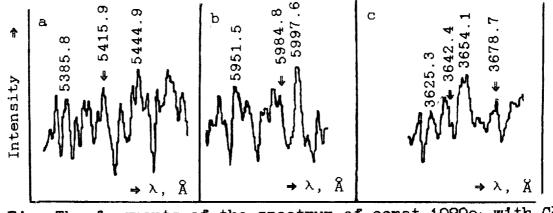

Fig. The fragments of the spectrum of comet 1989e₁ with C₂⁻

CONCLUSIONS

1.It has been shown that emissions of C_2^- in the cometary spectrum possibly exist. 2. The presence of ions C_2^- leads to the poverment of the singlet state of C_2 molecules and the enrichment of the triplet state of these molecules. This substantially enriches the chemical kinetics of C_2 and improves the model of the inner coma (the process of photochemical reactions).3.Calculation of molecular ions C_2^- column density with cross section 1 cm² gives

$$N = 1.44 \cdot 10^{12} \text{ cm}^2.$$

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