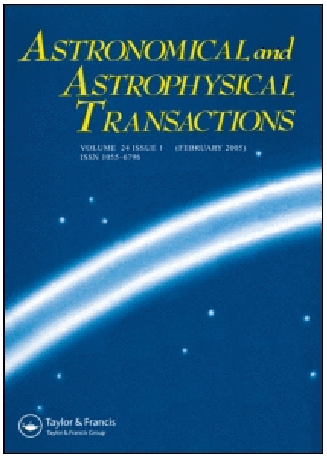

Astronomical & Astrophysical Transactions
The Journal of the Eurasian Astronomical Society
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713453505

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Online Publication Date: 01 July 1997
To cite this Article: Churyumov, K. I., Chorny, G. F. and Kleshchonok, V. V. (1997) 'Luminosity of the triplet band of neutral CO molecules in the atmosphere of comet Scorichenko-george (1990 VI)', Astronomical & Astrophysical Transactions, 13:3, 225 - 231
To link to this article: DOI: 10.1080/10556799708208135
URL: http://dx.doi.org/10.1080/10556799708208135

Astronomical and Astrophysical Transactions, 1997,
Vol. 13, pp. 225–231
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LUMINOSITY OF THE TRIPLET BAND OF NEUTRAL CO MOLECULES IN THE ATMOSPHERE OF COMET SCORICHENKO–GEORGE (1990 VI)

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(Received December 15, 1995)

Identification of the Asundi and Triplet bands of neutral CO molecules in the spectra of comets Bradfield (1980 XV) (Cosmovici *et al.*, 1982) and Scorichenko–George (1990 VI) (Churyumov, 1992) puts on the agenda decoding the real physical mechanism of the luminosity of the cometary CO in the visual spectral range. The results of the identification of the Triplet bands in the comet Scorichenko–George spectra, obtained with the TV-spectral scanner of the 6-m BTA reflector, are given. The g-factors of the CO molecule are calculated for the Triplet system $d^3\Delta_i - a^3\Pi_r$ ($\lambda\lambda$ 3770–7500 A) and for the Asundi band $a'^3\Sigma^+ - a^3\Pi_r$ ($\lambda\lambda$ 3900–8600 A). The flux of radiation, connected with the fluorescent excitation of the upper states $d^3\Delta_i$ and $a'^3\Sigma^+$ from the $x^1\Sigma^+$ ground state by the solar UV radiation, is sufficiently small. This confirms Biermann's (1976) supposition that if CO Triplet bands are observed in comets, the mentioned mechanism cannot be the single cause of their appearance.

KEY WORDS Comet Scorichenko–George, cometary spectrum, CO, Triplet bands

1 INTRODUCTION

The spectrum of comet Scorichenko–George (1990 VI) was observed by V. L. Afanasiev, K. I. Churyumov, and A. I. Shapovalova with the TV spectral scanner installed in the Nasmith focus of the 6-m telescope BTA (Special Astrophysical Observatory of Russian Academy of Sciences, Nizhny Arkhyz). In the spectrum, emissions of CN, C_2, CH, C_3, NH, Na, CO^+, CO, C_2^- and others were identified. After comet Bradfield (1979x), this is the second time when the triplet bands of CO (transitions $d^3\Delta_i - a^3\Pi_r$, $\lambda\lambda$ 443.7–628.6 nm) are observed in the spectrum in the visible range. Churyumov (1992) identified 33 lines of the triplet band, their wavelengths, with precision of ± 0.04 nm, coinciding with theoretical wavelengths. These are transitions 15–3, 13–2, 11–2, 9–1, 8–1, 7–1, 7–0, 5–0, and 4–0.

There exist several physical processes that lead to luminosity of CO in the triplet bands:

1. Dissociative recombination of ions containing the CO group.
2. Photodissociation of daughter molecules with emergence of CO in excited triplet state.
3. Direct intercombinatory transitions from the main state $x^1\Sigma^+$ of CO molecules to the triplet state in the field of solar radiation.
4. Population of the excited triplet state of CO molecules through preliminary photoexcitation of the singlet state with consequent intercombinatory transitions (intercombinatory fluorescence).
5. Population of the triplet state through collisions of the CO molecules with electrons.
6. Recombination of CO ions through collision with electrons.

None of these mechanisms of population of the triplet state $a'^3\Sigma^+$ and $d^3\Delta_i$ of CO molecules, where the observed Asundi bands and the triplet band system initiate, can explain our observations. Each of them is unlikely for comets. Possibly, the CO triplet bands are rarely observed in comets. However, in those cases when each of these processes in a cometary atmosphere is rather well developed, their combination causes weak but observable luminosity of cometary CO in triplet bands.

Nonefficiency of each of the first three processes was proven by Biermann (1976). Low efficiency of the fourth process, intercombinatory fluorescence, was investigated by Chorny (1992).

Presently the efficiency of the 5th and 6th processes as well as of the joint action of the above mechanisms of population of the CO molecule triplet state are being explored (Churyumov *et al.*, 1995).

2 OBSERVATIONS AND CALCULATIONS

The spectrum of the comet Scorichenko–George (1990 VI) was observed on Feb. 26.7 UT, 1990 using a TV scanner and a spectrograph in the Nasmith focus of the 6-meter telescope. 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 two spectra in the computer memory, one of which refers to the cometary nucleus, and the other one, to the coma region. Figure 1 shows such two spectra of the comet Scorichenko-George. Six spectra were recorded in three channels, which are characterized by the following spectral ranges: 1, 3350–4450Å; 2, 4290–5390Å; 3, 5190–6290Å. Spectral resolution for each of the channels is 1.1Å. Observational data are given in Table 1.

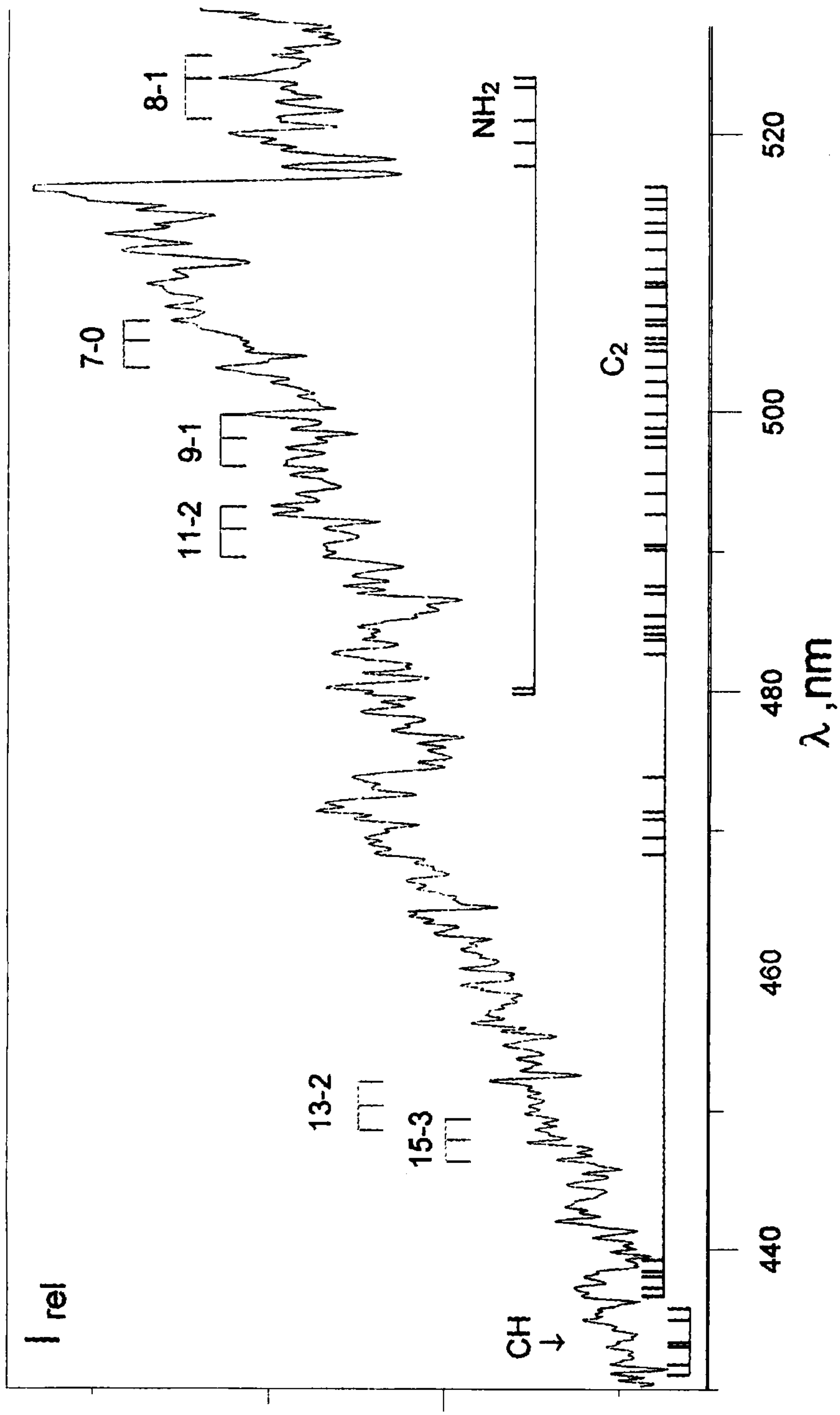

Figure 1 The region of the spectrum ($\lambda\lambda$430–530 nm) of comet Scorichenko–George (1990 VI) with several basic comet lines and lines of the Triplet band of the CO molecule (the transitions are 15–3, 13–2, 11–2, 9–1, 7–0, 8–1).

Table 1. Observational data

Data, UT	Δt	A	z	$p.a$	d''	$\Omega/4\pi$	m	*No.*
1990 Feb. 26.67174	786	120	63	53	2	5.876 10	9.0	1
1990 Feb. 26.68374	1186	122	66	51	2.5	9.181 10	9.0	2
1990 Feb. 26.70153	1123	126	70	49	3	1.322 10	9.0	3

Date, UT is the beginning of spectrum scanning; Δt, time; A, azimuth; z, zenith distance; p. a., the position angle of the slit (the "nucleus-coma" direction); d, the diameter of the diaphragm; $\Omega/4\pi$, the solid angle of the observed area; m, the integrated visual magnitude of the comet; $No.$, the number of the channel.

The comet was located at the heliocentric distance $r = 1.688$ AU and the geocentric distance $D = 2.163$ AU. The integrated brightness of the comet was estimated by K. I. Churyumov with the Assembi 80 × 40 binocular by the Bobrovnikoff–Bakharev–Vsekhsvyatsky method: $m_1 = 9.0^m$ (comparison stars from the SAO Catalog). After observations of the comet were completed, the spectrum of the morning sky was recorded with the aim of its use for extraction from the continuous spectrum of the comet.

The identification of the spectrum showed that it contained many typical cometary emissions (wavelengths of 360 emissions have been measured with the precision to ±0.4 A). Among them are: CN, C_2, C_2^-, C_3, CH^+, NH, Na, CO, CO^+, N_2^+, CH, CO_2^+, H_2O^+, etc. But the most interesting peculiarity of the spectrum of this comet was the presence of neutral CO in the Asundi and Triplet bands. By determination of the emission wavelengths, we found almost ten lines of the Asundi band and 60 lines of the Triplet band. In Table 2, observed and theoretical wavelengths of the Triplet band are given. So far, only one case of identification of the Asundi and Triplet bands, in the spectra of comet Bradfield 1980t, was known (Cosmovici *et al.*, 1982). The Figure shows the region of the spectrum of comet Scorichenko–George with several emissions of the Triplet band of the CO molecule. The ratio of signal/noise is equal to 20.

Flux of radiation in $v'–v''$ band (from Asundi or Triplet systems) observed at the distance ρ from the comet is:

$$H_{v'v''} = L_{v'v''}(r)/4\pi\rho^2 = g_{v'v''}(1\ \mathrm{AU})(N_x/4\pi\rho^2 r^2)h\nu_{v'v''},$$

where

$$g_{v'v''}(1\ \mathrm{AU}) = (\pi e^2/mc^2)\lambda^2_{xv'} f_{xv'} \pi F^{\odot}_{xv'} \omega_{v'v''}$$

is the fluorescence efficiency factor for the CO molecule in the $v'–v''$ band (g-factor); L is the luminosity of a subtended telescope part of the cometary atmosphere at the heliocentric distance of r AU; N is the total number of CO molecules in this part of the atmosphere; f_{xv}, is the absorption oscillator strength for the transition $X^1\Sigma^+ - (A^1\Pi, v) - (T, v')$, $T = a'^3\Sigma^+$ or $d^3\Delta_1$;$\lambda_{xv'}$, is the wavelength of the line of the X–A absorption that finished by the transition of $A - (T, v')$; $\pi F^{\odot}_{xv'}$ is the

Table 2. The comparison between observed and theoretical wavelengths of the Triplet band $d^3\Delta - a^3\Pi_r$

$v'-v''$	λ_{calc}	λ_{obs}	$\Delta\lambda$, *nm*	*Blended*
	446.29	446.59	−0.30	H_2O^+ (0,14,0)
5–3	447.88	447.78	+0.10	
	449.44	449.40	+0.04	
	452.07	452.10	−0.03	
13–2	450.55	450.37	+0.18	NH(0–0)+CN(5–7)
	448.84	448.75	+0.09	
	489.75	489.83	−0.08	
11–2	491.72	491.77	−0.05	
	493.50	493.50	0.	
	495.90	496.07	−0.17	
9–1	497.90	498.04	−0.08	
	499.69	499.87	−0.18	
	521.60	521.28	+0.32	Fe I(?)+CO
8–1	523.84	524.20	−0.36	
	525.83	525.82	+0.01	
	550.08	550.75	+0.05	
7–1	553.35	552.83	−0.48	
	555.41	555.35	+0.06	
	503.30	503.34	−0.04	C_2+CO
7–0	505.27	505.40	−0.13	
	507.09	506.80	+0.11	
	562.40	562.15	+0.25	
5–0	564.76	564.34	+0.42	
	567.05	566.98	+0.07	
	598.20	598.44	−0.16	
4–0	601.05	601.20	−0.15	
	603.70	604.14	−0.44	

solar photon flux in the vicinity of the wavelength of $\lambda_{xv'}$; $\omega_{v'v''} = A_{v'v''}/\Sigma_{v''}A_{v'v''}$ is the ratio of spontaneous transition probabilities.

The values of $f_{Xv'}$ were calculated using the formula (Lee and Guest, 1981)

$$f_{Xv'} = 113\sigma^T_{Xv'}[(\Delta\lambda)_{Xv'}/\lambda^2_{xv'})][(\mathrm{CO}+98)/92](135/92).$$

The dimension of the photoabsorption cross-section $[\sigma^T_{Xv'}]$ is Å^2, $[\Delta\lambda] = [\lambda]$ =Å. The values of $\sigma^T_{Xv'} = \sigma(X^1\Sigma^+ - T, v')$, of the halfwidth $\Delta\lambda$ of the $\sigma(\lambda)$ contour, and of λ_{Xv} are taken from the diagram in Lee and Guest (1981). The precision of the estimates is not better than 15%. The Franck–Kondon factors for Einstein $A_{v'v''}$- values are taken from McCallum *et al.* (1972). The values of $\lambda_{v'v''}$ were calculated on the basis of the spectroscopic data from McCallum *et. al.* (1972) and Huber and Herzberg (1979). Some of these λ coincide with the experimental values within 1 Å and some of them may differ by a few Ångströms from the experimental ones. The fluxes $\pi F^{\odot}_{xv'}$ were taken from Allen (1973).

Table 3. The wavelengths ($\lambda_{v'v''}$ in nm and g-factors ($10^{11} \times g_{v'v''}$ in s^{-1}) for triplet bands of the $d^3\Delta_2$ ($v' = 4, 5, 7$–10 – $a^3\Pi$ ($v'' = 0$–5) and $a'^3\Sigma^+$ ($v' = 4, 5, 7$–10 – $a^3\Pi$ ($v'' =$ 0–5) of the CO molecule.

v'	v'' 0	1	2	3	4	5
4	601.41	670.63	755.15	864.27	1000.58	1180.43
	7.39	0.332	1.64	0.699	0.176	0.447
5	565.02	625.68	698.64	791.04	907.64	1047.93
	26.11	0.324	7.94	0.0245	2.95	0.255
7	505.49	553.51	609.85	679.09	763.27	860.10
	5.41	2.66	0.447	1.39	0.128	0.672
8	480.86	524.11	574.35	635.37	708.47	791.14
	1.91	1.82	0.0001	0.755	0.0396	0.285
9	458.83	498.05	543.20	597.46	661.66	733.22
	2.55	3.92	0.394	0.897	0.591	0.162
10	439.23	475.05	515.94	564.65	621.66	684.41
	0.558	1.25	0.412	0.0784	0.329	0.0024
11	524.27	576.64	638.04	714.24	807.96	917.27
	0.674	2.86	3.24	0.587	0.283	0.716
14	455.11	493.66	537.98	591.16	653.94	723.75
	0.170	1.22	3.07	3.01	0.683	0.0954
17	404.51	434.69	468.69	508.54	554.32	603.68
	0.0739	0.735	2.90	5.70	5.12	1.51

3 DISCUSSION AND CONCLUSIONS

We shall consider, for example, the radiation in the v'–$v'' = 9$–0 band of the Triplet system. The g_{90} equals $2.55 \times 10^{11}\ s^{-1}$ (Table 3). The corresponding energy efficiency of the CO fluorescence at the wavelength $\lambda_{90} = 4588$Å is 1.102×10^{-22} erg/s. For comets, the typical value of the ratio $N/4\pi\rho^2 r^2$ is $\sim 10^{-3}$–10^4 cm^{-2}. Therefore, the flux in the 9–0 band has the value of $H_{90} \sim 10^{-20}$–10^{-18} ergs/s/cm^2, or $\sim 10^{-7}$ photons/s/cm^2. Supposing that detectivity of the instrumentation of the 4-m telescope is about 35 photons/s in the 1000Å range (Eccies *et al.*, 1983), one can see that the flux of 5×10^{-2} photons/s in the 5Å range will be practically unobservable.

The fluxes in the rest of the Triplet bands have approximately the same order as the above value for the 9–0 band. Therefore, there is practically no possibility to observe radiation from comets in the Triplet bands of the CO molecules if it originates only in the transitions of these molecules from the ground state $X^1\Sigma^+$ to the excited state $A^1\Pi$ and from there to the upper Triplet states. Simultaneously, there must exist other channels of creation of the population of the upper Triplet states of the cometary CO, or another, substantially more powerful, channel.

Acknowledgements

This investigation was supported in part by the Fundamental Research Foundation of the Ukrainian State Committee for Sciences and Technologies and by the ESOC & EE Program No. A-03-046.

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