CO IN THE IUE SPECTRUM OF COMET BRADFIELD (1979*l*)

(Letter to the Editor)

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Abstract. New identifications are reported of the fourth positive bands and Cameron bands of CO in the IUE satellite spectrum of Comet Bradfield (1979*l*). Although the predicted band intensities as well as the band identifications in Comet West (1976 VI) support the proposed assignments, VUV cometary spectra of higher resolution are necessary for conformation.

1. Introduction

Since the resonance transitions of most of the abundant cometary constituents lie in the vacuum ultraviolet region, there has been a strong upsurge in recent times in the investigations of cometary spectra below 3000 Å. Recent IUE satellite observations of Comet Bradfield (1979*l*) (Feldman *et al.*, 1980), Comet Seargent (1978m) (Jackson *et al.*, 1979) and rocket observations of Comet West (1975n) (Feldman and Brune, 1976) have clearly demonstrated that the most dominant features identified in the UV spectra of comets are H I Lyα (1216 Å) and OH (3085 Å), followed by O I, C I, S I, CO_2^+, CO^+, CO, CS, and NH. In addition to these species, one more new molecule, C_2, (whose presence, of course, is well known from the visible spectrum) has very recently been tentatively identified by Smith *et al.* (1980) in the rocket UV spectrum of Comet West (1976 VI). Despite these identifications, the UV spectra of comets exhibit many more moderately intense and weak unidentified emission features.

We report herein the identification of some of the emission signatures in the IUE spectrum of Comet Bradfield, as being due to the CO fourth positive bands and Cameron bands. The proposed identifications are found to be in accord with the evaluated band intensities (Krishna Swamy, 1979), based on the resonance fluorescence theory (see Feldman *et al.*, 1976). Furthermore the band identifications in the rocket UV spectrum of Comet West (1976 VI) provide additional support to the proposed assignments.

2. CO Identifications

It is well known that atomic carbon is an abundant constituent of the cometary coma and that a large fraction of the carbon is produced in the metastable ^{1}D state (see Feldman *et al.*, 1974; Opal *et al.*, 1974). The analysis of the rocket UV spectrum of Comet West (1975n) by Feldman and Brune (1976) has shown that carbon and carbon monoxide have comparable production rates of about one-third the water production rate.

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Feldman *et al.* (1980) identified the (2, 0) and (1, 0) bands of the fourth positive system ($A^1\Pi$–$X^1\Sigma^+$) of CO in addition to the H I, O I, C I, and S I lines in the short wavelength, low dispersion spectrum (1200–2000 Å) of Comet Bradfield. The long wavelength spectrum (2000–3000 Å) reveals the presence of emission features due to CO^+, CO_2^+, CS, OH and O I. In addition to these features, several other moderately intense and weak features observed in the spectrum (see Figures 1 and 2 of Feldman *et al.*, 1980) have been speculated as due to additional CO fourth positive bands.

We present in Table I the proposed assignments of the emission signatures in the region between 1430 and 2450 Å of the spectrum of Comet Bradfield. Column (1) gives the approximate position of the identified emission feature. The laboratory wavelengths of the CO bands (Rosen, 1970) are set out in column (2), followed by column (3) which gives the band intensity (Krishna Swamy, 1979); intensities of the Cameron bands are the visual estimates (Rosen, 1970). Columns (4) and (5) contain respectively the transition and band head assignment.

A brief discussion on the identified band systems of CO is presented in what follows.

2.1. Fourth Positive Bands

In the region between 1400 and 1900 Å of the short wavelength spectrum of Comet Bradfield, 9 emission features are identified with the CO fourth positive system ($A^1\Pi$–$X^1\Sigma^+$). Of these 9 features, the (2, 2), (0, 3), (1, 4), (2, 7), and (3, 8) are newly identified while the remaining 4 have already been reported by Feldman and Brune (1976) in the spectrum of Comet West (1975n). Of the 5 new bands, the (1, 4) band at 1727 Å is observed to be intense followed by the (2, 2) band at 1575 Å. This observation is consistent with the predicted band intensities as seen from Table I. We also note that the newly identified bands (with the exception of the very weak (2, 7) band, whose identification is doubtful) are of comparable intensity with those of the previously assigned features.

If it could be possible to identify these new features in any other comet, it will certainly be an added evidence for the proposed assignments. It is indeed gratifying to note that the intense 1727 Å (1, 4) emission feature is evident in the spectrum of Comet West (1976 VI) (see Figure 2 of Smith *et al.*, 1980), while the other (2, 7) and (3, 8) bands are identified only weakly. A search for these bands in Comet Seargent is not possible because of the available very low dispersion spectrum. Also, since Comet Seargent is three magnitudes fainter than Comet West, the CO emission are expected to be very weak in Comet Seargent (Jackson *et al.*, 1979).

2.2. Cameron Bands

The Cameron bands of CO have been tentatively identified for the first time in cometary spectra by Smith *et al.* (1980). Two weak features at 2065 and 2149 Å in the spectrum of Comet West (1976 VI) have been identified as due to the (0, 0) and (0, 1) bands respectively of the $a^3\Pi$–$X^1\Sigma^+$ system of CO. The presence of these bands in the Martian atmosphere supports their identifications in Comet West. The spectrum of Mars is known

TABLE I

CO emission features in the spectrum of Comet Bradfield

Wavelength (Å) comet (1)	Wavelength (Å) lab (2)	Intensity (3)	Transition (4)	Band assignment v', v'' (5)
1437	1435.3	0.12	$A^1\Pi - X^1\Sigma^+$	5, 1
1475	1477.5	1.05	A–X	2, 0
1510	1509.7	1.00	A–X	1, 0
1575	1576.7	0.28	A–X	2, 2
1595	1597.1	0.58	A–X	0, 1
1710	1712.2	0.23	A–X	0, 3
1727	1729.3	0.30	A–X	1, 4
1875	1878.3	0.10	A–X	2, 7
1900	1897.8	–	A–X	3, 8
2390	2388.8	(7)	$a^3\Pi - X^1\Sigma^+$	1, 4
2410	2409.2	(7)	a–X	2, 5

to be dominated by the CO Cameron bands in the region between 1900 and 2800 Å (Barth *et al.*, 1972). In the spectrum of Comet Bradfield, we note that the two emission features at 2390 and 2410 Å, albeit very weak, correlate rather well with the a–X (1, 4) and (2, 5) bands respectively. It is interesting to note that these two features may also be identified in the spectrum of Comet West (1976 VI); the 2410 Å feature is seen to be more intense than the 2390 Å feature (see Figure 2 of Smith *et al.*, 1980). The laboratory spectrum of CO shows that the 2575 Å (4, 8) band is the most intense band of the a–X system, followed by the (1, 4) and (2, 5) bands. It is very likely that the 2575 Å band could contribute to the intense feature at 2576 Å (0, 0) band of CS. If higher dispersion cometary spectra are available, it will be possible to establish the presence of CO Cameron bands in comets by identifying these along with the other intense bands at 2452 Å (4, 7), 2511 Å (1, 5) and 2553 Å (3, 7).

3. Concluding Remarks

Identifications of new CO features in both the spectra of Comet Bradfield and Comet West strengthen the view (Feldman *et al.*, 1980) that the UV spectra of comets are remarkably similar, despite large differences between them in gas-to-dust ratio and the different heliocentric distances at which they were observed. This implies that in general, the primary composition and origin of all comets are nearly identical.

Even though the band intensities based on resonance fluorescence calculations as well as band identifications in Comet West support the present assignments of CO in Comet Bradfield, a conclusive evidence would come only from high dispersion UV spectra of comets. Hopefully, the present identifications will further stimulate a strong observational effort to obtain higher resolution UV spectra of comets in as much as, the studies of cometary spectra of atomic and molecular species are of paramount importance in understanding the physical and chemical processes taking place in comets, besides holding forth clues to further our knowledge of the origin of the solar system.

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