Asteroids, Comets, Meteors 1991, pp. 183–186
Lunar and Planetary Institute, Houston, 1992

-13-90
140897

Production rates for comet P/Temple 2 from long slit CCD spectroscopy

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N93-19156

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Since comet P/Temple 2 is one of the potential targets for the CRAF (Comet Rendezvous Asteroid Flyby) mission we obtained long slit spectroscopic data with our CCD spectrograph during its 1988 apparition. As the same spectrograph had been extensively used for observations of P/Halley this allowed a direct spectroscopic comparison between the two objects. Furthermore we could choose a P/Halley spectrum which was taken at a heliocentric distance very close to that of P/Temple 2. Finally, we could adjust the integration windows along the slit to compensate for the different geocentric distances, so that roughly the same projected distance of the comets' comae was observed. The parameters for our observations are given in Table 1.

The spectra of the two comets using the integration windows in Table 1 were both divided by a solar type comparison star. These resulted in a flat ratio spectrum and required that the absolute flux scale at the left be given as fractional solar flux. Both comets show emission by the C_2 $\Delta v = -1$ band sequence, a number of NH_2 bands, the red CN system and the forbidden O ^1D lines at 6300Å and 6364Å. All of these emission bands are labelled in the figure. To facilitate visual comparison between the two spectra they were scaled to make the emission intensities by C_2, NH_2 and CN roughly equal. This immediately points out a major difference in chemical composition between the two comets. Comet P/Temple 2 exhibits a considerably stronger OI emission relative to the other species than comet P/Halley. In addition P/Temple 2 has a lower continuum level.

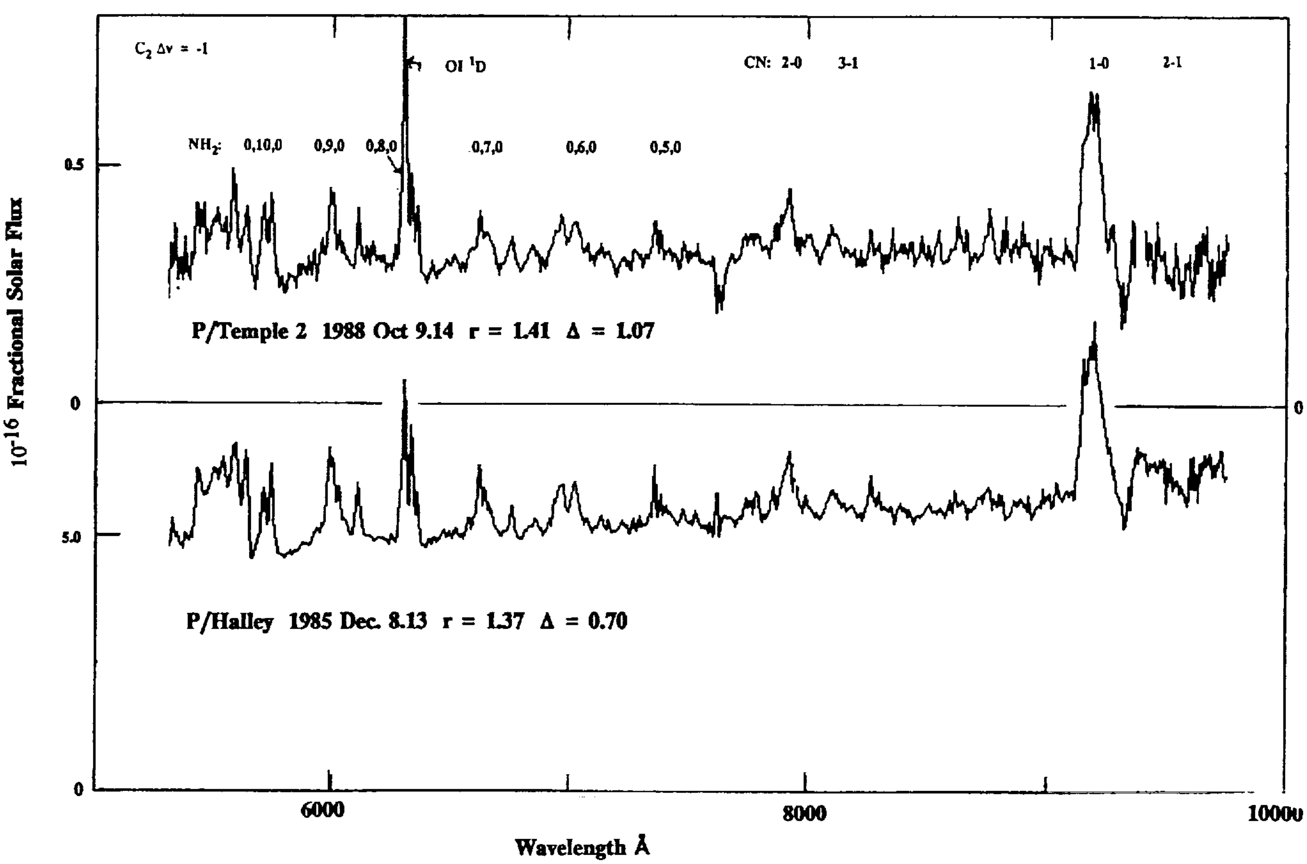

Fig. 1. Ratio spectra of comet P/Temple 2 (top) and P/Halley (bottom) with solar type comparison stars BS 8148 and BS 8931 respectively. The two comets were observed at very similar heliocentric distances. Lack of a comparison star with close air-mass match leaves some residual telluric bands such as O_2A and H_2O in the P/Temple 2 spectrum.

Table 1. Circumstances of Observations

	P/Temple 2		P/Halley	
Perihelion passage:	1988 Sept. 16.73		1986 Feb. 9.45	
Observation date:	1988 Oct. 9.14	(1) 20 min exposure	1985 Dec. 8.13	(4) 5 min exposures
Sun/Earth distances:	r = 1.41 AU	Δ = 1.07 AU	r = 1.37 AU	Δ = 0.70 AU
Integration window:	106" x 2.5"	(72,650km x 1,984km)	151" x 2.5"	(77,220km x 1,270km)

Table 2. Fluxes and production rates: P/Halley 1985 Dec. 8.13

Species	Flux in slit photons s^{-1} m^{-2}	Band Luminosity 10^{28} photons s^{-1}	g-factor 10^{-3} s^{-1}	Production rate 10^{26} molecules s-1	Q Adopted 10^{26} molecules s^{-1}
H_2O (from OI)	1702	1.17	—	1870	1870
C_2 Δv=-1	20810	232	30.4	7.0	7.0
NH_2 0,10,0	4080	6.50	2.82	2.4	2.6
0,8,0	5810	9.2	2.64	3.1	
0,7,0	5170	8.2	2.94	2.4	
0,6,0	5030	8.0	0.98	7.0	
CN 1-0	14500	436	17.1	4.3	4.3
2-1	4480	135	5.4	4.1	
2-0	5320	160	5.1	5.2	
3-1	2170	65	2.0	5.5	
Continuum	photons / s m^2 Å				
6250Å	257				

P/Temple 2 1988 Oct. 9.14

Species	Flux in slit photons s^{-1} m^{-2}	Band Luminosity 10^{28} photons s^{-1}	g-factor 10^{-3} s^{-1}	Production rate 10^{26} molecules s-1	Q Adopted 10^{26} molecules s^{-1}
H_2O (from OI)	562	0.70	—	1120	1120
C_2 Δv=-1	2530	58	28.7	1.8	1.8
NH_2 0,10,0	480	1.5	2.66	0.47	0.60
0,8,0	700	2.3	2.49	0.76	
0,7,0	490	1.9	2.78	0.57	
0,6,0	680	2.2	0.92	1.9	
CN 1-0	2030	116	16.1	1.14	1.2
2-1	—	—	5.1	—	
2-0	1060	66	4.9	2.1	
3-1	530	26	1.9	2.2	
Continuum	photons / s m^2 Å				
6250Å	15.0				

In order to determine the production rates for the observed species we integrated each band over its spectral extend and along the slit over the integration window given in Table 1. The raw counts were converted to photons/s m^2 by observing an absolutely calibrated flux standard, BS 718 and BS 3314 in the case of P/Halley and BS 718 for P/Temple 2 (Johnson 1980). For these standard stars the slit was opened to 10" yielding photometric calibrations. After correction to unit airmass the observed fluxes collected by our slit aperture are listed in column 2. Next the band luminosities were calculated by using a Haser model correction factor and the appropriate dilution factor ($4\pi\Delta^2$) for each comet. These band luminosities are given in column 3. For the Haser model corrections we employed our recently determined scale lengths (Fink, Combi, and DiSanti 1991 a,b). Since the two comets were observed at nearly identical heliocentric distances, this makes any model dependent errors in a composition comparison between the two comets quite small. Not considering the different projected slit widths, the Haser corrections for the slightly larger distance of P/Temple 2 were about 1.16 times higher for all species.

For transitions excited by solar resonance fluorescence such as those of C_2, NH_2 and CN the proper fluorescence efficiencies, or g-factors must be applied to obtain production rates. For the C_2 $\Delta v = -1$ sequence we used the standard value of Schleicher et al. (1987) for the $\Delta v = 0$ band sequence, multiplied by 0.50. The latter number came from measurements of a number of spectra showing both the $\Delta v = 0$ and $\Delta v = -1$ C_2 emissions (e.g. A'Hearn 1975). For NH_2 we used the values recently calculated by Tegler and Wyckoff (1989). For the CN red system we used the same numbers as in our analysis of 4 comets some years ago (Johnson, Fink and Larson 1984). We calculated these values using the average "f" values given in Sneden and Lambert (1982), Cartwright and Hay (1982), Duric et al. (1978) and Lambert (1968). The g factors listed in Table 2 have been converted to the appropriate heliocentric distances.

The OI emission is not produced by fluorescence but results from the direct photo-dissociation of H_2O to the ^1D state. The procedure to obtain H_2O production rates follows that given in our recent paper on the production rate of H_2O for comet P/Halley (Fink and DiSanti 1990). The variation in branching ratio for this process with change in solar activity is discussed in DiSanti and Fink (1991) and concludes that for equal OI 6300 luminosity the rate of production of water is a factor of 1.23 smaller during periods of active sun. Since this is not a significant change we did not consider variations in solar activity in this analysis. The production rates for H_2O and the parents of C_2, NH_2, and CN for the bands used in our analysis are given in column 5 of Table 2. Of the four NH_2 bands used the most reliable one is 0,8,0 while 0,6,0 gives a rather deviant production rate either due to a contamination in that band or to an erroneous g-factor. The production rate adopted (in column 6) is a weighted average of the other three bands. For CN the most reliable number is that for the 1-0 band which was therefore given most weight for our adopted value.

The comparison of the production rates between P/Halley and P/Temple 2 is illustrated in Table 3. Since we have recently carried out such a comparison for P/Brorsen-Metcalf (DiSanti and Fink 1991), production rates for this comet are also included as are nominal values for a number of comets from photometry given by Schleicher et al. (1987).

Table 3. Production rate comparison

	P/Halley 1986 Dec. 08 $r=1.37$ $\Delta=0.70$	P/Temple 2 1988 Oct.09 $r=1.41$ $\Delta=1.07$	P/Brorsen-Metcalf 1989 July 13 $r=1.36$ $\Delta=0.89$	"Nominal comets"
H_2O:	1870[a] ~ 100%	1120 ~ 100%	257 ~ 100	100
C_2:	7.0 ~ 0.37%	1.8 ~ 0.16%	0.94 ~ 0.36%	0.20%
NH_2:	2.6 ~ 0.14%	0.60 ~ 0.054%	0.15 ~ 0.06%	—
CN:	4.3 ~ 0.23%	1.2 ~ 0.11%	0.47 ~ 0.18%	0.30%
$\frac{\text{Cont.}}{H_2O}$ $Å^{-1}$	0.15	0.027	0.0085	

[a] All production rates are in 10^{26} molecules/sec.

We note that the water production rate of P/Temple 2 is actually quite close to that of P/Halley at a comparable distance. At first sight this result may appear incongruous since the continuum flux for P/Temple 2 was down by a factor of ~17. However, inspection of Fig. 1 shows that the OI lines are much stronger relative to other emissions and the continuum in P/Temple 2. The OI flux gathered by our slit aperture is thus only a factor of 3.0 lower for P/Temple 2 and after the dilution factor is taken into account the water production rate is only a factor of 1.7 lower. Our P/Temple 2 water production rate is considerably higher than the IUE values of ~350×10^{26} reported by Roettger et al. (1990). We offer the following comments on this discrepancy. The lightcurve of P/Temple 2 (Sekanina, 1991) can allow a factor of ~1.75 variation. Changing solar activity yields a factor of 1.23. The IUE H_2O production rates are a factor of 2.6 lower than ground based measurements by A'Hearn et al. (1989) and are also lower than values of Spinrad (reported in Roettger et al., 1990)

If we compare the production rates of the observed species with that of water (=100), we find that the abundance of C_2 and NH_2 is roughly one third that of P/Halley while CN is about one half. For P/Brorsen-Metcalf on the other hand, C_2 and CN are in similar proportion (w.r.t. water) as P/Halley but NH_2 is down by a factor of 3 close to the P/Temple value. The values for nominal comets are reasonably close for C_2 but are somewhat higher for CN which could come from differences in g values between the CN blue and red system. The continuum flux compared to water is largest for comet P/Halley, a factor of 5 lower for P/Temple 2 and another factor of 3 lower for P/Brorsen-Metcalf.

We conclude that P/Temple 2 is either enhanced in H_2O over P/Halley if the abundances of C_2, CN and NH_2 are comparable; or if the water abundance in the two comets is equivalent, P/Temple 2 is depleted in C_2, CN and NH_2. The absolute H_2O production rate does not give a clue as to which of the above two scenarios is correct since it depends on the size of the area active in each comet.

This research was supported by NASA grant NAGW 1549.

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