Asteroids, Comets, Meteors 1991, pp. 211–214
Lunar and Planetary Institute, Houston, 1992

A STRONG 3.4μm EMISSION FEATURE IN COMET AUSTIN 1989c1

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ABSTRACT

High resolution 2.8-4.0μm spectra of the "new" comet Austin 1989c1, taken on May 15 & 16 1990 confirm the presence of the broad emission features around 3.4 and 3.52μm seen in a number of bright comets and ascribed to organic material. Both the 3.4μm band strength and the 3.52/3.36μm flux ratios are among the largest so far observed. The data are consistent with the relationship between band strength and water production rate derived by Brooke et al (Astron. J., **101**, 268 1991). Excess emission at 3.28 and 3.6μm cannot be unambiguously identified as features due to the poor signal-to-noise ratio.

3.4μm EMISSION IN COMETS

Our knowledge of the composition of comets, believed to be the most primitive material in the solar system, and perhaps retaining relatively unprocessed interstellar grains, has advanced in recent years through direct sampling by spacecraft and the consequent intensive observing campaigns. A 3.4μm infrared emission band first detected in Comet P/Halley (Wickramasinghe & Allen, 1986; Knacke et al 1986; Danks et al, 1987; Baas et al, 1986; and Tokunaga et al, 1987) together with infrared spectral features observed by the Vega I IKS experiment (Combes et al, 1986; Moroz et al, 1987) have been interpreted as superpositions of C-H band stretching vibrations in gaseous or solid hydrocarbons. The presence of a substantial organic component in small (10^{-19}-10^{-15}kg) cometary grains was confirmed by the Giotto and Vega mass spectrometers, PIA and PUMA (Kissel et al, 1986a; 1986b). The 3.4μm emission feature has been observed in several, but not all, bright comets over the last few years with detections for Comet Wilson 1986l (Allen & Wickramasinghe 1987; Brooke et al, 1989), Bradfield 1987s (Brooke et al, 1990), Austin 1989c1 (this paper) and Levy 1990c (Davies et al, 1991) but not for Encke (Gehrz et al, 1989), West 1975n (Oishi et al, 1978), Iras-Araki-Alcock 1983d (Hanner et al, 1985) or pre-perihelion in Halley (Gehrz et al, 1989).

The observed emission bands exhibit considerable structure presumably due to differences in the C-H band strength and frequencies in different molecules. For example, 3.4μm emission is characteristic of the C-H stretching frequency of saturated hydrocarbons (Bellamy, 1975) which shortens to 3.3μm for unsaturated hydrocarbons. The specific molecules responsible for the range of observed features are not known, and it is not certain if they are in the gaseous or solid (or both) phases. The features have been observed above both the scattered solar continuum and the grain thermal emission continuum, dependent on heliocentric distance, for comet Halley. Since the observed feature near 3.4μm can be produced by almost any molecule containing CH_3 and CH_2 clusters, the identification of parent molecules will depend not only on detailed structure within the spectral region but the presence or absence of features in other spectral regions, and the provision of a plausible emission mechanism. The major features at 3.28 and 3.36μm are interpreted by Encrenaz et al (1987) as due to resonance (fluorescence) scattering of solar infrared radiation by unsaturated and saturated hydrocarbon gas molecules respectively. However, this requires hydrocarbon abundances of ~ 30% of that of H_2O, and high resolution spectra of comet Halley (Drapatz et al, 1987) showed no prominent line structure typical of gas-phase emission (Chyba et al, 1989) while Brooke et al (1991b) found that the methane abundance is less than 0.0034 of that of water in comet Levy 1990c. Much lower abundances are required by Chyba et al for thermal emission from sub-micron organic grains. Predicted features at longer wavelengths which are not observed are masked by thermal emission from the larger, non-carbonaceous grain population in their two-component model. A third mechanism, requiring molecular production of only 0.15% of water, involves UV excited infrared fluorescence from very small grains (large molecules) (Baas et al, 1986).

Emission features around 3.52μm and near 3.6μm have been attributed to formaldehyde (Knacke et al, 1986; Danks et al, 1986; Moroz et al, 1987) although Brooke et al (1989) found a very poor fit between the observations of comets Halley and Wilson and their predicted model spectrum for formaldehyde. They suggest that poly-oxymethylene (POM, paraformaldehyde) could contribute to the observed emission but saturated and unsaturated hydrocarbons are also required. Although the 3.52μm feature is observed in all comets exhibiting infrared emission in this region, the 3.6μm band is not always seen. Tokunaga et al (1987) observed an unidentified emission band at 2.8-2.9μm in comet Halley, later seen in comets Wilson (Brooke et al, 1989) and Bradfield (Brooke et al, 1990). This has been tentatively assigned to the long wavelength component of H_2O gas emission bands (Bockelée-Morvan & Crovisier, 1989). Other, less pronounced, features may be present in some data.

Brooke et al, (1991a; hereafter BTK) conclude, from ratios of the 3.4μm feature and continuum with water production rate, that organics are present in all comets at comparable abundances with respect to water, although there are potentially significant differences in details of their spectra. They deduced that the 3.4μm band strengths were correlated with water production rate rather than dust production.

After its discovery in December 1989 at a heliocentric distance of 2.4A.U., comet Austin 1989c1 did not brighten as expected but still reached a total visual magnitude ~4 in April 1990 after perihelion passage at 0.35A.U., providing an ideal opportunity for detailed spectroscopic study of a "new" comet. IUE spectra taken during the period 7-13 May were characteristic of a non-dusty comet (Festou et al, 1990).

OBSERVATIONS AND DATA REDUCTION

Observations of comet Austin were made with the cooled grating spectrometer CGS2 on the UK Infrared Telescope (UKIRT) on Mauna Kea, Hawaii during service observations on 15 and 16 May 1990 when the comet was at a heliocentric distance of 0.97A.U. Service observations attempted on 3, 4 and 14 May were prevented by cloud which was also present to a lesser extent on the two nights when spectra were obtained. Multiple scans were made in the wavelength ranges 2.8-3.65μm and 3.15-3.9μm on the 15th and in the longer range only on the 16th. Sampling was at 1/4 resolution element steps (0.0022μm at a wavelength of 3.4μm) to allow for complete sampling despite the loss of 2 of the 7 elements in the detector array. Sample time was 1.5s per point with an aperture of 5 arcseconds centred on the peak signal. Details are in Table 1. The stars BS8130 and BS8430 (F2IV, mag 2.60 at 3.45μm with blackbody temperature 6800K and F5V, mag 2.59 at 3.8μm with blackbody temperature 6400K respectively) were used for flux calibration. Corrections for the thin cloud attenuation were made by normalising scans to those with the maximum average signal. Uncertainties in the flux calibration are estimated at ~25%. Despite the generally poor quality of the raw data, the presence of emission in the 3.4μm region is confirmed and some structure is evident. In order to improve the signal-to-noise ratio, each spectrum has been gaussian filtered with a profile having FWHM~1/2 a resolution element (0.004μm). These are shown in figure 1. The "combined" spectrum has been produced from a weighted mean of the three datasets, normalised to the flux for the 16th May over the region of overlap. The "features" apparent around 3.2 and at 3.31μm are due to incorrect atmospheric correction for strong telluric absorption lines.

TABLE 1. Observations.

Date	15 May	15 May	16 May
Wavelength range (μm)	2.8-3.65	3.15-3.9	3.15-3.9
Mid-observation time (UT)	14:01	14:57	13:39
Number of scans	7	6	10
Mean airmass	1.37	1.16	1.43
Heliocentric distance (AU)	0.96	0.96	0.98
Geocentric distance (AU)	0.32	0.32	0.30
Calibration star	BS8130	BS8430	BS8130

DISCUSSION

The broad 3.4μm emission band seen in other bright comets is confirmed in comet Austin, together with the band centred on 3.52μm. The slowly rising continuum is consistent with grain thermal emission which will be dominant at these wavelengths for a heliocentric distance of less than 1A.U. Possible emission at ~3.62μm is present in all three spectra but data longward of 3.52μm are too noisy to positively confirm any structure present. Although atmospheric water absorption is high below 2.85μm the data indicate the edge of a bright emission feature peaking shortward of this cut-off. No 3.28μm feature is apparent above the noise in these spectra although there is emission at that wavelength in excess of the continuum

Using an interpolation of the continuum (between 2.9-3.2 and 3.6-3.9μm) the 3.36μm flux to continuum ratio is 3.5±0.4. This value is higher than for most comets observed at the same heliocentric distance but consistent with the results of BTK who find high feature-to-continuum ratios for comets with low dust-to-gas ratios. Following their procedure, the continuum flux at 3.36μm and the continuum-subtracted integrated flux (between 3.31 and 3.56μm) have been corrected to an effective instrument aperture projected radius of 980km and geocentric distance of 1A.U., for comparison with results from other comets. The corrected continuum flux $F^*_{cont} = (0.18\pm0.05)\times10^{-14}$ $W\ m^{-2}\ \mu m^{-1}$ and integrated 3.4μm flux $I^*_{3.4} = (0.8\pm0.2)\times10^{-15}\ W\ m^{-2}$. The water production rate deduced from IUE spectra (Festou et al, 1990) was $1.1\times10^{29}\ s^{-1}$ on 9 May and similar on 13 May. Allowing for uncertainties of 50% in this value for 15/16 May,

$$F^*_{cont} / Q_{H_2O} = 0.16 \pm 0.09\ (10^{-14}\ W\ m^{-2}\ \mu m^{-1}/10^{29}\ s^{-1})$$

$$\Gamma^*_{3.4}/Q_{H_2O} = 0.7 \pm 0.4 \ (10^{-15}\ W\ m^{-2}/10^{29}\ s^{-1})$$

These values are consistent with the results of BTK who found that the 3.4μm band strength is better correlated with water production rates rather than with dust production rate. The relative strength of the 3.52μm feature to the broad emission ~3.4μm appears higher for comet Austin than any other comet. The ratio of continuum subtracted fluxes, $F_{3.52}/F_{3.36} = 0.5\pm0.2$, is twice the typical value for other comets. Interpretation of such observations is difficult because of the uncertainty in continuum determination and relative strengths of scattered and thermal continua at different heliocentric distances. It is clear, however, that real differences are present in the structure of these features since BTK find the 3.52μm peak strongest for the dust-poor comets Okazaki-Levy-Rudenko 1989r and P/Brorsen-Metcalf, despite the fact that they were observed at small heliocentric distances where the thermal emission continuum dominates and might be expected to mask the longer wavelength feature to a greater extent. The FWHM of the broad feature in comet Austin is ~0.15μm, comparable with the range 0.12-0.18 found for other comets. No detailed interpretation of the shape is possible due to the poor signal-to-noise.

Comet Austin displayed the characteristics of a "new" comet both dynamically and physically (high activity at large heliocentric distance pre-perihelion but with a subsequent low heliocentric brightness power law exponent, n<3). There appears to be no obvious correlation between age of the comet and the presence (or absence) of particular features in the 3 to 4μm region. Although the 3.4μm emission may be ubiquitous (previous non-detections in comets West, Encke and Iras-Araki-Alcock being explainable by low signal to noise) real compositional differences in the organic content of comets may be present. In order to understand fully the structure and composition of the emitting material, high resolution observations of a number of comets, both 'old' and 'new', at different heliocentric distances, are required. These will permit a combination of detailed modelling to fit the range of observed features, and an understanding of the evolution of cometary material as it 'ages'.

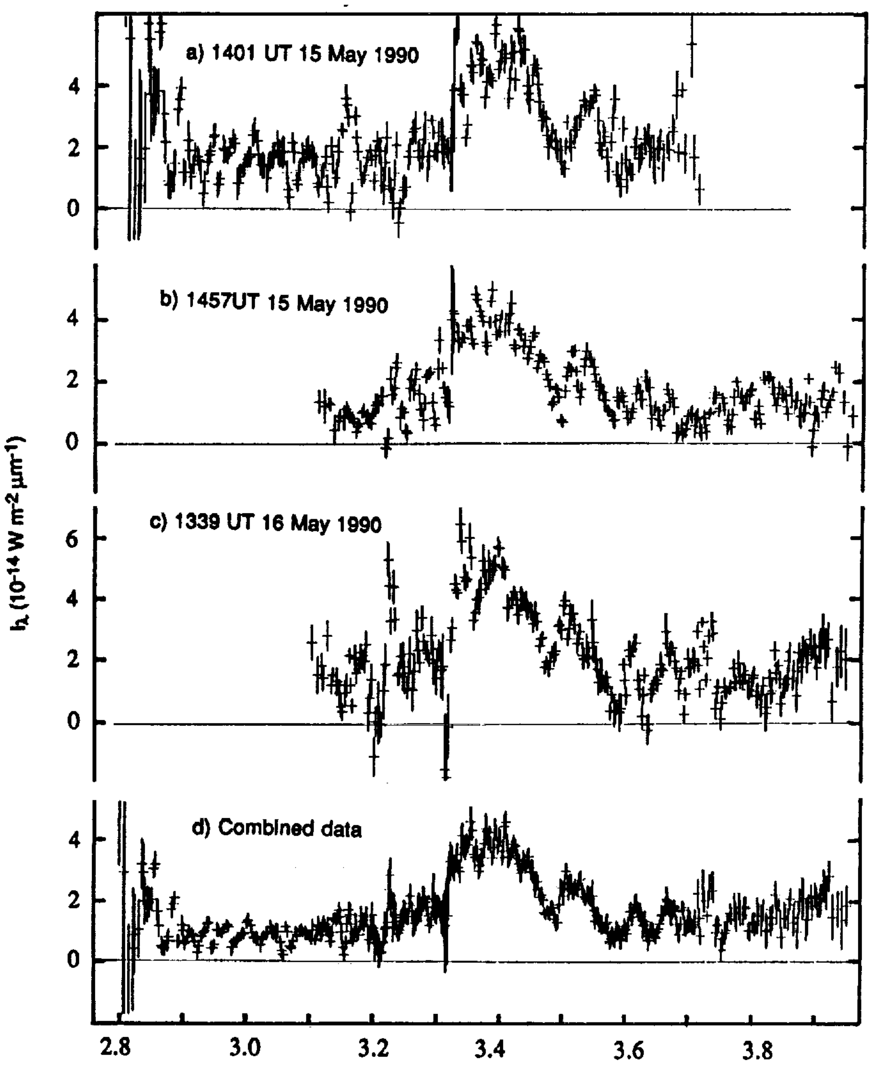

Figure 1. CGS2 spectra of comet Austin 1989c1. Data have been filtered with a gaussian profile with σ=0.002μm (i.e FWHM~1/2 resolution element). Spectrum d is a normalised weighted mean of all the data. Error bars are standard deviation of counts from co-added scans.

Acknowledgements

UKIRT is operated by the Royal Observatory Edinburgh on behalf of the Science and Engineering Research Council. We thank all UKIRT staff involved in the service observing programme. Data reduction was performed partly on the Starlink computer network.

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