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A STRONG 3.4 μ m EMISSION FEATURE IN COMET AUSTIN 1989c1

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ABSTRACT

High resolution 2.8-4.0 μ m 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 3.52 μ m seen in a number of bright comets and ascribed to organic material. Both the 3.4 μ m band strength and the 3.52/3.36 μ m 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 3.6 μ m cannot be unambiguously identified as features due to the poor signal-to-noise ratio.

3.4 μ m 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 3.4 μ m 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 (10⁻¹⁹-10⁻¹⁵kg) cometary grains was confirmed by the Giotto and Vega mass spectrometers, PIA and PUMA (Kissel et al, 1986a; 1986b). The 3.4 μ m emission feature has been observed in several, but not all, bright comets over the last few years with detections for Comet Wilson 1986I (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, 3.4 μ m emission is characteristic of the C-H stretching frequency of saturated hydrocarbons (Bellamy, 1975) which shortens to 3.3 μ m 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 3.4 μ m can be produced by almost any molecule containing CH₃ and CH₂ 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 3.36 μ m 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 H₂O, 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 3.52 μ m and near 3.6 μ m 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 polyoxymethylene (POM, paraformaldehyde) could contribute to the observed emission but saturated and unsaturated hydrocarbons are also required. Although the 3.52 μ m feature is observed in all comets exhibiting infrared emission in this region, the 3.6 μ m band is not always seen. Tokunaga et al (1987) observed an unidentified emission band at 2.8-2.9 μ m 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 H₂O gas emission bands (Bockelée-Morvan & Crovisier, 1989). Other, less pronounced, features may be present in some data.

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Brooke et al, (1991a; hereafter BTK) conclude, from ratios of the 3.4 μ m 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 3.4 μ m 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 \sim 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 2.8-3.65 μ m and 3.15-3.9 μ m on the 15th and in the longer range only on the 16th. Sampling was at 1/4 resolution element steps (0.0022 μ m at a wavelength of 3.4 μ m) 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 3.45 μ m with blackbody temperature 6800K and F5V, mag 2.59 at 3.8 μ m 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 \sim 25%. Despite the generally poor quality of the raw data, the presence of emission in the 3.4 μ m 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 \sim 1/2 a resolution element (0.004 μ m). 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 3.31 μ m are due to incorrect atmospheric correction for strong telluric absorption lines.

TABLE 1. Observations.

| Date | 15 May | 15 May | 16 May |
|-----------------------------|----------|----------|----------|
| Wavelength range (μ m) | 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 3.4 μ m emission band seen in other bright comets is confirmed in comet Austin, together with the band centred on 3.52 μ m. 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 \sim 3.62 μ m is present in all three spectra but data longward of 3.52 μ m are too noisy to positively confirm any structure present. Although atmospheric water absorption is high below 2.85 μ m the data indicate the edge of a bright emission feature peaking shortward of this cut-off. No 3.28 μ m 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 3.6-3.9 μ m) the 3.36 μ m 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 3.36 μ m and the continuum-subtracted integrated flux (between 3.31 and 3.56 μ m) 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 $F_{\text{cont}}^* = (0.18 \pm 0.05) \times 10^{-14} \text{ W m}^{-2} \mu\text{m}^{-1}$ and integrated 3.4 μ m flux $I_{3.4}^* = (0.8 \pm 0.2) \times 10^{-15} \text{ W m}^{-2}$. The water production rate deduced from IUE spectra (Festou et al, 1990) was $1.1 \times 10^{29} \text{ s}^{-1}$ on 9 May and similar on 13 May. Allowing for uncertainties of 50% in this value for 15/16 May,

$$F_{\text{cont}}^* / Q_{\text{H}_2\text{O}} = 0.16 \pm 0.09 (10^{-14} \text{ W m}^{-2} \mu\text{m}^{-1} / 10^{29} \text{ s}^{-1})$$

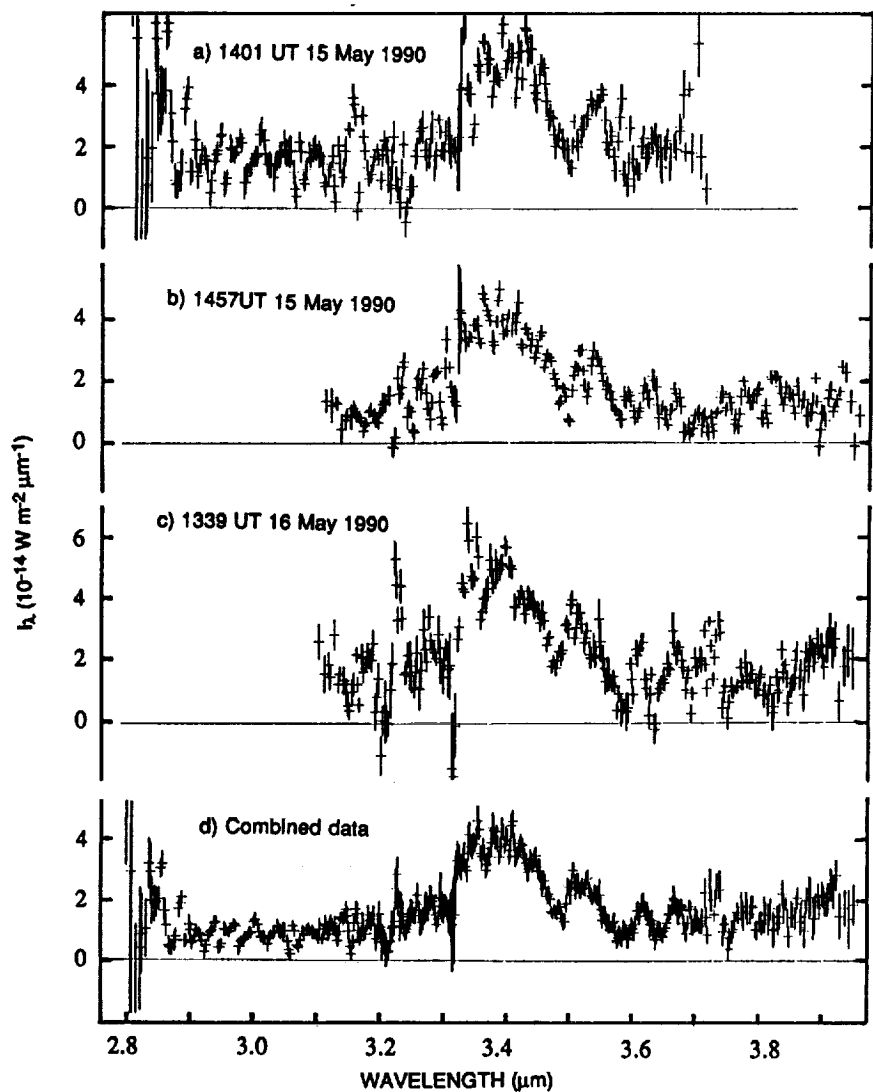
$$\Gamma_{3.4}/Q_{H_2O} = 0.7 \pm 0.4 (10^{-15} \text{ W m}^{-2}/10^{29} \text{ s}^{-1})$$

These values are consistent with the results of BTK who found that the $3.4\mu\text{m}$ band strength is better correlated with water production rates rather than with dust production rate. The relative strength of the $3.52\mu\text{m}$ feature to the broad emission $\sim 3.4\mu\text{m}$ appears higher for comet Austin than any other comet. The ratio of continuum subtracted fluxes, $F_{3.52}/F_{3.36} = 0.5 \pm 0.2$, 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 $3.52\mu\text{m}$ peak strongest for the dust-poor comets Okazaki-Levy-Rudenko 1989r and P/Brosen-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 $\sim 0.15\mu\text{m}$, comparable with the range $0.12\text{--}0.18$ 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 $4\mu\text{m}$ region. Although the $3.4\mu\text{m}$ 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 $\sigma = 0.002\mu\text{m}$ (i.e FWHM $\sim 1/2$ resolution element). Spectrum d is a normalised weighted mean of all the data. Error bars are standard deviation of counts from co-added scans.



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References

- Allen, D.A. & Wickramasinghe, D.T. (1987) Discovery of organic grains in comet Wilson. *Nature*, **329**, 615-616.
- Baas, F., Geballe, T.R. & Walther, D.M. (1986) Spectroscopy of the 3.4 μ m emission feature in comet Halley. *Astrophys. J.*, **311**, L97-L101.
- Bellamy, L.J. (1975) *The infrared spectra of complex molecules Vol. 1*. Chapman & Hall, London.
- Bockelée-Morvan, D. & Crovisier, J. (1989) The nature of the 2.8 μ m emission feature in cometary spectra. *Astron. Astrophys.*, **216**, 278-283.
- Brooke, T.Y., Knacke, R.F., Owen, T.C. & Tokunaga, A.T. (1989) Spectroscopy of emission features near 3 microns in comet Wilson (1986l). *Astrophys. J.*, **336**, 971-978.
- Brooke, T.Y., Tokunaga, A.T., Knacke, R.F., Owen, T.C., Mumma, M.J., Reuter, D. & Storrs, A.D. (1990) Detection of the 3.4- and 2.8 μ m emission features in comet Bradfield. *Icarus*, **83**, 434-440.
- Brooke, T.Y., Tokunaga, A.T. & Knacke, R.F. (1991a) Detection of the 3.4 μ m emission feature in comets P/Brorsen-Metcalf and Okazaki-Levy-Rudenko (1989R) and an observational summary. *Astron. J.*, **101**, 268-278.
- Brooke, T.Y., Tokunaga, A.T., Weaver, H.A., Chin, G. & Geballe, T.R. (1991b) A sensitive upper limit on the methane abundance in comet Levy (1990c). *Astrophys. J. Lett.*, @@@, L113-116.
- Chyba, C.F., Sagan, C. & Mumma, M.J. (1989) The heliocentric evolution of cometary infrared spectra: Results from an organic grain model *Icarus*, **79**, 362-381.
- Combes, M., Moroz, V.I., Crifo, J.F., Lamarre, J.M., Charra, J., Sanko, N.F., Soufflot, A., Bibring, J.P., Cazes, S., Coron, N., Crovisier, J., Emerich, C., Encrenaz, T., Gispert, R., Grigoryev, A.V., Guyot, G., Krasnopolsky, V.A., Nikolsky, Yu.V. & Rocard, F. (1986) Infrared sounding of comet Halley from Vega I. *Nature*, **321**, 266-268.
- Danks, A.C., Encrenaz, T., Bouchet, P., LeBertre, T. & Chalabaev, A. (1987) The spectrum of comet Halley from 3.0 to 4.0 μ m. *Astron. Astrophys.*, **184**, 329-332.
- Davies, J.K., Green, S.F. and Geballe, T.R. (1991) The detection of a strong 3.28 μ m emission feature in comet Levy. *Mon. Not. R. astr. Soc.*, **251**, 148-151.
- Drapatz, S., Caron, H.P. & Davis, D.S. (1987) Search for methane in comet P/Halley. *Astron. Astrophys.*, **187**, 497-501.
- Encrenaz, T., Puget, J.L., Bibring, J.P., Combes, M., Crovisier, S., Emerich, C., d'Hendecourt, L. & Rocard, F. (1987) On the interpretation of the 3.4 μ m emission feature in the spectrum of comet Halley: Abundances in comet Halley and in interstellar matter. *ESA-SP-278*, 369-376.
- Festou, M.C., A'Hearn, M.F., Budzien, S.A., Feldman, P.D. & Roettger, E.E. (1990) *IAUC 5012*.
- Gehrz, R.D., Ney, E.P., Piscitelli, J., Rosenthal, E. & Tokunaga, A.T. (1989) Infrared photometry and spectroscopy of comet P/Encke 1987. *Icarus*, **80**, 280-288.
- Hanner, M.S., Aitken, D.K., Knacke, F., McCorkle, S., Roche, P.F. & Tokunaga, A.T. (1985) Infrared spectrophotometry of comet IRAS-Araki-Alcock 1983d: A bare nucleus revealed? *Icarus*, **62**, 97-109.
- Kissel, J., Sagdeev, R.Z., Bertaux, J.L., Angarov, V.N., Audouze, J., Blamont, J.E., Büchler, K., Evlanov, E.N., Fechtig, H., Fomenkova, M.N., von Hoerner, H., Inogamov, N.A., Khromov, V.N., Knabe, W., Krueger, F.R., Langevin, Y., Leonas, V.B., Lévassieur-Regourd, A.C., Managadze, G.G., Podkolzin, S.N., Shapiro, V.D., Tabaldyev, S.R. & Zubkov, B.V. (1986) Composition of comet Halley dust particles from Vega observations. *Nature*, **321**, 280-282.
- Kissel, J., Brownlee, D.E., Büchler, K., Clark, B.C., Fechtig, H., Grün, E., Hornung, K., Igenbergs, E.B., Jessburger, E.K., Krueger, F.R., Kuczer, H., McDonnell, J.A.M., Morfill, G.M., Rahe, J., Schwehm, G.H., Sekanina, Z., Uterback, N.G., Völk, H.J. & Zook, H.A. (1986) Composition of comet Halley dust particles from Giotto observations. *Nature*, **321**, 336-337.
- Knacke, R.F., Brooke, T.Y. & Joyce, R.R. (1986) Observations of 3.2-3.6 micron emission features in comet Halley. *Astrophys. J.*, **310**, L49-L53.
- Moroz, V.I., Combes, M., Bibring, J.P., Coron, N., Crovisier, J., Encrenaz, T., Crifo, J.F., Sanko, N., Grigoryev, A.V., Bockelée-Morvan, D., Gispert, R., Nikolsky, Y.V., Emerich, C., Lamarre, J.M., Rocard, F., Krasnopolsky, V.A. & Owen, T. (1987) Detection of parent molecules in comet P/Halley from the IKS-Vega experiment. *Astron. Astrophys.*, **187**, 513-518.
- Oishi, M., Kawara, K., Kobayashi, Y., Maihara, T., Noguchi, T., Okuda, H., Sato, S., Iijima, T. & Ono, T. (1978) Infrared observations of comet West (1975n). *Publ. Astron. Soc. Japan*, **30**, 149.
- Tokunaga, A.T., Nagata, T. & Smith, R.G. (1987) Detection of a new emission band at 2.8 μ m in comet P/Halley. *Astron. Astrophys.*, **187**, 519-522.
- Wickramasinghe, D.T. & Allen, D.A. (1986) Discovery of organic grains in comet Halley. *Nature*, **323**, 44-46.