A MODEL OF THE 2–4 μm SPECTRUM OF COMET HALLEY

(Letter to the Editor)

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Abstract. Recent observations of Halley's Comet show a broad absorption band centred at 3.4 μm and which can be explained on the basis of a bacterial grain model.

For over a decade two of the present authors have argued that grains in cometary comae are of a complex organic nature (Wickramasinghe and Vanýsek, 1975; Hoyle and Wickramasinghe, 1977, 1981). It has also been argued that cometary grains in common with interstellar grains must possess infrared spectral properties closely similar if not identical to those of dessicated micro-organisms (Hoyle *et al.*, 1982). In particular the 2.9–3.9 μm spectrum of the galactic centre infrared source GC-IRS7 has been shown to imply opacity values $\varkappa(\lambda)$ for interstellar grains which are in close agreement over this entire waveband with the laboratory measurements for the dessicated bacterium *E.coli.*

Over the same waveband (2.9–3.9 μm) Comet P/Halley was observed at the AAT on the nights of March 30, 31 and April 1, 1986 (Wickramasinghe and Allen, 1986a, b). The observations on March 31 led to the strongest signal and we confine our attention here to data obtained on this particular night which are reproduced in Figure 1. The points and the two segments of heavy solid curve represent flux values derived from these observations. We note that an emission feature centred at the 3.4 μm wavelength clearly stands out over and above a scattered sunlight background at shorter wavelengths and a grey thermal emission at longer wavelengths.

For a distribution of particle sizes such as found for Halley's comet (McDonnell *et al.*, 1986) it would seem reasonable to suppose that the average scattering cross-section of coma grains has a neutral dependence on wavelength so that the scattered radiation would follow a spectral distribution that is not significantly different from the solar spectrum. We thus adopt a scattering component that passes through the observed point at $\lambda = 1.6$ μm in Figure 1, and follows the solar relative intensity curve at shorter wavelengths.

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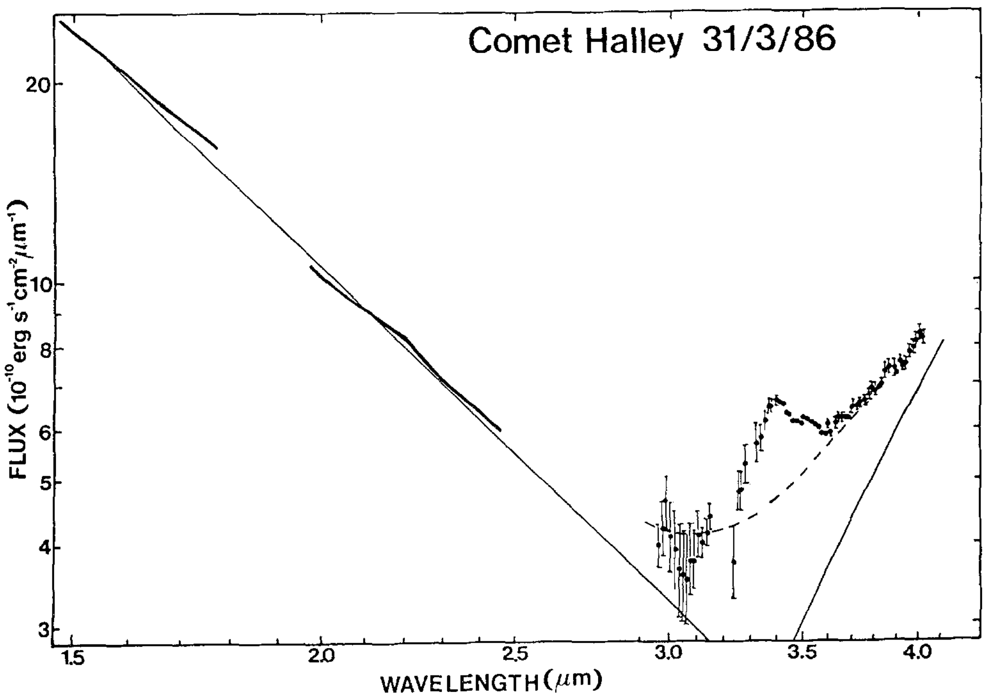

Fig. 1. The infrared spectrum of Comet P/Halley on 31 March 1986.

To determine the infrared re-emission spectrum of dust in the coma from the observations we would need to subtract this scattered solar spectrum given by

$$F_{sca}(\lambda) = (20 \times 10^{-10})\, F_{solar}(\lambda)/F_{solar}\,(1.6\ \mu m) erg\ cm^{-2}\ s^{-1}\ \mu m^{-1} \quad (1)$$

from the total flux measurements. The quantities $F_{solar}(\lambda)$ are taken from tabulated data for the Sun (Allen, 1973).

As in earlier discussions relating to interstellar dust we base our model calculations on laboratory measurements of transmittance for dessicated bacteria shown in Figure 2. With $\tau(\lambda)$ defined by Figure 2 the flux emitted from an optically thin cloud of cometary grains at a temperature T is given by

$$F(\lambda) = A\tau(\lambda) B_\lambda(T), \quad (2)$$

where B_λ(T) is the Planck function, and A is a constant depending on the amount of emitting material at the source and the distance of the source. The laboratory procedure adopted for determining $\tau(\lambda)$ entailed a careful effort to set a correct zero point for τ. However, it has not hitherto been possible to test our calibration of τ because models of GC–IRS7 give a flux proportional to $e^{-\alpha\tau(\lambda)}$ where α is a constant, and a change of $\tau(\lambda)$ by an additive constant does not accordingly produce any change in the normalised flux. The cometary flux given by Equation (2), on the other hand,

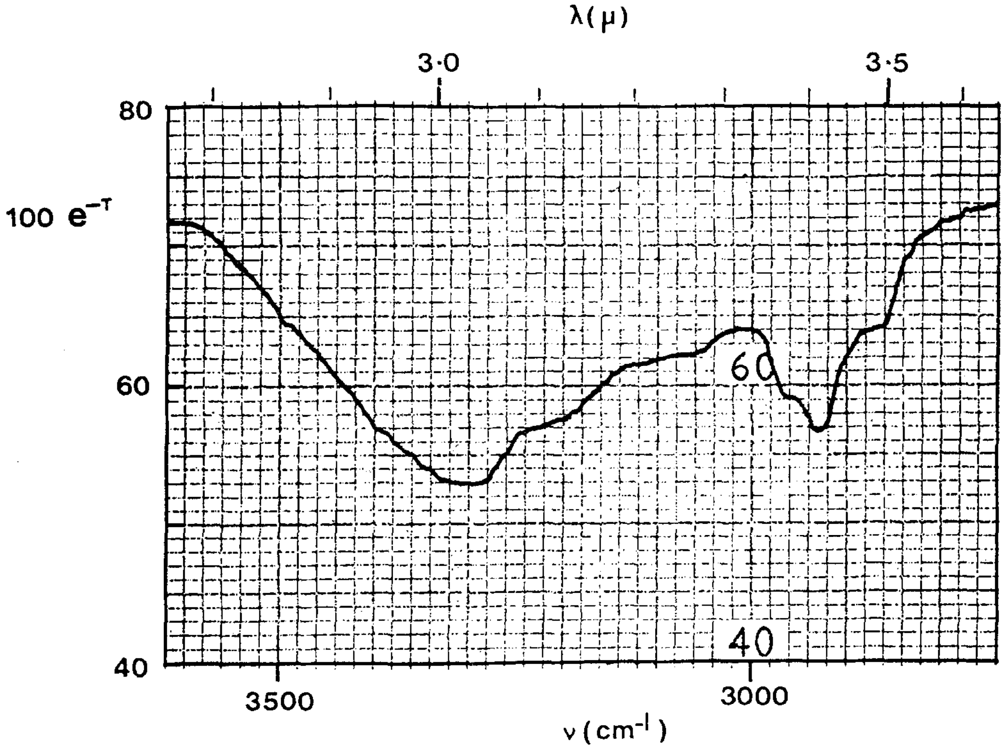

Fig. 2. Transmittance data for *E. coli* dessicated by heating to 350 K.

involves $\tau(\lambda)$ as a linear factor and so provides a sensitive test of the zero point of τ in our laboratory measurements.

We consider temperatures T between 300–360 K. To compare with the curves calculated from Equation (2) for a given value of T with observational data we chose A so that $F(\lambda) \cong 8.0 \times 10^{-10}$ erg s^{-1} cm^{-2} μm^{-1} at 4.0 μm, and add to this a function $F_{sca}(\lambda)$ given by (1) at all wavelengths, to take account of the scattering background. The general agreement between the solid curve and the data points in Figure 3 is obtained for a temperature $T = 320$ K whichis only slightly above the black sphere temperature at 1.17 AU. To obtain a satisfactory fit to the observational data within the marked error bars the requirement is that $\tau(\lambda)$ should not depart from the transmittance curve plotted in Figure 2 by more than a single graticule marking at any wavelength in the range 2.9–3.9 μm.

The largest significant mis-match of the solid curve is seen near 3.5 μm. It is worth noting that this is precisely the wavelength region over which a considerable degree of fine structure shows up in spectra of bacterial samples that are subjected to large doses of ionizing radiation under cryogenic conditions. For *E.coli* irradiated to a 1.5 Mrad level at 77 K the resulting modifications to the transmittance data of Figure 2 leads to the flux values shown by the dashed curve in Figure 3 (ordinate scale

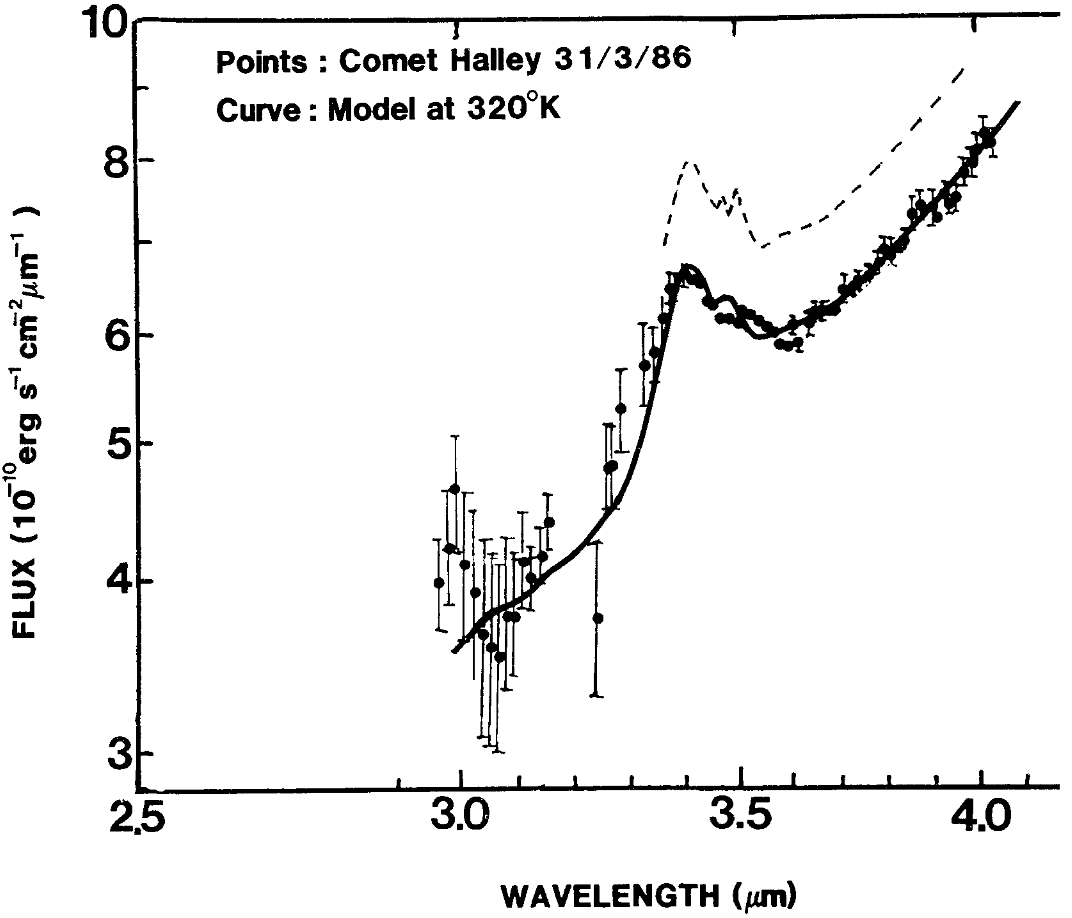

Fig. 3. Infrared measurements of Comet P/Halley on 31 March 1986 compared with predictions for models at 320 K. The solid curve is normalised flux for particles with transmittance values given in Figure 2. The dashed curve is flux calculated for bacterial sample irradiated to 1.5 Mrad at a temperature of 77 K. (The curve is displaced vertically relative to solid curve by an arbitrary amount.)

is displaced by an arbitrary amount). It is clear that the agreement with the data points near 3.5 μm is now considerably improved.

We next proceed to estimate the total mass of grain material in the observed region which on the night in question had a projected sky area of about 5″ × 10″. If the emitting area at the comet acted like a black body surface at temperature 320 K the flux emitted at 3.4 μm would be 1487.13 erg cm^{-2} s^{-1} μm^{-1}. For a rectangular patch θ_1(radians) × θ_2(radians) at the distance R of the comet the emission would be 1487.13 $\theta_1\theta_2R^2$ and at a distance R away the flux received would be

$$\Phi = 1487.13\ \theta_1\theta_2R^2/4\pi R^2 = 1.39 \times 10^{-7}\ \text{erg cm}^{-2}\ \text{s}^{-1}\ \mu\text{m}^{-1}, \qquad (3)$$

where $\theta_1 = 5''$, $\theta_2 = 10''$ are expressed in radians. The actual flux from the comet from Figure 3 is $F_{3.4\,\mu\text{m}} = 6.6 \times 10^{-10}$ erg cm^{-2} s^{-1} μm^{-1} implying an optical depth of $\tau \approx 4.75 \times 10^{-3}$. For the measured mass absorption coefficient at 3.4 μm of 820 $cm^2\ g^{-1}$ and a depth of $\sim 10^9$ cm for the emitting region the mass density of the emitting grains is

$$\varrho \cong 5.8 \times 10^{-15}\ \text{g cm}^{-3}. \tag{4}$$

For an estimated volume of the emitting region of 10^{26} cm^3 we get a total mass of $\sim 10^6$ tons, nearly a full day's supply of grains from the nucleus. In this connection it is worth noting that the flux at 3.4 μm increased by a factor of about 5 from 30/3/86 to 31/3/86 dropping again by a factor of 2 on 1/4/86. Of the order of a single day's dust production from the nucleus would thus seem to be involved in determining the detailed absorption profile near 3.4 μm. It is also worth noting that the detailed shape of the profile appears to be somewhat variable from day-to-day, suggesting an *in situ* break-up of grains giving rise to gaseous organic molecules that contribute in a variable way to fine structure within the 3.4 μm band. It is possible that on 31/3/86 the observed emission was dominated by intact bacterial grains, whereas contributions from break-up products affected the spectra on other days.

References

Hoyle, F. and Wickramasinghe, N. C.: 1977, *Lifecloud*, Dent, London.

Hoyle, F. and Wickramasinghe, N. C.: 1981, in C. Ponnamperuna (ed.), *Comets and the Origins of Life*, D. Reidel, Dordrecht.

Hoyle, F., Wickramasinghe, N. C., Al-Mufti, S., and Olavesen, A. H.: 1982, *Astrophys. Space Sci.* **83**, 405.

McDonnell, D. *et al.*: 1986, *Nature*, May 15, issue

Vanýsek, V. and Wickramasinghe, N. C.: 1975, *Astrophys. Space Sci.* **33**, L19.

Wickramasinghe, D. T. and Allen, D. A.: 1986a, *IAU Circ.*, No. 4205.

Wickramasinghe, D. T. and Allen, D. A.: 1986b, submitted to *Nature*.