INFRARED SPECTROSCOPY OVER THE 2.9–3.9 μM WAVEBAND IN BIOCHEMISTRY AND ASTRONOMY *

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Abstract. The infrared spectrum of the galactic centre source GC-IRS 7 over the 2.9–3.9 μm waveband is interpreted as strong evidence for bacterial grains.

The infrared spectra of micro-organisms sealed within KBr discs show remarkable stability as they are heated in an inert atmosphere up to temperature of at least 380 °C. Laboratory spectra so obtained are compared with astronomical data for the source GC-IRS 7. We show below that a remarkably close correspondence exists between the astronomical spectrum and biology, implying the possibility of a firm spectroscopic identification.

Figure 1 shows the transmittance curves over the wavelength range 2.6–3.9 μm for three systems we have studied in the laboratory: (a) *E. coli* at room temperature, (b) *E. coli* at 350 °C and (c) dehydrated vegetative yeast cells. For this investigation micro-organisms obtained in a pure form were dried in a dessicator and sealed in KBr discs of radii 0.65 cm under a pressure of 6.8 tonnes cm^{-2}. A cell containing such a disc was then placed in a furnace, specially designed to be operated in conjunction with a Perkin Elmer 257 infrared spectrometer, where an assigned temperature could be maintained as the furnace itself was continuously flushed with nitrogen gas at a pressure of 28 atmospheres. Infrared spectra over the wavelength range 2.5–15 μm were thus obtained for various temperatures. Our experiments indicated thermal stability of the biological material to temperatures of about 400 °C. By 350 °C all traces of free water disappeared, but the chemical integrity of the biomaterial as judged by infrared spectroscopy was otherwise preserved.

The mass of *E. coli* used was 1.50 mg, yielding a mass absorption coefficient at 3.4 μm of 501.7 cm^2 g^{-1}. The resolution of the laboratory measurement is to $\Delta\lambda/\lambda \sim 1/600$ over the entire experimental waveband. Whilst the transmittance curve is seen to be generally the same for the whole wavelength range shown in Figure 1, we note that there is a surprising invariance of shape between 3.3 and

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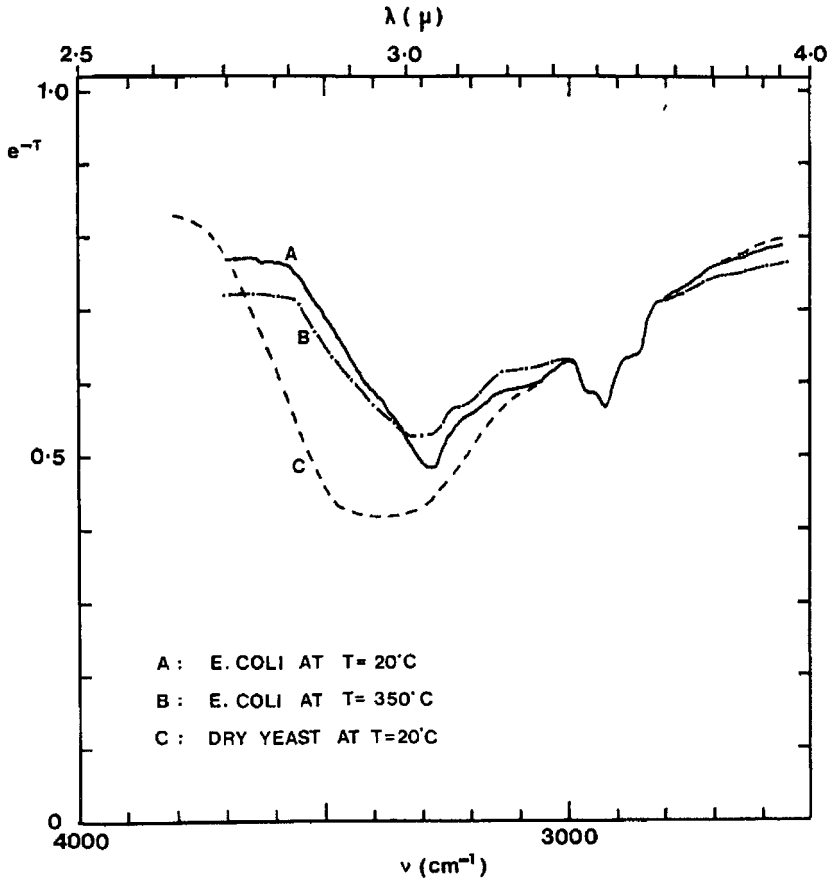

Figure 1. The measured transmittance curves of micro-organisms. For *E. coli* a dry mass of 1.5 mg was dispersed in a KBr disc of radius 0.65 cm. The transmittance data for yeast was normalised to agree with the *E. coli* curves at $\lambda = 3.406$ μm.

3.5 μm. Still more strikingly, the same invariance is seen to hold for eukaryotes as the curve for yeast cells shows.

When these spectra were first obtained on 21 May, 1981 it was noticed that the 3.3–3.9 μm opacity behaviour bore a general resemblance to the spectrum of GC-IRS 7 published in 1980 (Hoyle *et al.*, 1981). The significance of this particular comparison arises because GC-IRS 7 happens to be ideally placed for studying the properties of interstellar dust over a 10 kpc path length from the solar system to the galactic centre.

The astronomical source GC-IRS 7 was recently re-examined at a higher spectral resolution than before and over a slightly more extended wavelength region (Allen and Wickramasinghe, 1981). The points in Figure 2 show the new flux measurements for this source. The solid curve of Figure 2 is the predicted behaviour of

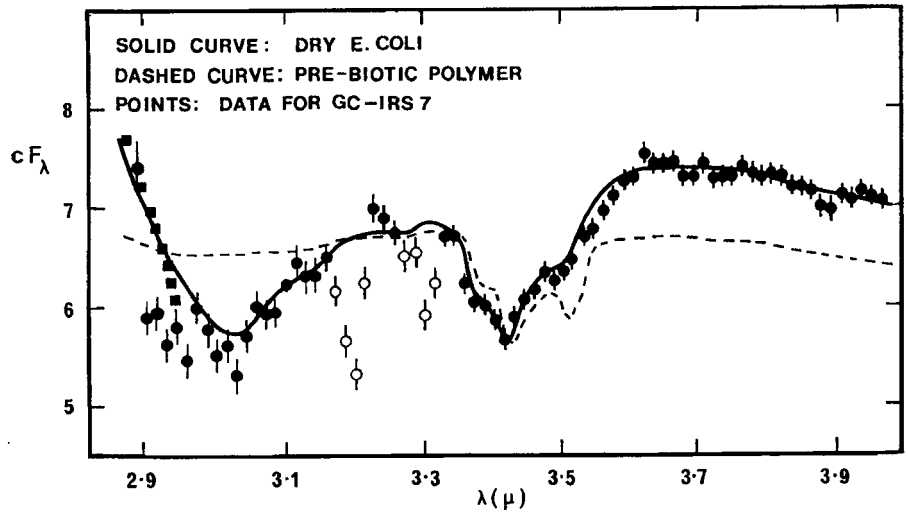

Figure 2. The observed relative fluxes for GC-IRS 7 compared with two models. The circles (open and filled), all of which have equal weight, represent data for IRS 7 obtained in May 1981. The filled squares represent data over the shortest infrared wavelengths obtained in July 1980. The solid curve is the predicted curve for bacteria (heated to 350 °C), the dashed curve is the least bad fit for a prebiotic polymeric mixture obtained by ultraviolet irradiation in a reducing atmosphere.

E. coli for the transmittance values measured at 350 °C as described earlier and shown by the curve with a grid in Figure 3 (see also Figure 1).

The underlying star for GC-IRS 7 is inferred from studies of the CO band and near infrared filter photometry to be a reddened M supergiant with an effective temperature near 3200 K. However, irrespective of the nature of the underlying source and its reddening, the observed flux points over the 2–2.2 μm waveband and near 4 μm have an envelope that is remarkably like a Planck distribution at a temperature of between 1000 and 1200 K. By using this observed feature of the data we can proceed to calculate the effect of absorptions against an essentially thermal background adopting an exceedingly simple model. If we choose a continuum approximated by a Planck distribution of 1100 K, the observed flux at the Earth is then given by

$$F_\lambda \propto B_\lambda(T)\ \exp(-A\tau), \tag{1}$$

where B_λ is the Planck function; $T = 1100$ K; A, a constant depending on the column density of absorbing matter along the line of sight; τ, the opacity of the laboratory sample; and a scale factor is chosen to enable comparison with the astronomical data. The solid curve of Figure 2 is for $A = 1.3588$ implying a column density of *E. coli* of 1.53×10^{-3} g cm^{-2}, accounting for dust near the galactic centre and along the entire path length from the solar system to the galactic centre. (This curve is identical to that calculated from the same column density of *E. coli* assuming an underlying continuum defined by a Planck function at 3200 K

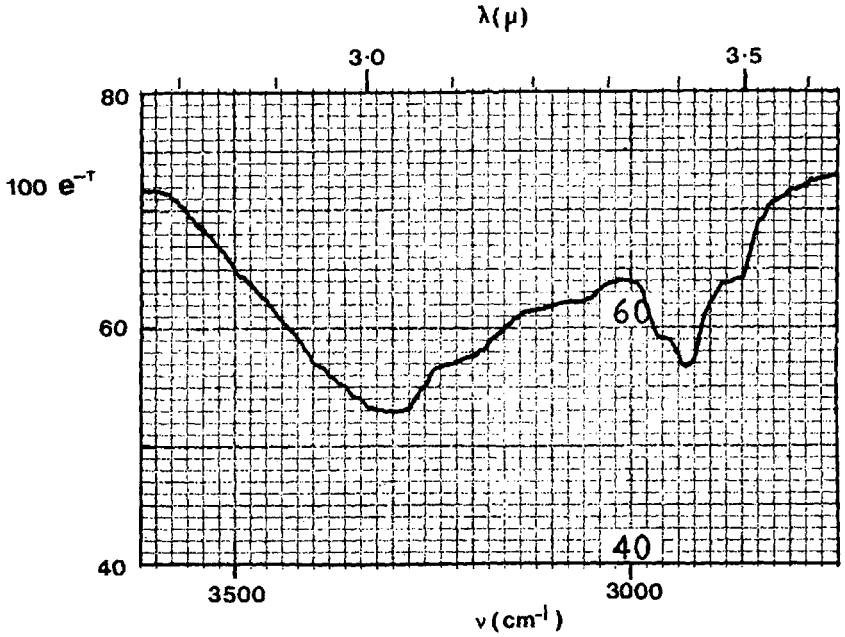

Figure 3. Enlarged laboratory spectrum over the 2.6–3.6 μm region for *E. coli* heated to 350 °C from which transmittance values were measured for the calculations in Figure 2.

reddened due to pure scattering according to a $\lambda^{-2.02}$ law with 2.5 mag of reddening at $\lambda = 2.2$ μm.)

Over the waveband 3.3–3.9 μm the spectral agreement is almost precise, either within or very close to the observational limits at nearly all points. Over the waveband 2.9–3.16 μm the correspondence must also be regarded as good, considering the fact that the astronomical data have inherent uncertainties due to absorptions in the Earth's atmosphere and the laboratory data for various types of micro-organisms for a range of ambient conditions is also variable as seen in Figure 1. The points shown as open circles represent unusually sharp absorption features at $\lambda \cong 3.2$, 3.3 μm which are not present in our laboratory samples, and which are generally not present as such sharply defined features due to CH for intramolecularly bonded structures. However, under interstellar conditions of irradiation by energetic photons, we expect concentrations of trapped radicals such as CH, CN to build up within grains (Pimental, 1960). It is of interest that irradiation by hard quanta of the system Ar:CH_3Cl under low temperature conditions in the laboratory produced a sharp absorption feature at 3.29 μm due to trapped methyl radicals (Jacox and Milligan, 1970). Other data shows that NH radicals, which are similarly produced, can produce an absorption line near 3.2 μm (Florent and Leach, 1952). The entire spectrum of Figure 2 could thus be explicable on the basis of a single grain model subject to irradiation by hard ultraviolet and X-ray quanta.

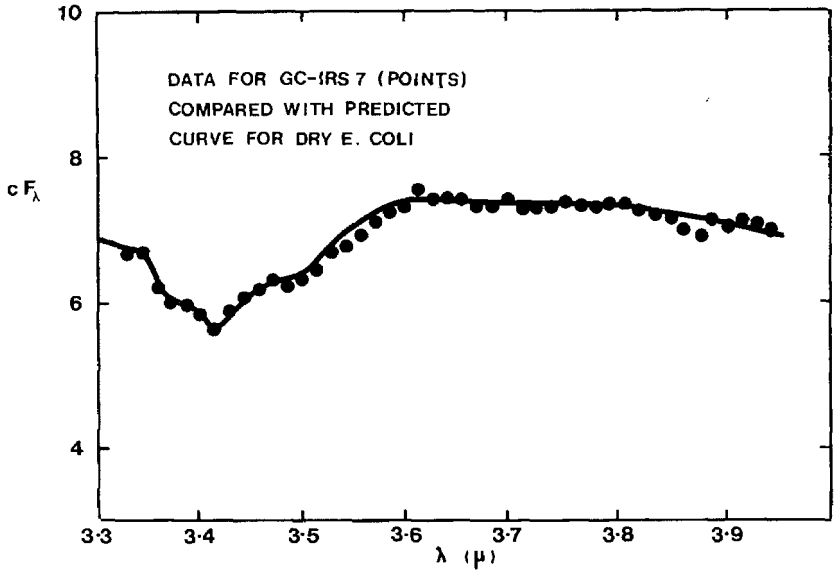

Figure 4. The waveband 3.3–3.9 μm showing the detailed agreement between bacteria and IRS 7. We note that the flux is on a linear scale, so that the maximum departures seen here are no more than a couple of percent. The size of the points represents the extent of the estimated errors in both wavelength and flux.

The similarity between the astronomical data and the laboratory spectra, which can be seen from even a cursory inspection of Figures 2 and 3, cannot be lightly dismissed. Although many organic polymers do of course have absorptions over the same general waveband, the precise-band shape within and around the 3.4 μm band as well as the relationship between the 3 μm and the 3.4 μm features imposes exceedingly stringent constraints.

Our searches for cosmically relevant organic polymers to produce an even tolerable fit to the data in Figure 2 led to negative results. The only material that may be thought a possible rival to biological material is the polymeric material formed by the action of ultraviolet light in a reducing atmosphere (Khare and Sagan, 1973; Knacke, 1977). The available experimental data for this case (see Knacke, 1977) leads to the dashed curve ($T = 900$ K, $A = 0.4206$ in Equation 1) as the *least* bad fit that could be obtained. From Figure 2 we see that the choice between a prebiotic polymer and biology is clearly in favour of the latter. To separate the complexities that we have discussed at $\lambda \sim 3$ μm, 3.2 μm and 3.3 μm from the rest of the data, we show the agreement between biology and astronomy for 3.3 μm $< \lambda <$ 3.9 μm on an expanded scale in Figure 4. We note that the plot has a linear flux scale so that the maximum deviation of the theoretical curve from the observations is no more than a few percent at any point.

Our laboratory spectra over the waveband 4–15 μm will be published and discussed in detail elsewhere. We merely state here that absorption bands occur at 6.05

and 6.5 μm due to peptide linkage and that these features together with the 3.4 μm band persist in spectra up to temperature close to 400 °C. Heated grains could thus produce emissions at 3.4, 6.05, and 6.5 μm. We note finally that balloon observations showing some evidence of absorptions over the 6–6.5 μm waveband have been reported for the astronomical sources GC-IRS 7 (Willner *et al.*, 1979) and for K3-50 and W5 I-IRS 2 (Puetter *et al.*, 1979). These observations are consistent with our laboratory spectra.

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