matters arising

Interstellar grains: organic or refractory?

IT has become fashionable to discuss the possibility that interstellar grains may contain significant quantities of organic material (see ref. 1 and refs therein). I draw attention here to new data which preclude the presence of most organic solids as a significant component of the grains in two typical dark clouds. As pointed out by Duley and Williams[2], virtually all organic compounds containing C and H possess an infrared absorption feature due to C—H stretching at 3.3–3.4 μm. The spectra of several dust-embedded stars in the Ophiuchus and Corona Austrina dark clouds were recently observed with the Anglo-Australian Telescope (Whittet and Blades[3]), in a programme primarily aimed at studying the 3.1 μm ice band. None of these sources, whose visual absorption falls in the range 5–20 mag. shows a feature at 3.3–3.4 μm: the detection limit is an order of magnitude less than the optical depth predicted by Fig. 1 of ref. 2. Similarly (as noted in ref. 2) the spectra of molecular cloud sourcesswith deep ice bands observed by Merrill *et al.*[3] show no C—H feature. It must therefore be concluded that organic grains cannot constitute a significant part of interstellar grain material, even in dense clouds where from other considerations, grain growth is known to occur[5,6].

It seems that the only model for interstellar grains which can simultaneously satisfy their well established dielectric properties[3,7], cosmic abundance constraints[8], and the infrared spectra of highly reddened stars[3,4,9], is one involving a mixture of refractory particles involving compounds of oxygen—silicates and metal oxides—with a possible addition of water ice in the densest regions. Most of the carbon in interstellar clouds is likely to be tied up in gas-phase CO. Candidate grain materials, such as SiO_2, FeO and MgO, are, indeed, abundant in the carbonaceous chomdrites[10].

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SAGAN AND KHARE REPLY—We have proposed[1] that a complex organic material, called tholins, produced by electrical discharge or ultraviolet (UV) light from mixtures of cosmically abundant gases, is an important candidate material for the interstellar grains (although other material such as ices and silicates must, of course, be present); and that the sputtering and spallation products of tholins can explain the gas phase organic molecules discovered in the interstellar medium by microwave line spectroscopy. As noted in Fig. 3 of our paper[1] and elsewhere[2], little or no IR absorption is evident in the interstellar medium in the 3.3–3.4 μm region, characteristic of the C—H vibrational transitions of many organic molecules. The observational upper limits correspond, for example, to 10% of carbon in interstellar grains in alkenes and aromatics and 1% in alkanes (ref. 2), and an order of magnitude less according to Whittet. However, as clearly indicated in Table 1 of our paper[1], the atomic abundance of hydrogen by number in tholins is only a few per cent; and, as is apparent from Fig. 2 of our paper, in most laboratory tholins there is no trace of absorption features in the 3.3–3.5 μm range. We have re-examined various IR spectra of tholins and find no clear C—H stretch peak for raw UV tholins; for UV tholins with elemental sulphur removed; for UV tholins with elemental sulphur removed and the sample heated to 450 °C; for spark tholins; and for spark tholins heated to 650 °C. Tholins have a significantly different structure from graphite. We also re-emphasise that a range of other IR absorption features, reliably identified in the interstellar medium, cannot be understood by refractory materials and ices alone; but have a natural explanation if tholins are a constituent of the interstellar grains. The missing ingredient in the interstellar medium seems to be a complex organic solid which has a very weak C—H absorption feature; tholins seem to satisfy these requirements.

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The maximum entropy method

THE exposition of the maximum entropy method (MEM) given by Gull and Daniell[1] has been strongly criticised[2] on the basis that it led to some definite solution in situations in which different types of solution are possible (for example, one-peak (one source in astronomical language) and two-peak (double source) solutions). Here we defend Gull and Daniell's theory.

No matter how precise the measurements are, for sufficiently small δ, a point source gives the same observational information as do two nearby point sources at distance δ. Therefore among all brightness distributions, I, that are in accordance with observations, there are values of I corresponding to many-component sources (with as many components as one wishes) with very complicated structure. Astrophysicists want the distribution that contains, crudely speaking, the minimum possible number of components, or, more precisely, the simplest possible distribution in some formal sense. We show here that MEM solves this problem satisfactorily.

How can we formalise this demand? Assuming that complexity is a functional $\int s(I)$. We suppose that it can be represented in the form

$$s_0 + \int s_1(\bar{\sigma}, I\bar{\sigma}))\,d\bar{\sigma} + \int s_2(\bar{\sigma}_1, \bar{\sigma}_2, I(\bar{\sigma}_2), I(\bar{\sigma}_2))\,d\bar{\sigma}_1\,d\bar{\sigma}_2 + \cdots$$

(any analytic functional can be represented in such form). Axiomes for S are as follows. (1) Many-component source. Assume

$$I = I_1 + I_2, \text{supp } I_1 n \text{ supp } I_2 = \phi, \text{supp } I_1 = \text{supp } I_{1'}$$

We demand that

$$S(I_1) < S(I_1) \rightleftarrows S(I_1 + I_2) < S(I_{1'} + I_2)$$

(if one component is fixed, the image is simpler if the second is simpler). (2) Translational invariance. For any translation T: $S(I_1) < S(I_2) \rightleftarrows S(TI_1) < S(TI_2)$. (3) Independence on choice of unit for flux I: if $S(I_1) > S(I_2)$ and I_1, I_2 are consistent with the same observations (that is

$$\int I_j(\bar{\sigma}) \int A_i(\bar{\sigma}) = C_i \text{ for } j = 1, 2$$

and some fixed $C_i, A_i, A_0 = 1$), then $S(\lambda I_1) > S(\lambda I_2)$.

In looking for the simplest values of I an additive constant in S is inessential. Assuming $S_1 = S_2$ if $S_1 - S_2 = \text{const.}$, then one can prove the following. If S satisfies

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