mean energy of emitted photoelectrons and F_α is the flux of Ly-α photons. For $y = 0.1$, $E_e = 0.5$ eV we obtain

$$\Gamma_\alpha \quad (0.38\text{–}1.5)\times 10^{-26}\left\{\frac{\sigma n_g Q_{abs}}{n_H(6\times 10^{-22}\ \mathrm{cm}^2)}\right\} n_H\,\mathrm{erg\,cm^{-3}\,s^{-1}} \quad (4)$$

for F_α in the adopted range.

With $\sigma n_g Q_{abs}/n_H \simeq 6\times 10^{-22}$ cm^2 (ref. 15) we get from equation (4) a heat input rate which is significantly higher than the corresponding rate calculated for photoemission by ultraviolet continuum photons. For graphite grains with $|\Phi| \lesssim 1.0$ V (in both cloud and intercloud regions, $y = 3\times 10^{-3}$ and $E_e \sim 4$ eV) we find

$$\Gamma_\alpha \quad (0.1\text{–}0.36)\times 10^{-26}\left\{\frac{\sigma n_g Q_{abs}}{n_H\,(6\times 10^{-22}\ \mathrm{cm}^2)}\right\} n_H\,\mathrm{erg\,cm^{-3}\,s^{-1}} \quad (5)$$

Again with $\sigma n_g Q_{abs}/n_H \simeq 6\times 10^{-22}$ cm^2 we obtain a heating rate which is consistent with available data on gas temperatures and cooling rates in both clouds and intercloud regions. The observed high flux of Ly-α photons could thus provide a major source of heating for the interstellar medium through their photoelectric effect on grains.

The line-centre photons of Ly-α cannot ionise hydrogen atoms, which have an ionisation threshold wavelength of 912 Å. Because of the natural width of the emitted and scattered line photons, there would be photons with energies > 13.6 eV in the line wing which could contribute to the ionisation rate of the interstellar gas. We can show, however, that the contribution of this process is not very significant compared with other mechanisms which have been proposed unless the Ly-α flux is equal to or higher than the larger value adopted in the preceding discussion.

We conclude that the recently observed large flux of diffuse galactic Ly-α photons would have an important effect in controlling physical processes in the interstellar medium. In particular the electric charge on grains, particularly silicate grains, will be primarily determined by photoejections caused by Ly-α photons. The heating of the interstellar medium will also mainly be caused by this process. If external galaxies emit an equally high fraction of their luminosity in Ly-α radiation as is indicated in our own galaxy, their effect on the intergalactic medium as well as their possible cosmological role will need to be considered. A more precise determination of the Galactic Ly-α flux is clearly a matter of paramount astrophysical importance.

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Primitive grain clumps and organic compounds in carbonaceous chondrites

We show here that the physical conditions in prestellar molecular clouds favour the condensation of complex organic polymers, including amino acids, within a matrix of smaller refractory particles. Such composite grain clumps with dimensions exceeding 1 μm could be expelled along with gaseous material in protostellar cocoons, causing the widespread dispersal of biological activity in the Galaxy. We argue that grain clumps of the type considered here may be identified with μm-sized inclusions in carbonaceous chondrites.

Carbonaceous chondrites, with a carbon content of several per cent mainly in the form of aromatic polymers, and including amino acids in trace quantities, are generally believed to be among the most primitive solid bodies in the Solar System. The compaction of mineral particles with a substantial admixture of trapped volatiles must have occurred at temperatures in the range 350–500 K, with no subsequent reheating above ~500 K (refs 1 and 2).

Several striking isotopic anomalies have been discovered in mineral separates from carbonaceous chondrites[3-7]. Such anomalies have tentatively been attributed to inclusions of interstellar grains which condensed in novae or supernovae explosions[3,5,8,9]. This explanation is consistent with the occurrence of heavily irradiated μm-sized mineral separates rich in ^{22}Ne in the Orguel meteorite[10]. The presence of μm-sized inclusions, each comprised of closely packed aggregates of grains of 100 Å (ref. 11), is also suggestive of interstellar grain clumps within carbonaceous chondrites.

An understanding of the origin of carbonaceous chondrites may have an important bearing on the early history of the solar nebula, and in particular on theories of planetary formation. The efficient adhesion of relatively cold refractory grains (for example, graphite or silicate particles) in low velocity grain–grain collisions could occur if these grains possessed mantles composed of organic polymers which are adhesive at temperatures ~300 K. Such organic polymers have been tentatively identified by their infrared spectral features in cometary as well as interstellar dust[12,13].

We argue here that interstellar molecular clouds which are the most probable sites for the condensation of polymeric mantles around grains are also likely to provide suitable venues for the formation of composite grain aggregates, by the adhesion of such coated grains in grain–grain encounters. Such grain clumps of sizes ~1 μm pre-existing in the solar nebula could have served as aggregation centres for the growth of carbonaceous chondrites, perhaps representing the earliest stage of planet formation.

Large molecular clouds with masses in the range ~10^4–10^6 $M_\odot$ are widespread in the galactic disk. Such clouds, typified by W3, OMC-2, NGC2024, Sg B2, are generally believed to be progenitors of OB associations. In a typical extended cloud of diameter ~10 pc, observations of molecular CO at millimetre wavelengths leads to an estimate $n_{H_2} \simeq 3\times 10^3$ cm^{-3} for the smeared out hydrogen density[14]. More complex molecules, including HCN, H_2CO, tend to be more localised in their spatial distribution, generally associated with infrared knots, OH masers and presumably protostellar clouds. Molecular densities in such clouds are difficult to estimate. The requirement for collisional excitation of optically thin lines of H_2CO, HCN by neutral particles gives a lower limit $n_{H_2} > 10^5$ (ref. 14), but densities ~10^6 cm^{-3} or higher are most probably appropriate to protostellar clouds.

One may also argue that molecular clouds are not in a state of free-fall collapse[14]. Condensation may be slowed down by several processes, including effects of magnetic pressure, rotation and turbulence. We assume here that typical collapse times for an entire cloud, as well as for fragments within it, are of the general order of 10^6 yr. Such a condensation time, together with the estimated total mass of protostellar clouds, gives a rate of star formation which is consistent with observations.

A molecular cloud fragment collapsing towards a protostellar situation will contain a mass fraction of $\sim 10^{-2}$ of refractory grains such as graphite, silicate and iron particles of mean radius $a_i = 2\times 10^{-6}$ cm. The first stages of collapse will be accompanied by accretion of organic molecules on to these grains. Since a significant mass fraction of C and O is initially in solid grains, the maximum extent of mantle growth is not likely to exceed 50% of the original radius. This gas phase accretion would proceed to effective completion on a time scale which is short compared with the estimated collapse time of $\sim 10^6$ yr. The grain radius may now be assumed to be 3×10^{-6} cm (50% increase) in accord with our earlier remarks. The precise composition of molecular mantles is uncertain, but a hybrid mixture of organic polymers is likely to ensue.

Refractory grains with such tar-like polymeric coatings tend to stick to one another in low velocity grain–grain collisions at temperature $T \simeq 300$ K. Suppose n_H $(= 2n_{H_2})$ is the total hydrogen density and n_g is the grain density at this stage of protostellar collapse. Assuming an initial grain mass fraction of $\sim$ 1%, we have (for any reasonable grain specific gravity)

$$\frac{n_g}{n_H} \simeq 3\times 10^{-10} \qquad (1)$$

The rate of growth of a grain clump of radius r by this process is given by

$$\frac{dr}{dt} = \frac{\alpha n_g}{s}\left[\frac{kT\left(\frac{4}{3}\pi a_1^3 s\right)}{2\pi}\right]^{\frac{1}{2}}$$

$$= \alpha n_g \left[\frac{2kTa_1^3}{3s}\right]^{\frac{1}{2}} \qquad (2)$$

where α is the sticking probability, s is the mean specific gravity of the grain clump material, a_1 $(= 3\times 10^{-6}$ cm) is the radius of polymer coated grains, n_g is the number density of grains, and T is the kinetic temperature. We assume in equation (2) equipartition of energy between grains and gas and a Maxwellian distribution of grain velocities. Sticking of grains occurs by collisions during their Brownian motion with relative speeds of $\sim$ 10 cm s^{-1}. With $\alpha \simeq 1$, $T \simeq 300$ K, $s = 1$, $a_1 = 3\times 10^{-6}$ cm and using equation (1) we obtain

$$\frac{dr}{dt} = 8.2\times 10^{-18}\, n_H \text{ cm yr}^{-1} \qquad (3)$$

In the available time, $\sim 10^6$ yr, we obtain clump diameters $2r \sim 1$ μm for a typical value of the molecular density $n_{H_2} \simeq 3\times 10^6$ cm^{-3}. Larger clumps could arise from higher density regions.

The ultimate dispersal of a protostellar cocoon, including large grain clumps, may have a role in the removal of angular momentum from a central protostellar condensation, thus permitting further contraction and evolution on to the main sequence. A large fraction of composite grain clumps in such cocoons could probably survive the 'switching on' of the stars in an OB association, and they may be carried along with systematic gas flows into the general interstellar medium. Such grain clumps could indeed constitute an appreciable fraction by mass of all interstellar dust.

Large grain clumps of the type discussed here in a protoplanetary disk could also serve as accretion sites for smaller grains which condense within the disk, the process leading to the formation of planetisimals in the first instance, and eventually to planets. With a minor degree of metamorphism, such objects at an intermediate stage of aggregation would seem to resemble the carbonaceous chondrites.

It is tempting to speculate that amino acids which have been discovered in carbonaceous chondrites[15-17] had their origin in presolar grain clumps of the type considered here. The formation of simple amino acids (for example, glycine) is expected to take place in dense interstellar molecular clouds which may well be the cradle of life. The possible precursors of glycine, namely formic acid (HCOOH) and methanimine (CH_2NH), have already been observed in dense molecular clouds, and the reaction

$$HCOOH + CH_2NH \rightarrow NH_2CH_2COOH$$

leading to the production of glycine is known to be exothermic. It may be relevant that glycine is the most abundant of the amino acids detected in chondrites[17]. Amino acids of this type, and of greater complexity may be trapped in the tarry polymeric component of our grain clumps, and be dispersed throughout interstellar space, being securely protected from destruction by ultraviolet photons by the matrix of smaller refractory grains in which they are embedded.

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Comparative ionospheric and plasmaspheric electron contents from three world regions

THE radio beacon experiment[1-3] aboard the geostationary Applied Technology Satellite ATS-6 enables the determination of total electron content (TEC) to be made by two independent methods. The first—the Faraday polarisation rotation technique—has been widely used in obtaining TEC data. Faraday rotation is dependent on the Earth's magnetic field, and, since its magnitude is heavily weighted near the Earth, it is considered to provide integrated electron content values for altitudes below $\sim$1,500 km. The second—the dispersive-group-delay technique, in which the phase of the modulation envelope between a carrier and its sideband is compared at two frequencies—is independent of the Earth's magnetic field and thus yields the integrated electron content between the observer and the satellite signal source. The Faraday content, N_F, and the dispersive-group-delay content, N_T, therefore, yield the TEC up to $\sim$1,500 km and geostationary altitudes, respectively. The difference between N_T and N_F yields the content above $\sim$1,500 km, which is referred to as the plasmaspheric content, N_P.

The ATS-6 satellite was launched into a geostationary orbit in May 1974. During phase I of its operation, when