INTERSTELLAR DUST–GAS RELATIONSHIPS

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ABSTRACT. The evolutionary chemical and morphological properties of interstellar dust are shown to provide a basis for varying the correlation factor between dust, hydrogen and CO.

1. Introduction

The questioning of the mass of molecular hydrogen in the galaxy has come into prominence partly as a result of the reduced estimates made by the group of Wolfendale (1,2,3) based on cosmic gamma-ray methods. Since the dust is generally assumed to be well coupled to the gas this raises a further question about the amount of dust assuming that the dust is constrained by the local "cosmic" abundance of the heavy (so-called condensable) elements. In the neighbourhood of the sun this abundance ratio is assumed to be very similar to that in the solar system. In the galactic center there are reasons, both observational and theoretical, to expect higher abundances of heavy elements. The aim of this paper is to discuss the interstellar dust consistency or inconsistency with derived values of the molecular hydrogen density. In particular whether there is a lower limit on the value of the ratio of the column density of hydrogen to the integrated CO intensity, \( \frac{N(H_2)}{I_{CO}} \), for providing the observed dust density and the required molecular (other than \( H_2 \)) densities.

2. Interstellar dust and cosmic abundance constraints.

2.1 Interstellar dust.

Currently we have knowledge of a wide variety of material constituents of the dust. Some of these are volatiles in the form of frozen ices, the others being relatively non-volatile or refractory. However even the refractories have varying degrees of volatility. The major refractory components which have been observed may be characterized as silicates and organics.

The core-mantle model of interstellar dust is the basis for explaining many of the observed properties of the solid particles in the space between the stars (4,5). The silicate cores are formed in the atmospheres of cool evolved stars and, from their infrared absorption spectra, are deduced to be in an amorphous form. After being ejected from the stars these particles undergo a series of cyclic processes. First, they accrete mantles of molecular ices –predominantly \( H_2O \) and CO in dense molecular clouds. The CO is actually accreted while the \( H_2O \) is predominantly formed by surface reaction on the grain surface. The "dirty ice" mantles containing other molecules as well (but in generally lower abundance) are subjected to the ultraviolet photons which are present in adequate abundance even in the shielded region of
dense clouds to produce chemical modifications. Simple molecules are broken and recombination between the fragments lead to new and generally more complex molecules. During the molecular cloud phase, the more volatile molecules are explosively desorbed about every $10^5$ years as a result of triggered reactions among the ultraviolet produced radicals. The subsequently reaccreted molecules are again subjected to photoprocessing along with the less volatile (H$_2$O) molecules. The result of this recurring accretion, desorption, accretion and photoprocessing is creation of a layer of complex organic molecules (organic refractories). When the molecular cloud is dispersed after about $5 \times 10^6$ years, the grains are sent into the low-density diffuse medium where all the volatiles are removed by various destructive processes from which the grains have been shielded in the molecular cloud phase. The resulting grains then consist of silicate cores with organic refractory mantles. These organic mantles are further subjected to ultraviolet photoprocessing in the harsh ultraviolet environment of the diffuse medium leading to partial dehydrogenation and reduction in the abundance of O and, to a lesser extent N, with respect to C. Such grains are later swept up again into molecular clouds and the accretion/photoprocessing of ice mantles is repeated. In the mean one diffuse/molecular cloud cycle takes about $10^6$ years. Ultimately, a grain is consumed (totally destroyed) by being incorporated into a new star; i.e., the interstellar gas and dust is cycled through stars every $5 \times 10^6$ years by star formation. This is then the maximum mean lifetime for a core-mantle grain which has undergone of the order of 50 complete diffuse/molecular cloud cycles of volatile mantle formation and destruction.

It is primarily from infrared absorption that we are made aware of the molecular constituents of the dust whereas the molecular constituents of the gas are observed in the radio region. Just as the identifications of molecular constituents in the gas are based on laboratory measurements, so the identifications of the molecular constituents of the dust are based on laboratory spectra. It has been possible to recreate in the laboratory the physical conditions leading to the chemical evolution of interstellar dust - low temperature, high vacuum, vacuum ultraviolet radiation. Laboratory infrared absorption spectra of various ice mixtures, photoprocessed as well as unirradiated have provided the basic data. In fact, the photoprocessing of interstellar type ices was studied in the laboratory by infrared and other analytical techniques before many of the observations were made (6,7). A major prediction of the laboratory analog studies was the presence of organic residues with a 3.4 μm absorption feature. Among other facts it has been established that all interstellar ice mantles are amorphous and that only in regions near newly forming stars or in the atmospheres of certain cool types of stars can this ice be crystalline. In the latter case one may say that the dust is not truly interstellar.

Among the many cases in which not all the dust is consumed by star formation there is the one in which the dense cloud collapses to a disk out of which the planets and comets are formed around the star - as was the case 4.5 Gyr ago around the sun. The dust in this protoplanetary disk, if it has not been raised to too high a temperature, will resemble the dust in dense molecular clouds. In fact, the process of gas accretion may proceed unchecked in the final stage of contraction if the desorption process is sufficiently reduced. The time scale for accretion is $\tau_{\text{acc}} = (2 \times 10^9 / n_0)$ yr where $n_0$ is the hydrogen density.