

Chapter 1

General Introduction

Study of the dust particles in the universe is an exciting and challenging area of current astronomy. This comes from various considerations. Dust is at the centre of all important events in the universe, like star formation, distance determination etc. Dust particles influence the thermal, dynamical, ionization and chemical states of matter of the interstellar and intergalactic medium. It may be noted, about half of the elements heavier than helium is in the form of dust in the interstellar medium of our Galaxy. Dust grains are effective absorbers of radiation energy and momentum. The collisional coupling between grains and gas in dense regions around evolved stars, in molecular cloud cores and protoplanetary disks have consequences for the temperature and the dynamical evolution of the gas component. The mass loss from evolved stars, stability of molecular clouds and their fragmentation into smaller clumps etc. are directly linked to the presence of dust. Infrared observations arising due to thermal emission from dust particles probe regions of star formation. The low temperature inside clouds arising from shielding of radiation by the dust particles leads to complex chemistry between dust and atoms and molecules. The formation of molecular hydrogen takes place on the surface of grains. The dust and complex chemistry of the material present in comets appear to be the same as in these clouds. May be these are the precursors to life on earth! However due to historical reasons and also due to lack of facilities both with regard to bigger telescopes and technology, most of the studies had to be concentrated on the local universe, particularly our Galaxy and nearby ones. Even here, until recently, studies were concentrated on brighter objects. Things have improved enormously with the advent of space and new technology telescopes. It is now possible to push the limit of observations to fainter and fainter sources. Also it has been possible to study objects farther in space

and hence well back in time.

Nature and composition of dust in the Galaxy have come from many kinds of observations such as extinction, scattering and polarization of starlight, infrared continuum emission, spectral features in the infrared region, interstellar depletion of elements, presence of isotopic anomalies in meteorites etc. These studies have been carried out on different kinds of objects such as diffuse and dense clouds, Reflection nebulae, star forming regions, HII regions, circumstellar shells of stars, meteorites, interplanetary dust particles etc. High resolution spectral observations in the infrared region have given enormous information about the composition of dust particles. All these studies have shown that dust particles are mainly made up of crystalline and amorphous silicates and of carbonaceous material in some form. The near and mid-infrared spectra of many sources are dominated by strong emission features at 3.3, 6.2, 7.7, 8.6 and $11.3\mu\text{m}$. These are collectively known as unidentified infrared (UIR) bands. However it is suggestive that they could arise from the large sized molecules containing about 50 to 100 atoms, such as Polycyclic Aromatic Hydrocarbon (PAHs). However no specific molecule has been identified and it is further complicated by the fact that emission arises not from a single molecule but from a host of molecules. However the carrier appears to be aromatic in character. In view of this, We prefer to use the term "Aromatic Unidentified Infrared Bands" (AUIBs) to describe this generic spectrum. The grains inside molecular clouds are heavily processed with a mantle of various ices. Nature of the dust is also dependent on the radiation field present in the environment.

The major supply of dust comes from circumstellar shell of evolved stars such as oxygen-rich and carbon-rich stars producing silicate type and carbonaceous type of materials respectively. Stellar winds eject these dust particles into interstellar medium. These particles cycle several times through dense and diffuse clouds which could modify their original composition. The chemical and physical structure of dust grains are also modified by a host of processes including UV photon irradiation, gas-phase chemistry, accretion and grain surface reactions, cosmic ray bombardment and destruction by shock waves generated by supernova explosion etc. Therefore the nature and chemical composition of grains in the Galaxy is a function of the environment and quite complicated.

An understanding of the chemical complexity of the grain material in Galaxy is crucial for an understanding of the chemical state of dust in extragalactic systems and in the universe. It may be noted that the conditions

existing in astrophysical objects are diverse and extreme. The temperature, particle density and radiation field can vary over a wide range of values. Therefore the success of the study of dust grains in the Galaxy and in extragalactic systems is critically dependent upon laboratory studies of dust carried out under astrophysical conditions. Extensive laboratory studies carried out with dust analogues have helped enormously our understanding of the chemical composition of dust in various locations. Since the laws of physics and chemistry are the same throughout we can extend the studies of local environment to the universe.

Other galaxies in the universe can have various shapes defined as spirals (our Galaxy), ellipticals etc. which themselves form clusters and superclusters. Dust is present, as we have seen above, not only within the galaxies but in the intergalactic and intracluster media as well. One major difference of course is that chemical composition of the gaseous material in the past is not the same as that of the Galaxy. The earliest heavy elements could not have been created until after the first stars and the first supernova, roughly at redshift $z \sim 6$. This could in principle have an effect on the nature of dust present in these objects. Dust condenses out of the gaseous material. This is the processed material inside stars due to nucleosynthetic processes. The processed gaseous material inside the star is returned to the interstellar medium which enriches the original material. The stars formed out of the new material will be richer in heavier elements compared to the previous generation of stars. Once the dust is formed within the galaxies it can be expelled to extragalactic space by several processes like galactic wind, explosions etc. The modification of the material has been going on through such a cycle over the age of the universe.

As mentioned earlier, dust manifests in different ways. However detailed nature of the dust can be determined from objects which are close by. As one goes out to larger and larger distances objects become fainter and fainter. Therefore one can estimate only some gross property of the grains. This situation should improve in future with the availability of bigger telescopes and sensitive detectors. However at the present time, Quasars, the highly redshifted objects are well suited for this study at large distances as they are very bright. At the present time they have traced the state of the universe upto redshift of $z \sim 6$.

In the succeeding chapters we would like to elaborate on some of these aspects. We will first present some of the Laboratory studies relating to the nature of dust, like silicates, carbonaceous materials etc. This will then be followed by the available information on the nature and composition of

dust grains in the universe from a representative sample of various kinds of objects present in the universe from the present epoch to earlier epochs. i.e. first galactic dust and then extragalactic dust. We follow this approach since we have a reasonably good idea on the nature, composition and formation of dust in the Galaxy. In the same spirit we will discuss the galactic dust in a little more detail. In this manner we hope to arrive at the present status of the study of dust in the universe.

References

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