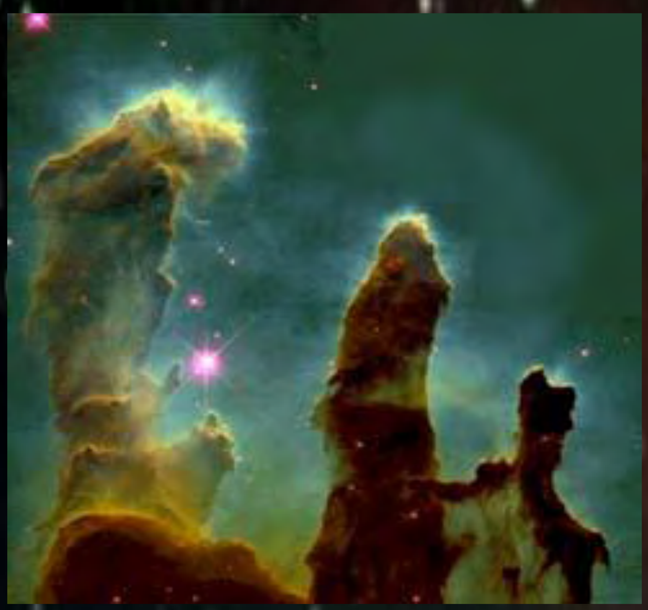
DUST IN THE UNIVERSE

Why study the ISM

The most beautiful component of galaxies is the ISM or interstellar medium – the gas and dust between the stars! 10% of the baryonic mass of the galaxy is in the ISM. Its importance stems from the fact that it is the material from which new stars are born.



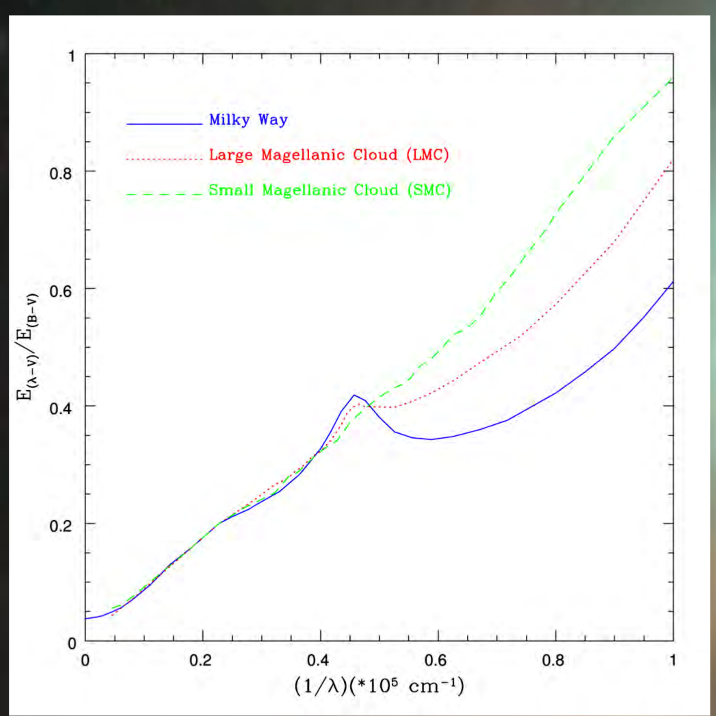
The pillars of creation in the Eagle Nebula also known as IC4703, is a region of active current star formation at a distance of 7000 light years.

The ISM consists of the following constituents:

- Gas – Ions, molecules and atoms in the gas phase, mainly H and He
- Dust – Small solid particles with sizes < 1 μm
- Cosmic rays – High energy ions and electrons
- E.M. Radiation – Photons from various sources
- Magnetic fields – The field from electric currents in the ISM

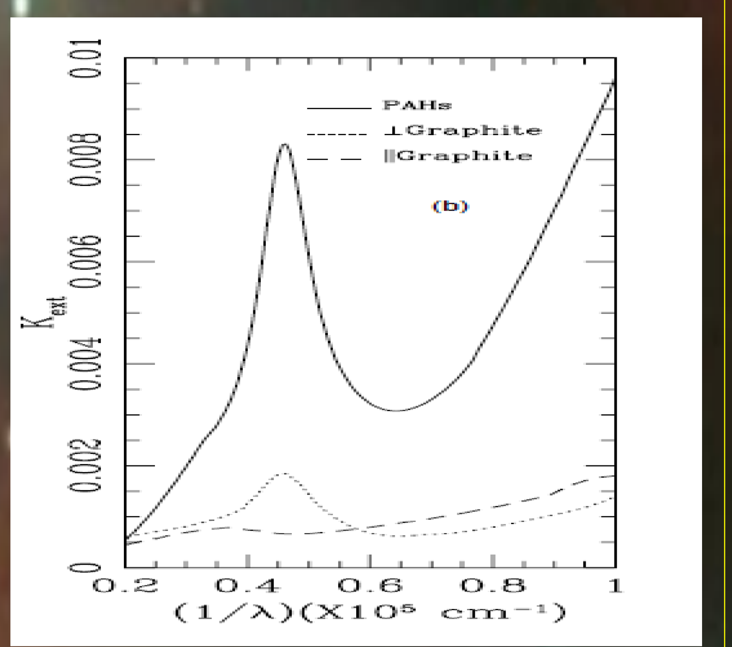
Interstellar Dust and Extinction

Dust constitutes 1% of the mass of ISM (Interstellar Medium). It plays the most important role in which the light seen form stars suffers extinction (absorption as well as scattering). Recent space probes have confirmed that the dust grains are highly porous and fluffy (i.e. aggregates or clusters) rather than having regular shapes (spherical, cylindrical or spheroidal), homogeneous in composition and structure. Composite fluffy dust grains are being used by many researchers to explain the observed interstellar extinction curve .

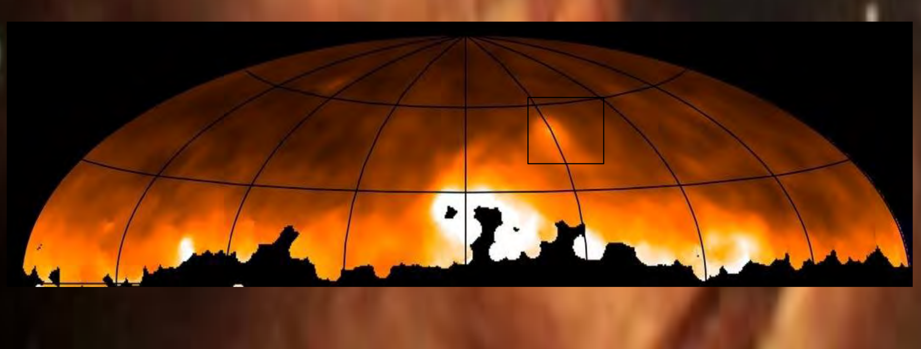


The figure to the left shows the colour excess or average interstellar extinction produced in Milkyway, LMC and SMC (cf. Whittet). The bump seen around 2200Å clearly indicates the presence of similar dust material/component in Milky Way and LMC, and its absence in SMC. These dwarf galaxies are deficient in heavy metals as compared to Milkyway.

It was first proposed in 1956 that very small grains of around 10Å size could be present in Interstellar Dust (ISD). These were later found to be Polycyclic Aromatic Hydrocarbons or PAH's, which are molecules containing aromatic rings with varying ring numbers. Studies over the past few decades have shown the ubiquity and importance of PAH's as a constituent of ISD.
The adjacent figure shows the extinction due to equal volumes of Graphite and PAH's (with PAH's size range 5-50Å). Roy A. et. al. JQSRT 2012. The importance of PAH's is very evident from the figure. PAH's are now considered to be one of the major components of the model which previously contained only graphite and silicates first proposed by B. Draine & A. Li.



The diffuse UV background and haloes around stars

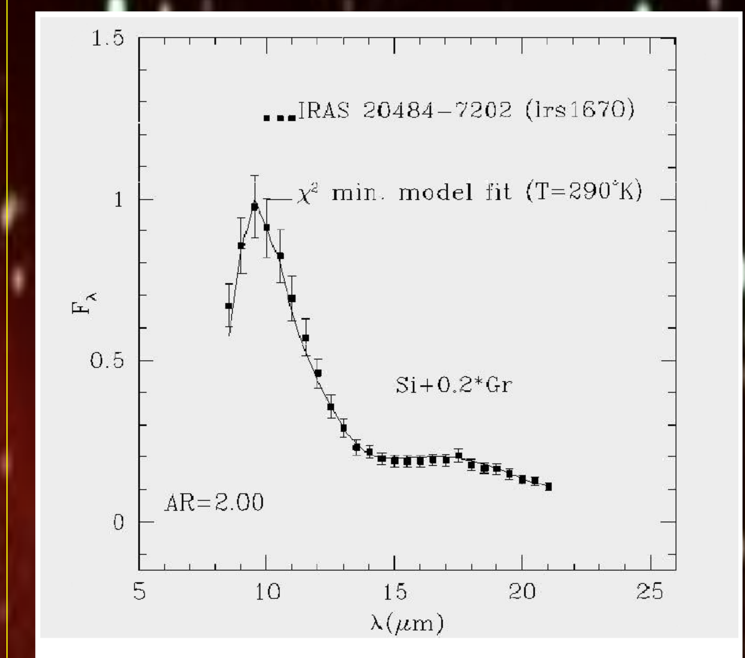


GALEX image showing the diffuse FUV background at Northern Galactic latitudes. The FUV halo around Spica is shown in the square box (Murthy et al. 2010, ApJ, 724, 1389).

An important property of dust grains is the scattering of stellar radiation. This results in a diffuse component of the radiation field in galaxies which is coming from clouds or sheets of dust. The intensity and direction of the scattering depends on the size and composition of the grains and is a function of the wavelength of the incident radiation. The above figure shows a map of this diffuse component in the UV observed by GALEX. Detailed modeling of this diffuse radiation can give information about the type of grains and their distribution in different regions in the Galaxy.

Haloes have also been observed (indicated by a square box in the above figure) around some bright stars in the UV that are produced by scattering of starlight by dust grains in thin foreground clouds that are not physically associated with the star. Scientists at IUCAA in collaboration with scientists at IIA(Bangalore) have used simple scattering models in order to derive the scattering properties of grains and the distribution of the dust layer towards a bright UV emitting star, Spica (Alpha Vir).

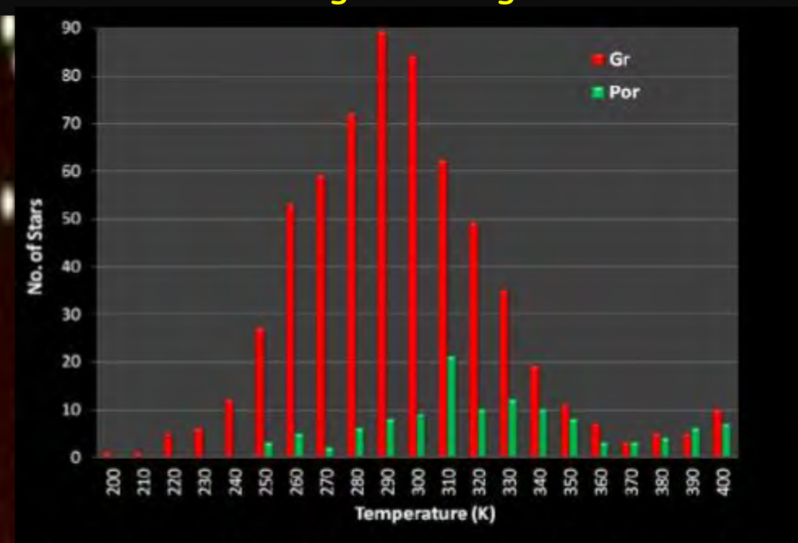
Circum-Stellar Dust



Normalized infrared flux vs. wavelength, with dots representing actual data, smooth curve representing the best fit model.

Circum-stellar dust shells are usually found around young evolving stars and completely evolved stars. Dust shells present around evolved stars are significant sources of new grain material.
The Infrared Astronomical Satellite (IRAS), during its survey of the sky, observed many such stars with dust shells around them. In a study done to model the dust grains that make up such shells, infrared flux from dust shells around 732 stars from the IRAS database were used. The observed flux was compared with the flux obtained using various grain models.

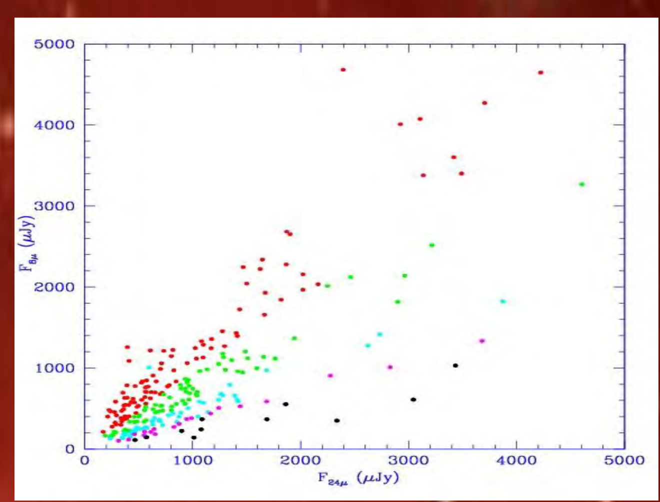
Oblate spheroid dust grain composed mainly of silicates with some porosity or containing varying quantities of graphite, with different dimensions, were used to find the best fit model. The grain models composed of silicates and graphite were found to provide the best fit for majority (615 of 732) of these stars, while the rest 117 stars gave better fit with silicates and porous models. The temperature of the grain models was found to lie between 200 K and 400 K.



Histogram showing the number of stars vs. the best fit dust temperature, for Silicate + Graphite and Silicate + Porous grain models. For the graphite model maximum temperature is seen at 290 K, while for the porous model the maximum temperature is seen around 310 K.

Dust in other galaxies

Most of the emission in the infrared region from star-forming galaxies is due to thermal emission from dust grains heated by stellar radiation. Therefore studying this part of the electromagnetic spectrum can also give us important information about the emitting dust grains.

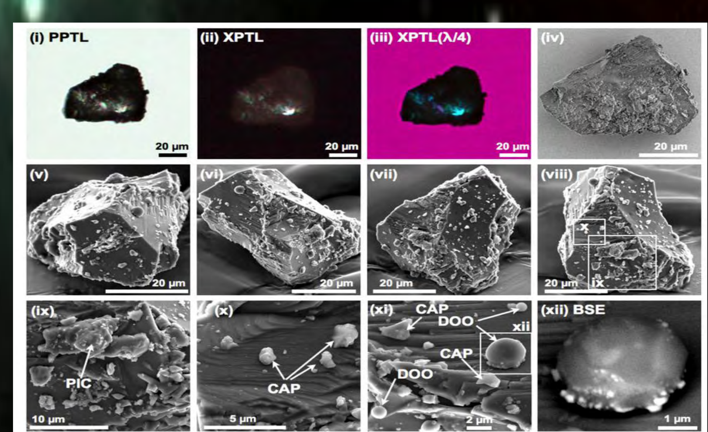


The variation in the relative fluxes at 8μm and 24μm for galaxies with different levels of radiation fields. The lowest radiation field galaxies are plotted as red circles while the highest radiation field galaxies are shown as black circles.

By studying the dust emission in the mid-infrared observed by the Spitzer space telescope together with UV observations from GALEX, scientists at IUCAA have been able to classify galaxies in the ELAIS-N1 field based on their dust and stellar content. At these wavelengths there are broad emission features (e.g. the 7.7μm feature) due to PAH molecules and continuum emission which peaks at around 24μm from very small dust grains. By looking at the correlation between the IR emission from these two types of carriers and UV radiation from hot stars, they find that for most of the galaxies in the sample the PAH molecules are the chief absorbers of the UV radiation from stars. On the other hand for galaxies which have high radiation fields, the UV radiation is being absorbed not only by the PAH molecules but also by the very small dust grains . This can be seen as a change in the ratios of the two types of emission for galaxies with different radiation fields.

Asteroid Dust

Asteroids are small rocky worlds that occupy the region between Mars and Jupiter. They are classified into 3 types based on their composition. The C-type or carbonaceous asteroids are the most common and are composed mainly of clay and stony silicate rocks. The other two types S and M are relatively fewer in number and are composed of silicates and nickel-iron.
There have been missions to comets (Deep Impact mission, NASA) and asteroids (Hayabusa, JAXA) and they have provided us with valuable information about the composition of these objects.



To the left are the microscopic views of an asteroid sample collected by Japan's Hayabusa 1 probe, it shows tiny bits of grain that have adhered to it from impacting meteorites.
CREDIT: PNAS

To the right is an artist's concept of Hayabusa 2 spacecraft.
CREDIT: JAXA/Akihiro Ikeshita

The Hayabusa 2 spacecraft (JAXA) aims to reach asteroid 1999JU3 and bring back samples to the earth. It is an impact mission, where an impactor would be hurled at the surface of the asteroid resulting in a plume of dust ejecta.
In collaboration with scientists from Chitech (Chiba, Japan) and CPS (Kobe Universtiy, Japan), scientists at IUCAA are developing models to predict the dust scattering properties of the ejecta plume of this asteroid.