Dust in the interstellar medium

- Interstellar dust is an important constituent of the Galaxy. It obscures all but the relatively nearby regions in visual and ultraviolet wavelengths, and reradiates the absorbed energy in the far-infrared part of the spectrum, thereby providing a major part ($\sim$ 30 percentage) of the total luminosity of the Galaxy.

- Significance of Dust in the ISM :

  1. The FIR radiation from dust removes the gravitational energy of collapsing clouds, allowing star formation to occur.
  2. Dust is crucial for interstellar chemistry by reducing the ultraviolet (UV) radiation which causes molecular dissociations and providing the site of the formation of the most abundant interstellar molecule, H_2.
  3. Dust controls the temperature of the interstellar medium (ISM) by accounting for most of the elements which provide cooling, but also providing heating through electrons ejected photoelectrically from grains.

- Types of interstellar grains :-

  1. SiO,SiO_2,H_2O(S),NH_3 - micron size
  2. PAHs which contains 20-100 Carbon atoms in aromatic hydrocarbon form and have typically nanometer size.

- The scheme followed in detecting the presence of dust can be either Direct detection of radiation emitted by heated dust or Indirect detection by the absorption and scattering of starlight by dust

- Direct detection involves probing the sky in the wavelength $600\mu m$ - $6\mu m$ where the interstellar dust emission dominates.Vibrational emission by PAH (polycyclic aromatic hydrocarbon) molecules dominates dust emission at $\lambda \leq 50\mu m$ (non-thermal)

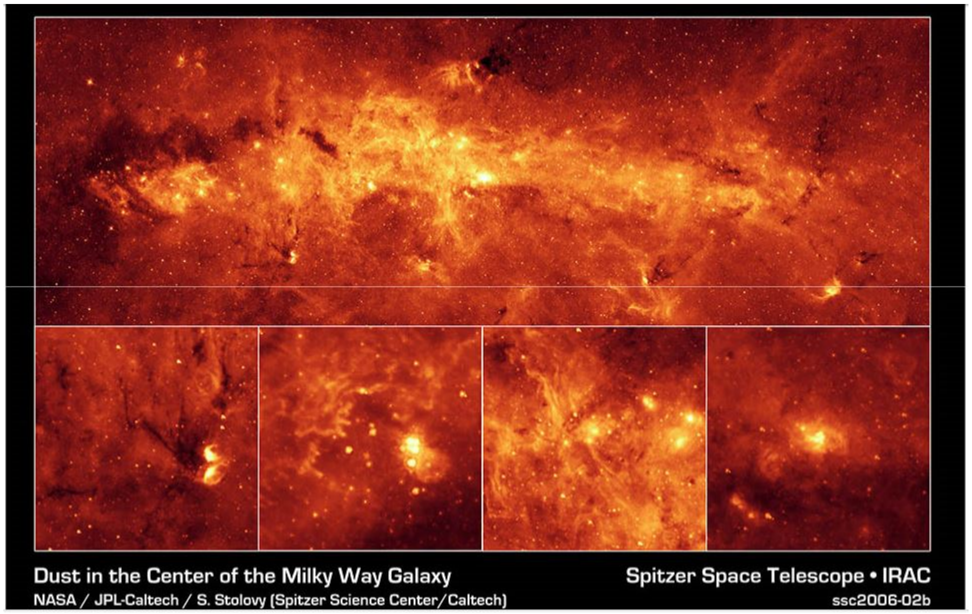

Figure 1: $8\mu m$ image from the Spitzer infrared space telescope of the dust emission from the centre of the Galaxy, encompassing the region of the central molecular zone,covering a region 240 x 80 parsecs

- In the figure,Inserts are (from L to R):(i) obscuration from a foreground spiral arm, (ii) the Quintuplet star cluster, dominated by the emission from 5 bright embedded, embedded, massive massive stars (with the Pistol nebula and star to their right-below and the remnant dust pillars of the Sickle to their left), (iii) dust emission from the Arched Filaments and (iv) the Sgr A cluster in the very centre of the Galaxy, around the massive black hole at the Galaxy's core.

Equilibrium temperature of a Dust grain

- The Dust grain will remain at equilibrium when there is a balance between the power absorbed (from starlight) and the power radiated by the dust.
- The power absorbed by the dust is given by,

$$P_a = (1 - a) f \pi {r_g}^2 \tag{1}$$

- Where, Luminosity of the star is L and f is the flux due to the star incident on the grain,

$$L = 4\pi {r_s}^2 \sigma {T_s}^4 \tag{2}$$

$$f = \frac{L}{4\pi d^2} \tag{3}$$

- And the Power Radiated is,

$$P_r = (1-a)4\pi {r_g}^2 \sigma {T_g}^2 \tag{4}$$

- In equilibrium,Power absorbed = Power radiated.Hence the equilibrium temperature is:

$$T_g = \frac{T_s {R_s}^{1/2}}{2d^{1/2}} \tag{5}$$

- So the dust emits radiation at a wavelength corresponding to this temperature.It is also known that Thermal blackbody emission dominates at $\lambda \geq 50\ \mu m$.
- The indirect method of detection of dust is based on measuring the amount of extinction it causes, which alters the apparent magnitude of stars.

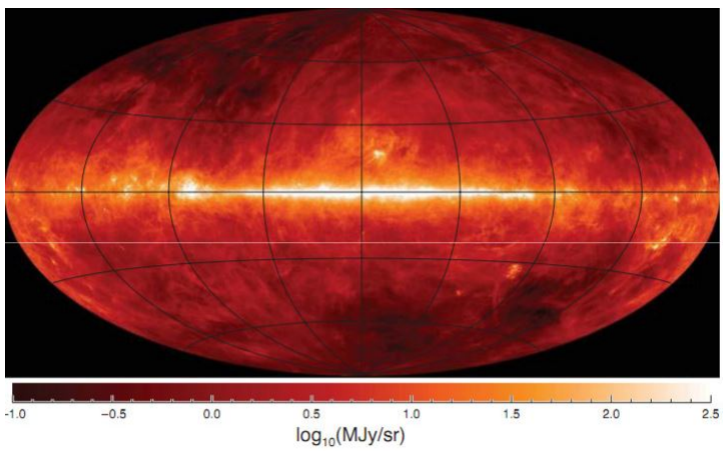

Figure 2: The $100\mu m$ sky,after subtracting the emission from warm interplanetary dust particles within the solar system.The LMC and SMC are visible at (l,b)=(280^o,-33^o)and (303^o,-44^o).The bright emission near l=80^o(in cygnus) corresponds to dust in the perseus arm and the cygnus OB2 association ,at a distance of 1.45Kpc.Based on observations with the IRAS and COBE satellites

- A well known example which emphasise the effect of interstellar extinction is while imaging Barnard 68 in optical and IR bands.It is almost invisible in optical band starting from $0.44\mu m$ but shows up, rather progressively, as wavelength is increased upto near-IR.The sequence of observations are show in the figure below.

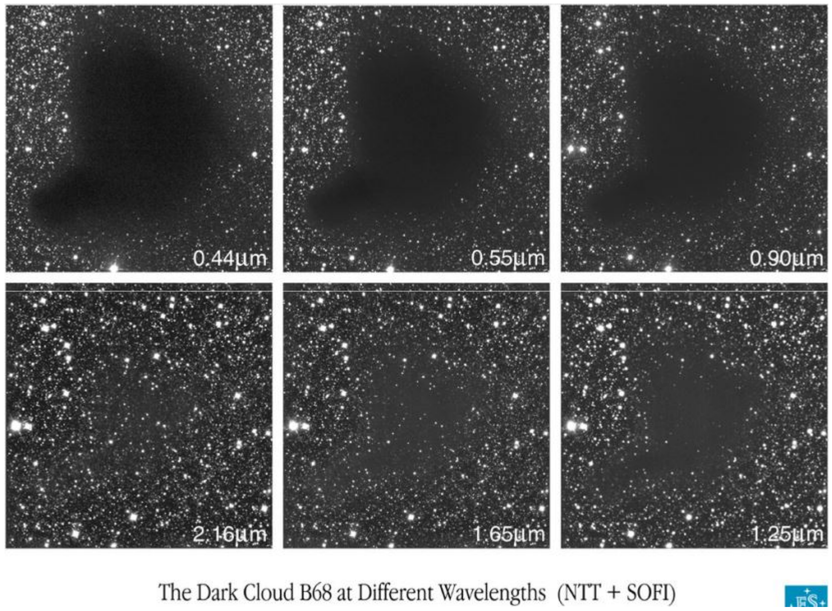

Figure 3: The dark cloud B68 at different wavelengths

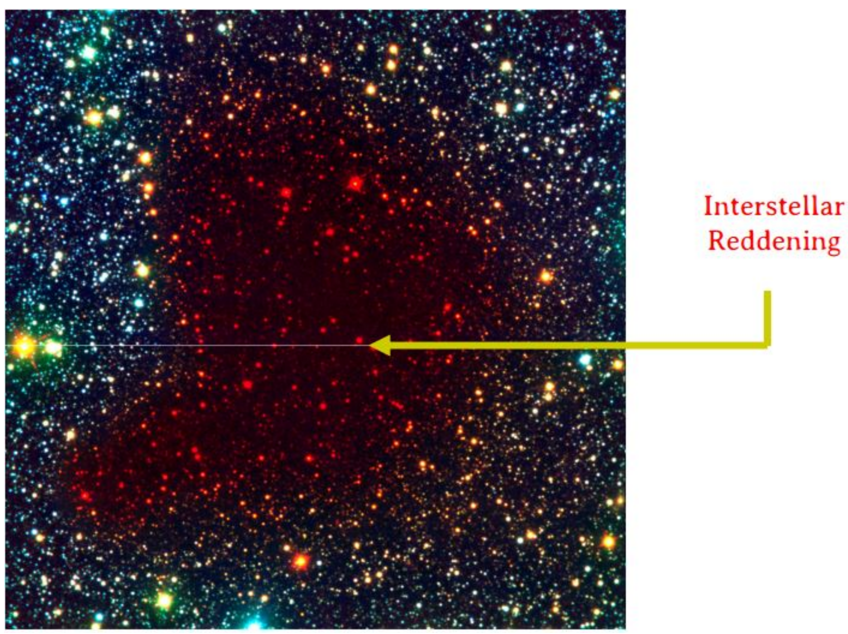

Figure 4: Seeing through the pre-collapse black cloud B68

- The amount of extinction can be studied by measuring the color excess corresponding to two wavelength bands.So due to extinction,the distance modulus formula can be re-written with an additional coefficient to correct for the effects of extinction as

$$m - M = 5log_{10}(d) - 5 + A_\lambda \tag{6}$$

- If separate measurements are taken in both V and B bands then the color excess can be obtained.

$$E(B-V)_{tot} = (m_B - m_V) - (M_B - M_V) \tag{7}$$

- The difference in absolute magnitudes can be obtained from models because the difference in magnitudes in B and V bands is the same for all stars of the same spectral type.The apparent magnitudes are directly observable.This gives the total color excess.

Extinction Curve

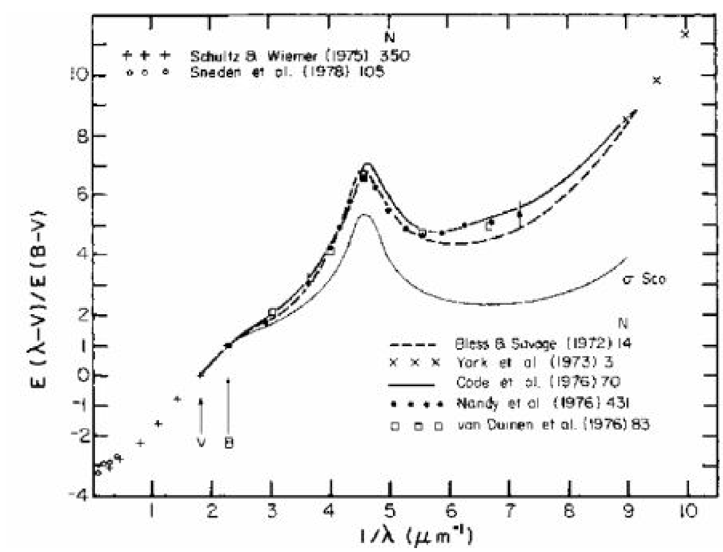

Figure 5: Average normalised interstellar extinction is plotted vs $1/\lambda$ in μm^{-1}. E(λ-V) refer to extinction in magnitudes between a wavelength λ and the V band.

- The bump in the curve is due to absorption by graphite at 217.5nm which is present along all line of sight.

- The relation between the column density of HI regions and the extinction caused by this is given as:

$$E(B-V)_{gas} = \frac{N(HI)}{5.8 \times 10^{21}} mag \tag{8}$$

- Thus the gas to dust ratio can be obtained which enables one to calculate the extinction due to gas and dust separately.