Color Excess, estimating gas - to - dust ratio

Color Excess and extinction curve

The extinction is the sum of two physical processes: absorption and scattering. The amount of extinction and reddening along a line of sight depends on the density of dust along it. Hence each line of sight has its own "extinction law", or variation of extinction with wavelength as can be seen from the plot given below(Fig.1). It is characterized by extinction coefficient. The extinction coefficient can be determined from the distance modulus formula,

$$m - M = 5log(d) - 5 + A \tag{1}$$

where A is the extinction coefficient. As estimating the value of A is a difficult task, hence we go for another quantity known as 'color excess'. The slope of the extinction curve gives 'color excess'.

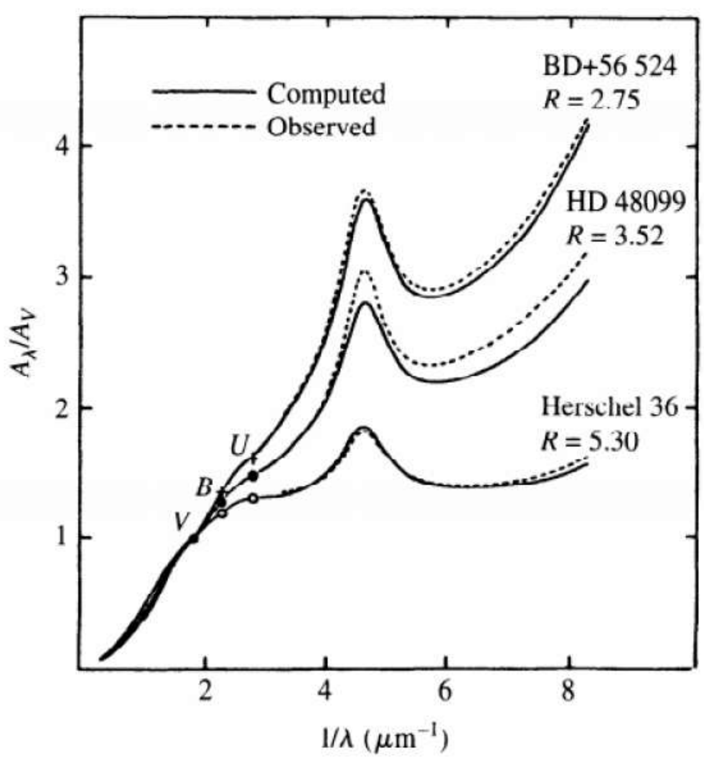

figure 1

There is a general increase in absorption towards shorter wavelengths which gives rise to the effect of reddening. The most common measure of reddening is the color excess, E_{B-V}

$$E_{B-V} = A_B - A_V \tag{2}$$

A_B and A_V are the total extinctions in the photometric B (450 nm) and V (550 nm) bands.

Expressing the extinction law is not unique; it has been common practice to use the ratios of two colors, E $_{\lambda} - V/$ E_{B-V}, also known as the total normalized extinction instead of A_λ, extinction coefficient as shown in Fig 2

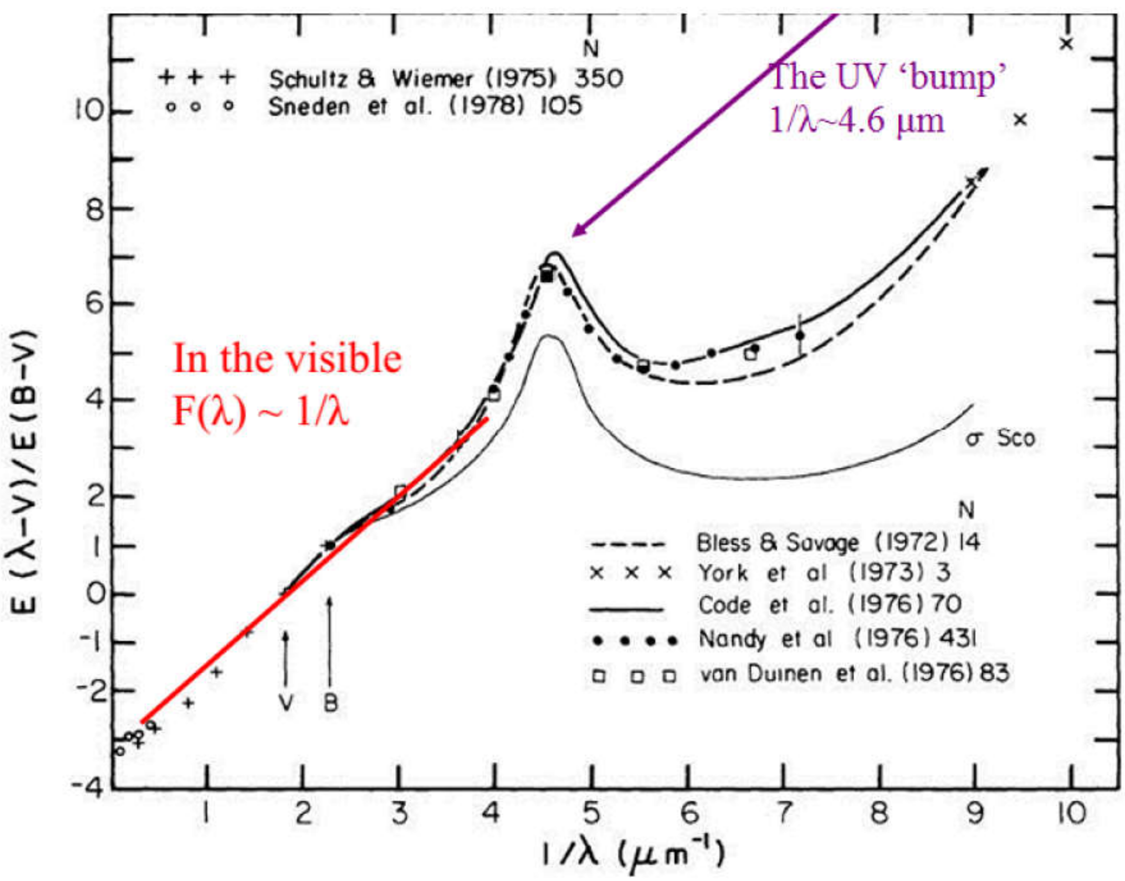

figure 2

Total to Selective Extinction:

Total-to-selective extinction ratio, R_V is yet another parameter used to observe extinction laws. R_V is determined by extrapolating NIR extinction to infinite wavelength. Its given by,

$$R_V = \frac{A_V}{E_{B-V}} \tag{3}$$

The value of R_V depends upon the ISM along the line of sight. A direction through low-density ISM usually has a rather low value of R_V (about 3.1). Lines of sight penetrating into a dense cloud, such as the Ophiucus or Taurus molecular clouds, usually show $4 < R_V < 6$. However, it is not possible to estimate R_V quantitatively from the environment of a line of sight; for example, the star VI Cyg 12 lies behind a dense cloud of dust, but has an R_V of 3.1 , a value appropriate for the diffuse ISM. As a further example, R_V is approximately 3.0-3.5 in parts of the Taurus cloud.

Dust to Gas Ratio in ISM

ISM dust constitutes of large fraction of hydrogen(which is basically a combination of atomic and molecular hydrogen). We have the column density of hydrogen,N_H,

$$N_H cm^{-2} = 5.8 \times 10^{21} E_{B-V} mag \tag{4}$$

$$\Rightarrow E_{B-V} = \frac{N_H}{5.8 \times 10^{21} cm^{-2} mag^{-1}} \tag{5}$$

This equation can be rewritten in terms of extinction coefficient as,

$$A_V = R_V \frac{N_H}{5.8 \times 10^{21} cm^{-2} mag^{-1}} \tag{6}$$

where R_V is taken as 3.1. A_V can be related to optical depth τ_ν as,

$$A_\nu = 1.086 \tau_\nu \tag{7}$$

We have, the optical depth τ_ν for a column of length L,

$$\tau_\nu = \int_0^L n_{dust} \sigma_v dl \tag{8}$$

$$= \int_0^L \frac{\rho_{dust}}{m_{dust}} \sigma_v dl \tag{9}$$

where σ_v is the scattering cross-section and n_{dust} is the number density of the dust. This can be rewritten as,

$$\tau_\nu = \int_0^L \left(\frac{\rho_{dust}}{\rho_{gas}}\right) \left(\frac{m_{gas}}{m_{dust}}\right) n_H \sigma_v dl \tag{10}$$

where $n_H$is the number density of the gas. As we know,

$$\int_0^L n_H dl = N_H \Rightarrow \tau_\nu = \left(\frac{\rho_{dust}}{\rho_{gas}}\right) \left(\frac{m_{gas}}{m_{dust}}\right) N_H \sigma_v \tag{11}$$

Hence, from (7) and(11)

$$A_V = 1.086 \left(\frac{\rho_{dust}}{\rho_{gas}}\right)\left(\frac{m_{gas}}{m_{dust}}\right) N_H \sigma_v \tag{12}$$

$$\frac{\rho_{dust}}{\rho_{gas}} = \frac{A_V}{1.086 N_H \sigma_v}\left(\frac{m_{gas}}{m_{dust}}\right) \tag{13}$$

We can take,

$$m_{gas} = 1.4 m_H \tag{14}$$

$$m_{dust} = \rho_{grain} V \tag{15}$$

We assume that the size of the grain is comparable to λ

$$\frac{\pi a^2}{\lambda} \approx 1 \tag{16}$$

We thus estimate the dust to gas ratio as

$$\frac{\rho_{dust}}{\rho_{gas}} = 0.006 - 0.01 \tag{17}$$