

EXTINCTION OF RADIATION IN THE UNIVERSE: FROM F. G. W. STRUVE UP TO NOW

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Abstract. We briefly overview the most important studies that led to the understanding of the vital role of extinction of radiation in the Universe. We also point to the existing uncertainties in the determination of extinction corrections for stars and galaxies.

Key words: ISM: extinction – Earth: atmospheric extinction – galaxies: intergalactic and circumgalactic dust

1. BRIEF HISTORICAL OVERVIEW

The first documented observation of dark regions in stellar distribution is that of William Herschel. He observed in 1784 the sections of the sky containing no stars. The nature of such dark spots remained a mystery for tens of years. F. G. W. Struve (1847) found that the apparent number of stars per unit volume drops with distance from the Sun. He introduced extinction as large as 1 mag per kpc to explain this effect. This estimate is remarkably close to modern estimates (0.7–1.0 mag per kpc). After tens of years the astronomers concluded that the dark spots in the stellar background are due to the presence of irregularly distributed diffuse matter that causes the absorption and scattering of the radiation of stars. Trumpler (1930a,b) demonstrated that stellar light is reddened by submicron particles (interstellar dust) in the central plane of the Milky Way. He proved that extinction depends on wavelength approximately as $1/\lambda$ in the visible spectral range, which is close to the results of modern studies.

2. EXTINCTION OF RADIATION

For Earth-bound observers, extinction arises from the interstellar medium (ISM), intergalactic medium, and the Earth's atmosphere. It may also arise from the circumstellar and circumgalactic dust around an observed object. The strong atmospheric extinction in some wavelength regions (for example γ - and X-rays, ultraviolet and infrared) requires the use of Space-based observations.

The Earth's atmospheric extinction varies with location, altitude and wavelength. Atmospheric extinction has three main components: Rayleigh scattering by air molecules, scattering by aerosols and molecular absorption. Molecular (telluric) absorption is mainly caused by oxygen and ozone, which absorb strongly

in the near-ultraviolet, and water, which absorbs in the infrared. The amount of atmospheric extinction is the lowest at the zenith and is at a maximum near the horizon. In the visual range the amount of atmospheric extinction in the zenith is about 0.2 magnitudes.

3. INTERSTELLAR EXTINCTION

Interstellar extinction varies with wavelength, such that the shorter the wavelength the stronger the extinction. Superimposed on this general trend are absorption features which have various origins. Strong discrete absorption features include the 2175 Å bump, the 3.1 μm water ice feature and 10 and 18 μm silicate features. The origin of the broad bump peaking near 2175 Å is still not well understood. Draine (2009) suggests that this feature is due to π - π^* excitations in aromatic carbon, such as graphite or polycyclic hydrocarbons. Some authors think that this feature is produced by the polycyclic aromatic hydrocarbons (PAH). Extinction curves contain besides these strong discrete features about 200 weak diffuse interstellar bands (DIBs) which have not yet been reliably identified.

The IS extinction curve (the dependence of extinction on wavelength) is usually determined (plotted) in the form of color excesses relative to E_{B-V} :

$$k(\lambda - V) = E(\lambda - V)/E(B - V). \quad (1)$$

The color excess is defined as

$$E(\lambda - V) = A_\lambda - A_V = (m_\lambda - m_V) - (m_\lambda - m_V)_\circ, \quad (2)$$

where $(m_\lambda - m_V)_\circ$ denotes the intrinsic value for the color index of the star under consideration (m is the observed magnitude) and A_λ and A_V are the total extinctions expressed in magnitudes. E_{B-V} is the colour excess in the Johnson photometric system bands B and V . The colour excess may be determined, even when the total extinction is not known in any of the photometric bands. The extinction curve presented by Equation 1 gives us relative values of extinction. To find the total (absolute) extinction at some wavelength, we need to know at least one value of the absolute extinction, for example in the V passband (A_V). The widely used parameter is the total-to-selective extinction ratio $R_V = A_V/E(B - V)$. Usually the value of R_V is determined by extrapolation to $1/\lambda = 0$. The extinction for infinite wavelength should be zero by definition. It is very difficult to correctly determine R_V because in the IR range the re-emission term of the dust cannot be ignored and also because the absorption coefficient of the gaseous component of stellar winds and envelopes increases substantially with the increase of wavelength.

4. METHODS OF INTERSTELLAR EXTINCTION ESTIMATES

Two different methods can be used for finding the relative IS extinction curve. The first approach is the “pair method”. According to this method the extinction curve is constructed by comparing the fluxes of a reddened star with an identical unreddened (standard) star. The problem is that it is difficult to find suitable standard stars in the sky. The second approach is the “model atmosphere” method. Here the extinction is determined by comparing the fluxes of a reddened star with the theoretical models. This method is good only for the stars with weak stellar

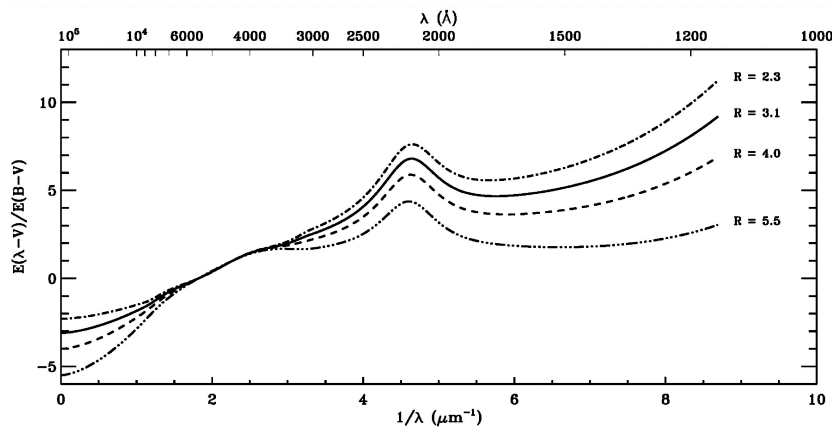


Fig. 1. Interstellar extinction curves for different R_V .

winds, because the atmospheric models of stars with strong winds depend on many individual parameters. Both these methods give quite reliable relative extinction curves, but for absolute extinction estimates it is needed to know R_V . In most cases the galactic mean extinction curve with the mean value $R_V = 3.1$ is used for the IS extinction corrections. In some cases this approach may lead to substantial errors. Figure 1 presents the widely used IS extinction curve of Fitzpatrick (1999) for different values of R_V . The value of R_V ought to be larger in the regions where larger grains are expected to reside. Gao et al. (2009) found by the IR extinction study that $R_V = 5.5$ in the Galactic plane. They demonstrated the existence of systematic variations of extinction with Galactic longitude and found that there may not exist an universal IR extinction law at all. Fitzpatrick & Massa (2007) concluded that the use of average extinction law to deredden may result in significant errors.

In the near future the situation ought to improve after massive determinations of correct distances for millions of stars in our Galaxy and in the LMC and SMC by the GAIA mission. It then becomes possible to determine absolute extinctions A_λ for many stars by using the absolute magnitude method. This method demands, besides the correct distances, also the knowledge of stellar parameters.

Individual extinction curves have been determined with sufficient accuracy also for the nearest external galaxies (LMC, SMC, M31, M33). The differences from the extinction curve of our Galaxy are mainly appearing in the UV spectral range.

5. CIRCUMSTELLAR EXTINCTION

Circumstellar (CS) extinction is usually small and is observed only via absorptions due to some atomic or molecular lines. But the circumstellar envelopes of young stars and of the stars with strong stellar winds and shell ejections may consist a lot of dust that causes extinction of stellar radiation in the continuum. Many very young stars are totally obscured by the CS dust in the visual range. In the case of Herbig Ae/Be stars the extinction by the dusty CS shells is quite strong and the dependence on wavelength in the visible and IR ranges is nearly the same as for the IS extinction.

Circumstellar envelopes ought to exist around the pre-SN Ia stars as found by Patat et al. (2007). Therefore the environments of SN may have both a remnant dust and a freshly formed dust due to collision of the explosion matter with the circumstellar envelope. Fries and Steele (2008) suggested that unusual large dust grains (graphite whiskers) can form around Type Ia supernovae, and these grains may be responsible for the dimming of a SN Ia light at large distances instead of the cosmological “dark energy”.

6. INTERGALACTIC AND CIRCUMGALACTIC EXTINCTION

The presence of dust in the intergalactic and intra-cluster medium is concluded both from direct observations and from indirect considerations. The estimates of the relative and absolute amount of extinction caused by IG and CG dust is not well known. The extinction caused by dust between the Galaxy and LMC/SMC is estimated to be about 0.2–0.3 magnitudes in the visual range. In the case of other galaxies the intergalactic extinction is estimated to be up to 1 magnitude in the visual range. Usually it is difficult to distinguish between the contributions of IG and CG extinctions. In some cases CG extinction may fully obscure the light of a galaxy in the visual range (for example the galaxy Maffei 2).

Intergalactic and circumgalactic dust may have some cosmological implications. This dust will absorb the energy from the optical/UV background and re-emit in the far-IR/microwave range. Cosmic microwave background (CMB) and cosmic infrared background (CIB) may be influenced by the IG and CG dust (especially CIB).

7. CONCLUSIONS

Dust seems to be present everywhere in the observable part of the Universe. The extinction of radiation caused by dust and gas distorts the observations. The ongoing and future space missions ought to clarify the situation and help to unveil the true (intrinsic) nature of stars and galaxies.

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