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Properties of dust extinction in NGC 2076

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Abstract. Early-type galaxies with large-scale dust are suitable objects to investigate the properties of dust extinction in extragalactic environments because the underlying galaxies have fairly smooth distribution of the starlight. Total dust content and the physical properties of dust grains may be a function of time and galaxy environment, and thus detailed studies of dust properties may provide important clues about the nature, origin and subsequent evolution of dust in galaxies.

In this paper we present multiband CCD surface photometry of NGC 2076, a lenticular, having a very prominent dust lane running parallel to the apparent major axis of the galaxy. The main objective is to investigate the wavelength dependence of the dust extinction and to estimate dust mass from optical as well as FIR data. The extinction curve is very similar to our Galaxy, having a value of 2.7 for R_V, defined as the ratio of total visual extinction A_V to selective extinction between B and V, E(B–V). The smaller value of R_V for NGC 2076 than the canonical value for our Galaxy R_V = 3.1, implies that the size of dust grains responsible for extinction in NGC 2076 is less than that in our Galaxy. The estimate of dust mass from optical colour excess, total extinction as well as from FIR flux are found to be of the same order and are therefore consistent with one another.

1. Introduction

Dust is now known to be frequently present in early-type galaxies, detected through optical (Ebneter et al., 1988) as well as FIR emissions (Knapp et al., 1989). Dusty early-type galaxies have received systematic attention after their importance in studying the origin and subsequent evolution of the interstellar matter and the underlying galaxy, has been realized (Schweizer 1987). Further, the broad dust lane in these galaxies were also used to investigate properties of dust in extragalactic environments (Goudfrooij et al., 1994, Brosch et al., 1991). The basic tool to study the dust properties is to examine the behaviour of dust extinction in different wavebands i.e. the extinction curve. In this paper we report detailed study of a dusty galaxy

NGC 2076. Some of the observational parameters of this galaxy are listed in Table 1. As the dust lies parallel to the major axis, Ebneter & Balick (1985) have categorised the dust configuration as oblate.

Table 1. Observational parameters of NGC 2076.

1. Alternative names : MGC -03-15-12, IRAS 05445-1648, PGC 17804.
2. Position (epoch 1950) : $\alpha = 05^h44^m33^s.6$; $\delta = -16°47^m59^s$.
3. Dimensions : 2.2 × 1.3.
4. Velocity : 2156 km s^{-1}.
5. Photometric properties :
   (a) Magnitude : $B_T = 14.0$.
   (b) Colours : $(B-V)_T = 1.01 \pm 0.02$: $(U-B)_T = 0.43 \pm 0.04$.
   (c) FIR :
   - [12μ m] = 0.77±0.029 Jy.; [25μ m] = 0.90±0.037 Jy.;
   - [60μ m] = 14.62±0.047; [100μ m] = 30.10±0.12 Jy. (Knapp et al., 1989)

2. Observation and reduction

Broad band Johnson B, V and Cousins R and I images of NGC 2076 were taken at the Prime focus of the 2.3m Vainu Bappu telescope of the Vainu Bappu Observatory, Kavalur, India during March, 1996, as a part of a CCD imaging programme on a sample of early-type galaxies. We obtained one frame each in B, V, R and I filters, with exposure times 40, 30, 15 and 15 minutes respectively, to obtain good signal-to-noise ratio in all the filters. Observations were taken under photometric conditions and seeing was in the range 2″.5 - 3″.0 (FWHM). Several sky flats in each filter and bias frames were taken for preprocessing of the CCD data.

Cleaning of these images was done using standard tasks within IRAF[1]. Galaxy frames in different filters were aligned to an accuracy better than 0.1 pixel by translation. The sky background was determined at the regions far off from the galaxy and not affected by the foreground stars.

3. Analysis technique

The isophotal shape analysis was carried out using the 'ellipse' task within "STSDAS"[2], which is based on the method described in detail by Jedrzejewski (1987). We have determined the centre of the median filtered I band image and used the same centre for isophotal shape analysis of all the well aligned frames. While fitting ellipses to the isophotes, the centre was kept fixed. We have derived the surface brightness and shape parameters of this galaxy by masking out the regions occupied by the dust lane and foreground stars. Aperture photometry

[1]IRAF is distributed by the National Optical Astronomy Observatories (NOAO), which is operated by the Association of Universities, Inc. (AURA) under co-operative agreement with the National Foundation.

[2] The Space Telescope Science Data Analysis System STSDAS is distributed by the Space Telescope Science Institute.

of this galaxy in optical broad band filters was done by Boisson et al. (1994). Detailed surface photometry of this galaxy has not been reported in the literature. We have used the aperture photometry of Boisson et al. (1994) to calibrate our frames. The surface brightness profile and shape parameter profiles are shown in Fig. 1. The parameter b_4 characterizes the deviation of isophote from the pure ellipse and it appears as the coefficient of the fourth order cosine term of the Fourier expansion of the ellipse fitting procedure.

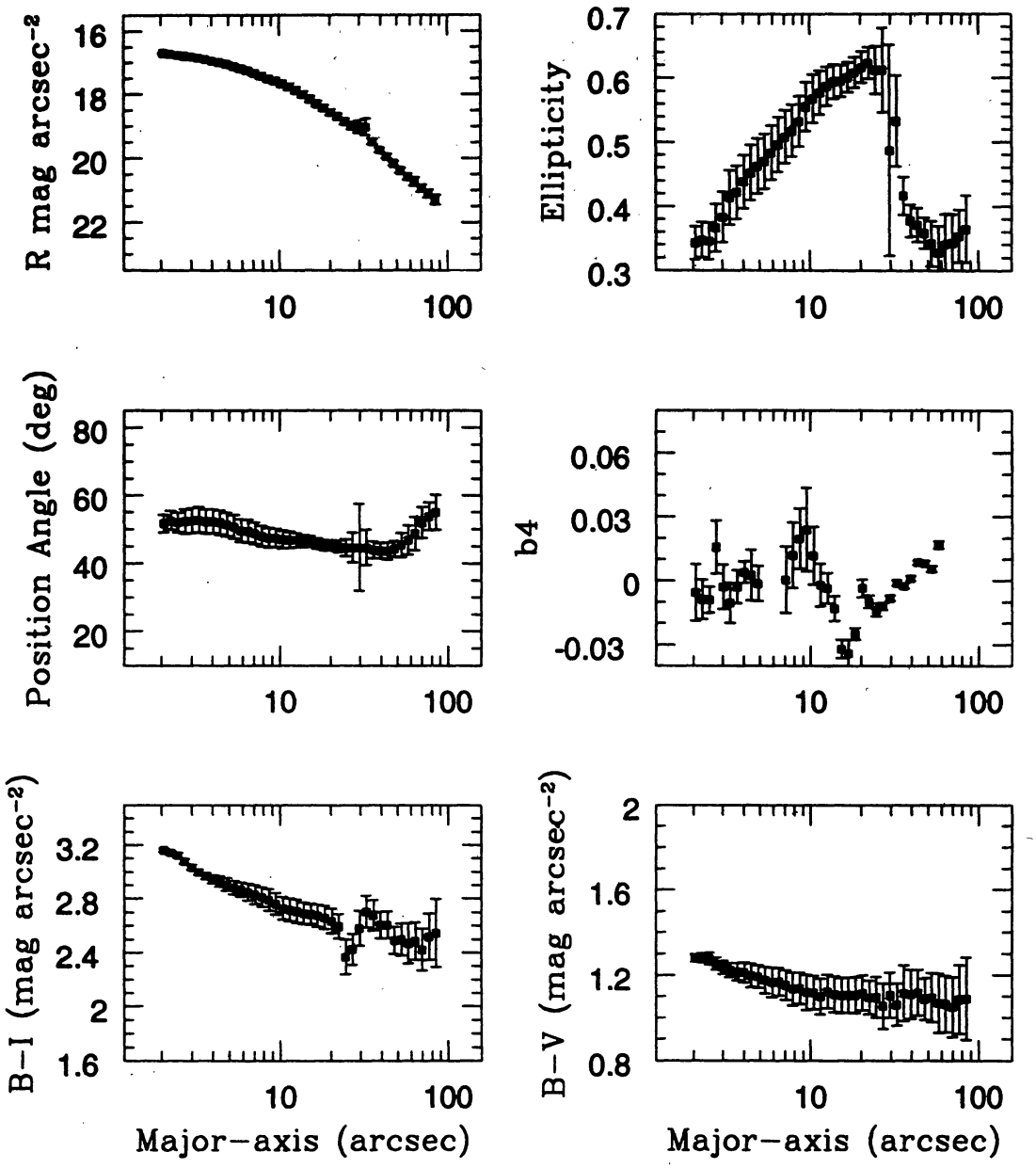

Figure 1. Surface brightness, ellipticity, position angle, b4 parameter, colour profiles of NGC 2076.

3.1 Generation of colour-index and extinction maps

Colour-index map : To calculate the mass of the dust residing in the galaxy we have generated the colour-index maps (B–V, V–R, B–I, V–I) using the broad band images. These maps were used to determine the dust distribution and colour-excess in the dusty region. The B–I colour map is shown in Fig. 2.

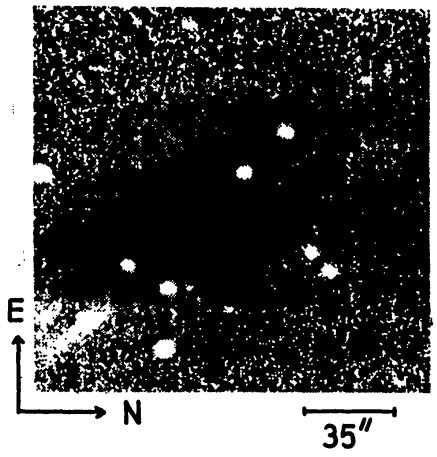

Figure 2. B-I colour image of NGC 2076, darker shade represents the redder region.

Extinction maps : The amount of extinction is determined by comparing the actual light distribution collected from the galaxy with that expected in the absence of dust lane. The extinction map was generated by dividing the original galaxy frame by a smooth model of it. The smooth model was obtained using the isophotal parameters generated by the ellipse fitting process. While fitting ellipses the regions occupied by dust and foreground stars were masked and ignored. The fits were carried out with all the fitting parameters allowed to vary, except the centres. By applying polynomial fit to the fitted data a smooth model of the galaxy was obtained. The model images were used to get the extinction map at each wavelength in the following manner

$$A_\lambda = -2.5 \log (I_{\lambda,obs}/I_{\lambda,model}), \quad (1)$$

where, I stands for the ADU counts. This gives the desired extinction map in magnitude scale.

4. Results

4.1 Extinction curve

Extinction A_λ at different location of dust lane was calculated in each filter, local colour excess was also obtained with this. Linear regression between different extinction values were calculated and the best fitting slope were obtained. The value of R_V, i.e. the ratio of total extinction A_V in the V band to the selective extinction E_{B-V} between B and V bands, is found to be 2.70 ± 0.28, whereas its Galactic value is reported as 3.1 (Savage & Mathis 1979).

Extinction curve for this galaxy alongwith the Galactic extinction curve has been plotted in Fig. 3. The relative grain size ($< a >/a_{Gal}$; a_{Gal} is the characteristic grain size of dust in our Galaxy) is obtained by shifting the extinction curve along $1/\lambda$ axis until it best matches with the Galactic curve. The relative grain size thus obtained is $< a >/a_{Gal} = 0.89 \pm 0.02$.

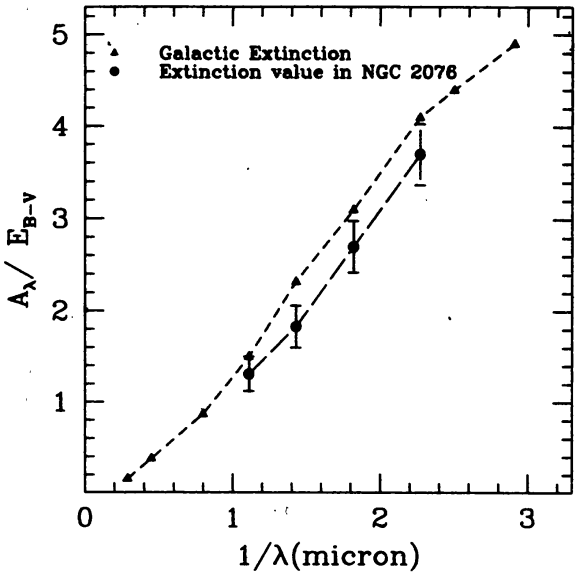

Figure 3. Extinction curve of NGC 2076 alongwith Galactic Extinction curve.

4.2 Dust mass estimation

Dust mass has been estimated using optical colour excess, total extinction and FIR data.

- *Dust mass from colour excess* : The average colour-excess E(B-V) across the dust lane is found to be 0.16 ± 0.02. Assuming that the dust properties in NGC 2076 is similar to that in our Galaxy, we have estimated the neutral hydrogen column density using the relation given by Bohlin et al. (1978). Neutral hydrogen column density is then integrated over the region occupied by dust to get the total neutral hydrogen content of this galaxy. Assuming as gas-to-dust ratio of ~ 100 the dust mass is calculated, which is 1.8×10^6 $M_\odot$.

- *Dust mass from total extinction* : We have made an attempt to derive the dust content of this galaxy using the extinction values. For a given grain size distribution n(a), the specific grain mass density ρ_d, and length of the dust column l_d, the dust column density can be calculated using the relation

$$\Sigma_d = \int \tfrac{4}{3} \pi a^3 \rho_d n(a)\, da \times l_d \qquad (2)$$

We have used the dust size distribution of Mathis et al. (1977) i.e.

$$n(a) = n_0 a^{-3.5} \quad (a_- \leq a \leq a_+) \qquad (3)$$

The upper and lower dust particle sizes are taken to be

$$a_+ = < a > / a_{Gal} \times 0.22\mu m \; a_- = 0.005\mu m, \quad (4)$$

respectively. The value of $< a > / a_{Gal}$ is 0.89 ± 0.02 for NGC 2076 as calculated in section 4.1. We have assumed that the dust is composed of silicate and graphite grains with equal abundance ratio and typical grain size of $a_{silicate} = 0.1\mu m$, $a_{graphite} = 0.05\mu m$. The dust mass estimated in this manner turns out to be $3.2 \times 10^6 M_\odot$.

Dust mass from FIR data : We have used FIR flux of this galaxy to calculate temperature of dust and total dust content of this galaxy. Dust temperature in this galaxy is found to be 36K. Dust mass is calculated using the relation given by Thronson et al. (1986). The total dust content, estimated using FIR flux is $3.67 \times 10^6 M_\odot$.

5. Conclusion

The main conclusions of present work are as follows :

1. Extinction curve for NGC 2076 is similar to that in our Galaxy. The smaller value of R_V than that of our Galaxy indicates that the dust grain size in this galaxy is smaller than the Galactic dust particle size.

2. The estimate of dust mass from optical colour excess, total extinction as well as from FIR flux are found to be of the same order and are therefore consistent with one another.

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