

Research Note

The typical interstellar extinction in the Small Magellanic Cloud*

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Summary. We give a mean UV extinction curve for the Small Magellanic Cloud which corresponds to the most common case and consequently to the most probable typical extinction law. The curve is almost linear in λ^{-1} without any evidence of the 2200 Å galactic feature. This is consistent with almost pure silicate interstellar grains and little graphite grains, as expected from the large underabundance of carbon in the SMC with respect to other heavy elements.

Key words: Small Magellanic Cloud – interstellar medium: extinction

Introduction

The study of ultraviolet interstellar extinction in the Small Magellanic Cloud (SMC) has proved very difficult because of the extreme scarcity of known reddened stars and of their apparent faintness. The usual method for determining the extinction law consists in comparing pairs of reddened and unreddened stars matched in spectral type, observed with the International Ultraviolet Explorer (Boggess et al., 1978). In a preliminary paper, Rocca-Volmerange et al. (1981) derived the first UV extinction curve for the SMC: it was characterized by the absence of the 2200 Å excess, a major feature of the galactic curve (Savage and Mathis, 1979) and by the steep rise of the UV extinction at the shortest wavelengths, higher than in the Galaxy and even than in the LMC (Nandy et al., 1981; Koornneef and Code, 1981).

This result was confirmed later by Hutchings (1982) but in a somewhat redundant way as this author used a large fraction of our IUE spectra. Nandy et al. (1982) and Bromage and Nandy (1983) published also extinction curves for the SMC; although partly based on new observations, they must be looked at as considerably uncertain, owing to the lack of visible observations which are required for determining accurate spectral types and colour excesses.

We have carried on new IUE observations in the SMC, making simultaneously a special effort to obtain *UBV* and MK classifications of the observed stars. We are now in position to present an

UV extinction curve which should correspond to the typical extinction law for the SMC. A comprehensive study of interstellar matter in this galaxy, based on our complete sample, will be published later.

Observational data

The pair method for deriving extinction curves has been very carefully used for seven reddened stars and eleven unreddened or slightly reddened stars in the SMC. The great majority of these stars have been reobserved by us at ESO in *UBV* photometry (1 m telescope) as well as in spectrography (1.52 m telescope equipped with the RV Cass spectrograph or the Boller and Chivens image tube spectrograph) in order to get accurate and homogeneous photometric data and MK spectral types. The details of these new observations will be given in a forthcoming paper (Maurice et al., 1984). Moreover, the ESO and SRC sky surveys, as well as SMC Schmidt plates taken for this purpose, have been investigated to be sure that the sample stars are not detectable multiple objects.

Star pairs have then been formed *i*) within at most one spectral subclass, the O class being considered as a single subclass since the intrinsic UV colours of O stars do not differ more than those of two consecutive B subclasses (Nandy et al., 1976; Bohlin, 1982) and *ii*) within one magnitude in luminosity between the reddened star and its comparison star. This procedure tends to minimize the effect of spectral type mismatch and to avoid the strong bias introduced by comparing stars of too different luminosities, the effect of which is particularly evident in the region around 1900 Å (Fe III feature, see below).

The ultraviolet spectra have been obtained with the IUE Satellite in the low resolution mode (resolution ~ 7 Å) with both SWP and LWR cameras (wavelength ranges 1150–1975 Å and 1900–3200 Å) through the large aperture ($10'' \times 20''$). A few IUE spectra of comparison stars obtained from the data bank have been added to our observations.

Table 1 gives the data pertaining to the stars which are used in the present paper. In particular one must note the presence of the new heavily reddened star AV398 which will give a much higher weight to our determination of the extinction curve.

The typical ultraviolet extinction curve in the SMC

The IUE spectra have been processed at Marseille Observatory with an original programme developed by G. Muratorio. Low quality pixels have been systematically eliminated, and old data (obtained before the IUE software changeover) were reprocessed

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* Based on observations with the International Ultraviolet Explorer (IUE) at the Villafranca Satellite Tracking Station of the European Space Agency, and on observations at the European Southern Observatory, La Silla, Chile

Table 1. Observational data

Star name ^a	MK Sp	V	B-V	U-B	n	$\Delta(B-V)$	ΔV_o^b	SWP image	t min	LWR image	t min
Reddened star											
AV 398	09.7I ^c	13.85	+0.08	-0.79	3			18911	220	14963	110
Comparison stars											
Sk 18	07+Neb ^d	12.47	-0.20	-0.96	3	0.28	0.51	8294	16	7240	10
Sk 32	04-5V: ^{e,f}	13.71	-0.23	-1.09	2.5 ^g	.31	-0.82	16253 ^h	45	12493 ^h	40
Sk 76	B0.5I: ^e	12.76	-0.13	-0.91	2.5 ^g	.21	0.44	18910	40	14949	20
Sk 82	B0-0.5Ia	12.13	-0.14	-0.93	4	.22	1.04	8293	16	7239	8
Sk 103	B0Ia	12.37	-0.15	-0.94	3	.23	0.77	16049	22	12345	11
Sk 107	09.5III	12.90	-0.20	-1.00	2 ^g	.28	0.08	10315 ⁱ	18		
Sk 142	OV: ^e	13.62	-0.20	-0.98	3 ^g	.28	-0.64	18909	60	14948	25
Sk 159	B0.2Ia	11.88	-0.17	-0.94	3	.25	1.20	6590	10	5642	6
Reddened star											
Sk 13	B2-2.5Ia	12.40	+0.01	-0.76	3			8295	63	7241	29
Comparison stars											
Sk 94	B2Iab	12.38	-0.16	-0.90	3	0.17	-0.51	7638 ^j	25	12349	15
Sk 119	B2-(3)Ia	12.16	-0.09	-0.83	4	.10	-0.07	16050	27	12346	14
Sk 145	B2Ia	12.57	-0.16	-0.88	2.5 ^g	.17	-0.70	10316 ⁱ	36		
Reddened star											
Sk 191	B1.5Ia	11.85	-0.04	-0.85	5.5 ^g			16052	28	12348	12
Comparison stars											
Sk 85	B1.5Ia	12.03	-0.12	-0.90	3	0.08	-0.43	8296	17	7242	8
Sk 94	B2Iab	12.38	-0.16	-0.90	3	0.12	-0.90	7638 ^j	25	12349	15
Sk 145	B2Ia	12.57	-0.16	-0.88	2.5 ^g	0.12	-1.09	10316 ⁱ	36		

a Catalogues of Sanduleak (1968, 1969) and of Azzopardi and Vigneau (1975).

b Estimate of the luminosity difference: $\Delta V_o = \Delta V - 3.1 \Delta(B-V)$.

c Weak metallic lines.

d Classification from Ardeberg and Maurice (1977).

e Moonlight contamination.

f Crampton and Greasley (1982) give a spectral type 05V.

g UVB photometry from literature: we adopt a weighted mean (according to the telescope used) between Azzopardi and Vigneau (1975), Ardeberg and Maurice (1977), Isserstedt (1978) and Ardeberg (1980) measurements.

h IUE data bank: image obtained by Mc Lachlan

i IUE data bank: image obtained by Parsons

j IUE data bank: image obtained by Benvenuti

with the new absolute calibration (Bohlin and Holm, 1980). Spectra were smoothed over $\sim 50 \text{ \AA}$ in the SWPrange and $\sim 100 \text{ \AA}$ in the LWP range, from $1250 \text{ \AA}$ and $1950 \text{ \AA}$, respectively. Indeed, below $1250 \text{ \AA}$ the spectrum is severely affected by absorption in the damping wings of interstellar Lyman α , and below $1950 \text{ \AA}$ the sensitivity of the LWR camera is strongly decreasing. No correction has been made to cancel the so-called "FeIII feature" around $1900 \text{ \AA}$ (Swings et al., 1973; Koornneef and Code, 1981), as we feel that such a correction is more or less arbitrary and may hide some real behaviour of the extinction curve. Moreover we expect that this effect will not be important when the pairs of stars are reasonably well matched, especially in luminosity.

The comparison of the smoothed fluxes of a reddened star and its comparison star of about the same spectral type and luminosity gives the absorption corresponding to a colour excess $E(B-V)$ equal to the difference $\Delta(B-V)$ between the colours of the two stars. When normalized to $A_V=0$ and $E(B-V)=1$ one obtains the conventional extinction curve $E(\lambda-V)/E(B-V)$ versus λ^{-1} .

The three most reddened stars in our sample (Table 1) are compared to several stars which bracket the programme stars in spectral types, enabling thus to reduce notably the various random and systematic errors. They give the same extinction curves, well within the expected errors ($\sim 1.5 \text{ mag}$ at $\lambda^{-1}=6.5$, see Massa et al. (1983) for a discussion of the errors involved in the extinction pair method). Most of the other SMC stars give also similar curves, although the smaller values of $\Delta(B-V)$ lead to a larger spread in the results. We recall however that two stars present extinction curves which differ appreciably from this scheme: Sk 143 which has a galactic-type ultraviolet extinction (Lequeux et al., 1982) and Sk 124 which has an intermediate curve more similar to the LMC mean curve (Lequeux et al., 1983); the case of the latter has to be studied further because of its high luminosity and possible spectral peculiarities. We find on the other hand that the gas-to-colour excess ratio for these two stars differs noticeably from the mean value we have for the other SMC stars, a value which is 17 times larger than the galactic value (Lequeux et al., 1983).

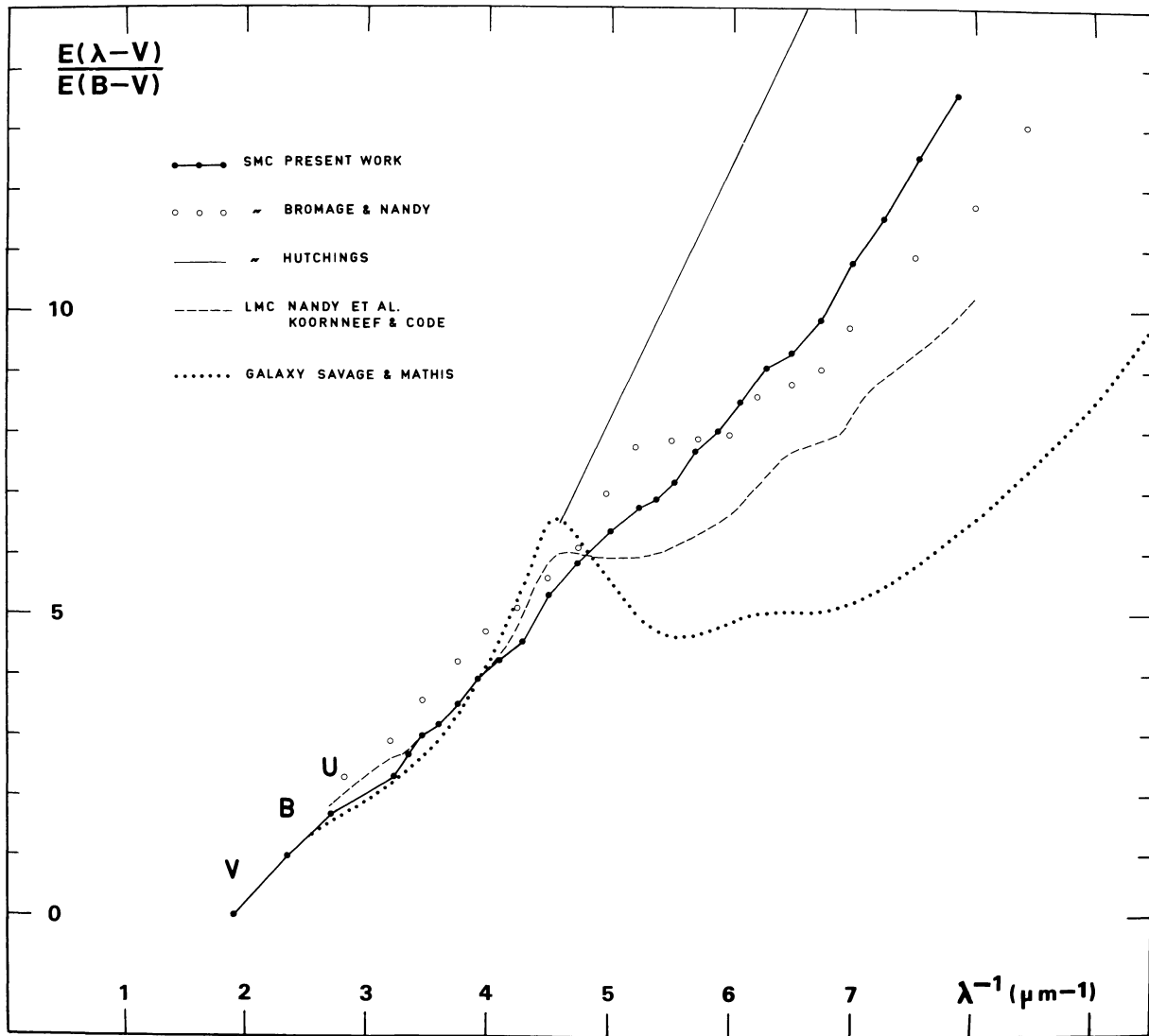


Fig. 1. SMC extinction curve (present work) compared to Hutchings (1982) and Bromage and Nandy (1983) results. The galactic mean curve (Savage and Mathis, 1979) as well as the LMC mean extinction [average of Nandy et al. (1981) and Koornneef and Code (1981) results] are shown for comparison

On account of these arguments, we feel reasonable to consider that the average curve derived from the study of star pairs in Table 1 depicts the more common or typical ultraviolet interstellar extinction in the SMC (Table 2). Each pair has been weighted according to its $\Delta(B-V)$. The standard error on the average (column 5) is obtained by dividing the RMS deviation by $(N/2)^{1/2}$ where N is the number of different reddened and comparison stars.

This curve is surprisingly smooth, practically linear and most of the irregularities may be accounted for by important stellar or interstellar lines (Civ 1550, AlIII 1859, FeIII feature, FeII 2342–2382, MgII 2798) which are not completely removed in the pair method.

Discussion

Validity of the proposed UV extinction law

As far as we know, the SMC stars that we selected constitute the only sample for which we dispose simultaneously of i) large true

colour excesses ii) accurate MK spectral classifications and *UBV* photometry and iii) suitable well classified comparison stars with similar luminosities. The results of Table 2 are qualitatively in good agreement with the curve published by Rocca et al. (1981). However they constitute a considerable improvement over it and over other determinations as well. The extinction curve given by Hutchings (1982) is much higher than ours (Fig. 1); it is essentially based on our IUE spectra of Sk 13 and Sk 124, and probably also on Sk 101, a highly “reddened” star with a red close-by companion which is likely at the origin of the apparent colour excess. Anyhow, in the absence of precision about the pairs of stars, it is difficult to consider Hutchings’ result as well established. The extinction curve proposed by Bromage and Nandy (1983) is more comparable to ours (although more irregular) except in the extreme UV where it is lower (Fig. 1). Apart from our IUE spectra of Sk 13 and Sk 124, they have used a material questionable as can be inferred from a careful scrutiny of their stars: the pair HD 4976/Sk 57 is definitely very late (B6Ia) for studying interstellar extinction, more

Table 2. Typical SMC extinction law

λ^{-1} (μm^{-1})	λ (Å)	$E(\lambda-V)$ $E(B-V)$	RMS deviation	Standard error
7.84	1275	13.54	1.53	.65
7.52	1330	12.52	1.54	.66
7.23	1385	11.51	1.22	.48
6.98	1435	10.80	1.11	.43
6.72	1490	9.84	1.01	.40
6.48	1545	9.28	.99	.39
6.27	1595	9.06	.90	.35
6.07	1647	8.49	.87	.34
5.88	1700	8.01	.92	.36
5.70	1755	7.71	.90	.35
5.52	1810	7.17	.75	.30
5.38	1860	6.90	.82	.32
5.24	1910	6.76	.95	.37
5.00	2000	6.38	.77	.33
4.73	2115	5.85	.65	.28
4.50	2220	5.30	.80	.34
4.28	2335	4.53	.78	.33
4.09	2445	4.24	.49	.21
3.92	2550	3.91	.61	.26
3.75	2665	3.49	.42	.18
3.60	2778	3.15	.46	.21
3.46	2890	3.00	.59	.25
3.34	2995	2.65	.55	.23
3.22	3105	2.29	.64	.27
2.70	U	1.67	.17	.07
2.35	B	1.00		
1.89	V	0		

especially as the luminosity difference is quite large ($\Delta V_0 \sim -1.73$). Their most “reddened” star, BBB 280, has no spectral type from observation in the visible (and a very doubtful Crv line in the UV spectrum), and a crude photographic photometry which is, in addition, certainly affected by the presence of a close-by companion. Bromage and Nandy compare not validly BBB 280 to Sk 32, and O5V star after Crampton and Greasley (1982). These reasons explain why they found such a large $\Delta(B-V)$ for this pair of stars. Moreover, these authors have used the pair AZZ 393/Sk 32, which is in fact Sk 124/Sk 32: this association is not valid as the spectral types are respectively B1.5–2I and O5V. Consequently we consider their determination of the extinction in the SMC as much less reliable than ours.

Conclusions

The ultraviolet extinction curve that illustrates (Fig. 1) the values given in Table 2 is clearly a linear function of λ^{-1} within the probable errors, without any evidence of the 2200 Å feature. It differs from the galactic curve (Savage and Mathis, 1979) and from the LMC curve (Nandy et al., 1981; Koornneef and Code, 1981) for $\lambda^{-1} > 4$. The shape of the SMC curve can be accounted for by

scattering and absorption by silicate grains alone with a size distribution slightly steeper than the galactic one. The absence of graphite may be related to the large underabundance of carbon in the SMC (C/H about 30 times smaller than in the Galaxy after Dufour et al., 1982 and Dufour, 1983). The validity of our statement is strenghtened when examining the typical $N_H/E(B-V)$ ratio we obtain for the SMC: it reaches $10^{23} \text{ cm}^{-2} \text{ mag}^{-1}$, 17 times the galactic value and four times the LMC one. If the extinction is due to silicates, the ratio Si (in grains)/H is about one tenth of the solar neighborhood value; as the SMC is underabundant in most heavy elements (except C and N) by about this factor, this is consistent with most of Si being in grains.

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References

Ardeberg, A.: 1980, *Astron. Astrophys. Suppl.* **42**, 1
Ardeberg, A., Maurice, E.: 1977, *Astron. Astrophys. Suppl.* **30**, 261
Azzopardi, M., Vigneau, J.: 1975, *Astron. Astrophys. Suppl.* **22**, 285
Boggess, A., et al.: 1978, *Nature* **275**, 327 and 377
Bohlin, R.C.: 1982, in *Advances in Ultraviolet Astronomy: Four years of IUE Research*, NASA CP-2238, p. 68
Bohlin, R.C., Holm, A.V.: 1980, *IUE NASA Newsletter* **10**, 37
Bromage, G.E., Nandy, K.: 1983, *Monthly Notices Roy. Astron. Soc.* **204**, 29P
Crampton, D., Greasley, J.: 1982, *Publ. Astron. Soc. Pacific* **94**, 31
Dufour, R.J.: 1983, in *Structure and Evolution of the Magellanic Clouds*, IAU Symp. **108**, Tübingen, Sept. 1983
Dufour, R. J., Shields, G.A., Talbot, R.J.: 1982, *Astrophys. J.* **252**, 461
Hutchings, J.B.: 1982, *Astrophys. J.* **255**, 70
Isserstedt, J.: 1978, *Astron. Astrophys. Suppl.* **33**, 193
Koornneef, J., Code, A.D.: 1981, *Astrophys. J.* **247**, 860
Lequeux, J., Maurice, E., Prévot, L., Prévot-Burnichon, M.L., Rocca-Volmerange, B.: 1982, *Astron. Astrophys.* **113**, L15
Lequeux, J., Maurice, E., Prévot, L., Prévot-Burnichon, M.L., Rocca-Volmerange, B.: 1983, in *Structure and Evolution of the Magellanic Clouds*, IAU Symp. **108**, Tübingen, Sept. 1983
Massa, D., Savage, B.D., Fitzpatrick, E.L.: 1983, *Astrophys. J.* **266**, 662
Maurice, E. et al.: 1984 (in preparation)
Nandy, K., Thompson, G.I., Jamar, C., Monfils, A., Wilson, R.: 1976, *Astron. Astrophys.* **51**, 63
Nandy, K., Morgan, D.H., Willis, A.J., Wilson, R., Gondhalekar, P.M.: 1981, *Monthly Notices Roy. Astron. Soc.* **196**, 955
Rocca-Volmerange, B., Prévot, L., Ferlet, R., Lequeux, J., Prévot-Burnichon, M.L.: 1981, *Astron. Astrophys.* **99**, L5
Sanduleak, N.: 1968, *Astron. J.* **73**, 246
Sanduleak, N.: 1969, *Astron. J.*, **74**, 877
Savage, B.D., Mathis, J.S.: 1979, *Ann. Rev. Astron. Astrophys.* **17**, 73
Swings, J.P., Jamar, C., Vreux, J.M.: 1973, *Astron. Astrophys.* **29**, 207