Extinction coefficients for Calar Alto

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Abstract

Measurements of near-UV to near-IR (U to K') extinction coefficients between 1986 and 2002 done at the Calar Alto Observatory are reported. Average values are presented and discussed in comparison to measurements at other sites and in comparison to theoretical expectations. While the best records approach the condition of a so-called Rayleigh atmosphere, some records point to severe influence of aerosols on the extinction, especially during the summer season.

1 Introduction

In clear nights, ground based optical and near-infrared observers are still limited by effects of the earth atmosphere, namely seeing, sky brightness and extinction. All three effects are believed to be site dependent and must be studied to describe the performances of an observatory. Many observatories offer parameter for standard extinction at their place either on their web-pages, in handbooks or manuals. Table 1 summarizes some of the available sources and papers for the convenience of the reader.

Table 1: Collection of extinction coefficient for various large observatories. The second and third column list the extinction coefficient κ in the Johnon-V and K bands, respectively, in magnitudes per airmass.

Observatory	κ_V	κ_K	Reference
CTIO	0.172	-	AJ 88, 439
KPNO	0.150	0.13	AJ 116, 2341
La Palma	0.113	0.12	New Astron. Rev 42, 453
La Silla	0.124	0.11	A&A 165, 286; A&AS 144, 235
	0.11	-	ESO User Manual 1990
Lick	0.196	-	AJ 116, 2341
Palomar	0.183	-	
Paranal	0.128	-	ESO web page
San Pedro M.	0.140	-	Rev. Mex. A&A 37, 187
Calar Alto	0.23	0.083	this paper

Seeing tests have been done for Calar Alto before the establishment of the big telescopes (Birkle et al., 1976), and a regular monitor recently started to survey this parameter again. Extinction values are not publicly available to our knowledge, except a few reports in photometry papers on individual nights. Here, we will present a more systematic and homogeneous collection of observational results mostly obtained in various runs in which the authors have been involved. We will present values from the U to the K'-band.

2 Background

Under normal astronomical observing condition, the radiative transfer of the optical and near-infrared light of astronomical objects through the atmosphere of the earth can be described in a plan-parallel approximation. The wavelength-dependent extinction has been described since long, especially in its linear approach (e.g. Hardie, 1962). Nowadays, the approach is part of standard text books for astronomical observation techniques. Here, we will follow Walker (1987).

The extinction law describes the absorption dI of intensity I radiated by an astronomical object above the earth atmosphere while the light travels along the line of sight dx through the atmosphere which has an absorption coefficient τ:

$$dI \;=\; -\,I\;\tau\;dx \tag{1}$$

As the objects are observed at various zenith distances X, the absorption integrated over the complete path through the atmosphere x varies proportional to that path length, and in astronomical units, this is normally described by

$$m_{0,\lambda} \;=\; m_\lambda - 2.5\;\tau\;x \;=\; m_\lambda - k_\lambda\;X \tag{2}$$

where m_0 is the astronomical magnitude in a given filter band above the atmosphere, m the same as observed through the atmosphere, k_λ the wavelength-dependant extinction coefficient, and X the so-called zenith distances, is given by:

$$X \;=\; sec(z) \;-\; 0.0018167\;(sec(z)-1) \;-\; 0.002875\;(sec(z)-1)^2 \;-\; ... \tag{3}$$

and

$$sec(z) \;=\; [sin(\Phi)\;sin(\delta) \;+\; cos(\Phi)\;cos(\delta)\;cos(h)]^{-1} \tag{4}$$

where Φ is the latitude of the telescope, h the hour angle, and δ the declination, as usual.

The total extinction sums up from several contributions, namely the Rayleigh scattering at the atmospheric atoms and molecules, extinction due to aerosol particles, and extinction due to Ozone. The Rayleigh scattering A_1 can be described by

$$A_1(\lambda, h_{obs}) \;=\; const_1\;\lambda^{-4}\;n'^2\;exp(-h_{obs}/7.996) \tag{5}$$

where λ is the wavelength of observation, h_{obs} the height of the observatory above sea level and n' the normalized (wavelength dependent) refractive index of air. The Aerosol particles produce a similar absorption term A_2 as

$$A_2 \;=\; const_2 \; A_0 \; \lambda^{-\alpha} \; exp(-h_{obs}/H) \tag{6}$$

where H is a scale length ~ 1.5 km, and $\alpha \sim 0.8$. The Ozone contribution A_3 can be describes as

$$A_3 \;=\; \kappa_\lambda \; T_O \tag{7}$$

with T_O the total amount of Ozone above the observatory and κ the absorption coefficient of that molecule. While A_3 is mostly a function of λ only, A_2 and A_1 also depend on the observatory height, and A_1 further on pressure and temperature of the atmosphere. In the following, we will attribute the total amount of observed extinction A to the three contributions by fitting the wavelength dependent function

$$A \;=\; f_1 \; A_1 \;+\; f_2 \; A_2 \;+ f_3 \; A_3 \tag{8}$$

The above constants *const* are derived through a normalization with the very detailed observations of Tüg (1961ab) at 550 nm for the atmosphere above La Silla. Figure 1 shows the wavelength dependence of the three contributions and a mean extinction curve with $f_1 = 1.5, f_2 = 0.75, f_3 = 0.05$. In the following, we will compare the f_i for various conditions and for several sites to elaborate the relative importance of the three contributions to A. A similar discussion for San Pedro Martir can be found by Schuster & Parrao (2001).

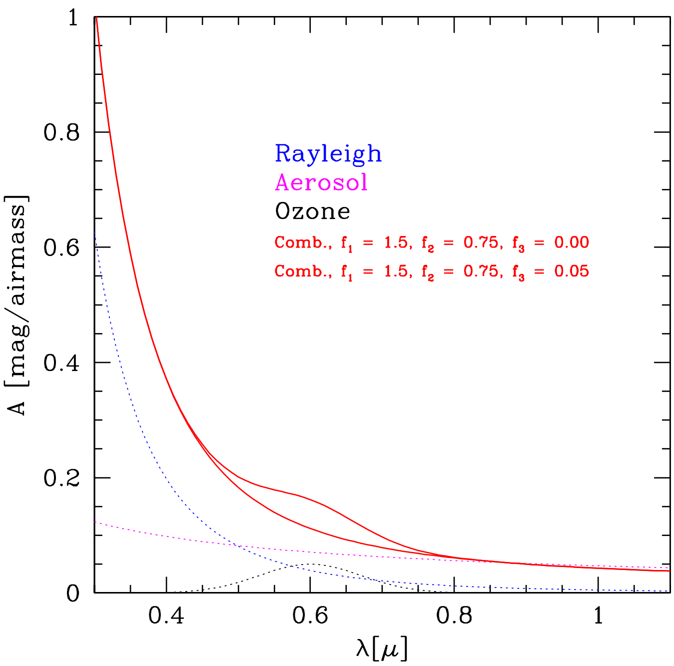

Figure 1: Wavelength dependence of the different contribution to the extinction following Walker (1987). The two red curves show a linear combination of the three contributions with the f-ratios as given in the inlet. The upper curve has some Ozone contribution, the lower one is only for Rayleigh scattering plus Aerosol.

3 Observations

Observations of standard stars either of the lists of Landolt (1992), Neckel & Chini (1980), or of Christian et al. (1985) were obtained in various runs using the optical photometers or CCD imagers available at the Calar Alto telescopes. Details are given in table 2. For the near-infrared observations, the standards were taken from Casali & Hawarden (1992). The observations were taken during normal science observing runs from which we selected those with a good coverage of standard star observations in time and airmass as well as in spread of spectral type (color) of the standard stars. We further restricted the data set to observations of nights which were photometric according to visual inspection and yielded stable transformation coefficients with reliable errors. The number of individual standard star observations is typically about 25 (for photoelectric photometry) and uo to about 100 (for CCD observations) per selected night. As the observations were taken during normal science runs to calibrate the flux of the astronomical targets, the amount of used filters vary from run to run and not all filters were covered equally well. While B and V were included in most runs, R, I, and especially U were less often included. In total, we deal with optical observations in 74 nights while U was observed in 42 nights, only. Due to the large spread in time, various CCD chips were used in combination with the mentioned instrumentations. J and K observations were obtained in 7 nights in the late ninties. Strömgren ubvy observations taken by D. Schönberner at the 1.23 m telescope are fully in agreement with the UBVRI results presented here, but we make only use of his y-extinction coefficients (converted to V).

Table 2: Details for the observations used in this study.

Telescope	Instrument	Runs	Filters
3.5 m	PF-CCD	Dec. 1986	BR
	PF-CCD	Jul. 1986	BVR
	PF-CCD	Jun. 1989	BVRI
	PF-CCD	Jul. 1989	BVRI
	PF-CCD	Aug. 1990	BI
	PF-CCD	Jan. 1991	BI
	OmegaP	1996-2001	JK'
2.2 m	CCD	Jul. 1991	BRI
	Cafos	Jun. 1997	BVRI
	Cafos	Aug. 1998	UBVRI
	Cafos	Jun. 1999	VRI
	Cafos	Dec. 1999	VRI
	Cafos	Dec. 2000	VRI
	Cafos	Jan. 2002	B
1.5 m	Phot	Jul. 1988	UBV
	Phot	Feb. 1989	UBV
	Phot	Aug. 1990	UBVRI
	Phot	Nov. 1990	UBVRI
	Phot	Jun. 1991	UBVRI
	Phot	Nov. 1991	UBVRI
1.23 m	Phot-2	Jan. 1986	uvby
	Phot-2	Sep. 1986	uvby
	Phot-2	Feb. 1987	uvby
	Phot-2	Jan. 1988	UBVRI
	Phot-2	Jan. 1988	UBVRI
	Phot-2	Jan. 1991	UBVRI
	CCD	Jan. 1999	BVRI
	CCD	Sep. 2000	RI

The observations have already some representative distribution, but are still limited in their seasonal distribution. Most of the observations were done in the summer season, thus, June to

August are well covered. Further observations have been done in winter time, with records in November through January while we hold almost no results for February to May and September and October.

The extinction coefficients k were usually taken from linear least square fits which simultaneously also fitted the zero-point for the night while the so-called color-term were obtained for complete runs. The fits were either done to obtain κ_λ directly for every filter (UH) or to obtain coefficient for astronomical colors directly (e.g. $\kappa_{\rm U-B}$) together with κ_V (MF). For the convenience of the reader, we transformed the later all to κ_λ.

4 Results

Figure 2 shows the result for two different nights, one with observations obtained in August 1998 at the 2.2 m telescope and CAFOS, the other obtained in January 1998 with the CCD imager of the 1.23 m telescope.

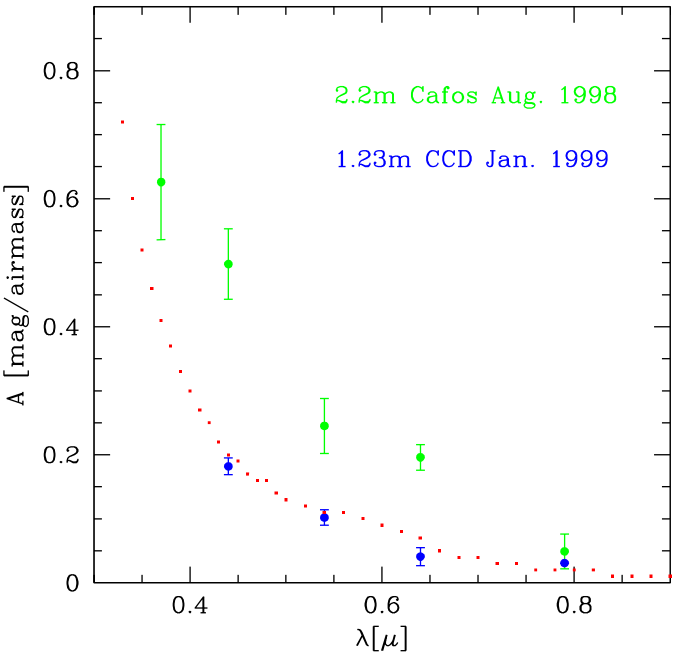

Figure 2: Johnson-Cousins UBVRI extinction observations in January (blue) and August (green) 1998 at Calar Alto. For comparison, the La Silla measurements of Tüg (1961ab) are shown with small red dots.

Obviously, the extinction in the two nights differed substantially. The observations at the 1.23 m telescope were done under conditions approaching the quality reported for sites in the Atacama dessert. The observations obtained with the 2.2 m telescope suffered from much worse conditions resulting in a severe loss in depth of the exposures. This experience motivated us to collect further determinations of the extinction coefficient. The collection should enable to study whether pronounced variations of the extinction coefficient are common or rare and if one can constrain the source of the variability. A further aim was to study whether average extinction coefficients can be established.

The average coefficient are given in table 3 for U to K' from all available nights and are illustrated in figure 4. They are calculated from all available values. One should keep carefully in mind that the given mean values are still based on a limited data set which does not fully sample seasonal variations or long term climatic changes. The rms-scatter of the data indicates a rather large night-to-night variability. Indeed, we have several records were the extinction coefficient vary by more than a factor of two from one night to the consecutive night. Most often, these changes go hand in hand with an increase of visible haze, meaning that the observing conditions getting worse from night to night. But we also hold records in the opposite sense that the following night is much more transparent than the previous one.

Under very good conditions, the extinction approaches Rayleigh scattering with little Aerosol contribution and the coefficient are totally comparable to the one for La Silla as measured by Tüg (Fig. 2). In poorer circumstances, Aerosol particle severely influence the observing conditions. Ozone is hardly constrained. Table 4 gives the fit parameters for f_i for the average coefficients as well as for some seasonal averages in comparison to values for other sites. Figure 3 illustrates the distribution of κ_V.

The most important conclusion which can be drawn is that one has to be aware of the relatively large variations of the extinction coefficient, even night by night. Applying average coefficient or standard coefficient as done frequently might yield quiet misleading results, especially in the summer season. Thus, for precession photometry, the coefficient should be monitored independently in every night, in best case by a small monitoring telescope.

The average optical extinction values (U to I) as obtained here for Calar Alto are not as good as those published for many other observatories (Fig. 5) while the infrared extinction values are as good or even better than those reported for La Palma, La Silla, and KPNO. Guerro et al (1998) have monitored the extinction over La Palma over 14 years and found strong seasonal variations due to dust in the atmosphere coming from the Sahara desert. While the median κ_V-value for La Palma was found to be 0.113 mag/airmass, individual records range up to 0.65 mag/airmass typically in the late summer season. Similar event are also known to some extent at Calar Alto, especially during the early summer season. Our observations include two nights with $\kappa_V \geq 0.6$ while many observations are near the value expected for pure Rayleigh scattering (fig. 4). Given the still limited data base used here as well as the fact, that many of the data were obtained during summer season, we can not exclude that the relatively large average extinction values are affected by such events. So far, we can hardly estimate the relative importance or frequency of haze or dust events as regular extinction monitoring is still missing. However, the median value of the κ_V distribution (Fig. 3) points to a regular quality similar to other sites. The fewer values (one third of the data) obtained in the winter season when the appearance of dust or haze is rarely observed, indicate much better extinction values of a quality comparable to the best astronomical sites (Fig. 4, 5). Table 5 lists some seasonal average values which also supports this view (we do not have enough coverage to study the full seasonal variation with monthly averages). Finally, our data point to the fact that the extinction values are pretty stable from one night to the next in winter seasons while we observed sometimes considerable changes from one night to the next in

Table 3: Average extinction values for UBVRIJK' for Calar Alto and for winter observations only together with the rms scatter of the observations, σ, and the number of nights, n. The few NIR data do not allow a seasonal split.

λ	κ	σ_κ	n	κ_{winter}	σ_{winter}
0.37	0.47	0.20	42	0.39	0.07
0.44	0.35	0.16	60	0.25	0.05
0.54	0.23	0.13	58	0.17	0.06
0.64	0.17	0.12	40	0.12	0.05
0.79	0.09	0.16	40	0.07	0.05
1.20	0.093	0.008	7		
2.20	0.083	0.02	7		

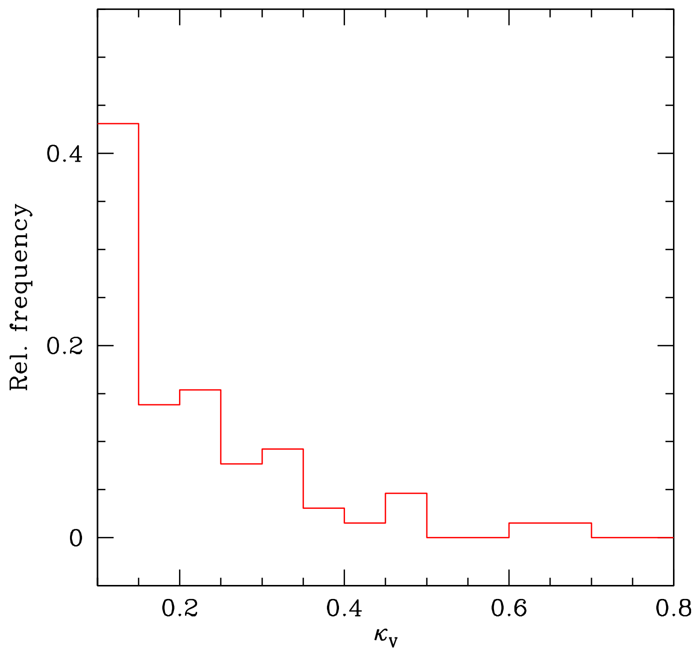

Figure 3: Frequency distribution of the measured V-extinction coefficients above Calar Alto. The median value of the distribution is at 0.16 mag/airmass. The tail to high extinction values indicate Sahara dust events which normally appear during the early summer, similarly to the Canary Islands.

summer season (see above).

5 Conclusion

The presented results indicate that a regular monitoring of the extinction coefficient would be very helpful for a full exploration of the valuable Calar Alto observations. It seems pretty dangerous to apply so-called standard coefficient for the reduction of flux measurements, at least in the optical. Naturally, a regular monitoring is better done with an auxiliary small monitor than with the bigger telescopes devoted to their science projects.

The near-infrared atmospheric transmission at Calar Alto can easily compete with other astronomical sites. In the optical bands, good transmission as at other sites is almost always obtained in winter season. During the summer season, while there still appear a good fraction of nights with good transparency, a severe fraction of the nights show severely reduced transmission.

Table 4: Comparison of the fit-parameters f_i for various sites describing the relative contribution of Raleigh scattering (f_1), Aerosol extinction (f_2), and Ozone extinction (f_3)

Site	height [m]	f_i	f_2	f_3
Calar Alto (all)	2168	1.5	1.25	0.05
Calar Alto (Winter)	2168	1.25	1.0	0.00
Lick	1290	1.25	0.8	0.00
Palomar	1706	1.65	0.35	0.03
KPNO	2120	1.4	0.75	0.00
CTIO	2215	1.5	1.1	0.00
La Silla	2347	1.55	0.03	0.03

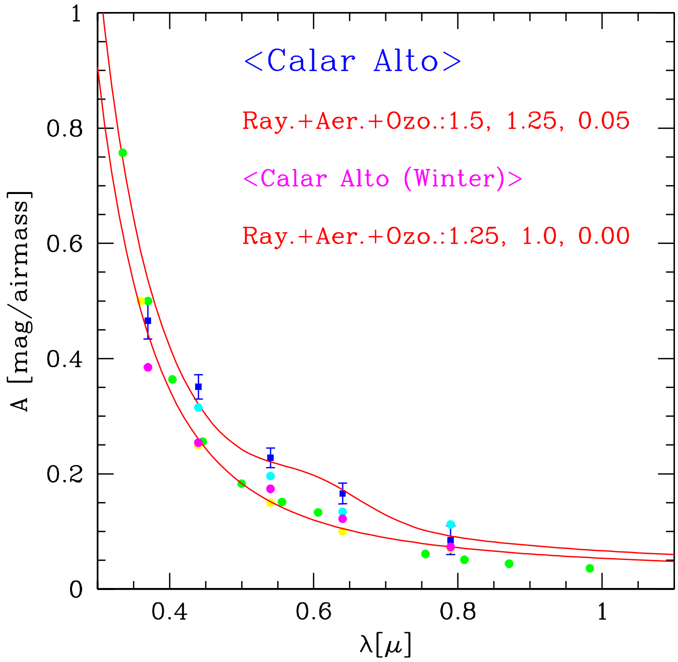

Figure 4: Average Johnson-Cousins UBVRI extinction observations at Calar Alto (blue) compared to standard extinction curves as measured at similar sites: Palomar (green dots), KPNO (yellow) and Lick (cyan). The Calar Alto values are above the one for the other sites which can be attributed to enhanced Aerosol extinction and perhaps some Ozone extinction. Also shown are the average Calar Alto observations for the winter season only (magenta). Those values corresponds pretty well to those of Palomar and KPNO. The two red lines describe the average Calar Alto observations with the f_i parameters as given by the inlet (upper curve) and the typical situation at Palomar and at Calar Alto in winter time (lower curve). For details see section 2, formula (8), and table 4.

A better understanding of the transmission conditions at Calar Alto would be helpful for future planing and development for the site. Therefore, we invite other photometric observers to communicate their observations of extinction coefficients either to the observatory staff or to the first author of this note.

Table 5: Monthly averages of κ_V and its error. n is the number of nights.

Season	κ_V	n
January	0.146 ± 0.012	6
June	0.283 ± 0.039	18
July	0.267 ± 0.059	9
August	0.187 ± 0.030	9
Nov./Dec.	0.188 ± 0.025	9

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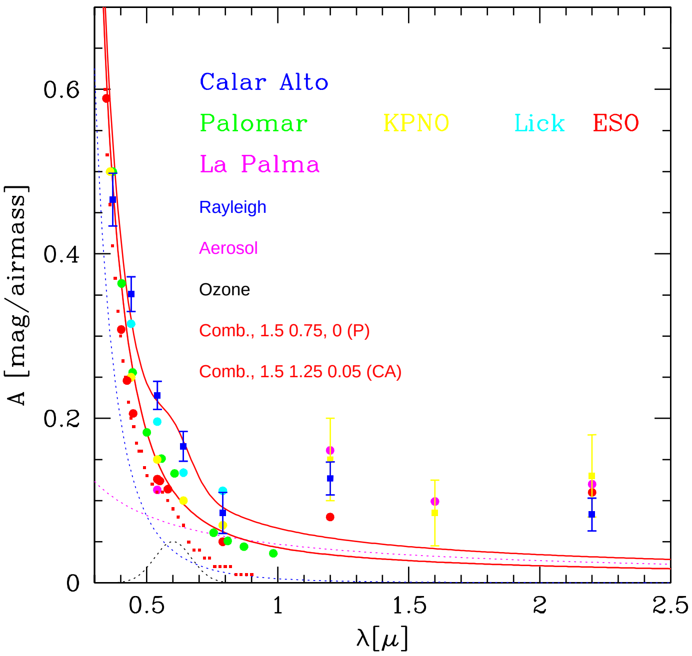

Figure 5: Average Johnson-Cousins UBVRI and JK' extinction observations at Calar Alto compared to standard extinction data of other sites. For comparison, the wavelength dependence of the Rayleigh scattering, the Aerosol and Ozone extinction are also included. The two red lines describe the average Calar Alto observations with the f_i parameters as given by the inlet (upper curve) and the typical situation at Palomar and at Calar Alto in winter time (lower curve). For details see chapter 2.

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