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Atmospheric extinction at the Brno and Skalnaté Pleso observatories

III. A model of Skalnaté Pleso extinction derived from IHW/IAU medium-band photometrical observations of comets in 1985-90

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Abstract. 75 measurements of atmospheric extinction obtained during observations of bright comets 1P/Halley in 1985/1986, 23P/Brorsen-Metcalf in 1989 and C/1989 X1 (Austin) in 1990 in the *IHW/IAU* six-colour intermediate band photometric system at the Skalnaté Pleso Observatory confirmed validity of the two-component model of atmospheric extinction published in Paper II. That is a superposition of a more or less constant component of Rayleigh scattering on temporary clumps of molecules of air and a heavily variable component of scattering on dust particles (aerosols). The found value of a spectral parameter α of the dust component of atmospheric extinction, $\alpha = 1.01 \pm 0.28$, suggests that the scattering centres are tiny dielectric dust particles. The results of *IHW/IAU* extinction study have been compared with the results of *UBV* extinction coefficients gained mostly as a by-product of the photoelectric photometry of variable stars (407 nights in the period from 1962 to 1995).

Key words: atmospheric extinction – Skalnaté Pleso Observatory – *IHW/IAU* photometric system

1. Introduction

This paper is a continuation of a series of papers concerning the characteristics of atmospheric extinction at the urban Brno Observatory and the mountain Skalnaté Pleso Observatory. Two previous papers (Mikulášek et al., 2000 = Paper I, Mikulášek et al., 2001 = Paper II) were based on the treatment of a huge sample of *UBV* extinction coefficients obtained as a by-product of observations of variable stars at both observatories in 1962-1965. It was shown that the atmospheric extinction at the Skalnaté Pleso Observatory could satisfactorily be described by a standard two-component model which consists of a more or less constant component given by Rayleigh scattering on accidental clumps of the molecules of air and a strongly variable component of scattering on the dust particles floating in the atmosphere. In order to explain properties of the Brno extinction, we were forced to introduce an additional variable called a *particular component* acting mainly in the U and B colours. Relations derived in Paper II make it possible to predict values of atmospheric extinction depending on altitude, effective wavelength and time of observation. These relations can serve as a test of validity of the proposed model of extinction.

Extinction measurements obtained as a by-product during the observations of bright comets 1P/Halley in 1985/1986, 23P/Brorsen-Metcalf in 1989 and C/1989 X1 (Austin) in 1990 in the intermediate band *IHW/IAU* system are used to study extinction characteristics of the atmosphere at the Skalnaté Pleso Observatory. The method of observations used and some particular conclusions that are in agreement with the model of atmospheric extinction described in Paper II are given in Svoreň et al. (2002). The observational material mentioned above is the basis of the following, more exhaustive analysis of extinction characteristics of the atmosphere at the mountain Skalnaté Pleso Observatory.

2. Material used

The observational material used comprises of 75 values of extinction coefficients obtained during 20 nights at the Skalnaté Pleso Observatory in the years 1985-1990. Measurements done in six different intermediate band *IHW/IAU* filters in the wavelength interval from 365 to 514 nm give a small but relatively representative sample of the extinction status of the atmosphere and due its quality it can be compared to considerably more extensive samples.

Table 1. Average extinction coefficients. The mean values of extinction and their uncertainty were calculated using robust regression eliminating outliers. The method is briefly described in Mikulášek et al., 2003

colour	eff. wavelength [nm]	number of nights	mean extinction [mag/air mass]	model prediction
U continuum	365.0	13	0.73±0.08	0.72
CN	387.1	17	0.59±0.06	0.59
C_3	406.0	16	0.50±0.05	0.51
CO^+	426.0	8	0.44±0.09	0.48
B continuum	484.5	13	0.36±0.05	0.34
C_2	514.0	8	0.29±0.07	0.30

Characteristics of the six-colours intermediate band photometric system used are described in detail in Svoreň et al. (2002) the names of filters and their effective wavelengths are also listed in Table 1, together with some global characteristics of the observational material – the number of measurements of extinction in each filter, the mean values of extinction coefficients and the uncertainty of their determination.

The measured values on individual nights are listed in Table 2, together with the time of the middle of the observational interval with a precision of a thousandth of a year (a third of a day). The extinction coefficients are always expressed in magnitudes per air mass.

Table 2. Measured and calculated extinction coefficients. Δ X is the absolute value of the difference of air masses between the first and the last observations, and $D(416)$ represents the dust extinction coefficient related to 416 nm (the mean of effective wavelengths of the *IHW/IAU* photometric system).

Year	Δ X	UC	CN	C_3	CO^+	BC	C_2	$D(416)$
1985.616	0.65			0.86				0.56±0.07
1985.625	2.85			0.42				0.13±0.07
1985.795	0.84			0.14				−0.15±0.07
1985.855	0.79		0.37	0.26		0.40		0.00±0.05
1985.863	0.82	0.63	0.48	0.48	0.33	0.25	0.16	0.13±0.03
1985.874	0.86		0.92	0.62				0.43±0.05
1985.876	0.23	0.50	0.29	0.24	0.00			−0.03±0.04
1985.877	0.88	0.75	0.63	0.46	0.33			0.21±0.04
1985.879	0.74	1.29	0.52	0.72	0.52			0.28±0.05
1985.947	0.20	0.71	0.87			0.70		0.55±0.05
1985.950	0.34	0.21	0.47	0.40		0.30		0.13±0.04
1985.996	0.19		0.47			0.32		0.15±0.05
1986.013	0.29	0.80	0.65	0.57	0.62	0.40		0.31±0.03
1986.331	0.49		0.36			0.18	0.29	0.07±0.05
1986.333	0.48	0.66	0.78	0.46		0.28	0.23	0.17±0.04
1986.336	0.48	0.73	0.78			0.34	0.21	0.26±0.04
1986.339	0.67	0.66	0.62	0.39		0.24	0.20	0.16±0.04
1989.586	0.84	0.60	0.19	0.41	0.40	0.29	0.23	0.15±0.04
1989.599	0.24	1.29	1.07	1.04	0.86	0.74	0.76	0.71±0.03
1990.403	1.97	0.68	0.54	0.48	0.42	0.29	0.26	0.19±0.03

3. Parameters of a two-component model of extinction

As it was found in Paper II (Mikulášek et al., 2001), based on an extensive collection of *UBV* extinction measurements at the Skalnaté Pleso Observatory (407 nights in the period from 1962 to 1995), the atmospheric extinction at the Skalnaté Pleso Observatory can satisfactorily be described by a standard two-component model. The extinction in the colour c, $E(c)$, is the sum of the extinction produced by the scattering on dust particles and a more or less constant component given by Rayleigh scattering $R(c)$ on incidental clumps of molecules of air, proportional to an instantaneous barometric pressure.

Applying the expressions in Paper II on the situation of the Skalnaté Pleso Observatory at an altitude of 1783 m above sea level, we obtain the following approximate relation for $R(c)$:

$$R(c) = 0.262 \left[\frac{\lambda(c)}{416}\right]^{-4}, \tag{1}$$

where $\lambda(c)$ is the effective wavelength expressed in nanometres.
The spectral dependence of the variable term $D(c)$ on the effective wavelength could be satisfactorily expressed by the power function:

$$D(c) = D \left[\frac{\lambda(c)}{416}\right]^{-\alpha}, \tag{2}$$

where the term D corresponds to the instantaneous dust extinction at the central wavelength 416 nm.

The extinction measurements at the Brno observatory were analysed together with the Skalnaté Pleso data. They were used in a calculation of the spectral parameter α in Paper II, whose value was found to be 1.04±0.04. This value indicates that the prevailing part of the time-variable extinction is caused by the standard Mie scattering on dielectric particles − dust or aerosols, concentration of which is strongly variable.

The quality of the material of the sample of extinction coefficients used enables us to derive the value of the spectral parameter α without using any other data. We assume that the standard two-component model would be valid for atmospheric extinction in the colour c in the form:

$$E(c) = R(c) + D(c) = 0.262 \left[\frac{\lambda(c)}{416}\right]^{-4} + D \left[\frac{\lambda(c)}{416}\right]^{-\alpha}. \tag{3}$$

In this model, we looked for the value of the spectral parameter α of the dust extinction and for 20 values of the mean dust extinction D_j at 416 nm for the j-th night, so that relation (3) represents the best fit for our data.

A gradient method of non-linear regression in its robust variant (Mikulášek et al., 2003) was used to find the above 21 parameters using all 75 extinction coefficients obtained in six colours characterised by their efficient wavelengths $\lambda(c)$. This method reduces the influence of possible outlier measurements very effectively.

After several iterations, we found a unique, well-defined solution characterised by the following value of spectral parameter of dust extinction: $\alpha = 1.01 \pm 0.28$. The average values of dust extinction D_j referred to 416 nm, including the uncertainty for individual nights, are listed in columns 9 and 10 of Table 2. The parameters α and D_j make it possible, employing equation (3), to forecast the value of the extinction coefficient for any colour characterised by its efficient wavelength $\lambda(c)$. The adequacy of the model can be demonstrated by Fig. 1, where the x-axis represents the predicted values and the y-axis the real measured values.

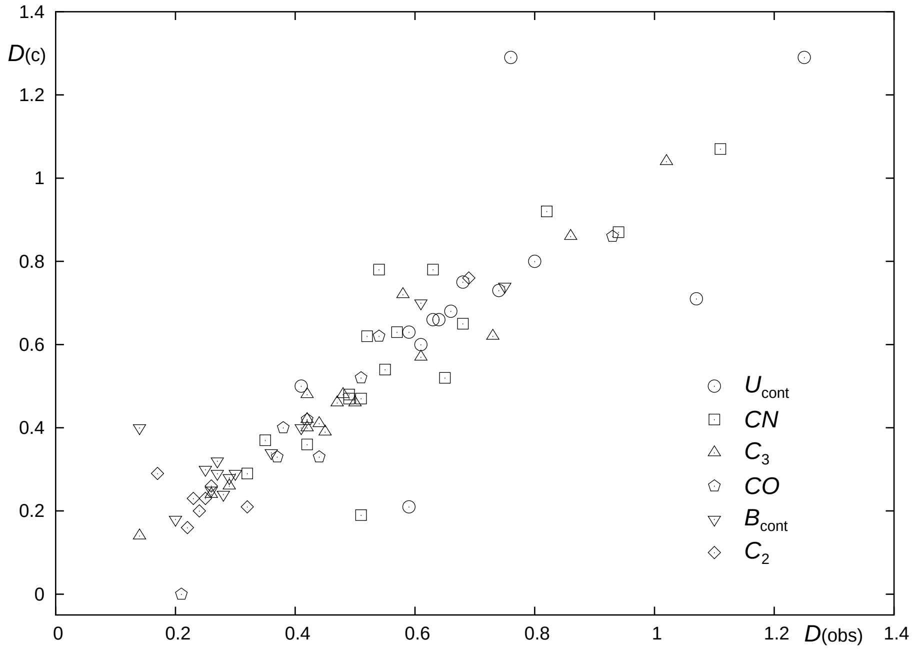

Figure 1. Comparision between the measured extinction coefficients and predicted ones

4. Results and conclusions

The measurements of extinction coefficients as a by-product of the photometric observations of comets are relatively reliable: the average weighted uncertainty of the extinction's determination in one colour is roughly 0.075 mag/air mass. One can compare it with an equivalent value in Paper II - the mean error in B colour was 0.23 mag/air mass!

(1) The most important, physically well-interpreted result gives the value of the spectral parameter: $\alpha = 1.01 \pm 0.28$, which perfectly agrees with the same value found in Paper II. Disregarding its relatively high uncertainty, the result supports our confidence that the main source of the so-called dust extinction is the classic Mie scattering on tiny dielectric dust particles sent to the atmosphere by brisk air streams.

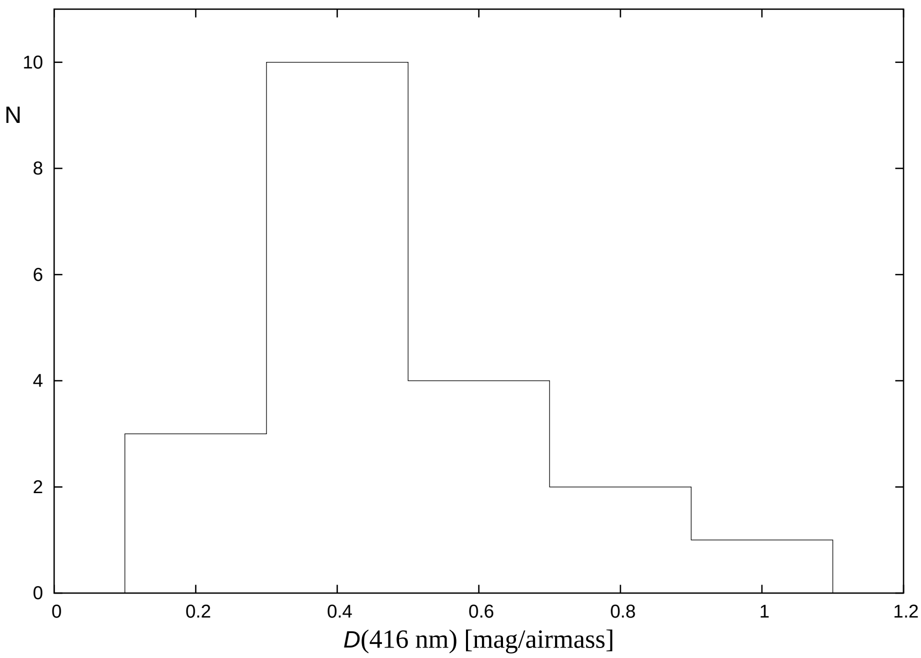

Figure 2. The histogram of the occurence of individual extinction coefficient values

(2) The arithmetic average of the dust extinction at 416 nm is (0.220±0.046) mag/air mass, the total extinction is (0.482±0.046) mag/air mass. The variability of the dust component is extraordinary large, its standard deviation being 0.21 mag/air mass. One can see (Fig. 2) that, in agreement with the analysis of behaviour of extinction in Paper I, the distribution curve of numbers of nights with various extinction coefficients is asymmetric. The asymmetry is also confirmed by the fact that the median of extinction coefficients, 0.165 mag/air mass, differs considerably from the arithmetic mean. As it was shown in Paper I, it is useful to introduce a special dimensionless quantity z, called the asymmetry of the distribution function, defined by the relation:

$$z = \frac{[D(5/6) - D(1/2)] - [D(1/2) - D(1/6)]}{D(5/6) - D(1/6)}, \tag{4}$$

where $D(1/6)$, $D(1/2)$ and $D(5/6)$ are the first sextile, the median and the fifth sextile of the set of extinction coefficients, respectively. As $D(1/6) = 0.08$ mag/air mass and $D(5/6) = 0.41$ mag/air mass, the asymmetry of the distribution function $z = 0.48$.

The found asymmetry of the extinction distribution function z agrees well with the mean value of that asymmetry found in the years 1962−1980 from the Skalnaté Pleso *UBV* measurements, but it undoubtedly differs from the value found in the years 1985−1990, which tends to zero. The fact strengthens our suspicion, already mentioned in Paper II, that the low value of asymmetry in recent years is a consequence of growing criticism of non-perfect nights by the observers, which are then omitted and a sample of extinction coefficients is influenced by a selection effect.

(3) There are nights where mean dust extinction is negative. This evidently physically unrealistic result is an art'fact of the method used for extinction determination. This method requires non-variable extinction during the whole interval of observation. In fact, the condition of non-variable extinction is never strictly satisfied. The variability of extinction results in a scatter of the measured values and, occasionally, it leads even to negative values of extinction.

(4) Our model of extinction justifies and supports the empirically found experience that atmospheric extinction is significantly higher in the short-wave region of radiation. This is demonstrated in Fig. 3, where the dashed line represents the model prediction of the mean value of the dust extinction for the studied data set, the points are the mean measured values for different effective wavelengths.

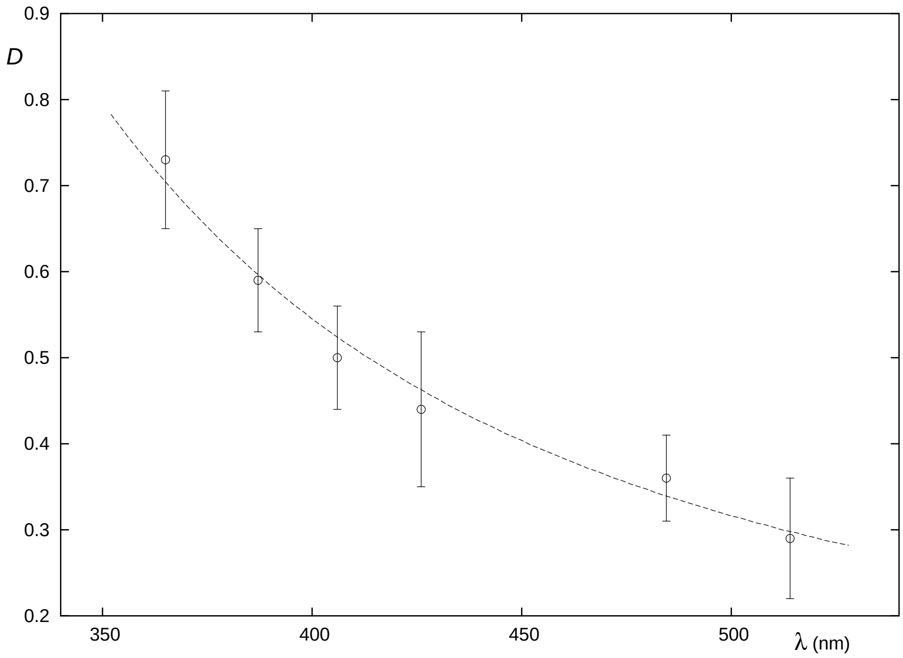

Figure 3. The dependence of extinction on the wavelength

(5) In column 5 of Table 2 the prediction of the dust component of the extinction coefficient at 416 nm for the respective nights, based on the model (see Paper II) of both long-term and seasonal variability, is given. Here some discrepancy was found - the mean difference between the observed and predicted

value is (0.08 ± 0.05) mag/air mass. This shift (which is just at the limit of significancy) can be explained by the fact that during the campaigns of cometary observations the photometry was performed even during nights which were not of the best quality. On the other hand, observers of variable stars simply omitted non-perfect nights.

(6) The dust extinction exhibits apparent seasonal variations with its minimum in the coldest Skalnaté Pleso months: December, January and February and maximum in the warmest ones: June, July and August. The ratio of the maximum to minimum beeing 1.9 ± 1.1. The result is in an excelent agreement with the same ratio 1.9 ± 0.3 as deduced from relation (39) in Paper II.

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