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ATMOSPHERIC EXTINCTION AND NIGHT-SKY BRIGHTNESS AT MAUNA KEA

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ABSTRACT

We present a summary of atmospheric extinction values obtained at the 4200-m and 2800-m elevations of Mauna Kea over the years 1980 to 1986. The wavelengths of the 17 filters in question range from 0.44 μm to 32 μm. While it is possible to obtain an accurate mean extinction value at a given wavelength, there is considerable scatter about the mean for all infrared wavelengths. At visual wavelengths the extinction at the Mauna Kea summit exhibits much less variance. At the summit we find median extinction values of $B = 0.19$, $V = 0.11$, $J = 0.10$, $H = 0.05$, and $K = 0.07$ mag/air mass, respectively. At the 2800-m level we find a median V band extinction of 0.18, and mean reddening $k_{bv} = 0.125 \pm 0.020$ for a star with $(B-V) = 0.0$. During 1986 the night-sky brightness at the 2800-m level was measured to be $V = 21.5$, $B = 22.3$ mag sec^{-2}.

Key words: data analysis–atmospheric extinction–night-sky brightness

I. Introduction

Given well-engineered hardware (telescope plus detectors) on a site with predictable atmospheric extinction, it is possible to set up appropriate lookup tables in the computer system such that real-time magnitudes can be obtained which are within a few hundredths of a magnitude of the values carefully reduced after the fact. These instantaneous magnitudes are extremely useful diagnostics for user facilities at which a relatively small number of instruments is used by a large number of observing teams. It is possible to discover rapidly if the whole system has response consistent with recent observations. One first sets up a table of nominal calibration parameters based on recent observations of standard stars. At the beginning of a night if the real-time preliminary magnitude of the first standard star is found to be "wrong", then one may check such things as focus, alignment, or how many weeks it has been since the primary mirror was washed or realuminized, or one may suspect that the atmospheric extinction is markedly different from the nominal value used to calculate the preliminary reduced magnitude. If the real-time magnitude of a standard star matches its standardized value very closely, then one may confidently proceed with further observations.

The United Kingdom Infrared Telescope (UKIRT) serves as an example of the above procedures. It presently operates three photometers: two 1–5 μm InSb instruments with broad-band filters (UKT6 and UKT9) and a bolometer (UKT7), which operates from 4–20 μm and has broad-band (*L′MNQ*) and narrow-band (8.7, 9.5, 11.7, and 12.5 μm) filters. In the interests of providing a user-friendly environment (by giving useful diagnostic information) and of producing near-publishable magnitudes as observations are being made, UKIRT has computer software for its VAX 11/730 system such that appropriate lookup tables are used to convert instrumental magnitudes to preliminary reduced magnitudes. This allows a rapid checkout of the system at the start of a night of observing and allows one to monitor any changes in sky transparency. If no problems are diagnosed during start-up and the derived preliminary magnitudes are systematically too faint or too bright, one can tie in the observing to the last standard star observed (for all filters and apertures being used). The computer system also saves a copy of the "latest offsets" (i.e., latest arithmetic zero points). If the computer crashes and one resumes observing, one may retrieve the "nominal offsets" (from recent standard star observations on a number of nights) or the "latest saved" set for the purpose of calculating the preliminary reduced magnitudes without having to reobserve a standard star. On the following night the user may simply continue from the night before.

At UKIRT and the IRTF the signal from the infrared photometers is demodulated with a lock-in amplifier, the output of which is converted to pulses and counted in Camac modules. The computer normalizes the counts obtained to counts per second at unit gain (C). If we observe a star with standardized magnitude M at air mass X, then a star of magnitude 0.00 would have instrumental magnitude Z, which is a function of the filter and also the aperture, given by

$$\begin{aligned} Z(\text{filter,aperture}) = \quad & -2.5 \log C(\text{filter,aperture}) \\ & - E(\lambda)\, X \\ & - M \quad , \end{aligned}$$

where $E(\lambda)$ is the atmospheric extinction at wavelength λ, measured in magnitudes per air mass. The extinction values also depend on the elevation above sea level of the site in question. At visual wavelengths the extinction primarily results from scattering by molecules and aerosols, while at infrared wavelengths it is primarily a function of the atmospheric water vapor content (see Hall and Genet 1982, Chap. 9; Mountain *et al.* 1985). In both cases the higher the site is above sea level the lower the extinction.

The calculation of the air mass is a standard calculation using spherical trigonometry (Hall and Genet 1982, eq. (9-2)). A list of standard stars with known magnitudes M can be stored in the computer system. As long as there are sensible extinction values E, one can compute the family of offsets Z for one's telescope, instrument, and data system. Then, the real-time normalized counts, nominal extinction values, and adopted offsets are used to calculate real-time preliminary reduced magnitudes.

In this paper we present a summary of extinction values measured at Mauna Kea from December 1980 to December 1986. The visual wavelength extinction values were obtained from December 1983 through December 1986. The visual wavelength extinction measurements reported here were obtained long enough after the eruption of El Chichón in April 1982 that the effect of that eruption on extinction was certainly diminishing. (Lockwood and Thompson (1983) show in their Fig. 3 that the average residual effect of El Chichón had diminished by half at Strömgren y by December 1983.) What few infrared measurements we have in the first few months after the eruption do not appear markedly different from values obtained before or after. The effect of the El Chichón eruption on the *average* extinction values reported here is negligible, though the effect of clumpy clouds of volcanic material still circulating in the atmosphere would contribute to the *scatter* of the extinction data.

L' and M extinction values given by Sinton and Tittemore (1984) are included in our data set here. The lead author (Krisciunas) has derived extinction values throughout 1986 from UKIRT raw data filed in the VAX/ADAM data files, and he is entirely responsible for the data obtained at the 2800-m level of Mauna Kea (Section II).

Also included here are extinction values derived for the comet Halley monitoring program of Tokunaga *et al.* (1986). They rank their nights A, B, or C for decreasing quality. We include none of their C nights and have not included three of their B nights, as the extinction in one or more filters from J through L' was found to be significantly less than zero, indicating nonstable sky conditions.

After compiling various lists of extinction measurements, a check was made of the UKIRT telescope use records to eliminate the measurements made on nights of questionable atmospheric quality. The UKIRT weather records were begun in June 1980. We had to throw out 39 extinction measurements at a variety of wavelengths which were obtained from December 1979 to June 1980 because there were no weather records to check. About 10% of the nights in Sinton's data set since June 1980 were eliminated because of comments in the UKIRT records on the order of "cirrus most of night" or "spectroscopic, not photometric". While we are combining extinction values obtained by a variety of observers, with various instruments and telescopes, our results should fairly represent the actual extinction at Mauna Kea for clear nights during the years in question.

Most of the Mauna Kea summit visual wavelength data (19 V and B extinction values) are by Tholen. The other eight values at V and B were obtained by Christian at the Canada-France-Hawaii Telescope. Tholen's extinction values are based on as much as a couple dozen observations each night of one or more stars rising and setting. On the other hand, many infrared extinction values represent the bare minimum: measurements of a single star in a given filter at two differing air masses. If on such nights the sky transparency is improving or degrading, systematically high or low extinction values would result, the sense of which depends on which way the sky quality was going and whether one is observing a star rising or setting. Particularly for the H band (1.6 μm), slightly negative values are not unusual. A qualitative estimate of the typical stability of the sky is obtained from noting the relative number of nights with derived negative extinction which, of course, has no physical meaning.

The mean and median values of visual wavelength and infrared extinction are summarized in Table I and Figure 1. Further details are given in Sections II and III below.

II. Extinction and Night-Sky Brightness at Visual Wavelengths at the 2800-m and 4200-m Levels of Mauna Kea

Values of the atmospheric extinction in the *B* and *V* bands, as measured at the Mauna Kea summit, have been provided by Tholen and Christian. Tholen's data were obtained from December 1985 to August 1986. Christian's data were obtained from December 1983 to September 1985; two of her values at *B* and *V* from December 1983 are unusually high, indicating the possible effect of clumpy clouds of material from El Chichón. Tholen used a photometer containing a thermoelectrically cooled photomultiplier and either the University of Hawaii 2.2-m telescope or the UH No. 1 0.4-m telescope. Christian used a CCD detector on the UH 2.2-m telescope or the 3.6-m Canada-France-Hawaii Telescope. Histograms of their *B* and *V* band extinction values are presented in Figures 2(a) and 2(b). Tholen's *B*-band data included in Table I and Figure 2(b) (19 values) include a small correction for second-order color effects. Tholen was observing solar-type stars ($(B-V) \approx 0.65$), and his photometer exhibits a second-order color term of $k''_B = -0.015$. Therefore, to correct his *B* extinction values to those corresponding to a star with $(B-V) = 0.00$, we have *added* 0.01 mag/air mass.

The photometer system used by Krisciunas at the 2800-m level of Mauna Kea with his 0.15-m telescope is described elsewhere (Krisciunas 1981) and uses electronics based on a design by Dick *et al.* (1978). His system employs an uncooled RCA 931A photomultiplier and *UBV* filters. Krisciunas's data were obtained from September 1985 to December 1986.

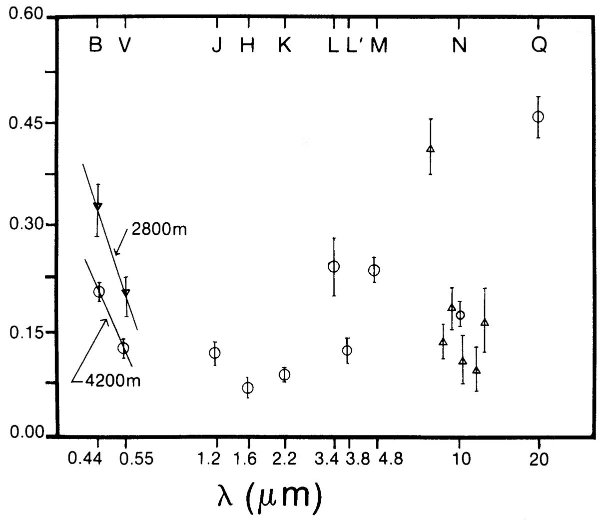


FIG. 1–Mean extinction values (in magnitudes/air mass) vs. wavelength in microns. Data are taken from Table I. Circles correspond to broad-band filters used at Mauna Kea summit; triangles with points down—broad-band filters used at 2800-m elevation; triangles with points up—narrow-band filters used at summit.

TABLE I

Summary of extinction values at Mauna Kea (1980–1986).

Wavelength (microns)	Filter	Mean Extinction (mag/air mass)			Median	n	Notes
0.44	B	0.331	±	0.031	0.307	10	1,2
0.55	V	0.206		0.023	0.182	12	1
0.44	B	0.204		0.011	0.195	27	2,3
0.55	V	0.123		0.007	0.113	27	3
1.2	J	0.117		0.014	0.101	44	
1.6	H	0.067		0.012	0.051	42	
2.2	K	0.086		0.008	0.070	73	
3.4	L	0.241		0.043	0.162	19	
3.8	L'	0.120		0.015	0.088	50	
4.8	M	0.239		0.017	0.220	57	
7.8		0.413		0.040	0.458	17	4
8.7		0.134		0.024	0.120	21	4
9.8		0.181		0.029	0.151	15	4
10.0	N	0.172		0.018	0.151	42	5
10.3		0.109		0.032	0.074	16	4
11.6		0.095		0.034	0.081	15	4
12.5		0.163		0.044	0.125	18	4
20.0	Q	0.457		0.031	0.419	32	5,6
32.0		1.62		0.42	1.54	4	7

1. elevation 2800-m
2. for B-V = 0.00
3. elevation 4200-m
4. narrow band filters used at IRTF
5. 5 micron bandwidth
6. 2 values › 1.5 excluded
7. 7 micron bandwidth

The lowest values of the *V*-band extinction at the 2800-m level (7 of the 12 values) give a mean of 0.149 ± 0.012 mag/air mass. From ten nights on which measurements were made at *B* and *V* we find mean atmospheric reddening from outside the atmosphere instrumental colors of

$$k'_{bv} = 0.098 \pm 0.016$$
$$k''_{bv} = -0.057 \pm 0.023 \ .$$

For a star of $(B-V) = 0.00$ we obtain an outside-the-atmosphere instrumental color of −0.48. This gives a mean reddening of $k_{bv} = 0.125 \pm 0.020$ mag/air mass for a star with $(B-V) = 0.00$. We have added this value to the mean and median E_V in Table I and Figure 1 to obtain E_B. The "best case" *B* and *V* extinction values fall slightly above the extinction curve given in Hardie's classic article (Hardie 1962, p. 185) instead of below his line as expected. While Hardie's graph is based on data at Mount Wilson and McDonald observatories, which are at significantly lower elevations, it is presumably based on very selected data. Angione and de Vaucouleurs (1986) give a more representative mean *V*-band extinction at McDonald Observatory (from 1960 to 1980) of 0.172 mag/air mass. The midlevel facility at Mauna Kea, where Krisciunas's measurements were made, is usually just above the local inversion layer, and mixing of the atmosphere would affect the locally observed extinction. Also, Krisciunas's data set extends over 16 months only.

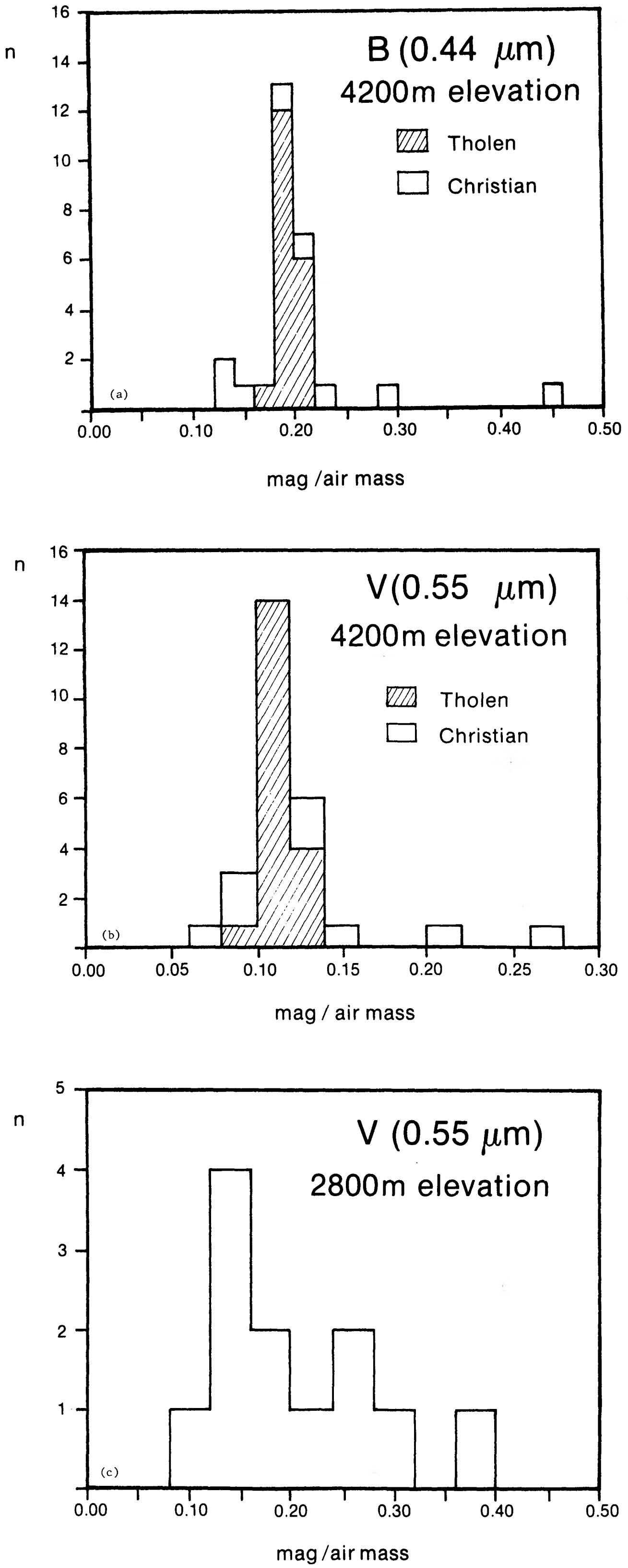


FIG. 2–Frequency histograms of extinction values at visual wavelengths. Consult Table I for mean and median values. In Figures 2(a) and 2(b) the two highest points were obtained in December 1983 and may be affected by clouds of material from El Chichón.

Krisciunas has also measured the night-sky brightness at the 2800-m level of Mauna Kea. To determine the plate scale the focal length of his 0.15-m telescope was measured to the nearest millimeter. The nominal 1-mm diaphragm was measured under a microscope to the nearest 0.01 mm in each axis (the photometer observes an elliptical piece of sky). The expected area of sky is known to within ± 3%. This has been double-checked with differential photometry of the nucleus of the Andromeda nebula, for which the measured magnitude is a function of the aperture size. The results are consistent with those compiled by Sharov and Lyutyi (1980, p. 266) for larger and smaller diaphragms. For further details see Krisciunas (1987).

Another double check was obtained by making drift scans of a star through the beam (both major axis and minor axis). Given the resulting beam profile $P(r)$, the effective beam radius can be obtained as follows:

$$\pi r^2_{\mathrm{eff}} = \int_{P(r)>0} P(r)\, 2\pi r\, dr \ .$$

Given an elliptical beam of known major axis and minor axis size, the beam area is calculated. The observed beam area (6.07 square arc minutes) agrees well with the expected beam area (6.01 square arc minutes) obtained from laboratory calibration of the optics. The 1% difference is small compared to the scatter of observational data. Any error in our night-sky brightness measurements would be due to strip-chart digitization errors or the presence of faint stars in the sky beam (stars fainter than about $V = 12$), not due to any large systematic error in our beam size.

The night-sky brightness was measured by taking a "blank" sky reading near the zenith on the highest amplifier gain (with the strip chart cranked up to give sufficient resolution) along with a dark current reading, and referencing the net result to one or more standard stars observed at about the same time of night. Using the extinction appropriate for the night, to correct for the fact that the comparison stars were not observed exactly at the zenith, along with known gain values and standard star magnitudes, the equivalent magnitude of the blank field was computed. Then, using the known beam size this can be converted to S_{10} units (the number of 10th-magnitude stars per square degree) or the equivalent number of magnitudes per square arc second. From measurements on clear, moonless nights we obtain the mean values given in Table II. The individual values are plotted in Figure 3.

In Figure 3 we also give the values of net sky brightness due to airglow and permanent aurora, obtained as follows. Using the equatorial celestial coordinates where the sky brightness was measured, we converted right ascension and declination to galactic coordinates and differential

TABLE II

Zenith night sky brightness at 2800-m level

Year	Filter	$\langle S_{10} \rangle$		mag/sec^2		n
1985	V	443	± 27	21.17	± 0.07	6
1986	V	325	12	21.50	0.04	7
1986	B	158	6	22.29	0.04	4

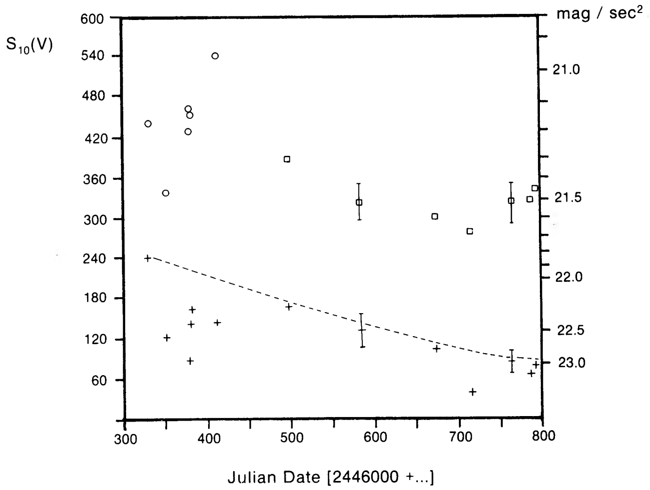


FIG. 3–V-band night-sky brightness near the zenith vs. Julian Date. S_{10} (V) is the number of V = 10th magnitude stars per square degree. Measurements were made on clear, moonless nights. Circles = 1985 data; squares = 1986 data; +'s are the net residuals after subtracting mean contributions due to diffuse galactic light (Toller 1981) and zodiacal light (Roach and Gordon 1973, Appendix 3-A).

ecliptic coordinates (with celestial longitude in the sense $\lambda - \lambda_{\odot}$). Using mean values of the zodiacal light given by Roach and Gordon (1973, Appendix 3-A), and mean galactic light given by Toller (1981) from data of *Pioneer 10* when it was beyond 3 AU from the Sun, we obtained the residuals plotted in the bottom half of Figure 3. The decreasing envelope is presumed to be due to the fact that the solar minimum occurred sometime in late 1986.

It is to be noted that the night-sky brightness measurements in Figure 3 were made through a broad-band V filter, which includes the significant contribution of the emission line at 5577 Å due to atomic oxygen. Roach and Gordon (1973) find that the airglow is typically only 50 S_{10} (V), less than our average residual (after galactic and zodiacal contributions are subtracted). However, their value is based on narrow-band measurements at 5300 Å, for which one would expect a considerably lower value than for broad-band V.

Others have found that the night-sky brightness varies with the phase of the solar cycle. At Siding Spring Mountain, Australia, it has been found that the night-sky brightness in 1986 was about equal to that of 1975 (both times of solar minimum), while in 1980 (solar maximum) the night-sky brightness was about 0.6 mag sec^{-2} brighter (Cannon 1987). The night-sky brightness readings presented here are consistent with a solar cycle effect which, if real and reproduceable, must necessarily be taken into account in planning the use of present and new-generation telescopes.

Let us compare the extinction and night-sky brightness at the 2800-m level of Mauna Kea with those values obtained at the 2400-m level of La Palma in the Canaries. Murdin (1985) states that on a good night at La Palma the V band extinction is 0.15 mag/air mass and the mean $(B-V)$ reddening (for good and not-so-good nights) is 0.11 mag/air mass. The night-sky brightness at La Palma is $V = 21.4$, $B = 22.3$ mag sec^{-2}, based on observations by D. H. P. Jones with the Kapteyn Telescope in June 1984. We obtain a V-band extinction on the better nights of 0.15 mag/air mass, $(B-V)$ reddening of 0.125 ± 0.020, and a night-sky brightness of V = 21.2 to 21.5 mag sec^{-2}, B = 22.3 mag sec^{-2}. Within the errors, the La Palma values are identical to the results for the 2800-m level of Mauna Kea. Thus, the midlevel facility area of Mauna Kea (which, incidentally, is not fully protected from local sources of artificial illumination) is as good as one (probably many) of the other promising (or fully established) sites of the world. The conclusion is obvious that development of a mountain for astronomical observing need not be limited to the summit, at least for visual wavelength photometry.

Tholen has begun a program of monitoring the night-sky brightness at the Mauna Kea summit at a variety of galactic and ecliptic coordinates and at various elevation angles above the horizon. Some of his preliminary values are in the range B = 22.2 to 23.1 mag sec^{-2}. Recently a similar program has been initiated at Kitt Peak; on two nights in December 1986 Pilachowski *et al.* (1987) found $V = 21.9$, $B = 22.9$ mag sec^{-2}. We look forward to comparing the two data bases as they are built up.

III. Extinction at Infrared Wavelengths at the 4200-m Summit of Mauna Kea

The nominal infrared extinction values at Mauna Kea, which are given in Table I and Figure 1, are based on infrared observations with the UH 2.2-m telescope, the 3.8-m UKIRT, and the NASA 3.0-m IRTF with a number of InSb instruments and bolometers. If one has done differential photometry at Mauna Kea and not explicitly measured the atmospheric extinction, data should be reduced with the median values from Table I for the wavelength in question. Note in Table I that the median values are typically less than the arithmetic mean values. This is because of the skewed shape of the histograms of extinction values (Figs. 2 and 4). This is easy to understand. The lower limit of extinction at a given wavelength is set by the minimum amounts of scattering, dust, and water vapor in the atmosphere. It is possible to have almost any value of extinction greater than the lower limit. For example, on a B quality night of Tokunaga *et al.* (1986), the *K*-band extinction was 0.18, while the 20 μm extinction was 4.56 mag/air mass.

Figures 4(a) to 4(h) show that even at Mauna Kea there is a wide range of atmospheric transparency at infrared wavelengths, primarily because of the variation of the atmospheric water vapor content. The near-infrared (*JHK*) extinction on a photometric night can be a few hundredths or as much as 0.5 mag/air mass. Thus it is important always to measure the extinction for proper data reduction.

Are there systematic seasonal variations of extinction? From plots of extinction vs. day of year (see Fig. 5 for a representative plot at *K*), it is found that low extinction can occur at any time of the year but that higher extinction values occur statistically more often in the spring and summer.

Morrison *et al.* (1973) state that the 8–14 μm extinction was found to be 0.10 ± 0.05 mag/air mass. For broadband 10 μm data we obtained a mean value of 0.172. Morrison *et al.* give a histogram of the 17–28 μm extinction, for which the mean value is 0.34 mag/air mass. We find a mean 20 μm extinction of 0.457, once again somewhat higher. This is not too surprising, however. The *K*-band extinction values, averaged year by year from 1980 to 1986, show a range of 0.05 to 0.14 mag/air mass, almost a factor of three, so that any short-term average may not be typical.

Because extinction at infrared wavelengths is primarily a result of the atmospheric water vapor content, the extinction at one wavelength is well correlated with extinction at other wavelengths. (See Sinton and Tittemore (1984) for a plot of L' vs. M values.) Thus, to first order,

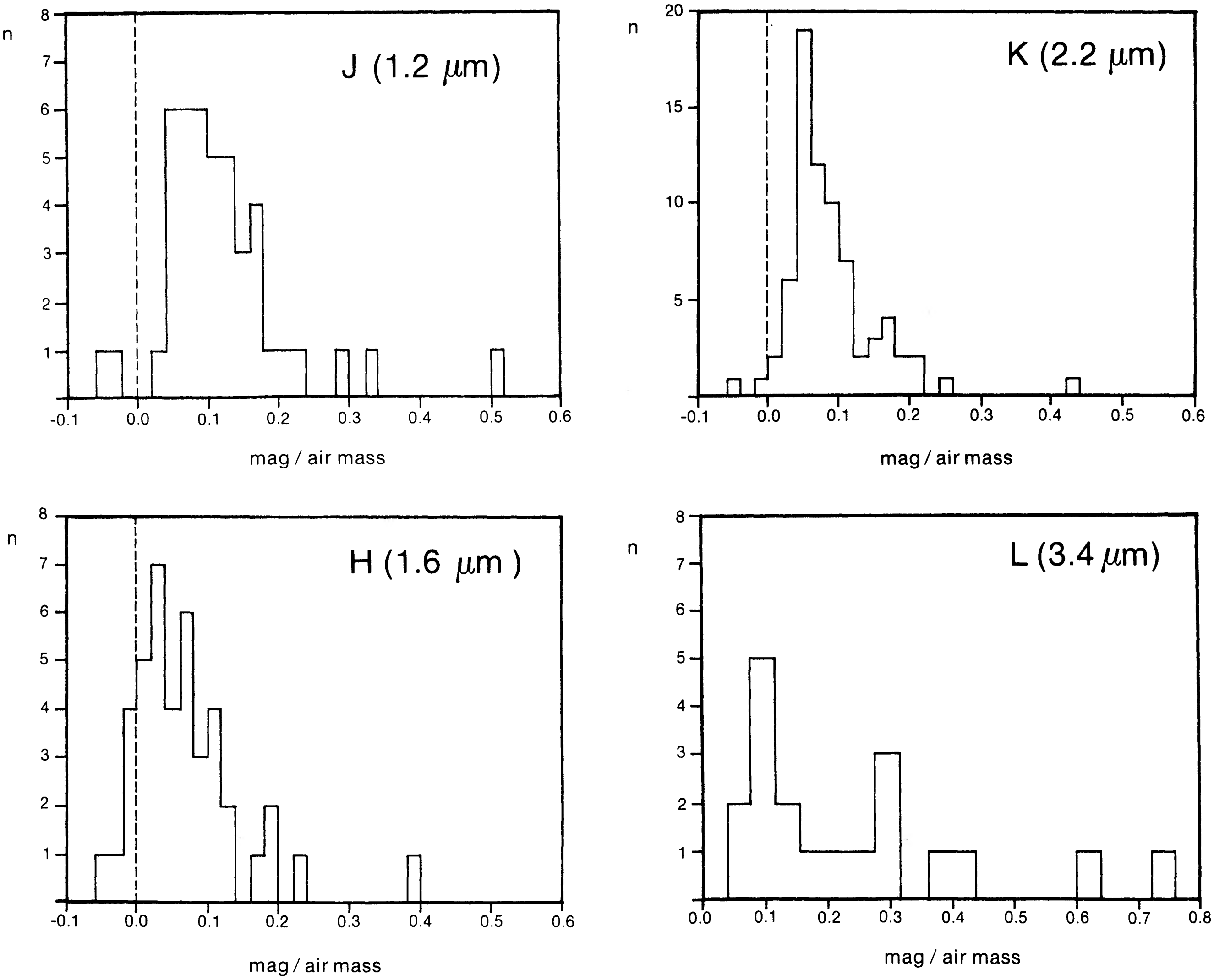
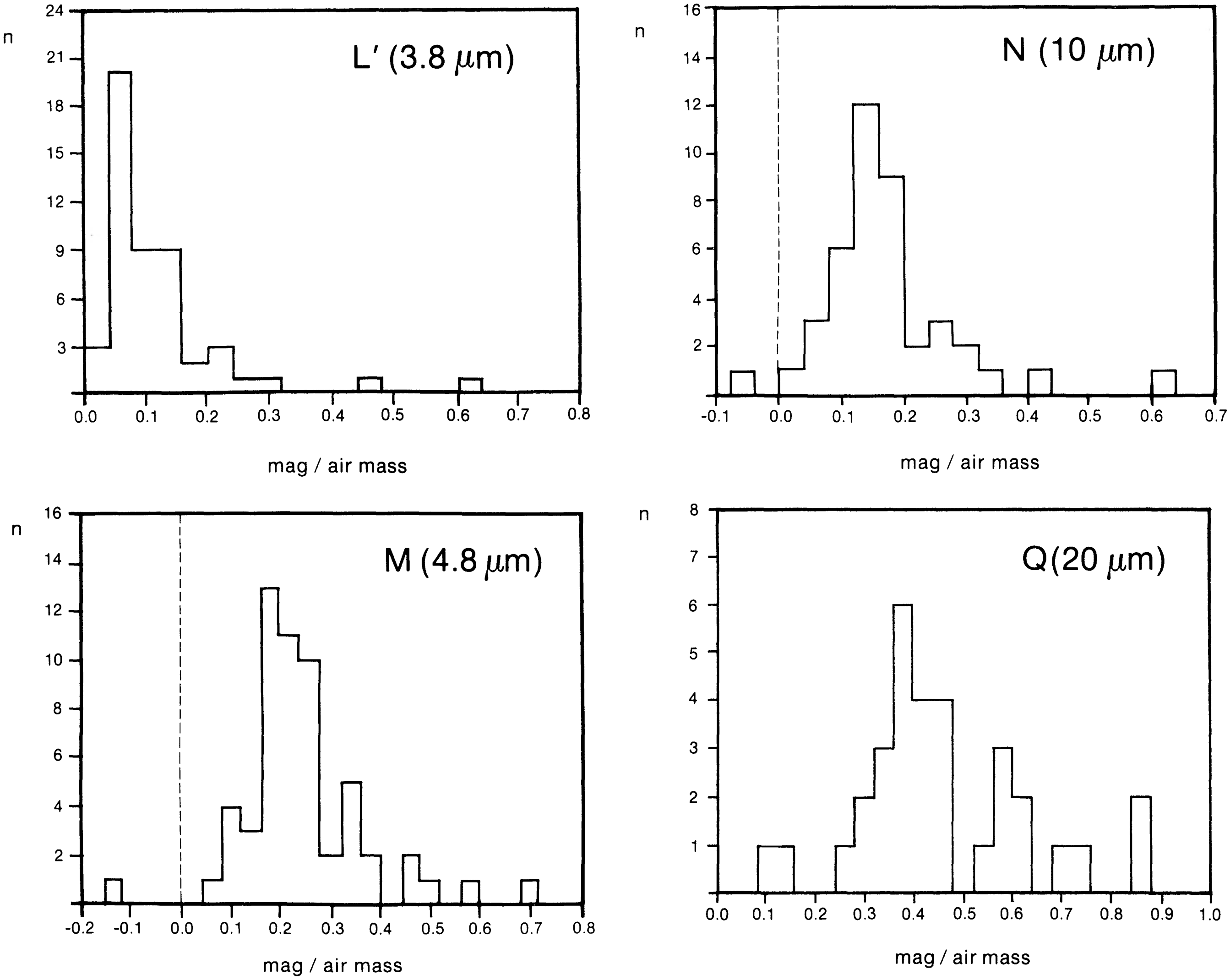


FIG. 4–Frequency histograms of extinction at infrared wavelengths, as measured at Mauna Kea summit. Consult Table I for mean and median values.



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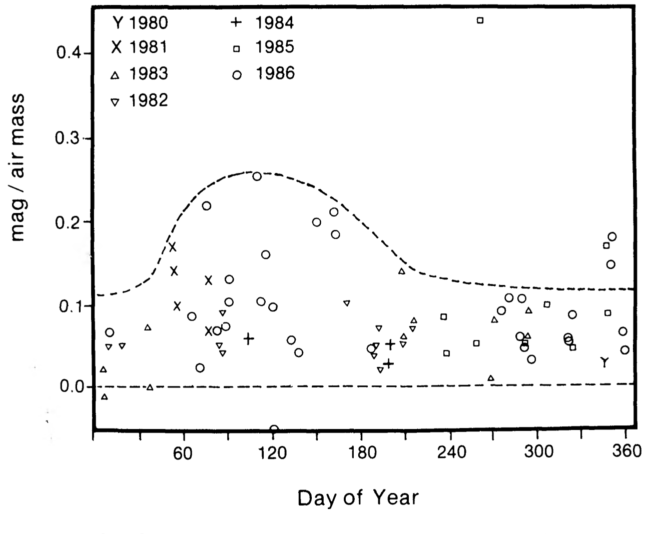

FIG. 5–*K*-band (2.2 μm) extinction vs. day of year, December 1980 to December 1986.

one may estimate the extinction at one infrared wavelength by measuring, say, the *K* extinction, then using the ratio of mean values given in Table I of this paper. While this is not the most accurate way to do photometry, depending on one's experiment such an algorithm may lead to sufficiently accurately reduced photometric magnitudes when insufficient effort has been expended measuring the extinction.

With the imminent completion of the UK/Netherlands 15-m James Clerk Maxwell Telescope and the Caltech 10.4-m Kresge Telescope, millimeter and submillimeter wavelength astronomy at Mauna Kea is expected to flourish. At such wavelengths astronomers prefer to work in flux units rather than magnitudes, and the atmospheric opacity τ_λ is used instead of extinction $E(\lambda)$. The latter are related as follows:

$$E(\lambda)\ \text{mag/air mass} = 1.086\,\tau_\lambda\ .$$

Parrish *et al.* (1987) and de Zafra *et al.* (1983) have published data on the atmospheric opacity at Mauna Kea at a wavelength of 1.1 mm. A typical value is $\tau_{1.1} = 0.10$, with a range of about a factor of 2 under clear sky conditions. The atmospheric opacity at $\lambda = 0.8$ mm is nominally 2.5 times as great, while the middle of the 350 μm and 450 μm atmospheric windows exhibit opacities an order of magnitude greater than $\tau_{1.1}$. Detailed information will be forthcoming over the next few years.

IV. Conclusions

The data presented here should be very useful for the following:

1. Long-term studies of the quality of Mauna Kea as an astronomical site (extinction and night-sky brightness).
2. Real-time checkout procedures for photometry programs carried out at Mauna Kea.
3. Data reduction by those doing sensible differential photometry, for whom it is not possible to measure the atmospheric extinction explicitly. (By "sensible" we mean observing program objects and standard stars at comparable air masses on nights without clouds.)
4. Showing that some types of astronomy need not only be carried out at the summit of a mountain.

The relatively long list of authors given at the beginning of this paper would be much longer if all the observers were included whose data were compiled by Sinton. Such a complete list would include, but not necessarily be limited to, these additional observers: D. Backman, W. Bonsack, M. Buie, D. Cruikshank, N. Devereaux, B. Ellis, J. Goguen, M. Hanner, and W. Tittemore.

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REFERENCES

Angione, R. J., and de Vaucouleurs, G. 1986, *Pub. A.S.P.*, **98**, 1201.
Cannon, R. 1987, private communication.
de Zafra, R. L., Parrish, A., Solomon, P. M., and Barrett, J. W. 1983, *International J. Infrared and Millimeter Waves*, **4**, 757.
Dick, R., Fraser, A., Lossing, F., and Welch, D. 1978, *J.R.A.S. Canada*, **72**, 40.
Hall, D. S., and Genet, R. M. 1982, *Photoelectric Photometry of Variable Stars* (Fairborn, OH: IAPPP).
Hardie, R. H. 1962, in *Stars and Stellar Systems*, Vol. **2**, *Astronomical Techniques*, ed. W. A. Hiltner (Chicago: University of Chicago Press), p. 178.
Krisciunas, K. 1981, *International Amateur-Professional Photoelectric Photometry Commun.*, No. 6, 24.
———. 1987, *International Amateur-Professional Photoelectric Photometry Commun.*, No. 28, in press.
Lockwood, G. W., and Thompson, D. T. 1986, *A.J.*, **92**, 976.
Morrison, D., Murphy, R. E., Cruikshank, D. P., Sinton, W. M., and Martin, T. Z. 1973, *Pub. A.S.P.*, **85**, 255.
Mountain, C. M., Leggett, S. K., Selby, M. J., and Zadrozny, A. 1985, *Astr. Ap.*, **150**, 281.
Murdin, P. 1985, *Vistas Astr.*, **28**, 449.
Parrish, A., de Zafra, R. L., Barrett, J. W., Solomon, P., and Connor, B. 1987, *International J. Infrared and Millimeter Waves*, **8**, 431.
Pilachowski, C., Africano, J., Goodrich, B., and Binkert, W. 1987, *NOAO Newsletter*, No. 9, p. 8.
Roach, F. E., and Gordon, J. L. 1973, *The Light of the Night Sky* (Dordrecht: Reidel).
Sharov, A. S., and Lyutyi, V. M. 1980, *Soviet Astr.*, **24**, 259.
Sinton, W. M., and Tittemore, W. C. 1984, *A.J.*, **89**, 1366.
Tokunaga, A. T., Golisch, W. F., Griep, D. M., Kaminski, C. D., and Hanner, M. S. 1986, *A.J.*, **92**, 1183.
Toller, G. N. 1981, Ph.D. thesis, State University of New York at Stony Brook.