ASTRONOMY & ASTROPHYSICS
SUPPLEMENT SERIES

JULY 1981, PAGE 5

Astron. Astrophys. Suppl. Ser. **45**, 5-9 (1981)

Infrared observations of southern bright stars (*)

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Received October 20, accepted December 4, 1980

Summary. — Infrared magnitudes in the standard bands *J, H, K, L,* and *M* for 61 southern bright stars and 26 solar type stars are presented. *K*-magnitudes range between -3^m and $+7^m$. The magnitude scale is defined by Johnson's *JKL*-system. The bright stars provide a standard star system with an accuracy of $0\overset{m}{.}03$ magnitudes in all bands. We also discuss briefly the infrared extinction at La Silla and experience with daytime observations.

Key words : stars — infrared photometry.

1. **Introduction.** — In the southern hemisphere, there are few measurements of stars for calibrating infrared observations, especially for the M-band. Those available are in several different photometric systems making comparisons subject to systematic errors. We have therefore established an internally consistent infrared magnitude system which in the mean is compatible with the *Johnson system* (Johnson, 1965).

We used stars in the Catalogue of Bright Stars (Hoffleit, 1964) which had infrared data available : Johnson *et al.,* 1966 ; Neugebauer and Leighton, 1969 ; Gehrz and Woolf, 1971 ; Thomas *et al.,* 1973 ; Glass, 1974 ; Blair, 1976 and Persson (private communication). Only a small part of this data was complete in all *J H K L M* magnitudes for each star — generally *H* and *M* values were missing.

2. **Observations.** — The observations were made with an InSb-photometer developed by the MPIfR Bonn (Kreysa, 1980) attached to the 1 m-telescope at ESO – La Silla. The InSb-photometer, cooled with liquid nitrogen at 77 K is equipped with a set of 5 filters at effective wavelengths and bandwidths $J = 1.25$ μm ($\Delta\lambda = 0.3$), $H = 1.65$ μm ($\Delta\lambda = 0.4$), $K = 2.2$ μm ($\Delta\lambda = 0.6$), $L = 3.7$ μm ($\Delta\lambda = 0.7$), $M = 4.8$ μm ($\Delta\lambda = 0.8$). The observations were made with a fixed diaphragm, 13 arcsec in diameter. A complete description of the system is given by ESO, 1979. The data for the bright stars were collected in 7 observing runs between August 1977 and July 1980. Data for the solar type stars were collected independently in several other observing runs. Good telescope pointing and good weather enabled us to make observations by day as well as by night. Hence a great part of the sample could be observed in each run. When bad seeing occurred (usually in the afternoon), difficulties arose because of light loss. Although we did not use these observations in our reduction, correction for this loss can be determined under stable weather conditions from frequent standard star observations. This is further discussed in the Appendix (see also Fig. 2).

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3. **Reduction.** — Initially we reduced the bright-star-data by the following method. The incoming intensity I_λ was transformed to IR magnitudes m_λ by

$$m_\lambda = -2.5 \log I_\lambda - K_\lambda \cdot \text{Airmass} + ZP_\lambda \qquad (1)$$

where K_λ is an adopted approximate extinction coefficient and the zeropoint ZP_λ was determined by measuring a standard star near the zenith at the start of the observing run. The difference between the observed magnitude and the published IR magnitude, initially adopted as the standard IR magnitude for that object, gave the $(O\text{-}C)_\lambda$ value.

We split the data to 24 hour sets starting in the early evening. The starting time was chosen this way, because in some cases no measurements in the afternoon were done due to seeing problems.

In each set, representing one day, a regression for each filter was made using the $(O\text{-}C)_\lambda$ values as a function of the airmass. $(O\text{-}C)_\lambda$ values greater than 3σ of the scatter around the regression line were omitted and the regression repeated. The resulting regression line determines a new extinction coefficient K_λ and a new zeropoint ZP_λ. Using (1) we computed new infrared magnitudes m_λ and corrections, $(O\text{-}C)_\lambda$, with these values. Averaging the

$(O\text{-}C)_\lambda$ values over all days for each star and each filter, we determined new standard magnitudes adding the mean $(O\text{-}C)_\lambda$ values to the published IR magnitudes.

This reduction method was repeated twice using the new magnitudes determined in the previous step to compute the new $(O\text{-}C)_\lambda$ values. We stopped the reduction after the third iteration as the changes of the standard magnitudes became smaller than our observation errors.

The transformation of this instrumental system to Johnson's *JKL*-system and the set of the zeropoints for the *H* and *M*-filter is described by Wamsteker, 1981. Also the transformation of our system to the systems of Thomas *et al.*, 1973 and of Glass, 1974 is given there. Finally the magnitudes of the solar type stars were determined relative to the new standard system.

4. **Extinction in the infrared.** — In table I the final values of the extinction coefficients K_λ and their mean errors for observations between 1 and 2.5 air masses are presented. The wavelength dependence of the extinction in *JHK* is similar to that found at KPNO ($0\overset{m}{.}11$, $0\overset{m}{.}06$, $0\overset{m}{.}09$) having the minimum extinction at *H*. The values obtained are compatible with theoretical results from Manduca and Bell (1979). The transmission curves of ESO filters *J* and *H* are similar to those of the KPNO filters, while the bandpass of the ESO filter *K* is much broader, resembling more Johnson's original *K*-filter. Therefore the extinction coefficient of $K_{2.2\,\mu m}$ is nearer the theoretical value of Johnson's original *K*-filter.

5. **Results.** — Our results are listed in Tables II and III. The tables contain the BS-number, coordinates for epoch 1950.0 from the SAO-Catalogue, spectral class and visual magnitude from Johnson *et al.*, 1966 or from the Catalogue of Bright Stars (Hoffleit, 1964) and the infrared magnitudes for *J, H, K, L,* and *M.*

5.1 SOUTHERN BRIGHT STARS. — The standard deviation of a single observation of any given star of Table II is $0\overset{m}{.}025$ in *J*, $0\overset{m}{.}019$ in *H*, $0\overset{m}{.}018$ in *K*, $0\overset{m}{.}021$ in *L* and $0\overset{m}{.}028$ in *M.* The larger error in *J* compared to that of *H* and *K* is due to sensitivity inhomogeneities of the *J*-filter, which could not be removed totally during the reduction.

5.2 SOLAR TYPE STARS. — We included this set of stars mainly because they are, in the mean, fainter than our standard stars. They might be used as transformation stars to standard star systems used at larger telescopes. In general only the faintest stars of table II can be observed with larger telescopes because of saturation effects of the photometer. The errors of the magnitudes in table III are $\leqslant 0\overset{m}{.}05$ in *JHK* and generally higher in *L* and *M* for $L > 5^m$ and $M > 3^m$.

5.3 VARIABILITY. — To exclude large-scale variations, all stars (including Table III) were observed in at least two different observing runs. No evidence was found for variation on the time scale of several years by comparison with Johnson's data for the stars in common. We have paid special attention to the possibility that small scale variability may be present for the standard stars in table II. Several stars of table II were observed frequently for 7 and more consecutive days. No indications for short term variations were found. For some stars observed frequently in several observing runs (BS 1713, 1790 4023, 6603, 6746 and 7236) we searched for small-scale variations during the three years in which measurements were made. For BS 6603 (β Oph) small variations may be present over months (Fig. 1). The indicated variations are less than $0\overset{m}{.}05$, which is within the 2σ-error of our system, but the similar course of the variation in all filters supports their presence. Generally, we do not have enough observations of our standard stars to exclude such small-scale variations. Therefore the inclusion of a star in the standard star system of table II is determined by its not showing variations greater than $0\overset{m}{.}05$.

6. **Conclusion.** — A set of infrared standard stars for the bands *J, H, K, L* and *M,* covering the whole sky of the southern hemisphere is presented. The system is compatible with Johnson's *JKL*-system. Errors of single observations are less than $0\overset{m}{.}03$ magnitudes in all filters.

Appendix : Experience with daytime observations. — Variable seeing may cause difficulties with daytime observing. In figure 2 we show an *O-C versus* universal time diagram (April 8/9, 1979) for the *K*-filter. This picture is typical for the changes seen on many days and in all filters. 18 different stars contribute to this diagram. Obviously the internal consistency of our system of standard stars is good enough, to reproduce well the change in atmospheric transmission during the observing time. Soon after sunset ($\sim 23^h$ UT) the seeing improved substantially, remaining constant till 14^h UT, which is 10^h local time in the morning. Using these diagrams made for each 24 hours, corrections for light loss can be made. Daytime observations can, under stable weather conditions, reach similar accuracy to those made at night.

Acknowledgements. — We thank Prof. J. Dachs, D. Groote, Dr. J. P. Kaufmann and Dr. J. Koornneef for the provision of some measurements and for helpful discussions. We like to acknowledge also the comments of Dr. F. C. Gillett.

This work was supported partly by the DFG/SFB 131 and by DFG grant Schm 167/20.

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TABLE I. — *Atmospheric extinction at La Silla. Theoretical values were computed from Table IIa of Manduca and Bell (1979).*

Mean Extinction at - ESO - La Silla			Theoretical values		
λ	Filter	K_λ	λ	Filter	K_λ
1.25	J	0.081 ± 0.008	1.25	J (KPNO)	0.075 - 0.096
1.65	H	0.058 ± 0.006	1.65	H (KPNO)	0.053 - 0.066
2.2	K	0.113 ± 0.005	2.2	K (Johnson)	0.111 - 0.126
3.6	L	0.130 ± 0.005	—	—	—
4.8	M	0.268 ± 0.010	—	—	—

TABLE II. — *Infrared magnitudes of Southern Bright Stars.*

BS	RA(1950) H M S	DEC(1950) DG M S	SPECTRAL CLASS	VISUAL MAG	INFRARED MAGNITUDES J	H	K	L	M
3	0 2 46.5	-5 59 14.0	K1 III	4.61	2.88	2.34	2.21	2.09	2.18
15	0 5 47.8	28 48 52.1	B9 P	2.06	2.33	2.39	2.37	2.33	2.41
39	0 10 39.4	14 54 20.6	B2 IV	2.84	3.40	3.43	3.50	3.49	3.57
74	0 16 52.8	-9 6 3.4	K2 III	3.55	1.67	1.12	.98	.88	1.08
519	1 44 8.4	-51 3 56.8	G M4	5.49	2.09	1.34	1.08	.91	1.21
718	2 25 29.8	8 14 13.1	B9 III	4.29	4.43	4.43	4.43	4.43	4.41
721	2 25 9.2	-47 55 39.3	B5 III	4.25	4.52	4.57	4.60	4.59	4.64
1003	3 17 17.5	-21 56 19.6	G M3	3.70	.00	-.85	-1.11	-1.29	-1.06
1084	3 30 34.4	-9 37 34.8	K2 V	3.73	2.26	1.79	1.69	1.59	1.67
1195	3 47 34.9	-36 21 2.4	G5 III	4.17	2.67	2.23	2.11	2.01	2.13
1239	3 57 54.4	12 21 2.1	B3 V	3.41	3.67	3.65	3.66	3.60	3.71
1264	4 0 10.1	-62 17 54.8	G M5	4.46	.70	-.11	-.42	-.62	-.37
1457	4 33 2.9	16 24 37.5	K5 III	.86	-1.80	-2.45	-2.75	-2.90	-2.67
1713	5 12 8.0	-8 15 28.6	B8 IA	.13	.26	.22	.20	.11	.13
1790	5 22 26.8	6 18 21.7	B2 III	1.64	2.17	2.23	2.30	2.29	2.36
1791	5 23 7.7	28 34 1.7	B7 III	1.65	1.96	1.98	2.00	1.98	2.11
2326	6 22 50.5	-53 40 3.4	F0 IB	-.75	-1.13	-1.26	-1.31	-1.40	-1.35
2491	6 42 56.7	-16 38 46.4	A1 V	-1.46	-1.33	-1.35	-1.36	-1.40	-1.34
2580	6 52 3.4	-24 7 12.9	K3 IAB	3.92	1.28	.65	.44	.18	.51
2693	7 6 21.4	-26 18 45.4	F8 IA	1.84	.78	.54	.41	.27	.28
2902	7 31 30.1	-14 24 52.0	M2 IABEP+B	4.98	1.25	.44	.11	-.14	.17
2943	7 36 41.1	5 21 16.8	F5 IV	.37	-.41	-.60	-.66	-.73	-.69
3634	9 6 9.3	-43 13 47.6	K5 IB	2.21	-.56	-1.30	-1.53	-1.77	-1.41
3748	9 25 7.8	-8 26 27.5	K4 III	1.97	-.36	-1.02	-1.21	-1.37	-1.16
3982	10 5 42.6	12 12 44.5	B7 V	1.35	1.58	1.57	1.59	1.56	1.61
4023	10 12 38.0	-41 52 25.2	A2 V	3.85	3.81	3.76	3.75	3.69	3.72
4167	10 35 11.7	-47 57 55.7	F2+A3	3.84	3.40	3.21	3.18	3.11	3.14
4174	10 34 53.6	-78 20 53.7	M0 III	4.10	1.35	.55	.33	.17	.39
4216	10 44 36.8	-49 9 19.7	G5 III	2.69	1.17	.74	.63	.52	.62
4450	11 30 32.3	-31 34 50.7	G7 III	3.54	2.15	1.63	1.50	1.38	1.50

TABLE II *(continued)*.

BS	RA(1950) H M S	DEC(1950) DG M .S	SPECTRAL CLASS	VISUAL MAG	J	H	K	L	M
4763	12 28 22.7	-56 50 .3	M3 II	1.62	-2.00	-2.76	-3.04	-3.28	-3.04
5056	13 22 33.3	-10 54 3.4	B1 V	.97	1.55	1.59	1.67	1.70	1.76
5192	13 46 32.4	-34 12 6.7	G M6	4.19	-.52	-1.32	-1.66	-1.84	-1.40
5288	14 3 43.9	-36 7 29.6	K0 III-IV	2.06	.40	-.10	-.22	-.34	-.21
5384	14 20 41.7	1 28 29.6	D G3	6.27	5.13	4.74	4.68	4.61	4.62
5603	15 1 8.2	-25 5 12.3	M4 III	3.27	-.28	-1.14	-1.40	-1.60	-1.35
5824	15 37 19.2	-23 39 25.5	G K4	4.96	2.84	2.24	2.06	1.92	2.13
6072	16 16 5.3	-50 2 5.7	G8 III	4.02	2.33	1.78	1.64	1.55	1.71
6084	16 18 8.7	-25 28 28.1	B1 III	2.88	2.51	2.41	2.41	2.38	2.43
6461	17 21 8.3	-55 29 6.1	K3 IB	2.84	.58	-.03	-.22	-.43	-.15
6603	17 41 0.0	4 35 11.8	K2 III	2.77	.95	.38	.24	.11	.32
6698	17 56 16.3	-9 46 9.1	G9 III	3.34	1.77	1.27	1.15	1.07	1.24
6736	18 0 48.4	-24 21 48.7	O5	5.97	5.85	5.82	5.83	5.80	5.99
6746	18 2 35.7	-30 25 35.8	K0 III	2.99	1.28	.80	.67	.57	.70
6832	18 14 14.6	-36 46 43.5	M3 II	3.11	-.42	-1.24	-1.50	-1.70	-1.40
7120	18 52 5.8	-22 44 8.2	K3 III	4.98	2.87	2.20	2.04	1.87	2.12
7217	19 1 41.2	-21 48 59.5	G G8	3.77	2.09	1.64	1.50	1.39	1.53
7236	19 3 35.7	-4 57 32.7	B8 V	3.43	3.64	3.64	3.65	3.62	3.68
7429	19 31 38.8	7 16 16.9	K3 III	4.45	2.56	2.01	1.83	1.70	1.85
7446	19 34 12.1	-7 8 24.7	B0.5 III	4.96	5.03	5.02	5.04	5.01	5.01
7525	19 43 52.9	10 29 24.4	K3 II	2.72	.33	-.36	-.54	-.71	-.62
7557	19 48 20.6	8 44 5.7	A7 V	.76	.39	.27	.22	.18	.21
7710	20 8 43.5	-0 58 16.1	B9.5 II	3.22	3.40	3.38	3.39	3.34	3.41
7754	20 15 16.9	-12 42 4.5	G9 III	3.58	2.07	1.61	1.49	1.39	1.50
7951	20 45 6.0	-5 12 43.3	M3 III	4.44	.91	.07	-.18	-.39	-.17
8204	21 23 48.9	-22 37 44.3	G4 IBP	3.74	2.34	1.98	1.86	1.76	1.89
8232	21 28 55.6	-5 47 31.7	G0 IB	2.87	1.61	1.26	1.14	.97	1.00
8430	22 4 40.8	25 6 .7	F5 V	3.76	2.97	2.78	2.69	2.59	2.70
8560	22 26 46.7	-44 0 20.8	G M6	4.11	.26	-.59	-.83	-1.04	-.77
8728	22 54 53.5	-29 53 15.8	A3 V	1.16	1.06	1.04	1.03	1.00	1.04
8781	23 2 16.1	14 56 9.1	B9.5 III	2.48	2.56	2.55	2.53	2.48	2.50

TABLE III. — *Infrared magnitudes of solar type stars. The star without BS-number is HD 28099.*

BS	RA(1950) H M S	DEC(1950) DG M S	SPECTRAL CLASS	VISUAL MAG	J	H	K	L	M
77	0 17 28.8	-65 10 6.7	G2 V	4.23	3.23	2.92	2.90	2.83	2.86
88	0 20 18.0	-12 29 14.9	D G2	6.44	5.32	5.00	4.93	4.87	4.92
98	0 23 9.4	-77 32 8.5	G2 IV	2.80	1.73	1.42	1.39	1.31	1.38
512	1 39 8.9	-83 13 47.3	G2 V	5.86	4.86	4.53	4.48	4.40	4.38
1006	3 16 40.8	-62 45 57.8	G2 V	5.54	4.47	4.14	4.02	3.95	4.13
1008	3 17 55.9	-43 15 35.7	G5 V	4.27	3.02	2.63	2.53	2.42	2.56
	4 23 47.7	16 38 7.3	G0	8.10	6.99	6.68	6.65	6.56	6.56
2290	6 18 47.1	-48 42 49.8	G0	6.60	5.55	5.22	5.16	5.11	5.13
2318	6 22 47.3	-28 44 58.5	G0	6.24	5.29	5.00	4.94	4.87	4.92
2354	6 24 5.5	-63 23 53.0	G0	6.45	5.45	5.14	5.03	4.99	5.02
2667	7 2 25.2	-43 32 15.6	G3 V	5.80	4.52	4.18	4.14	4.10	4.28
2668	7 2 26.8	-43 32 27.6	G0	6.92	5.57	5.09	5.02	4.94	4.99
2882	7 28 56.1	-37 14 1.8	G5	6.64	5.49	5.21	5.12	5.09	5.02
3138	7 56 51.6	-60 10 6.3	G2 V	5.59	4.57	4.28	4.23	4.14	4.26
3176	8 4 49.4	21 43 42.4	G2 IV	5.36	4.14	3.91	3.83	3.75	3.92
4030	10 13 46.3	23 45 8.4	D G2	5.87	4.79	4.46	4.40	4.32	4.42
4523	11 44 7.6	-40 13 41.2	G5 V	4.90	3.75	3.40	3.32	3.24	3.35
4883	12 49 15.9	27 48 44.7	G0 III	4.94	3.71	3.46	3.34	3.24	3.34
5459	14 36 11.2	-60 37 48.8	G2 V	.33	-1.14	-1.38	-1.48	-1.59	-1.42
5460	14 36 11.2	-60 37 48.8	D K1	1.70	-.01	-.49	-.60	-.69	-.52
8042	20 58 54.4	-43 11 52.3	G3 IV	6.63	5.47	5.16	5.10	5.01	5.11
8283	21 38 49.8	-14 16 17.4	G2 IV	5.28	4.11	3.75	3.65	3.57	3.72
8477	22 11 35.7	-41 37 9.7	G5 V	6.22	5.09	4.79	4.75	4.68	4.75
8531	22 21 38.0	-58 2 47.9	D G0	5.30	4.14	3.79	3.74	3.73	3.78
8700	22 50 40.8	-48 51 48.3	G3 IV	6.03	5.04	4.74	4.70	4.61	4.74
8701	22 51 12.6	-70 20 29.1	G1 V	6.04	5.01	4.68	4.61	4.54	4.61

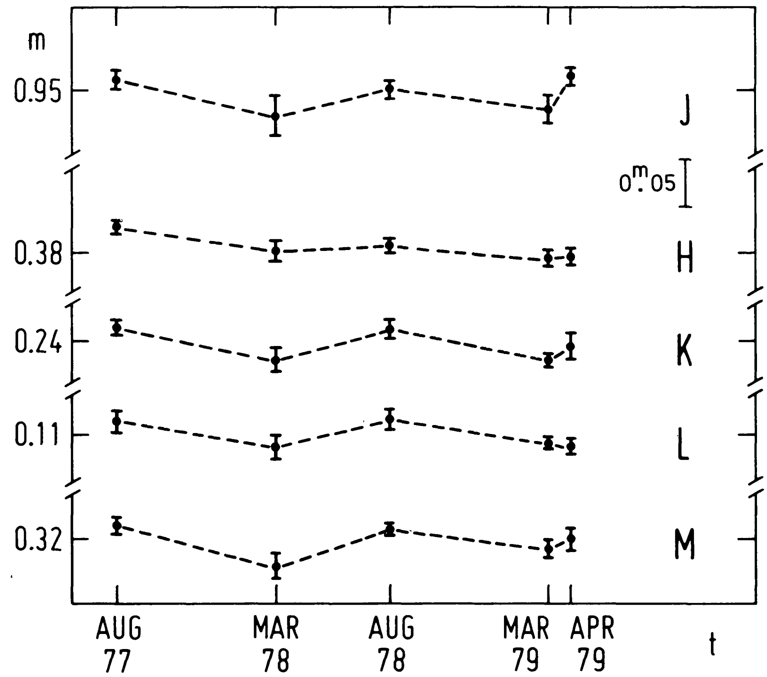

FIGURE 1. — Variation of infrared magnitudes of BS 6603.

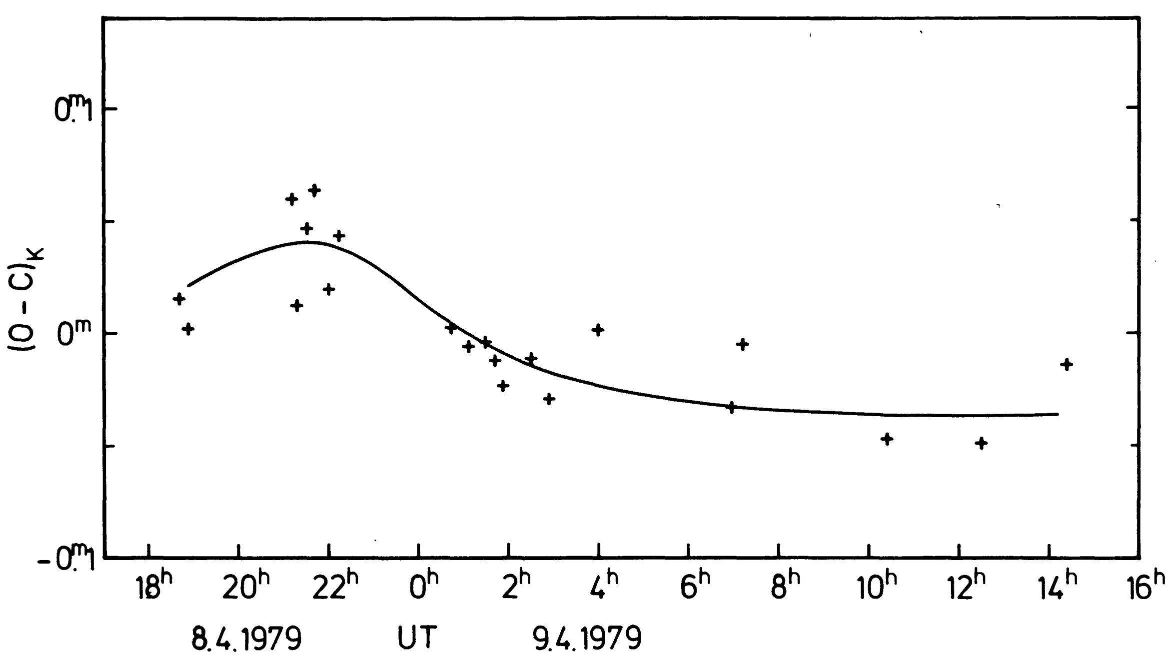

FIGURE 2. — Observed minus standard magnitude (*O-C*) *versus* universal time for Filter *K* on April 8/9, 1979 (18 stars).