Astronomy & Astrophysics

The Calar Alto lunar occultation program: update and new results[*],[**]

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ABSTRACT

We present an update of the lunar occultation program which is routinely carried out in the near-IR at the Calar Alto Observatory. A total of 350 events were recorded since our last report (Fors et al. 2004, A&A, 419, 285). In the course of eight runs we have observed, among others, late-type giants, T-Tauri stars, and infrared sources. Noteworthy was a passage of the Moon close to the galactic center, which produced a large number of events during just a few hours in July 2004. Results include the determinations of the angular diameter of RZ Ari, and the projected separations and brightness ratios for one triple and 13 binary stars, almost all of which representing first time detections. Projected separations range from 0.″09 to 0.″007. We provide a quantitative analysis of the performance achieved in our observations in terms of angular resolution and sensitivity, which reach about 0.″003 and $K \approx 8.5$ mag, respectively. We also present a statistical discussion of our sample, and in particular of the frequency of detection of binaries among field stars.

Key words. astrometry – occultations – binaries: close – binaries: visual

1. Introduction

Among the various methods to achieve high-angular resolution beyond the limits set by atmospheric turbulence and by the telescope diffraction, lunar occultations (LO) stand out for their relative simplicity. LO have been used intensively for investigations of stellar sources for a few decades, and have led to systematic determinations of angular diameters and binary stars. A recent census of LO results was provided by Richichi et al. (2005). In recent years attention and resources are shifting to methods such as long-baseline interferometry (LBI), which offer almost complete freedom of choice in the targets and times of observation, although with much more demanding technical requirements. However, in our opinion LO can still offer a significant scientific contribution with relatively small effort, and attempts to continue routine LO observations should be encouraged. One important advancement in this area has been the recent availability of all-sky near-infrared surveys, such as 2MASS (Cutri et al. 2003) and DENIS (Paturel et al. 2003). Such catalogues have increased by almost an order of magnitude the number of predictions for events observable with 1 m-class telescopes and above.

In this paper, we provide an overview of the data we have accumulated since our last publication on the subject (Fors et al. 2004, F04 hereafter), adding 350 LO events. We present new approaches in data analysis, suited to the automated reduction of large volumes of LO, and we provide details on 11 new binaries and one triple star, 2 known binaries, and one angular diameter determinations. We also discuss the statistics of our sample, with some considerations on the detection of binaries in random observations of field stars.

2. Observations, data handling and data reduction

Most of the observations reported here were carried out with the 1.5 m telescope of the Observatorio Astronómico Nacional in Calar Alto (Spain). On two occasions, we used the 3.5 m and

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[*] Based on observations collected at TIRGO (Gornergrat, Switzerland), and at Calar Alto (Spain). TIRGO is operated by CNR–CAISMI Arcetri, Italy. Calar Alto is operated jointly by the Max-Planck Institut für Astronomie and the Instituto de Astrofísica de Andalucía (CSIC).

[**] Table 5 is only available in electronic form at http://www.edpsciences.org

Table 1. Observing runs.

Run	Telescope	Dates	Nights	# LO
A	TIRGO 1.5 m	Oct, Nov. 01	2	2
B	CA 1.5 m	Feb. 03	5	0
C	CA 1.5 m	Nov. 03	5	9
D	CA 1.5 m	Dec. 03	5	0
E	CA 1.5 m	Feb. 04	6	29
F	CA 1.5 m	Mar. 04	7	3
G	CA 2.2 m	Jul. 04	0.5	54
H	CA 3.5 m	Oct. 04	1	0
I	CA 1.5 m	Nov. 04	6	45
J	CA 1.5 m	Dec. 04	5	7
K	CA 1.5 m	Jan. 05	6	105
L	CA 1.5 m	Feb. 05	6	96
		Total	54.5	350

2.2 m telescopes of the Centro Astronómico Hispano-Alemán, located at the same site. Among the present results we have included also two earlier observations obtained at the TIRGO 1.5 m telescope, for which a detailed re-analysis has shown a positive binary detection. The above telescopes, the associated instrumentation and the filter bandpasses used for LO work have been described elsewhere (Richichi et al. 1996, F04). Concerning the K-filter of the MAGIC cameras used at 1.5 m and 2.2 m telescopes of Calar Alto, we have determined an improved, accurate transmission curve at operating temperature, and applied it in all relevant cases. For this purpose we have used the same MAGIC camera in the laboratory, taking exposures with and without the filter, using the same resin-replica grism used for astronomical observations at liquid nitrogen temperature. As a light source we employed a source without significant emission in the J band, thus avoiding contamination of short-wavelength light from a different order. For the observation of the very bright star RZ Ari we employed a narrow band filter, with $\lambda_0 = 2.26\,\mu m$ and $\Delta\lambda = 0.06\,\mu m$.

Observations were carried out during eleven observing runs at the Calar Alto Observatory over a period of two years, as detailed in Table 1. On average, each run consisted of a few nights allocated in periods of crescent Moon close to full phase, in order to maximize the number of occultations of field stars and observe disappearances rather than reappearances. On two occasions (runs G and H), very short runs were allocated to follow up passages of the Moon close to the galactic center and over the Taurus star-forming regions, respectively. Note that three runs were completely devoid of results due to weather. The two earlier results from TIRGO are collectively grouped as run A, although their respective observations were collected at different dates in 2001. Details of the 350 recorded events and the characteristics of the corresponding objects can be found in Table 5, available only on-line. Here we show an excerpt in Table 2, which contains the details of the sources explicitly mentioned either for a positive result or for other comments. The format of this table is similar to the one used in F04. In Col. (3), the codes T, CB and CC are for the TIRGO telescope equipped with a fast InSb photometer, and for the Calar Alto 1.5 m and 2.2 m telescopes equipped with MAGIC cameras, respectively.

The availability of near-IR all-sky surveys has represented a major step forward in the possibilities of LO investigations, especially at medium and large-sized telescopes. Roughly speaking, a 1.5 m telescope equipped with an InSb fast photometer can record LO events with millisecond time sampling and signal-to-noise ratio (*SNR*) above unity for sources having magnitudes $K \lesssim 7$ (Richichi et al. 1996). An instrument based on the fast readout of a subwindow of an array detector can add more than one magnitude in sensitivity (F04). Moving to larger telescopes brings gain in sensitivities which are essentially, for moderate lunar phases and faint sources, proportional to the area of the telescope (Richichi 1996). While these guidelines are obviously strongly dependent on a number of instantaneous parameters, they show that LO observations can be adequately recorded on sources with magnitudes as faint as $K \approx 10$. Until recently, no comprehensive coverage of the near-IR sky was available. The Two Micron Sky Survey (TMSS, Neugebauer & Leighton 1969) was incomplete in declination and only extended to $K \lesssim 3$. In the past, LO predictions were compiled by the present authors using a variety of other catalogues. Even a very rich run would consist of about 10–20 sources per night at most. We have now implemented the 2MASS survey (Cutri et al. 2003) in our predictions, and the number of events observable has jumped up by very large factors. A typical night would offer in excess of 100 sources close to maximum lunar phase. Even more dramatic are the improved conditions for special events. For example, on the occasions of passages of the Moon in crowded regions near the Galactic Center (see Sect. 3.8), thousand of events would be easily accessible to a medium-sized telescope over few hours. Table 3 lists some statistics for such events in the near future. In this regime, the number of events effectively observable will depend on the overheads of telescope pointing, instrument operation and data storing.

Of course, the increase in the number of observed events is not reflected linearly in the number of results, such as the positive detection of field binaries, mainly because the majority of the events will be faint and offer limited dynamic range. We will return to this point in Sect. 4. The increase in the sheer number of observed events, on the other hand, implies a significant load of data inspection and analysis, particularly since data from IR arrays are substantially more demanding than those from photometers. This has prompted us to handle the bulk of raw data by means of automated processing. A new reduction pipeline was designed and implemented for the automated generation of preliminar lightcurve fits, which are then improved interactively. In particular, we concentrated our effort in two different areas. On one hand, we performed a comparative study of different algorithms of light curve extraction, such as aperture photometry, Gaussian profile fit, object detection based on segmentation analysis and subtraction of fixed number of faintest to brightest pixels. The latter was found to offer the best performance over the range of *SNR* present in our data sets, using 30 and 15 pixels for the extraction of the background and star signals, respectively. On the other hand, a new algorithm was developed to estimate automatically the lightcurves parameters (occultation time, stellar and background intensity). A particular wavelet transform of the lightcurve was chosen for this purpose, as it was capable of

Table 2. List of selected occultation events and of the circumstances of their observation.

(1) Source	(2) Date UT	(3) Tel.+ detector	(4) D ″	(5) Δt ms	(6) τ ms	(7) V mag	(8) K mag	(9) Sp.	(10) Dist. pc
SAO 164567	25-10-01	T	21	3.0	3.4	7.4	3.2	K5III	278
SAO 110325	28-11-01	T	21	2.0	2.4	6.4	4.1	K0	147
SAO 80310	03-03-04	CB	7	8.5	3.0	6.9	5.6	F8	35
SAO 80764	01-04-04	CB	7	8.4	3.0	7.8	4.0	K2	1429
SAO 185661	28-07-04	CC	5	8.4	3.0	9.9	5.9	K5	
IRC -30319	28-07-04	CC	5	8.4	3.0	8.8	1.8	K2	
17454891-2809333	28-07-04	CC	5	8.3	3.0		6.1		
SAO 164601	18-11-04	CB	7	8.6	3.0	6.2	5.7	A0 m...	110
SAO 165154	19-11-04	CB	7	8.4	3.0	9.0	6.2	K1III	
SAO 109617	22-11-04	CB	7	8.4	3.0	8.2	5.5	K2	21
SAO 110089	23-11-04	CB	7	8.4	3.0	8.5	6.7	K0	47
SAO 92659	23-11-04	CB	7	8.5	3.0	5.9	5.1	F2Vw	43
RZ Ari	18-01-05	CB	7	8.4	3.0	5.8	-0.9	M6III	124
SAO 76214	19-01-05	CB	7	8.5	3.0	8.2	5.4	K0	
LH 98-106	19-01-05	CB	7	8.5	3.0	7.3	6.0	F5	37
DL Tau	20-01-05	CB	7	8.4	3.0	13.6	8.0	GV:e...	
GN Tau	20-01-05	CB	7	8.5	3.0	15.1	8.1	M2.5	
Elias 3-18	20-01-05	CB	7	8.5	3.0			B5	
ITG 31	20-01-05	CB	7	8.5	3.0	9.1	5.2	K0	565
LkHA 332	21-01-05	CB	7	8.4	3.0	14.7	7.9	K5	
IRAS 04395+2521	21-01-05	CB	7	8.5	3.0		5.5		
04440885+2540333	21-01-05	CB	7	8.6	3.0		6.9		
05415664+2707323	22-01-05	CB	7	8.5	3.0				
SAO 78540	23-01-05	CB	7	8.6	3.0	6.9	5.3	G0	36
HD 283610	16-02-05	CB	7	8.5	3.0	9.6	5.4	K5III	
04264187+2500314	17-02-05	CB	7	8.4	3.0		6.7		
SAO 77000	17-02-05	CB	7	8.4	3.0	9.1	5.4	G5	244

Table 3. Statistics of three passages of the Moon in the Galactic Center (GC) region in 2006, as predicted for the Calar Alto Observatory to the limit $K \leq 8.5$ mag.

Date	Start (UT)	End (UT)	Minimum GC approach	Number of LO
11 June	21:01	02:46	1°.95	2899
9 July	20:31	01:48	4°.74	1586
5 August	19:03	23:29	0°.88	2315

cirrus and lunar halo) and of the stellar intensity (due to image motion and scintillation), can be fitted and accounted for by means of Legendre polynomials as described in the above mentioned papers. Another approach is to use a model-independent method (CAL, Richichi 1989), which is particularly suited for the detection or confirmation of companions at very small separations. This method is also of great advantage in cases when the source may not be a simple circular disk, or in the presence of extended circumstellar emission.

3. Results

The stars for which a positive result could be obtained are listed in Table 4, using the same format already used in F04. In summary, the columns list the absolute value of the fitted linear rate of the event V, its deviation from the predicted rate V_t, the local lunar limb slope ψ, the position and contact angles, the signal-to-noise ratio (SNR). For binary detections, the projected separation and the brightness ratio are given, while for RZ Ari the angular diameter ϕ_{UD} is reported, under the assumption of a uniform stellar disc. All angular quantities are computed from the fitted rate of the event. Only in 2MASS 04264187 +2500314 we were not able to reliably fit a rate, due to the low SNR. For this source, the predicted values are listed in parentheses. Note that in the tables of this paper the 2MASS prefix is omitted.

isolating the desired frequency signature while preserving the temporal information. The algorithm showed great robustness even in worst SNR conditions. This work will be described in detail in a separate paper.

The data were analyzed by means of various methods, as already described in Richichi et al. (2002, 2003) and references therein. The main engine for data analysis is based on a model-dependent least squares method (LSM). Free parameters include the stellar intensity, the rate of the event, the intensity of the background and its time drift. For single stars another parameter is the angular diameter, and additionally for binary stars the angular diameter of the companion, the projected separation and the brightness ratio are included. Spurious frequencies due to pick-up of mains power and other effects may be present occasionally, and can be digitally filtered. Relatively slow, random fluctuations of the background (due to thin

Table 4. Summary of results.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Source	$|V|$ (m/ms)	$V/V_t - 1$	ψ(°)	PA(°)	CA(°)	*SNR*	Sep. (mas)	Br. ratio	ϕ_{UD} (mas)
SAO 164567	0.7325	3%	7	78	14	49.2	8.4 ± 0.2	6.8 ± 0.2	
SAO 110325	0.8571	−0%	−1	59	−7	37.0	7.8 ± 0.8	13.4 ± 1.1	
SAO 80764	0.6568	−3%	−2	73	−45	26.3	42.5 ± 0.3	14.9 ± 0.3	
SAO 185661	0.3287	−5%	−2	155	60	23.7	37.9 ± 1.1	19.3 ± 0.7	
IRC -30319 A-B	0.5647	3%	2	136	44	52.6	15.0 ± 0.1	8.74 ± 0.04	
IRC -30319 B-C						16.1	21.8 ± 0.1	1.98 ± 0.01	
17454891-2809333	0.7720	4%	3	98	6	25.0	39.3 ± 0.7	17.3 ± 0.9	
SAO 165154	0.5870	24%	14	117	62	6.2	43.0 ± 1.9	4.7 ± 0.4	
RZ Ari	0.6520	−2%	10	73	11	41.3			10.6 ± 0.2
SAO 76214 A-C	0.3500	−5%	−2	131	56	7.8	13.0 ± 0.7	2.4 ± 0.1	
IRAS 04395+2521	0.6301	11%	8	135	49	21.4	6.5 ± 0.2	2.9 ± 0.1	
04440885+2540333	0.8013	−0%	−0	77	−10	3.9	15.6 ± 0.8	1.4 ± 0.1	
05415664+2707323	0.9208	−2%	−3	108	12	17.4	24.8 ± 0.3	7.8 ± 0.3	
HD 283610	0.5244	−5%	−3	121	38	9.1	19.4 ± 0.7	6.1 ± 0.3	
04264187+2500314	(0.8900)	−	−	(86)	(0)	3.8	89.5 ± 1.0	2.5 ± 0.1	
SAO 77000	0.4995	2%	−2	109	37	16.0	12.6 ± 0.3	1.49 ± 0.03	

3.1. SAO 164567

This star was revealed as a binary in a Calar Alto observation reported in F04. On the same night, the star was observed also from TIRGO. The binarity is clearly confirmed, but it is difficult to extract a true position angle from the combination of the value reported in F04 with that presented in Table 4. This is due partly to the relatively small difference in position angle predicted for the two sites (only 3°), and partly to the fact that the Calar Alto event was fitted with a speed that, in spite of just 2.9% excess over the predicted value, does not allow to compute unambiguously the exact position angle. This happens occasionally when a LO event has a very small contact angle.

We can only conclude that the companion is generally oriented towards the North, at a separation that could be significantly larger than the projected value of Table 4, up to ≈50 mas. Attempts to confirm the true position angle by techniques such as speckle interferometry are possible. From the two events we have reliable magnitude differences both in the R and the K bands. This permits us to infer that the secondary is bluer, by $R - K \approx 1.5$ mag, than the primary. The primary is classified as a K5 giant (Houk & Smith-Moore 1988), therefore we estimate that the secondary should have $R - K \approx 0.9$, which would be consistent with a late A or early F star.

3.2. SAO 110325

This newly detected binary was the subject of several previous observations by speckle interferometry (McAlister 1978; Hartkopf & McAlister 1984) as well as LO (Evans & Edwards 1981). The star was reported as unresolved also by Hipparcos. The fact that none of these previous records revealed the companion can be explained by the small projected separation that we list in Table 4, and possibly by the brightness ratio equivalent to $\Delta K = 2.8$ mag, which might be even larger at shorter wavelenghts.

3.3. SAO 165154

A LO event for this star was reported by Evans et al. (1985), who did not find evidence of binarity. We note that the star is relatively faint in the visual and the secondary might not have been detected previously for reasons of dynamic range.

3.4. RZ Ari

The bright, O-rich M6 star RZ Ari (45 Ari, ρ_2 Ari, HR 867) has been the subject of several investigations by high angular resolution methods. Five previously available angular diameter determinations are listed in the CHARM2 catalogue (Richichi et al. 2005). The results are somehow heterogeneous, including observations at various wavelengths in the optical and near-IR by LO and LBI, and referring to either uniform, partially or fully limb-darkened disk diameters (UD, LD, FD respectively).

The star is an irregular long-period variable, although the amplitude is relatively small (0.6 mag, Kukarkin et al. 1971). In the near-IR the amplitude of variability is not well documented, and it can be assumed to be even smaller. An examination of the data available from the AAVSO shows a slight trend of increasing luminosity by about 0.5 mag over the past 30 years in which diameter measurements are available. Neglecting in a first approximation significant changes of angular diameter due to variability, we plot all available determinations in Fig. 1, using UD values. The conversion from LD and FD to UD has been done by using guidelines and conversion factors provided in the original references. The uncertainties in this conversion can be considered smaller than the error bars on the diameter determinations. It can be noted that there is a general agreement among the various determinations. A weighted mean yields the UD value 10.22 ± 0.12 mas.

No definite trend of the characteristic size with wavelength seems to be present, as would have been expected in the presence of circumstellar matter, due to scattering at shorter wavelengths and thermal emission at longer ones. Therefore we can
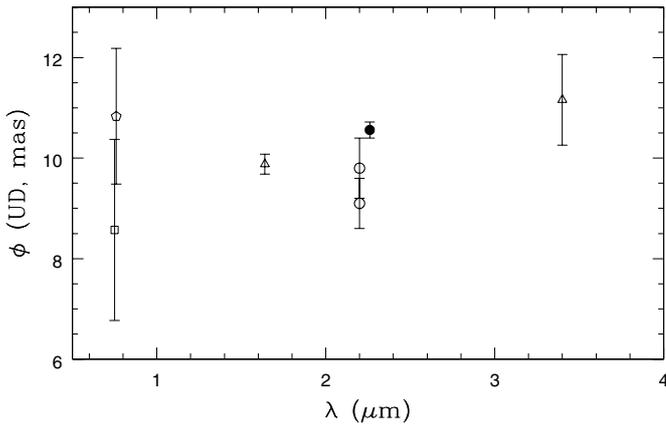
Fig. 1. Angular diameter determinations for RZ Ari. The filled circle is our result, while the open symbols are: square Africano et al. (1975), pentagon Beavers et al. (1981), triangles Ridgway et al. (1980), circles Dyck et al. (1998).

conclude that circumstellar matter is not dominant. This is independently confirmed by mid-infrared spectra, that show a featureless continuum around 10 μm (Speck et al. 2000). Also, there seems to be no evidence of binarity, a possibility which had initially been postulated on the basis of Hipparcos results. Percy et al. (2002) have discussed the origin of the problem with the Hipparcos data. Also speckle interferometry investigations by Mason et al. (1999) did not find companions. From our LO result, we can put an upper limit of $\approx$1:40 on the brightness ratio of a hypothetical companion with a projected separation in the range ±70 mas.

RZ Ari has been used as a building block in several empirical $T_{\rm eff}$ calibrations, such as those by Barnes (1976, 1978), Ridgway et al. (1980), Di Benedetto (1993). Dyck et al. (1998) provided a revised value of the bolometric flux, and using their own LBI diameter derived $T_{\rm eff} = 3442 \pm 148$ K. Of course, diameter variations must exist in this star, and therefore it seems of secondary importance at this point to discuss the accuracy of the various determinations and to refine the $T_{\rm eff}$ value. It would be more important to follow diameter and temperature variations with a dedicate monitoring, a possibility which is made available by several of the current interferometers.

3.5. SAO 76214

Although this star is a known binary (Mason et al. 2001b), our detection corresponds to a new component, with the characteristics listed in Table 4. We detect also the previously known component in our LO event record, with a separation consistent with PA = 270° and separation 0".5 listed by Mason et al. (2001b), but it is outside the scope of our observations to deal with such wide components. Moreover, the quantitative evaluation of the trace for SAO 76214 is hampered, especially on long time scales, by significant scintillation. We estimate the brightness ratio between the B and the A-C components to be 0.56 ± 0.10 in the K band. It is interesting to note that the Tycho Double Star Catalogue (Fabricius et al. 2002) examined

this pair and found a $\Delta V = 2.59$, however, LO (Africano et al. (1975) and visual estimates (most recently, Worley 1989) find a much smaller value, $\Delta V \approx 0.3$.

3.6. SAO 77000

This star has been repeatedly observed by filar micrometry (Couteau 1972, 1975, 1979, 1987, 1989; Heintz 1980) as well as by Hipparcos. Orbital motion is apparent over the period of 20 years spanned by the observations, however no clear orbital trend can be deduced yet. Due also to the intrinsically larger errors associated with visual observations, it is hard to extrapolate a possible position of the component for the epoch of our LO event (2005.13). Nevertheless we note a general consistency of quadrant and magnitude of the separation. Our measurement provides a significant constraint, since it follows about 14 years after the most recent available measurement. Assuming to a first approximation that the magnitude difference observed by Hipparcos ($\Delta Hp = 0.58$ mag) is similar to that in the V band, the comparison with the K band brightness ratio provided in Table 4 indicates that the two components have almost the same color, i.e. similar spectral types.

3.7. Other binaries

The remaining stars listed in Table 4 have no previous report of binary detection. Among these, the following objects have at least one bibliographical entry present in the *Simbad* database: SAO 80764, SAO 185661, the triple star IRC -30319, IRAS 04395+2521, and HD 283610. However these publications are on subjects not related to high angular resolution observations. There are no known previous publications associated with the four 2MASS objects present in Table 4.

We also mention that we have detected binarity in three further stars from Table 2, namely SAO 109617, SAO 110089 and SAO 78540. These are relatively wide systems, with separations of order 0".5, and therefore easily accessible to standard observations. For this reason, and also because LO are not very accurate for such large separations due to possible differences in local limb slope for the two components, we have not included these results in Table 4. However, we consider it possibly useful to report the brightness ratios in the K band. The values are 1.26 ± 0.02, 1.70 ± 0.03 and 0.5 ± 0.1, in the above order. It is noteworthy that all three stars have been measured at visual wavelengths by speckle interferometry and/or by Hipparcos. We quote, among others, Δm values of 1.66 mag (G band, Balega et al. 2004) and 1.87 mag (Hp band, Fabricius & Makarov 2000) for SAO 109617, and ΔHp values of 0.49 mag and 1.73 mag for SAO 110089 and SAO 78540, respectively (Fabricius & Makarov 2000). We note that these latter authors provide also Tycho B and V magnitude differences. We do not speculate at this point on the combination of all these values with our K-band determination, in view of the diversity of spectral bandpasses used in the visual.

A number of stars from Table 5 are additionally wide binaries with separations of several arcseconds, and we do not concern ourselves with them here.

3.8. Other stars of interest

Among the stars for which we did not detect binarity, a few are worthy some comments either because of their nature or because of previous attempts by high angular resolution techniques. SAO 80310 was investigated by Mason et al. (2001a) by speckle interferometry, with negative conclusions. The same result with the same technique was reported by Hartkopf & McAlister (1984) for SAO 92659. Both these stars were also found unresolved by Hipparcos.

SAO 164601 is a spectroscopic binary, which was previously observed as double by Evans et al. (1986). These authors reported a separation close to 1 mas, although without information on the brightness ratio. We have analyzed our trace ($SNR = 18.7$) with both the LSM and CAL methods, without finding evidence of binarity. In any case, due to the near-IR wavelength and the relatively slow sampling, we are insensitive to separations of less than about 3.5 mas on this trace. We notice that the position angle of our event ($110°$) was almost orthogonal with that of the event observed by Evans and collaborators.

We also recorded occultations during the passage of the Moon over two regions of special interest. On July 28th, 2004 the Moon reached a minimum distance of $0°.59$ from the Galactic Center. In this crowded, heavily obscured region we could record 54 events at the 2.2 m telescope in 3.4 h, being limited by overheads in telescope pointing and data storing. The majority (50) of the objects has no counterpart in optical catalogues. Spectral types on the other hand are known for about half the sample, thanks mostly to the work of Raharto et al. (1984). With very few exceptions, the stars are all of M spectral type. From the photometry available in the 2MASS catalogue (Cutri et al. 2003), it can be observed that about half of the stars have a color $J-K > 1$, indicating significant reddening. This is presumably due to interstellar dust in the direction of the Galactic Center, however in some cases colors as red as $J - K = 3.5$–5.0 are present, possibly pointing to additional circumstellar extinction.

In January 2005, we were able to record a passage of the Moon over the Taurus star-forming region. These passages are relatively frequent, and have been used in the past especially to derive important insights on the frequency of binaries in the early stages of stellar evolution (see Simon et al. 1995, and references therein). In our case, included were the following known young stellar objects: LH 98-106, DL Tau, GN Tau, Elias 3-18, ITG 31, LkHA 332. A few IR sources without optical counterpart were also recorded. Unfortunately, the sensitivity offered by the 1.5 m telescope was not sufficient to obtain quantitative results. Details on the full sample of occulted objects can be found in Table 5, available only on-line.

4. Considerations on performance and statistics

In F04 we reported the limiting sensitivity computed for LO observations with the MAGIC instrument. It was shown that the logarithm of the SNR of a LO light curve is approximately in inverse linear relation to the K magnitude. At the 1.5 m telescope, with the typical integration and sampling times of 3
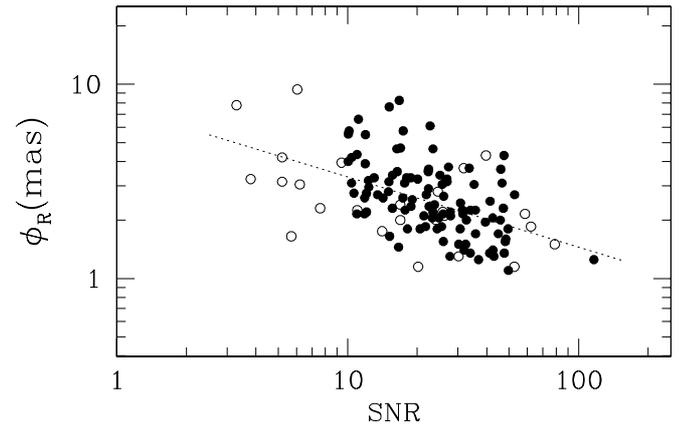
Fig. 2. Limiting resolution for the sources in our sample, as a function of SNR (solid dots). Only points with $SNR > 10$ are included. Also shown as open circles are the determinations from Fors et al. (2004). The solid line is a log–log fit through all points.

and ≈ 8 ms respectively, it can be expected to detect objects having $K \approx 8$ mag with $SNR = 3$. The present sample is much larger than that of F04. Excluding the sources observed from TIRGO (since those observations employed an entirely different detector and a comprehensive statistics for that configuration was already provided by Richichi et al. 1996), RZ Ari which was observed with a narrow-band filter, and a number of sources which were deemed too faint and plainly not binary and consequently without a detailed analysis, we are left with 285 events. However, the $SNR - K$ relationship of the present sample is not straighforward to interpret. Firstly, about 20% of the stars were observed with the 2.2 m telescope and show a trend which is offset from the main relationship by the expected factor of mirror area. Secondly, about 2/3 of the runs at the 1.5 m telescope were carried out with a wrong position of the pupil wheel which holds the cold stop. This had no effect on the stellar signal, but has produced a large increase in thermal background, resulting in higher noise, resulting in lower SNR than expected for a given stellar magnitude. As a consequence our sample is more inhomogeneous than that of F04, although the general characteristics of the relationship are confirmed. At the 1.5 m telescope we recorded about 20 events for stars with K between 8 and 8.5 mag. At the 2.2 m telescope, used only for the very crowded passage near the Galactic Center, we had a sufficient number of bright sources and the real limiting magnitude was not reached.

Similarly to what was done in F04, we have computed also the limiting angular resolution associated with the unresolved sources, following the same approach of Richichi et al. (1996). This has been done for 103 stars in our sample having $SNR > 10$, or about 4 times more numerous than in the sample of F04. The result, including a comparison with this latter work, is shown in Fig. 2.

It can be noted that the current sample and the previous from F04 have an almost identical distribution of limiting resolution against SNR, and can be fitted by the same log-log relationship. This is reassuring, since the behaviour be independent of the source, and be determined by the instrumental

characteristics and in particular by the integration time. The large spread in the relationship can be understood in terms of large variations of *SNR* from one LO light curve to another due to different situations of background and also to the specific conditions of signal extraction from the discrete pixels of the detector. Broadly speaking, the average relationship is such that *SNR* = 10 ensures a limiting resolution of about 3 mas. In the few cases in which *SNR* close to 100 could be recorded, the limiting resolution improves but remains above, as already noted in F04, the performance of fast InSb photometers which can operate with faster sampling.

A final consideration can be made about the statistics of binary detections in our sample. We have observed a total of 14 binaries (counting as such also the triple star IRC -30319), out of a total sample size of 350 stars. This points to a fraction of 4.0%, or more than two times smaller than what observed by Richichi et al. (1996) and in F04. This result seemed puzzling at first, since all the samples considered have a broad sky distribution and should have similar characteristics. It is not excluded that the targets that we observed in the direction of the Galactic Center have an actual deficit of binaries, due to the fact extinction introduced a bias towards stars that for a given apparent magnitude are more distant than in the previous samples. Therefore, hypothetical companions would have smaller angular separations for the same statistics of semi-major axis. However, only 20% of the stars in our sample were observed in the direction of the Galactic Center, and another explanation must exist for the lower binary fraction that we observe in the present work.

In fact we note that with the introduction of large, deep IR catalogues such as 2MASS in our predictions, we have effectively shifted the distribution of *K* magnitudes in our sample much closer to the limiting sensitivity of the technique. Therefore, we can expect that most of the LO light curves will have on average lower *SNR* than in the previous samples. As a result, it will become effectively more difficult to detect companions, especially those with brightness ratios larger than unity. Although we have not performed a detailed computation of this effect, its magnitude could easily explain the observed apparent deficit of binary detections. We conclude that the introduction of large catalogues, while increasing the number of predictions and correspondingly of observed LO, does not automatically produce a higher rate of results.

5. Conclusions

We have provided an update on the program of lunar occultation observations which is operational at Calar Alto Observatory, previously described by Fors et al. (2004), including 350 lunar occultation events. Although no major changes have occurred with respect to instrumentation, the program has been expanded to include, in addition to the Spanish 1.5 m telescope, also the 2.2 m telescope. Additionally, we have developed and made use of new methods of light curve extraction and characterization, suitable to perform in an automated fashion the preliminary analysis of large volumes of lunar occultation data. This has been made necessary by the availability of large, deep near-IR catalogues such as the 2MASS

(Cutri et al. 2003) and DENIS (Paturel et al. 2003), which permit the prediction and observation of a much increased number of occultation events.

The results include the detection in the near-IR of one triple and 13 binary systems. For all but two stars, these represent first time detections. Projected separations range from $0\rlap{.}''09$ to $0\rlap{.}''007$, and brightess ratios reach up to 1:20 in the *K* band. We have also determined the angular diameter of the M 6 star RZ Ari, which we have discussed in comparison with previous determinations. Our observations have included a passage of the Moon over a crowded region in the vicinity of the Galactic Center (resulting in 54 events observed in about 3 h), and a passage in the Taurus star-forming region. Passages of the Moon close to the Galactic center are taking place in these years, and we have provided some examples. These events provide a unique opportunity to extract milliarcsecond resolution information on a large number of objects in obscured, crowded and relatively unstudied regions, and can be adequately observed with 2–4 m -class telescopes.

We have discussed the performance achieved in our observations in terms of limiting magnitude and angular resolution. We have shown that at 1–2 m class telescopes equipped with a rather traditional array detector it is possible to achieve $\approx 0\rlap{.}''003$ on sources as faint as $K \approx 8$ mag. The rate of binary detection in random observations of field stars that emerges from the present work is $\approx 4\%$, considerably lower than established earlier by similar studies (Richichi et al. 1996; Fors et al. 2004). We attribute this effect largely to the fact that the use of catalogues such as 2MASS has increased dramatically the number of occultation observable per night, but this increase is realized mostly at the faint magnitude end, where the dynamic range available is much smaller than for brighter stars.

References

Africano, J. L., Cobb, C. L., Dunham, D. W., et al. 1975, AJ, 80, 689
Balega, I., Balega, Y. Y., Maksimov, A. F., et al. 2004, A&A, 422, 627
Barnes, T. G., & Evans, D. S. 1976, AJ, 174, 489
Barnes, T. G., Evans, D. S., & Moffett, T. J. 1978, AJ, 183, 285
Beavers, W. I., Eitter, J. J., & Cadmus, R. R. 1981, AJ, 86, 1404
Couteau, P. 1972, A&AS, 6, 177
Couteau, P. 1975, A&AS, 20, 391
Couteau, P. 1979, A&AS, 36, 11

Couteau, P. 1987, A&AS, 70, 193

Couteau, P. 1989, A&AS, 79, 385

Cutri, R. M., Skrutskie, M. F., van Dyk, S., et al. 2003, VizieR Online Data Catalog, 2246

di Benedetto, G. P. 1993, A&A, 270, 315

Dyck, H. M., van Belle, G. T., & Thompson, R. R. 1998, AJ, 116, 981

Evans, D. S., & Edwards, D. A. 1981, AJ, 86, 1277

Evans, D. S., Edwards, D. A., Frueh, M., et al. 1985, AJ, 90, 2360

Evans, D. S., McWilliam, A., Sandmann, W. H., & Frueh, M. 1986, AJ, 92, 1210

Fabricius, C., & Makarov, V. V. 2000, A&A, 356, 141

Fabricius, C., Høg, E., Makarov, V. V., Mason, B. D., Wycoff, G. L., & Urban, S. E. 2002, A&A, 384, 180

Fors, O., Richichi, A., Núñez, J., & Prades, A. (F04) 2004, A&A, 419, 285

Hartkopf, W. I., & McAlister, H. A. 1984, PASP, 96, 105

Heintz, W. D. 1980, ApJS, 44, 111

Houk, N., & Smith-Moore, M. 1988, Michigan Spectral Survey, Ann Arbor, Dep. Astron., Univ. Michigan, 4

Kukarkin, B. V., Kholopov, P. N., Pskovsky, Y. P., et al. 1971, General Catalogue of Variable Stars, 3rd ed.

Mason, B. D., Martin, C., Hartkopf, W. I., et al. 1999, AJ, 117, 1890

Mason, B. D., Hartkopf, W. I., Holdenried, E. R., & Rafferty, T. J. 2001a, AJ, 122, 3224

Mason, B. D., Wycoff, G. L., Hartkopf, W. I., et al. 2001b, AJ, 122, 3466

McAlister, H. A. 1978, PASP, 90, 288

Neugebauer, G., & Leighton, R. B. 1969, Two-micron sky survey. A preliminary catalogue, NASA SP, Washington: NASA

Paturel, G., Petit, C., & Rousseau, J. 2003, A&A, 405, 1

Percy, J. R., & Hosick, J. 2002, MNRAS, 334, 669

Raharto, M., Hamajima, K., Ichikawa, T., Ishida, K., & Hidayat, B. 1984, Ann. Tokyo Astron. Obs., 19, 469

Richichi, A. 1989, A&A, 226, 3

Richichi, A., Baffa, C., Calamai, G., & Lisi, F. 1996, AJ, 112, 2786

Richichi, A., Calamai, G., & Stecklum, B. 2002, A&A, 382, 178

Richichi, A., & Calamai, G. 2003, A&A, 399, 275

Richichi, A., Percheron, I., & Khristoforova, M. 2005, A&A, 431, 773

Ridgway, S. T., Jacoby, G. H., Joyce, R. R., & Wells, D. C. 1980, AJ, 85, 1496

Simon, M., Ghez, A. M., Leinert, Ch., et al. 1995, ApJ, 443, 625

Speck, A. K., Barlow, M. J., Sylvester, R. J., & Hofmeister, A. M. 2000, A&AS, 146, 437

Worley, C. E. 1989, Publ. USNO 25, Pt. 3

Online Material

Table 5. Complete list of occultation events and of the circumstances of their observation.

Source	Date UT	Telescope +detector	Filter	D ″	Δt ms	τ ms	V mag	K mag	Sp.	Dist. pc
SAO 164567	25-10-01	T	K	21	3.42	3.0	7.4	3.2	K5III	278
SAO 110325	28-11-01	T	K	21	2.42	2.0	6.4	4.1	K0	147
SAO 128864	05-11-03	CB	K	7	8.40	3.0	9.7	8.2	G0	
AG-00 73	05-11-03	CB	K	7	8.40	3.0	10.4	7.2	M0	
SAO 109803	06-11-03	CB	K	7	8.40	3.0	8.1	6.7	F8	
SAO 109820	06-11-03	CB	K	7	8.40	3.0	9.9	8.0	K0	
AG+04 167	06-11-03	CB	K	7	8.40	3.0	10.3	7.8	K0	
SAO 109832	06-11-03	CB	K	7	8.40	3.0	7.5	6.5	F0	102
AG+05 155	06-11-03	CB	K	7	8.40	3.0	10.2	7.7	K0	
SAO 109888	07-11-03	CB	K	7	8.33	3.0	9.3	6.9	K5	
SAO 109901	07-11-03	CB	K	7	8.40	3.0	8.7	7.8	F5	214
GSC 01902-00718	01-03-04	CB	K	7	8.48	3.0	9.3	6.2		
AG+26 730	01-03-04	CB	K	7	8.47	3.0	9.9	6.9	G5	
IRAS 06528+2641	02-03-04	CB	K	7	8.34	3.0		5.2		
06575655+2637589	02-03-04	CB	K	7	8.44	3.0		6.7		
SAO 78914	02-03-04	CB	K	7	8.46	3.0	8.6	5.9	K2	
GSC 01902-00833	02-03-04	CB	K	7	8.43	3.0	10.7	5.9		
AG+25 900	02-03-04	CB	K	7	8.34	3.0	10.5	8.1	G5	
SAO 79629	02-03-04	CB	K	7	8.37	3.0	9.4	7.5	G5	
AG+26 855	02-03-04	CB	K	7	8.35	3.0	10.5	7.5	K0	
76 Gem	02-03-04	CB	K	7	8.40	3.0	5.3	1.7	K5III	182
GSC 01916-01291	02-03-04	CB	K	7	8.47	3.0	10.2	7.9		
SAO 79672	02-03-04	CB	K	7	8.45	3.0	7.4	3.8	K5III	529
SAO 79684	02-03-04	CB	K	7	8.10	3.0	8.8	5.7	K7	
SAO 79685	02-03-04	CB	K	7	8.40	3.0	8.5	6.9	G5IV	53
AG+26 864	02-03-04	CB	K	7	8.49	3.0	10.0	6.2	K5	
SAO 79702	02-03-04	CB	K	7	8.38	3.0	9.3	6.7	K2	
07531704+2527173	03-03-04	CB	K	7	11.63	6.0		8.1		
GSC 01929-00425	03-03-04	CB	K	7	8.34	3.0	9.9	6.0		
GSC 01930-01242	03-03-04	CB	K	7	8.52	3.0	9.7	7.1		
08382433+2328215	03-03-04	CB	K	7	8.40	3.0		7.8		
SAO 80310	03-03-04	CB	K	7	8.51	3.0	6.9	5.6	F8	35
GSC 01942-02645	03-03-04	CB	K	7	8.45	3.0	9.9	7.7		
SAO 80370	03-03-04	CB	K	7	8.36	3.0	9.7	7.3	K0	
GSC 01943-00150	04-03-04	CB	K	7	8.38	3.0	10.5	7.0		
08483998+2235329	04-03-04	CB	K	7	8.52	3.0		7.8		
SAO 80442	04-03-04	CB	K	7	8.45	3.0	9.3	6.8	K0	201
SAO 80456	04-03-04	CB	K	7	8.40	3.0	9.5	7.1	G5	
SAO 80469	04-03-04	CB	K	7	8.44	3.0	9.0	6.5	K0	202
SAO 80481	04-03-04	CB	K	7	8.46	3.0	9.5	7.3	K0	
SAO 80735	31-03-04	CB	K	7	8.40	3.0	8.7	5.9	K0	1282
SAO 80764	01-04-04	CB	K	7	8.40	3.0	7.8	4.0	K2	1429
SAO 80772	01-04-04	CB	K	7	8.36	3.0	8.7	5.0	K5	
[RHI84] 10- 333	28-07-04	CC	K	5	8.46	3.0		4.9	M6.5	
17411783-2816159	28-07-04	CC	K	5	8.42	3.0		7.0		
[RHI84] 10- 379	28-07-04	CC	K	5	8.43	3.0		6.4	M6.5:	
[RHI84] 10- 396	28-07-04	CC	K	5	8.54	3.0		5.1	M7	
17413954-2819536	28-07-04	CC	K	5	8.51	3.0		6.6		
IRAS 17396-2805	28-07-04	CC	K	5	8.45	3.0		5.6	M4	
[RHI84] 10- 421	28-07-04	CC	K	5	8.52	3.0		6.2	M5	
[RHI84] 10- 389	28-07-04	CC	K	5	8.40	3.0		6.4	M5	
SAO 185638	28-07-04	CC	K	5	8.40	3.0	8.3	3.8	G8Iab	
[RHI84] 10- 423	28-07-04	CC	K	5	8.77	3.0		4.4	M1	

Table 5. continued.

Source	Date UT	Telescope +detector	Filter	D "	Δt ms	τ ms	V mag	K mag	Sp.	Dist. pc
IRAS 17399-2811	28-07-04	CC	K	5	8.50	3.0		4.0	M6.5:	
[RHI84] 10- 431	28-07-04	CC	K	5	8.35	3.0		5.2	M4	
17425620-2820370	28-07-04	CC	K	5	8.48	3.0		4.6		
17431472-2754338	28-07-04	CC	K	5	8.44	3.0		7.1		
17431415-2753091	28-07-04	CC	K	5	8.45	3.0		6.9		
[RHI84] 10- 456	28-07-04	CC	K	5	8.37	3.0		4.8	M4	
17432850-2754372	28-07-04	CC	K	5	8.37	3.0		6.7		
17433423-2755331	28-07-04	CC	K	5	8.34	3.0		7.2		
17435106-2801060	28-07-04	CC	K	5	8.36	3.0		6.6		
17434896-2758595	28-07-04	CC	K	5	8.47	3.0		6.7		
[RHI84] 10- 441	28-07-04	CC	K	5	8.31	3.0		3.7	M6	
17432189-2751590	28-07-04	CC	K	5	8.37	3.0		5.7		
17431718-2822397	28-07-04	CC	K	5	8.36	3.0		6.3		
[RHI84] 10- 465	28-07-04	CC	K	5	8.34	3.0		5.5	M2	
17441302-2808449	28-07-04	CC	K	5	8.39	3.0		7.6		
[RHI84] 10- 482	28-07-04	CC	K	5	8.31	3.0		4.8	M5	
SAO 185661	28-07-04	CC	K	5	8.39	3.0	9.9	5.9	K5	
17443008-2758255	28-07-04	CC	K	5	8.32	3.0		6.7		
V744 Sgr	28-07-04	CC	K	5	8.38	3.0	13.0	2.9	M7	
[RHI84] 10- 518	28-07-04	CC	K	5	8.35	3.0		4.3	M6.5	
17450844-2810286	28-07-04	CC	K	5	8.35	3.0		6.8		
[RHI84] 10- 523	28-07-04	CC	K	5	8.35	3.0		3.7	M4	
IRC -30319	28-07-04	CC	K	5	8.39	3.0	8.8	1.8	K2	
17454657-2809090	28-07-04	CC	K	5	8.36	3.0		5.3		
17454891-2809333	28-07-04	CC	K	5	8.32	3.0		6.1		
IRAS 17428-2802	28-07-04	CC	K	5	8.38	3.0		5.2		
[RHI84] 10- 565	28-07-04	CC	K	5	8.40	3.0		3.4	M1	
[RHI84] 10- 564	28-07-04	CC	K	5	8.34	3.0		5.9	M8	
17455791-2821113	28-07-04	CC	K	5	8.55	3.0		7.8		
17454872-2823210	28-07-04	CC	K	5	8.46	3.0		6.8		
17464520-2809135	28-07-04	CC	K	5	8.43	3.0		7.3		
17463693-2820212	28-07-04	CC	K	5	8.30	3.0		6.7		
17470407-2811365	28-07-04	CC	K	5	8.44	3.0		5.9		
17471145-2810386	28-07-04	CC	K	5	8.38	3.0		6.2		
17471850-2812592	28-07-04	CC	K	5	8.50	3.0		4.7		
17472312-2810014	28-07-04	CC	K	5	8.39	3.0		7.3		
17472282-2813443	28-07-04	CC	K	5	8.30	3.0		6.3		
[RHI84] 10- 610	28-07-04	CC	K	5	8.32	3.0		7.5	M4:	
17464703-2753028	28-07-04	CC	K	5	8.37	3.0		5.5		
17473721-2812078	28-07-04	CC	K	5	8.31	3.0		7.6		
17473925-2803207	29-07-04	CC	K	5	8.36	3.0		6.9		
17473481-2759092	29-07-04	CC	K	5	8.33	3.0		6.7		
17473524-2818529	29-07-04	CC	K	5	8.45	3.0		6.6		
[RHI84] 10- 658	29-07-04	CC	K	5	8.44	3.0		5.1	M7	
21394110-1947036	18-11-04	CB	K	7	8.42	3.0		8.1		
HD 206048	18-11-04	CB	K	7	8.40	3.0	10.1	7.7	G8IV	
HD 206205	18-11-04	CB	K	7	8.40	3.0	10.3	8.0	G8/K0V	
HD 206232	18-11-04	CB	K	7	8.40	3.0	10.0	7.3	K1III:	
SAO 190556	18-11-04	CB	K	7	8.53	3.0	7.0	4.3	K1III	173
HD 206339	18-11-04	CB	K	7	8.53	3.0	10.4	8.1	G6/G8III:	
HD 206355	18-11-04	CB	K	7	8.40	3.0	10.0	5.6	M0/M1	
SAO 164601	18-11-04	CB	K	7	8.58	3.0	6.2	5.7	A0m...	110
HD 206530	18-11-04	CB	K	7	8.40	3.0	9.9	8.2	G5/G6IV	
22313353-1507204	19-11-04	CB	K	7	8.40	3.0		4.9		

Table 5. continued.

Source	Date UT	Telescope +detector	Filter	D $''$	Δt ms	τ ms	V mag	K mag	Sp.	Dist. pc
SAO 165154	19-11-04	CB	K	7	8.40	3.0	9.0	6.2	K1III	
PPM 723098	19-11-04	CB	K	7	8.53	3.0	9.8	7.5		
GSC 05817-01033	19-11-04	CB	K	7	8.40	3.0	10.9	8.4		
BD-15 6246	19-11-04	CB	K	7	8.40	3.0	10.5	7.8		
BD-14 6307	19-11-04	CB	K	7	8.40	3.0	9.6	7.5		
SAO 165182	19-11-04	CB	K	7	8.53	3.0	8.8	6.1	K1III	
BD-14 6314	19-11-04	CB	K	7	8.53	3.0	10.6	8.2		
SAO 165199	19-11-04	CB	K	7	8.40	3.0	8.3	5.7	K0III	223
BD-14 6322	19-11-04	CB	K	7	8.40	3.0	9.7	7.5		
HD 220142	20-11-04	CB	K	7	8.53	3.0	10.5	7.8	K2	
SAO 146681	20-11-04	CB	K	7	8.40	3.0	8.7	7.5	G0	77
HD 220374	20-11-04	CB	K	7	8.40	3.0	9.5	8.4	F8	
SAO 146683	20-11-04	CB	K	7	8.40	3.0	6.7	4.6	K0	160
SAO 146688	20-11-04	CB	K	7	8.40	3.0	8.9	6.5	K0	
SAO 146701	20-11-04	CB	K	7	8.53	3.0	9.4	6.4	K2	287
SAO 146718	20-11-04	CB	K	7	8.53	3.0	9.5	7.8	G5	
SAO 146726	20-11-04	CB	K	7	8.40	3.0	8.7	7.0	G5	166
AG+03 113	22-11-04	CB	K	7	8.53	3.0	10.5	7.5	K2	
SAO 109568	22-11-04	CB	K	7	8.53	3.0	7.6	6.4	F8	61
GSC 00015-01007	22-11-04	CB	K	7	8.40	3.0	10.8	8.0		
SAO 109599	22-11-04	CB	K	7	8.40	3.0	7.8	6.5	F5	88
GSC 00022-00601	22-11-04	CB	K	7	8.40	3.0	10.2	7.9		
SAO 109617	22-11-04	CB	K	7	8.40	3.0	8.2	5.5	K2	21
GSC 00622-01301	23-11-04	CB	K	7	8.53	3.0	9.6	7.5		
SAO 110089	23-11-04	CB	K	7	8.40	3.0	8.5	6.7	K0	47
SAO 110096	23-11-04	CB	K	7	8.40	3.0	8.4	7.7	F0	535
SAO 110099HIC 8110 inc	23-11-04	CB	K	7	8.40	3.0	8.6	6.7	F5	
SAO 110100	23-11-04	CB	K	7	8.40	3.0	8.0	6.6	F2	70
AG+09 168	23-11-04	CB	K	7	8.53	3.0	10.5	7.7	K0	
IRC +10022	23-11-04	CB	K	7	8.40	3.0	9.0	2.8	M...	
GSC 00625-01112	23-11-04	CB	K	7	8.53	3.0	10.1	7.0		
AG+10 200	23-11-04	CB	K	7	8.40	3.0	9.7	8.2	G5	
GSC 00625-00649	23-11-04	CB	K	7	8.40	3.0	10.0	7.0		
AG+10 202	23-11-04	CB	K	7	8.40	3.0	9.5	4.6	M0	
SAO 92659	23-11-04	CB	K	7	8.53	3.0	5.9	5.1	F2Vw	43
SAO 147041	18-12-04	CB	K	7	8.40	3.0	5.1	5.4	B7III-IV	125
HD 224959	18-12-04	CB	K	7	8.44	3.0	9.6	7.3	R...	513
SAO 128550	18-12-04	CB	K	7	8.53	3.0	8.7	7.9	A5	
SAO 110016	20-12-04	CB	K	7	8.40	3.0	8.5	5.5	K2	418
SAO 110020	20-12-04	CB	K	7	8.40	3.0	7.6	6.5	F5	170
AG+09 150	21-12-04	CB	K	7	8.53	3.0	9.3	4.9	K5	
SAO 110027	21-12-04	CB	K	7	8.40	3.0	8.8	7.7	G0	
G 3-38	17-01-05	CB	K	7	8.41	3.0	11.5	8.2	K7	46
GSC 00633-00057	17-01-05	CB	K	7	10.40	5.0	10.9	8.1		
GSC 00636-00646	17-01-05	CB	K	7	8.38	3.0	10.6	7.8		
AG+12 224	17-01-05	CB	K	7	8.42	3.0	9.5	8.1	G5	
AG+12 226	17-01-05	CB	K	7	8.48	3.0	9.3	4.8	M0	
SAO 92788	17-01-05	CB	K	7	8.38	3.0	9.1	7.6	K0	
SAO 92789	17-01-05	CB	K	7	8.46	3.0	7.9	6.7	F5	78
SAO 92795	17-01-05	CB	K	7	8.45	3.0	7.2	4.8	K0	141
SAO 92823	17-01-05	CB	K	7	8.49	3.0	8.9	6.6	G5	
GSC 01227-01287	18-01-05	CB	K	7	8.49	3.0	10.6	7.4		
GSC 01227-01318	18-01-05	CB	K	7	8.36	3.0	10.3	7.4		
RZ Ari	18-01-05	CB	NB	7	8.36	3.0	5.8	-0.9	M6III	124

Table 5. continued.

Source	Date UT	Telescope +detector	Filter	*D* ″	*Δt* ms	*τ* ms	*V* mag	*K* mag	Sp.	Dist. pc
GSC 01247-00517	19-01-05	CB	*K*	7	8.34	3.0	10.7	7.8		
03423832+2216449	19-01-05	CB	*K*	7	8.40	3.0		7.3		
CSS 80	19-01-05	CB	*K*	7	8.46	3.0	9.7	3.8		
03482003+2232543	19-01-05	CB	*K*	7	8.44	3.0		5.5		
SAO 76214	19-01-05	CB	*K*	7	8.47	3.0	8.2	5.4	K0	
LH 98-106	19-01-05	CB	*K*	7	8.47	3.0	7.3	6.0	F5	37
SAO 76283	20-01-05	CB	*K*	7	8.33	3.0	7.6	5.9	G0	27
03521570+2245296	20-01-05	CB	*K*	7	8.53	3.0		7.2		
04330652+2505165	20-01-05	CB	*K*	7	8.43	3.0		7.8		
04330286+2511447	20-01-05	CB	*K*	7	10.44	5.0		8.4		
DL Tau	20-01-05	CB	*K*	7	8.44	3.0	13.6	8.0	GV:e...	
04343950+2513544	20-01-05	CB	*K*	7	8.50	3.0		7.4		
HD 283715	20-01-05	CB	*K*	7	8.53	3.0	10.6	6.5	K1III	
04345591+2521351	20-01-05	CB	*K*	7	8.59	3.0		6.4		
IRAS 04320+2519	20-01-05	CB	*K*	7	8.43	3.0		4.3		
04361037+2512529	20-01-05	CB	*K*	7	8.43	3.0		6.3		
04363513+2526425	20-01-05	CB	*K*	7	8.40	3.0		7.1		
04365667+2521061	20-01-05	CB	*K*	7	8.42	3.0		7.4		
Elias 3-29	20-01-05	CB	*K*	7	8.43	3.0		6.8	G9III	
04372451+2524318	20-01-05	CB	*K*	7	8.59	3.0		5.7		
IRAS 04349+2522	20-01-05	CB	*K*	7	8.56	3.0		5.2		
IRAS 04357+2528	20-01-05	CB	*K*	7	8.60	3.0		4.9		
GN Tau	20-01-05	CB	*K*	7	8.47	3.0	15.1	8.1	M2.5	
AG+25 438	20-01-05	CB	*K*	7	8.58	3.0	10.7	7.4	K5V	
Elias 3-18	20-01-05	CB	*K*	7	8.45	3.0		6.3	B5	
04405597+2531312	20-01-05	CB	*K*	7	8.54	3.0		7.2		
ITG 31	20-01-05	CB	*K*	7	8.48	3.0		5.2		
04413015+2527019	20-01-05	CB	*K*	7	8.39	3.0		7.6		
LkHA 332	21-01-05	CB	*K*	7	8.39	3.0	14.7	7.9	K5	
IRAS 04395+2521	21-01-05	CB	*K*	7	8.53	3.0		5.5		
[GKH94] 10	21-01-05	CB	*K*	7	8.41	3.0		7.1		
04440885+2540333	21-01-05	CB	*K*	7	8.59	3.0		6.9		
SAO 76732	21-01-05	CB	*K*	7	8.38	3.0	9.6	7.7	A0III	
Elias 3-19	21-01-05	CB	*K*	7	8.58	3.0		6.0	M4III	
HD 283878	21-01-05	CB	*K*	7	8.59	3.0	10.8	6.5	G5III	
IRC +30094	21-01-05	CB	*K*	7	8.55	3.0		2.3		
05265156+2659299	21-01-05	CB	*K*	7	8.58	3.0		7.5		
AG+26 492	21-01-05	CB	*K*	7	8.53	3.0	10.3	6.7	K0	
IRAS 05236+2646	21-01-05	CB	*K*	7	8.42	3.0		4.4		
05270549+2715022	21-01-05	CB	*K*	7	8.43	3.0		7.3		
05273859+2716477	21-01-05	CB	*K*	7	8.39	3.0		7.1		
05291081+2718030	21-01-05	CB	*K*	7	8.42	3.0		7.4		
GSC 01856-00734	21-01-05	CB	*K*	7	8.38	3.0	10.2	5.8		
05295303+2706414	21-01-05	CB	*K*	7	8.39	3.0		6.0		
05300059+2727115	21-01-05	CB	*K*	7	8.56	3.0		6.9		
05303373+2708008	21-01-05	CB	*K*	7	8.77	3.0		7.8		
HD 244308	21-01-05	CB	*K*	7	8.77	3.0	9.8	4.6	K7	
05311866+2730551	21-01-05	CB	*K*	7	8.60	3.0		6.4		
05321151+2708449	21-01-05	CB	*K*	7	10.52	5.0		8.1		
05323754+2727475	21-01-05	CB	*K*	7	8.47	3.0		7.5		
05330539+2713357	21-01-05	CB	*K*	7	8.41	3.0		7.5		
05330852+2710533	21-01-05	CB	*K*	7	8.57	3.0		7.6		
05333882+2715046	21-01-05	CB	*K*	7	8.57	3.0		7.4		
05335555+2715363	21-01-05	CB	*K*	7	8.57	3.0		7.4		

Table 5. continued.

Source	Date UT	Telescope +detector	Filter	D ''	Δt ms	τ ms	V mag	K mag	Sp.	Dist. pc
SAO 77258	21-01-05	CB	K	7	8.77	3.0	7.9	4.3	K0	532
SAO 77266	21-01-05	CB	K	7	8.54	3.0	8.1	7.1	F0	116
05345840+2724187	21-01-05	CB	K	7	8.56	3.0		6.4		
GSC 01869-01803	22-01-05	CB	K	7	8.58	3.0	11.4	7.6		
GSC 01869-01378	22-01-05	CB	K	7	8.41	3.0	10.2	7.4		
SAO 77280	22-01-05	CB	K	7	8.40	3.0	8.8	4.1	M0	
GSC 01869-01288	22-01-05	CB	K	7	8.53	3.0	10.6	7.7		
GSC 01869-01804	22-01-05	CB	K	7	8.41	3.0	10.3	7.0		
GSC 01869-01778	22-01-05	CB	K	7	8.39	3.0	9.4	6.5		
GSC 01869-01436	22-01-05	CB	K	7	8.37	3.0	10.0	6.9		
05380288+2721511	22-01-05	CB	K	7	8.57	3.0		6.6		
05400930+2714478	22-01-05	CB	K	7	8.43	3.0		7.1		
05403514+2715388	22-01-05	CB	K	7	8.37	3.0		7.1		
05404432+2725221	22-01-05	CB	K	7	8.55	3.0		7.2		
05415664+2707323	22-01-05	CB	K	7	8.45	3.0		5.2		
SAO 78242	22-01-05	CB	K	7	8.77	3.0	8.8	6.6	K0	
AG+27 643	22-01-05	CB	K	7	8.51	3.0	9.9	7.5	K0	
AG+27 644	22-01-05	CB	K	7	8.54	3.0	9.9	6.9	K7	
SAO 78291	22-01-05	CB	K	7	8.47	3.0	7.7	4.5	K0Ib	735
06241536+2746220	22-01-05	CB	K	7	8.53	3.0		7.3		
06250582+2756209	22-01-05	CB	K	7	8.54	3.0		6.8		
06253942+2738004	22-01-05	CB	K	7	8.52	3.0		6.3		
AG+27 661	22-01-05	CB	K	7	10.61	5.0	10.3	7.8	K2	
AG+27 662	22-01-05	CB	K	7	8.53	3.0	8.9	6.7	K0	
SAO 78396	22-01-05	CB	K	7	8.59	3.0	9.8	7.2	K0	
SAO 78410	22-01-05	CB	K	7	8.49	3.0	7.7	4.7	K1III	463
AG+27 677	23-01-05	CB	K	7	8.38	3.0	9.9	7.7	G0	342
SAO 78434	23-01-05	CB	K	7	8.56	3.0	8.6	5.4	A2	
06301773+2746270	23-01-05	CB	K	7	8.57	3.0		7.5		
06301839+2752010	23-01-05	CB	K	7	8.60	3.0		7.0		
IRAS 06277+2747	23-01-05	CB	K	7	8.54	3.0		5.0		
06322702+2739440	23-01-05	CB	K	7	8.43	3.0		7.7		
SAO 78486	23-01-05	CB	K	7	10.61	5.0	9.5	8.2	A7	
06335778+2728365	23-01-05	CB	K	7	8.41	3.0		7.5		
SAO 78509	23-01-05	CB	K	7	8.54	3.0	9.7	7.1	K2	
06345678+2732546	23-01-05	CB	K	7	8.41	3.0		6.6		
SAO 78527	23-01-05	CB	K	7	8.58	3.0	9.3	6.8	K0	
SAO 78540	23-01-05	CB	K	7	8.57	3.0	6.9	5.3	G0	36
GSC 01888-01733	23-01-05	CB	K	7	8.48	3.0	10.1	5.4		
04183702+2434105	16-02-05	CB	K	7	8.48	3.0		6.7		
HD 283610	16-02-05	CB	K	7	8.49	3.0	9.6	5.4	K5III	
Elias 3-3	16-02-05	CB	K	7	8.38	3.0		5.8	K2III	
SAO 76596	16-02-05	CB	K	7	8.38	3.0	9.3	6.0	G8III	
04255198+2503159	16-02-05	CB	K	7	8.40	3.0		6.3		
04264187+2500314	17-02-05	CB	K	7	8.44	3.0		6.7		
SAO 76615	17-02-05	CB	K	7	10.42	5.0	9.0	7.5	A1III	111
05095433+2648584	17-02-05	CB	K	7	10.36	5.0		6.9		
SAO 77000	17-02-05	CB	K	7	8.42	3.0	9.1	5.4	G5	244
IRAS 05087+2702	17-02-05	CB	K	7	8.36	3.0		4.8		
SAO 77040	17-02-05	CB	K	7	10.48	5.0	9.7	8.2	G0	115
SAO 77061	17-02-05	CB	K	7	10.45	5.0	10.0	8.2	G0	83
SAO 77070	17-02-05	CB	K	7	8.43	3.0	8.9	6.0	G5	164
05162746+2714049	17-02-05	CB	K	7	8.40	3.0		7.2		
05165224+2700265	17-02-05	CB	K	7	8.49	3.0		6.0		

Table 5. continued.

Source	Date UT	Telescope +detector	Filter	D ″	Δt ms	τ ms	V mag	K mag	Sp.	Dist. pc
05171636+2709420	17-02-05	CB	K	7	10.45	5.0		7.9		
05171881+2656220	17-02-05	CB	K	7	8.41	3.0		7.8		
05174804+2700307	17-02-05	CB	K	7	8.42	3.0		7.0		
05175703+2653281	17-02-05	CB	K	7	8.48	3.0		7.5		
IRAS 05156+2654	17-02-05	CB	K	7	8.42	3.0		4.5		
SAO 77108	18-02-05	CB	K	7	8.43	3.0	9.4	7.9	G5	112
05201417+2654113	18-02-05	CB	K	7	8.48	3.0		7.5		
05212000+2652578	18-02-05	CB	K	7	10.37	5.0		7.2		
05220164+2659311	18-02-05	CB	K	7	8.41	3.0		5.7		
06051402+2809214	18-02-05	CB	K	7	8.35	3.0		6.1		
06055838+2751298	18-02-05	CB	K	7	8.42	3.0		7.3		
06064765+2805259	18-02-05	CB	K	7	10.43	5.0		8.1		
SAO 77969	18-02-05	CB	K	7	8.41	3.0	9.5	7.9	G0	
GSC 01872-01897	18-02-05	CB	K	7	8.44	3.0	9.8	7.0		
06073307+2809556	18-02-05	CB	K	7	8.46	3.0		7.1		
06075805+2751369	18-02-05	CB	K	7	8.37	3.0		7.0		
AG+28 611	18-02-05	CB	K	7	8.47	3.0	10.4	6.9	K0	
CSS 188	18-02-05	CB	K	7	8.45	3.0	13.9	5.5	S	
06085962+2755026	18-02-05	CB	K	7	8.40	3.0		5.6		
06093373+2759385	18-02-05	CB	K	7	10.48	5.0		7.8		
06093876+2801211	18-02-05	CB	K	7	10.49	5.0		7.6		
06100794+2800555	18-02-05	CB	K	7	8.37	3.0		6.9		
06103125+2757078	18-02-05	CB	K	7	8.46	3.0		7.1		
GSC 01885-00864	18-02-05	CB	K	7	8.37	3.0	9.5	5.5		
GSC 01885-01082	18-02-05	CB	K	7	8.39	3.0	10.3	7.3		
06113254+2751170	18-02-05	CB	K	7	8.42	3.0		7.7		
GSC 01885-00849	18-02-05	CB	K	7	8.48	3.0	10.0	7.2		
GSC 01885-01059	18-02-05	CB	K	7	8.41	3.0	10.3	7.5		
GSC 01885-01003	18-02-05	CB	K	7	8.44	3.0	10.2	7.6		
GSC 01885-01024	18-02-05	CB	K	7	8.39	3.0	9.6	5.6		
06132916+2758550	19-02-05	CB	K	7	8.40	3.0		7.2		
GSC 01885-01197	19-02-05	CB	K	7	8.45	3.0	10.2	6.4		
06143648+2756007	19-02-05	CB	K	7	8.47	3.0		6.3		
SAO 78128	19-02-05	CB	K	7	8.35	3.0	8.3	5.8	K2	178
06151320+2752458	19-02-05	CB	K	7	8.44	3.0		7.3		
06152640+2749330	19-02-05	CB	K	7	8.47	3.0		6.1		
SAO 78149	19-02-05	CB	K	7	8.52	3.0	8.0	4.4	K2	255
Kiso C2-125	19-02-05	CB	K	7	8.40	3.0	14.2	6.5		
06164415+2754332	19-02-05	CB	K	7	8.45	3.0		6.9		
06172566+2744429	19-02-05	CB	K	7	10.40	5.0		8.1		
GSC 01886-01909	19-02-05	CB	K	7	8.43	3.0	9.9	6.9		
06173933+2731055	19-02-05	CB	K	7	8.44	3.0		7.9		
06174326+2752319	19-02-05	CB	K	7	8.45	3.0		7.0		
06181909+2732294	19-02-05	CB	K	7	8.43	3.0		6.3		
SAO 78917	19-02-05	CB	K	7	8.39	3.0	8.3	4.4	M0	
06584528+2747087	19-02-05	CB	K	7	10.47	5.0		8.1		
06595289+2744549	19-02-05	CB	K	7	8.42	3.0		7.4		
AG+27 746	19-02-05	CB	K	7	10.38	5.0	9.2	8.0	F8	429
GSC 01903-01226	19-02-05	CB	K	7	8.34	3.0	10.6	7.2		
SAO 78965	19-02-05	CB	K	7	8.42	3.0	9.0	6.4	K0	
SAO 78964	19-02-05	CB	K	7	8.40	3.0	8.9	4.1	M...	
AG+27 757	19-02-05	CB	K	7	10.48	5.0	10.3	7.3	K0	
SAO 78974	19-02-05	CB	K	7	8.40	3.0	9.1	6.6	K2	
GSC 01903-01256	19-02-05	CB	K	7	8.43	3.0	10.1	7.4		

Table 5. continued.

Source	Date UT	Telescope +detector	Filter	D "	Δt ms	τ ms	V mag	K mag	Sp.	Dist. pc
GSC 01903-01683	19-02-05	CB	K	7	8.36	3.0	10.3	7.1		
GSC 01903-01680	19-02-05	CB	K	7	8.48	3.0	10.2	7.5		
GSC 01903-01497	19-02-05	CB	K	7	10.48	5.0	10.4	7.9		
07051697+2726124	19-02-05	CB	K	7	10.36	5.0		7.8		
GJ 265 A	19-02-05	CB	K	7	8.42	3.0	10.2	6.8	K5	24
GSC 01903-01419	19-02-05	CB	K	7	10.41	5.0	10.2	8.5		
07064204+2711078	19-02-05	CB	K	7	8.45	3.0		5.8		
GSC 01904-00825	20-02-05	CB	K	7	8.47	3.0	9.8	6.9		
07101734+2655104	20-02-05	CB	K	7	8.39	3.0		6.1		
FBS 0707+270	20-02-05	CB	K	7	8.48	3.0		5.4	C...	
SAO 79141	20-02-05	CB	K	7	8.43	3.0	5.8	5.4	A4IV	120
AG+26 773	20-02-05	CB	K	7	10.46	5.0	10.0	7.6	K0	
IRAS 07089+2711	20-02-05	CB	K	7	8.49	3.0		3.9		
GSC 01904-01000	20-02-05	CB	K	7	8.35	3.0	10.5	7.1		
07125078+2707059	20-02-05	CB	K	7	10.44	5.0		7.1		
GSC 01929-00326	20-02-05	CB	K	7	8.47	3.0	9.4	6.6		
GSC 01929-00388	20-02-05	CB	K	7	10.37	5.0	10.5	8.3		
SAO 79763	20-02-05	CB	K	7	8.43	3.0	8.6	6.1	K0	
GSC 01929-00556	20-02-05	CB	K	7	8.38	3.0	10.5	7.4		
SAO 79788	20-02-05	CB	K	7	8.38	3.0	9.5	6.0	K5	
GSC 01930-00682	21-02-05	CB	K	7	8.40	3.0	10.0	5.7		
SAO 79861	21-02-05	CB	K	7	8.43	3.0	5.9	3.9	G8III:	345
SAO 79869	21-02-05	CB	K	7	8.49	3.0	6.3	6.2	A1V	183
SAO 79874	21-02-05	CB	K	7	8.42	3.0	8.6	4.2	K7	1370
SAO 79888	21-02-05	CB	K	7	8.39	3.0	8.2	5.0	K5	
08043031+2502030	21-02-05	CB	K	7	8.36	3.0		7.5		
SAO 79921	21-02-05	CB	K	7	8.41	3.0	9.6	7.4	K0	