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Infrared high angular resolution measurements of stellar sources*

V. Angular diameters of ten late-type stars

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Abstract. In the framework of an ongoing series of high angular resolution observations by lunar occultations in the near infrared, we present accurate angular measurements for ten late-type giant stars, seven of which were measured for the first time. The sample includes one K and seven M stars. It also includes two S stars, representing to our knowledge the first direct determination of the angular diameter for this class of stars. The measured angular diameters range from 2.50 to 4.82 milliarcsec, with an average accuracy $<5\%$. An exception is represented by the case of a star with a faint companion, where we have been able to investigate in detail the bias on the diameter determination, and hence on the effective temperature, which would be caused if the companion had not been included in the analysis. We suggest that faint undetected companions could explain at least some of the hitherto known cases of stars with effective temperatures remarkably lower than the standard calibration. For seven of the stars in the sample, we have used our own photometry in conjunction with values from the literature, to compute the bolometric fluxes and the effective temperatures, which we discuss in the context of existing calibrations. With the achieved accuracy level in the angular diameter, such measurements are also valuable as calibrators or science verification targets for modern large ground-based interferometers.

Key words. stars: fundamental parameters – stars: late-type

1. Introduction

This paper is the continuation of a series, dedicated to angular diameter measurements of late-type stars obtained by the method of lunar occultations (LO). Previous papers included or directly related to the series can be found in Richichi et al. (1998). The main aim is to obtain reliable angular diameters in a highly homogenous way by using a few instruments with well-understood properties, and by using one single data analysis method which includes corrections for several potential biases and a consistent definition of the formal errors.

The results of this observational program have been used mainly to derive, in conjunction with the bolometric fluxes of the sources inferred often by means of our own photometry, the effective temperatures of K and M giants and carbon stars. A temperature scale, derived in a homogenous way using our LO measurements only, was presented by Richichi et al. (1999). Additional measurements of other properties, such as limb-darkening, circumstellar shells and photospheric pulsation, have also been obtained for some stars and have been detailed in other papers of this series.

Another aim of this program is to identify objects suitable for calibration of modern long-baseline interferometers, as well as for follow-up investigations. Large facilities such as CHARA, Keck and VLTI are active or about to begin operations, and they will explore a range of sensitivities and angular resolutions, the combination of which has been accessible until now only to LO observations. It is therefore important to establish a database of sources already measured by an independent technique such as LO. Some of the sources in this series of papers, moreover, should be investigated more fully because of variability or non symmetrical geometry, and long-baseline interferometers are in an ideal position for this.

With the present paper, we add accurate angular measurements for ten late-type giant stars, with spectral types K, M and S. We also compute, when possible on the basis of available photometry, their bolometric fluxes and effective temperatures. The method of observation and the data analysis are briefly summarized in Sect. 2. More details can be found in the previous papers of this series.

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* Based on observations collected at TIRGO (Gornergrat, Switzerland). TIRGO is operated by CNR – CAISMI Arcetri, Italy.

Table 1. Summary of the occultation observations.

(1) Source	(2) Date UT	(3) Tel.	(4) PA °	(5) D ″	(6) Δt ms	(7) τ ms
YZ Ari	07-01-98	T	110	21	2.41	2.00
EI Tau	10-01-98	T	78	21	2.68	2.26
W Tau	05-11-98	T	244	28	2.41	2.00
SAO 93950	05-11-98	T	306	28	2.41	2.00
IRC +20083	05-11-98	T	240	28	2.41	2.00
DY Tau	07-11-98	T	287	28	1.42	1.00
IRC +20156	19-01-00	T	51	21	4.42	4.00
IRC +20128	13-03-00	T	60	21	2.41	2.00
VV Cnc	15-03-00	T	124	14	2.41	2.00
IRC −20422	10-08-00	T	73	21	4.42	4.00

In Sect. 3 we present and discuss the results individually for each star. A discussion in the context of existing effective temperature calibrations, as well as with respect to large ground-based interferometers, is given in Sect. 4.

2. Observations and data analysis

Table 1 summarizes the details of the observations, following the format of previous papers (see for instance Richichi et al. 1998). In Cols. (1) and (2) we list the source name and the date of the event. Column (3) lists the symbol to identify the telescope used, which for the stars presented here was always the 1.5 m TIRGO telescope. In Cols. (4) through (7) we list the predicted position angle of occultation, the aperture of the photometer, the sampling time of the light curve and the integration time of each data point.

All occultations were observed with the TIRGO facility fast photometer, in a standard broad-band K filter. Details can be found in Richichi et al. (1997), and references therein. The same photometer was also used to obtain near-IR photometry of some of the sources in our sample, as described in Sect. 3.

The analysis of the LO data was carried out, as in the other papers of this series, by a program based on the least-squares method. The program includes correction of scintillation, of pick-up frequencies, and of the bias due to the finite time response of the instruments when required. These features, as well as the details of the error estimation, have been described in Richichi et al. (1992).

Table 2 lists cross-identifications of the observed sources in various catalogues, as well as some photometric and spectroscopic data.

3. Results and discussion

Our angular diameter results are listed in Table 3. They have been obtained under the hypothesis of a uniform disk. A thorough discussion of the center-to-limb brightness variations (CLV) in non-Mira stars has been given in Hofmann & Scholz (1998), from which it can be inferred that at near-IR wavelengths the effects of limb-darkening are relatively small for the sources in our list. Therefore, we prefer to present here the uniform disk values only, which are clearly defined and can be converted as needed to diameters under different limb-darkening assumptions. For example, Richichi et al. (1999) have used a grid of numerical CLV models to analyze a set of LO data, and have derived a conversion factor between uniform disk and limb-darkened disk, for different assumptions. The conversion factors that would apply to the stars and wavelengths ranges considered in this paper are typically ≈1–3%.

In this section, we present the results separately for each individual star, in connection with earlier findings and available literature. We do not present LO lighcurves and model fits for all stars, and rather we give in Fig. 1 one example for illustration. As a measure of the quality of each data set, we list in Table 3 the signal-to-noise ratio (SNR), computed as the ratio of the stellar intensity outside the occultation to the average standard deviation of the fit residuals. Additionally, we compute and list in Table 3 also the bolometric flux, when possible. Since for many of the stars in our sample little or no photometric data were available, a number of photometric measurements were obtained, also with the TIRGO telescope, and are reported in the individual subsections. Even after this effort, the photometric coverage remains insufficient, resulting in some cases in a large uncertainty on the amount of extinction or in the absence of a bolometric flux estimate. For this reason, we do not attempt in this paper to derive explicitly effective temperatures of the stars in our sample.

3.1. YZ Ari

The LO light curve for this source shows a well-resolved angular diameter which represents a first time measurement for this star.

YZ Ari is seen as a very faint object in the PSS plates, although the Combined General Catalogue of Variable Stars (Kholopov et al. 1988) quotes a maximum magnitude of 5. In the infrared however, this source is quite prominent, being listed among the brightest IRAS sources above the galactic plane (Hacking et al. 1985). Near-IR photometry is available by Fouque et al. (1992), as well as by Whitelock et al. (1994) who covered a wide range of epochs. Photometry was also obtained at the TIRGO telescope on the night after the occultation event, with magnitudes of 5.74 ± 0.01, 4.42 ± 0.01, 3.48 ± 0.01, 2.25 ± 0.05 in the J, H, K, L bands respectively. The analysis of all available near-IR data shows a semi-regular variability, with a main period of $\approx 450^{\rm d}$ close to the value derived by Whitelock et al. (1994). The source is tentatively classified as a Mira variable, and a spectral type of M8 is reported by these latter authors, although not confirmed by Kwok et al. (1997).

Table 2. Cross identifications of the occulted sources and their characteristics.

Source	TMSS	IRAS	SAO	HD	Other	V	K	Sp.	Notes
YZ Ari		02547+1106			RAFGL 5087	≤5	3.5	M8	Mira, OH/IR
EI Tau		05440+1753			S1 116	13.0	3.9	Svar	binary
W Tau		04250+1555		28236	BD+15 628a	9.1	1.1	M6	
SAO 93950	+20079	04255+1614	93950	28292	75 Tau	5.0	2.2	K2	binary, biased value
IRC +20083	+20083	04272+1603	93969	28484	BD+15 635	7.9	2.0	M3	
DY Tau	+20119	05390+1831	94779	246450	S1 112	9.6	2.6	M.../S	
IRC +20156	+20156		78609	47548	BD+20 1521	8.0	2.3	M0/M...	conflicting sp. types
IRC +20128	+20128	05539+2016			NSV 2736		2.1	M6/M7	candidate OH/IR
VV Cnc	+20197	08083+1917	97631		BD+19 1947	9.6	1.4	M5	
IRC −20422	−20422						2.7	M4	no opt. counterpart

YZ Ari also shows a marked IR excess especially at 25 and 60 μm, which was recognized as characteristic of a OH/IR star by Eder et al. (1988), who detected double-lined maser emission at 1612 MHz. Searches for SiO and OH maser emission at 22 GHz gave negative results both with the Haystack and the Arecibo radio telescopes (Benson & Little-Marenin 1996; Engels & Lewis 1996).

We have attempted to derive an effective temperature for this star, under the assumption that we have indeed detected and resolved the photosphere. For this, we have estimated the bolometric flux at the date of the occultation using the timely TIRGO photometry, and the IRAS fluxes which we assume to be non-variable (for comparison, K-band variations have an amplitude of about 1 mag). A fit to the photometric points was obtained by a simple two black-body model; the resulting bolometric flux was $6.8 \pm 0.7 \times 10^{-11}$ Wm^{-2}, with the infrared excess accounting for about 22% of the total flux. Note that our LO data at 2.2 μm show no evidence for extended emission on $\approx 0.''1$ around the star, with a SNR of 40 (per data point). Investigation over a wider angular range was not possible due to slow background fluctuations.

Clearly, significant temperature changes can be expected with the variability phase and follow-up studies combining adequate angular resolution with frequent photometric monitoring would be desirable.

3.2. EI Tau

We obtained the first angular diameter measurement for this S star. Together with that of DY Tau, this is to our knowledge the first one for a star of this spectral class. TIRGO photometry on the same night as the LO event showed 5.43 ± 0.01 and 3.92 ± 0.02, in the J and K bands respectively. Unfortunately the available photometry is not sufficient to compute a reliable bolometric flux and derive an effective temperature for this source.

It is to be noted that, in addition to the angular diameter measurement, our LO light curve also showed the presence of a nearby companion, as described in Richichi et al. (2001).

3.3. W Tau

The LO light curve for this source yielded a quite accurate angular diameter. Previously, three measurements for W Tau were obtained by means of LO by Ridgway et al. (1980, 1982). The resulting angular diameters, in the H and K near-IR bands, were between 3.81 and 4.38 mas, roughly consistent within the quoted errors among themselves, as well as with our determination. We can thus conclude that the angular diameter of this star is relatively constant.

On the nights of November 5–6, 1998, we also obtained near-IR photometry from TIRGO, with mean values 2.91 ± 0.04, 1.71 ± 0.04, 1.12 ± 0.06, 0.86 ± 0.04 in the J, H, K, L bands respectively. Kerschbaum & Hron (1994) quote very similar values, confirming the very limited variability, if any, of this source in the near-IR.

We have computed the bolometric flux for this star by means of a two components model, although we note that the IR excess accounts for $\lesssim$1% of the total flux. In this context, we also note that no water maser emission was detected in a search by Lewis (1997). The result is $46.8 \pm 4.5 \times 10^{-11}$ Wm^{-2}. Kwok et al. (1997) assigned a spectral type of M 6 to W Tau.

3.4. SAO 93950

We have recorded two occultations of this source, and an initial report regarding the detection of a companion has been given in Richichi et al. (1998), where also a summary of previous LO observations was given. For this paper, we have analyzed in detail the first of our two LO traces to derive the angular diameter.

We have found that, in spite of its small intensity relative to that of the primary, the presence of the companion is indeed important in the outcome of the data analysis. Contrary to what we had stated in Richichi et al. (1998), the companion is indeed detected also in this LO light curve, in spite of some slow scintillation-induced fluctuation of the signal (Richichi et al. 2001). Indeed, the result for the angular diameter would be seriously biased without taking the companion into account, resulting in

3.06 ± 0.20 mas. This is probably the explanation of previous results, such as that by Ridgway et al. (1982), who had found a similarly large value for the angular diameter, which in turn resulted in a peculiarly low effective temperature for this star. This had been remarked also by Dyck et al. (1996), who used the LO result for this star for their effective temperature calibration.

When the companion is included in the fit, the resulting angular diameter for the primary is significantly smaller. However, the actual value of the diameter depends strongly on the brightness ratio. Just by changing this latter from $\Delta K = 3.6$ to 3.4, the resulting angular diameter of the primary changes from 2.50 to 1.70 mas, respectively. We note that the result mentioned in Richichi et al. (1998) concluded that $\Delta K \approx 4.7$. Obviously, the conclusions on this star must be refined, however we can already explain the discrepant conclusions presented in previous publications. Further observations with good sensitivity are needed to put stronger constraints on this system, and hence obtain a bias-free angular diameter. For the purpose of this paper, we adopt the value 2.1 ± 0.4 mas for the angular diameter, where the large error is chosen to account for the scatter in the results obtained under various assumptions.

On the same night of the LO event, we also obtained near-IR photometry from TIRGO, with magnitudes 3.10 ± 0.02, 2.40 ± 0.01, 2.25 ± 0.03, 2.24 ± 0.04 in the J, H, K, L bands respectively. Since this star is not presumed to be variable, we have relied on the bolometric flux value computed by Dyck et al. (1996).

3.5. IRC +20083

Several LO of this source were recorded in the previous Saros cycle. It is noteworthy that all observers in the visual range reported an unresolved source (Radick & Lien 1980; Fekel et al. 1980; Evans & Edwards 1981; Radick et al. 1982). In the near-IR, where the source is considerably brighter, Ridgway et al. (1980, 1982) reported instead uniform angular diameters in the H band of 2.00 ± 0.47 and 3.06 ± 0.30 mas respectively. Our value is in good agreement, and in fact indistinguishable from the weighted average of the 3 near-IR determinations, confirming the quality of such measurements. We note that differential limb-darkening between H and K is almost negligible for the spectral type of this star, which is quoted as M3 by Noguchi (1989).

Our photometry, obtained from TIRGO on the same night of the LO event, showed magnitudes of 3.51 ± 0.02, 2.55 ± 0.01, 2.03 ± 0.03, 1.89 ± 0.05 in the J, H, K, L bands respectively. An accurate computation of the bolometric flux should take into account the visual extinction, which is significant for this source. Our computed value of $49.4 \pm 5.7 \times 10^{-11}$ Wm^{-2}, was based on an estimate of $A_{\rm V} \approx 1.5$ mag, which however cannot be considered more accurate than ≈0.5 mag due to the insufficient photometric coverage.

3.6. DY Tau

Our LO has allowed us to measure for the first time the angular diameter of DY Tau with high precision.

This is one of the brightest S stars in the sky at 2 μm (Wing & Yorka 1977), and to our knowledge together with EI Tau the first one for which the angular diameter could be measured directly.

Unfortunately the available photometric data are not a good match to the precision obtained on the angular diameter. Only Kerschbaum et al. (1996) measured this source. The K magnitude is very close to the IRC determination. We combined these data with the IRAS fluxes, to derive a bolometric flux. However this is not sufficient to impose strong constraints on the visual extinction. A rough estimate indicates $A_{\rm V} \approx 2$ mag. With this assumption, the resulting flux would be $36.2 \pm 6.1 \times 10^{-11}$ Wm^{-2}, but additional photometric data are required before making use of this result.

3.7. IRC +20156

The angular diameter of 4.77 ± 0.18 mas derived for this star is considerably larger than expected for a source of this brightness with the listed spectral type (M0 in the SAO catalogue). We have carried out near-IR photometry for this star on the same night of the LO event, obtaining 3.81, 2.65, 2.34, 2.07 in the J, H, K and L bands respectively (formal errors were 0.02 mag for all filters). After combining this with the visual and infrared fluxes available from Tycho and IRAS, we obtain a bolometric flux of $17.4 \pm 0.8 \times 10^{-11}$ Wm^{-2}, with no indication of IR excess. To verify this, we have also fitted the spectral energy distribution by a single black body model, to derive an indirect but independent estimate of the angular diameter. The result was ≈3 mas, smaller than the direct LO measurement but still in excess of empirical estimates based on the spectral type and magnitude.

The problem is that the angular diameters, whether derived by LO or by a fit to the spectral energy distribution, lead to effective temperatures of 2200 to 2800 K, considerably lower than expected for a normal early M giant. We have analyzed the LO light curve to investigate whether a second component could be present, with negative result. A previous LO observation was recorded, without any remarks, by Eitter & Beavers (1979) in the B and V filters. The problem of the temperature of this object remains open and should be investigated by further observations. We note however that the Simbad database lists a type M..., which is an indication of a subtype much cooler than M0.

3.8. IRC +20128

The LO light curve of IRC +20128 shows a well resolved angular diameter, which represents the first determination for this star.

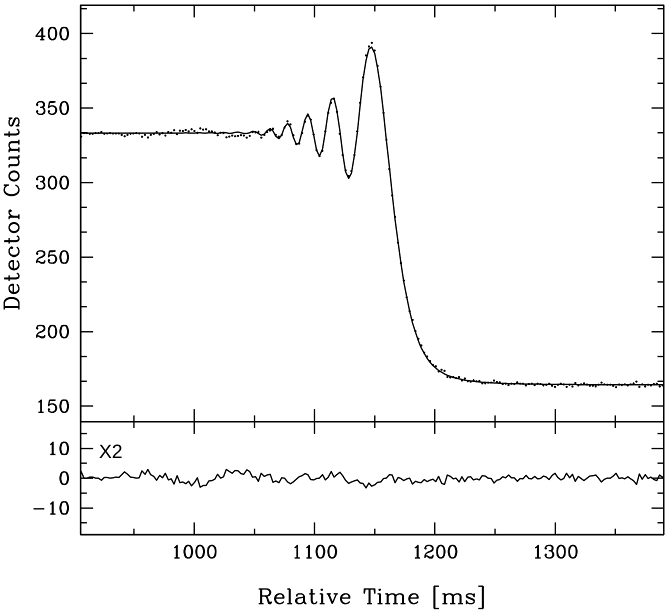

Fig. 1. The occultation trace of IRC +20128 (dots), and our model fit (solid line). The lower panel shows the fit residuals, on an enlarged scale.

IRC +20128 is classified as M6/M7 (Kwok et al. 1997), on the basis of its IRAS LRS spectrum. This source is associated with DO 11744, a star with magnitude 11.0 in a filter intermediate between V and R. Photometry obtained at TIRGO on March 15, 2000, i.e. less than two days after the LO event, yielded magnitudes of 3.72 ± 0.10, 2.43 ± 0.11, 2.10 ± 0.03 in the J, H and K bands respectively.

The very red colors of IRC +20128 make it a candidate OH/IR star, but surveys for OH and SiO maser emission yielded negative detections (Chengalur et al. 1993; Jiang et al. 1996). Lewis (1992) has suggested that OH/IR colors can be mimicked by systems in which a red giant star, undergoing mass loss, is surrounded by a degenerate companion. This latter would accrete the mass loss from the red giant, giving rise to an intense UV flux that would dissociate the molecules which would give rise to the maser emission. Since our LO observation does not have the sensitivity necessary to detect such a companion, no conclusions can be made in this respect.

The spectral energy distribution shows some IR excess, which however contributes to the bolometric flux at the level of $\lesssim$2% only. A fit by a two black-body model yielded $18.9 \pm 1.6 \times 10^{-11}$ Wm^{-2}.

3.9. VV Cnc

We have obtained a first-time accurate angular diameter for this source. VV Cnc is classified as a pulsating variable star. The amplitude of the photometric variations is about 1.0 mag in photographic plates (Kukarkin 1971). Unfortunately we could not obtain photometry of this source from TIRGO.

Table 3. Summary of results.

Source	$\phi_{\rm UD}$ (mas)	SNR	Bolom. flux 10^{-11} Wm^{-2}
YZ Ari	4.82 ± 0.15	38.8	6.8 ± 0.7
EI Tau	2.50 ± 0.28	47.2	–
W Tau	4.28 ± 0.10	108.2	46.8 ± 4.5
SAO 93950	2.10 ± 0.40	95.0	41.5 ± 6.2
IRC +20083	2.91 ± 0.21	82.0	49.4 ± 5.7
DY Tau	3.04 ± 0.06	109.4	36.2 ± 6.1
IRC +20156	4.77 ± 0.18	77.0	17.4 ± 0.8
IRC +20128	4.13 ± 0.11	143.4	18.9 ± 1.6
VV Cnc	4.80 ± 0.10	78.2	–
IRC −20422	4.56 ± 0.19	70.0	–

Some discrepancy exists in the literature about the spectral classification, which ranges from M3 (Jacoby et al. 1984; Schmidt-Kaler & Oestreicher 1998) to M5 (Hansen & Blanco 1973; Kwok et al. 1997). The difference could be indicative more of intrinsic difficulties to reconcile the conclusions of spectral classifications methods based on different criteria and wavelength ranges, than of actual variations in the star itself. However, we note that on the basis of current calibrations (see for instance Richichi et al. 1999), the difference between M3III and M5III would amount to ≈200 K in the effective temperature, or ≈12% in the angular diameter. This should be compared with the 2% formal accuracy of our result, which could then be used, in conjunction with a bolometric flux which unfortunately cannot be computed at the present time for lack of published photometry, to understand the spectral characteristics of this star.

3.10. IRC −20422

We obtained a first-time angular diameter for this source, which has no bright optical counterpart. A spectral type of M4 was assigned by Hansen & Blanco (1973). The source is clearly heavily obscured, however its location on the galactic plane in the direction of the galactic center, as well as its relatively early spectral type, indicate that the source of extinction is probably galactic dust. The lack of any photometry, apart from the IRC determination, unfortunately hampers at the moment any estimate of the bolometric flux and effective temperature for this source.

4. Discussion and concluding remarks

The classical goal of angular diameter measurements is to establish a calibration of the effective temperature with spectral types. While such a calibration has been reasonably well established for giant stars hotter than ≈4500 K, corresponding to types earlier than K1-K2III, the situation for late K stars and especially for M giants has been less clear. Nevertheless, also in this area significant improvements have been made recently, especially thanks to the contributions of observational techniques such as long-baseline interferometry (LBI, see for instance Perrin et al. 1998) and LO (Richichi et al. 1999). At present, the calibration can be considered relatively well established for temperatures hotter than ≈3300 K, or types about M6 and earlier (in the sense that calibrations from different authors show agreement within errors). Even so, interesting special cases remain to be understood (Dyck et al. 1998; Richichi et al. 1999).

The situation is much more complex for stars cooler than M6. In this range, stellar pulsations, mass loss, changes in spectral type and in general Mira-like phenomena are the norm. In addition to the spectral type, further distinctions must be made depending on the type of variability and the chemical composition (Miras, carbon stars, long-period variables, and so forth). Determinations of the effective temperature must necessarily be made as a function of time, and even the mere definition of an angular diameter can be problematic due to limb-darkening and optical depth effects. Furthermore, the presence of circumstellar emission very close to the stellar photosphere complicates the interpretation of high angular resolution observations.

In this area of research, a clear bifurcation takes place between what is investigated by LBI and by LO. In the case of LBI, which is currently limited to rather bright near-IR magnitudes, the targets of choice are usually well-studied stars, for which a wealth of information is available on the spectral classification, photometry, and variability. In the case of LO, which are more sensitive but are limited to those objects which happen to be occulted by the Moon, the targets tend to be more anonymous objects, often very poorly studied, for which it is necessary to obtain additional information before a meaningful interpretation can be attempted.

Some of the stars in our sample reflect this situation very well. For three of them, namely EI Tau, VV Cnc and IRC −20422, the available photometry is not sufficient to compute a bolometric flux, and our result is confined to the measurement of their angular diameter.

In the case of W Tau, IRC +20083, and DY Tau, we have been able to compute a bolometric flux and an effective temperature which can be considered as relatively reliable. These three stars are relatively well fitted by the current effective temperature calibrations, although especially for the last two there is space for considerable improvement of the available photometry and of the estimate of extinction.

The cases of IRC +20156 and IRC +20128 are more problematic, or more interesting depending on the point of view. Both seem to exhibit a much cooler effective temperature than expected. However, in both cases some peculiarities have been noted: IRC +20156 is a star with very conflicting spectral type determinations, and IRC +20128 has colors that mimic an OH/IR star although no maser emission could be detected.

YZ Ari is the coolest star in our sample. Both its angular diameter and its bolometric flux are sufficiently reliable, and they indicate a very low effective temperature of 1700 K. This finds some justification in the very extreme AGB character of this star, which has marked IR excess and OH/IR characteristics. Further monitoring by other techniques, such as sensitive IR interferometry, would be highly desirable.

The case of SAO 93950, an early K giant for which the effective temperature calibration has always been relatively undisputed, was in fact a puzzle since previous measurements assigned a temperature to this star which was strikingly lower than expected. We have demonstrated that the presence of a faint companion can explain this discrepancy, and have obtained an effective temperature which is much closer to the standard calibration, although further measurements of the companion are required to reduce the uncertainty on the diameter of the primary.

The solution to this apparently discrepant case could also be the explanation of a few similar cases of stars which were found to have remarkably low effective temperatures (Dyck et al. 1998; Richichi et al. 1999). We suggest that in at least some of these cases the determination of the angular diameter could have been biased by an undetected faint and close-by companion. Such cases should be investigated in detail by LBI observations with high sensitivity and long baselines. In the case of SAO 93950, where we could confirm the companion thanks to an independent LO observation, the difference between the two components is $K \approx 4$, and yet the bias on the effective temperature determination is of several hundreds degrees.

We note that apart from this latter case, the relative errors on the angular diameters in our sample are on average <5%. This makes them, as well as many other measurements previously reported in this series, ideal candidates for calibration and verification of large LBI facilities, where the emphasis will be on relatively faint and well-known stars. To make an example, we consider an interferometer with a baseline of 100 m working at 2.2 μm: these characteristics match well what is expected for example in the case of the ESO VLTI. Considering that in normal operation such an interferometer will study objects with squared visibilities between 10% and 80%, the range of angular diameters of interest is 1.3 to 3.9 mas. At the smaller end of this range, an accuracy of 5% in the angular diameter translates to 2% in the squared visibility. Although some of the modern large interferometers have more ambitious goals than this, they will need a network of calibrators with small and accurate angular diameters, and results such as those presented in this paper can be a valuable first step in this direction.

We conclude that the measurements that we have presented add important novel data to the calibration of the effective temperature of late M giants. We note that in many cases the actual error on the derived effective temperature is dominated, especially for relatively poorly studied objects, by uncertainties in the bolometric fluxes and in the extinction. Extensive photometric monitoring is required to establish better estimates of these quantities, and to determine variability. This task is well suited to small telescopes equipped with near-IR instruments.

At the same time, we have shown that the stars in our sample and in the previous papers of this series have the potential to be used by large modern interferometric facilities for calibration and verification.

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