FIRST LUNAR OCCULTATION RESULTS FROM THE 2.4 m THAI NATIONAL TELESCOPE EQUIPPED WITH ULTRASPEC

A. Richichi1, P. Irawati1, B. Soonthornthum1, V. S. Dhillon2, and T. R. Marsh3

1 National Astronomical Research Institute of Thailand, 191 Siriphanich Building, Huay Kaew Road, Suthep, Muang, Chiang Mai 50200, Thailand; andrea4work@gmail.com
2 Department of Physics and Astronomy, University of Sheffield, Sheffield S3 7RH, UK
3 Department of Physics, University of Warwick, Gibbet Hill Road, Coventry CV4 7AL, UK

Received 2014 May 30; accepted 2014 July 31; published 2014 October 17

ABSTRACT

The recently inaugurated 2.4 m Thai National Telescope (TNT) is equipped with, among other instruments, the ULTRASPEC low-noise, frame-transfer EMCCD camera. At the end of its first official observing season, we report on the use of this facility to record high time resolution imaging using small detector subarrays with a sampling as fast as several $10^2$ Hz. In particular, we have recorded lunar occultations of several stars that represent the first contribution to this area of research made from Southeast Asia with a telescope of this class. Among the results, we discuss an accurate measurement of $\alpha$ Cnc, which has been reported previously as a suspected close binary. Attempts by several authors to resolve this star have so far met with a lack of unambiguous confirmation. With our observation we are able to place stringent limits on the projected angular separation ($<0.003$) and brightness ($\Delta m > 5$) of a putative companion. We also present a measurement of the binary HR 7072, which extends considerably the time coverage available for its yet undetermined orbit. We discuss our precise determination of the flux ratio and projected separation in the context of other available data. We conclude by providing an estimate of the performance of ULTRASPEC at TNT for lunar occultation work. This facility can help to extend the lunar occultation technique in a geographical area where no comparable resources were available until now.

Key words: binaries: general – occultations – stars: individual (alpha Cnc, HR 7072) – techniques: high angular resolution

Online-only material: color figures

1. INTRODUCTION

Lunar occultations (LOs) are a method used to obtain high angular resolution by means of analysis of the diffraction pattern generated when a background source is occulted by the lunar limb. One major advantage of LOs is the fact that the achieved angular resolution is mainly dependent on relations between the wavelength and the distance to the Moon rather than the aperture of the telescope as in standard imaging. Thus, the measurement of angular sizes well beyond the diffraction limit of even the largest telescopes on the ground or in space becomes possible. Significant limitations of the method are that the sources cannot be chosen at will, that the events are time-critical, and that opportunities to repeat the observations are rare. In order to detect and measure the diffraction fringes, it is necessary to sample the light curves with time resolutions of the order of 1 ms.

At least three major goals can be achieved by LOs: the measurement of stellar angular diameters, the detection and characterization of circumstellar envelopes and extended emissions, and finally, the study of small-separation binary stars. For decades, LOs have made some contributions in the first two areas mentioned above, but currently long-baseline interferometry, which is more time consuming but more complete in its results, is used more often (see CHARM2 catalog; Richichi et al. 2005). Concerning binary stars, however, LOs maintain an edge in that they are quick to observe, easy to analyze, and offer a combination of sensitivity and dynamic range that remains unsurpassed. In the course of a long program of occultations with the ISAAC instrument at the ESO Very Large Telescope, Richichi et al. (2014, and references therein) have recorded over a thousand occultation events with an $\approx 8\%$ detection rate of mostly new binary or multiple systems, the majority of which are out of reach of other techniques. The ISAAC instrument has now been decommissioned and only a few observatories around the world remain suitably equipped to observe LOs.

In this paper we first introduce the Thai National Telescope (TNT), in conjunction with the ULTRASPEC fast camera, as a new facility capable of recording high-quality LO light curves in a geographical area where this technique was so far precluded. We then present the first LO results obtained at the TNT and discuss in detail two of them: $\alpha$ Cnc, an assumed binary star for which we can set stringent upper limits on the separation and flux of the putative companion, and HR 7072, a known binary star for which the numerous prior measurements available do not always seem to be in agreement and for which we provide a new accurate flux and separation determination.

2. A NEW FACILITY FOR HIGH TIME RESOLUTION ASTRONOMY

The Thai National Observatory, which also includes the flagship 2.4 m TNT, is located on one of the highest ridges of Doi Inthanon, the tallest peak in Thailand. At 2457 m elevation, the site has observing conditions that compare favorably with those of most other locations in the region in terms of seeing and photometric conditions. It has a dry season that runs approximately from November to April, while the rest of the year is largely lost to observations due to high humidity and rainy conditions. The TNT was erected in 2012 and inaugurated in 2013 January. It is a Ritchey–Chrétien with two Nasmyth foci, one of them being equipped with a multi-instrument port to which the ULTRASPEC instrument is also permanently mounted. Although a similarly named instrument based on the same detector has been
used before, e.g., at the ESO New Technology Telescope in Chile (Dhillon et al. 2008; Ives et al. 2008), the one described here is novel in several aspects: in particular, the optics have been specifically developed for TNT, and specific data acquisition modes have been developed. ULTRASPEC at the TNT had its first light in 2013 November and is described in detail elsewhere (Dhillon et al. 2014). Here, we summarize only its capabilities for LO work.

In order to increase the time sampling, ULTRASPEC offers the possibility to read out only parts of the detector. One of its features is the 2 k × 1 k EMCCD chip, half of which is used for imaging and half for fast frame transfer. One or several subarray windows can be defined and read out simultaneously, and this is optimal to reach rates up to about 10 Hz. For LO measurements, however, faster rates are needed. For this, the so-called drift mode of the related instrument ULTRACAM (Dhillon et al. 2007) has been specifically adapted. In summary, so-called drift mode of the related instrument ULTRACAM (Dhillon et al. 2007) has been specifically adapted. In summary, we adopt the instrument electronics, the control computer, and the data reduction machine, it is possible to obtain uninterrupted data sequences of any desired duration and to examine the data almost in real time. Finally, we mention that a dedicated Global Positioning System receiver is used to stamp each frame with its position and time.

3. OBSERVATIONS AND DATA ANALYSIS

The first LO observations recorded from TNT with ULTRASPEC are listed in Table 1, in chronological order. D and R refer to disappearances and reappearances, respectively. The magnitudes and spectra are quoted from Simbad. Concerning the filters, we adopted mainly narrow-band ones in an attempt to reduce the lunar background. The latter is strongly wavelength dependent, and also diffraction is inherently chromatic. Thus, the red part of the spectrum is usually better suited for LO observations. In the table, Hα and Hβ differ slightly in central wavelength (6564 and 6554 Å, respectively), and in FWHM (54 and 94 Å, respectively). We also employed a standard Sloan Digital Sky Survey z′ filter. Columns “Sub” and “Bin” list, respectively, the size of the detector subarray adopted in the drift mode and the on-chip rebinning such that Sub 32 × 32 and Bin 2 × 2 would effectively result in a 16 × 16 output. The frame integration time and the sampling time between frames are denoted by τ and Δτ in the table. This latter is the average value across all frames. In reality, there are small variations (always <1%) in the time differences between subsequent frames. In our data analysis, the actual individual time stamps are used. S/N is the signal-to-noise ratio, measured as the unocculted stellar signal divided by the rms of the fit residuals.

The raw binary output from ULTRASPEC is then converted to FITS cubes with the first two dimensions set by the combination of Sub and Bin, and thousands of frames long. From this point, our data analysis procedure follows closely the methods already described in our previous papers; see, e.g., Richichi et al. (2014; and references therein). In summary, we adopt a mask extraction that allows us to reject unnecessary signal (and related noise) from the background, and end up with fast photometry sequences which are further restricted to very few seconds around the events.

We use a model-independent maximum-likelihood (composed algorithm, CAL; Richichi 1989) method to estimate the brightness profile of the source, for example, to detect possible multiple components in the light curve. A model-dependent least-squares method, whose convergence in χ^2 is driven by noise components derived from the unocculted and totally occulted portions of the light curve, is used to derive precise values and errors of parameters such as intensities and separation in a binary model (Richichi et al. 1996). This reference also describes additional features used in our fits such as the modeling of low-frequency scintillation.

4. RESULTS

The first three sources in Table 1 were found to be point-like, with upper limits on the angular size of 2.4 and 1.5 mas for SAO 93721 and SAO 97913, respectively. These are consistent with the values expected from their spectral types and distances. The S/N of the SAO 96543 light curve was insufficient for an upper limit determination. There were no previous literature reports on the possible binarity for two of these sources, while SAO 93721 is listed in the Washington Double Star Catalog. It has a faint, distant companion at about 170′ which is not included in our observation and is also listed as a spectroscopic binary which we could not resolve. In the following, we concentrate on the remaining two stars in our list.

Although these first measurements are few, Table 1 can be used for an initial estimate of the performance of LO with ULTRASPEC at the TNT. Using S/N = 1 as a detection limit, the sensitivity achieved in the five light curves ranged from 9.3 to 10.4 mag with a dynamic range that, in the best case, was 5 mag. The ability to resolve close companions was tested by means of simulations on the data of SAO 93721 and α Cnc. We conclude that hypothetical companions with a 1:1 flux ratio could have been detected as close as 2 mas.

### Table 1: Summary of Observed Events

| Date (UT) | Time  | Type | Source   | V (mag) | Sp | Filter | Sub (pixels) | Bin (pixels) | τ (ms) | Δτ (ms) | S/N | Notes       |
|-----------|-------|------|----------|---------|----|--------|--------------|--------------|--------|--------|-----|-------------|
| 2014 Jan 11 | 17:12 | D    | SAO 93721 | 5.9     | F4V | z′    | 16 × 16     | 2 × 2        | 6.6    | 6.8    | 34  | Unresolved  |
| 2014 Feb 11 | 16:10 | D    | SAO 96543 | 7.5     | F5V | Hα    | 16 × 16     | no           | 11.8   | 12.1   | 10  | Unresolved  |
| 2014 Mar 12 | 18:26 | D    | SAO 97913 | 6.3     | K0III| Hα    | 16 × 16     | 2 × 2        | 6.6    | 6.8    | 45  | Unresolved  |
| 2014 Apr 9  | 13:20 | D    | α Cnc    | 4.3     | A5m | Hα    | 16 × 16     | 2 × 2        | 6.6    | 6.8    | 104 | Not Binary  |
| 2014 Apr 20 | 21:44 | R    | HR 7072  | 6.5     | AIV+K III| Hα   | 32 × 32     | 2 × 2        | 12.3   | 12.8   | 18  | Binary      |
of mainly from previous LO observations but also from the analysis et al., available online 4; INT4 hereafter). The two claims Interferometric Measurements of Binary Stars (by Hartkopf note that of high-quality data. The Bright Star Catalogue mentions in a
curves labeled (a) and (b) are models for a binary star with equal components and projected separations of 3 and 10 mas, respectively. They are shown, shifted by arbitrary vertical offsets for clarity, to prove the inconsistency of the data with such scenarios.

(A color version of this figure is available in the online journal.)

Figure 1. Top panel: occultation data (dots) for α Cnc, and best fit by a point-like source (solid line). The fit residuals are shown in the lower panel, enlarged for clarity. The curves labeled (a) and (b) are models for a binary star with equal components and projected separations of 3 and 10 mas, respectively. They are shown, shifted by arbitrary vertical offsets for clarity, to prove the inconsistency of the data with such scenarios.

(A color version of this figure is available in the online journal.)

4.1. Alpha Cancri

We obtained a good quality (S/N = 104) light curve of the bright star α Cnc (HR 3572, Acubens), shown in Figure 1, along the position angle (P.A.) 77°. The diffraction fringe pattern is well resolved thanks to the use of a narrow-band filter and also to a contact angle of 40° that contributed to slowing down the apparent fringe motion. We could thus accurately measure the local limb slope, found to be close to 0°, obtaining in turn a reliable conversion from time to angular scale. The star is known to have a companion forming the ADS 7115 pair, however, it is about 10′ away and several magnitudes fainter, and we do not concern ourselves with it here.

More interestingly, α Cnc has been claimed as a close double, mainly from previous LO observations but also from the analysis of Hipparcos data. These are listed in the Fourth Catalog of Interferometric Measurements of Binary Stars (by Hartkopf et al., available online4; INT4 hereafter). The two claims from previous occultations come from observations by amateur astronomers with small telescopes, and are not well documented. They claim a binary with equal components separated by 50 mas in one case (with no P.A. listed), or 4.2 mas along P.A. = 113° in the other. We note that the ability to measure such a small separation by LO usually demands a rigorous treatment of high-quality data. The Bright Star Catalogue mentions in a note that α Cnc is an LO binary with 0′.1 separation, but without a reference. Several speckle measurements with the SOAR 4.1 m telescope (Tokovinin et al. 2010; Hartkopf et al. 2012) have not detected the companion, with upper limits ≤0′.15 on the angular separation and 4–6 mag on the flux difference. In fact, for ∆m ≤ 1 mag the separation limit is 25 mas (A. Tokovinin 2014, private communication).

Our data appear to be the first LO light curve recorded for this bright star with professional equipment at a medium-sized telescope. We can reliably exclude two components of similar brightness to projected separations as small as 3 mas (see Figure 1). In fact, an analysis by a method developed

4 http://www.usno.navy.mil/USNO/astrometry/optical-IR-prod/wds/int4

for unresolved sources (see Richichi et al. 1996, 2012) results in a limit of 1.35 mas on the angular size of the star. This is consistent with a stellar dimension roughly comparable to solar and a distance of 53 pc as derived by Hipparcos. For a simple comparison, we assume that the 50 mas binary separation previously claimed was at a random P.A., and we consider an average projection factor of 2/π. The resulting estimated 79 mas true separation, against our upper limit of 3 mas, would indicate a likelihood of 1 − (acos(3/79)/90°) ≈ 2% that our lack of detection was due to projection effects. We note that the previously claimed binary separation would imply a period of very few years and therefore any link between the geometry during our measurement in 2014 and the previous ones (as much as 30 yr earlier) would not be preserved. The S/N of our light curve can also be used to assess an upper limit in flux on the presence of a companion with a more significant separation, of about 5 mag in the red part of the spectrum. We also mention two light curves of α Cnc, the disappearance and reappearance of the same event, observed with a 30 inch telescope in a 5214 Å interference filter by Africano et al. (1978). The authors also found no evidence of binarity, but given the small telescope size, scintillation was significant and the constraint on a putative companion was weaker than that from our data.

The other indication of binarity in α Cnc comes from Hipparcos, which detected an acceleration in the proper motion, interpreted as being due to a companion. However, no orbital solution could be derived and the nature of the companion (separation and mass, hence brightness) remains undetermined and likely unrelated to the putative companion claimed by previous LO reports. Frankowski et al. (2007), after examining several radial velocities catalogs, found no evidence of α Cnc being a spectroscopic binary.

4.2. HR 7072

Our reappearance light curve of HR 7072 (Kui 88AB, HIP 92301) is shown in Figure 2 and it clearly reveals a companion. We find a flux ratio of 3.38 ± 0.01, and a projected separation of 90.7 ± 0.2 mas along P.A. = 238°. In order to successfully record the reappearance event, we opted for a larger subarray, which resulted in a relatively slow sampling. Thus, we are not able to determine independently the speed of the fringe pattern, and in turn we have an uncertainty on

Figure 2. Light curve data for HR 7072 (dots) and the best fit by a binary star model (solid line). The fit residuals are shown in the lower panel. (A color version of this figure is available in the online journal.)

Our reappearance light curve of HR 7072 (Kui 88AB, HIP 92301) is shown in Figure 2 and it clearly reveals a companion. We find a flux ratio of 3.38 ± 0.01, and a projected separation of 90.7 ± 0.2 mas along P.A. = 238°. In order to successfully record the reappearance event, we opted for a larger subarray, which resulted in a relatively slow sampling. Thus, we are not able to determine independently the speed of the fringe pattern, and in turn we have an uncertainty on

Our reappearance light curve of HR 7072 (Kui 88AB, HIP 92301) is shown in Figure 2 and it clearly reveals a companion. We find a flux ratio of 3.38 ± 0.01, and a projected separation of 90.7 ± 0.2 mas along P.A. = 238°. In order to successfully record the reappearance event, we opted for a larger subarray, which resulted in a relatively slow sampling. Thus, we are not able to determine independently the speed of the fringe pattern, and in turn we have an uncertainty on

Our reappearance light curve of HR 7072 (Kui 88AB, HIP 92301) is shown in Figure 2 and it clearly reveals a companion. We find a flux ratio of 3.38 ± 0.01, and a projected separation of 90.7 ± 0.2 mas along P.A. = 238°. In order to successfully record the reappearance event, we opted for a larger subarray, which resulted in a relatively slow sampling. Thus, we are not able to determine independently the speed of the fringe pattern, and in turn we have an uncertainty on

Our reappearance light curve of HR 7072 (Kui 88AB, HIP 92301) is shown in Figure 2 and it clearly reveals a companion. We find a flux ratio of 3.38 ± 0.01, and a projected separation of 90.7 ± 0.2 mas along P.A. = 238°. In order to successfully record the reappearance event, we opted for a larger subarray, which resulted in a relatively slow sampling. Thus, we are not able to determine independently the speed of the fringe pattern, and in turn we have an uncertainty on

Our reappearance light curve of HR 7072 (Kui 88AB, HIP 92301) is shown in Figure 2 and it clearly reveals a companion. We find a flux ratio of 3.38 ± 0.01, and a projected separation of 90.7 ± 0.2 mas along P.A. = 238°. In order to successfully record the reappearance event, we opted for a larger subarray, which resulted in a relatively slow sampling. Thus, we are not able to determine independently the speed of the fringe pattern, and in turn we have an uncertainty on

Our reappearance light curve of HR 7072 (Kui 88AB, HIP 92301) is shown in Figure 2 and it clearly reveals a companion. We find a flux ratio of 3.38 ± 0.01, and a projected separation of 90.7 ± 0.2 mas along P.A. = 238°. In order to successfully record the reappearance event, we opted for a larger subarray, which resulted in a relatively slow sampling. Thus, we are not able to determine independently the speed of the fringe pattern, and in turn we have an uncertainty on
the local limb slope and correspondingly on the P.A. and projected separation. However, an analysis of the lunar limb at the given point of contact and libration angles was made using the altimetry data from the Kaguya probe (D. Herald 2014, private communication), and no significant local limb slope was found.

HR 7072 is a known sub-arcsecond binary, with over 30 previous astrometric and LO determinations, starting from the initial discovery by Wilson (1950) and extending over 54 yr. A list can be found in INT4 and additionally, we mention Muller (1958). Our result extends the time coverage to almost 65 yr. An orbital solution has not yet been established, and in fact, the interpretation of the available data is not straightforward.

The left panel of Figure 3 shows the right ascension (R.A.) and declination (decl.) position of the companion. For the LO results, which only provide a projected separation, we have plotted the lines that represent the loci of equivalent position. At a first glance, it can be noted that the positions tend to cluster around the [+150, −400] mas region, with the notable exception of the points on the negative R.A. half-plane which are all prior to 1960. These were visual determinations, while later measurements were obtained by speckle interferometry. The right panel of Figure 3 puts the measurements, expressed now as P.A. and separation, along a time sequence. It can be seen that both quantities follow an almost linear evolution with time, with the noticeable exception of two points. These are marked as outlined rather than solid symbols on both panels of Figure 3. The first one is the discovery measurement by Wilson (1950) and the second one is the latest measurement, prior to ours, obtained by Mason et al. (2004). The former was obtained by visual interferometry, the latter by speckle, but both at relatively smaller telescopes than the majority of the other determinations. We remark that most of the literature values do not have an associated error, so it is difficult to verify quantitatively any possible discrepancies.

In the right panel of Figure 3 we have made an attempt to estimate P.A. and separation for the two previous LO measurements and our own, also based on a visual fit to the rest of the points in the left panel. It can be seen that in this view, the apparent discrepancy of the Wilson (1950) measurement could in fact be reconciled given a reasonable error, as expected from the method. The Mason et al. (2004) measurement is critical, in that taken at face value, it points to a significant turn in the orbit. Accordingly, we provide two P.A.–separation equivalents for our LO result. One fits a linear trend in time of P.A. and separation, consistent with a very long orbital period and the other follows the indication of the Mason et al. (2004) measurement and reinforces the view of a closed orbit which would then seem to have a period of a few $10^2$ yr.

Concerning the flux ratio, the available data span the range from 400 to 800 nm, and are quite consistent in their trend, indicating that significant variability of either component can probably be excluded; see Figure 4. Our own determination is in close agreement with this trend. The conclusion is that one of the two stars is significantly bluer than the other. Andersen et al. (1985) measured the radial velocity of this system on two dates only, separated by just 1 yr. They did not detect any variations. They quote the spectrum as composed of A1 and K0. Houk & Smith-Moore (1988) reported A1V and K1III. This, together with the integrated color of $V - K = 2.8$ mag, points to the fact that the two stars have similar brightness in the blue, but that at longer wavelengths the K0 component is the primary. This is consistent with Jaschek et al. (1991), who found a 12 $\mu$m excess for this star and mentioned binarity as a possible explanation.

![Figure 3](image-url)  
*Figure 3. Left: astrometric (circles) and LO (lines) determinations of the position of the companion of HR 7072 with respect to the primary (cross). The LOs are (a) Africano et al. (1978), (b) Edwards et al. (1980), and (c) our measurement. Right: the same data, converted to P.A. (top) and separation (bottom) and plotted as a function of time. In this plot, the crossed symbols represent estimated LO positions, extrapolated from the lines in the left panel. The open symbols in both plots are discussed in the text. Errors are mostly not available. (A color version of this figure is available in the online journal.)*

![Figure 4](image-url)  
*Figure 4. Flux ratio of the two components of HR 7072, as a function of wavelength. Solid dots are previous results; the outlined circle is our measurement. Some error bars are too small to be seen clearly on this scale.*
5. CONCLUSIONS

We reported the first LO observations from the TNT equipped with the ULTRASPEC instrument. Using the specifically developed drift mode, time sampling of a few milliseconds can be achieved. In the first observing season of this new facility, we have recorded five LO light curves and we have discussed two of them in detail.

In the case of $\alpha$ Cnc, a duplicity has been previously claimed although not convincingly demonstrated. We do not detect the companion, with an upper limit of 3 mas in projected separation and 5 mag in flux ratio. In the case of HR 7072, our measurement complements a set of over 30 previous determinations, extending the time coverage from 54 to 65 yr. We show that the data are still ambiguous, pointing to the detection of an orbital arch and a few $10^2$ yr period, or alternatively, to a much wider and longer orbit. Observations using adaptive optics would quickly confirm one of the two scenarios. The flux ratios are consistent with early-A and early-K spectral types, with similar brightness in the blue but with the K-type component dominating at longer wavelengths.

The TNT with ULTRASPEC in drift mode has successfully demonstrated high performance LO results, with a sensitivity estimated at $I \approx 10$ mag at $S/N = 1$, an angular resolution close to 1 mas, and a dynamic range of at least 5 mag. This facility is especially attractive in consideration of the fact the LO events are observable only along restricted ground tracks and that no comparable capabilities existed until now in Southeast Asia.

V.S.D. and T.R.M. acknowledge the support of the Royal Society and the Leverhulme Trust for the operation of ULTRASPEC at the TNT. We are grateful to Dr. A. Tokovinin for useful discussions. The estimation of the lunar limb slope for the occultation of HR 7072 was provided by Dr. D. Herald. This research made use of the Simbad database, operated at the CDS, Strasbourg, France.

REFERENCES

Africano, J. L., Evans, D. S., Fekel, F. C., Smith, B. W., & Morgan, C. A. 1978, AJ, 83, 1100
Andersen, J., Nordstrom, B., Ardeberg, A., et al. 1985, A&AS, 59, 15
Dhillon, V. S., Marsh, T. R., Atkinson, D. C., et al. 2014, MNRAS, 444, 3504
Dhillon, V. S., Marsh, T. R., Copperwealth, C., et al. 2008, in AIP Conf. Proc. 984, High Time Resolution Astrophysics: The Universe at Sub-Second Timescales, ed. D. Phelan, O. Ryan, & A. Shearer (Melville, NY: AIP), 132
Dhillon, V. S., Marsh, T. R., Stevenson, M. J., et al. 2007, MNRAS, 378, 825
Edwards, D. A., Evans, D. S., Fekel, F. C., & Smith, B. W. 1980, AJ, 85, 478
Frankowski, A., Jancart, S., & Jorissen, A. 2007, A&A, 464, 377
Hartkopf, W. I., Tokovinin, A., & Mason, B. D. 2012, AJ, 143, 42
Houk, N., & Smith-Moore, M. 1988, Michigan Catalogue of Two-dimensional Spectral Types for the HD Stars, Vol. 4, Declinations $-26^\circ$ to $-12^\circ$ (Ann Arbor, MI: Univ. Michigan)
Ives, D., Bezawada, N., Dhillon, V., & Marsh, T. 2008, Proc. SPIE, 7021, 10
Jaschek, C., Jaschek, M., Egret, D., & Andrillat, Y. 1991, A&A, 252, 229
Mason, B. D., Hartkopf, W. I., Wycoff, G. L., et al. 2004, AJ, 128, 3012
Muller, P. 1958, JO, 41, 109
Richichi, A. 1989, A&A, 226, 366
Richichi, A., Baffa, C., Calamai, G., & Lisi, F. 1996, AJ, 112, 2786
Richichi, A., Cusano, F., Fors, O., & Moerchen, M. 2012, ApJS, 203, 33
Richichi, A., Fors, O., Cusano, F., & Ivanov, V. D. 2014, AJ, 147, 57
Richichi, A., Percheron, I., & Khristoforova, M. 2005, A&A, 431, 773
Tokovinin, A., Mason, B. D., & Hartkopf, W. I. 2010, AJ, 139, 743
Wilson, R. H., Jr. 1950, AJ, 55, 153