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# An investigation of the multiple star Zeta Cnc by a lunar occultation*

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**Abstract.** We analyze and discuss a lunar occultation of the multiple star $\zeta$ Cnc, obtained in the near-infrared. The long-sought D component, recently imaged with the help of adaptive optics also by Hutchings et al. (2000), is clearly seen in the occultation light curve, and we determine its projected separation and brightness ratio with high accuracy. Regarding the suggested binary nature of D, we provide an estimate of the upper limit of its separation. In addition, we find evidence for a further component in the system. The signal from this latter is at the limit of detection, but it is confirmed by three independent data analysis methods. We discuss the astrometry and photometry of the system, and the implications for the mass and spectral characteristics of the components. With a projected separation of $0\farcs064$, the proposed E component could form a close pair with $\zeta$ Cnc C. However, at the present stage we have to consider it only as tentative, and further observations by large telescopes or large interferometric facilities will be needed to confirm and study it in detail.

**Key words:** astrometry – occultations – stars: binaries: close – stars: binaries: visual – stars: fundamental parameters – stars: individual:

## 1. Introduction

The bright star $\zeta$ Cnc is a well-studied multiple system, also known as ADS 6650. The system is formed by SAO 97645 and SAO 97646 at about $8''$ distance: moreover, each of these is in fact itself a binary or, as we shall discuss, a multiple star. Thanks to its brightness, both as a whole and of the individual components, and to the favorable separation, this source has attracted binary star observers for a long time, and therefore holds one of the longest observational records in its class. The subsequent discovery of its multiple nature has attracted interest also from more modern observers. An interesting and detailed account of the history and importance of this star has been given recently by Griffin (2000). Orbital parameters and masses have been estimated, as well as spectral types. However, definitive conclusions are still needed, especially concerning the $\zeta$ Cnc C sub-system of this multiple star.

In this paper, we analyze in detail a lunar occultation (LO) of $\zeta$ Cnc. The observation and the geometric configuration of the lunar occultation event are described in Sect. 2. The data analysis has been crucial to detect not only the four main components in the system, but also a possible fifth component which is at the limit of the available signal-to-noise ratio (SNR). Three independent data reduction methods have been employed, which are described in Sect. 3 together with our determinations of the projected separations and brightness ratios. Finally, we discuss in Sect. 4 these results, and compare them to available ephemerides and other determinations.

To avoid the possible confusion generated by the different names found in the literature for the various components of $\zeta$ Cnc, we define immediately our naming scheme. Throughout this paper, A and B are the stars (in order of brightness at both visual and near-IR wavelengths) which form the subsystem which is presently to the west. The stars in the eastern subsystem are named starting from C, in order of brightness in the near-IR. Of these, only C has been detected in the visual. In the case of possible close unresolved pairs, as has been suggested for $\zeta$ Cnc D, we do not use additional letters.

## 2. Observations

A lunar occultation reappearance of the multiple star $\zeta$ Cnc was recorded on December 7, 1998, at the 1.23 m telescope of the Calar Alto observatory. The measurement was part of a routine program of LO observations, as described in detail in Richichi et al. (2000) and references therein. A low-resolution version of the LO light curve is shown in Fig. 1.

In summary, the observation was carried out in a standard broad-band K filter, with a $24''$ diaphragm, using the InSb fast photometer FIRPO described in Richichi et al. (2000) and references therein. A sampling rate of 500 Hz was used. The data were found to be free from spurious pick-up frequencies, and the detector response can be considered flat up to the sampling frequency. It should be noted that, regrettably, at the time of the

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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 by the German-Spanish Astronomical Center.

** On leave from Osservatorio Astrofisico di Arcetri

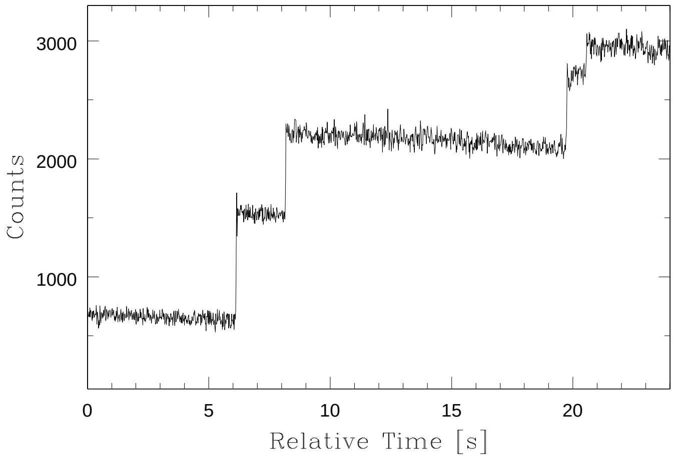


**Fig. 1.** The occultation trace of SAO 97645, shown with a time resolution rebinned by a factor of 8. From left to right, the four reappearance events corresponding to components A, B, C and D are clearly visible, while the suspected E component close to C is hard to distinguish at this resolution. Note also the drift in the background level, caused by the receding Moon.

**Table 1.** Main parameters of the LO event

| | |
|---|---|
| Date | Dec. 7, 1998 |
| UT Time[a] | 02:11:23 |
| JD | 2451154.6 |
| Filter | $\lambda_0 = 2.19\mu$m |
| | $\Delta\lambda = 0.49\mu$m |
| Sampling | 2 ms |
| Field of view | 24″ |
| Predicted rate[a] | 0.6818 m/ms |
| Predicted PA | 287.°4 |
| Predicted CA | 188.°1 |
| A-B pair | |
| Fitted rate (average) | 0.6799 m/ms |
| Slope $\psi$ | −3.°8 |
| Actual PA (B wrt A) | 103.°6 |
| C-D pair | |
| Fitted rate | 0.6548 m/ms |
| Slope $\psi$ | +9.°9 |
| Actual PA (D wrt C) | 117.°3 |

[a]: Prediction for SAO 97645.

observation the telescope primary mirror was affected by surface defects and therefore parts of it were covered. The resulting collecting area was equivalent to a clear diameter of about 70 cm only.

Also, photometry of $\zeta$ Cnc was obtained on January 15, 2000, at the TIRGO 1.5 m telescope. A standard broad-band K filter at 2.2$\mu$m was used, and a 21″ diaphragm that included both the A-B and the C-D pairs. A total magnitude of K=$3.50 \pm 0.03$ was measured. This value is used in Sect. 3 to derive the magnitudes of the individual components.

Table 1 lists the main parameters of the LO event, either predicted or derived from a best fit to the data as described in Sect. 3. A LO event only yields a one-dimensional scan of the brightness profile of the source, along the position angle (PA) along which the lunar limb moves. In particular, all separations between the $\zeta$ Cnc components that we derive are projected values, along the PA as listed. The actual PA can differ from the predicted one, owing to the so-called limb slope $\psi$. As a result, also the rate of the event can differ from the predicted one. If the LO light curve is properly sampled, it is possible to determine the actual rate of the event from the observed data, and therefore to determine the actual PA and limb slope, as was done in our case.

It is worthy noting that in the present LO observation A-B and C-D were separated by such a large (projected) angle, that the actual point of occultation at the lunar limb was significantly different for the two pairs: ≈5″, i.e. ≈9 km. Even if the predicted PA is the same for all practical purposes, it was expected that the slope $\psi$ could be significantly different. Therefore, we have fitted the rates of the A-B and C-D pairs independently. Correspondingly, different values are found for the PA and $\psi$ angles, as shown in Table 1. The difference in the limb slope at the two points of occultation is found to be ≈14°, a reasonable value in our experience of LO observations.

In fact, even the A and B stars are sufficiently separated, that each was occulted at a slightly different rate. For all practical purposes, it is sufficient to compute then the weighted mean of the two rates, and this is the value listed in Table 1. For the C-D pair no significant difference was measured. We also note that the contact angle (CA) of the event, i.e. the angle between the normal to the limb at the occultation point and the direction of the lunar motion, was close to 180°. When this happens, two solutions can be found for the limb slope. For instance, for the A-B pair the two solutions would be $\psi = -3.^\circ8$ and $-12.^\circ4$. We have used the smaller absolute value, which is more likely and also gives a better agreement with the ephemerides, as mentioned in Sect. 4.

We stress that the above considerations, while showing that the LO technique is not ideal for wide-angle binary measurements, do not affect the accuracy of the results for the small-angle determinations. In particular, the separation and brightness ratio results within the C subsystem, which constitute the main topic of the present paper, are not affected and can be considered reliable.

## 3. Data analysis and results

The data analysis was carried out by means of three methods: a least-square model-fitting method (LSM), a model-independent iterative algorithm (CAL), and the so-called "bridge of Bolzano" method (BB). The first two have been widely used and described in the literature. Details on our implementation of LSM and CAL and examples of applications can be found for instance in Richichi (1989) and Richichi et al. (1992, 2000 and references therein).

In summary, the LSM method uses a model to fit the LO light curve. In the case of binary or multiple (unresolved) stars,

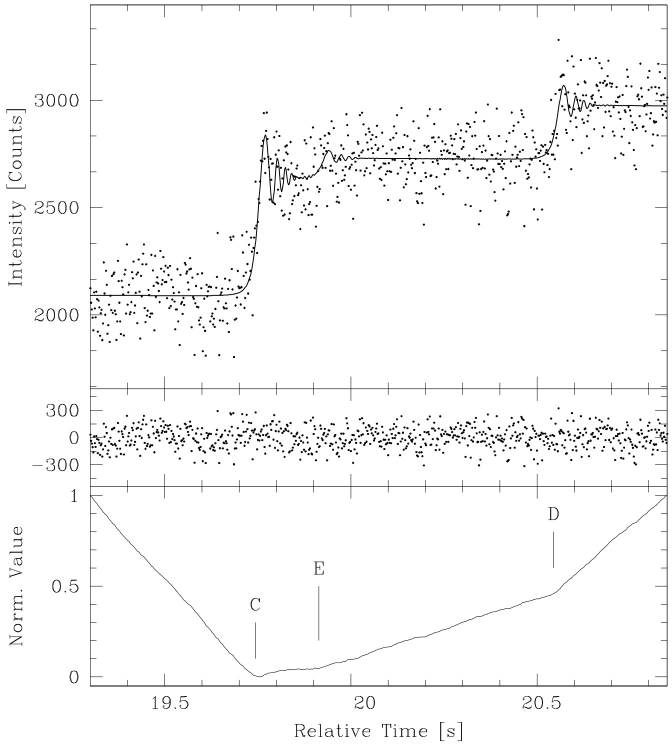


**Fig. 2.** Top panel: the best LSM fit (solid line) to a section of the light curve encompassing the C-D system only. The dots are the LO data. A 3-component model has been used. Middle panel: the fit residuals (rescaled). Bottom panel: the integral plot of the same section of the ligh curve computed by the BB method. The points at which changes in the slope occur are indicative of the presence of stellar (point-like) components, and are marked by the C,D,E labels. Note the correspondence with the position of the 3 components in the top plot.

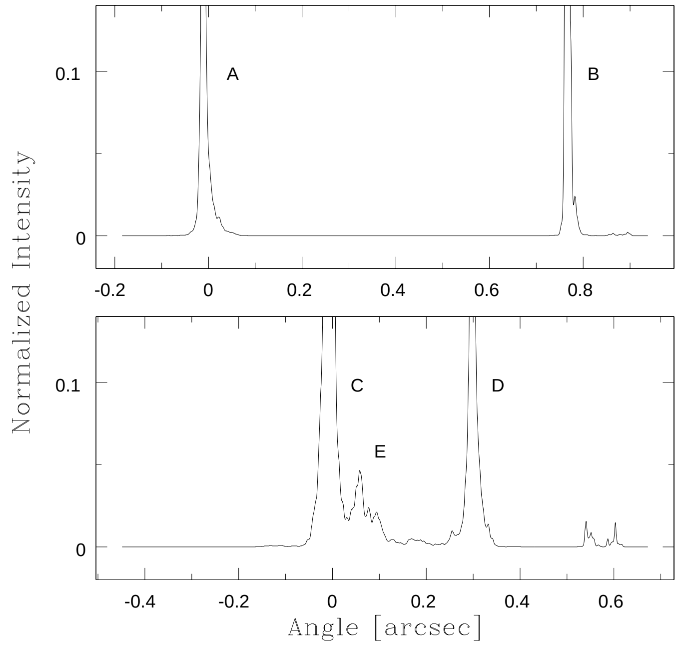


**Fig. 3.** Top panel: brightness profile recovered by the CAL method, for a 3.2 s section of the light curve centered around the A-B pair. Bottom panel: same, for a 3.2 s section centered around the C-D pair. In this latter, note the additional peak above the noise level, indicative of the presence of component E. The profiles have not been filtered nor apodized, and the irregularities are indicative of the noise level.

the model parameters are the position and brightness of each component, in addition to the rate of the event and the background level. A linear drift of the background was also included in our case. Iterations are stopped when convergence is reached on each parameter, or when changes in the standard deviation of the fit are not significant with respect to the noise. The method is powerful when an a priori model of the source is known. In the case under consideration, models with 2 and 3 components were tried for the C-D pair. Their statistical significance is discussed in Sect. 4.

The CAL method is used when no a priori information is known on the source brightness profile. An initial profile (a flat one in our case) is iteratively modified using a Lucy-Richardson algorithm, until some convergence criterion is satisfied. In our case, we stopped iterations when the same standard deviation obtained with the LSM method was reached.

The BB method has been used less widely in the literature. It has been adapted to LO work from the field of civil engineering by Bartholdi, and used for instance by Dunham et al. (1973) and Africano et al. (1976). It consists in computing a kind of integral running average of the data. The resulting plot consists ideally in a segmented line, where changes in the slope occur at the points at which a star disappears or reappears in the data. The method is largely insensitive to white noise and atmospheric fluctuations, and is powerful to detect faint sources which are not readily seen by a visual inspection of the light curve.

The results of the analysis of the LO data by these methods are shown in Figs. 2 and 3. For simplicity, we show the LSM and BB results for the C-D system only. The A-B pair poses no problem of interpretation and only the CAL result is shown in Fig. 3.

The main point is that all 3 methods lead to the presence of an additional component (which we have labelled "E"), in the C-D system. In the case of the LSM analysis, we show the fit for a 3-component model. Note that the fit residuals have a very smooth distribution. To assess the significance of this result, we have computed the normalized $\chi^2$ (i.e., taking into account the number of parameters used in the model) for the best fits obtained by models with 2 and 3 components. For this, the noise has been estimated on sections of the light curve well separated from the section where the C-D occultation occurs. The result is $\chi^2$=1.061 and 1.007 respectively. In terms of goodness-of-fit, the probability that the models with 2 and 3 components represent a good description of the data are 12% and 44% respectively: although this is not sufficient to rule out the 2-component model altogether, it shows that the 3-component model is statistically more significant.

In the case of the BB analysis, the integral plot shown also in Fig. 2 has an obvious change of slope at the time of the reappearance of component C, and an equally clear although less prominent one around the time of component D (note that the

**Table 2.** Summary of results

| Pair | PA | Sep. (mas) (projected) | Br. Ratio | $m_1$ | $m_2$ |
|---|---|---|---|---|---|
| | | | | $K$-band | |
| A-B | 99°.3 | 774.7±2.1 | 1.305±0.003 | 4.60 | 4.89 |
| A-C | 114° | 5060±19 | 1.668±0.006 | 4.60 | 5.15 |
| C-D | 117°.3 | 292.8±1.3 | 2.170±0.015 | 5.15 | 5.99 |
| C-E | 117°.3 | 63.7±0.6 | 5.582±0.089 | 5.15 | 7.02 |

amount of slope rotation is proportional to the intensity of the star and to the fraction of data in which the star signal is present). A smaller slope change can be appreciated also about 0.2 s after C, in agreement with the position of component E in the LSM plot. Note that a small indentation of the plot just after the time of C (and before that of E) is due to the first of the diffraction fringes of C, and not to noise. Also note that both the LSM and the BB analysis have been carried out on a section of the light curve about two times longer than shown, for purpose of clarity, in Fig. 2.

Finally, a third independent indication of the E component is given by the CAL analysis shown in Fig. 3. In this case, a 3.2 s section of data (longer than that shown in Fig. 2) was analyzed both around the A-B and the C-D pair. The results are superimposed to allow an estimate and a comparison of the noise level of the reconstructions. This is significantly better in the A-B than in the C-D case, owing to the higher combined signal. Several minor structures can be attributed to noise in the C-D reconstructed profile, but what we have identified as E is several sigmas above them. The C-E separation from the CAL analysis is in excellent agreement with that found by the previous methods.

Having commented the evidence for the E component, we think it is also fair to note that its detection is indeed at the limit of what is detectable at the SNR of the light curve. It would be presumptuous to exclude completely the possibility that what we interpret as the E component could be fictitious. We note however that signal fluctuations caused by atmospheric scintillation should average out in the relatively long sections of data that we have considered, and that at least the BB and the CAL method should be insensitive to them. Perhaps the best support for the conclusion that the detection of the E component could indeed be real, comes from the fact that 3 independent approaches to the data analysis, each with a different behaviour against spurious signals, have led to the same result.

Additional evidence from other observations is clearly very desirable, to confirm the reality of E. In Sect. 4, we attempt to explain its presence in the context of all available information, but we stress that at this stage, we have to consider our detection of the E component as tentative only.

The (projected) separation and brightness parameters for this system are listed in Table 2. They have been derived from the LSM fit which, among the three mentioned above, is the only method of analysis capable of giving estimates of the parameters and their formal errors. As said in Sect. 2, the A-B and C-D pairs are separated by such a large angle that the limb slope is actually different in the two cases. To compute the PA and separation shown under the A-C entry, we have then used the average of the fitted rates for A-B and C-D listed in Table 1. The error is correspondingly large in this case. However, the importance of the determination for this wide-angle pair is relative, since it is an easy target for other observational techniques and it is reported here only for completeness.

We note that the results of Table 2 do not depend strongly on the tentative presence of component E in the system. In particular, the projected separations are unaffected, and the C-D brightness ratio would have to be increased by 5.4%, in case of a fit without the E component.

## 4. Discussion

The $\zeta$ Cnc has been recognized initially as a binary star, and later as a triple, already by visual observers and studied as such for over 200 years. Literally thousands of observations have been recorded, sometimes with conflicting interpretations, and often with confusing conventions on the designations of the components. Already in 1831, J.F.W. Herschel recognized that the more distant C companion had an apparent orbit which showed perturbations, and a fourth, unseen companion was postulated by O. Struve, leading to a heated debate with C. Flammarion. An excellent detailed account, with many interesting historical insights, has been provided recently by Griffin (2000). We refer the reader to this latter, since it is not possible in the limited space of this paper to condense all the astrometric, photometric, and spectroscopic observations and interpretations on this star.

For the purpose of the present discussion, we will summarize the basic information on the system as follows. Our choice of designations has been stated already in the introduction. Stars A and B have masses estimated at 1.11 and 1.00 $M_\odot$ respectively, and form a system with an orbital period of about 59 years and a mean angular separation just under $1''$ (secular perturbations are also present, see Heintz 1996, H96 hereafter). The C companion is more distant, and orbits the A-B pair in about 1100 years. Its motion shows epicycles, which have led to the inference of an unseen D companion. The period of D around C is about 17 years, and masses for C and D were estimated in H96 at 0.99 and 0.93 $M_\odot$ respectively. Thus the system is fairly unusual, in that its components seem to have very similar masses.

For what concerns the astrometry of the A-B pair, we note that our result listed in Table 2 is in good agreement with the H96 ephemerides. Since this is a relatively well-studied pair, we do not concern ourselves further with it and we turn our attention to the C-D system.

The D component has escaped numerous attempts of detection by visual observers first, and by speckle interferometry more recently (McAlister 1977, 1978; McAlister & Degioia 1979; McAlister & Hendry 1982; Bagnuolo et al. 1992; Al-Shukri et al. 1996; Douglass et al. 1997; Fu et al. 1997; Hartkopf et al. 1997; Germain et al. 1999). A LO of $\zeta$ Cnc was also observed in the visible by Meyer et al. (1995), who did not detect the D component. In this context, it should be mentioned that McCarthy (1983, 1986) reported infrared speckle observations

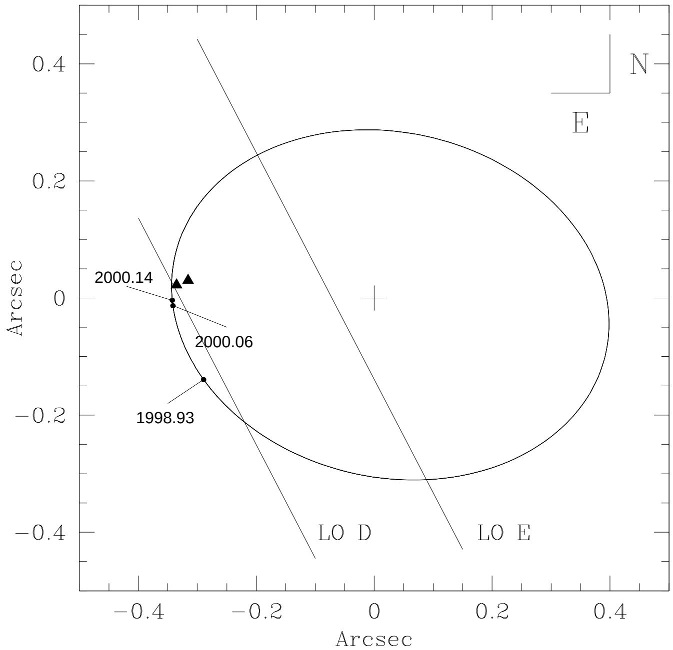


**Fig. 4.** The orbit of $\zeta$ Cnc D around the C component, computed from the orbital parameters and the mass ratio given by H96 (solid line). The D positions observed by HGM are superimposed as solid triangles, together with the lines of possible solutions for the positions of the D and E components from Table 2. Also marked are the epochs of the AO and LO observations on the H96 orbit (dots labeled by dates).

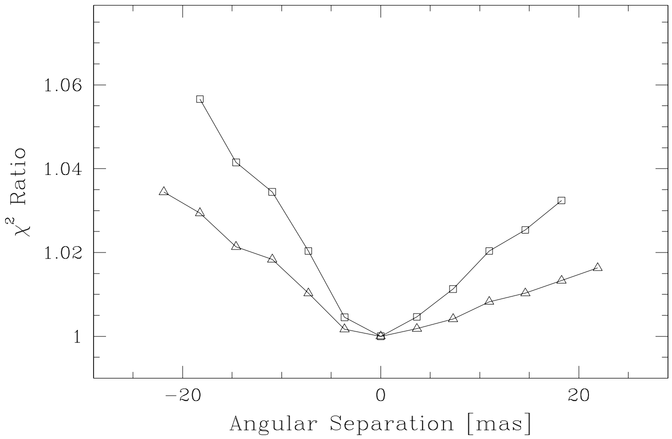


**Fig. 5.** Quality of a fit to the data shown in Fig. 2, when a binary is replaced for component D. The binary has K-band brightness ratio of 1:1 (squares) and 2:1 (triangles). The $\chi^2$ ratio is relative to the fit with D as a single star.

in which he detected $\zeta$ Cnc C to be a triple star. However, quantitative details of this interesting report are missing, and Griffin (2000) has noted additional difficulties.

Therefore, at the time of the present LO observation, the D component still constituted somewhat of a puzzle, and it was repeatedly suggested that it could be a cool white dwarf. This component is well detected in the LO data. However, we must first mention that during the preparation of this paper, we have learned about adaptive optics near-IR imaging observations carried out at the beginning of 2000, which also detected the D component (Griffin priv. comm., and Hutchings et al. 2000, HGM hereafter). Although their observation took place at a later date than ours, these authors independently and more promptly identified the D component and discussed its properties.

In addition to a general agreement with the H96 ephemerides, the main result of HGM is that the near-IR brightness of the D component is not consistent with a single star having the mass estimated by astrometric considerations. Rather, HGM postulate that D itself is a binary, composed of two M dwarf stars.

With the present LO observation, we are in a position to add further data on the D component. To start with the astrometry, it is useful to convert the H96 ephemerides for the C component, into an orbit of D around C. For this, we have assumed the mass ratio $f$=0.99/0.93 between C and D given in H96. The result is shown in Fig. 4. It can be noted that the agreement of the observed D positions, both by adaptive-optics (AO) and LO, with the H96 ephemerides is satisfactory at a first approximation. These latter predict 116° and $0\farcs32$ in 1998.93, and 91° and $0\farcs34$ in 2000.10 (Heintz, priv. comm.).

A closer inspection however reveals that both the LO and the AO determinations of the position of the D component fall a little short of the H96 prediction. In the case, of the LO measurement, the discrepancy is about 25 mas. We also note that the Hipparcos Transit Data (HTD) seem to indicate a similar trend, as discussed in the note added in proof. Further observations, as well as a more detailed analysis of the HTD, are needed to verify the H96 orbit, and possibly to reveal the effect of an additional component in the system.

For what concerns the brightnesses, HGM did not obtain absolute photometry of the C-D system, and only report relative color differences in the J band and in FeII and Br$\gamma$ narrow filters. We can reinforce their argument, by providing standard K-band photometry. The value for D is close to K=6.0 mag (see Table 2). This rules out the possibility of a white dwarf. HGM have used the argument of mass and brightness, to suggest that if the C component has spectral type G0V (Griffin 2000), then D cannot be a single star and should be composed of two early M dwarfs. Our photometry is consistent with this conclusion.

However, we must note that what we have tentatively identified as the E component does not fulfil the requisites of the companion to $\zeta$ Cnc D postulated by HGM. In particular, it is too far from D itself. In the HGM hypothesis, the two D components should have similar masses. In case of a relatively large separation, a substantial perturbation of the radial velocity of C would have been noticed – not to mention the likely instability of the system.

Therefore, we have to conclude that the D component was unresolved also in our observation. We have tried to estimate the maximum separation of a binary, which would still be consistent with our data. We have plotted in Fig. 5 the relative $\chi^2$ increase in the fit when a binary is replaced for component D, with different values of separation and brightness ratio. Note that the curves are not symmetric, since it is easier to detect a binary companion when the primary is occulted. As expected, Fig. 5 shows that the detection would be problematic for a brightness ratio significantly different from unity. Using a 3% increase in the relative $\chi^2$ of the fit as a criterion for possible detection (the E component is at a 5.5% level, as mentioned in Sect. 3), we conclude that a (projected) separation $\lesssim$20-30 mas constitutes an upper limit for a companion to D with comparable K-band brightness.

Concerning our suggested E component, we would be led to conclude that, if confirmed, this should constitute an additional star in the system. The main difficulty is to explain why no effects of its presence were noticed so far, either in the astrometry or in the radial velocities. Based on a distance of about 25 pc, the absolute brightness of E should be K$\approx$6.0, suggesting a M2 to M5 spectral type. Correspondingly, its mass should be approximately one-half that of D. The LO result would imply a minimum C-E separation of $\approx$1.6 AU. With a total mass of $\approx$1.4 $M_\odot$, the minimum period would be less than two years. The astrometric effect on C would be at a level of 1/3 of the C-E separation, i.e. $0\farcs02$. We note that all three AO and LO observations of the D component show a positive difference of observed minus predicted position angle, possibly hinting at a (small) systematic correction needed in the ephemerides.

As for the effect on the radial velocities, the frequency and length of the available measurements are adequate in principle to detect 2-years periodicities. The peak amplitude in radial velocity expected for a 2-year orbit of 0.5 AU (again, assuming a 1:3 mass ratio between E and C) would be $\approx$7 km/s. The rms scatter of the O-C residuals of the most recent solution by Griffin (2000), who combined data from different instruments, is about 0.5 km/s. Therefore, one would have to assume a rather small inclination angle of the orbit ($|i| < 5°$). We note however, that this depends strongly on parameters such as the actual semi-axis and eccentricity, (and less strongly on the actual mass), for which no sufficient information is available.

We conclude that the presence of the E component is not ruled out by the currently available astrometric and spectroscopic data, although strong constraints would have to be imposed. Of course, it is premature at this stage to draw any quantitative conclusions, and clearly further observations are very desirable to confirm the reality of E.

## 5. Conclusions

We have analyzed in detail a lunar occultation of $\zeta$ Cnc, obtained in the course of a routine program of binary star observations described by Richichi et al. (2000).

This star is a multiple system, that can be conveniently separated into the A-B and the C sub-systems. In addition to the well-studied A, B and C components, we detect the D component which has long been inferred from orbital perturbations. This component was also imaged by adaptive optics (Hutchings et al. 2000) while the present paper was in preparation. We confirm their results, and provide independent K-band photometry, which strengthens the argument that led Hutchings et al. (2000) to suggest that D should be composed of two close early M dwarf stars. The D star is unresolved in our observation, and we provide upper limits for the separation of a companion with different brightness ratios.

Additionally, we detect a further signature in the lunar occultation trace. Although the detection of this component is at the limit of what can be extracted from the data, it is confirmed by three independent data analysis methods, two of which are largely insensitive to signal fluctuations introduced by atmospheric noise. Tentatively, we interpret this as a further component (E) in the system. If real, E should be much closer to C than D. It could be a M2 to M5 dwarf, with a period as short as $\approx$2 years. We estimate the effects expected on the astrometry and radial velocity of C, and conclude that they are not inconsistent with the measurements currently available, although strong contraints on the orbital inclination of C-E would have to be assumed.

Obviously, further observations of the $\zeta$ Cnc C system are very desirable, both in the near-IR and in the visual range. These will permit to confirm the presence of the E component, to estimate the spectral types, and to follow the orbits and obtain direct determinations of the masses. The radial velocities are already at a level that permits to constrain very significantly the range of permitted inclination angles. Further observations with high accuracy might confirm or rule out the E component.

Brightnesses between V=9.5 and 11.5 mag can be predicted for the D and E components. Given also the small separations involved, direct infrared detections of the E component should be possible at very large telescopes by means of speckle interferometry or adaptive optics. Visual observations could be significantly more difficult, in view of the difficulties to use such methods at shorter wavelengths. No other LO observations can be observed until the next series, which will begin in 2010 only. The $\zeta$ Cnc C system will constitute an ideal target for the large interferometers soon to become operative, such as the Keck and the VLTI.

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## References

Africano J.L., Evans D.S., Fekel F.C., Ferland G.J., 1976, AJ 81, 650
Al-Shukri A.M., McAlister H.A., Hartkopf W.I., Hutter D.J., Franz O.G., 1996, AJ 111, 393
Bagnuolo W.G., Mason B.D., Barry D.J., Hartkopf W.I., McAlister H.A., 1992, AJ
Douglass G.G., Hindsley R.B., Worley C.E., 1997, ApJS 111, 289
Dunham D.W., Evans D.S., McGraw J.T., Sandmann W.H., Wells D.C., 1973, AJ 78, 482

Fu H.-H., Hartkopf W.I., Mason B.D., et al., 1997, AJ 114, 1623
Germain M.E., Douglass G.G., Worley C.E., 1999, AJ 117, 1905
Griffin R.F., 2000, Obs. 120, 1
Hartkopf W.I., McAlister H.A., Mason B.D., et al., 1997, AJ 114, 1639
Heintz W.D., 1996 (H96), AJ 111, 408
Hutchings J.B., Griffin R.F., Ménard F., 2000 (HGM), PASP 112, 833
McAlister H.A., 1977, ApJ 215, 159
McAlister H.A., 1978, ApJ 225, 932
McAlister H.A., Degioia K.A., 1979, ApJ 228, 493
McAlister H.A., Hendry E.M., 1982, ApJS 48, 273
McCarthy D.W., 1983, In: Philip A.G.D., Upgren A.R. (eds.) IAU Colloquium 76, p. 107
McCarthy D.W., 1986, In: Kafatos M.C., Harrington R.S., Maran S.P., Upgren A.R. (eds.) Astrophysics of Brown Dwarfs. p. 9
Meyer V., Rabbia Y., Froeschle M., Helmer G., Amieux G., 1995, A&AS 110, 107
Richichi A., 1989, A&A 226, 366
Richichi A., Di Giacomo A., Lisi F., Calamai G., 1992, A&A 265, 535
Richichi A., Ragland S., Calamai G., Richter S., Stecklum B., 2000, A&A in press

**Note added in proof:** The referee, Dr. C. Fabricius, pointed out that the Hipparcos Transit Data (HTD) permit to detect $\zeta$ Cnc D. A full analysis of these data is outside of the scope of the present paper, but the preliminary evaluation by the referee shows that HTD has the potential to obtain an important constraint on the orbit of the D component. In particular, a fit to the HTD in the approximation of a linear motion of the components (admittedly inadequate, since the system was observed over 2.6 years while the period of C-D is about 17 years) yields a separation C-D of $0\farcs26$ along PA=$255°$ at the average epoch 1991.25. This seems to fall somewhat short of the H96 ephemerides, as was noted also for the AO and LO measurement, however no certain conclusion can be drawn until a more refined orbital model is included and actual errors are computed. Clearly, a more refined analysis of the HTD is warranted and should be included in future works dealing with follow-up observations.

It is interesting to note that, after well over 150 years of unsuccessful attempts, the elusive $\zeta$ Cnc D, component has been detected almost simultaneously and quite independently by three methods, i.e. lunar occultations, adaptive optics and space astrometric observations.