SPECKLE MASKING IMAGING OF THE SPECTROSCOPIC BINARIES GLIESE 150.2 AND 41 DRACONIS

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1. Introduction

Despite a history of micrometric observations dating back more than 150 years, and many decades of astrometric and interferometric study of low-mass main sequence binary stars in the solar neighborhood, their masses and luminosities are known with much lower accuracies than for massive ($1.5 \leq \mathcal{M}/\mathcal{M}_{\odot} \leq 10$) stars of early spectral types. The latest "conservative" list of 45 binaries with normal components, whose masses and radii are measured with an error $\leq 2\%$, includes only 3 objects of spectral type G, one pair of the type M, and no K-type binaries (Andersen, 1991). Only 3 systems from this list are within 50 pc from the Sun. This is explained by the observation selection effect which confines the list of stars with fundamental masses and luminosities to double-lined eclipsing binaries. The HIPPARCOS astrometric mission will not change the situation significantly because its parallax errors will be too high to satisfy the 2% accuracy criterion even for stars within 25 pc from the Sun. Therefore, we decided to focus our attention on spectroscopic pairs recently discovered by cross-correlation spectroscopy. For nearby solar-type stars the most extensive surveys of radial velocities have been done by Duquennoy and Mayor (1991) and Tokovinin (1988). From Tokovinin's list, a few spectroscopic binaries with fast orbital motion were first resolved by speckle interferometric observations at the 6-

m telescope of the Special Astrophysical Observatory (SAO) in Zelenchuk. All of them are interesting new candidates for precise mass determination.

Here we present the first results for two binaries included in our observational program in 1993: the nearby (π=49 mas), 7.7 magnitude, K2 dwarf star Gliese 150.2 and the F7V star 41 Dra. The 41 Dra binary is a member of the hierarchical quadruple system ADS 11061AB=40/41 Dra. Both 40 and 41 Dra pairs are SB2 (Tokovinin, 1995). For Gl 150.2 and 41 Dra we present diffraction-limited images obtained by the speckle-masking method. The images allow us to determine not only the geometry of the binaries, but also their exact maginitudes. The 41 Dra system could become one of the most interesting multiples for overall study by means of different methods.

2. Observations and image reconstructions

Gl 150.2 and 41 Dra were first resolved at the 6-m telescope in 1993 using the SAO speckle camera (Balega *et al.*, 1994). Speckle interferograms were recorded through 605/24 nm and 667/20 nm interference filters with 20 ms exposure time under 1-1.5$''$ seeing. Later, the measurements were continued using the Max-Planck-Institut für Radioastronomie speckle camera (Baier and Weigelt, 1983) which provides higher dynamic range and better astrometric accuracy. The new detector of this camera is a Thompson 512^2 pixels CCD optically coupled to a 3-stage electrostatic image intensifier. The new data were collected through a 656/30 nm red filter, with the magnification $40\times$ corresponding to an image scale of 4.97 mas/pixel. In addition, in 1996 we recorded 41 Dra speckle images in the K-band (filter 2191/411 nm) with a 256^2 pixels NICMOS-3 camera. For infrared observations the exposure time of the speckle interferograms was 150 ms, and the scale in the image plane was 33.2 mas/pixel. A system of Digital Signal Processors was used for real-time speckle-masking computations, so we could see the evolution of the restored image during observing. Simultaneously, the data were recorded on Exabyte streamers for future detailed analysis.

Diffraction-limited images in the visible and in the infrared were reconstructed from speckle interferograms by the speckle-masking method (Weigelt,1977; Lohmann *et al.*, 1983). The following processing steps were applied to the speckle data:

1. Subtraction of the detector average dark current and division by the flatfield for each speckle interferogram;
2. Calculation of the average power spectrum of all speckle data;
3. Subtraction of detector noise bias terms from the average power spectrum;
4. Calculation of the average bispectrum of all speckle interferograms;
5. Subtraction of detector noise bias terms from the average bispectrum;

6. Compensation of the speckle interferometry transfer function in the bias-compensated average power spectrum to obtain the Fourier modulus;
7. Retrieval of Fourier phase from the bias-compensated average bispectrum;
8. Reconstruction of the diffraction-limited image from the object modulus and phase.

The object Fourier phase was reconstructed from the bias-compensated average bispectrum using the phase recursion method (Lohmann *et al.*, 1983). The bispectrum of each frame consisted of $\approx 31.7 \times 10^6$ elements (maximum length of bispectrum vectors: u=50 px, v=95 px = diffraction cut-off frequency). For correct recursive phase reconstruction each bispectrum element was weighted with its SNR.

3. Results

During the observations of Gl 150.2 in 1993 we suspected the existence of three components in the system at the following position angles and separations: $\theta_{AB} = 107°$, $\rho_{AB} = 186$ mas; $\theta_{AC} = 134°$, $\rho_{AC} = 45$ mas. The contrast of the secondary peaks in the correlation was rather low because of the large magnitude difference between the stars in Gl 150.2.

TABLE 1. Interferometric measurements of Gl 150.2 and 41 Dra

Binary	Date	$\theta°$	ρ mas	Filter $\lambda/\triangle\lambda$, nm	$\triangle m$
Gl 150.2AB	1993.8418	107	186	667/20	2.2
	1994.7130	102.2	249	656/30	2.49
Gl 150.2AC(?)	1993.8418	134	45	667/20	1
41 Dra	1993.3492	320	102	605/24	0.2
	1993.7646	328	93	605/24	0.3
	1993.8437	327	92	605/24	0.3
	1994.7129	296.0	25	656/30	0.38
	1995.7757	316.9	101	850/30	–
	1996.2667	321.9	113	2191/411	0.47

The bispectrum image reconstruction of Gl 150.2AB through the red 656/30 nm filter is shown in Fig.1a. The measurements of the geometry and magnitude difference are reported in Table 1. No evidence for the third star was found in 1994. The upper limit for the separation of suspected companion is about 10 ms for an equal brightness pair. Orbital motion of such a close secondary would cause radial velocity variations with a period of 1 yr and an amplitude of $\sim$ 10 km/s. Such variations have never been reported for Gl 150.2, so we conclude that the suspected triple structure of the system is spurious. A year after the first resolution, the angular distance

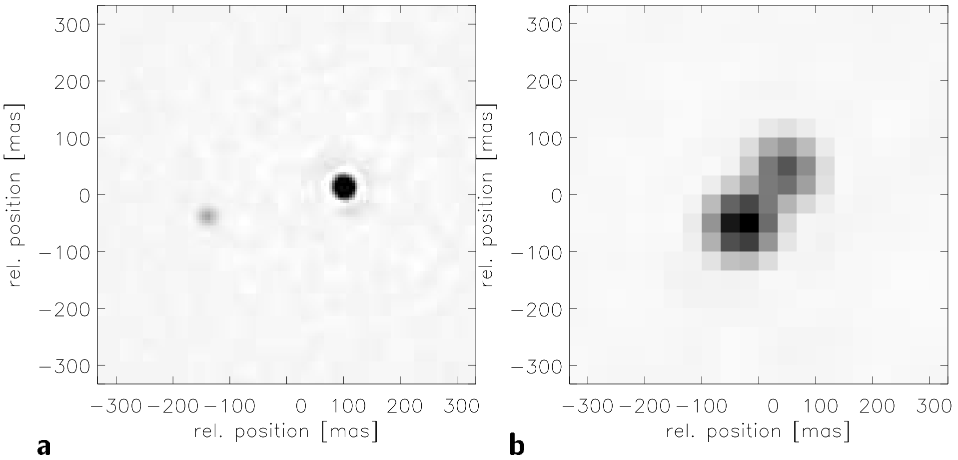

Figure 1. (a) Diffraction-limited 656/30 nm image of spectroscopic binary Gl 150.2AB reconstructed by the speckle masking method from 1600 speckle interferograms. (b) Image reconstruction of 41 Dra from 533 infrared speckle interferograms recorded through a 2129/411 nm filter. The scale and orientation are identical in both images: each panel covers $0.7'' \times 0.7''$, north is up and east is to the left.

in Gl 150.2AB system increased by 63 mas thus confirming the identity of spectroscopic and interferometric pairs. From the estimated magnitude difference $\triangle m = 2.49$ we obtain for the second star $m_R = 10.3$. The absolute magnitude for the main K2V star must be close to M_V=6.4 (Allen, 1973), corresponding to $m - M$=1.4 and π_{ph}=52 mas. The absolute magnitude for the secondary is then M_V=8.9 and its spectral type is M0V. Estimation of the masses of the A and B components are $0.7\mathcal{M}_\odot$ and $0.5\mathcal{M}_\odot$ respectively, and their orbital period is $\sim$10 yrs. In the following years, speckle measurements combined with radial velocity data and HIPPARCOS parallaxes will provide high precision masses and luminosities for Gl 150.2AB.

Speckle measurements of 41 Dra are given in Table 1. In 1994.7129, 40 days after the periastron passage, the weaker star of the binary was observed in the NW direction at ρ=25 mas - the separation equal to the diffraction limit of the 6-m telescope at 650 nm. In Fig.1b it is shown one of the speckle masking images of 41 Dra, recorded through the 2191/411 nm filter where the diffraction limit of the telescope is 75 mas.

As was recently shown by Tokovinin (1995), all four components of 40/41 Dra = ADS 11061AB system have very similar spectral types and masses. The wide pair ADS 11061Aab shows the highest eccentricity among known spectroscopic binaries. By combining P, T, e elements from the spectroscopic orbit with our 6 speckle measurements in different filters, we can define the parameters of the visual orbit. This was done with the help of the Monet method (1979) giving us the following:

$P^* = 3.4147$, $T^* = 1994.5988$, $e^* = 0.9754$,
$a'' = 70$ *mas*, $i^\circ = 50$, $\Omega^\circ = 358$, $\omega^\circ = 130$.

The corresponding ellipse of the relative motion is shown in Fig.2. From the known values for $(\mathcal{M}_{Aa} + \mathcal{M}_{Ab}) \sin^3 i = 1.100\mathcal{M}_\odot$ and $K_{Ab}/K_{Aa} = 1.07$ (Tokovinin, 1995), we can now estimate the masses of the Aa and Ab components:
$\mathcal{M}_{Aa} = 1.26\mathcal{M}_\odot$, $\mathcal{M}_{Ab} = 1.18\mathcal{M}_\odot$.
Taking into account the bolometric correction for an F7V star, the dynamic parallax of the system is π_{dyn}=21 mas, which is in agreement with the published trigonometric parallax (Turon *et al.*, 1992). It is interesting to note that exactly the same parallax has been reported during this Workshop for the wide system ADS 10061AB by A.Kiselev, as a result of astrometric measurements at the Pulkovo observatory.

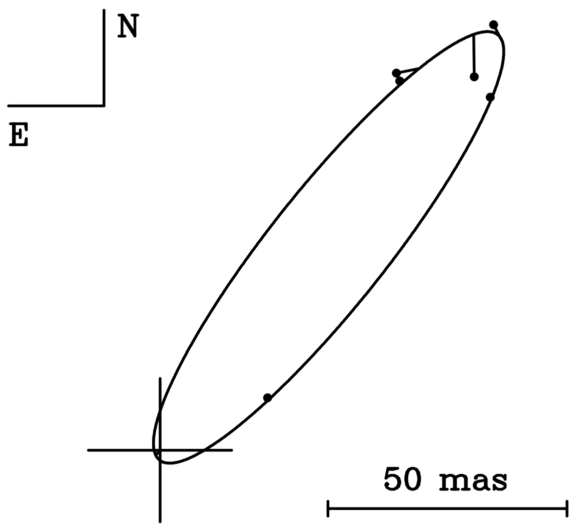

Figure 2. The relative interferometric orbit for 41 Dra=ADS 11061Aab. Speckle measurements with the 6-m telescope are connected to their predicted positions on the orbit.

Close to the periastron passage the two components of 41 Dra are separated by only 1–2 mas, or 5–10 stellar radii. Short-term tidal frictions near the periastron could cause the evolution of orbit eccentricity, period, and semi-major axis. The quadruple system ADS 11061AB as a whole is therefore a critical test object for the verification of theories of multiple stars origin and evolution.

4. Conclusion

We obtained the first diffraction-limited images of the nearby spectroscopic binaries Gl 150.2 and 41 Dra. For 41 Dra, speckle observations were made both at visible wavelengths and in the K-band. This pair with K2V and M0V components shows orbital motion with a period of about 10 years. Because of a significant magnitude difference between the two stars of Gl 150.2, it can be observed only as SB1. For this system, precise parallaxes and new speckle measurements at different wavelengths can improve our knowledge about the physical characteristics of the components.

The pair 41 Dra is a rare case of a relatively short-period SB2 with an eccentricity close to 1, and it is at the same time a member of a quadruple system. The preliminary combined spectroscopic-interferometric orbit is derived for 41 Dra, yielding the masses $1.22\mathcal{M}_\odot$ and $1.18\mathcal{M}_\odot$ for its F7V and F9V component. The dynamic parallax of the system is $\pi_{dyn} = 21$ mas.

All the astrometric and photometric measurements for the two stars were made with the speckle-masking method. The use of Digital Signal Processors for bispectrum computations allows diffraction-limited image reconstruction in real time. For binary star application, the speckle-masking method has significant advantages. It provides diffraction-limited image with high photometric and astrometric accuracy from 400 nm to the infrared.

References

Allen, C.W. Astrophysical Quantities. Univ. of London. Atlone Press, 1973
Andersen, J. (1991) *Astron. Astropys. Rev.* **3**, 91
Balega, I.I. et al. (1994) *Astron. Astrophys. Suppl.Ser.* **105**, 503
Baier, G. and Weigelt, G. (1983) *Astron. Astrophys.* **121**, 137
Duquennoy A. and Mayor M. (1991) *Astron. Astrophys.* **248**, 485
Hofmann, K.-H. and Weigelt, G. (1986) *Astron. Astrophys.* **167**, L15
Lohmann, A.W. et al. (1983) *Appl. Optics* **22**, 4028
Monet, D.G. (1979) *Astrophys. J.* **234**, 275
Tokovinin, A.A. (1988) *Astrophysics* **28**, 173
Tokovinin, A.A. (1995) *Astronomy Lett.* **21**, 286
Turon, C. et al. (1992) The HIPPARCOS Input Catalogue, ESA SP-1136, **4**
Weigelt, G. (1977) *Opt. Commun.* **21**, 55

5. Discussion

H.A.McAlister: Have you compared your magnitude differences with lunar occultation observations? What is the accuracy of $\triangle m$ measurements using the speckle-masking method?

Y.Balega: No, we do not have lunar occultation binaries in our program list. The mean error of $\triangle m$ measurement is 0.05–0.1 magnitude. The high quality of speckle-masking reconstructions was confirmed by HST observations of star clusters and other objects, for example, η Carinae, R136, NGC 3603 whose images were published years before the launch of the HST.

H.Zinnecker: (The question of Zinnecker about the comparison of speckle interferometry and adaptive optics was answered during the Workshop – see special forms).