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The orbit of the visual binary ADS 8630 (γ Vir)

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We present a new orbit for the visual binary ADS 8630 = γ Vir. Although it is one of the first visual double stars discovered, its orbital elements were still poorly known. Indeed the very high eccentricity of the orbit and the difficulty of observing the pair at periastron passage in 1836 has meant that it is only now that sufficient measures of the recent close approach in 2005 have allowed an orbital analysis which predicts the angular motion to an acceptable degree of accuracy.
We present a series of 35 speckle measurements of ADS 8630 obtained with PISCO in Merate between 2004 and 2006. Those measures have been crucial for determining the new orbital elements since they cover an arc of 130 degrees in the apparent orbit and include the periastron passage of 2005. The masses of the individual F0V components of the binary are found to be 1.40 $M_\odot$ with an accuracy of about 3%.
We also investigate in detail the possibility of the presence of a third body in the system, that was proposed by other authors. The high-angular resolution infra-red image of γ Vir that we obtained in June 2006 with the LuckyCam instrument on the ESO NTT shows the absence of any companion as faint as a M0V star at a distance larger than $0.''4$. Combined with the analysis of the residuals of our orbit, the values found for the masses of the individual components and the radial velocity measurements, this observation rules out the presence in the system of a third companion with a mass larger than 0.3 $M_\odot$.

1 Introduction

Gamma Virginis (Σ 1670 = ADS 8630 = WDS 12417-0127 = HD 110379/110380) is one of the first binary stars discovered in history and it is still closely followed by the observers nowadays. Despite all those efforts, the position angle ephemerides computed with the latest orbits failed to represent the observed position angles in 2005. In this paper we present a new orbit that is significantly better than all previous orbits since it takes advantage of the many observations that we made during the last periastron passage of 2005.

The first measurement of the relative positions of the components of γ Vir were made in 1718 March by Bradley and Pound in Wanstead, London (see Rigaud 1832). In his entry for Σ 1670 Lewis (1906) says that Father Richaud first noted the duplicity of γ Vir at Pondicherry in 1689 but later argues that it would have been unlikely and in fact in his introduction to the same volume, he gives the discoverer as Bradley. It seems likely that Lewis has mistaken γ Vir for α Centauri in this instance.

Accurate measurements started with F.G.W. Struve in 1820 and have continued ever since. The WDS observations catalogue (Mason et al. 2006) contained 1515 mean measures of position angle and separation in his version of February 2006. However the first observed periastron passage in 1836 was poorly followed due mainly to the lack of adequate telescopic power. That fact and the large eccentricity ($e > 0.88$) have meant that the period of revolution was still not adequately known until the second observed periastron passage occurred in mid-2005. Even so, Lewis (1906) lists 22 orbits up to 1903. All agree closely on the value of the eccentricity but estimates of the period varied mostly between 130 and 200 years. This uncertainty has remained to some extent until now: although using Hipparcos observations and the results of speckle interferometry, the last orbit of Söderhjelm (1999) gives angular residuals of almost 20° for mid-2005, with the companion trailing the ephemeris.

To solve this problem, we have regularly observed γ Vir with PISCO in Merate between 2004 and 2006. Those observations appeared as crucial for determining an orbit of good quality.

In Sect. 2, we describe the observations that we made for this work: speckle measurements and high resolution imaging in the infra-red. We present the new orbit that we derived in Sect.3, and in Sect. 4 we investigate in detail the possibility of the presence of a third body in the system, that was proposed by other authors.

In this paper, following the Fourth Interferometric Catalogue (Hartkopf et al. 2006), component A will be HD 110379 ($m_V = 3.56$) also known as γ Vir N (although between 1997 and 2005 it was the southernmost component), whilst component B will be HD 110380 ($m_V = 3.65$) and also γ Vir S. Note that there is a confusion between those two components in the SIMBAD astronomical data base (http://simbad.u_strasbg.fr), with a wrong assignment of the photometry.

2 The observations

We observed γ Vir intensively in 2004–2006 with PISCO (Fig. 1a) on the 102-cm Zeiss telescope at the I.N.A.F. – Osservatorio Astronomico di Brera in Merate (Italy). PISCO is a multi-purpose speckle camera fitted with a Philips intensified CCD detector (Prieur et al. 1998). Built in the early 1990's by the Observatoire Midi-Pyrénées for the 2-meter telescope at Pic du Midi (France), PISCO was used there for short missions between 1993 and 1998. Since 2004 it has been mounted on the Zeiss telescope in Merate and operated on a regular basis. All the observations of γ Vir were made with the 10-mm eyepiece, yielding an image scale of $0\farcs03202 \pm 0\farcs00012$ per pixel. Particular care was taken with the calibration of scale in the plane of the detector with a specially designed objective grating (Scardia et al. 2006b). Details of the observations made in 2004 and 2005 can be found in Scardia et al. (2005, 2006a, 2006b). Those of 2006 will be reported in a forthcoming paper.

Complementary observations of γ Vir were made on June 5th 2006 using the LuckyCam Lucky Imaging system (Law et al. 2006) on the 3.6m ESO New Technology Telescope (NTT) at La Silla Observatory, Chile (Fig. 1b). The LuckyCam is fitted with a high speed L3CCD detector and performs a selection of short-exposure images up to a rate of 100 frames/s. The L3CCD consists of a CCD chip equipped with an extended output register, clocked with a higher voltage than conventional CCD's, which thus performs a much higher amplification of the detected photoelectrons up to the photon-counting mode (Mackay et al. 2002). By selecting the good-quality short-exposure images among all those randomly perturbed by the atmospheric turbulence, the LuckyCam system provides a substantial gain in angular resolution. Although the FWHM seeing was $1''.1$ on June 5th 2006, we will see in Sect. 4.5 that the two components of γ Vir separated by only $0.''5$ appear well detached on the image obtained with LuckyCam.

3 The new orbit

We then used our series of 35 speckle measurements to compute a new orbit for γ Vir, in combination with the data available in the USNO observations catalogue (Mason et al. 2006), as of February 2006, four micrometric measurements of 2005 from Alzner (2006) and two others made by R. W. Argyle. A total of 1553 measurements were used for the first iteration.

Each observation was corrected for precession, proper motion and radial velocity according to the relation outlined by Fletcher (1931). Although these corrections are small, they are necessary for the derivation of a definitive orbit. The orbital elements were then computed with an iterative least-squares method. For the PISCO observations we assigned a weight of 4.0, which corresponded to about 1.4 times the average weight.

For the last differential correction to the orbit, we rejected the observations with the largest residuals, i.e., position angle residuals greater than 4.2° (i.e., $3\,\sigma$) or separation residuals greater than $0\farcs2$ (i.e., $1.7\,\sigma$). It should be noted that the first criterion lead to the rejection of 39 measurements only. The scatter in position angle of the measurements is thus surprisingly small, considering the range of epoch over which the observations were made (1718 to 2006) and the large number of observers using every type of telescope, the apertures of which range from 10 cm to 400 cm. Those arguments well account for the scatter obtained in separation, which is larger. The application of the second criterion led to the rejection of 343 measurements, i.e. 22% of the total number, which is quite common when computing orbits with old measurements. Note also that γ Vir is not an easy target for the observers of the Northern hemisphere (since $\delta_{2000} = -1^\circ\ 27'$) and that the rather large brightness of the two stars hinder accurate separation measurements with the micrometer.

The final selected set containing 1514 measurements of the position angle and 1210 measurements of the separation led to the orbital elements printed in Table 1. In Cols. 1 and 2, Ω and ω are the position angle of the ascending node and the longitude of the periastron, respectively. The former is measured in the plane of the sky from north through east; the latter in the plane of the true orbit, from the ascending node to the periastron, in the direction of motion of the companion, i is the inclination of the orbit relative to the plane of the sky, e the eccentricity, T the epoch of periastron passage, P the period, n the mean angular motion, and a is the semi-major axis. The four parameters A, B, F, and G are the Thiele-Innes constants (useful for an easier computation of the ephemerides).

The apparent orbit is shown in Fig 2a, with an expanded view in Fig 2b. This figure shows the importance of the 2004–2006 PISCO observations for determining the orbital elements: they cover an arc of 130° around the periastron.

Residuals from this orbit are given in Table 2 for the observations made since the beginning of 2000. For each observation, the date in Besselian years is given in Col. 1, the observed angular separation $\rho(O)$ in Col. 2, and the residuals $O - C$ (observed minus computed) for the separation ρ and position angle θ in Cols. 3 and 4, respectively.

The ephemeris from these orbital elements for the years 2006–2015 is given in Table 3, with the date in Besselian years in Col. 1, the computed angular separation $\rho(C)$ and the position angle $\theta(C)$ in Cols. 2 and 3, respectively.

Using the Hipparcos parallax of $0\farcs08453 \pm 0\farcs00118$ (ESA 1997), the systemic mass is $M_A + M_B = 2.8$ M$_\odot$ with an error of 4.2%, i.e. 0.1 M$_\odot$. The semi-major axis is 43.0 AU. The dynamical parallax as derived from the Baize-Romani relationship (Baize & Romani 1945) is $0\farcs0824$ with an estimated error of 4%. It is difficult to evaluate an error for this quantity as it includes spectral type in a tabulated form. The trigonometrical and dynamical parallaxes agree to within their respective errors, and the correspond-

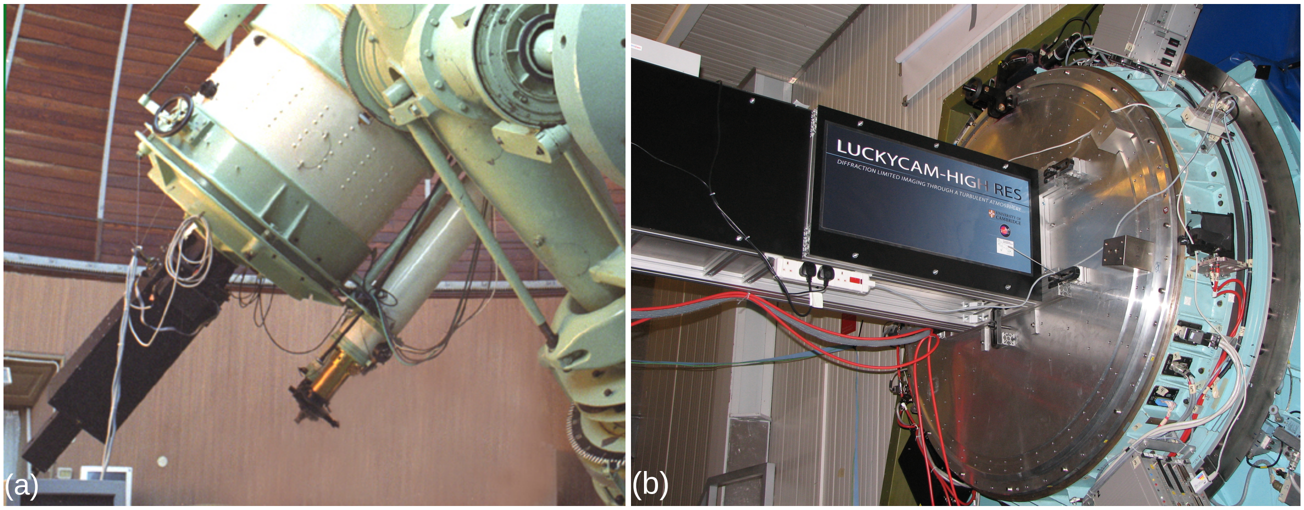

Fig. 1 PISCO on the Zeiss telescope in Merate (a) and LuckyCam at the Nasmyth focus of the ESO NTT (b).

ing Baize-Romani mass sum is $3.0{\pm}0.1$ $M_\odot$, which is in agreement by about 10% with that calculated using the Hipparcos parallax.

4 The third-body hypothesis

The idea that there might be a third body in the system originated with John Herschel although this may have been due to the difficulty he had had in trying to compute an orbit. He says (Herschel 1847) "The apparently systematic alternation of positive and negative errors, each prevailing over considerable arcs of the orbit, might indeed be regarded, in a more advanced state of the subject, as indicative of some disturbing cause of a periodical character, but at present such a conclusion would be premature". We will only consider bodies of stellar mass in the following discussion. There are three possible combinations : either the primary or secondary is accompanied by a lower mass companion C, orbiting close in, or C orbits at a distance from AB. This latter possibility is dismissed because C would have to revolve at a great distance to remain unperturbed by the motions of AB in their very eccentric orbits, and the period would be extremely long, not compatible with the periodical errors noticed by Herschel.

There are several ways in which the existence of a third star may be inferred and below we discuss each in turn.

4.1 Residuals from the visual orbit

We examined the observations which were deemed to be most accurate: the photographic measures taken mainly at the USNO for the period 1950–1975 and speckle measurements from 1980 onwards. Fig 3 shows the residuals from the orbit for these observations. The photographic results, at least, show no features with amplitude greater than about $0.''02$.

From 1994 to 2005 however, the USNO speckle results do seem to show a systematic residual. Over this period the separation of the pair reduced from over $2''$ to less than $0.''4$. Fig 4a shows the residuals for the USNO speckle results only. There is clearly a small systematic offset in separation from the predicted orbital position. This agrees with the conclusions drawn by Germain et al. (1999) who note that "...pairs observed with the 10-power microscope objective show a 20 mas proximity effect for separations less than $1.''5$". In other words, the observed separation is measured to be smaller than it really is. In the USNO speckle program, the background of the average auto-correlation function is estimated by applying an unsharp masking with a boxcar filter. Germain & Douglass (2001) have shown that this technique could sometimes induce a "proximity effect" for close binaries, due to an incomplete removal of non-uniform background arising from seeing and from additive noise.

Alternatively, Brian Mason (private communication) suggested that the systematic effects in Fig. 4a would disappear if a slightly smaller major axis was used. We have tested this hypothesis (and also attributed larger weights to USNO speckle observations), but this resulted in the USNO photographic data not fitting the calculated orbit quite as well. So we decided to keep the initial orbital elements unchanged.

Let us now examine the influence of a possible third companion on the residuals of the two-body visual orbit. If star B, for instance, were to be accompanied by a red dwarf of mass 0.5 $M_\odot$ what effect would this have on the relative astrometry of AB? From a sample of F and G triple systems within 50 parsecs of the Sun, Tokovinin (2004) estimates that the relationship between the periods of the outer and inner binaries in a system depends on the eccentricity of the outer orbit. Specifically, for γ Vir his relation gives a period ratio P_{out}/P_{in} of at least 165 implying that the period of the inner orbit is likely to be of order 1 year. If we further assume that this inner orbit is circular and coplanar with the visual orbit, the corresponding semi-major axis would be $0.''11$ and the relative movement of star A with respect to B at periastron (where the minimum distance AB is

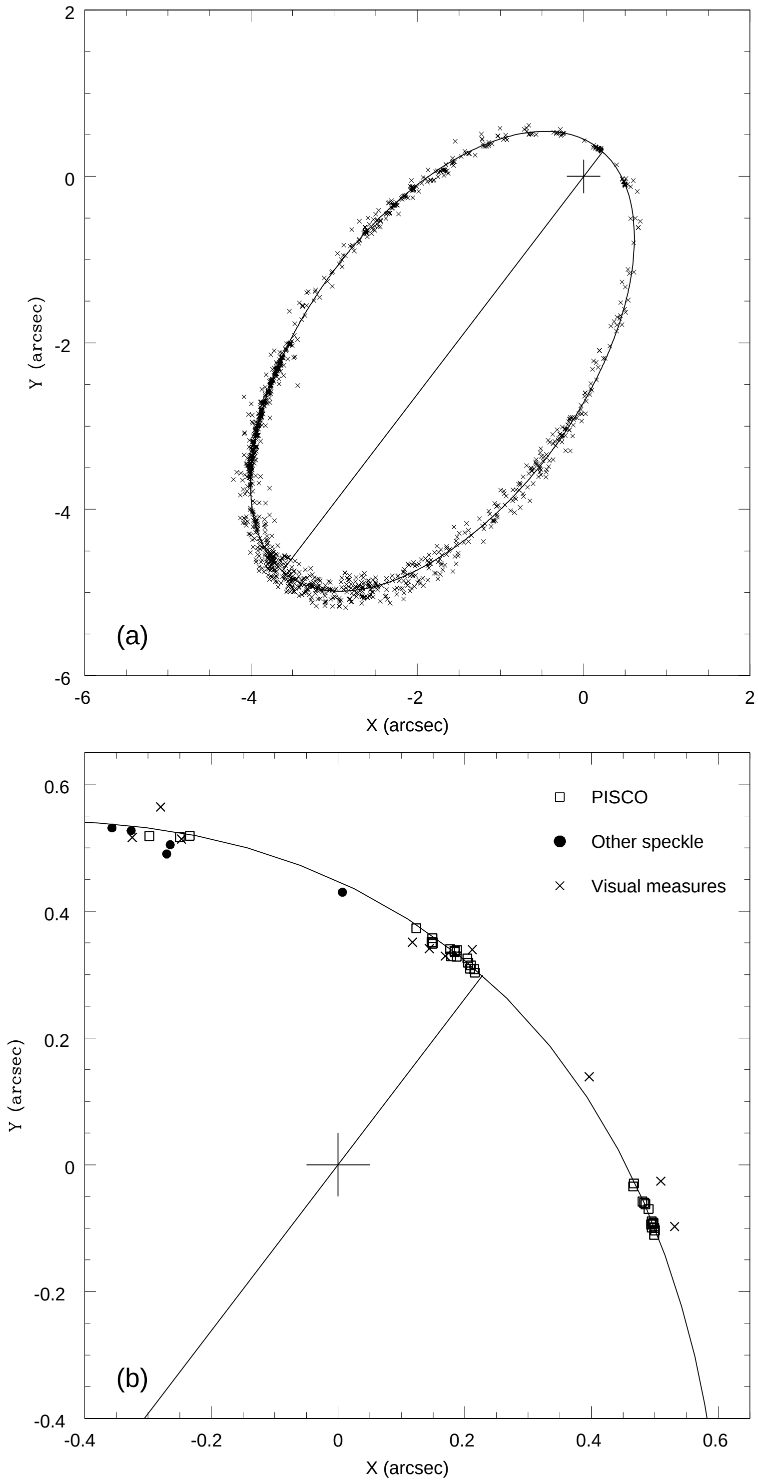

Fig. 2 The apparent orbit of γ Vir (a) and enlarged view around periastron (b) (North to the bottom, East to the right).

Table 1 New orbital elements for γ Vir

Ω (2000) (°)	ω (°)	i (°)	e	T (yr)	P (yr)	n (°/yr)	a ($''$)	A ($''$)	B ($''$)	F ($''$)	G ($''$)
35.34	255.02	149.46	0.8815	2005.511	169.104	2.12886	3.639	−2.51886	1.92543	2.39886	2.69458
±0.42	±0.37	±0.16	±0.00018	±0.0019	±0.011	±0.00014	±0.008				

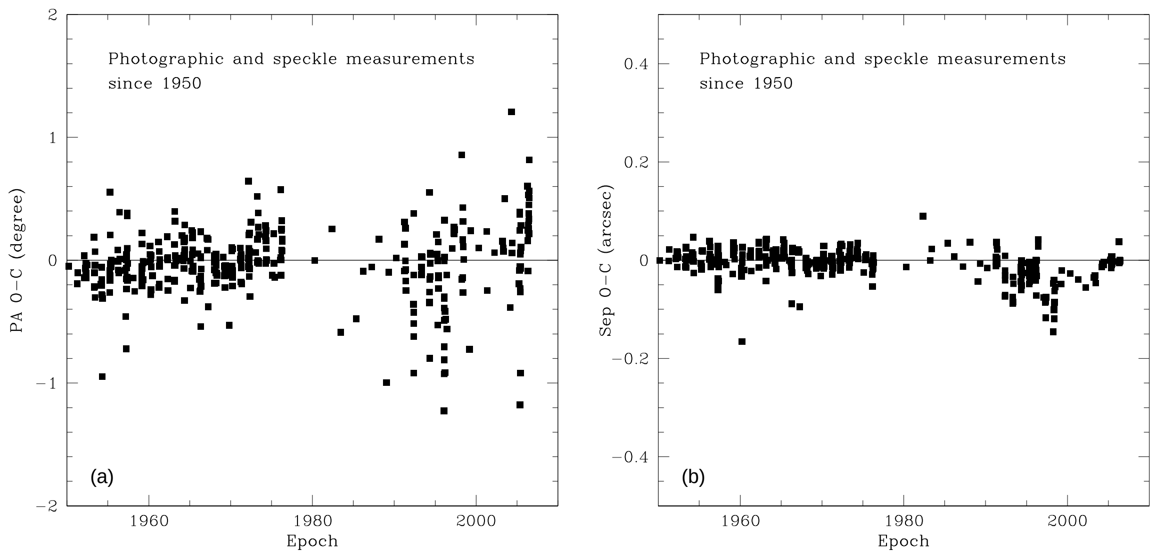

Fig. 3 Orbital residuals in position angle (a) and in separation (b) for the period 1950–2006.

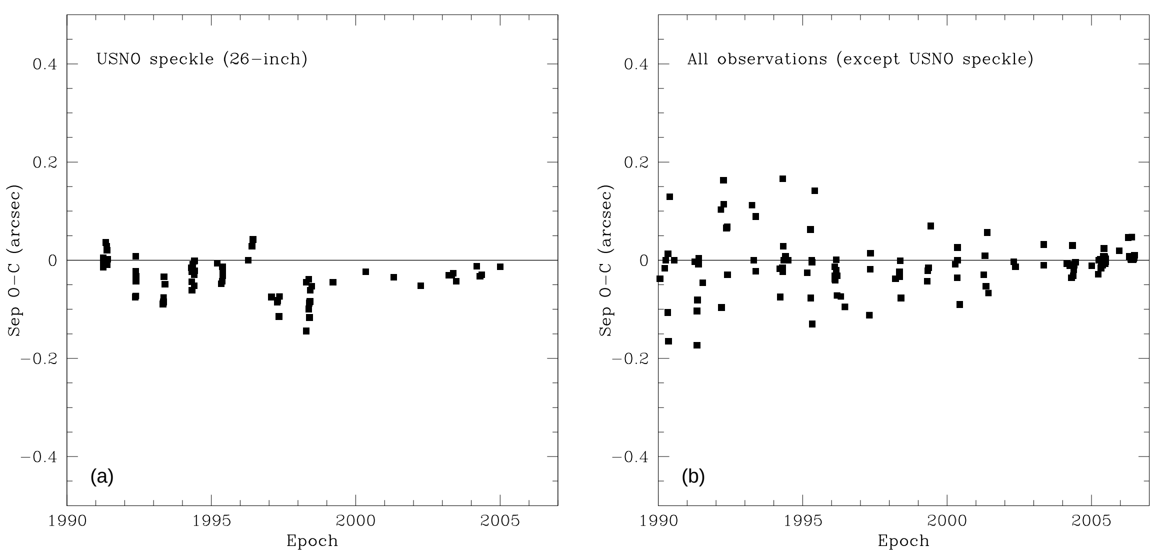

Fig. 4 Orbital residuals in separation for the period 1990–2006: USNO speckle measurements only (a) and other measurements (b).

0.″37) would be ±0.″04. This would translate the relative position angle between A and B by an amplitude of about ±5°. No perturbations of this magnitude appear in the residuals from the two-body Keplerian orbit around the last periastron passage. The scatter in the angular residuals is about 0.7° r.m.s. which is more than five times less than expected with a 0.5 $M_\odot$ companion. Hence in this scenario, the observations show that the mass of the hypothetical third component is smaller than 0.1 $M_\odot$.

4.2 Radial velocities

We have examined the 41 published measurements of radial velocities of the two components (23 of star A and 18 of star B) which come with an associated epoch. Fig 5 shows this data with the radial velocities predicted by the orbit in Table 1 shown as solid lines. The error bars plotted in this figure correspond to the internal errors which are smaller than the true errors. Due to calibration problems, those measurements have a typical error of $\sigma_V \approx 2$ km.s^{-1} and present a scatter of this order of magnitude. They do not show any reliable variation at more than the two-sigma level around the systemic velocity $V_0 \approx -20$ km.s^{-1}. The predicted radial velocity curves only exceed $V_0 \pm 2\sigma_V$ during the period close to the periastron of 2005. Only two velocities were found in the literature from that period and agree with the predicted values to about 1 σ.

More measurements are clearly needed, but are difficult to obtain because of the large equatorial rotational velocity of each component (about 25 km.s^{-1} in each case). The consequent broadening of the lines precludes the use of CORAVEL-like instruments (R.F. Griffin, private communication).

Table 2 Orbital residuals of measurements in 2000–2006 (begin). The PISCO observations are flagged with ^{P} in Col. 2.

Epoch	$\rho(O)$ ($''$)	$\Delta\rho(O-C)$ ($''$)	$\Delta\theta(O-C)$ ($^\circ$)
2000.280	1.440	−0.00	−0.1
2000.340	1.410	−0.02	+0.1
2000.345	1.400	−0.03	−0.1
2000.350	1.650	+0.22	−0.5
2000.360	1.460	+0.03	−0.5
2000.438	1.330	−0.09	+0.9
2001.260	1.240	−0.03	+0.3
2001.310	1.270	+0.01	−0.2
2001.320	1.220	−0.04	+0.2
2001.350	1.200	−0.05	−0.2
2001.397	1.300	+0.06	−1.9
2001.433	1.170	−0.06	−1.2
2002.252	1.020	−0.05	+0.1
2002.314	1.060	+0.00	−1.8
2002.360	1.040	−0.01	+0.3
2003.229	0.830	−0.03	+0.2
2003.320	0.810	−0.03	+0.1
2003.340	0.830	−0.01	+1.4
2003.349	0.870	+0.04	+1.0
2003.379	0.800	−0.03	+0.1
2003.485	0.760	−0.04	+0.5
2004.147	0.640	−0.01	+0.3
2004.196	0.620	−0.01	−0.4
2004.250	0.610	−0.01	+1.6
2004.306	0.598^P	−0.01	+1.2
2004.309	0.570	−0.04	−1.1
2004.333	0.630	+0.03	−1.6
2004.365	0.560	−0.03	+1.9
2004.380	0.570	−0.02	−0.8
2004.397	0.572^P	−0.01	+0.1
2004.443	0.567^P	−0.01	+0.1
2004.998	0.430	−0.01	−0.0
2005.228	0.370	−0.03	−2.8
2005.259	0.392^P	−0.01	−0.2
2005.319	0.386^P	−0.01	−0.1
2005.326	0.370	−0.02	−0.0
2005.328	0.380^P	−0.01	+0.4
2005.330	0.380^P	−0.01	+0.2
2005.333	0.378^P	−0.01	+0.4
2005.382	0.373^P	−0.01	−1.2
2005.385	0.382^P	−0.00	+0.1
2005.390	0.370	−0.01	+0.6
2005.396	0.383^P	+0.00	−0.2
2005.398	0.382^P	−0.00	−0.2
2005.404	0.386^P	+0.00	+0.0
2005.409	0.377^P	−0.01	−0.3
2005.427	0.400	+0.02	−1.3
2005.440	0.378^P	−0.00	−0.9
2005.442	0.383^P	+0.00	−0.1
2005.464	0.377^P	−0.00	+0.1
2005.470	0.372^P	−0.01	+0.3
2005.478	0.375^P	−0.00	−0.1
2005.486	0.371^P	−0.01	+0.1
2005.964	0.420	+0.02	+2.3
2006.304	0.510	+0.05	−0.7
2006.308	0.466^P	−0.01	+0.6
2006.311	0.465^P	−0.01	+0.2
2006.360	0.482^P	−0.00	−0.1

Table 2 Orbital residuals of measurements in 2000–2006 (end). The PISCO observations are flagged with ^{P} in Col. 2.

Epoch	$\rho(O)$ ($''$)	$\Delta\rho(O-C)$ ($''$)	$\Delta\theta(O-C)$ ($^\circ$)
2006.371	0.485^P	−0.00	+0.2
2006.376	0.487^P	−0.00	+0.3
2006.396	0.540	+0.05	−2.1
2006.398	0.493^P	−0.00	+0.5
2006.439	0.501^P	−0.00	+0.3
2006.442	0.504^P	−0.00	+0.3
2006.447	0.504^P	−0.00	+0.4
2006.450	0.501^P	−0.01	+0.2
2006.453	0.505^P	−0.00	+0.5
2006.464	0.503^P	−0.01	+0.3
2006.475	0.508^P	−0.01	+0.8
2006.477	0.509^P	−0.01	+0.5
2006.497	0.509^P	−0.01	+0.6

Table 3 New ephemeris of γ Vir

Epoch	$\rho(C)$ ($''$)	$\theta(C)$ ($^\circ$)
2006.0	0.409	104.5
2007.0	0.655	60.1
2008.0	0.924	41.3
2009.0	1.168	30.7
2010.0	1.389	23.7
2011.0	1.591	18.5
2012.0	1.777	14.5
2013.0	1.951	11.2
2014.0	2.114	8.4
2015.0	2.268	6.0

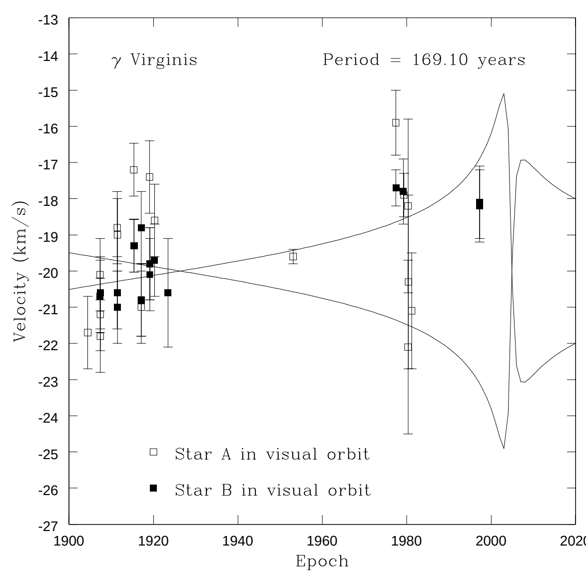

Fig. 5 Observed individual radial velocities and predicted velocity curves.

4.3 Mass of the third companion

We will investigate now whether the sum of masses found in Sect. 3 allow the inclusion of a third body.

As the two components have the same spectral type, F0V, and are approximately equally bright, they must have similar masses. The value found in Sect. 3 implies therefore that the individual masses of the A and B components are both equal to 1.4 $M_\odot$ with an error of about 3%. In fact, the two stars have not exactly the same brightness. In the Hipparcos catalog (ESA 1997), we find: $m_{Hp,\,A} = 3.550 \pm 0.08$ and $m_{Hp,\,B} = 3.601 \pm 0.09$, for the A and B components, respectively. If we assume in this region of the HR diagram, as proposed by Svechnikov & Taidakova (1984), that the luminosity is proportional to the fourth power of the mass, $\Delta\, m_V = 0.05$ then corresponds to a mass ratio of 1.01, which is smaller than the errors.

This estimation for the mass of the components of γ Vir has a more general interest because mass-spectrum relationships in the literature suggest that the range of F0V masses is fairly large, and because the only other visual binary with equally bright F0V stars and a reliable orbit is FIN 350 (Hartkopf et al. 1996), for which the masses were found to be 1.25 $M_\odot$ but with an uncertainty of 28%.

For Allen (1973), F0V stars have a mass of 1.3 $M_\odot$, whilst Svechnikov & Taidakova (1984) give 1.46 $M_\odot$, Trimble (1974) gives 1.55 $M_\odot$, and Lang (1992) quotes Schmidt-Kaler giving 1.6 $M_\odot$. Harmanec (1988), using an updated analysis of the data given by Popper (1980) found that for F0 main-sequence stars the range of mass is between 1.08 and 1.55 $M_\odot$ with an average of 1.33 $\pm$0.10 $M_\odot$.

Hence the individual masses that we find, i.e. 1.40 ± 0.05 $M_\odot$, come close to both the average of the values from the work by Allen through to Schmidt-Kaler and also that of Harmanec. Whilst this inspires some confidence in the accuracy of the current orbital analysis, it also suggests that the intrinsic uncertainty in the mass of an F0V star is 10%–15%. Considering the combined mass, a proposed third component of about 0.3 $M_\odot$ could therefore be entertained from this perspective.

4.4 Photometric variability

There are historical reports of the variations in magnitude in one or other of the two components of the visual binary. Based on the evidence of Otto Struve (1878, 1893) — visual estimates covering a period of almost 50 years between 1840 and 1889 — star A, on occasion, was thought to be brighter than B by as much as 0.5 magnitude. Krisciunas & Handler (1995) used these observations to nominate star A as a candidate γ Doradûs star. This was also proposed very recently by de Cat et al. (2006),

Nevertheless it seems that precise work has shown that there are no significant photometric variations. Abt & Golson (1962) found a scatter of 0.015 magnitude in V from eight observations for the system as a whole. Smith (1990) investigated the possibilities of oscillations and found no effects at the levels of 50 and 65 ms^{-1} in stars A and B respectively. Adelman (2001) used Hipparcos observations to limit the range of the combined light to no more than $\pm$ 0.0005 magnitude in H_p over 93 Hipparcos transits covering 1166 days.

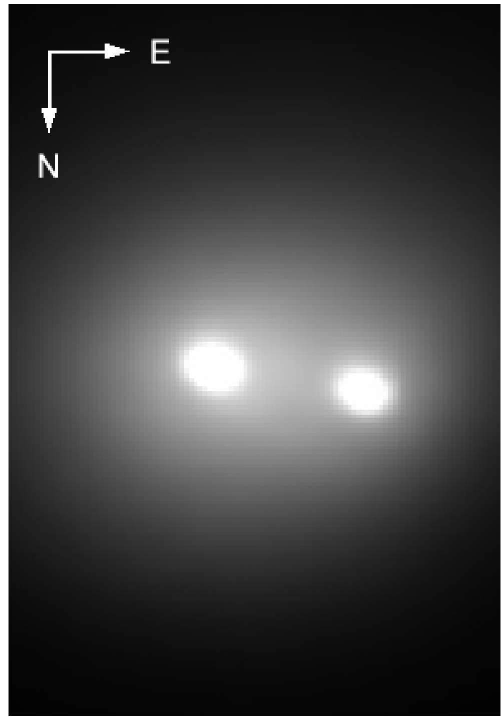

Fig. 6 Unsharp masked SDSS i'-band image of γ Vir A and B obtained with LuckyCam on the 3.6m ESO NTT on June 5th 2006, when the angular separation was $0''.5$.

Finally, it is unlikely that eclipses by a third star C orbiting either A or B would occur as the orbit of C would then probably be co-planar with that of the main binary.

4.5 High resolution imaging

Another approach to detect a third companion is direct detection using high angular resolution imaging in the near-infrared. An M0V star whose V absolute magnitude is 8.8 would have a V apparent magnitude of 9.2 at the distance of γ Vir, almost 6 magnitudes fainter than the A and B components. In the I band however, the same star would appear at $m_I = 7.0$ whilst the primary stars are both at about $m_I = 4.0$ (Bessell 1990).

High angular resolution observations of γ Vir were made on June 5th 2006 (see Sect. 2). The image presented in Fig 6 is a Lucky Imaging composite constructed using the best 20% of 10,000 short-exposured images at a rate of 50 frames/s, and thus has an effective exposure time of ∼40 seconds. Unsharp masking has been applied to facilitate the detection of faint companions. Those observations did not detect a third star in the field of view of $14''.6\times$ $5''.7$, and a lower limit for the magnitude of this companion in the

SDSS i' band (used for the Sloan Digital Sky Survey, close to the I band) is estimated to be $m_{i'} \sim 7$ at $0''.4$ from the primary.

This image does not rule out the presence of an M0V star which may well be tightly bound to A or B and therefore too close to be resolved. But in this case, such a tightly bound companion would induce strong perturbations on the orbit of the AB components with significant short-period variations on the residuals, that have not been found (see Sect. 3), and also on the radial velocity curves that would have been detected in Fig 5 (see Sect. 4.2).

Finally it should be noted that a third star of M0V type, with $m_V = 9.2$, at a distance larger than one arcsecond would have not been missed by the numerous visual observers.

5 Conclusion

Our numerous observations with PISCO in 2004–2006 in Merate of γ Vir cover an arc of 130° in the apparent orbit and include the periastron passage of 2005. They have allowed us to obtain a new orbit with a good quality for this object and derive the mass of the individual F0V components with an accuracy of about 3%.

We have made a complementary study in order to test the hypothesis of the existence of a third stellar companion and found the following results:

(i) The two-body orbit presented here gives small residuals for the critical part of the orbit through periastron. The level of those residuals suggests that the mass of a hypothetical third body must be very small, less than 0.1 $M_{\odot}$.
(ii) We find no evidence of a significant extra mass in the γ Vir system with an upper limit of about 0.3 $M_{\odot}$.
(iii) The radial velocity measurements do not show any significant perturbation from a tightly bound third stellar component.
(iv) High resolution imaging obtained with LuckyCam in the infra-red failed in detecting any stellar companion as faint as a M0V star at a distance larger than $0.''4$.

Hence all those results converge and rule out the presence in the γ Vir system of a stellar companion with a mass larger than 0.3 $M_{\odot}$.

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