A&A 441, 695–699 (2005)
DOI: 10.1051/0004-6361:20053400

Astronomy & Astrophysics

Research Note

An old nearby quadruple system Gliese 225.2[⋆]

A. Tokovinin[1], O. Kiyaeva[2], M. Sterzik[3], V. Orlov[4], A. Rubinov[4], and R. Zhuchkov[5]

[1] Cerro Tololo Inter-American Observatory, Casilla 603, La Serena, Chile
e-mail: `atokovinin@ctio.noao.edu`
[2] Central Astronomical Observatory at Pulkovo, Pulkovskoe sh. 65/1, St. Petersburg 196140, Russia
e-mail: `kiyaeva@gao.spb.ru`
[3] European Southern Observatory, Casilla 19001, Santiago 19, Chile
e-mail: `msterzik@eso.org`
[4] Sobolev Astronomical Institute, St. Petersburg State University, Universitetskij pr. 28, Staryj Peterhof, St. Petersburg 198504, Russia
e-mail: `[vor;rav]@astro.spbu.ru`
[5] Chair of Astronomy, Kazan State University, Kremlevskaya ul. 18, Kazan 420008, Russia
e-mail: `gilgalen@yandex.ru`

Received 11 May 2005 / Accepted 27 July 2005

Abstract. We discovered a new component E in the nearby multiple system Gliese 225.2, making it quadruple. We derive a preliminary 24-yr astrometric orbit of this new sub-system C,E and a slightly improved orbit of the 68-yr pair A,B. The orientations of the A,B and C,E orbits indicate that they may be close to coplanarity. The orbit of AB,CE is rather wide and does not allow to determine its curvature reliably. Thus, the 390 yr orbit computed by Baize (1980, Inf. Circ. IAU Comm., 26(80)) was premature. The infrared colors and magnitudes of components A, B, and C match standard values for dwarfs of spectral types K5V, M0V, and K4V, respectively. The new component E, 3 magnitudes below the Main Sequence, has an anomalously blue color index. We estimate its mass as roughly 0.2 solar from the astrometric orbit, although there remains some inconsistency in the data hinting on a higher mass or on the existence of additional components in the system. Large space velocities indicate that Gliese 225.2 belongs to the thick Galactic disk and is not young. This quadruple system survived for a long time and should be dynamically stable.

Key words. stars: binaries: visual – stars: individual: HD 40887

1. Introduction

A multiple stellar system HD 40887 = HIP 28442 = Gliese 225.2 has been known since long time. The wide subsystem A,C has been discovered by J. Hershel (1847) and is designated as HJ 3823. The closer pair A,B discovered by Hussey in 1911 is HU 1399. This object, despite its brightness and proximity to the Sun, has received very little attention of observers. The location on the Southern sky (2000: $6^{\rm h}00^{\rm m}18^{\rm s}$ $-31°01'52''$) has certainly contributed to this circumstance.

Our interest in this system comes from the fact that both wide pair AB,C and the inner system A,B have computed visual orbits. The periods of A,B and AB,C (68 and 390 yr, respectively) are such that the system does not satisfy any criteria of dynamical stability. Is it really unstable?

Below we report new observations of this system, reanalysis of all data and physical modeling of the components. To put some order in the confusing world of multiple-star designations, individual components are designated here by capital letters, the systems are designated by pairs of components joined by comma, and the centers-of-mass that act as "super-components" at higher levels of hierarchy are designated by pairs of letters, e.g. AB means the center-of-gravity of the system A,B.

A $12.8^{\rm m}$ visual companion D at $20''$ from AB listed in the WDS catalog under the name B 2595 is optical. The observations from 1927 to 1977 show that the relative position of AD has changed by $30''$. If this displacement is interpreted as due to the proper motion (PM) of this system, we derive a PM of ($-0\farcs451$, $+0\farcs413$) relative to D, close to the Lyuten's (1976) PM measurement ($-0\farcs400$, $+0\farcs392$). Large PM and large radial velocity ($+101.7$ km s^{-1}) indicate that Gl 225.2 belongs to the thick Galactic disk and is not young. Its space velocity

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[⋆] Based on observing run 74.C-0074(A) at the Very Large Telescope of the European Southern Observatory at Paranal in Chile.

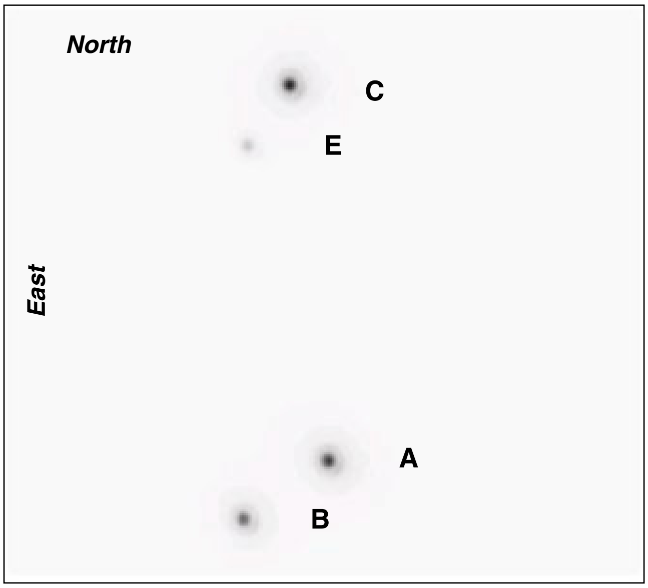

Fig. 1. Narrow-band image of HIP 28442 at 2.12 μm. The components are marked by capital letters.

modulus is about 110 km s^{-1} (Gliese 1969). An absence of detectable X-ray radiation also suggests that these stars have no active chromospheres and are old.

2. Observations

High spatial resolution images of this object have been obtained using the NAOS-Conica adaptive optics system[1] mounted at the VLT on November 9, 2004. The object was observed as a calibrator star for the program 74.C-0074(A) (search of tertiary companions to spectroscopic binaries). To our surprise, in addition to the three known visual components we saw the fourth star, E, close to C (Fig. 1). Images in the narrow band around 2.12 μm and in wide photometric bands J, H, K_s, L' were taken. The new component is clearly seen in all images.

The images were processed in the standard way. The sky background and detector bias were estimated and subtracted by median filtering of series of 5 frames dithered on the sky. The de-biased images were then flat-fielded and recombined. The positions and instrumental magnitudes of the components were determined by the DAOPHOT procedure by fitting the image of the A-component (Point Spread Function) to all sources. Relative coordinates of the components in detector pixels were transformed to the on-sky positions using astrometric calibration of the NAOS-Conica with two known wide binaries, HIP 108797 and HIP 116737. The accuracy of this calibration is entirely determined by the known positions of the "calibrators", because the internal precision of the measurements is about 0.5 mas in both coordinates (except the trend in the AC separation with wavelength, possibly of instrumental origin). We adopted the pixel scale 13.30 ± 0.01 mas/pixel and added the offset of $-0.4° \pm 0.1°$ to the observed angles.

The results are presented in Table 1. The last line gives the rms scatter of individual positions. The formal errors of relative photometry as reported by DAOPHOT do not exceed $0.005^{\rm m}$. We looked carefully at the relative photometry of CE and re-processed this pair by alternative techniques, ensuring that there are no systematic errors above $\pm 0.05^{\rm m}$ (conservative estimate).

3. The orbit of A,B

The orbital elements of the system A,B were computed by Söderhjelm (1999) in an effort to re-reduce the Hipparcos data. The original reduction of HIP 28442 by the Hipparcos consortium did not succeed to model all three components (so-called "X-solution", parallax error 24 mas, wrong PM of $-0''.378$, $+1''.105$).

In order to re-analyze critically the orbits, we asked all archival observations from the WDS database. Those were kindly provided by Gary Wycoff from USNO. Adding the new 2004.86 measurement, we re-computed the orbit by applying differential corrections to the elements using the program ORBIT (Tokovinin 1992). The result is not very different from Söderhjelm's (Table 2).

The systematic character of residuals (Fig. 2) indicates that this orbit is not quite satisfactory. However, upon critical examination of the data and potential alternative solutions we conclude that the orbit of A,B is secure, only minor adjustments of the elements are expected in the future. No strong perturbations of the A,B orbit from the system C,E are detected.

4. The orbit of AB,C

The separations of A,B and A,C are comparable. Thus, before computing the orbit of AB,C we must remove the motion of A in the A,B orbit. The "waves" caused by this motion are apparent in the plots of raw data from WDS. A measurement of AB,C from Hipparcos (1991.25: $x = -0''.487$, $y = 2''.165$, errors 5 mas) has been provided by Söderhjelm (2005), and the deviant points from Prieto (1997) and Tycho were rejected.

The reflex motion of A around the center of gravity AB corresponds to the semi-major axis of A,B $a_{\rm AB} = 0''.912$ reduced by $\alpha = q/(1+q) = 0.44$ times, where $q = 0.8$ is the mass ratio (cf. Sect. 5). We subtracted this correction and analyzed the motion of C around AB. Some observations, though, refer to the unresolved photocenter which is closer to the center-of-mass. For these observations the correction for A,B is proportional to $(\alpha - \beta) a_{\rm AB}$, where $\beta = 1/(1+10^{0.4\Delta m}) = 0.29$. We interpreted as unresolved the observations of those authors who did not measure A,B on the same epoch, but there remains some ambiguity in this interpretation.

The two very first measurements made by J. Hershel in 1835.48 and 1836.86 are very discordant in separation ($3''.3$ and $4''.84$, respectively). Baize (1980) averaged those two critical points and did not subtract the reflex motion of A around AB, the orbit of A,B was not known at the time. Thus, his 390-yr orbit of AB,C is in error and contradicts modern observations (Fig. 3). Use the Baize's orbit led Orlov & Zhuchkov (2005)

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[1] `http://www.eso.org/instruments/naco`

Table 1. Relative positions and magnitudes of the components (2004.861).

Pair	A,B			A,C			C,E		
Wavelength	ρ,″	θ, °	Δm	ρ,″	θ, °	Δm	ρ,″	θ, °	Δm
J 1.2 μm	0.722	124.161	0.536	2.648	5.458	–0.349	0.514	145.119	2.651
H 1.6 μm	0.720	124.165	0.520	2.644	5.467	–0.238	0.514	145.158	2.721
K_s 2.2 μm	0.720	124.152	0.481	2.643	5.466	–0.190	0.514	145.178	2.642
NB 2.12 μm	0.720	124.153	0.477	2.642	5.465	–0.172	0.514	145.147	2.665
L' 3.4 μm	0.718	124.161	0.398	2.637	5.459	–0.123	0.513	145.202	2.394
Average	0.720	124.158	–	2.643	5.463	–	0.514	145.161	–
rms	0.001	0.005	–	0.004	0.004	–	0.001	0.028	–

Table 2. Orbital elements in standard notation.

System	Author	P, yr	T	e	a,″	Ω, °	ω, °	i, °
AB,C	Baize, 1980	390.6	1716	0.27	3.95	142.8	245.3	110.2
A,B	Söderhjelm, 1999	68.0	1998.0	0.45	0.9	125	279	103
A,B	This work	67.70	1996.805	0.513	0.912	127.5	275.7	100.4
C,CE	This work, astrom.	23.7	1980.4	0.17	0.120	132	171	124
		±0.5	±1.1	±0.04	±0.004	±10	±22	±13

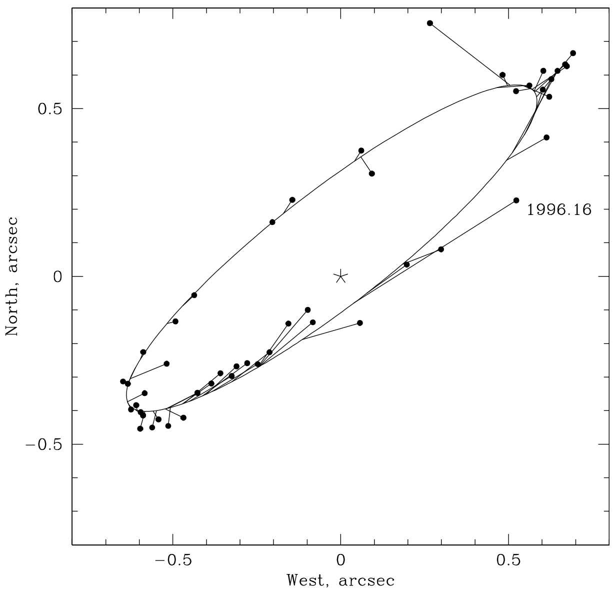

Fig. 2. The visual orbit of the A,B sub-system. The A-component is marked by the star at the coordinate origin, the measured positions of the B-component are joined to ephemeris' locations.

to the conclusion that the triple system AB,C is dynamically unstable.

In an effort to improve the orbit of AB,C we found that the observed motion is nearly rectilinear. Rejecting the first 2 points in the fit, we obtained by least squares the quadratic ephemeris

$$\begin{aligned} x &= -2.370(30) + 0.0181(9)\,\tau + 0.00004(1)\,\tau^2 \\ y &= -1.050(22) + 0.0373(6)\,\tau - 0.00001(1)\,\tau^2, \end{aligned} \qquad (1)$$

where $\tau = t - 1900$ and the formal errors of coefficients are indicated in the brackets. The axis x is directed to the West and y to the North, as in Fig. 3. The curvature is marginally significant. The 0.″1 astrometric motion of C around CE is subtracted in Fig. 3.

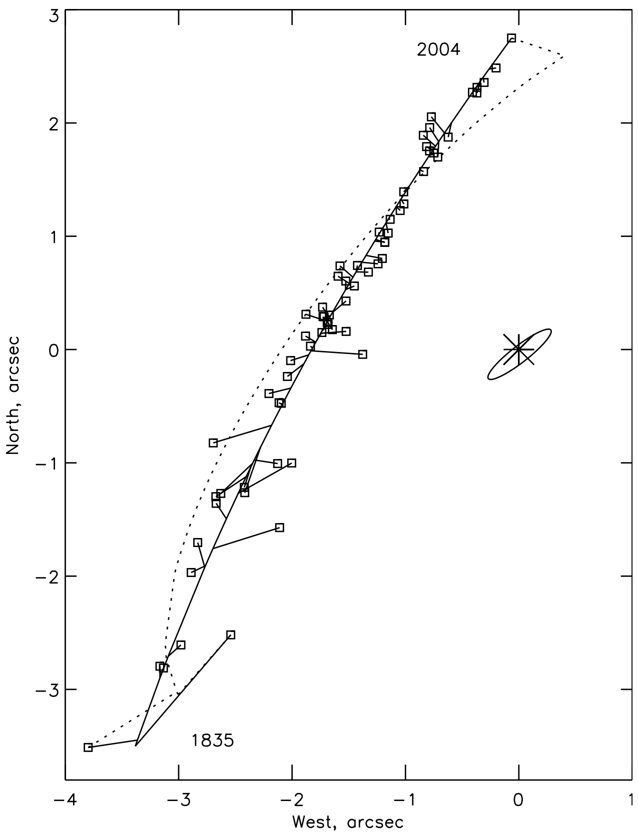

Fig. 3. The apparent motion of AB,CE. The relative positions of the centers-of mass CE are plotted as squares, the center of mass AB is marked by a large star at coordinate origin, the small ellipse shows the motion of A around AB. The dotted line is the orbit of Baize (1980), the full line is the quadraric ephemeris (1).

5. The astrometric orbit of C,E

The deviations of coordinates from the formulae (1) for the period 1930 to 2005 (reasonably good data) are plotted in Fig. 4.

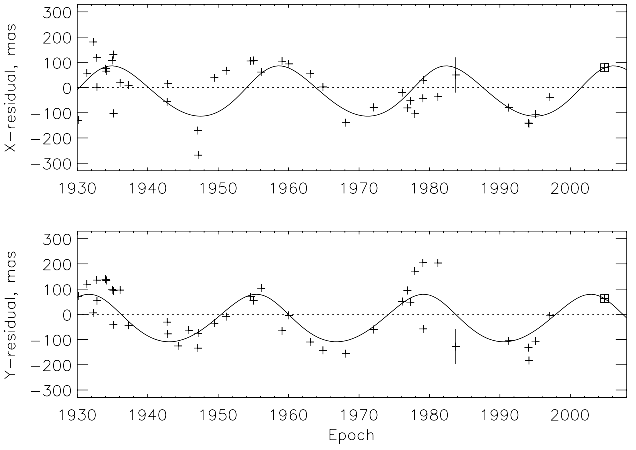

Fig. 4. Deviations of the relative positions of AB,C from the ephemeride (1) in x (*upper*) and y (*lower*). The full line depicts the proposed astrometric orbit, the observations are plotted by pluses, the last observation is marked by a rectangle. A typical error bar of 70 mas is shown.

We fitted a preliminary astrometric orbit, traced by full line. The rms residuals decrease from 105 mas in x and y to 79 and 68 mas when the motion of C around CE is subtracted. The measurements of 1991.25 and 2004.86 were heavily weighted. Adding the pre-1930 data increases the residuals and does not improve the orbit. The orbital elements and their formal errors are listed in Table 2. We also computed 20 orbital solutions with data perturbed by random errors of 70 mas. This method gives larger errors of eccentricity (±0.4) and semi-major axis (±0.″021) and confirms other formal errors. The orbit is stable against interpretation of A,C measurements (resolved A or photocenter) and small variations of the ephemeris (1).

Assuming the mass of 0.25 $\mathcal{M}_\odot$ for E (Sect. 6), the predicted apparent position of C,E in 2004.86 is (ρ, θ = 0.″38, 128°), to be compared to the actual position (0.″514, 146°). We did not use the resolved CE observation in the orbit calculation, hence this agreement is a strong argument in support of the new orbit. In order to match the ratio between predicted and observed separations, the semi-major axis $a_{\rm CE}$ should be around 0.″6. Interestingly, with this $a_{\rm CE}$ the predicted position of C, E in 1996.164, (0.″55, 288°), matches the position of A,B measured by Prieto (1997), (0.″57, 293.4°), marked in Fig. 2. Thus, it is possible that Prieto actually measured C,E in 1996 and attributed this observation to the pair A,B unresolvable at that time (0.″09, 250°).

6. Modeling

The combined *JHK* photometry of this multiple star is given in the 2MASS Point Source Catalog[2] as J = 5.659 ± 0.020, H = 5.070 ± 0.027, K = 4.902 ± 0.018. The wide 2.″6 pair is unresolved in the 2MASS images. We derive magnitudes and colors of individual components by combining 2MASS data with our relative photometry (Table 3). The unpublished photometry in the Hippracos band from Söderhjelm (2005) is also given.

Table 3. Photometry and estimated component parameters.

Comp.	J	H	K_s	Hp	Mass	Sp.
A	6.891	6.250	6.072	9.09	0.65	K5V
B	7.427	6.770	6.553	10.05	0.52	M0V
C	6.542	6.012	5.882	8.79	0.69	K4V
E	9.193	8.733	8.524	–	0.2:	M4V?

The components are plotted on the color-magnitude diagram (CMD) in Fig. 5 using the distance modulus 1.4$^{\rm m}$. The three previously known stars A, B, and C fit the standard Main Sequence (MS). Thus, their spectral types and masses can be found from standard MS relations. These estimated parameters (Table 3) fit the combined spectral type K5V given by Gliese (1969) and match the combined color $B - V$ = 1.15. The combined light is dominated by very similar components A and C.

The masses of A and B together with our orbital elements lead to a dynamical parallax $\pi_{\rm dyn}$ = 52.1 mas. Söderhjelm (1999) found the trigonometric parallax $\pi_{\rm tr}$ = 55.4 ± 1.8 mas and combined it with his orbit to derive the mass sum of 0.91 $\mathcal{M}_\odot$ (1.17 in our model). In any case the distance to the system is established as 19 pc to within few percent, and the distance modulus 1.4$^{\rm m}$ matches the photometry (Fig. 5).

The new component E is below the MS by almost 3$^{\rm m}$. Its effective temperature is close to that of C, because the magnitude difference between C and E in all bands from J to L is very similar (Table 1). Can it be optical, i.e. a chance projection? According to the 2MASS catalog, there are only 92 stars brighter than J = 17 within 5′ radius from the object. A probability to find one of those stars within 0.″5 from C is 2.5×10^{-4}. But even the brightest of these field stars has J = 11.3, or 2.15$^{\rm m}$ fainter than E. Hence a chance projection is most unlikely. Indeed, if this component were a background star with a small PM, it would be located at a distance of some ~40″ ahead from AB,C in 1927 (the PM of AB,C is 0.″56 per year) and, being brighter than D (V = 11$^{\rm m}$, ..., 12$^{\rm m}$), would have certainly been recorded by the visual observers. Our tentative astrometric orbit also supports the physical relation between C and E.

The star E can not be a white dwarf – in that case it would be some 10$^{\rm m}$ below the MS. The errors of photometry are too small to explain its strange location in the CMD. We estimate the mass of E from the astrometric orbit. If the semi-major axes of C and E relative to the center-of-mass CE are a_1 and a_2, respectively, then the combination of the 3rd Kepler law $(a_1 + a_2)^3 = (\mathcal{M}_1 + \mathcal{M}_2)P^2$ (all values in solar units) and $a_1/a_2 = \mathcal{M}_2/\mathcal{M}_1$ leads to $\mathcal{M}_2 = a_1(\mathcal{M}_1 + \mathcal{M}_2)^{2/3}P^{-2/3}$. Solving this for $\mathcal{M}_1$ = 0.69 and distance 19 pc, we get $\mathcal{M}_2$ = 0.25. The absolute magnitude of E also corresponds to a dwarf of ~0.25 $\mathcal{M}_\odot$.

Dwarf stars with similar masses and colors are known. Crosses in Fig. 5 show binary dwarfs from Table 5 of Henry & McCarthy (1993) with photometric errors below 0.1$^{\rm m}$, dotted lines joining the components of the same systems. Two pairs with nearly equal components similar to E are Gliese 661 (0.26 $\mathcal{M}_\odot$) and 725 (0.37+0.32 $\mathcal{M}_\odot$), whereas Gliese 860 (0.26+0.17 $\mathcal{M}_\odot$) has an apparently anomalous secondary, hotter and fainter than the primary. We have no explanation of these color differences between low-mass dwarfs.

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[2] `http://www.ipac.caltech.edu/2mass/`

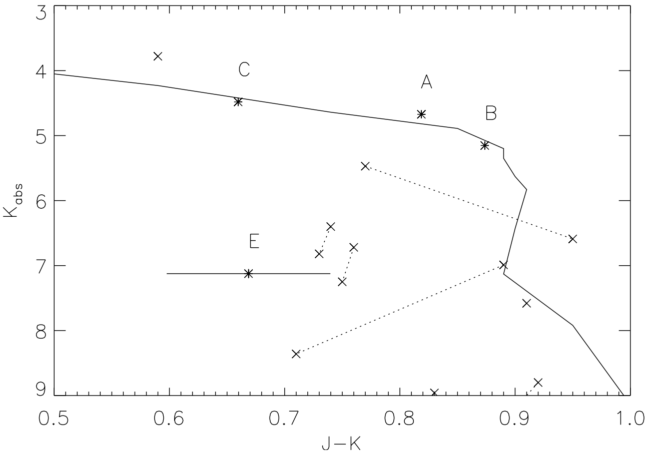

Fig. 5. Four components on the $(K, J-K)$ color–magnitude diagram. The error bars of all components except E are smaller than the symbol size. The standard Main Sequence from Lang (1992) is shown by a line, the crosses mark dwarf stars from Henry & McCarthy (1993).

According to our model, the mass sum of C,E is 0.9 $\mathcal{M}_\odot$, hence the orbital period and distance correspond to a semi-major axis $a_{\rm CE} = 0\farcs42$. On the other hand, matching our resolved observation to the astrometric orbit calls for $a_{\rm CE} = 0\farcs6$, hence unrealistically large mass sum of 2.6 $\mathcal{M}_\odot$. This "mass paradox" will be resolved by future observations. It is possible that the mass of the C,E system is indeed around 2 $\mathcal{M}_\odot$ because there is an additional unseen component, e.g. a white dwarf. On the other hand, our astrometric orbit derived from historic visual measurements with uncertain errorrs is only preliminary. With different astrometric elements, the measured separation of $0\farcs51$ could correspond to a smaller $a_{\rm CE}$. We prefer to wait for more observations of C,E instead of forcing a match between existing data and model.

7. Discussion

We discovered a new component E in the system and derived its preliminary astrometric orbit. Interestingly, the inclinations and position angles of nodes of A,B and C,E indicate that these pairs may be close to coplanarity. Unfortunately, no radial velocity data is available to fix the ascending nodes of both orbits without ambiguity. The new component is most likely a low-mass (~0.2 $\mathcal{M}_\odot$) red dwarf with peculiar $J-K$ color. However, there is some inconsistency between the astrometric orbit, separation of C,E and our mass estimates. Further observations of this sub-system will lead to a good measurement of the masses, resolving this discrepancy and adding new data to the empirical "mass-luminosity-age" relation. Possible existence of additional component in this quadruple system is yet another reason to continue its study.

Our study has shown that the visual orbit of the outer sub-system AB,C was premature. The observed motion shows only marginal curvature and corresponds to a large, yet unknown orbital period. The fact that AB and CE are seen close to each other may be explained by projection. There is no reason to claim dynamical instability. This quadruple system is likely old and has survived for a long time.

If further investigation reveals that Gl 225.2 is dynamically unstable, its origin could still be explained by several mechanisms: by temporary capture of two binaries in unstable configuration, by perturbation of a stable multiple system by a massive field object, or by disruption of a stellar group or a cluster. Possible scenarios of such events are discussed by Zhuchkov & Orlov (2005). Although the probabilities of these processes in the solar vicinity are low, few such systems could be expected within 200 pc from the Sun. We hope to clarify this issue by further observations and simulations.

Acknowledgements. We thank S. Thomas for her help in the image processing. Constructive comments of the Referee, S. Söderhjelm, and his communication of unpublished data are gratefully acknowledged. This work makes use of data products from the Two Micron All Sky Survey, which is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation.

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