Astron. Astrophys. 360, 991–996 (2000)

ASTRONOMY
AND
ASTROPHYSICS

Research Note

Search for companions around Sirius[⋆]

J.M. Bonnet-Bidaud[1], F. Colas[2], and J. Lecacheux[3]

[1] Service d'Astrophysique, DSM/DAPNIA/SAp, CE Saclay, 91191 Gif sur Yvette Cedex, France
[2] Institut de Mécanique Céleste, 77 Av. Denfert Rochereau, 75014 Paris, France
[3] DESPA, Observatoire de Paris-Meudon, 5 Pl Jules Janssen, 92195 Meudon, France

Received 27 December 1999 / Accepted 30 May 2000

Abstract. Since the discovery of Sirius-B about 130 yr ago, there have been several claims of a possible second companion around the brightest star Sirius-A. Such a companion could, in particular, be responsible for the suspected colour change of the star, now strongly suggested from two independent historical sources. We reported here on a new observation of the sky region around Sirius, to search for such a companion, using a coronographic device.

By comparison of the new stellar field with a similar image obtained by us ∼13 yr ago and using the Sirius proper motion, we are able to eliminate the most obvious companion candidates down to a magnitude $m_v \sim 17$ in a field from 30 arcsec to 2.5 arcmin of the central star. None of the visible stars appears consistent in magnitude and colours with what expected from current theoretical models and observations of low-mass stars.

From the study of the same field, it is also shown that the Sirius companion, consistently reported by observers during the years 1920–1930, is most probably an unrelated $m_g \simeq 12$ background star, now ∼ 1 arcmin away but located precisely on the Sirius proper motion trajectory. The closest apparent conjunction with Sirius was realized in 1937 with a minimum angular distance of 6.9 arcsec, of the same order as the Sirius A-B binary separation.

The reported observations do not eliminate the possibility of a second companion but now confined the search to the more central 30 arcsec region around Sirius. In particular, the existence of a long period companion cannot definitively be ruled out since the arbitrary orientation of the orbit can yield an observed projected position on sky inside this more central region.

Key words: stars: low-mass, brown dwarfs – astrometry – stars: binaries: visual – stars: individual: Sirius

1. Introduction

Sirius is the brightest star in the sky. Outshining the sun by a factor 25 in absolute luminosity, it displays at a distance of 2.64 pc an apparent visual brightness that exceeds by a factor 2 the one of the second brightest star, Canopus (Gatewood & Gatewood 1978). Due to its fast relative motion through the sky with a radial motion of 1.6 AU/yr and a proper motion projected on sky of 1° in about 2700 yr, it will not always be the dominant star in the sky though this status is already true for 90 000 yr and will remain valid for at least 210 000 more years (Tomkin 1998). Its velocity will bring Sirius at a minimal distance from the Sun of 2.3 pc in about 65 000 yr (Garcia-Sanchez et al. 1999). It is from the study of this apparent fast motion through the sky, first noted by Halley, that the existence of the famous white dwarf companion, Sirius -B, has been predicted by Bessel (1844), making of Sirius-B one of the first example of dark matter body whose existence has been inferred from its gravitational action only. Sirius-B was finally discovered in the early days when the first modern refractor was put into service in Massachusetts (USA) (for an historical review see Brecher 1979, Hetherington 1980, Wesemael and Fontaine 1982). After the discovery of Sirius-B, the binary system has been extensively observed first visually (Volet 1932, Zagar 1932), then by photographic techniques (Lindenblad 1970) to accurately determine the orbit. Since the discovery, the orbit has now been covered a little more than twice so that the orbital elements are now relatively well established (Gatewood & Gatewood 1978, Benest & Duvent 1995). The distance and proper motion of the system were also recently refined by the Hipparcos satellite observations (ESA 1997).

The existence of possible additional companion(s) to Sirius-A is still however an open question. The star itself is well known but the sky region immediately around it is poorly explored. Observations are strongly affected by the central star strong contamination by diffusion, and a direct evidence of a companion is still extremely difficult to establish even with modern techniques.

There have been several repetitive claims that a visual (m_v=12?) companion has been detected during the years 1920–1930 (Fox 1925, Innes 1929, van den Bos 1929, see Baize

---

Send offprint requests to: J.M. Bonnet-Bidaud

[⋆] Based on data collected at the Pic du Midi-Toulouse Observatory (France)

Correspondence to: bobi@discovery.saclay.cea.fr

1931 for a review). Studies of Sirius orbital perturbations (Volet 1932, Zagar 1932), as well as more recent detailed analysis of the orbital residuals (Benest & Duvent 1995), have also led to a persistent claim of a possible 6 years periodicity. This points towards a very low mass companion orbiting most probably Sirius-A with a suggested separation of the order of 2–3 arcsec.

Independently, there is increasing indirect evidences, that a second companion with a long period could be at the origin of a colour change of the bright star Sirius in historical times. The tidal interaction of this low-mass companion during the close-by encounter at periastron could cause enough matter to be expelled and produce an appreciable transient reddening of Sirius (Bonnet-Bidaud & Gry 1991). This event, which could have happened a few centuries before modern era, is now suggested from independent greek and chinese historical records (Gry & Bonnet-Bidaud 1990, Bonnet-Bidaud & Gry 1991, 1992). Such companion could be expected to reach a separation of the order of 60 arcsec.

From previous optical observations that we performed at ESO (Chile) in 1985, an image has been obtained around Sirius, showing for the first time all stars from $30''$ to $2.5'$ away from the binary, down to a magnitude $m_v \sim 17$. From this detailed image of the field, several possible candidates matching the apparent magnitude and positions expected from a long period companion have been singled out (Bonnet-Bidaud & Gry 1991).

We present here the follow-up of this program for the search of new companion(s) of Sirius-A. From the use of the two images obtained at a 13 years interval, a definitive identification test can be carried out, using the unusual large proper motion of Sirius-A.

2. Observations

Photometric observations of the Sirius field were carried out in good seeing conditions on January 18–24th, 1999 using a 288x384 pixels CCD camera at the Nasmyth secondary focus of the 1 meter telescope at the Observatoire of Pic du Midi-Toulouse (OPMT, France). To suppress most of the contamination from the bright central Sirius, a special coronographic device was designed. A small circular mask was fixed on a thin metallic wire and mounted on a two-dimension moving plate to allow for its precise positioning in the optical path. This mask was introduced at the intermediate focus of a f/D=6 focal reducer. The resulting field was 4.8x3.6 arcmin centered at Sirius with a pixel size of 0.75 arcsec and a reconstructed mask size of $\sim$ 22 arcsec in diameter. Different attempts were made to further reduce the strong cross-like spikes originating from the diffusion by the supports of the secondary mirror. For this, a plywood cache with four-circular apertures was set up at the entrance of the telescope. Through reducing the first order high spatial frequencies, this cache was found to introduce an additional diffusion in the central region of the field so images both with and without this cache were obtained.

Individual images were taken with 2–3 min. exposures using a Gz Gunn filter (Schott RG800) which, combined with the CCD response, yields a (830–950)nm response. Images were co-added to produced average images with equivalent exposures from 30 to 80 min. The occulting mask was shifted at different positions to allow the coverage of a wider field around Sirius.

3. Analysis and results

The photometric reduction was performed with standard techniques, using the stars Landolt 653 and 667 as comparisons. After offset and flat-field corrections, the images were further corrected from the residual Sirius diffusion by subtracting a background filtered by a radial gradient method. The resulting Gz Gunn image is shown in Fig. 1. The image is a composite of three exposures of 81min, 60min and 30 min. obtained with Sirius at center and displaced east and west respectively.

A total of $\sim$30 stars is detected in the field down to a magnitude of $m_g \sim 16$ for a region at a distance greater than 30 arcsec from the center of the mask. By computing the center of the diffusion profile through the image, we checked that the center of the mask corresponds to the Sirius position with an accuracy better than 0.5 arcsec. The positions of the different stars in the field were then measured by means of gaussian fits to the stellar images, yielding an accuracy in the relative positions with respect to Sirius better than 0.05 arcsec, except possibly for the few stars falling near regions of increased diffusion. Measurements were done both on raw and background-subtracted images. The positions and labels of the different stars are shown in Fig. 2 with their coordinates and magnitudes reported in Table 1. The accuracy on magnitudes is not better than 0.1 mag due to the high background subtracted. Absolute J2000 coordinates were computed by mean of the astrometric reduction program developed at the IMC/Bureau des Longitudes, using the J2000 position of Sirius-A at 1985.9589 (α= 6h 45m 9.36s, δ= -16d 42m 43.55s) as a reference. The relative accuracy is better than 0.1 arcsec but the absolute accuracy is only ($\sim$0.5 arcsec), dominated by the uncertainty in the Sirius position in the field.

This 1999 Sirius field was compared to a similar image obtained by us in 1985 with a different telescope. Within this time interval, Sirius is expected to have moved through the sky by more than 17 arcsec, so that any star dynamically linked to it will also show a significant proper motion. To judge of possible motion of stars in the field, the star positions of the 1999 image were cross-correlated with the corresponding positions measured on the 1985 image (see Table 1 of Bonnet-Bidaud & Gry 1991). Table 2 lists the corresponding residuals after transformation. The mean measured residuals are 0.18 and 0.14 arcsec respectively for the right ascension and declination. No significant changes are apparent. The maximum difference is seen for star 8 (0.5 arcsec), still comparable to the accuracy of the measurements. Some of this deviation may arise from a small proper motion of the star itself.

By comparison, the position of Sirius was also determined with respect to this cross-correlated stellar frame. The values are given in Table 3 with a shift of -(6.6±0.5) and -(12.0±0.7) arcsec, respectively in right ascension and declination. Based on the proper motion accurately determined from the recent Hipparcos

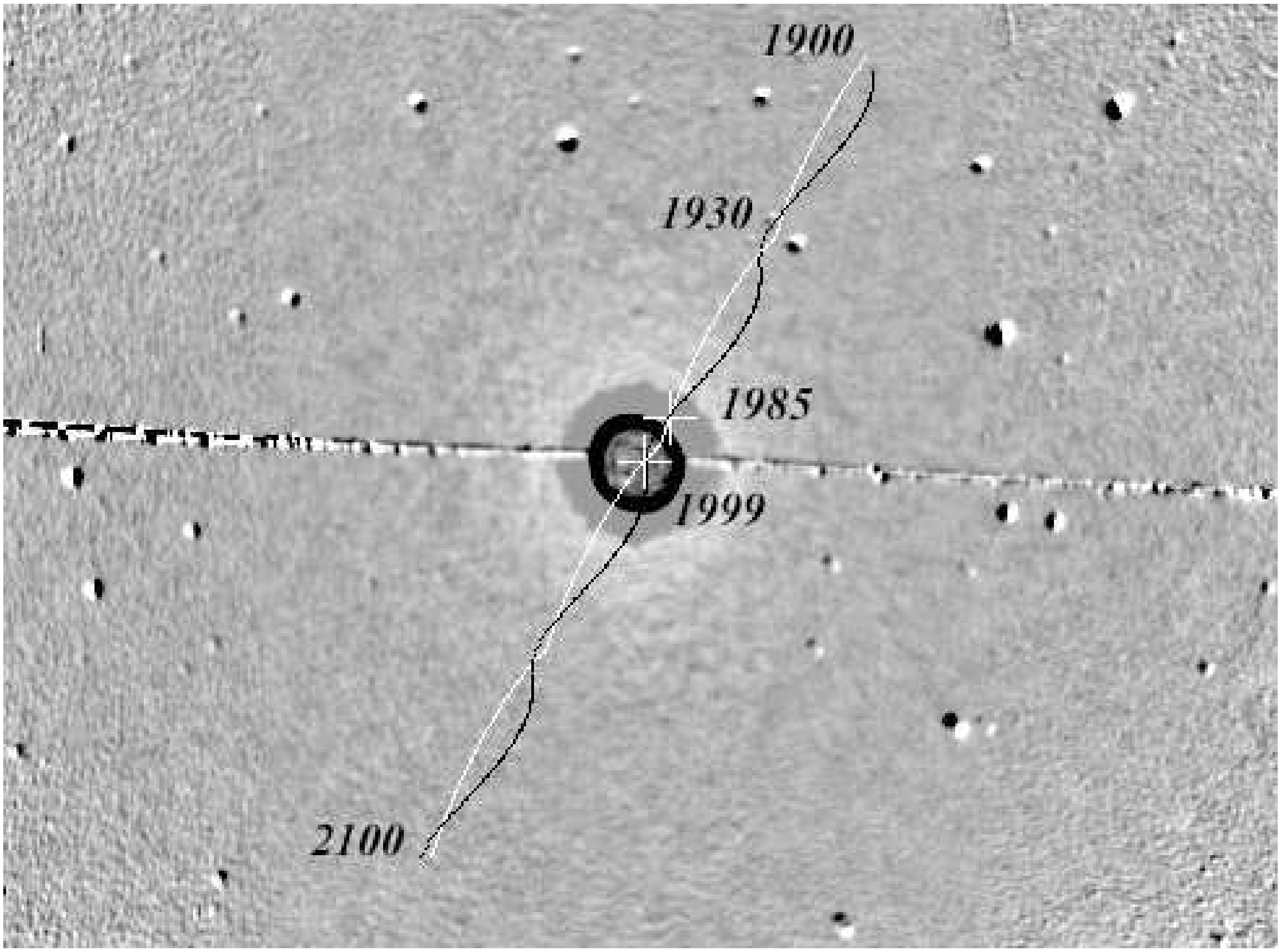

Fig. 1. The (4.5x6.0 arcmin) field centered on Sirius, obtained through a Gz Gunn (830–950nm) filter (North is up, East is right). The central mask has a reconstructed diameter size of $\sim$ 22 arcsec. The residual diffusion background have been removed by a radial gradient filter, which introduced the visible artifact asymmetry in the stellar images. Also drawn is the Sirius-A trajectory (white line), including the proper motion and the orbital influence of Sirius-B (black line). The positions of Sirius-A in 1985 and 1999 are marked by crosses.

data (ESA 1997), the expected shift for the center of gravity of Sirius A-B is listed in Table 3 together with the corresponding position of Sirius-A, computed using the orbital ephemeris of Gatewood & Gatewood (1978). The predicted change in Sirius-A position is -(6.32±0.02) in right ascension and -(12.51±0.02) arcsec in declination, in correct agreement with the measurements, if one allows for the uncertainty introduced by the mask.

4. Discussion

4.1. Historical claim of a companion

The influence of the unusual large proper motion of Sirius have often been neglected when discussing the properties of the system. The image obtained here allows the positions of the closest stars to the system to be confirmed. With the most recent proper motion measurements by Hipparcos, the precise position of Sirius-A within this stellar field can therefore be extrapolated backward in time. The exact trajectory of the star, including both the proper motion and the orbital influence of Sirius-B is shown in Figs. 1 and 2. The star path is very close to the bright ($m_g \sim 12$) star 2 and to the fainter star 20 of our list. The separation between Sirius and the stars 2 and 20 are computed along time in Fig. 3, together with the Sirius A-B separation for comparison.

The bright star 2 was less than 20 arcsec away from Sirius-A between 1923 and 1951 and within 10 arcsec in the 1932–1944 interval. The closest approach is reached in october 1937 with a separation of 6.9 arcsec, of the same order than the Sirius A-B separation. The fainter star 20 is even closer with a minimum at $\sim$2 arcsec around november 1934.

Interestingly enough, the presence of an additional star around Sirius has been repeatedly claimed by visual observers, more particularly in this period 1920–1930 when the system was extensively observed to refine the ephemeris near maximum elongation (see Fox 1925, van den Bos 1929, Innes 1929). Such claim was later found unsupported from photographic observations (Lindenblad 1973), casting doubts on the quality of

Table 1. Star magnitudes and positions

Star	mGz	Absolute position	
		α	δ
Sirius		6 45 09.35	-16 42 43.55
1	11.74	6 45 06.87	-16 41 23.85
2	12.63	6 45 11.61	-16 41 47.85
3	13.03	6 45 12.87	-16 43 19.35
4	13.76	6 45 12.68	-16 43 43.95
5	14.05	6 45 10.69	-16 41 06.45
6	13.66	6 45 03.82	-16 41 16.85
7	13.71	6 45 10.34	-16 43 53.25
8	15.41	6 45 08.16	-16 41 11.45
9	15.00	6 45 06.88	-16 40 58.95
10	13.49	6 45 01.64	-16 42 16.30
11	12.05	6 45 15.63	-16 44 02.43
12	12.46	6 45 16.23	-16 42 59.62
13	10.83	6 45 15.82	-16 42 08.37
14	14.08	6 45 15.15	-16 41 20.67
15	12.02	6 45 17.76	-16 41 00.48
16	13.89	6 45 13.72	-16 45 02.78
17	13.46	6 45 17.19	-16 43 00.88
18	13.83	6 45 15.59	-16 43 17.19
19	14.87	6 45 00.63	-16 42 22.73
20	14.69	6 45 11.09	-16 41 41.58
21	13.66	6 44 58.22	-16 43 44.12
22	13.20	6 44 57.62	-16 43 12.56
23	15.37	6 44 56.94	-16 41 37.07
24	15.22	6 45 01.19	-16 45 03.81
25	14.58	6 45 00.09	-16 43 25.11
26	14.90	6 45 20.44	-16 43 39.23
27	15.39	6 44 56.94	-16 44 32.52
28	15.88	6 44 58.95	-16 42 07.34
29	16.56	6 45 18.64	-16 40 45.51
30	15.46	6 45 18.78	-16 40 39.80
31	15.36	6 45 16.20	-16 44 01.48
32	15.98	6 45 16.60	-16 41 38.10

[*] for accuracy see text

Table 2. Star residuals[*]

Star	$\alpha\cos\delta$(”)	δ(”)
1	+0.03	+0.00
2	-0.03	-0.11
3	-0.03	+0.01
4	-0.05	-0.10
5	-0.05	-0.10
6	+0.29	-0.00
7	+0.04	-0.17
8	+0.49	+0.25
9	-0.41	-0.07

[*] with respect to 1985, see text

these past optical observations. The companion was quoted to be a relatively bright ($m_v \sim 12$) star. It is clear that the reported companion was either star 2 or 20 but most likely the brightest background star 2 which was at a very close distance at the same epoch and bright enough to be duly observed as such by the careful optical observers.

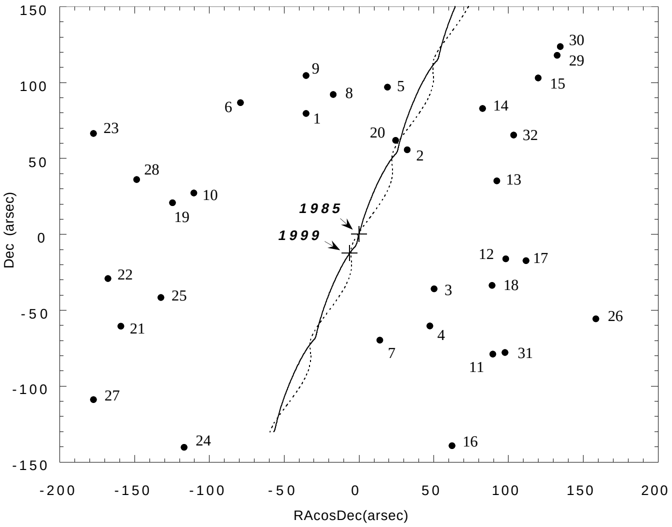

Fig. 2. Positions and identifications of the stars in the Sirius field. The positions of Sirius-A (full line) and B (dotted line) are also shown along time. Note the close approach between Sirius and star 2 and 20 in the past, around year 1930.

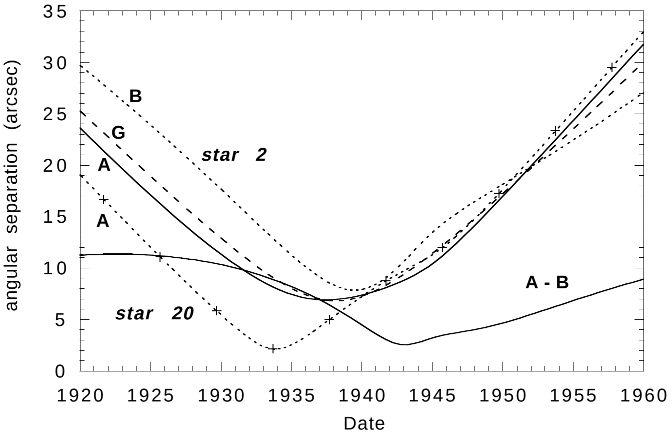

Fig. 3. The apparent separation projected on the sky along time between Sirius and star 2 (full line: Sirius-A, thin-dotted line: Sirius-B, dotted line: Sirius center of gravity) and 20 (thin-dotted-cross:Sirius-A). Also shown is the Sirius A-B separation (lower curve)

Table 3. Sirius positions

	Date	Relative position	
		$\alpha\cos\delta$(”)	δ(”)
	1985.959	0.00 (reference)	0.0 (reference)
A (measured)	1999.052	-6.65 (0.50)	-12.03 (0.70)
G (predicted)	1999.052	-7.150 (0.017)	-16.014 (0.016)
A (predicted)	1999.052	-6.320 (0.020)	-12.510 (0.019)

4.2. Characteristics of a Sirius low-mass companion

From the present observations, none of the brightest stars in the Sirius close field appears to have a proper motion comparable to Sirius A-B. From the constraints on the orbital period and periastron distance, the possible orbit of a long period companion is a highly eccentric ($e \geq 0.9$) orbit with a period $P \geq 2000$ yr and

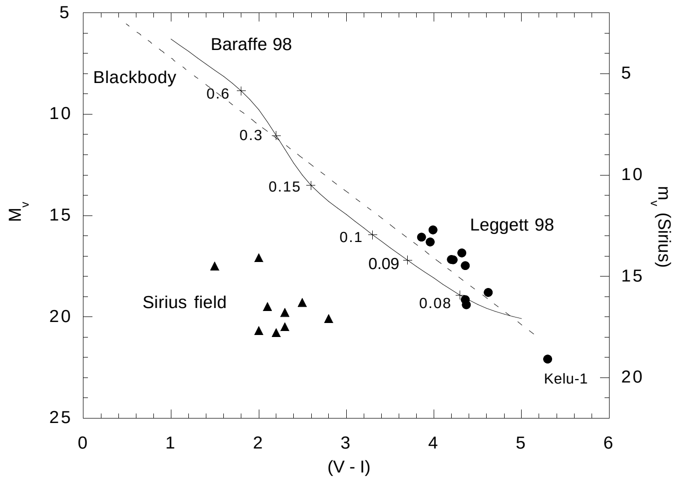

Fig. 4. Mv-(V-I) expected colour-magnitude diagram for potential companions of Sirius, down to the brown dwarf limit. Ordinate scales show both absolute magnitude (Mv) and apparent magnitude scaled at the Sirius distance (m_v). Full line: theoretical model (Baraffe et al. 1998) with stellar masses indicated; dotted line: equivalent colours of a blackbody atmosphere; full circles: observed low-mass red dwarfs (Leggett et al. 1998). Also shown are the measured stars in Sirius field (full triangles). All these stars appear too severely underluminous to be consistent with the assumed Sirius distance.

a semi-major axis $a \geq 230$ AU (Bonnet-Bidaud & Gry 1991). For an orbit with e=0.9 and a=230 AU, the maximum orbital velocity will be $V = 15\,\mathrm{km.s^{-1}}$ at periastron while it will drop to $0.8\,\mathrm{km.s^{-1}}$ at apastron, with a maximum separation of 160 arcsec. Outside the most inner part of the orbit, at a distance greater than 30 arcsec to the central binary, the upper limit on the companion orbital velocity will be $\leq 7.7\,\mathrm{km.s^{-1}}$ for $a \geq 230$ AU, therefore significantly less than the Sirius tangential velocity ($16.795\,\mathrm{km.s^{-1}}$). In the explored region, at a distance greater than $\sim$ 30 arcsec, one would then expect the proper motion of a companion to be closely comparable to the one of Sirius.

The investigation of the stellar field around Sirius is now complete down to a magnitude $\sim$17 in V and $\sim$16 in Gz, for distances between $30''$ and $160''$. The absence of a significant proper motion among the bright stars in the Sirius field rules out the existence of a plausible companion at a today projected distance greater than $\sim$30 arcsec from Sirius-A.

Since our last 1985 observations, considerable progress has been made in the understanding of low (0.1–$0.5\mathrm{M}_\odot$) and very low mass (0.07–$0.1\mathrm{M}_\odot$) stars, down to the brown dwarf limit, both theoretically (see Baraffe et al. 1998 and references therein) and observationally (see Leggett et al. 1998). The characteristics of a low mass companion at the Sirius distance can therefore be evaluated more precisely.

Fig. 3 shows a Mv-(V-I) color-magnitude diagram for a sample of observed small mass red dwarfs from the compilation by Leggett et al. (1998), in which the stars have been selected for their solar-metallic abundances [m/H]=0 and a mass $\leq 0.12\mathrm{M}_\odot$. The selection also includes the newly discovered brown dwarf, Kelu-1, for which a distance of 10pc have been estimated (Ruiz et al. 1997). Also shown is the most recent theoretical model for solar-metallicity low-mass stars, based on non-grey atmospheres (Baraffe et al. 1998) with masses indicated. As noted by the authors themselves, as a probable consequence of an underestimate of opacity, this best present model is however known to underestimate the V-I colour by about 0.5 mag for M $\leq 0.5\mathrm{M}_\odot$ as visible in Fig. 4. Excluding brown dwarfs, the expected apparent visual magnitude of a (0.08–$0.12\mathrm{M}_\odot$) red dwarf at the Sirius distance (2.64 pc) is in the range m_v=12–17 with corresponding colour (V-I)=3.0–4.5.

The measured stars in the Sirius close field are also shown in Fig. 3 with absolute magnitudes as if they were at the Sirius distance. Obviously, all candidates appear severely underluminous for their colours. The reddest candidates (star 3 and 4) have colour marginally consistent with low mass ($\sim$0.1–$0.15\mathrm{M}_\odot$) stars but their magnitudes will put them at distance respectively (50–60)pc and (40–50)pc if they are true standard main-sequence stars.

We note that the magnitude limit of $\mathrm{m}_v \sim 17$ allows us to exclude all possible main sequence stars above the brown dwarf limit but the faintest brown dwarfs such as Kelu-1 at a magnitude m_v=18–19 will be still undetectable.

5. Conclusion

The careful study of the Sirius stellar field at a several years interval allows one to exclude the presence of a main sequence low mass ($\geq 0.08\mathrm{M}_\odot$) companion at a separation greater than $\sim$30 arcsec of the Sirius A-B binary. Only the most extreme case of a brown dwarf star comparable to Kelu-1 can be still undetectable. The most central region around the binary is however still unexplored. Even in the case of a long period companion, a significant probability exists that an eccentric orbit will bring the low-mass star at a projected distance closer than 30 arcsec, according to the orientation of the orbit in space. As a result of a numerical simulation with random values for the relevant orbital parameters, the probability is computed to be $\sim 10^{-2}$ in the less favourable case of an object now at the maximal apastron distance for a representative orbit with a=230AU and e=0.9. This inner region could also harbour a short orbit companion which may be responsible for the suspected cyclic residual orbital variations. The orbital velocity of a close companion could prevent to use the proper motion discrimination such as used in this paper but the characteristics of the low and very low mass stars (luminosity and colours) are now sufficiently known to allow a secure identification among background stars. The Sirius pair is unique in showing for Sirius-A the earliest stellar type among white dwarf companions together with a very unusual high mass among white dwarfs for Sirius-B. Those peculiarities are still largely unexplained and could possibly be in relation with the evolution of a more complex system including a yet undetected third star. It is clear that the study of the most inner part of the sky region around Sirius would require the use of the infrared bands to take advantage of the reduced contribution of Sirius A-B together with the increase flux expected from low mass stars in this range. These wavelengths also benefit from the new possibilities of adaptive optics now available.

Acknowledgements. We are very grateful to J.M. Abaddie and the whole OPMT technical team for their efficient help in the short term planning of these observations. We also wish to thank Jérôme Blumberg for the realisation of a video film describing the set-up and the realtime observations. The film “Le compagnon de Sirius” is available at the CNRS Image Media, 27 rue Paul Bert, 94200 Ivry, France

References

Baraffe I., Chabrier G., Allard F., et al., 1998, A&A 337, 403
Baize P., 1931, L'Astronomie 45, 383
Benest D., Duvent J.L., 1995, A&A 299, 621
Bessel F., 1844, MN 6, 136
Bonnet-Bidaud J.M., Gry C., 1991, A&A 252, 193
Bonnet-Bidaud J.M., Gry C., 1992, La Recherche 23, 105
Brecher K., 1979, In: Brecher K., Feirtag M. (eds.) Astronomy of the Ancients. MIT Press, p. 91
ESA, 1997, ESA SP-1200
Fox P., 1925, Ann. Dearborn Obs. II, 115
Gatewood G., Gatewood C., 1978, ApJ 225, 191
Garcia-Sanchez J., Preston R., Jones D., et al., 1999, AJ 117, 1042
Gry C., Bonnet-Bidaud J.M., 1990, Nat 347, 625
Hetherington N.S., 1980, QJRAS 50, 319
Innes R.T.A., 1929, Observatory 52, 22
Leggett S.K., Allard F., Hauschildt P.H., 1998, ApJ 509, 836
Lindenblad I., 1970, AJ 75, 841
Lindenblad I., 1973, AJ 78, 205
Ruiz M., Leggett S., Allard F., 1997, ApJ 491, L107
Tomkin J., 1998, Sky Telesc., April 1998, vol. 95, no. 4, p. 59
van den Bos W.H., 1929, Observatory 52, 24
Volet Ch., 1932, Bull. Astron. Paris 8, 51
Wesemael F., Fontaine G., 1982, J. R. Astron. Soc. Can. 76, 35
Zagar F., 1932, Publ. Roy. Obs. Astron. Padova, 23