The Astronomical Journal, 123:2027–2032, 2002 April

A NEAR-INFRARED, WIDE-FIELD, PROPER-MOTION SEARCH FOR BROWN DWARFS

Joannah L. Hinz and Donald W. McCarthy, Jr.
Steward Observatory, University of Arizona, 933 North Cherry Avenue, Tucson, AZ 85721; jhinz@as.arizona.edu, mccarthy@as.arizona.edu

Doug A. Simons
Northern Operations Center, Gemini Observatory, 670 North A'ohoku Place, Hilo, HI 96720; dsimons@gemini.edu

Todd J. Henry
Department of Physics and Astronomy, Georgia State University, Atlanta, GA 30303; thenry@chara.gsu.edu

J. Davy Kirkpatrick
Infrared Processing and Analysis Center, MS 100-22, California Institute of Technology, Pasadena, CA 91125; davy@ipac.caltech.edu

and

Patrick C. McGuire
Universität of Bielefeld, D-33615 Bielefeld, Germany; mcguire@physik.uni-bielefeld.de
Received 2001 October 31; accepted 2002 January 9

ABSTRACT

A common proper-motion survey of M dwarf stars within 8 pc of the Sun reveals no new stellar or brown dwarf companions at wide separations (∼100–1400 AU). This survey tests whether the brown dwarf "desert" extends to large separations around M dwarf stars and further explores the census of the solar neighborhood. The sample includes 66 stars north of $-30°$ and within 8 pc of the Sun. Existing first-epoch images are compared with new *J*-band images of the same fields an average of 7 yr later to reveal proper-motion companions within a $\sim 4'$ radius of the primary star. No new companions are detected to a *J*-band limiting magnitude of ∼16.5, corresponding to a companion mass of ∼40 Jupiter masses for an assumed age of 5 Gyr at the mean distance of the objects in the survey, 5.8 pc.

Key words: stars: imaging — stars: low-mass, brown dwarfs — stars: statistics

1. INTRODUCTION

Although the substellar initial mass function (IMF) has been studied in a range of environments, such as star-forming clusters (Luhman et al. 1998; Luhman 2000; Najita, Tiede, & Carr 2000), young open clusters (Bouvier et al. 1998; Barrado y Navascues et al. 2001), and the field (Reid et al. 1999), the IMF of low-mass companions is not well understood, especially at "wide" (greater than 100 AU) separations. Radial velocity searches around solar-type, main-sequence stars (see, e.g., Mayor & Queloz 1995; Marcy & Butler 1996) have produced few confirmed brown dwarfs at separations less than 3 AU. Fewer than 0.5% of their sample have brown dwarf companions at those separations. A coronagraphic search for companions in the range 40–100 AU (Oppenheimer et al. 2001) produced only one brown dwarf, GJ 229B (Nakajima et al. 1995), well below the 17%–30% multiplicity observed for all stars (Reid & Gizis 1997). Other types of surveys, such as high spatial resolution, space-based observations (Lowrance et al. 1999, 2000) and ground-based adaptive optics (Els et al. 2001), have also resulted in discoveries of low-mass stellar and substellar companions. However, the frequency of stellar and substellar companions at close separations remains distinctly different, resulting in the idea that there is a "brown dwarf desert."

To date, there has been only one systematic search for brown dwarf companions at wide separations and with a volume-limited sample (Simons, Henry, & Kirkpatrick 1996, hereafter SHK96). This was mainly a color-based search around M dwarfs within 8 pc of the Sun and did not turn up any new brown dwarfs, although, given the surprisingly blue colors of GJ 229B, cool brown dwarfs with intermediate $J-K$ colors may have been overlooked in the survey.

Proper-motion searches for companions have been used for many years to identify low-mass objects (see, e.g., van Biesbroeck 1961) and offer a less biased way of finding low-mass companions than color-based surveys. Therefore, we have conducted the planned second-epoch survey of the SHK96 sample, in order to identify low-mass companions to M dwarfs at wide separations out to over 1000 AU. The choice of M dwarf primaries is significant: Reid & Gizis (1997) and Reid et al. (1999) show that the distribution of mass ratios for a sample of 80% M dwarfs has a peak at $q = 0.95$, where q is the ratio of the secondary mass to the primary mass. They conclude that their sample shows a distinct bias toward approximately equal-mass systems and that the mass function for stellar companions is different from the IMF of field stars. If these conclusions extend to brown dwarf masses, M primaries may harbor more substellar companions than other stellar types. On the other hand, Reipurth & Clarke (2001) suggest that brown dwarfs have been ejected by dynamical interactions during the star formation process and cannot accrete enough mass to become stars. In this case, M dwarf primaries may not be accompanied by such companions except in a multiple M dwarf system with a correspondingly large gravitational potential.

Thus, our proper-motion search around one spectral class of primaries fills a unique niche in the search for low-mass stellar and brown dwarf companions. We describe the data acquisition and reduction in § 2 and discuss the results of the survey in § 3.

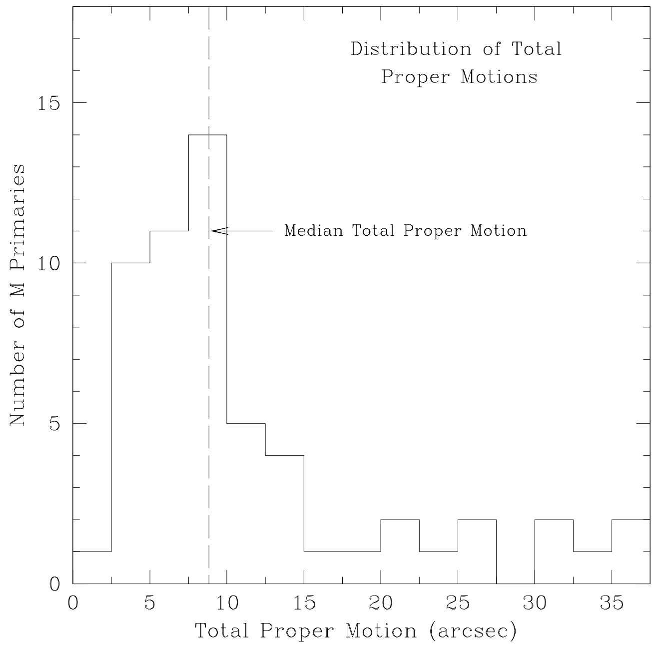

FIG. 1.—Histogram illustrating the distribution of total proper motions between epochs (in arcseconds) of the M dwarfs observed in this survey. The median total proper-motion value is 8''.8, as indicated above.

2. OBSERVATIONS AND DATA REDUCTION

2.1. *Sample Selection*

Our sample is identical to Henry's (1991) list of M dwarfs within 8 pc of the Sun. The M dwarfs were chosen initially from the Second Catalog of Nearby Stars (Gliese 1969) and its updates (Gliese & Jahreiss 1979), along with other additions from more recent literature (e.g., LHS 292; see SHK96 for more details). The sample consists of 75 M dwarf primaries with $M_V \geq 8.0$ mag, trigonometric parallaxes $\geq 0''.125$, and declinations north of $-30°$. SHK96 observed 66 of these systems, discarding three because of confusion toward the galactic plane (GJ 701, 729, and 752), leaving a total of 63 systems.

Of the original 75 systems, we observed 74 targets. Table 1 contains a list of the targets, their proper motions, the dates of observation and those of SHK96, and other relevant parameters. The median distance of the M dwarf targets is 5.8 pc, corresponding to a median search radius of 1480 AU in the present survey. Over the complete distance range, the search radius varies from 800 to 2100 AU. Figure 1 shows the distribution of total proper motions of our objects between the first- and second-epoch observations. Due to discoveries of new objects and to the measurement of more accurate parallaxes, the SHK96 list is no longer a complete volume-limited sample. Table 1 has five objects from the original sample whose updated parallaxes move them beyond the 8 pc limit (GJ 185, 623, 686, 1230, and 884) and separately lists four objects whose redetermined parallaxes or recent discoveries (e.g., G 180-060; Ducourant et al. 1998) place them within the survey criteria.

2.2. *Imaging*

First-epoch images (SHK96) were obtained at the University of Hawaii's 24 inch (0.6 m) telescope between 1991 August and 1992 August with a facility 256 × 256 NICMOS camera in both the *J* and *K'* bands with a scale of 2''.0 pixel^{-1}. Exposure times were typically 1 hr, and images were processed using conventional techniques. A custom program searched for point sources above a 3 σ detection level and performed photometry on all sources using a 10'' aperture.

Between 1998 April and 2000 December, *J*-band images of the same fields were taken with the PISCES camera (McCarthy et al. 2001) at the Bok 2.3 m Telescope on Kitt Peak. PISCES has an 8'.5 diameter field of view and a 0''.5 pixel^{-1} plate scale at this telescope. Nine 30 s exposures were obtained, centered on a program M dwarf, with a 10'' dither between each exposure. All images were corrected for quadrant cross-talk effects known to be present in HAWAII arrays (McCarthy et al. 2001). The images were then dark-subtracted, flat-fielded, masked for hot pixels, corrected for geometric distortion, and combined with standard IRAF tasks. The flat field was produced through a median combination of the dithered science frames. The flat field is predictably poor in the region of the bright M star, which was allowed to saturate the detector. However, the flat fielding does not affect the astrometry of the field, changing the position of the M dwarf by less than half a pixel in multiple test cases. In addition, because accurate photometry of the objects has already been carried out by SHK96, the resulting flat field is adequate for this survey.

Figure 2 shows a sample fully reduced field (GJ 752), along with the identical field observed by SHK96. The field-of-view sizes are almost perfectly matched, except that PISCES has a circular inscribed field. The SHK96 images show an internal reflection due to the optics in the camera to the lower right of the M dwarf primary that is not in the second-epoch set. The SHK96 survey has a limiting magnitude of $m_J \sim 16.5$ and is sensitive to companions down to 40 $M_{\rm Jupiter}$ assuming an age of 5 Gyr at the mean distance of the survey, 5.8 pc, based on the models of Burrows et al. (1997). We use 5 Gyr, following the findings of Henry (1991) on this sample; however, because age dating M dwarfs is difficult, 5 Gyr may not be an accurate average age. If the M dwarfs are instead 1 Gyr old, the survey is sensitive to 16 $M_{\rm Jupiter}$. The sensitivity of the PISCES images matches or exceeds that of the SHK96 images in all cases with $m_J \sim 17.0$.

Each second-epoch image is compared with its matching first-epoch image using an IRAF script originally designed to identify supernovae in nearby galaxies (Van Dyk et al. 2000). Using input coordinates of identical objects in the two frames, the script matches the pixel scales of the two cameras, accounts for any differences in geometric distortion, matches the point-spread functions for the two images, and subtracts them. Typically, 10–15 background stars from each M dwarf field were used as input references for the program. The total number of background stars ranges from 50 to over 1000 sources for the crowded fields near the galactic plane. The mean total proper motion of the M dwarfs between epochs is 8''.8 (~18 pixels on the PISCES camera). Moving objects are revealed by adjacent positive and negative images. Companion objects would have proper-motion vectors identical to the M dwarf primaries that have been accurately measured by *Hipparcos* (Perryman et al. 1997). Objects with such large proper motions can easily be detected by visually examining the subtracted images.

TABLE 1

PARAMETER LIST FOR TARGET PROGRAM STARS

Primary Name (1)	Components (2)	Trig. Parallax (3)	Proper Motion (4)	First Epoch (5)	Second Epoch (6)	M_V (7)	Sp. Type (8)
GJ 1002	...	0.2128 ± 0.0033	2.041	...	1999 Jan	15.4	M5.5
GJ 1005	AB	0.1919 ± 0.0172	0.863	1992 Jan	1999 Jan	12.9	M4.0
GJ 15	AB[a]	0.2802 ± 0.0011	2.912	1991 Aug	1999 Jan	10.3	M1.5
GJ 2005	ABCD	0.1328 ± 0.0091	0.614	...	1999 Jan	15.4	M5.5
GJ 54.1	...	0.2690 ± 0.0076	1.345	...	1999 Jan	13.7	M4.5
GJ 65	AB	0.3807 ± 0.0043	3.368	1992 Jan	1999 Jan	15.4	M5.5
GJ 83.1	...	0.2238 ± 0.0029	2.907	1991 Aug	1999 Jan	14.0	M4.5
GJ 109	...	0.1324 ± 0.0025	0.923	1992 Jan	1999 Jan	11.2	M3.0
GJ 185	AB	0.1203 ± 0.0017	0.308	1992 Feb	1999 Jan	8.9	K7.0
GJ 205	...	0.1757 ± 0.0012	2.235	1992 Jan	1998 Dec	9.1	M1.5
GJ 213[b]	...	0.1728 ± 0.0039	2.571	1991 Oct	1998 Dec	12.7	M4.0
LHS 1805	...	0.1322 ± 0.0029	0.831	...	1998 Dec	12.3	M3.5
G099-049	...	0.1863 ± 0.0062	0.241	...	1998 Dec	12.7	M3.5
GJ 229	AB	0.1732 ± 0.0011	0.737	1992 Mar	1998 Dec	9.3	M1.0
GJ 234	AB	0.2429 ± 0.0026	0.997	1992 Feb	1998 Dec	13.0	M4.5
GJ 251	...	0.1813 ± 0.0019	0.851	1992 Jan	1998 Dec	11.2	M3.0
GJ 1093	...	0.1289 ± 0.0035	1.225	...	1999 Jan	15.4	M5.0
GJ 268	AB	0.1572 ± 0.0033	1.052	1992 Jan	1999 Jan	12.5	M4.5
GJ 273	...	0.2633 ± 0.0014	3.761	1992 Jan	1999 Jan	12.0	M3.5
GJ 285	...	0.1686 ± 0.0027	0.604	1992 Mar	1999 Jan	12.3	M4.0
GJ 299	...	0.1480 ± 0.0026	5.211	1992 Mar	1999 Jan	13.7	M4.0
GJ 300	...	0.1700 ± 0.0102	0.707	1992 Jan	...	14.2	M3.5
GJ 1111	...	0.2758 ± 0.0030	1.29	1992 Jan	1999 Jan	17.0	M6.5
GJ 1116	AB	0.1913 ± 0.0025	0.874	1992 Jan	1999 Jan	15.5	M5.5
GJ 338	AB[a]	0.1616 ± 0.0052	1.662	1992 Jan	1999 Jan	8.7	M0.0
GJ 380	...	0.2052 ± 0.0008	1.454	...	1999 Jan	8.2	K7.0
GJ 388	...	0.2039 ± 0.0028	0.506	1992 Feb	1999 Jan	11.0	M3.0
GJ 393	...	0.1383 ± 0.0021	0.949	1992 Mar	1999 Jan	10.3	M2.0
LHS 292	...	0.2210 ± 0.0036	1.644	1992 Feb	1999 Jan	17.3	M6.5
GJ 402	...	0.1775 ± 0.0230	1.15	1992 Mar	1999 Jan	12.9	M4.0
GJ 406	...	0.4183 ± 0.0025	4.696	1992 Mar	1999 Jan	16.6	M6.0
GJ 408	...	0.1510 ± 0.0016	0.465	1992 Mar	1999 Jan	10.9	M2.5
GJ 411	...	0.3925 ± 0.0009	4.807	1992 Jan	1999 Jan	10.5	M2.0
GJ 412	AB[a]	0.2069 ± 0.0012	4.528	1992 Mar	1999 Jan	10.3	M1.0
GJ 445	...	0.1855 ± 0.0014	0.863	1992 Feb	1999 Jan	12.1	M3.5
GJ 447	...	0.2996 ± 0.0022	1.348	1992 Mar	1999 Jan	13.4	M4.0
GJ 1156	...	0.1529 ± 0.0030	1.301	...	1999 Jan	14.7	M5.0
GJ 473[b]	AB	0.2322 ± 0.0043	1.811	1992 Mar	2000 Jan	14.3	M5.5
GJ 514	...	0.1311 ± 0.0013	1.552	1992 Jan	2000 Jan	9.6	M1.0
GJ 526	...	0.1841 ± 0.0013	2.325	1992 Mar	2000 Jan	9.8	M1.5
GJ 555[b]	...	0.1635 ± 0.0028	0.69	1992 Mar	1998 Jul	12.4	M3.5
LHS 3003[b]	...	0.1610 ± 0.0060	0.965	...	1998 Jul	18.1	M7.0
GJ 581[b]	...	0.1595 ± 0.0023	1.224	1992 Mar	1998 Jul	11.6	M2.5
GJ 623[b]	AB	0.1243 ± 0.0012	1.231	1991 Aug	1998 Jul	10.7	M2.5
GJ 625[b]	...	0.1519 ± 0.0011	0.42	1992 Mar	1998 May	11.3	M1.5
GJ 628	...	0.2345 ± 0.0018	1.175	1992 Mar	2000 Jul	12.0	M3.0
GJ 644[b]	ABCD + 643[a]	0.1539 ± 0.0026	1.183	1992 Aug	1998 May	10.7	M2.5
G203-047	AB	0.1378 ± 0.0090	0.428	...	1998 May	12.5	M3.5
GJ 661[b]	AB	0.1595 ± 0.0031	1.582	1991 Aug	1998 May	11.0	M3.0
GJ 673	...	0.1295 ± 0.0010	1.315	...	1998 May	8.1	K7.0
GJ 686	...	0.1230 ± 0.0016	1.361	...	1998 May	10.1	M0.0
GJ 687	...	0.2209 ± 0.0009	1.304	...	1998 May	10.9	M3.0
GJ 699[b]	...	0.5493 ± 0.0016	10.31	1991 Aug	1998 May	13.2	M4.0
GJ 701[b]	...	0.1283 ± 0.0014	0.644	1992 Aug	1998 May	9.9	M0.0
GJ 1224	...	0.1327 ± 0.0037	0.664	...	1998 May	14.3	M4.5
LHS 3376	...	0.1373 ± 0.0053	0.623	...	1998 Jul	14.1	M4.5
GJ 1230	ABC	0.1209 ± 0.0072	0.501	1991 Aug	1998 May	12.8	M4.5
GJ 725	AB[a]	0.2802 ± 0.0026	2.273	1991 Oct	1998 May	11.1	M3.0
GJ 729[b]	...	0.3365 ± 0.0018	0.72	1992 Aug	1998 May	13.6	M3.5
GJ 752	AB[a]	0.1703 ± 0.0014	1.466	1992 Aug	1998 May	10.3	M3.0
GJ 1245	AB[a]C	0.2120 ± 0.0043	0.731	1991 Aug	1998 Jul	15.0	M5.5
GJ 809	...	0.1420 ± 0.0008	0.772	1991 Oct	2000 Nov	9.3	M0.0
GJ 829	AB	0.1483 ± 0.0019	1.058	1991 Aug	2000 Nov	11.2	M3.5
GJ 831	ABC	0.1256 ± 0.0045	1.194	1992 Aug	2000 Nov	12.6	M4.5

TABLE 1—*Continued*

Primary Name (1)	Components (2)	Trig. Parallax (3)	Proper Motion (4)	First Epoch (5)	Second Epoch (6)	M_V (7)	Sp. Type (8)
LHS 3799..........	...	0.1341 ± 0.0056	0.778	...	2000 Nov	13.9	M4.5
GJ 860...............	AB	0.2495 ± 0.0030	0.943	1991 Oct	2000 Nov	11.6	M3.0
GJ 866...............	ABC	0.2943 ± 0.0035	3.254	1992 Aug	2000 Nov	14.4	M5.0
GJ 873...............	AB[a]	0.1981 ± 0.0021	0.901	1991 Aug	2000 Nov	11.6	M3.5
GJ 876...............	AB	0.2127 ± 0.0021	1.143	1992 Aug	2000 Nov	11.8	M3.5
GJ 880...............	...	0.1453 ± 0.0012	1.071	1992 Aug	2000 Nov	9.5	M1.5
GJ 884...............	...	0.1228 ± 0.0009	0.911	...	2000 Nov	8.3	K5.0
GJ 896...............	ABCD	0.1601 ± 0.0028	0.56	1992 Aug	2000 Nov	11.3	M3.5
GJ 1286.............	...	0.1386 ± 0.0035	1.157	1992 Aug	2000 Nov	15.4	M5.5
GJ 905[b]	...	0.3156 ± 0.0016	1.617	1991 Aug	2000 Nov	14.8	M5.5
GJ 908...............	...	0.1675 ± 0.0015	1.37	1992 Aug	2000 Nov	10.1	M1.0
M Dwarfs That Would Now Meet Survey Criteria							
GJ 382...............	...	0.1273 ± 0.0015	0.287	...	...	9.3	M1.5
G180-060	...	0.1560 ± 0.0040	...	...	...	14.8	M5.0
GJ 793..............	...	0.1251 ± 0.0011	0.526	...	1998 Jul	10.4	M2.5
LP 816-060........	...	0.1822 ± 0.0037	0.308	...	2000 Nov	12.7	M

NOTES.—Column header explanations. Col. (1): Primary M star designation. Col. (2): Known companions. Col. (3): Trigonometric parallax (in arcseconds) from SHK96 or from Perryman et al. 1997. Col. (4): Proper motion of primary star (arcseconds per year). Col. (5): Date of first-epoch observation. Col. (6): Date of second-epoch observation. Col. (7): Absolute *V*-band magnitude of the primary star. Col. (8): Spectral type of the primary star.

[a] The companion was detected in the proper-motion search.

[b] The primary was not centered in the second-epoch image, so the search radius is not exactly 4!25.

Figure 3 shows the detection of the known low-mass companion VB 10 (GJ 752B). Other known wide companions were also detected as indicated in Table 1. These results demonstrate the reliability of the subtraction method. GJ 570A, known to have a T dwarf companion at a separation of 258″.3 (Burgasser et al. 2000), was not included in the sample because the primary is a K4 dwarf.

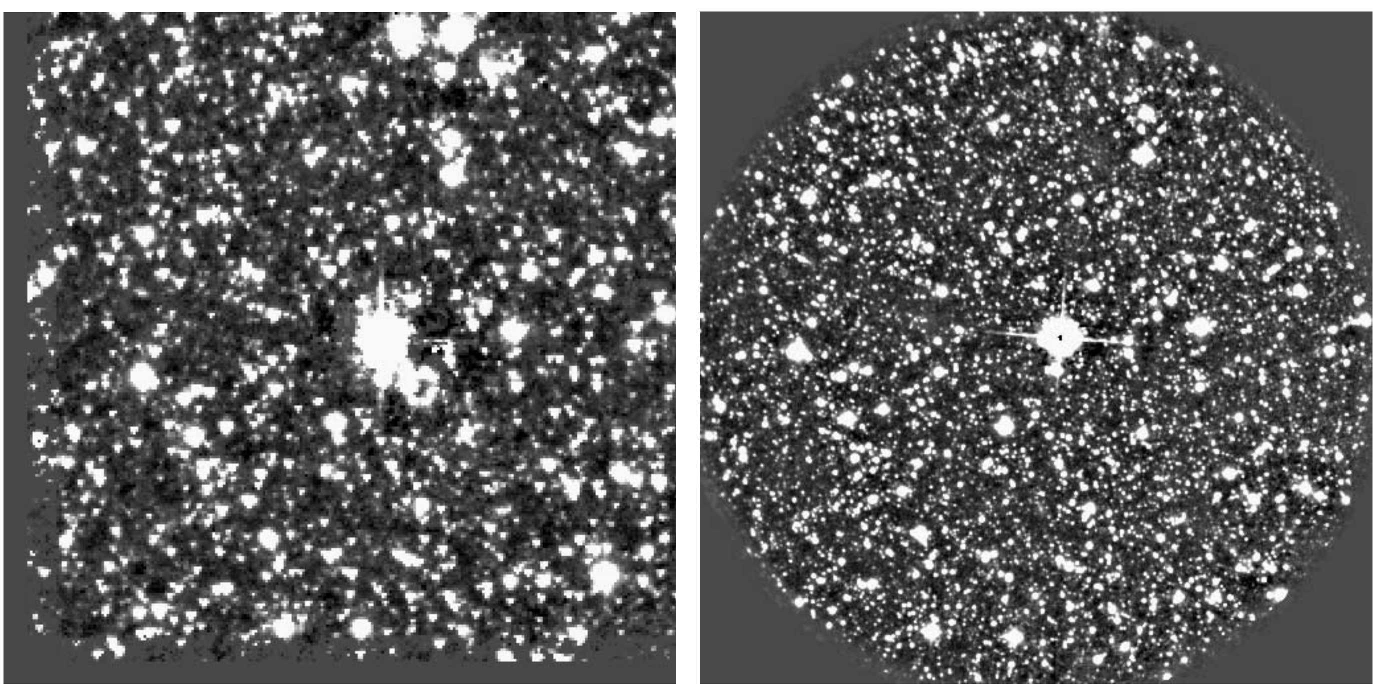

FIG. 2.—Sample *J*-band images of GJ 752 from the first (*left*) and second (*right*) epochs. North is up, and east is to the left. The field of view is 8′.5 on a side, corresponding to a radial separation of 1500 AU from the primary star. The first-epoch image (SHK96) was obtained in 1992 and has a pixel scale of 2″.1 pixel^{-1}. The second-epoch image taken with the PISCES camera has a pixel scale of 0″.5 pixel^{-1}. Limiting *J*-band magnitudes are ∼16.5 and 17, respectively. The ring of flux in the SHK96 image to the lower right of the primary star is an internal reflection in the optics of the infrared camera.

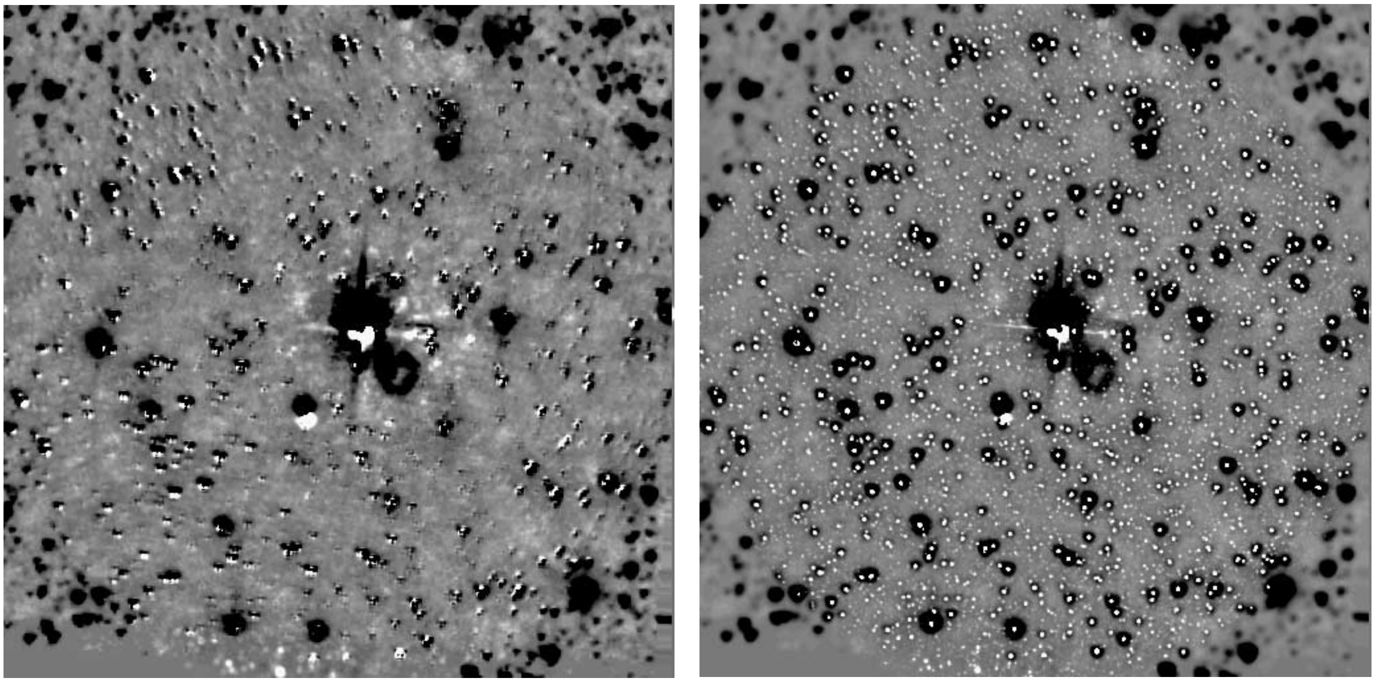

FIG. 3.—Difference images obtained by subtracting the first- and second-epoch images of GJ 752, as shown in Fig. 2. Results are shown with (*left*) and without (*right*) matching the point-spread functions of the two cameras before subtraction. The adjacent positive and negative images of the primary star show the motion over ~6 yr. The proper-motion companion VB 10, $m_J \sim 9.90$, is visible to the lower left of the primary star.

3. RESULTS

No new low-mass stellar or brown dwarf companions were detected in this 8 pc sample of M dwarfs. The same conclusion was reached by SHK96 from a $J-K'$ color search. However, as many as nine wide ($3600 \geq \Delta \geq 120$ AU) companions have recently been detected around nearby (9.6–39 pc) stars using the Two Micron All-Sky Survey (2MASS) database (Kirkpatrick et al. 2000, 2001; Burgasser et al. 2000; Wilson et al. 2001). Seven of these new objects are common proper-motion companions. In general, it is difficult to compare the 2MASS results with the present survey because the 2MASS primary stars have uncertain ages and generally higher luminosities. Based on initial 2MASS results, Gizis et al. (2001) estimate that ~1% of primaries with masses 0.6–1.5 $M_\odot$ ($M_V < 9.5$) have wide ($\geq$1000 AU) L dwarf companions and that the frequency of all wide brown dwarf companions is 5–13 times greater. Extending this analysis to our M dwarf sample of 63 objects with masses between 0.08–0.6 $M_\odot$, we would expect to detect between three (5% of our sample) and nine (13%) brown dwarf companions. The apparent difference between our results and Gizis et al. (2001) might be resolved if the frequency of brown dwarf companions depends strongly on primary mass and orbital separation. This possibility could be tested either by systematic data mining of the 2MASS survey or by extending the present PISCES survey to other spectral types.

J. L. H. thanks Chien Peng, Rose Finn, and Roelof de Jong for valuable discussions concerning near-infrared data reduction and Michael Meyer for comments on early drafts of this paper. The HAWAII detector and electronic controller for PISCES were purchased by the Air Force Office of Scientific Research through grant F49620-96-1-0285. The PISCES camera was also briefly supported by the National Science Foundation through grant NSF 96-23788. D. A. S. was supported by the Gemini Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under a cooperative agreement with the National Science Foundation on behalf of the Gemini partnership: the National Science Foundation (US), the Particle Physics and Astronomy Research Council (UK), the National Research Council (Canada), CONICYT (Chile), the Australian Research Council (Australia), CNPq (Brazil), and CONICET (Argentina).

REFERENCES

Barrado y Navascues, D., Stauffer, J. R., Bouvier, J., & Martin, E. L. 2001, ApJS, 134, 103
Bouvier, J., Stauffer, J. R., Martin, E. L., Barrado y Navascues, D., Wallace, B., & Bejar, V. J. S. 1998, A&A, 336, 490
Burgasser, A., et al. 2000, ApJ, 531, L57
Burrows, A., et al. 1997, ApJ, 491, 856
Ducourant, C., Dauphole, B., Rapaport, M., Colin, J., & Geffert, M. 1998, A&A, 333, 882
Els, S. G., Sterzik, M. F., Marchis, F., Pantin, E., Endl, M., & Kürster, M. 2001, A&A, 370, L1
Gizis, J., Kirkpatrick, J. D., Burgasser, A., Reid, I. N., Monet, D. G., Liebert, J., & Wilson, J. C. 2001, ApJ, 551, L163
Gliese, W. 1969, Veröff. Astron. Rechen-Inst. Heidelberg, No. 22
Gliese, W., & Jahreiss, H. 1979, A&AS, 38, 423
Henry, T. 1991, Ph.D. thesis, Arizona Univ.
Kirkpatrick, J. D., Dahn, C. C., Monet, D. G., Reid, I. N., Gizis, J. E., Liebert, J., & Burgasser, A. J. 2001, AJ, 121, 3235
Kirkpatrick, J. D., Reid, I. N., Gizis, J. E., Burgasser, A. J., Liebert, J., Monet, D. G., Dahn, C. C., & Nelson, B. 2000, AJ, 120, 447
Lowrance, P. J., et al. 2000, ApJ, 541, 390
———. 1999, ApJ, 512, L69
Luhman, K. 2000, ApJ, 544, 1044
Luhman, K., Rieke, G. H., Lada, C. J., & Lada, E. A. 1998, ApJ, 508, 347
Marcy, G. W., & Butler, R. P. 1996, ApJ, 464, L147

Mayor, M., & Queloz, D. 1995, Nature, 378, 355
McCarthy, D. W., Jr., Ge, J., Hinz, J. L., Finn, R., & de Jong, R. S. 2001, PASP, 113, 353
Najita, J. R., Tiede, G. P., & Carr, J. S. 2000, ApJ, 541, 977
Nakajima, T., Oppenheimer, B. R., Kulkarni, S. R., Golimowski, D. A., Matthews, K., & Durrance, S. T. 1995, Nature, 378, 463
Oppenheimer, B. R., Golimowski, D. A., Kulkarni, S. R., Matthews, K., Nakajima, T., Creech-Eakman, M., & Durrance, S. T. 2001, AJ, 121, 2189
Perryman, M. A. C., et al. 1997, A&A, 323, L49
Reid, I. N., & Gizis, J. E. 1997, AJ, 113, 2246
Reid, I. N., et al. 1999, ApJ, 521, 613
Reipurth, B., & Clarke, C. 2001, AJ, 122, 432
Simons, D. A., Henry, T. J., & Kirkpatrick, J. D. 1996, AJ, 112, 2238 (SHK96)
van Biesbroeck, G. 1961, AJ, 66, 528
Van Dyk, S., Peng, C. Y., King, J. Y., Filippenko, A. V., Treffers, R. R., Li, W., & Richmond, M. W. 2000, PASP, 112, 1532
Wilson, J. C., Kirkpatrick, J. D., Gizis, J. E., Skrutskie, M. F., Monet, D. G., & Houck, J. R. 2001, AJ, 122, 1989