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# THE SOLAR NEIGHBORHOOD. VIII. DISCOVERY OF NEW HIGH PROPER MOTION NEARBY STARS USING THE SuperCOSMOS SKY SURVEY

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## ABSTRACT

Five new objects with proper motions between 1″.0 and 2″.6 yr$^{-1}$ have been discovered via a new Research Consortium on Nearby Stars (RECONS) search for high proper motion stars using the SuperCOSMOS Sky Survey. The first portion of the search, discussed here, is centered on the south celestial pole and covers declinations −90° to −57°.5. Photographic photometry from SuperCOSMOS and $JHK_s$ near-infrared photometry from the Two Micron All Sky Survey for stars nearer than 10 pc are combined to provide a suite of new $M_{K_s}$-color relations useful for estimating distances to main-sequence stars. These relations are then used to derive distances to the new proper motion objects, as well as previously known stars with $\mu \geq 1''.0$ yr$^{-1}$ (many of which have no trigonometric parallaxes) recovered during this phase of the survey. Four of the five new stars have red dwarf colors, while one is a nearby white dwarf. Two of the red dwarfs are likely to be within the RECONS 10 pc sample, and the white dwarf probably lies between 15 and 25 pc. Among the 23 known stars recovered during the search, there are three additional candidates for the RECONS sample that have no trigonometric parallaxes.

*Key words:* Galaxy: stellar content — solar neighborhood — stars: distances — stars: luminosity function, mass function — stars: statistics

## 1. INTRODUCTION

One of the primary goals of the Research Consortium on Nearby Stars (RECONS) is to discover stars that are currently missing from compendia of the Sun's nearest neighbors. As discussed in Henry et al. (1997), we estimate that as many as 30% of the nearby star systems lurk undiscovered within 10 pc, the horizon of the RECONS sample. The RECONS team is using both of the methods typically used to reveal nearby stars—high proper motion and photometric distance estimates—to discover new nearby systems. Here we report first results of a new initiative resulting in the discovery of five new high proper motion objects with $\mu > 1''.0$ yr$^{-1}$ in the region around the south celestial pole, along with an analysis of the revised sample of all similarly defined high proper motion stars in the same region.

To date, Luyten and Giclas have provided the bulk of high proper motion star systems. The valuable LHS Catalogue (Luyten 1979a, hereafter LHS) is a compendium of stars that includes 3583 objects with annual proper motions greater than 0″.5 yr$^{-1}$. Included in this list are 525 stellar systems that have motions greater than 1″.0 yr$^{-1}$. Many of these systems were also reported by Giclas and collaborators (Giclas et al. 1971). Both the Luyten and Giclas surveys were monumental undertakings in an era before extensive computer power was available and electronic data mining possible. Moreover, not all parts of the sky were covered uniformly in those surveys. Significantly lower completeness in the most southerly declinations is particularly noteworthy.

There is no doubt as to the scientific usefulness of the Luyten and Giclas surveys; however, there are two key shortcomings that have always dogged efforts to exploit those catalogs for quantifiably complete samples. First, the absolute astrometric accuracy of Luyten's catalog is poor by modern standards, making recovery of some of the cataloged objects very difficult (e.g., Bakos et al. 2002). This is despite the availability of finder charts in the LHS Atlas (Luyten 1979b). Second, and more significantly, the completeness of surveys produced using a variety of techniques (including manual plate "blinking") has been difficult to establish. Worries concerning the completeness of the LHS have been compounded over the past decade by a spate of new discoveries, for many of which there is no obvious reason as to why they were missed in the earlier surveys. Adding further fuel to the fiery completeness debates is the fact that invariably newly discovered objects turn out to be rather interesting, because completeness is chiefly an issue at relatively faint magnitudes and high proper motions where new types of intrinsically faint, high-velocity and potentially nearby stars tend to be found (e.g., Hambly et al. 1997). Clearly, if there is a large and unquantifiable bias against certain classes of objects in the early surveys, then statistical corrections (e.g., Dawson 1986) can never hope to recover an accurate estimate of the true numbers of all types of star. Recently, however, the availability of homogeneous, multicolor and multiepoch Schmidt survey plate collections along with fast, high-precision scanning machines capable of digitizing them has enabled significant progress. An example is the SuperCOSMOS Sky Survey (hereafter SSS, Hambly et al. 2001a; that paper also briefly describes some of the other major digitization programs). These newly digitized sky surveys have enabled much progress in systematic trawls for high proper motion stars (e.g., Ibata et al. 2000). Completeness questions can now be more accurately addressed (e.g., Monet et al. 2000) and recovery of many of Luyten's discoveries has become possible (e.g., Bakos et al. 2002), in addition to discovery of new objects.

Thus, recent astrometric efforts to reveal high proper motion stars are meeting with continued success. Several studies investigating the southern sky have yielded new systems with $\mu > 1\farcs0\ \mathrm{yr}^{-1}$. The large effort of Wroblewski and collaborators (Wroblewski & Costa 2001 and references therein) has resulted in discovery of two systems (WT 248 and WT 1827). The Calan-ESO survey of Ruiz and collaborators (Ruiz & Maza 1987 and Ruiz et al. 2001) has yielded three new systems (ER 2, ER 8, and CE 89). Work by Scholz and collaborators has used APM measurements of UK Schmidt Telescope survey plates (e.g., Reyle et al. 2002) and the SSS (e.g., Scholz et al. 2002 and references therein) to reveal three systems (APMPM J1957−4216, APMPM J2330−4736, and SSSPM J2231−7514AB). The study of Oppenheimer et al. (2001) also used the SSS and found new white dwarfs (e.g., WD 0205−053, WD 0351−564, and WD 2214−390). Furthermore, Pokorny et al. (2003) report a systematic high proper motion star survey employing SSS data; detailed follow-up of potentially interesting objects is underway by our group and others.

Astrometric searches of the northern sky also continue to yield high proper motion stars. In an innovative, systematic search of the sky north of declination $-2\fdg8$ and within 25° of the Galactic plane, Lepine et al. (2002) have found 18 new systems with $\mu > 1\farcs00\ \mathrm{yr}^{-1}$, by far the most productive recent effort, while Teegarden et al. (2003) have reported a remarkable system with $\mu = 5\farcs06\ \mathrm{yr}^{-1}$ by searching the SkyMorph database of Near-Earth Asteroid Tracking data (Pravdo et al. 1999).

In an effort to discover previously missed high proper motion objects in the southern sky, a new search by the RECONS team was initiated using SSS data. The new objects have been dubbed SCR sources, corresponding to the SuperCOSMOS RECONS search. In this paper, we present the first results of this search, which includes five new objects with motions larger than $1\farcs0\ \mathrm{yr}^{-1}$ in only ∼8% of the entire sky. We have extracted $JHK_s$ photometry from the Two Micron All Sky Survey (2MASS) to provide an extended color baseline that permits accurate photometric distance estimates. In a follow-up paper (Henry et al. 2004), we will present further optical photoelectric photometry, spectroscopy, and analysis of accurate photometric parallaxes for the sample.

## 2. TRAWLING SuperCOSMOS SKY SURVEY DATA

The SSS (Hambly et al. 2001a) is ideally suited to systematic searches for high proper motion stars. The survey consists of multicolor (*BRI*) Schmidt photographic observations with *R* at two distinct epochs, but in general all four passbands (plate magnitudes denoted by $B_J$, ESO−*R*, $R_{59\mathrm{F}}$, and $I_{\mathrm{IVN}}$, and hereafter referred to as $B_J$, $R_1$, $R_2$, and *I*) were observed at different epochs separated by up to 50 yr. Data for the entire southern hemisphere are currently publicly available (see Hambly et al. 2001a for details), and the survey program is currently being extended into the northern hemisphere. As described above, there have been several searches for high proper motion stars using SSS data. Each has had a different emphasis, with different science goals.

The survey of Pokorny et al. (2003) is an automated search primarily using the two *R*-band plates (UK and ESO Schmidt surveys) in each field of the SSS south of $\delta = -20°$, aimed at cataloging cool dwarfs to a lower proper motion limit of $\mu = 0\farcs18\ \mathrm{yr}^{-1}$. The search methodology employs software-automated multiple-pass pairing between only two *R* plates, and necessarily has rather stringent limits on image quality (e.g., profile class, proximity to bright stars and general morphology) to yield a clean catalog of thousands of stars; the intention was that no manual sifting of this automatically generated catalog would be required. The chief limitations of the search method are general incompleteness resulting from the stringent quality constraints, restriction of sky area covered due to necessary avoidance of crowded regions and incompleteness at high proper motions—cf. Pokorny et al. (2003) § 4—due to spurious pairing at large image displacement.

The trawl employed by Oppenheimer et al. (2001) was similar to that of Pokorny et al. but was aimed at cool (but relatively blue) white dwarfs. Detections therefore relied on presence on the $B_J$ plates, as well as the two *R* plates, and hence less stringent quality cuts could be used to obtain a clean sample. This survey was also generalized to use POSS−*I* "E" ($\equiv R$) data in the equatorial zone 0° > decl. > −20° in lieu of ESO−*R* material, but employed a proper motion threshold of $\mu = 0\farcs33\ \mathrm{yr}^{-1}$. In this case, some visual checking of candidate stars was employed after selection of stars via color and reduced proper motion. However, the Oppenheimer et al. (2001) survey also suffered from the same incompleteness problems at high proper motions and inability to probe more crowded, lower latitude regions of the sky.

### 2.1. *New Search Methodology*

For the purposes of supplying candidates for RECONS, a new search strategy is being employed that attempts to circumvent the completeness problems of previous SSS efforts by a combination of full use of all astrometric information between the four plates available in every field and relaxed quality/morphology criteria along with a final step of manual sifting to produce clean target lists. In some ways, this is an unsatisfactory return to the Luyten-style approach by including a subjective human element to the process, but it seems that at least for surveys employing parameterized image detection lists, this is the only way of ensuring high levels of completeness. Ultimately, it is likely that a whole-sky application of a pixel-based process like the SUPERBLINK algorithm of Lepine et al. (2002) is the only way of attaining the highest possible completeness from digitized Schmidt plate scans; even then the problems of saturation and scattered light near bright stellar cores remain (hence, areal completeness and completeness for close binaries will never be close to 100%).

Briefly, the new SCR search starts with each individual set of parameterized detections (the so-called Image Analysis Mode data; see Hambly et al. 2001b) from all plates in the same field positionally error-mapped to a common coordinate system using a rigorous application of the Evans & Irwin (1995) error mapping algorithm. The default SSS pairing (Hambly et al. 2001c) is then used to exclude all images that appear on all four plates having astrometric solutions indicating proper motion less than the limit (here $0\farcs4\ \mathrm{yr}^{-1}$) along with goodness-of-fit parameter $\chi^2 < 1.0$. Then, all images that are either unpaired or have inconsistent astrometric solutions (resulting from erroneous matching in the simple default SSS scheme) are processed one by one in all possible combinations among the available measurements out to a maximum displacement dictated by the upper proper motion limit chosen for the survey (here $10''\ \mathrm{yr}^{-1}$) and the maximum epoch difference between the set of plates. This "brute force" approach is made possible by modern computers and storage, which are capable of processing large amounts of data at high IO bandwidth. The other innovation in our latest SSS trawl for RECONS is that single cuts in a range of quality/morphology parameters are not made; rather a set of warning conditions is defined at levels set by maximizing completeness with respect

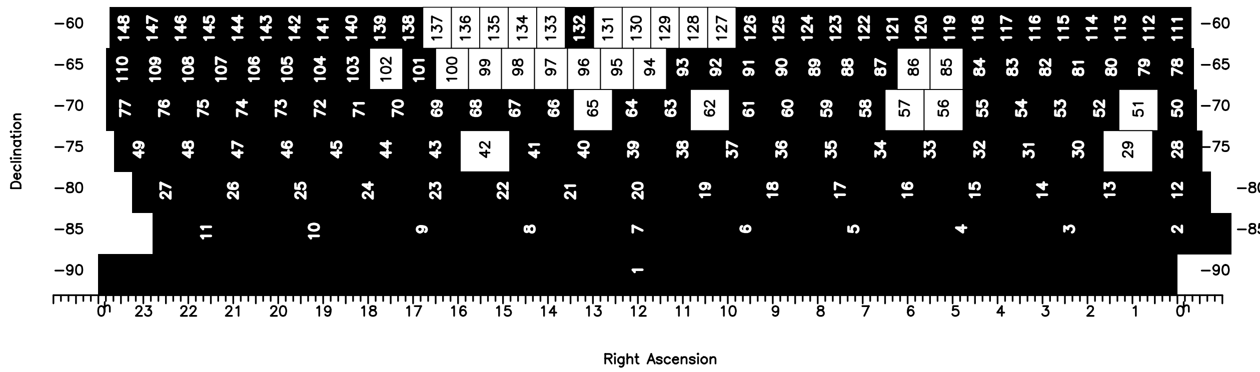


Fig. 1.—ESO/SRC standard fields covered in the SCR survey so far. Black cells indicate included fields; white cells indicate that fields that could not be reliably analyzed using the current data and algorithm (such fields have an unfavorable spread of epochs among the four SSS plates or are heavily crowded, being at low Galactic latitudes or near the cores of the Magellanic Clouds). Each field covers ~25 deg$^2$ of distinct sky (i.e., not including any overlap regions), and we have covered 121 out of 148 possible ESO/SRC fields. Hence, the sky area covered so far is ~3000 deg$^2$, or ~8% of the whole celestial sphere.

to the LHS (at the same time endeavoring to minimize contamination by spurious detections to make the final manual sifting problem tractable). A violation threshold is set such that only when three quality conditions are violated for a four plate detection (two for a three plate detection) will a candidate be thrown away as certainly dubious.

The SCR search is being carried out starting at the south celestial pole and is moving north. This paper describes the first phase of the search, which includes the region from $\delta = -90^\circ$ to $-57^\circ.5$. Figure 1 shows the fields currently surveyed. Number labels in Figure 1 are ESO/SRC standard Schmidt survey field designations; black areas represent fields included, while white areas indicate fields currently excluded because of crowding problems (areas of low Galactic latitude or areas within the Magellanic Clouds). In total, ~8% of the sky has been searched in this first effort.

The initial sift of the SSS data set for RECONS included sources with proper motions determined to fall between $0''.4$ and $10''.0$ yr$^{-1}$ and magnitude $R < 16.5$. The primary goal is to discover objects moving faster than $\mu = 0''.5$ yr$^{-1}$, but the lower boundary on $\mu$ was chosen to be $0''.4$ yr$^{-1}$ so that LHS objects with motions near $0''.5$ yr$^{-1}$ could be recovered if the computed proper motion was slightly less than the cutoff due to measurement errors in either SSS data or the LHS.

### 2.2. *Statistics of Results*

The total number of candidate objects detected with $\mu_{SCR} = 0''.4-10''.0$ yr$^{-1}$ in this initial search was 897. Spurious high proper motion detections can arise due to plate defects, blended sources, and halo "sources" around bright stars (for example, we note that the list of Pokorny et al. 2003 contains eight apparently spurious sources having $\mu > 4''$ yr$^{-1}$—one at more than $10''$ yr$^{-1}$). A multistep sifting process was used to vet the SCR search candidates for true and false detections, including checks of magnitudes, colors, and image ellipticities. The $R_1$ and $R_2$ magnitudes were checked for consistency, and the colors were examined to determine whether they matched that of a real object, i.e., both $B-R_2$ and $B-I$ positive, or both negative. If the candidate passed both checks, it was passed on to the visual inspection stage.

In cases where a candidate failed the first two tests, the ellipticity quality flag was also checked. Experience revealed that if two or more image ellipticities were larger than 0.2, the object was spurious. Detections that failed all three tests were classified as false without visual inspection. As a final check, all of the 99 candidates found between $\delta = -90^\circ$ and $-80^\circ$ were inspected visually (regardless of the checks), and all fell into the appropriate true or false detection bins.

For the true detections, coordinates were cross-correlated with the SIMBAD database and the NLTT catalog. If the coordinates agreed to within a few arcminutes and the magnitudes and proper motions were consistent, the detection was labeled as previously known. For detections without known proper-motion counterparts, visual inspection definitively confirmed or refuted a real proper-motion object. In a few cases, the coordinates agreed well, but the magnitudes did not. Several of these near matches turned out to be new common proper motion companions to a previously known proper motion object.

In summary, these checks revealed 443 false detections (49% of the candidates); additionally, 72 of the 897 candidates were duplicate detections resulting from the generous ESO/SRC plate overlap regions. Of the resulting 382 real, distinct objects, 262 were recoveries of previously cataloged objects, including many LHS/LTT objects and stars from the other surveys mentioned in § 1. Finally, 120 (13% of the initial candidate list) were found to be new discoveries, including a handful of new common proper motion companions to already known primaries.

## 3. DATA FROM SUPERCOSMOS—ASTROMETRY AND PLATE PHOTOMETRY

Of the 120 new objects discovered and the 262 known objects recovered in this phase of the SCR effort, we concentrate here on the subsample of 28 stars with $\mu_{\rm SCR} \geq 1''.0$ yr$^{-1}$, which are listed in Table 1. Names for the five new SCR stars are given in the first column (finder charts are given in Fig. 2), whereas the known names are given for the remaining 23 stars. Also listed are the SSS photographic astrometry and photometry for all 28 objects. Coordinates are precessed and proper motion corrected to equinox and epoch J2000.0 and are accurate to $\pm 0''.3$. Proper motions (and their errors) and the position angles for each target are given.

We quote photometry in Table 1 from the UK Schmidt $R$ original survey plates ($R_2$) because these data are, in general, of higher signal-to-noise and more uniformly calibrated than that from the ESO$-R$ copy plates ($R_1$). In addition, red objects sometimes do not have reliable detections at $B_J$, while blue objects are often faint on $I$ plates. Note that the absolute calibration of the individual passbands is subject to systematic errors that increase as the brightness of the source increases (Hambly et al. 2001b). However, because corrections to colors

TABLE 1
SuperCOSMOS-RECONS Search Data for Objects with $\mu > 1\farcs0\ \mathrm{yr}^{-1}$ and $R < 16.5$ Found between $\delta = -57\fdg5$ and $-90°$

| Object | R.A.[a] (J2000.0) | Decl.[a] (J2000.0) | $\mu$[b] | $\sigma_\mu$[b] | P.A.[b] | $R_2$[c] | $B_J-R_2$[c] | $R_2-I$[c] | Notes |
|---|---|---|---|---|---|---|---|---|---|
| New Discoveries | | | | | | | | | |
| SCR 0342−6407........ | 03 42 57.44 | −64 07 56.4 | 1.071 | 0.023 | 141.42 | 15.13 | 2.04 | 2.79 | Short time span for $\mu$ |
| SCR 1138−7721........ | 11 38 16.82 | −77 21 48.8 | 2.141 | 0.007 | 286.77 | 14.12 | 2.33 | 2.66 | Found twice |
| SCR 1845−6357[d]...... | 18 45 05.09 | −63 57 47.7 | 2.558 | 0.012 | 74.80 | 16.33 | ... | 3.80 | Blended in $B_J$ |
| SCR 1848−6855........ | 18 48 21.14 | −68 55 34.5 | 1.287 | 0.013 | 194.38 | 16.07 | ... | 2.11 | Blended in $B_J$ |
| SCR 2012−5956........ | 20 12 31.79 | −59 56 51.6 | 1.440 | 0.011 | 165.62 | 15.63 | 1.03 | 0.50 | Blue object |
| Previously Known Objects | | | | | | | | | |
| LHS 124.................... | 00 49 29.05 | −61 02 32.8 | 1.126 | 0.019 | 93.86 | 10.78 | 2.33 | 1.59 | |
| LHS 128.................... | 00 57 19.78 | −62 14 43.7 | 1.061 | 0.023 | 81.32 | 8.40 | 2.16 | 0.94 | |
| LHS 145.................... | 01 43 00.99 | −67 18 30.5 | 1.083 | 0.013 | 197.36 | 13.18 | 0.58 | 0.27 | |
| LHS 150.................... | 02 07 23.25 | −66 34 11.5 | 1.773 | 0.022 | 78.48 | 9.79 | 2.40 | 1.33 | |
| LHS 160.................... | 02 52 22.18 | −63 40 47.6 | 1.174 | 0.017 | 58.16 | 9.80 | 2.36 | 1.58 | |
| LHS 195.................... | 04 38 22.35 | −65 24 57.6 | 1.437 | 0.013 | 30.11 | 8.70 | 1.17 | 0.75 | |
| LHS 199.................... | 04 55 57.72 | −61 09 46.6 | 1.102 | 0.011 | 124.08 | 10.92 | 2.31 | 1.67 | |
| LHS 204.................... | 05 13 05.30 | −59 38 43.9 | 1.079 | 0.010 | 58.97 | 7.49 | 1.18 | 0.44 | Poor photometry[e] |
| LHS 205.................... | 05 16 59.72 | −78 17 20.6 | 1.139 | 0.012 | 177.15 | 10.74 | 2.09 | 1.67 | |
| LHS 34...................... | 07 53 08.15 | −67 47 31.6 | 2.128 | 0.009 | 135.75 | 13.55 | 1.02 | 0.45 | |
| LHS 263.................... | 09 17 05.36 | −77 49 23.7 | 1.045 | 0.009 | 141.21 | 12.15 | 2.02 | 2.27 | |
| LHS 268.................... | 09 24 20.94 | −80 31 21.1 | 1.284 | 0.011 | 11.94 | 9.37 | 1.19 | 0.25 | |
| LHS 271.................... | 09 42 46.45 | −68 53 06.0 | 1.150 | 0.008 | 357.17 | 11.24 | 2.52 | 2.22 | |
| LHS 328.................... | 12 28 40.09 | −71 27 51.4 | 1.183 | 0.010 | 338.89 | 12.88 | 1.93 | 1.83 | |
| LHS 329.................... | 12 28 43.10 | −71 27 56.4 | 1.172 | 0.007 | 338.10 | 14.99 | 2.00 | 2.31 | |
| LHS 475.................... | 19 20 54.36 | −82 33 16.3 | 1.278 | 0.012 | 164.26 | 11.83 | 1.91 | 1.69 | |
| LHS 493.................... | 20 28 03.78 | −76 40 15.9 | 1.444 | 0.011 | 149.11 | 12.93 | 1.97 | 2.20 | |
| LHS 499.................... | 20 51 41.64 | −79 18 40.1 | 1.221 | 0.013 | 143.89 | 10.81 | 2.25 | 1.38 | |
| PJH 4051................... | 21 15 15.20 | −75 41 52.4 | 1.079 | 0.009 | 143.58 | 13.37 | 2.10 | 2.24 | Pokorny et al. (2003) |
| J2231−7515.............. | 22 30 33.46 | −75 15 24.3 | 1.865 | 0.007 | 167.59 | 16.21 | 1.78 | 0.64 | Scholz et al. (2002) |
| J2231−7514.............. | 22 30 39.95 | −75 13 55.3 | 1.873 | 0.008 | 167.57 | 15.82 | 1.45 | 0.60 | Scholz et al. (2002) |
| LHS 531.................... | 22 55 45.46 | −75 27 31.4 | 1.484 | 0.011 | 224.20 | 9.39 | 2.17 | 1.93 | |
| LHS 532.................... | 22 56 24.69 | −60 03 49.4 | 1.076 | 0.011 | 208.73 | 13.19 | 2.21 | 2.53 | |

Note.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.
[a] Coordinates are precessed and proper-motion–corrected to equinox and epoch J2000.0 and are accurate to $\pm0\farcs3$ (e.g., Hambly et al. 2001a).
[b] Units of proper motion are arcseconds per year; position angle (P.A.) is measured in degrees east of north.
[c] As described in the text, individual passbands magnitudes are only accurate to $\sim$0.3 mag, while color indexes are accurate to $\sim$0.1 mag. Passbands are photographic: $B_J$, $R_{59F}$, and $I_{IVN}$.
[d] This object was also discovered in the final survey of Pokorny (Pokorny et al. 2004).
[e] This object is very bright and has a heavily saturated $R_2$ image—here, we have quoted $R_1$ (ESO−$R$) photometry, but note that all the photographic photometry for this object is potentially subject to large systematic errors.

are applied to the data with respect to the $B_J$ plates, these systematic errors are not present in color indexes (e.g., $B_J-R_2$, $R_2-I$). Consequently, the relative accuracy of SSS color indexes is much better than the absolute accuracy of individual passband photometry. As expected, the five new stars are fainter ($R_2 = 14.12$–$16.33$) than nearly all of the known stars ($R_2 = 7.49$–$14.99$) except the double white dwarf system ($R_2 = 15.82$ and 16.21) found by Scholz et al. (2002) using SuperCOSMOS data.

### 3.1. *Completeness and Other Checks*

We make no claim as to the absolute completeness of our new SCR search at this preliminary stage. However, we note that in the area surveyed, there are 169 LHS stars; we recover 127 of these. At first sight, this success rate of 75% seems rather poor, but this test requires closer examination. The LHS catalog is biased (particularly so in the southern hemisphere) toward brighter magnitudes, and the SCR search employs deep, sky-limited Schmidt survey plates upon which stars with $m < 10$ have heavily saturated and large, extended images. Moreover, the surveyed region in Figure 1 is at generally low Galactic latitude. LHS objects missed by our procedure are lost because of blending problems on the source plates and the consequent failure of the standard SuperCOSMOS image analysis software (Hambly et al. 2001b) in unscrambling and/or accurately parameterizing deblended components. This is illustrated in Figure 2, where the $B_J$ images of SCR 1845−6357 and SCR 1848−6855 are blended to such an extent as to render their $B_J$ parameters unusable (e.g., Table 1). Blending is particularly problematic for brighter images and, as already stated, the deep sky-limited Schmidt survey plates are not well suited to studies of stars brighter than $m \sim 10$. If we limit the LHS completeness comparison to magnitudes $R > 10.0$, we recover 112 out of 130 stars—a somewhat improved 86% success rate. If we further limit the comparison to stars with $\mu > 1\farcs0\ \mathrm{yr}^{-1}$, we recover 18 out of 18 LHS stars—100% success. Hence our search is most successful in the region of parameter space where the LHS is least complete: at fainter magnitudes and high proper motions. Note that images of moving stars are more susceptible to crowding than

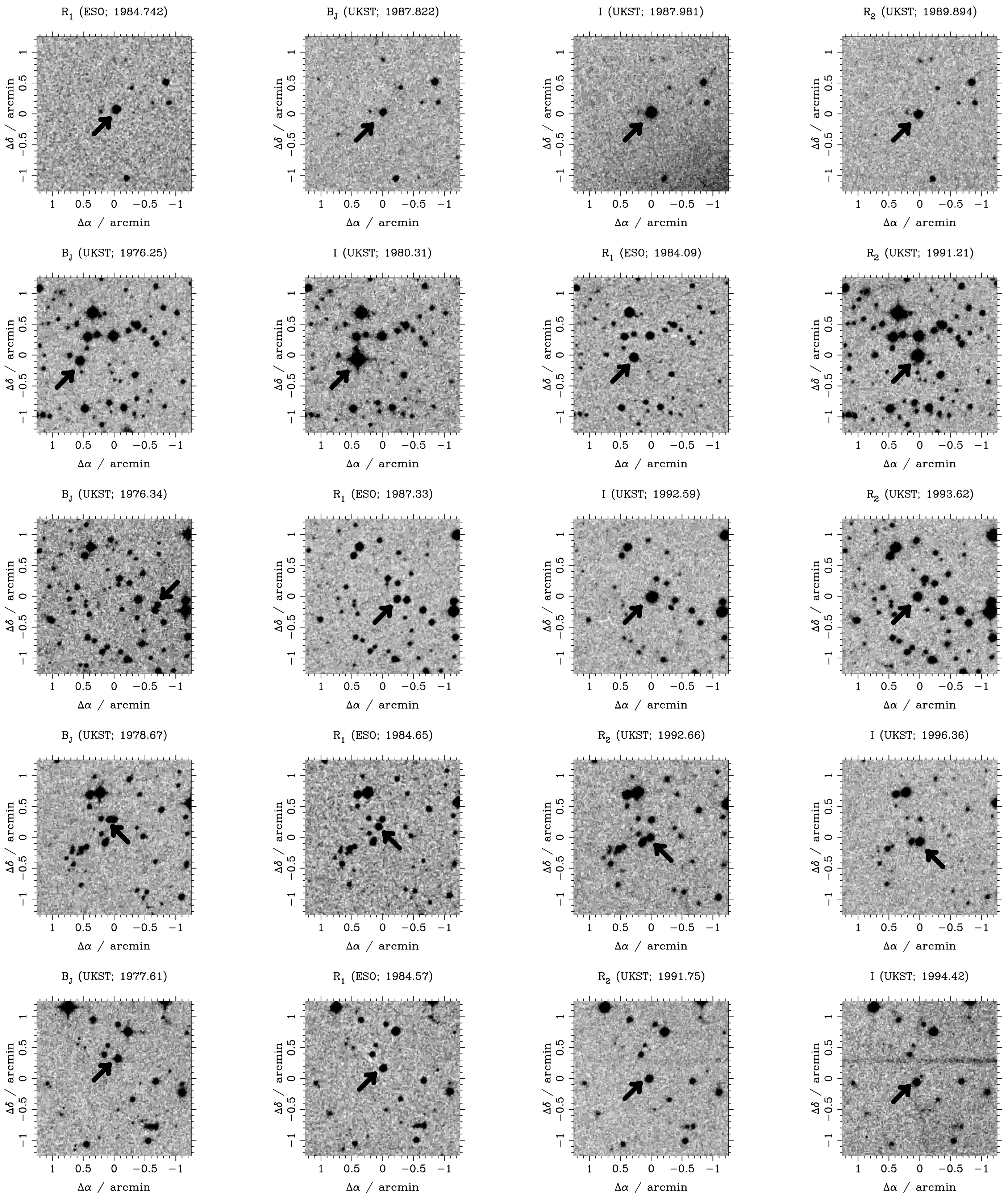


FIG. 2.—"Postage stamp" finders for the five newly discovered high proper motion stars. Rows are (1) SCR 0342−6407, (2) SCR 1138−7721, (3) SCR 1845−6357, (4) SCR 1848−6855, and (5) SCR 2012−5956. In each case, the four images are the $B_J$, $R_1$, $R_2$, and $I$ images in chronological order. Black arrows indicate the star in question in each case.

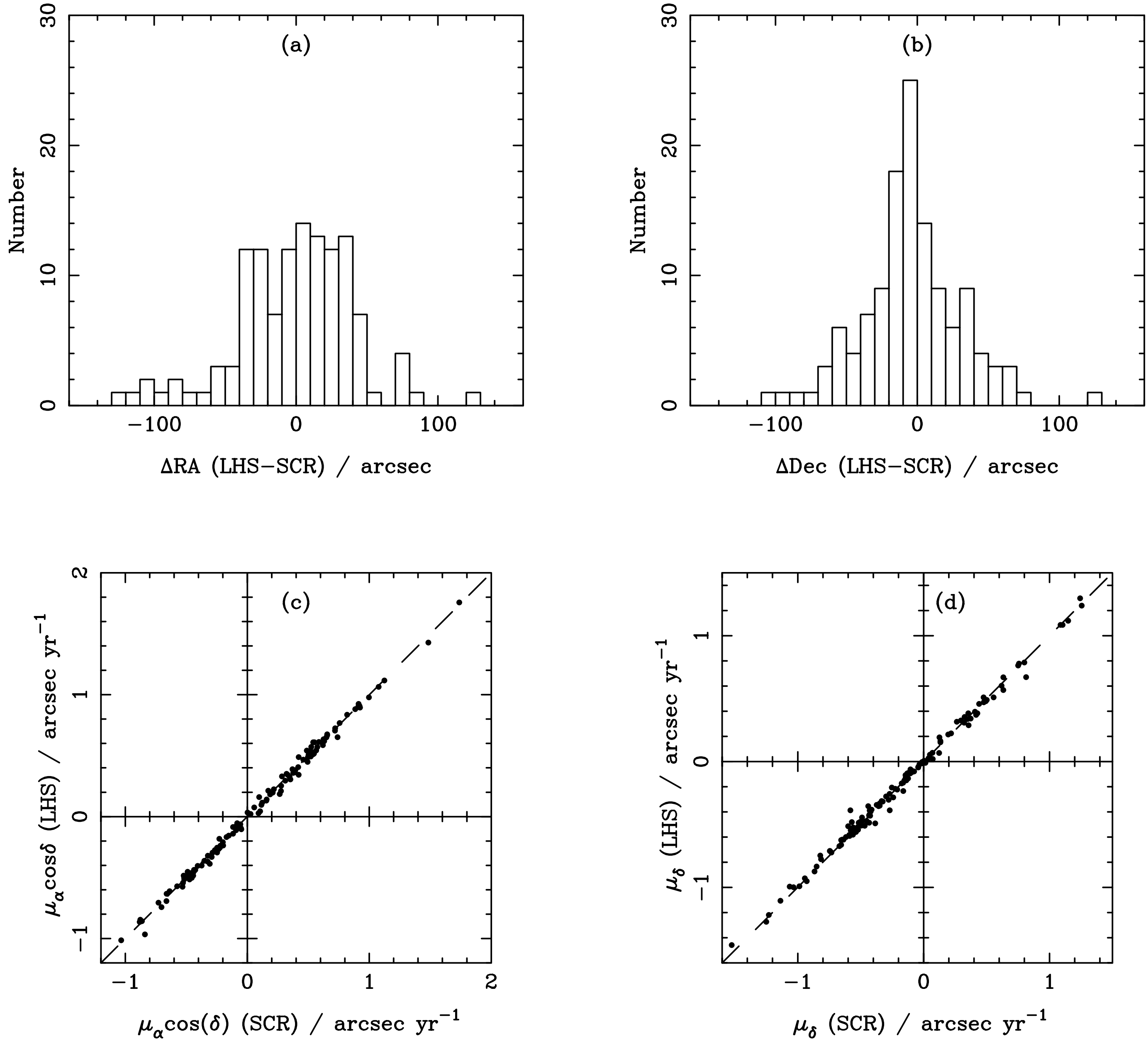


Fig. 3.—Comparison of LHS astrometry with new data from the SCR search: (*a*) right ascension, (*b*) declination, (*c*) proper motion in right ascension, and (*d*) proper motion in declination. Dashed lines in (*c*) and (*d*) are $y = x$ lines indicating perfect agreement.

nonmoving stars. If a high proper motion star is irretrievably blended on one *R* plate or on two or more of any of the four SSS plates, the SCR trawl will not detect it. Images of slow-moving stars are, of course, likely to be isolated on all plates if they are isolated on one; this is not the case for fast-moving stars, especially when they are traversing a crowded field. If we compare SCR success versus LHS for $\mu > 1''\!.0$ yr$^{-1}$ *without* a magnitude cut of $R > 10.0$, we recover 20 out of 29 stars—this low success rate of 69% illustrates the difficulty of finding bright, high proper motion stars using deep, sky-limited Schmidt plates. These 20 stars are listed in Table 1 with their LHS numbers.

The sample of 127 recovered LHS objects provides a control against which the SCR astrometric measurements were compared. In Figures 3 and 4 we show a comparison of our astrometric results with those of the LHS as originally published and using revised data (Bakos et al. 2002). In both cases, positions have been precessed and proper-motion–corrected to a common equinox and epoch (J2000.0 for both). Interestingly, although the Bakos et al. positions are far superior to the original LHS values, their proper motion determinations are clearly inferior, even allowing for the objects labelled "B" or "b" in their list (Fig. 4, *open circles*). The SCR and LHS proper motions are in much better agreement, indicating the quality of Luyten's original measurements. While the Bakos et al. positions are a vast improvement and enable easy recovery of LHS stars (e.g., as has been done here), their proper-motion estimates should not be used in place of the original LHS measurements.

## 4. DATA FROM 2MASS: INFRARED PHOTOMETRY

The infrared *J*, *H*, and $K_s$ photometry has been extracted from 2MASS using OASIS. Because these objects are high proper motion stars, all of them were manually identified

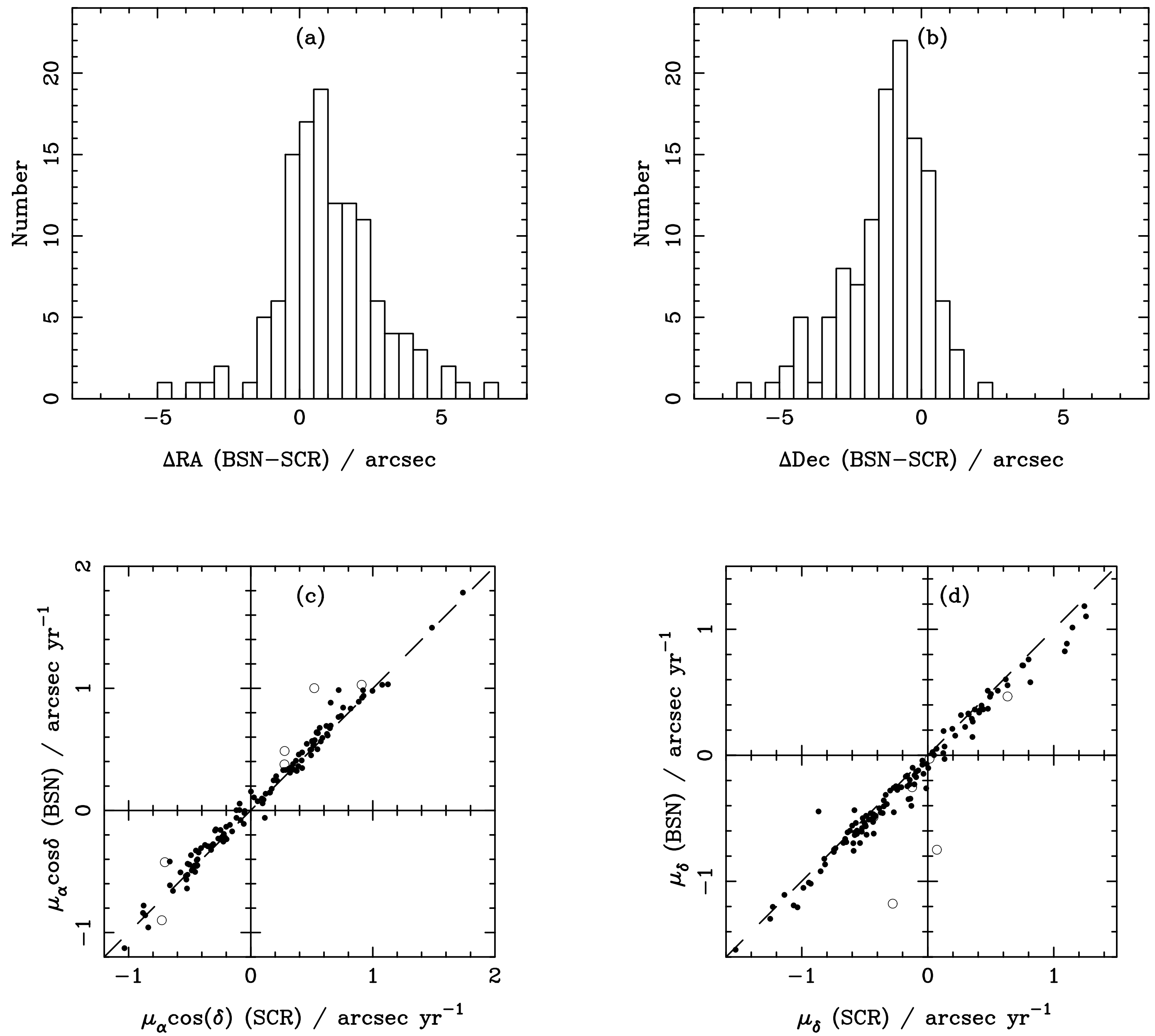


Fig. 4.—Comparison of revised astrometry (Bakos et al. 2002) with new data from the SCR search for LHS stars: (*a*) right ascension, (*b*) declination, (*c*) proper motion in right ascension, and (*d*) proper motion in declination. Open circles in (*c*) and (*d*) indicate sources for which Bakos et al. report unreliable proper-motion measurement "for some reason."

by comparison with finding charts instead of retrieving data by setting a search radius around a given right ascension and declination. The photometry is given in Table 2 for both the new SCR stars and the known stars. The errors (and here we adopt the $x_m$ sigcom errors, where $x$ is $j$, $h$, or $k$) that give a measure of the total photometric uncertainty, including global and systematic terms, are 0.02–0.03 mag in most cases and are less than 0.05 mag in all cases except SCR 2012−5956 (0.11 at $H$ and no given error at $K_s$ because it is at the limit of $K_s$-band detectability), J2231−7515 (0.06 at $H$ and 0.12 at $K_s$), and J2231−7514 (0.06 at $H$ and 0.08 at $K_s$). The 2MASS frames have also been used to confirm the proper motion for all five newly discovered stars.

The infrared photometry is useful because it permits a color extension from the optical $B_J$ band to $K_s$, thereby spanning more than a factor of 4 in effective wavelength. Diagnostics bridging the photographic and infrared bands are particularly good for the detection of blue and very red objects. $R_2$–$K_s$ is given in Table 2 as a color indicator because for the faintest red objects $B_J$ is not available. Given that SCR 2012−5956 is a fast-moving, faint object, yet appears rather blue, with $R_2 - H = 0.40$ (the value for $R_2 - K_s = 0.22$ is suspect because of the 2MASS faint $K_s$ limit), it is almost certainly a white dwarf. Computation of its reduced proper motion $H_R = m_R + 5 \log \mu + 5$ and $B_J$–$R_2$ places it firmly in the region of spectroscopically confirmed white dwarfs in Figure 1 of Oppenheimer et al. (2001). It is also evident that SCR 1845−6357 is a very red object ($R_2 - K_s = 7.82$) and therefore likely to be quite close, given its bright apparent magnitudes.

TABLE 2

Infrared Photometry for Objects with $\mu > 1''.0\ \mathrm{yr}^{-1}$ and $R < 16.5$ Found between $\delta = -57^\circ.5$ and $-90^\circ$

| Object | $J$ | $H$ | $K_s$ | $R_2-K_s$ | Notes |
| --- | --- | --- | --- | --- | --- |
| New Discoveries | | | | | |
| SCR 0342−6407..... | 11.32 | 10.89 | 10.58 | 4.55 | |
| SCR 1138−7721..... | 9.40 | 8.89 | 8.52 | 5.60 | |
| SCR 1845−6357..... | 9.54 | 8.97 | 8.51 | 7.82 | Very red |
| SCR 1848−6855..... | 11.89 | 11.40 | 11.10 | 4.97 | |
| SCR 2012−5956..... | 14.93 | 15.23 | 15.41 | 0.22 | White dwarf, $K_s$ suspect |
| Previously Known Objects | | | | | |
| LHS 124................. | 8.63 | 8.09 | 7.84 | 2.94 | |
| LHS 128................. | 7.08 | 6.49 | 6.28 | 2.12 | |
| LHS 145................. | 12.87 | 12.66 | 12.58 | 0.60 | White dwarf |
| LHS 150................. | 8.13 | 7.61 | 7.36 | 2.42 | |
| LHS 160................. | 7.67 | 7.12 | 6.83 | 2.97 | |
| LHS 195................. | 8.51 | 8.19 | 8.09 | 0.61 | |
| LHS 199................. | 9.04 | 8.51 | 8.31 | 2.61 | |
| LHS 204................. | 8.32 | 8.05 | 8.00 | −0.51 | Poor photographic photometry |
| LHS 205................. | 8.07 | 7.44 | 7.20 | 3.55 | |
| LHS 34................... | 12.73 | 12.48 | 12.36 | 1.19 | White dwarf |
| LHS 263................. | 8.33 | 7.77 | 7.45 | 4.71 | |
| LHS 268................. | 8.89 | 8.53 | 8.46 | 0.91 | |
| LHS 271................. | 7.95 | 7.39 | 7.04 | 4.20 | |
| LHS 328................. | 9.81 | 9.30 | 9.05 | 3.83 | |
| LHS 329................. | 10.98 | 10.50 | 10.18 | 4.81 | |
| LHS 475................. | 8.56 | 8.00 | 7.69 | 4.15 | |
| LHS 493................. | 9.36 | 8.88 | 8.60 | 4.33 | |
| LHS 499................. | 8.46 | 7.91 | 7.66 | 3.14 | |
| PJH 4051................ | 10.14 | 9.60 | 9.33 | 4.05 | |
| J2231−7515........... | 14.86 | 14.82 | 14.72 | 1.49 | White dwarf |
| J2231−7514........... | 14.66 | 14.66 | 14.44 | 1.38 | White dwarf |
| LHS 531................. | 6.62 | 6.08 | 5.81 | 3.58 | |
| LHS 532................. | 8.98 | 8.36 | 8.11 | 5.08 | |

## 5. NEW RELATIONS FOR ESTIMATING PHOTOMETRIC DISTANCES

In order to develop reliable color-$M_{K_s}$ relations, both SuperCOSMOS and 2MASS were searched for stars in the RECONS 10 pc sample. These stars are used because they generally have high-quality trigonometric parallax values and have been vetted better than any other sample of stars for close companions that would corrupt flux and color measurements.

Photographic $B_J$, $R_2$, and $I$ magnitudes were extracted for all stars south of the current declination cutoff of SuperCOSMOS (+3°.0). Single stars with reliable (unblended, unsaturated) photographic magnitudes were then examined in 2MASS, from which $JHK_s$ photometry was obtained. The final cut provided 54 main-sequence, single stars with reliable magnitudes in all six bandpasses. These were supplemented with one additional object, GJ 1001B (=LHS 102B), an L dwarf found in all bands but $B_J$. (The complete sample and magnitudes can be obtained from the authors upon request.)

In total, there are 15 possible color-$M_{K_s}$ relations that can be derived from the six bandpasses. Of these, $B_J-R_2$, $J-H$, $J-K$, and $H-K$ are not useful because in each case the range in color is quite restricted and does not predict reliable $M_{K_s}$ values. The remaining 11 relations are used as an ensemble to generate up to 11 different distance estimates for each star, provided that the star's color falls within the valid range. Each relation is locked to $M_{K_s}$ because practically all undiscovered nearby stars (and many brown dwarfs) of interest will have a reliable $K_s$ in 2MASS. Four exemplary relations are illustrated in Figure 5. The $B_J-I$ and $B_J-K_s$ relations represent the largest range in color for photographic only and photographic/infrared colors. The $B_J-K_s$ relation, in particular, shows the great strength in combining optical and infrared data, spanning more than 6 full magnitudes in color. The less reliable $R_2-I$ and $I-J$ relations are also illustrated. In these cases, the colors span only ~3.5 mag, and the scatter in the photographic magnitudes compromises the relations. Nonetheless, they still add weight to the final ensemble distance estimates. Details for each fit, including the number of objects used to create the fit, its applicable range, the coefficients, and the rms in magnitudes, are given in Table 3.

To provide a measure of the ensemble technique's reliability, the RECONS stars of known distance have been run back through the relations. Each star has up to 11 different distance estimates that are combined to produce a mean distance estimate and error, represented by the standard deviation of the individual estimates. The average offset between the estimated and true distances is 26%, which is remarkable given the imprecise nature of the photographic magnitudes, and of course, the intrinsic cosmic scatter in the stars due to metallicity and age effects. These relations can be used within the stated ranges for single, main-sequence stars with reliable magnitudes found in SuperCOSMOS and 2MASS. The distances derived using these relations will, of course, not be reliable for subdwarfs. Even for main-sequence stars, in a few cases the effects of age and metallicity will be severe enough that the predicted and true

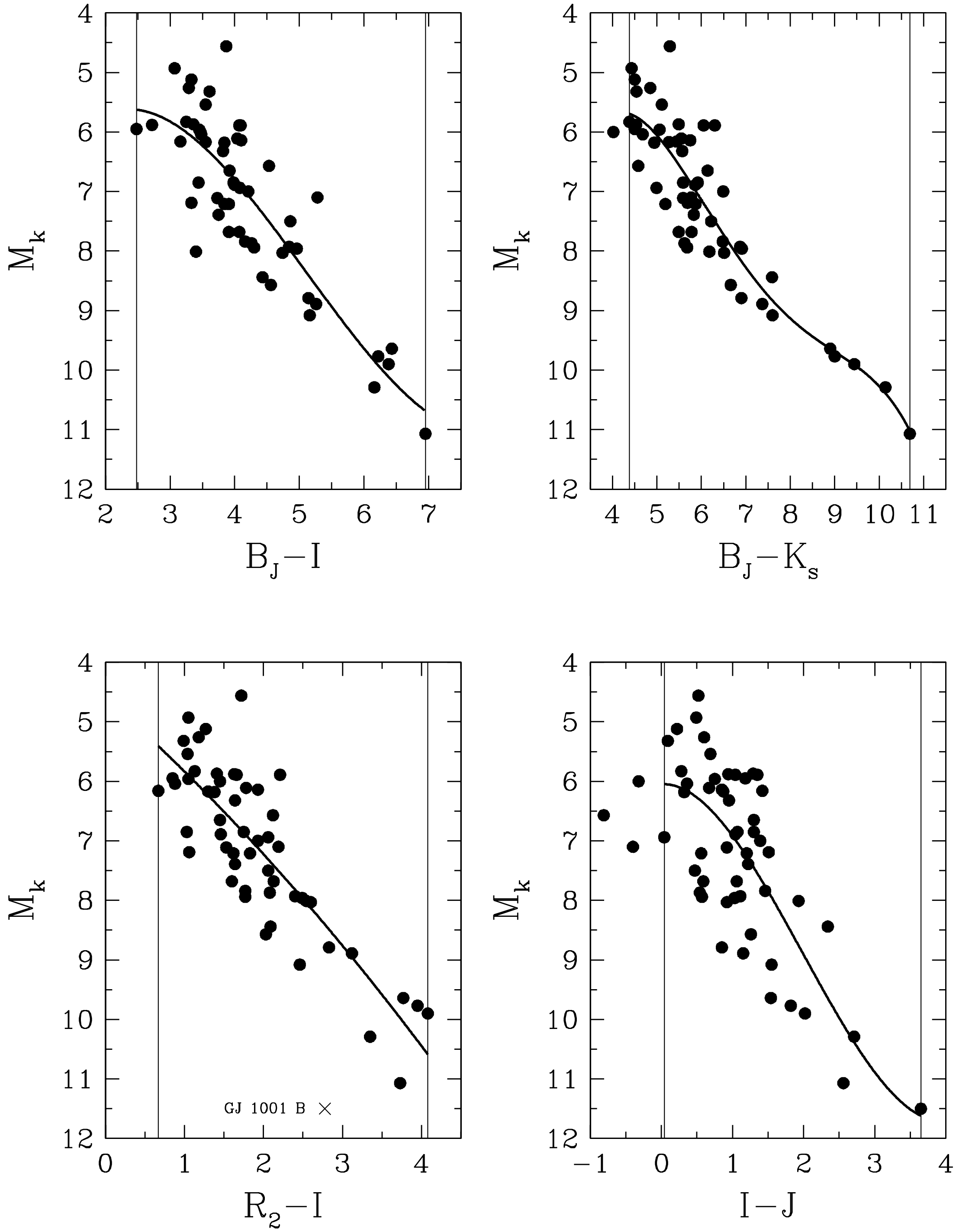


Fig. 5.—Four representative color-$M_{K_s}$ relations used to estimate distances to main-sequence stars. The points are for stars within 10 pc. Details about the fits are given in Table 3. In the $R_2-I$ plot, the cross represents the L dwarf GJ 1001B (=LHS 102B), which was not used in the fit because the relation doubles back at such faint $M_{K_s}$.

distances will differ by more than 50%, as is the case for 7 of the 55 stars used in the relations. In comparison, 14 of the 55 stars have estimated distances within 10% of their true distances.

## 6. DISCUSSION

Table 4 gives distance estimates and errors for the new SCR discoveries and the previously known stars that were recovered during the SCR search. Two of the four red SCR stars are likely to be within the 10 pc horizon of RECONS. SCR 1845−6357 is likely to be one of the nearest few dozen stars. Based on preliminary CCD *VRI* photometry and photometric distance relations for white dwarfs, we estimate a distance of ∼15–25 pc for SCR 2012−5956.

Only 11 of the 23 previously known objects have trigonometric parallax measurements, as given in the Yale Parallax Catalogue (van Altena et al. 1995; column labeled "Dist YPC") and from the *Hipparcos* mission (ESA 1997; column labeled "Dist HIP"). In general those that have trigonometric distances match the distance estimates well, although LHS 128 and LHS 531 may be unresolved multiples because they are

TABLE 3

DETAILS OF PHOTOMETRIC DISTANCE RELATIONS

| Color | No. Stars in Fit | Applicable Range | Coeff. 1 (× color$^4$) | Coeff. 2 (× color$^3$) | Coeff. 3 (× color$^2$) | Coeff. 4 (× color) | Coeff. 5 (constant) | rms (mag) |
|---|---|---|---|---|---|---|---|---|
| $B_J-R_2$ | 54 | Not useful | ... | ... | ... | ... | ... | ... |
| $B_J-I$ | 54 | 2.48–6.95 | ... | −0.06597 | +1.00958 | −3.65843 | +9.49477 | 0.74 |
| $B_J-J$ | 54 | 3.53–9.51 | +0.01720 | −0.44789 | +4.18392 | −15.61513 | +25.69047 | 0.62 |
| $B_J-H$ | 54 | 4.15–10.22 | +0.01736 | −0.49708 | +5.13558 | −21.71069 | +37.74852 | 0.64 |
| $B_J-K_s$ | 54 | 4.38–10.69 | +0.01385 | −0.41706 | +4.52981 | −20.08433 | +36.70961 | 0.63 |
| $R_2-I$ | 54 | 0.67–4.08 | ... | ... | +0.07403 | +1.16691 | +4.59375 | 0.76 |
| $R_2-J$ | 55 | 1.08–6.43 | +0.03685 | −0.53287 | +2.68760 | −4.56720 | +8.21182 | 0.70 |
| $R_2-H$ | 55 | 1.68–7.49 | +0.02066 | −0.37082 | +2.36926 | −5.37494 | +9.74196 | 0.72 |
| $R_2-K_s$ | 55 | 1.92–8.15 | +0.01260 | −0.25196 | +1.78947 | −4.36444 | +9.10891 | 0.71 |
| $I-J$ | 55 | 0.04–3.65 | ... | −0.19062 | +1.13456 | −0.07582 | +6.05024 | 1.00 |
| $I-H$ | 55 | 0.61–4.71 | ... | −0.17978 | +1.40873 | −1.58307 | +6.60017 | 1.03 |
| $I-K_s$ | 55 | 0.91–5.37 | ... | −0.16765 | +1.47110 | −2.23929 | +7.04432 | 0.99 |
| $J-H$ | 55 | Not useful | ... | ... | ... | ... | ... | ... |
| $J-K_s$ | 55 | Not useful | ... | ... | ... | ... | ... | ... |
| $H-K_s$ | 55 | Not useful | ... | ... | ... | ... | ... | ... |

significantly more distant than predicted. All of the SCR discoveries and previously known stars without trigonometric measurements that are predicted to be within 25 pc have been included in our Cerro Tololo Inter-American Observatory Parallax Investigation (CTIOPI), as indicated in the notes column. Several of these stars will likely fall within the 10 pc horizon of the RECONS sample.

It is useful to assess briefly the complete, whole-sky sample of high proper motion stars as it is currently known. At Georgia State, one of the authors of this work (Jao) has compiled a comprehensive list of objects with $\mu > 1''.0$ yr$^{-1}$. Although this list is the subject of a future paper, we note here that the distribution of systems is, as expected, tipped to the north. As of 2003 January 1, the counts of published systems

TABLE 4

DISTANCE ESTIMATES AND TRUE DISTANCES FOR OBJECTS WITH $\mu > 1''.0$ yr$^{-1}$ AND $R < 16.5$ FOUND BETWEEN $\delta = -57^\circ.5$ AND $-90^\circ$

| Object | No. Est. | Dist. Est. | Dist. YPC | Dist. HIP | Notes |
|---|---|---|---|---|---|
| New Discoveries | | | | | |
| SCR 0342−6407..... | 11 | 39.3 ± 11.7 | ... | ... | CTIOPI |
| SCR 1138−7721..... | 11 | 8.8 ± 1.7 | ... | ... | CTIOPI |
| SCR 1845−6357..... | 6 | 3.5 ± 0.7 | ... | ... | CTIOPI, no $B_J$ data, $R_2-J$ too red |
| SCR 1848−6855..... | 7 | 34.8 ± 9.8 | ... | ... | CTIOPI |
| SCR 2012−5956..... | 0 | ... | ... | ... | CTIOPI, white dwarf, distance 15–25 pc |
| Previously Known Objects | | | | | |
| LHS 124.................. | 11 | 19.6 ± 1.2 | ... | ... | CTIOPI |
| LHS 128.................. | 8 | 11.8 ± 1.1 | 16.9 ± 2.8 | 19.4 ± 0.4 | Too blue in 3 colors, multiple? |
| LHS 145.................. | 0 | ... | ... | ... | CTIOPI, white dwarf |
| LHS 150.................. | 11 | 18.3 ± 1.6 | 15.5 ± 4.6 | ... | CTIOPI |
| LHS 160.................. | 11 | 12.2 ± 0.8 | 12.3 ± 2.4 | 11.5 ± 0.3 | |
| LHS 195.................. | 0 | ... | Not useful | 58.8 ± 3.4 | Too blue, too bright |
| LHS 199.................. | 11 | 26.9 ± 3.2 | 22.5 ± 5.8 | ... | CTIOPI |
| LHS 204.................. | 0 | ... | 35.1 ± 13.5 | 68.7 ± 4.8 | Too blue, too bright |
| LHS 205.................. | 11 | 12.0 ± 0.8 | 12.9 ± 1.9 | ... | CTIOPI |
| LHS 34.................... | 0 | ... | 7.1 ± 0.4 | ... | CTIOPI, white dwarf |
| LHS 263.................. | 11 | 8.2 ± 1.2 | ... | ... | CTIOPI |
| LHS 268.................. | 0 | ... | 46.3 ± 21.2 | 60.8 ± 3.7 | Too blue, too bright |
| LHS 271.................. | 11 | 8.0 ± 1.4 | ... | ... | CTIOPI |
| LHS 328.................. | 11 | 25.1 ± 3.1 | ... | ... | |
| LHS 329.................. | 11 | 27.4 ± 4.6 | ... | ... | |
| LHS 475.................. | 11 | 11.8 ± 3.0 | ... | ... | CTIOPI |
| LHS 493.................. | 11 | 16.5 ± 1.9 | ... | ... | CTIOPI |
| LHS 499.................. | 11 | 16.7 ± 1.3 | 15.9 ± 3.1 | ... | |
| PJH 4051................. | 11 | 26.1 ± 3.5 | ... | ... | |
| J2231−7515............ | 0 | ... | ... | ... | CTIOPI, white dwarf |
| J2231−7514............ | 0 | ... | ... | ... | CTIOPI, white dwarf |
| LHS 531.................. | 11 | 6.2 ± 0.5 | 8.3 ± 0.7 | 8.6 ± 0.1 | Multiple? |
| LHS 532.................. | 11 | 9.1 ± 1.2 | ... | ... | CTIOPI |

in sky quartets of equal area are 143 from $\delta = +90°$ to +30°, 153 from $\delta = +30°$ to +00°, 127 from $\delta = -00°$ to $-30°$, and 126 from $\delta = -30°$ to $-90°$, yielding a total of 549 systems. The 8% overabundance in the north is an indicator that more fast-moving systems are likely to be found at southern declinations. The five new objects reported here are another step toward rectifying this incompleteness in the southern sky.

## 7. CONCLUSIONS

The five new stars reported here provide important new nearby star candidates, with proper motions ranking them in the top few hundred stellar systems. The two fastest movers, SCR 1845−6357 and SCR 1138−7721, rank, respectively, as the 34th and 54th fastest proper motion systems known. These are merely the harbingers of a set of new high proper motion objects that remain to be discovered in the southern sky using SuperCOSMOS Sky Survey data. In a follow-up paper (Henry et al. 2004), we present accurate optical photoelectric photometry and spectroscopy of high proper motion objects in this portion of the SCR survey, thereby revealing their true nature and allowing us to refine the distance estimates. In addition to the five stars highlighted here, there are 115 additional new discoveries with $\mu = 0\farcs4$–$1\farcs0$ yr$^{-1}$ that will also be the subjects of future efforts.

Such nearby stars are, of course, useful for bolstering the population statistics of the Galaxy and move us closer to an accurate census of the Sun's neighbors. The momentum for discovering new nearby stars comes from many directions, including the identification of systems for stellar mass determinations, planet searches, the detection of signatures of life, and SETI, simply because proximity is a key element in any search in which resolution is required or the intrinsic signals may be weak. The SCR search reported here is merely in its initial phase and will undoubtedly reveal many new nearby stars as we continue to push northward. This astrometric search is complementary to photometric and spectroscopic searches for nearby stars, such as Reid & Cruz (2002) and Henry et al. (2002). All of these searches continue to yield new nearby stars, bringing about a sort of nearby star renaissance, as large-scale surveys and significant computer power are turned to the discovery of solar neighbors.

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