Stars in the USNO-B1 Catalog with Proper Motions
Between 1.0 and 5.0 arcseconds per year

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ABSTRACT

This paper examines a subset of objects from the USNO-B1 catalogue with listed proper motions between 1.0 and 5.0 arcseconds per year. We look at the degree of contamination within this range of proper motions, and point out the major sources of spurious high proper motion objects. Roughly 0.1% of the objects in the USNO-B1 catalogue with listed motions between 1.0 and 5.0 arcseconds per year are real. Comparison with the revised version of Luyten's Half Second catalogue indicates that USNO-B1 is only about 47% complete for stars in this range. Preliminary studies indicate that there may be a dip in completeness in USNO-B1 for objects with motions near 0.1 arcseconds per year. We also present two new stars with motions between 1.0 and 5.0 arcseconds per year, 36 new stars with confirmed motions between 0.1 and 1.0 arcseconds per year, several new common proper motion pairs, and the recovery of LHS 237a (VBs3).

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1. Introduction

Can the USNO-B1 catalogue (Monet et al. 2003) be used to find previously unknown objects with large proper motions? Our motivation for examining the set of objects with large proper motions that are in the USNO-B1 catalogue is two-fold. First, we are looking to see if we have found any objects with large proper motions that were missed in previous surveys; these could well be interesting in their own right, and for studies of the local neighborhood. Second, we would like to understand how well the motion finding algorithm used in the construction of USNO-B1 worked, and how contaminated is the high motion sample.

Because objects with large proper motions tend to be relatively nearby, they are often intrinsically interesting astronomically. Given this consideration, we would like to know what fraction of

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objects in USNO-B1 with listed large motions are actually real, and how we can go about selecting clean samples of objects with large motions. In the construction of USNO-B1, Monet et al. (2003) erred on the side of retaining dubious objects. Some of the lessons learned here about cleaning up sub-samples should be readily applicable to many other subsets of objects in USNO-B1.

Gould (2003) has already examined in some detail how well USNO-B1 has done in finding previously known objects that are in the revised version of Luyten's Two Tenths Catalogue (Luyten 1979b; Gould & Salim 2003; Salim & Gould 2003, hereafter NLTT) (which contains star with $\mu > 0.180\,\mathrm{arcsec\,yr^{-1}}$). Only 6% of the NLTT stars are missing from USNO-B1, and an additional 4% have what they term large errors (Gould 2003). Hence, their conclusion was that USNO-B1 is roughly 90% complete, with incompleteness rising at both the brighter and fainter ends. They also find that incompleteness increases at larger proper motions (it is roughly 30% at $\mu = 1\,\mathrm{arcsec\,yr^{-1}}$), and near the galactic plane. The proper motion values given in USNO-B1 are generally in agreement with those in the NLTT.

The aim here is complementary. We are looking at the contents of the catalogue, and trying to assess what fraction of the moving objects in the high motion portion of the catalogue are in fact real objects. We also wish to know if the derived motions are reasonable. For the entries in the catalogue that correspond to non-real objects, we hope to gain some understanding of their characteristics, and hence learn how to exclude them in the future.

The USNO-B1 catalogue is an all-sky catalogue that has been compiled from digitizations of 7,435 Schmidt plates taken over the last 50 years (see Table 1 for a summary of the plate material that was used). Every point on the sky is covered at several epochs and at several wavelengths, making it possible to construct a catalogue that includes positions, proper motions, optical colors, star/non-star discriminators and the appropriate uncertainties (Monet et al. 2003). This catalogue is the natural successor to the USNO-A series of catalogues (Monet et al. 1996, 1998), and should fix a number of problems associated with them. Because of the nature of the plates, the images (and hence the catalogue) are best for fainter objects (in the magnitude range $V = 14$ to 22). The Tycho-2 catalogue (Høg et al. 2000) was copied in for completeness at brighter magnitudes (Tycho-2 is complete at the 99% level down to $V_T = 11$). In regions where confusion is not the limiting factor, the catalogue is complete to photographic magnitudes $B_{\mathrm{phot}} \approx 21$ and $R_{\mathrm{phot}} \approx 20$ (Monet et al. 2003; Munn et al. 2004).

It is prudent to note that USNO-B1 is an inclusive catalogue, by which we mean that in the construction of USNO-B1, Monet et al. (2003) erred on the side of including all possible objects, real and false. The aim was to avoid removing real objects during the assembly of the catalogue, and to give users some flexibility in designing their own selection algorithms. One of the results however is that some fraction of the objects in the catalogue are either contaminated, or completely false, and it is desirable to avoid selecting these entries.

One of the key improvements of this catalogue with respect to its predecessors is the determination of proper motions for all objects in the catalogue. Proper motions provide important

information about the motions of objects, and about the structure of our Galaxy. In addition, the proper motion can be a very useful discriminant when trying to find objects meeting specific criteria (e.g. objects that are close to us or those in the halo often have large apparent proper motions). To see this, one needs only to look at how fruitful studies have been of the objects in the catalogues of high proper motion stars of Luyten (1979a,b, hereafter LHS and NLTT respectively, where LHS is the Luyten Half Second Catalogue) and Giclas et al. (1971, 1978) (e.g. proper motion information has aided in the selection of nearby objects for study), and also how much has been learned about things like the structure of the local neighborhood in the Galaxy from the Hipparcos (ESA 1997) and Tycho-2 (Høg et al. 2000) catalogues (e.g. Dehnen & Binney 1998; Olling & Dehnen 2003).

The proper motions in the USNO-B1 catalogue have some known idiosyncrasies. Among these are that the motions given are strictly relative proper motions, since least squares has set the mean motion for stars of roughly 18th magnitude to zero on a field by field basis. The component of solar motion relative to this zero point is small when compared with the motions we are interested in here.

Both Munn et al. (2004) and Gould & Kollmeier (2004) have produced improved proper motion catalogues for the region contained in the intersection of the Sloan Digital Sky Survey Data Release 1 (Abazajian et al. 2003, hereafter SDSS DR1) with USNO-B1. In both cases, the contamination problem has largely been dealt with by using SDSS DR1 data as truth, and re-calibrating the overlapping region of USNO-B1. In addition, both catalogues use sources external to our galaxy like galaxies (Munn et al. 2004) or quasars (Gould & Kollmeier 2004) found in the SDSS sample to put the revised proper motions onto an absolute scale. Munn et al. (2004) note, and we concur, that as the number of detections of an object in USNO-B1 decrease from the maximum possible of 5, the likelihood that the object is contaminated or totally false increases dramatically (see Munn et al. 2004, Fig. 11).

Section 2 explains briefly the moving object detection algorithm used in the construction of the USNO-B1 catalogue. Sections 3 and 4 discuss how we went about finding fast moving objects in the catalogue, what portion of the listed objects are real, and what additional objects we found along the way. Notes about specific objects are given in section 5. Section 6 discusses briefly a comparison of the high proper motion samples in LHS and USNO-B1. The paper concludes with a bit of discussion.

2.   Moving Object Detection Algorithm

In the construction of USNO-B1, finding objects with large proper motions was handled as a special case of measuring proper motions for all objects (the discussion here closely follows Monet et al. 2003, which should be referred to for more complete details). The search for moving objects can be broken down into two parts: the first part was to find objects that do not move, or move only a little bit, and then the second was to look for objects with large motions.

In the catalogue construction, the sky was broken up into rings of $0°\!.1$ width in declination. Each ring initially contained the complete set of detections from all of the plates (at all epochs) that intersected that ring. Though magnitudes in USNO-B1 are referred to as being of first or second epoch, in reality, the second epoch can cover a wide range of time: for example, for POSS-II, the 3 "second epoch" plates could cover as much as 10 or 15 years of time. A three arcsecond aperture was moved through each ring. The cases where only a single detection fell within the aperture were ignored at this point. If detections from one or more first epoch surveys and one or more second epoch surveys were within this aperture, then these detections were matched up as an object and those detections were removed from the lists. This should have matched up detections for objects that move less than about $60 \, \mathrm{mas\,yr^{-1}}$.

Only those detections which were not matched up under the slow motion search radius, were passed on to the high proper motion search routine. For this step, when searching a band in declination, the two adjoining bands were also included so that in fact the search regions were $0°\!.3$ in width, in steps of $0°\!.1$ in declination. The search aperture was expanded to 30 arcseconds. Within the aperture, all combinations of second epoch detections were fit for linear motion. If a fit was significant, then the motion was extrapolated back to the first epoch surveys. A search around the predicted point was done, using a search radius that scaled with the size of the extrapolated error ellipse. All possible combinations with first epoch observations were followed up. If the best fit had a standard deviation less than than 0.4 arcsec in the tangent-plane coordinates, and a motion less than 10, 3 or 1 $\mathrm{arcsec\,yr^{-1}}$ for 5, 4 or 3 survey detections respectively, then the object was considered matched and the detections were removed from the lists.

After the explicit search for high motion objects, a last effort was made to match up any remaining objects. A search aperture of 20 arcseconds was used, and all combinations of 5, 4, 3, and 2 survey detection objects were examined. The first groups of observations with a standard deviation of less than 5 arcseconds in both tangent plane coordinates were considered matched, called an object, and removed from the detection lists. Only a small fraction of the objects in USNO-B1 came from this step in the processing. Presumably, many matches made at this stage will look like high motion objects.

It is useful to point out that no use was made in the matching process of magnitude data, or star/non-star separator information. After the object matching was done, duplicate objects were removed (Monet et al. 2003).

3. Selecting Real High Motion Objects

Retrieving real objects from USNO-B1 with large proper motions is not quite as simple a task as just asking for all of the catalogue objects with motions in a given range. To demonstrate this, we chose to search for previously unknown objects with proper motions (μ) between 1.0 and 5.0 $\mathrm{arcsec\,yr^{-1}}$.

We began by requesting all objects in USNO-B1 with $1.0 \leq \mu_{\text{total}} \leq 5.0 \, \text{arcsec} \, \text{yr}^{-1}$. This netted a total of 187,134 objects (see Fig. 1(a) and (d)). We then applied some basic sanity checks. We required each object to be detected on 4 or 5 of the 5 possible surveys ($N_{FitsPts} \geq 4$) used in the construction of USNO-B1. This reduced the number of objects to 186,554. This also had the effect of removing all of the Tycho-2 stars that were added in, since the number of survey detections for these stars was set to 0 in the catalogue. Then, we required that they have position errors less than 0.999 arcsec in both RA and Dec ($\sigma_\alpha < 999 \, \text{mas}$ and $\sigma_\delta < 999 \, \text{mas}$). This decreased the number of objects to be considered to 11,019 (see Fig. 1(b) and (e)). Further limiting the sample by applying limits to the second epoch photographic R magnitude ($0 \leq R_2 \leq 18.0$), brought the total down to 3,348 objects (see Fig. 1(c) and (f)). Not too surprisingly, after the application of the basic sanity checks, most of the potential objects lie near the galactic plane, and near the celestial poles (where the plate overlap regions grow larger).

This remaining sample of 3,348 objects was next examined by eye. The catalogue data around each potential high motion object were plotted and a decision was made as to the likelihood that this was a real object with a large proper motion. Typical things to look for and select against were diffraction spikes and other artifacts caused by bright stars (see Fig. 2(center)) and extended objects. These all tended to produce groups of objects in the catalogue that are closely clumped, or show obvious large scale structure (like the linear arms of the diffraction spikes, or the arcs of the halos of bright star ghost images). 951 objects passed this somewhat subjective test. Of the other 2,397 potential objects, only 7 turned out to be real, already known objects that we failed to recognize. 672 objects were rejected as being caused by proximity to a bright star or a bright star's diffraction spikes. 1,725 objects were mis-identifications and mis-matches caused by a variety of forms of confusion (dense field, extended object(s) that created multiple detections, etc). All 7 missed real objects fell into the latter category.

Of the 951 objects reaching this stage, 177 are stars that were already flagged in USNO-B1 as being known proper motion objects, leaving us with 774 candidates to check. The objects that were left were presumed to be decent candidates for being new high proper motion stars. Images from several epochs were extracted from the USNO Image and Catalogue Archive[1] and the images of each potential object were again looked at by eye. Of these, 741 objects turned out to be confused, diffraction spikes, near a bright star, or extended objects, leaving only 33 real, moving stars. To this, we added one more star found during preliminary testing.

The 34 real, unflagged moving objects were then checked against catalogues of known objects. Nine were found to be LHS objects that somehow did not get flagged in the construction of the catalogue (including LHS 237a, which we have recovered, and about which we have more to say below). (As a side note, it is worth pointing out that just by counting the number of objects in the USNO-B1 catalogue with the "known proper motion star" bit set shows that a fair fraction of these objects that were already known did not get flagged properly in the catalogue.) Seven

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[1]http://www.nofs.navy.mil/data/fchpix/

turned out to have been found recently by Lépine et al. (2002, hereafter LSR), and three more or less simultaneously by us and Lépine (2005). One was a brown dwarf found by the DENIS survey (Delfosse et al. 2001)(DENIS-P J104814.7-395606.1). One was a halo dwarf found by Oppenheimer et al. (2001) (WD0205-053). Two other objects were found recently by Hambly et al. (2004) using SuperCOSMOS (SCR0342-6407 and SCR2012-5956). Three were found by Pokorny et al. (2003, 2004)(LEHPM 4051, 3861, 4466), one by Reylé et al. (2002)(APMPM J1957-4216), and one object was recently found by Deacon et al. (2005)(SIPS0052-6201) (see Table 2).

Of the 6 remaining objects, four are moving objects with incorrect proper motions in USNO-B1; the objects are moving, just more slowly than the catalogue indicates. One of these objects is NLTT 9526, and the other three appear to be new (see Table 3). The final 2 objects are (to the best of our knowledge) new, high proper motion stars (see Table 4). The 30 objects with proper motions larger than 1 arcseconds are plotted in Fig. 3(a) and (b) as filled triangles for the new objects and as 3–pointed stars for previously known, but unflagged objects. The 4 with proper motions less than 1 arcsecond are plotted as filled hexagons for the 3 new ones, and as a 6–pointed star for the one already known. Finder charts showing the plate material for the 2 new high proper motion objects are given in Figures 4 and 5. In all, 6%, or 213, of the 3,348 objects are stars with motions between 1 and 5 $\mathrm{arcsec\,yr^{-1}}$.

In the 774 fields that were examined by eye, over 71 of them had a total of 82 other objects with apparent proper motions. These are discussed in more detail below in section 4 on Serendipitous objects.

3.1. How to speed up the winnowing process

Did we learn anything from the winnowing process described above that would help us to generate more easily clean(er) sub-samples out of USNO-B1? Without using information from outside of USNO-B1, the following simple things can be done quickly to help preselect for objects that are likely to be real.

Specify that objects have positional errors less than 999 mas in both RA and Dec. This reduced the sample by over an order of magnitude from $\sim 10^5$ objects to 10^4 objects. In Fig. 6 are plotted the distributions of position and motion errors of the 3,348 objects examined by eye. We see that almost all the real objects have a total positional error less than 350 mas. The false objects have a much wider distribution. An optimal cut is probably closer to 350 to 500 mas.

The next simple cut that we can apply is to the proper motion error and is based on Fig. 6 (right column). This shows that most of the real high motion objects have a proper motion error less than $12\,\mathrm{mas\,yr^{-1}}$, while the false objects have a larger secondary hump at $30\,\mathrm{mas\,yr^{-1}}$.

Another thing that can be done is to insist that objects be detected on at least 4 surveys. The benefit from this one is a little less clear. For the objects with large proper motions, insisting on

detection on 4 or 5 surveys out of a possible 5 only removed 580 objects out of 187,134 (or 0.3% of the total) in the original search. It is also a reasonable to presume that the position and proper motion errors will be anti-correlated with the number of detections. On the other hand, this is a very quick and simple culling criterion to implement, as the number of detections is carried as an integer in each object's catalogue record. In addition, for objects with lower motions, there will be more catalogue objects with 3 or 2 detections, hence this will likely be more useful for searches of things other than the high proper motion objects.

It is also instructive to be aware of where in the sky you are looking. In Fig. 1(a), there is a change across the line of $\delta \approx -33°$ that is largely due to the difference in the number of first epoch plates, and the epoch difference between the first and second epochs. North of this line, the first epoch Palomar Observatory Sky Survey (hereafter POSS-I) provides two plates at a mean epoch near 1950. South of that line, the first epoch is a single red plate with a mean epoch around 1980. There is a much shorter southern temporal baseline, and there is one fewer plate per field. Internal tests done during the construction of USNO-B1 showed that each additional plate dramatically reduced the false positive rate when looking for high motion objects (D. Monet, private communication). This is not particularly surprising, as the motion is presumed to be almost linear, and it becomes increasingly unlikely that N random points will be nearly co-linear as N increases.

We can now apply magnitude related criteria. This was not done in the original search, but is a simple test that enforces an additional degree of consistency upon the data. Requiring that the difference between the first epoch red magnitude (R_1) and the second epoch red magnitude (R_2) be less than 0.5 (or 1.0) magnitudes helps to exclude improperly matched detections.

We re-did the search for high proper motion objects, this time applying all the criteria listed in this section, EXCEPT that for the number of plates criterion, we allowed either 0, 4 or 5 plates to be accepted (this meant we included the Tycho-2 stars, which are the only ones in the catalogue with a value of 0 plates set). After applying cuts based solely on the position and motion errors the sample size is reduced to 8,576, and includes 196 of 207 known and flagged high proper motion objects (not including Tycho-2 objects). Once magnitude related cuts are applied, the data volume is reduced to 1,478 objects where $|R_1 - R_2| < 0.5 \, \mathrm{mag}$ (or 2,556 for a magnitude difference of 1), including 137 (168) of the already known high proper motion objects. Finally, when we limited our list to R_2 brighter than magnitude 18 (the same de facto restriction we used in generating our original list), that left us with 688 (or 1,090) objects out of an original 187,134 (a reduction of roughly 270 times). Of the 688 (1,090) objects, all 174 known Tycho-2 stars are included, bringing down the number to search to 514 (916). 135 (163) stars are included that were flagged as previously catalogued high proper motion objects (from either Giclas' or Luyten's catalogues).

We can see that we have lost 72 (44) flagged high motion objects, since there were 207 of them found in the original extraction which only had a limit on the value of the proper motion. Of the 72 (44), 23 fall below the R_2 brighter than 18.0 magnitude cut-off. Three more had position errors larger than 350 mas in each coordinate. Another seven had proper motion errors larger

than $12 \, \mathrm{mas \, yr^{-1}}$. An additional 39 (11) were removed by the requirement that the difference in R magnitudes be less than 0.5 (1.0) magnitude(s). Magnitude related selection criteria removed the bulk of the deleted real objects, 62 (34) out of 72 (44), leaving only 10 that were caught by the position and/or motion error criteria. The magnitude criteria also removed a very large fraction of the false objects. These numbers imply that 65% (79%) of the high motion objects make it through this set of culls, and that as we make the magnitude match tighter, while we lose more real objects, we also lose a larger number of not real objects. Comparing the samples left after the two magnitude cuts, we are left with only 56% of the number candidate stars to check, versus retaining 82% of the known real high motion stars in the larger ($|R_1 - R_2| < 1.0$) sub-sample.

4.   Serendipitous New Objects

As noted above, 774 fields, each $6' \times 6'$, were examined by eye. 71 of the fields contained 82 objects that appeared to show proper motions by simple examination of the images in sequence. Because these objects were not the nominal objective of the search, initially there was no systematic effort to look for other moving objects in each field. Once several were noticed, an effort was made to keep track of them, so in fact the 71 fields were found among a subset of the 774 fields checked. Taking a conservative approach, we will treat 774 as an upper bound on the total area examined.

Each field covers 0.01 square degrees, meaning we checked 7.74 square degrees. Of the possible 82 moving objects, 2 were found to be not moving upon more careful examination, leaving 80. Within the set of 80, there were two Tycho-2 stars (4492-01044-1, and 4133-00625-1), and 3 stars that were flagged as already known high proper motion stars (with motions of 0.218, 1.307, 0.263 $\mathrm{arcsec \, yr^{-1}}$). Thirteen of the stars have proper motions greater than $0.180 \, \mathrm{arcsec \, yr^{-1}}$, 20 greater than $0.150 \, \mathrm{arcsec \, yr^{-1}}$, and 46 greater than $0.100 \, \mathrm{arcsec \, yr^{-1}}$. The positions of these objects are plotted in Fig. 3, where the new objects are shown as filled squares, and the previously identified objects are crosses. The distribution of proper motions is shown in Fig. 7.

Under the simplest assumptions, this implies that there could be at least 69,000 objects with motions greater than $0.180 \, \mathrm{arcsec \, yr^{-1}}$, and on the order of 240,000 objects with detectable motions above $0.1 \, \mathrm{arcsec \, yr^{-1}}$. The number of objects with motion greater than or equal to $0.180 \, \mathrm{arcsec \, yr^{-1}}$ is in line with the number of objects already in the NLTT (just under $60,000$) which has a nominal lower detection threshold of $0.180 \, \mathrm{arcsec \, yr^{-1}}$.

4.1.   Position and Proper Motion Determination

A quick look at the USNO-B1 catalogue data for these serendipitous objects led to the realization that about half of the objects had incomplete or incorrect USNO-B1 entries; detections were mismatched or missing. As a result, we decided to re-do the position and proper motion determinations by hand for all of these objects.

We extracted digitized Schmidt plate material for fields around each of the 80 objects and re-computed the positions and proper motions of the moving objects. Because the scans of the Schmidt plates served by the USNO Archive server have not been merged spatially, if a pointing lies in the overlap region of two plates, the image data from BOTH are available. For many of these serendipitous objects, there are more than 5 images of the field available (from a minimum of 4 plates, to a maximum of 14, with a mean of 8 plates per field; 65 out of 80 of the objects were in plate overlap regions).

In each field, a moderate number of nearby stars (within several arcminutes of the object of interest) with no detectable motion (both by eye, and per the USNO-B1 catalogue information) were chosen as reference stars. We measured their centroids and the centroid of the moving object and then did a linear plate solution for each set on each plate. To the measured positions of the moving object, we fit a straight line for position and proper motion.

Among the caveats to keep in mind, many objects in USNO-B1 have proper motions of zero, with zero errors. This indicates that the fit for position and motion was not very good. No new work has been done to correct for the degradation in the astrometric solutions on the Schmidt plates out near the edges (see Monet et al. 2003, section 4, and Fig. 1 for their discussion of the fixed pattern astrometric errors on the plates; these rise to the order of arcseconds out near the plate edges). Finally, it is important to remember that the proper motions listed in USNO-B1 are relative proper motions, and the zero point was set by the least squares solutions for the plates at around magnitude 18 (Monet et al. 2003).

4.2. Results from the serendipitous objects

Of the 80 objects, 41 had good solutions in USNO-B1. By virtue of having re-done the fits for all the objects, we had a reference sample for the astrometry. The results of our hand fits were in good agreement with the numbers given in USNO-B1. This gave us a certain degree of confidence in the results for the other 39 for which USNO-B1 does not have complete or correct data.

Not all of the 39 objects for which we re-did the solutions had bad data in USNO-B1. Looking at objects where the USNO-B1 solution was based on 3 out of 5 possible plates ($N_{FitPts} = 3$), for 6 of them USNO-B1 has reasonable positions and proper motions, and for another 10 (14), USNO-B1 has a position that is correct to within 2 (4) arcsec. For objects where $N_{FitPts} = 4$, all 8 are mis-matched. For objects where $N_{FitPts} = 2$, all 8 have positions at least 5 arcsec away from the re-computed positions. In all these cases, when determining the position and motion by hand, we found the objects on at least 4 plates. So, it would be fair to say that USNO-B1 has reasonable positions and motions for 47 out of the 80 objects (59%), and decent positions for 10 more (71%).

These numbers are not as complete as we might hope, but they are actually not out of line with the completeness seen by Gould (2003), though the sample used does not contain many stars with motions slower than 150 mas yr^{-1}. Our own check against the complete revised LHS (Bakos

et al. 2002) similarly shows USNO-B1 to be roughly 80% complete between 0 and 1 arcsec yr^{-1}, though there are only a few hundred objects in that catalogue with motions below 500 mas yr^{-1} (see the section 6 discussion comparing the revised LHS with USNO-B1). In addition, we would be very cautious about deducing too much about the completeness of USNO-B1 from this sample, as it suffers from a variety of biases. First, almost half of the 80 objects were found in just 3 POSS-I fields, so if a given plate had some problem, that could affect the results. Second, when the objects were found, there was initially no systematic effort to keep track of them. Finally, the sample is small. With those caveats in mind, it is interesting to note that all of the objects for which we provide re-done solutions have motions between 0 and 300 mas yr^{-1}. J. Munn (private communication) when comparing USNO-B1 to the SDSS DR1 data sees a dip in completeness from about 95% to about 65% at motions of around 80 to 100 mas yr^{-1}, which does roughly correspond to where we find most of the objects that had incorrect data in USNO-B1. A more thorough study of this is warranted.

From examination of the digitized images, it appears that one of the primary reasons that almost half of these objects were mis-matched in the catalogue is that they fall in the overlap zones between fields (at least 65 of the objects lie in plate overlap regions). The detections on adjoining plates apparently were not culled completely in the duplicate detection removal process. Since the duplicate removal depends upon spatial coincidence, and the plate solutions are at their worst out near the plate edges, this could lead to larger than expected offsets between images of the same object on different plates, and hence alternate detections might slip through the duplicate removal process; the occurrence of multiple entries in USNO-B1 for the same object and the inability to properly match up some first and second epoch detections of the same object could also be explained by this. This type of error should be most pronounced among objects with moderate to large proper motion. This is potentially important as well because a non-negligible portion of the sky lies in overlap zones (on the order of 30 to 50% of the sky).

As noted above, 5 of the objects were flagged in USNO-B1 as previously known (i.e. in Tycho-2 or one of the high proper motion catalogues). We checked the rest of the objects against the catalogues and journal tables made available at CDS[2]. Another 6 turned up as previously known (including two that comprise the common proper motion pair LDS 4990; Luyten 1940). We have treated the remaining 69 as previously unknown. The distribution of total proper motions is shown in the histograms in Fig. 7. Position and motion data for all the objects are given in Tables 5 and 6, where Table 5 has the data for the objects with good solutions in USNO-B1, and Table 6 has the information on those objects which were re-done by hand.

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[2]http://cdsweb.u-strasbg.fr/

5.   Notes regarding specific objects

The serendipitous objects were originally numbered 1 through 82 starting with the prefix MUSR (hence MUSR 01 to MUSR 82). For those objects with good positions in USNO-B1, we refer to each by the USNO-B1 designator. For the objects re-fit by hand, we use the MUSR designator.

We constructed a reduced proper motion diagram to aid in the rough classification of the newly found objects (Fig. 8). The reduced proper motion in the photographic R band is defined as

$$H_R = R + 5 + 5\log_{10}(\mu) = M_R + 5\log_{10}(v_{\text{tan}}) - 3.38$$

where R is apparent magnitude, M_R is the absolute magnitude, and v_{tan} is the transverse velocity in $\text{km}\,\text{s}^{-1}$. The reduced proper motion has the benefit of being insensitive to the distance to the object, as the distance dependence of M_R and v_{tan} cancel out. This has been plotted against $R - K_s$ color and, as previously shown by Salim & Gould (2002), and Lépine et al. (2003a) does a reasonable job of distinguishing between disk dwarfs, halo subdwarfs and white dwarfs. Tentative classifications are given in Tables 3 through 6. Possible white dwarfs include objects USNO-B1 1686-0094267 and MUSR 39. Possible sub-dwarfs include USNO-B1 1180-0331814, 0484-0243338, 1540-0035963, 1522-0148544, 0867-0255338, 1663-0069093 and MUSR 40, MUSR 54, MUSR 65 and MUSR 82.

LHS 237a (0560-0118956): This object was originally thought to be new. Upon closer inspection (H. Harris, private communication), it was found to be LHS 237a (or VBs3). The LHS position given for this is off by $8'$ in declination. The RA and the proper motion both match. The finder given in van Biesbroeck (1961) matches the images of this object. In Bakos et al. (2002), this object is listed as not found. Correct positions and motions are given in Table 2 (see Fig 9).

5.1.   Objects with relatively large proper motion in galactic latitude

In a modest effort to point out stars that might be halo stars, we have singled out objects that meet the following criteria: $\mu > 0.75''\,\text{yr}^{-1}$ and $\mu_b > 2\mu_l$.

0258-0023144: At $(l, b) = 278°5505, -44°0139$ moving along $(\mu_l, \mu_b) = 391.8, 999.8\,\text{mas}\,\text{yr}^{-1}$ (Fig. 10(a) and Table 2).

0867-0249298: At $(l, b) = 269°6031, 54°7070$ moving along $(\mu_l, \mu_b) = -357.1, -1037.0\,\text{mas}\,\text{yr}^{-1}$ (Fig. 5 and Table 4).

1657-0005791 (MUSR 06): At $(l, b) = 121°5699, 12°8853$ moving along $(\mu_l, \mu_b) = 39.8, 159.2\,\text{mas}\,\text{yr}^{-1}$ (Fig. 10(b) and Table 5).

1540-0035963 (MUSR 12): At $(l, b) = 124°9866, 1°2375$ moving along $(\mu_l, \mu_b) = 2.6, 128.5\,\text{mas}\,\text{yr}^{-1}$ (Fig. 10(c) and Table 5); possible sub-dwarf.

1570-0182321 (MUSR 43): At $(l, b) = 98°7379, 37°8952$ moving along $(\mu_l, \mu_b) = -6.5, 100.9\,\mathrm{mas\,yr}^{-1}$ (Fig. 10(d) and Table 5).

1544-0281760 (MUSR 60): At $(l, b) = 109°9080, 4°8349$ moving along $(\mu_l, \mu_b) = -21.4, -83.7\,\mathrm{mas\,yr}^{-1}$ (Fig. 10(e) and Table 5).

1558-0247969 (MUSR 69): At $(l, b) = 112°3325, 5°2338$ moving along $(\mu_l, \mu_b) = -50.2, 104.9\,\mathrm{mas\,yr}^{-1}$ (Fig. 10(f) and Table 5).

5.2.   Objects with companions

In the process of putting together the tables and images of serendipitous objects, we noticed several pairs with very similar motions. They are listed here.

MUSR 40: There is a possible faint companion to the east of this object that is visible on the POSS-I 103aO (blue) plate for field 68, and on the POSS-II IV-N (near-IR) plate for field 67 (see Fig.11(a) and (c)). The faint companion is at the same position angle and distance with respect to MUSR 40 on both plates, though they were taken over 40 years apart. The POSS-I 103aO plate for field 69 also shows something peculiar near MUSR 40 (Fig 11(b)). The object is not seen on the other POSS-I and POSS-II plates that cover this object. The corresponding 103aE images for both POSS-I images are shown as Fig 11(d) and (e), and an additional POSS-II IV-N image from field 68 is shown in Fig 11(f) (see Table 6). MUSR 40 is a possible sub-dwarf.

LDS 4990 (MUSR 56) and 1543-0282460 (MUSR 57): The two components of LDS 4990 (Luyten 1940) are shown in Fig. 12, with data in Tables 5 and 6. In Fig. 12, MUSR 56 is marked with a circle on both images, MUSR 57 is marked with a square, and MUSR 58 (see next entry) is marked with an ellipse. We note in passing that MUSR 56 is coincident to within 3 arcseconds with 1RXS J224000.2+642310 (marked with a white X on Fig. 12(b)) (Voges et al. 1999).

1543-0282475 (MUSR 58): Very near to LDS 4990. This object's motion is in the same direction as that of the components of LDS 4990, but the magnitude of the motion in markedly smaller (see Fig 12 and Table 5).

MUSR 61 and MUSR 62: A probable co-moving pair, with a separation of roughly 58 arcseconds (see Fig. 13 and Table 6). MUSR 61 is marked with a circle, and MUSR 62 is marked with a square.

MUSR 76 and MUSR 77: A probable co-moving pair, with a separation of almost 6.6 arcminutes (see Fig 14 and Table 6). MUSR 76 is marked with a circle, and MUSR 77 is marked with a square. They have very similar magnitudes in both the optical and near IR, and their motions are quite similar as well.

MUSR 81: Its motion is very similar to that of MUSR 76 and MUSR 77 (Table 6), but is yet further separated from the previous two objects (about 57′ away), and is somewhat brighter than

either one.

6. Comparison with the High Motion part of rLHS and LSR

As part of our effort to understand how well the motion finder has done, we looked at the entries in the USNO-B1 catalogue for all the objects with motions between 1.0 and 5.0 arcsec yr^{-1} in the revised LHS catalogue (Bakos et al. 2002, hereafter rLHS), and the 18 new objects that meet this criterion found by Lépine et al. (2002, LSR).

For each of the 18 objects in LSR with motions between 1.0 and 2.0 arcsec yr^{-1}, we extracted the appropriate portion of USNO-B1, and images from the Schmidt photographic surveys that cover that object. Of the 18 objects, 7 were matched in USNO-B1 (the seven found in our search, and given in Table 2). Of the other 11, 3 were in fields confused enough that we had only modest expectations that we would have found them. One object was on a diffraction spike of a brighter object, and likely would not have been found by USNO-B1 because it would have been in a removed region. Seven of the 11 objects we should have found. In several of those cases, it looked like USNO-B1 matched up the wrong set of objects among the various survey epochs. It appears this happens because there are other objects near or along the line of motion that cause the code that predicts the motion to get confused. The LSR image difference method is complementary to the "comparison of detection lists" method used for USNO-B1. We would expect that LSR should be more sensitive to objects in highly confused areas (such as the Galactic plane).

The rLHS has 593 objects with motions between 1.0 and 5.0 arcsec yr^{-1}. We found that 171 of these objects are flagged in USNO-B1 as being Tycho-2 stars (these were added to USNO-B1 directly from Tycho2) and so don't tell us how well Monet et al. (2003) did in the construction of USNO-B1. For the remaining 422 rLHS stars, we compared the rLHS proper motions with those given in USNO-B1. 197 had proper motions that matched within 0.20 arcsec yr^{-1} and 20 degrees position angle (though most are much closer). Of these, 174 are flagged in USNO-B1 as being known high proper motion stars. 23 more are matched to other USNO-B1 entries, though they are not flagged as known motion stars.

There were 225 objects that did not have proper motions matched within the above limits. For the 158 of them with LHS catalogue number less than or equal to 552, we searched a 6′ square box around their position. For the other 67, we searched a 3′ square box. Fig. 15(right upper) and (right middle) panels show the distribution of proper motions of the matched and un-matched sets of rLHS objects respectively. The lower panel shows the percent of rLHS objects that were matched as a function of proper motion. For objects with motions between 1 and 2 arcsec yr^{-1}, the mix is pretty even. Above 2 arcsec yr^{-1}, more objects are not matched (though we are getting into the realm of small number statistics).

Similar data are shown in the left hand panel of Fig. 15 for objects in the rLHS with motions between 0 and 1 arcsec yr^{-1}. For objects with motions below about 400 mas yr^{-1}, the completeness

appears to dip a bit, but the sample size per bin is much smaller than for those bins with proper motions above 500 mas yr^{-1} (which is not surprising, given that the catalogue is only supposed to contain objects with motions larger than 500 mas yr^{-1}).

The USNO-B1 catalogue has decent matches for the position and motion of 47% of the rLHS objects with motions between 1.0 and 5.0 arcsec yr^{-1}. For these objects, the median distance between the rLHS and USNO-B1 positions is about 1.9 arcseconds (Fig. 16). This displacement is consistent with what the typical uncertainty in position in the rLHS which is about 2 arcseconds (Bakos et al. 2002). Fig. 16(b) and (c) shows the displacement between matched rLHS and USNO-B1 objects in total proper motion and position angle. The median difference in proper motion was 0.03 arcsec yr^{-1}, and the median position angle difference was 1.4 degrees.

Gould (2003) has recently undertaken a more extensive comparison of USNO-B1 with their revised version of NLTT (Gould & Salim 2003; Salim & Gould 2003). As noted above, they found USNO-B1 to be roughly 30% incomplete when $\mu = 1$ arcsec yr^{-1}; that the incompleteness should get worse as the motion increases above this is a natural assumption.

In preliminary testing of the moving object finding algorithm used in the construction of USNO-B1, we found that below 1 arcsec yr^{-1}, the object finding algorithm did substantially better at finding real motions than it did for the faster moving objects. Since a much greater percentage of the moving objects move more slowly than 1 arcsecond per year, even though we appear to have missed many with large motions, this is consistent with the work of Gould (2003).

7. Discussion

Out of 187,134 objects in USNO-B1 that had listed motions between 1.0 and 5.0 arcsec yr^{-1}, there are 207 objects in USNO-B1 with the flag bit set indicating that they match a high proper motion catalogue star (no cuts have been applied to these yet). Of those, 184 have a second epoch red magnitude less than or equal to 18, and 174 are matched from the LHS. There are another 23 unflagged objects that match LHS objects, 19 that were recently found in other searches and 2 new ones, for a total of 251 objects. There are another 174 Tycho-2 stars with motions in this range that were added in. Excluding the added Tycho-2 stars, 0.1% of the objects in USNO-B1 in this range are real. It seems fair to say that it is possible to find new high motion objects in the USNO-B1 catalogue, even with the large contamination fraction, though it is not easy. Given that we found just under half of the previously known high motion objects, and then also found another two new ones, this would imply that there should be at least another few waiting to be found.

In addition, we found another 80 objects in the fields we searched for high motion objects. For almost half, we had to match up the detections by hand and compute positions and proper motions. Out of the combined high motion and serendipitous sample, seven objects have motions with relatively large μ_b, and there are four pairs that appear to be common proper motion pairs, and maybe even one common motion triple. In the end, we found 2 new stars with proper motions larger

than 1 arcsec yr^{-1}, and 36 with proper motions between 0.1 and 1 arcsec yr^{-1}. We also recovered one previously known, but recently missed star (LHS 237a) with a motion of 1.67 arcsec yr^{-1}.

Applying several simple cuts to the catalogue reduces the number of false objects dramatically. (1) Require each object to have a positional error in each coordinate less than 0.999 arcsec (or smaller, e.g. less than 0.350 arcsec). (2) Require each object to have a small proper motion error (less than 12 mas yr^{-1}). (3) Limit objects to those where the difference between the R_1 and R_2 magnitudes is less than 1.0 or 0.5 magnitudes. These cuts alone can reduce the contamination in the returned data by several orders of magnitude. (4) Require each object to be detected on 4 or 5 out of 5 surveys.

By placing a limit on the position and motion errors, we are putting a tight constraint upon the acceptable matches, since we are imposing a linearity requirement in addition to the proximity criterion. Hence, the much greater reduction in the number of spurious objects. Fig. 2 shows an example of this. The left panel shows a POSS-I image of a field near a bright star. In the center panel, all of the objects in USNO-B1 that lie in this field are plotted (they number 704). If we require $|R_1 - R_2| \leq 1$, the total $\sigma_{\mathrm{position}} \leq 500\,\mathrm{mas}$ and the total $\sigma_\mu \leq 100\,\mathrm{mas\,yr^{-1}}$, then we are left with the 163 objects overplotted in the right panel. Almost 75% of the objects have been rejected by this cut. As can be seen, most of the artifact objects caused by the diffraction spikes and the halo around the star are gone. A few real objects have been deleted as well.

Requiring objects to be detected on at least 4 surveys did not appear to contribute much to reducing the contamination in the high motion sample. I would attribute this to several factors. First, the diffraction spikes on plates taken at the same pointing tend to line up well (hence the fairly large number of objects discarded as being due to diffraction spikes), and so provide large pool of objects close together at both epochs. These then often project onto or very near to other diffraction spike detections, thus making up spurious, though complete, objects with potentially large motions. Second, extended objects, much like diffraction spikes often give rise to multiple detections all in close proximity to each other. These again provide fertile territory for mis-matching.

The high motion problem is particularly taxing for the object matching, since there are often very many possible pairings of objects. With the larger motions, it becomes more likely that something will fall within the large projected error ellipse, and hence make up an object with at least 4 detections.

Finally, It is important to know what the object density is like in the region(s) you are interested in: if it is high (e.g. near the galactic plane), then the contamination rate will rise as it becomes progressively more difficult to unambiguously match up detections (see Figs. 1). J. Munn (private communication) noted during the construction of the merged proper motion catalogue using USNO-B1 and SDSS DR1 data (Munn et al. 2004) that requiring objects from USNO-B1 to have no neighbor within 7 arcseconds also helped to clean up the contamination.

This particular work examining the high proper motion part of USNO-B1 has not made use of additional outside data. As is clear from Munn et al. (2004) and Gould & Kollmeier (2004), it is

possible to do a better job of cleaning up the contamination in USNO-B1 if you have external data with which to compare (e.g. the SDSS DR1 data). If not, then you are limited to methods similar to those used here, but it is fair to say that the prospects of doing a decent job are still good.

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Table 1.   Photographic Source Material used in USNO-B1[a]

Survey	Emulsion	Wavelength [nm]	Color[b]	Declination[c] [deg]	Epoch
POSS-I	103aO	350–500	B	−30 to +90	1949–1965
POSS-I	103aE	620–670	R	−30 to +90	1949–1965
POSS-II	IIIaJ	385–540	B	0 to +90	1985–2000
POSS-II	IIIaF	610–690	R	0 to +90	1985–2000
POSS-II	IV-N	730–900	I	0 to +90	1989–2000
SERC-J	IIIaJ	395–540	B	−90 to −20	1978–1990
SERC-EJ	IIIaJ	395–540	B	−15 to −5	1984–1998
ESO-R	IIIaF	630–690	R	−90 to −35	1974–1987
AAO-R	IIIaF	590–690	R	−90 to −20	1985–1998
SERC-ER	IIIaF	590–690	R	−15 to −5	1979–1994
SERC-I	IV-N	715–900	I	−90 to 0	1978–2002
SERC-I[d]	IV-N	715–900	I	+5 to +20	1981–2002

[a]The contents of this table follow from Monet et al. (2003) Table 1.

[b]The colors listed here are rough PHOTOGRAPHIC colors. They correspond to the magnitudes given in USNO-B1.

[c]The range in declination of the field centers in each survey used in the construction of USNO-B1.

[d]These fields are an extension of the SERC-I that was done to fill in fields that were not taken during the POSS-II IV-N survey.

Table 2.   Known, Unflagged Objects with Motions Between 1.0 and 5.0 $''\,\mathrm{yr}^{-1}$.

USNO-B ID	μ^{a} [$''\,\mathrm{yr}^{-1}$]	θ^{a} [deg]	RA [hrs]	Dec [deg]	l [deg]	b [deg]	$B_2{}^{\mathrm{b}}$ [mag]	$R_2{}^{\mathrm{b}}$ [mag]	$I_2{}^{\mathrm{b}}$ [mag]	AltID[c]
LHS Objects[c]										
0121-0045493	1.03	142.7	09.28481	−77.8234	292.5559	−19.5296	14.38	12.11	10.14	263
0185-0249424	1.16	338.8	12.47781	−71.4644	301.1041	−8.6735	15.15	12.72	11.10	328
0185-0249438	1.18	338.9	12.47866	−71.4656	301.1083	−8.6743	16.48	14.72	12.19	329
0222-0190851	2.14	136.6	07.88561	−67.7924	280.2038	−19.4322	14.53	13.77	13.02	34
0289-0005722	1.11	93.7	00.82473	−61.0424	303.3558	−56.0842	13.03	11.50	10.05	124
0560-0118956	1.67	351.6	07.76069	−33.9311	248.9038	−4.6752	17.40	15.67	15.60	237a
1611-0086923	1.91	256.0	10.61735	+71.1830	136.8566	42.1223	17.31	16.14	15.47	285
1688-0078160	1.16	63.0	21.68144	+78.8227	114.2010	19.3348	14.77	12.91	10.89	514
1695-0027702	1.20	136.2	05.63677	+79.5221	133.7772	23.4244	19.93	17.26	13.77	207
LSR Objects[c]										
0872-0489450	1.01	214.9	18.16393	−02.7953	25.6449	7.9460	17.29	15.42	13.03	$1809-0247$
1042-0321115	1.00	235.4	17.97303	+14.2939	40.0841	18.0868	17.24	16.35	15.57	$1758+1417$
1068-0333681	1.00	117.0	17.92576	+16.8164	42.2300	19.7325	17.00	14.84	12.49	$1755+1648$
1207-0075220	1.10	148.5	05.08660	+30.7256	173.6030	-6.2643	18.12	16.33	14.73	$0505+3043$
1325-0110870	1.54	159.6	04.33114	+42.5585	158.6564	-5.4068	20.26	17.35	14.43	$0419+4233$
1491-0005115	1.47	217.9	00.19217	+59.1445	117.8254	-3.3310	16.70	14.85	11.38	$0011+5908$
1491-0151160	1.01	173.5	05.25859	+59.1883	151.5063	11.9084	19.97	16.60	14.35	$0515+5911$
Assorted Objects										
0143-0198407	1.04	143.8	21.25418	−75.6977	317.0296	−34.8155	16.13	13.44	11.24	SC,P
0258-0023144	1.06	140.9	03.71595	−64.1322	278.5502	−44.0139	17.15	15.04	12.66	SC
0279-0008695	1.10	82.3	00.87091	−62.0317	302.7644	−55.0962	19.65	16.72	13.33	SIPS
0300-0785973	1.42	165.4	20.20883	−59.9476	337.1327	−33.3064	16.63	15.37	14.86	P
0358-0039309	1.07	168.6	05.00438	−54.1077	261.9192	−37.7847	19.88	17.61	15.45	P
0393-0108806	1.00	326.5	08.50019	−50.6624	267.4696	−6.7440	15.67	13.76	12.52	L
0443-0286531	1.31	281.9	12.46300	−45.6879	298.6155	16.9854	16.37	14.49	13.16	L
0477-0913359	1.03	171.7	19.94933	−42.2729	357.5855	−29.5013	18.72	17.03	13.71	R,P
0500-0227632	1.52	229.4	10.80405	−39.9353	278.6839	17.0658	18.58	15.93	12.66	D
0510-0792885	1.07	109.6	22.24298	−38.9852	2.7952	−55.3720	16.39	15.05	15.09	P, O
0533-0785516	1.29	184.6	19.27960	−36.6349	1.3299	−20.5417	18.08	15.76	14.85	L
0847-0018930	1.04	67.3	02.08655	−05.2983	165.0326	−61.9816	18.86	17.86	17.24	O

[a]The proper motions are relative to the reference frame established by the YS4.0 catalogue stars (see Monet et al. 2003 for details).

[b]Photographic magnitudes from the second epoch Schmidt surveys (POSS-II in the north, SERC-J, SERC-EJ, AAO-R, SERC-ER, and SERC-I in the south).

[c]References: For the LHS objects, the AltID is the LHS (Luyten 1979a) catalogue number. For the LSR objects, the AltID is the id given in Lépine et al. (2002). For the assorted objects their source is given by this key: D=Delfosse et al. (2001), L=Lépine (2005), O=Oppenheimer et al. (2001), P=Pokorny et al. (2003, 2004), R=Reylé et al. (2002), SC=Hambly et al. (2004), SIPS=Deacon et al. (2005)

Table 3. Objects with Motions less than 1.0 $''$yr^{-1}.

USNO-B ID	μ^{a} [$''$ yr^{-1}]	θ^{a} [deg]	RA [hrs]	Dec [deg]	l [deg]	b [deg]	$B_2{}^{\mathrm{b}}$ [mag]	$R_2{}^{\mathrm{b}}$ [mag]	$I_2{}^{\mathrm{b}}$ [mag]	J^{c} [mag]	H^{c} [mag]	$K_s{}^{\mathrm{c}}$ [mag]	Class$^{\mathrm{d}}$	AltID$^{\mathrm{e}}$
0338-0848607	0.31	71.8	23.41315	−56.1517	325.1606	-57.0780	12.36$^{\mathrm{f}}$	10.41	10.06	9.36	8.74	8.59	d	NLTT 9526
1180-0331814	0.09	210.6	18.08276	+28.0142	54.2204	21.8639	14.93	14.45	14.05	13.46	13.24	13.12	sd	
1686-0094267	0.40	75.0	23.96100	+78.6681	120.2067	16.0819	17.64	17.46	17.55	16.31	15.49	15.68	wd	
1698-0001063	0.09	63.0	00.23815	+79.8183	121.2218	17.0701	19.18	17.29	16.46	14.89	14.30	14.05	d	

[a]The proper motions are relative to the reference frame established by the YS4.0 catalogue stars (see Monet et al. 2003 for details).

[b]Photographic magnitudes from the second epoch Schmidt surveys (POSS-II in the north, SERC-J, SERC-EJ, AAO-R, SERC-ER, and SERC-I in the south).

[c]Near IR magnitudes are from the 2MASS final release point source catalogue (Cutri et al. 2003).

[d]Classification: d = dwarf, sd = sub-dwarf, wd = white dwarf.

[e]Alternate Identification: NLTT = Luyten (1979b)

[f]Magnitude taken from another USNO-B1 catalogue entry, which was made up of additional detections of this objects.

Table 4. New Objects with Motions Between 1.0 and 5.0 $''\,\mathrm{yr}^{-1}$.

USNO-B ID	μ^{a} [$''\,\mathrm{yr}^{-1}$]	θ^{a} [deg]	RA [hrs]	Dec [deg]	l [deg]	b [deg]	$B_2{}^{\mathrm{b}}$ [mag]	$R_2{}^{\mathrm{b}}$ [mag]	$I_2{}^{\mathrm{b}}$ [mag]	J^{c} [mag]	H^{c} [mag]	$K_{\mathrm{s}}{}^{\mathrm{c}}$ [mag]	Class$^{\mathrm{d}}$
0484-0243338	1.20	282.6	11.13220	−41.5980	282.9517	17.2231	16.88	14.27	13.04	12.19	11.69	11.47	sd
0867-0249298	1.08	226.9	11.62128	−03.2934	269.6031	54.7070	16.23	14.12	12.35	10.87	10.36	10.09	d

[a]The proper motions are relative to the reference frame established by the YS4.0 catalogue stars (see Monet et al. 2003 for details).

[b]Photographic magnitudes from the second epoch Schmidt surveys (POSS-II in the north, SERC-J, SERC-EJ, AAO-R, SERC-ER, and SERC-I in the south).

[c]Near IR magnitudes are from the 2MASS final release point source catalogue (Cutri et al. 2003).

[d]Classification: d = dwarf, sd = sub-dwarf, wd = white dwarf.

Table 5. Serendipitous objects with good solutions in USNO-B1.

ID[a]	μ[b] [mas yr^{-1}]	θ[b] [deg]	RA [hrs]	Dec [deg]	l [deg]	b [deg]	B[c] [mag]	R[c] [mag]	I[c] [mag]	J[d] [mag]	H[d] [mag]	K$_s$[d] [mag]	#[e]	Class[f]	AltID[g]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
4492-01044-1	225.6	65.9	0.33483	76.1291	121.0064	13.3746	12.7	11.4	10.9	9.2	8.6	8.4	0	d	TYC2-4492-1044-1
1660-0002691	78.2	94.4	0.34624	76.0645	121.0401	13.3055	18.2	16.2	15.0	13.4	12.8	12.5	5	d	
1662-0002920	87.3	110.1	0.37893	76.2253	121.1795	13.4513	17.5	15.8	14.2	12.1	11.5	11.3	5	d	
1657-0005791	164.1	9.1	0.49845	75.7001	121.5699	12.8853	16.0	13.9	12.7	10.8	10.3	10.0	5	d	
1698-0004712	81.2	99.9	0.92103	79.8888	123.1074	17.0183	18.1	16.3	15.8	14.3	13.7	13.4	5	d	
1695-0005846	373.4	69.6	1.00922	79.5763	123.3623	16.7121	17.4	15.2	12.8	11.7	11.1	10.8	5	d	NLTT-3242
0855-0009685	189.7	65.1	1.01479	-4.4809	129.0295	-67.2407	14.7	12.8	11.8	10.7	10.1	9.9	5	d	UCAC2-30296684
0855-0009698	1321.5	70.3	1.01566	-4.4490	129.0551	-67.2077	14.4	12.3	10.4	9.0	8.5	8.2	5	d	LHS-130
1540-0035963	128.6	5.4	1.17036	64.0343	124.9866	1.2375	17.2	16.8	17.2	16.1	15.5	15.1	5	sd	
1407-0071339	120.9	145.8	2.66405	50.7820	139.8638	-8.4912	15.4	12.7[h]	11.4	10.7	10.1	9.9	4	d	
1683-0025701	93.3	135.0	3.73783	78.3068	131.3389	18.3639	15.5	14.7	13.9	12.4	11.8	11.7	5	d	
1544-0112254	84.4	148.6	4.12699	64.4990	142.1650	9.2308	20.2	17.4	16.6	15.2	14.4	14.3	5	d	
1522-0148544	113.6	118.4	4.32810	62.2920	144.7008	8.5851	19.8	17.5	16.4	15.2	14.5	14.4	5	sd	
1574-0111126	80.6	156.6	5.51495	67.4569	145.1288	17.6793	17.7	15.8	14.6	13.5	12.8	12.6	4	d	
1578-0121823	235.8	169.7	6.37029	67.8010	146.8259	22.2983	15.9	14.1	11.4	10.7	10.2	9.8	5	d	
1659-0050193	324.0	173.6	7.48851	75.9009	138.8070	28.5491	19.1	16.6	14.2	12.0	11.5	11.1	5	d	NLTT-17835
4133-00625-1	502.0	180.5	8.42792	66.4623	149.1560	34.0631	9.3	8.3	7.8	7.2	6.8	6.7	0	d	TYC2-4133-00625-1
1575-0148828	26.9	132.0	10.29553	67.5945	141.9665	43.4178	14.2	12.5	11.2	10.8	10.2	10.1	5	d	
1576-0150230	58.1	229.2	10.29363	67.6537	141.9141	43.3712	13.2	11.7	11.0	10.5	10.0	9.9	5	d	
0867-0255298	58.5	262.1	11.95509	-3.2049	277.5471	56.9749	16.6	15.6	14.2	13.5	12.8	12.6	5	d	
0867-0255338	57.3	282.1	11.95771	-3.2520	277.6467	56.9463	15.3	14.2	14.2	13.6	13.1	13.0	5	sd	
1662-0061497	84.3	292.3	12.50206	76.2446	124.6039	40.8144	19.7	17.2	16.0	14.3	13.8	13.6	5	d	
1663-0069093	76.1	273.0	15.09013	76.3685	113.4095	38.1747	14.8	14.3	14.0	13.2	12.9	12.9	5	sd	
1570-0182321	101.1	245.5	16.58837	67.0294	98.7379	37.8952	17.2	15.3	12.9	11.9	11.3	11.1	5	d	
1548-0247178	273.9	83.3	21.69641	64.8562	104.4654	9.0259	17.9	16.1	13.3	12.0	11.4	11.1	5	d	NLTT-51912
1371-0540717	90.0	90.0	22.12871	47.1923	96.2810	-7.0307	17.5	15.1	13.7	13.4	12.8	12.7	5	d	
1503-0343417	74.7	195.5	22.52417	60.3793	106.4534	2.0660	18.7	16.2	14.5	13.3	12.8	12.6	5	d	
1543-0282460	152.3	103.7	22.66878	64.3816	109.3223	5.0372	17.9	15.8	14.2	12.4	11.8	11.5	5	d	LDS-4990
1543-0282475	55.7	111.0	22.66946	64.3670	109.3190	5.0222	15.4	13.4	12.7	11.2	10.5	10.4	5	d	
1680-0117205	106.0	54.2	22.73451	78.0837	116.3959	16.8607	17.0	15.4	14.3	13.1	12.6	12.3	5	d	
1544-0281760	86.3	166.6	22.76294	64.4808	109.9080	4.8349	19.4	17.2	16.2	14.5	13.9	13.6	5	d	
1543-0289304	48.7	70.8	22.92054	64.3196	110.7505	4.2318	18.1	15.8	14.8	13.2	12.6	12.3	5	d	
1558-0247908	69.4	41.5	23.07854	65.8848	112.3157	5.2374	17.4	15.2	14.7	13.7	13.0	12.8	5	d	

Table 5—Continued

ID[a] (1)	μ[b] [mas yr⁻¹] (2)	θ[b] [deg] (3)	RA [hrs] (4)	Dec [deg] (5)	l [deg] (6)	b [deg] (7)	B[c] [mag] (8)	R[c] [mag] (9)	I[c] [mag] (10)	J[d] [mag] (11)	H[d] [mag] (12)	Ks[d] [mag] (13)	#[e] (14)	Class[f] (15)	AltID[g] (16)
1558-0247969	116.3	310.8	23.08128	65.8882	112.3325	5.2338	20.6	18.3[h]	16.5	14.8	14.3	14.1	4	d	
1559-0249177	139.7	99.1	23.14135	65.9357	112.6906	5.1324	17.8	15.4	14.6	12.7	12.0	11.8	4	d	
1691-0087337	154.1	92.2	23.36841	79.1872	118.6554	17.0646	16.8	15.4	13.8	12.4	11.8	11.6	5	d	
1675-0139929	157.5	82.0	23.59605	77.5049	118.7623	15.2500	17.4	15.4	14.2	12.6	12.1	11.8	5	d	
1675-0140048	103.7	129.5	23.60936	77.5253	118.8113	15.2566	16.8	15.0	14.0	12.8	12.2	12.0	5	d	
1675-0140100	109.3	34.6	23.61504	77.5031	118.8228	15.2300	17.4	16.1	14.2	12.4	11.8	11.5	5	d	
1675-0140133	434.8	93.4	23.61889	77.5720	118.8562	15.2922	14.7	12.9	10.8	10.2	9.7	9.4	5	d	NLTT-57436
1663-0113155	71.0	80.3	23.82149	76.3079	119.1870	13.8901	17.9	15.8	15.2	14.1	13.3	13.3	5	d	

[a]IDs of the form ZZZZ-NNNNNNN are from USNO-B1, and those of the form ZZZZ-RRRRR-N are from Tycho-2.

[b]The proper motions are relative to the reference frame established by the YS4.0 catalogue stars (see Monet et al. 2003 for details).

[c]B, R, and I magnitudes are photographic magnitudes from the USNO-B1 catalogue. The B and R magnitudes are preferentially from the second epoch plates; if no second epoch magnitude was available, then the first epoch magnitude was used.

[d]J, H, and Ks magnitudes are from the 2MASS final release point source catalogue (Cutri et al. 2003).

[e]Number of surveys out of the 5 in USNO-B1 on which the object was detected in the construction of USNO-B1.

[f]Classification: d = dwarf, sd = sub-dwarf, wd = white dwarf.

[g]Alternate Identification, if this is a previously known object. TYC2=Høg et al. (2000), NLTT=Luyten (1979b), LHS=Luyten (1979a), LDS=Luyten (1940), UCAC2=Zacharias et al. (2004).

[h]First epoch magnitude.

Table 6. Serendipitous objects with new Position and Proper Motion Solutions.

ID[a]	μ[b] [mas yr^{-1}]	θ[b] [deg]	RA [hrs]	Dec [deg]	l [deg]	b [deg]	B[c] [mag]	R[c] [mag]	I[c] [mag]	J[d] [mag]	H[d] [mag]	K$_s$[d] [mag]	#[e]	Class[f]	AltID[g]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
MUSR 01	155.5	94.3	0.30014	76.9962	120.9982	14.2501	18.2	16.3	14.8	13.0	12.5	12.2	3	d	
MUSR 04	64.2	39.9	0.36642	76.2059	121.1315	13.4372	17.5	15.9	14.6	13.0	12.4	12.1	3	d	
MUSR 07	91.4	95.6	0.52378	77.4410	121.8091	14.6129	19.3	17.2	15.7	14.2	13.5	13.3	4	d	
MUSR 13	114.0	121.7	1.86147	47.4891	133.3661	-14.1583	15.8	15.0	11.4	10.7	10.1	9.8	3	d	
MUSR 16	137.4	127.3	3.74106	78.0435	131.5250	18.1683	19.1	16.9	15.4	14.1	13.5	13.3	3	d	UB-1680-0031453
MUSR 17	194.3	122.7	3.84409	52.2317	148.5094	-1.5079	17.7	16.0	14.2	12.7	12.1	11.8	3	d	UB-1422-0127233
MUSR 19	85.3	130.6	4.26547	63.3473	143.6395	9.0300	16.8[i]	14.8[i]	13.4[i]	12.7	12.0	11.8	2	d	
MUSR 21	185.9	120.6	4.44636	63.1542	144.6443	9.7688	18.6	16.3	14.5	13.3	12.8	12.5	3	d	NLTT-13207
MUSR 22	85.1	138.6	5.22302	52.9614	156.5483	8.1374	15.1	13.8	13.4	12.2	11.5	11.4	3	d	
MUSR 23	150.3	115.9	5.25623	67.5593	144.2512	16.4504	18.5	16.6	14.9	13.7	13.2	13.0	3	d	
MUSR 25	41.7	210.3	5.52282	67.4864	145.1243	17.7331	16.6	15.4[h]	...	13.5	12.9	12.8	3	d	UB-1574-0111219
MUSR 27	230.9	145.9	5.84567	62.9571	150.3206	17.4703	13.5	12.4[h,i]	10.7[i]	9.9	9.3	9.2	3	d	
MUSR 31	57.6	74.8	10.28827	67.6570	141.9380	43.3458	17.3	15.4	14.1	13.3	12.6	12.4	4	d	
MUSR 35	115.7	286.0	11.95683	-3.2109	277.5956	56.9792	19.6	17.0	15.4	14.1	13.5	13.2	4	d	
MUSR 39	156.7	219.6	12.71622	65.7056	124.3272	51.3997	17.5	16.8[h]	15.7[i]	16.6	17.1	16.1	3	wd	UB-1557-0144114
MUSR 40	150.7	187.5	15.06479	68.2484	106.4694	44.4086	18.6[h]	16.3[h]	15.4	14.7	14.3	14.0	3	sd	UB-1582-0176403
MUSR 42	101.2	181.9	15.67851	68.6857	103.8286	41.6052	19.2[h]	16.5[h]	...	14.4	13.8	13.6	2	d	
MUSR 44	138.0	210.5	18.18237	6.3899	34.0677	11.9007	17.3	15.2	14.6	13.3	12.6	12.5	3	d	
MUSR 45	256.0	259.9	20.13456	62.8713	96.3361	15.8208	18.8[h]	16.5	15.0	13.4	12.9	12.7	4	d	
MUSR 46	102.6	38.1	21.28918	61.1952	99.8812	8.3154	18.1	15.8	14.1	12.6	11.9	11.7	3	d	
MUSR 49	49.6	90.3	22.38069	43.0352	96.1106	-11.9656	17.9	15.3	13.6	13.4	12.7	12.5	4	d	
MUSR 51	89.7	52.7	22.52580	60.3778	106.4630	2.0585	18.1	15.9	14.8	13.5	12.9	12.6	3	d	UB-1503-0343496
MUSR 52	119.0	78.1	22.54173	64.3235	108.5745	5.3966	19.3[h]	16.4[h]	...	13.5	12.9	12.7	2	d	
MUSR 53	89.2	119.2	22.62082	63.5496	108.6377	4.4657	18.3[h]	16.2[h]	...	13.1	12.4	12.2	2	d	
MUSR 54	144.0	14.8	22.64093	62.5719	108.2758	3.5469	16.4	14.5	14.1	13.1	12.5	12.4	3	sd	
MUSR 55	44.8	233.1	22.66454	66.7672	110.4644	7.1352	17.9	15.8	15.3	14.0	13.2	13.0	5	d	
MUSR 56	127.4	107.4	22.66674	64.3870	109.3132	5.0483	14.3	12.2	10.6	9.6	9.0	8.8	3	d	LDS-4990
MUSR 61	129.6	71.9	22.76775	64.5190	109.9534	4.8543	16.7	14.9	13.8	12.2	11.6	11.4	3	d	
MUSR 62	149.7	62.5	22.76936	64.5065	109.9568	4.8384	15.2[h]	14.1[h]	...	11.5	10.9	10.8	3	d	
MUSR 63	122.0	100.0	22.76986	63.6424	109.5576	4.0713	19.8[h]	19.3	17.9	13.6	12.9	12.6	4	d	
MUSR 64	107.7	263.0	22.79564	65.6343	110.6280	5.7618	15.5[i]	13.5[i]	13.1[i]	11.7	11.1	11.0	3	d	
MUSR 65	95.8	44.1	22.83035	64.2553	110.1941	4.4338	17.8[h]	16.4[h]	...	14.4	13.8	13.7	2	sd	
MUSR 67	105.4	241.7	22.94335	66.5543	111.8480	6.1862	20.3[h,i]	17.1	15.4	13.7	13.1	12.8	3	d	

Table 6—Continued

ID[a] (1)	μ[b] [mas yr^{-1}] (2)	θ[b] [deg] (3)	RA [hrs] (4)	Dec [deg] (5)	l [deg] (6)	b [deg] (7)	B[c] [mag] (8)	R[c] [mag] (9)	I[c] [mag] (10)	J[d] [mag] (11)	H[d] [mag] (12)	K$_s$[d] [mag] (13)	#[e] (14)	Class[f] (15)	AltID[g] (16)
MUSR 76	85.9	83.7	23.68831	78.5560	119.3635	16.1732	19.8[h]	16.6[h]	⋯	14.2	13.6	13.4	2	d	
MUSR 77	80.6	83.2	23.72320	78.5201	119.4573	16.1100	19.9[h]	16.8[h]	⋯	14.2	13.6	13.3	2	d	
MUSR 78	125.8	82.8	23.73681	79.7080	119.8311	17.2433	18.8[h]	16.3[h]	⋯	13.7	13.1	12.9	2	d	
MUSR 80	97.9	55.7	23.83274	78.5106	119.7836	16.0163	16.2	14.6	12.8	11.0	10.3	10.1	3	d	
MUSR 81	86.9	83.3	23.94682	79.1474	120.2736	16.5586	17.0	15.2	13.6	12.0	11.5	11.2	4	d	
MUSR 82	138.3	65.3	23.97094	78.9788	120.3055	16.3792	15.4[i]	14.4	13.8	13.1	12.7	12.6	3	sd	

[a]IDs of the form *ZZZZ*-NNNNNNN are from USNO-B1, and those of the form *ZZZZ*-RRRRR-N are from Tycho-2.

[b]The proper motions are relative to the reference frame established by the YS4.0 catalogue stars (see Monet et al. 2003 for details).

[c]*B*, *R*, and *I* magnitudes are photographic magnitudes from the USNO-B1 catalogue. The *B* and *R* magnitudes are preferentially from the second epoch plates; if no second epoch magnitude was available, then the first epoch magnitude was used.

[d]*J*, *H*, and *K$_s$* magnitudes are from the 2MASS final release point source catalogue (Cutri et al. 2003)

[e]Number of surveys out of the 5 in USNO-B1 on which the object was detected in the construction of USNO-B1.

[f]Classification: d = dwarf, sd = sub-dwarf, wd = white dwarf.

[g]Alternate Identification, if this is a previously known object. NLTT=Luyten (1979b), LDS=Luyten (1940), UB=USNO-B1 object ID where the USNO-B1 has a decent position and motion match, but used incomplete data.

[h]First epoch magnitude.

[i]Magnitude taken from another USNO-B1 catalogue entry, which was made up of additional detections of this objects.
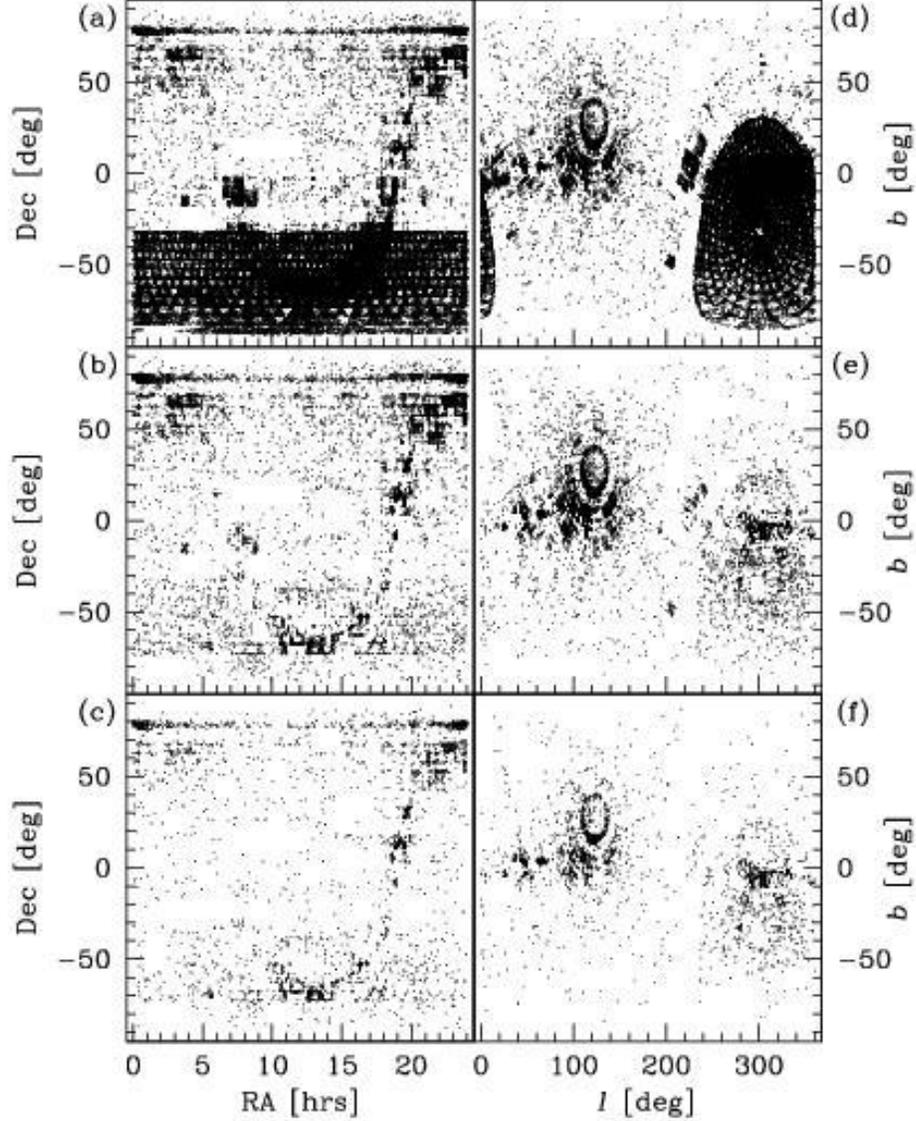
Fig. 1.— Positions of candidate objects shown in equatorial (panels a, b, c) and galactic (panels d, e, f) coordinates. In (a) and (c) are all the objects in USNO-B1 with $1 \leq \mu \leq 5 \, \mathrm{arcsec \, yr^{-1}}$. The points in (b) and (e) are those remaining after basic sanity checks have been applied ($N_{FitsPts} \geq 4$, $\sigma_\alpha < 999 \, \mathrm{mas}$ and $\sigma_\delta < 999 \, \mathrm{mas}$). Points in (c) and (f) are those remaining after a subsequent cut on the second epoch red magnitude ($0 \leq \mathrm{R}_2 \leq 18.0$).
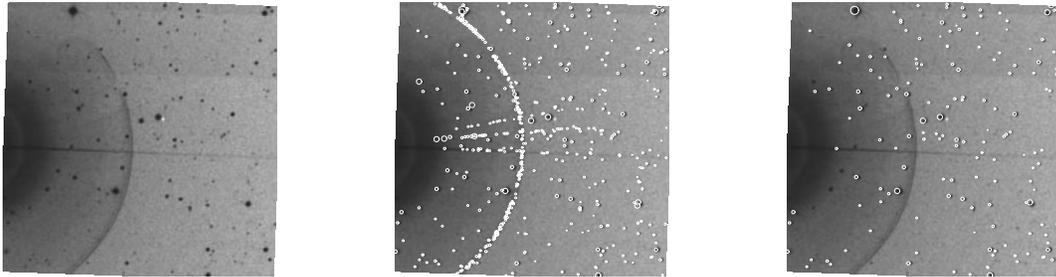
Fig. 2.— *left:* The POSS-II IIIaF image of a field near a bright star. *center:* The same image, with all of the 704 USNO-B1 objects that lie in the field overplotted. *right:* Only those 163 USNO-B1 objects that satisfy the criteria $|R_1 - R_2| \leq 1\,\mathrm{mag}$, $\sigma_{\mathrm{pos}} \leq 500\,\mathrm{mas}$, and $\sigma_\mu \leq 100\,\mathrm{mas\,yr^{-1}}$ are overplotted.
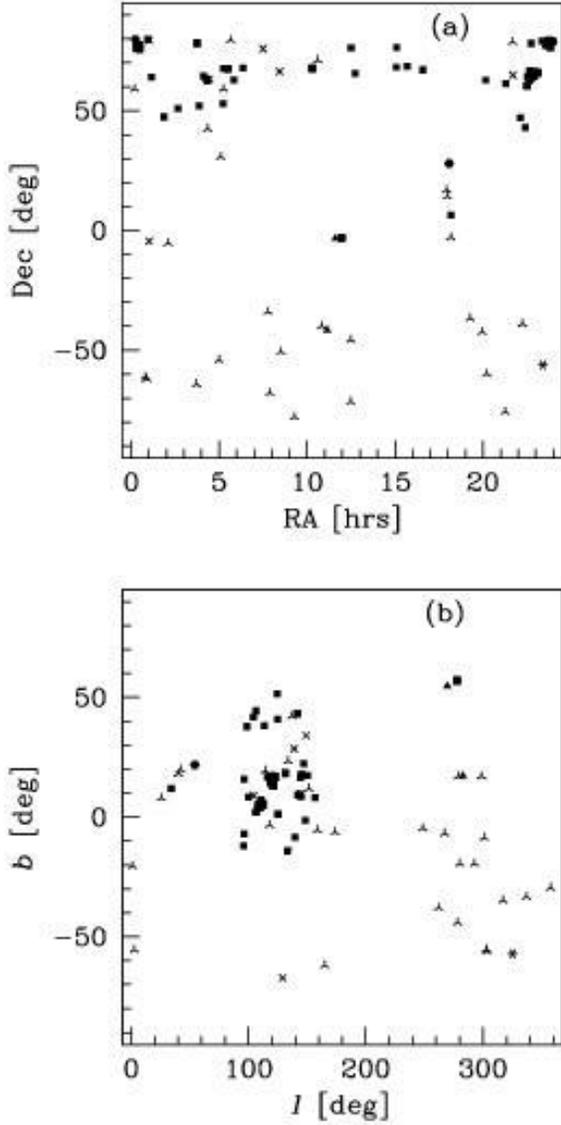
Fig. 3.— The high motion objects that made it all the way through the winnowing process. Filled triangles and 3 pointed stars represent objects with proper motion larger than 1 arcsecond that are respectively new, and known but not flagged in USNO-B1. Filled hexagons and 6 pointed stars are are objects listed in USNO-B1 with large motions that actually have motions less than 1 arcsecond, and are new and previously known respectively. Filled squares and crosses represent respectively new and known serendipitous objects. Panels (a) and (b) show the objects in equatorial and galactic coordinates respectively.
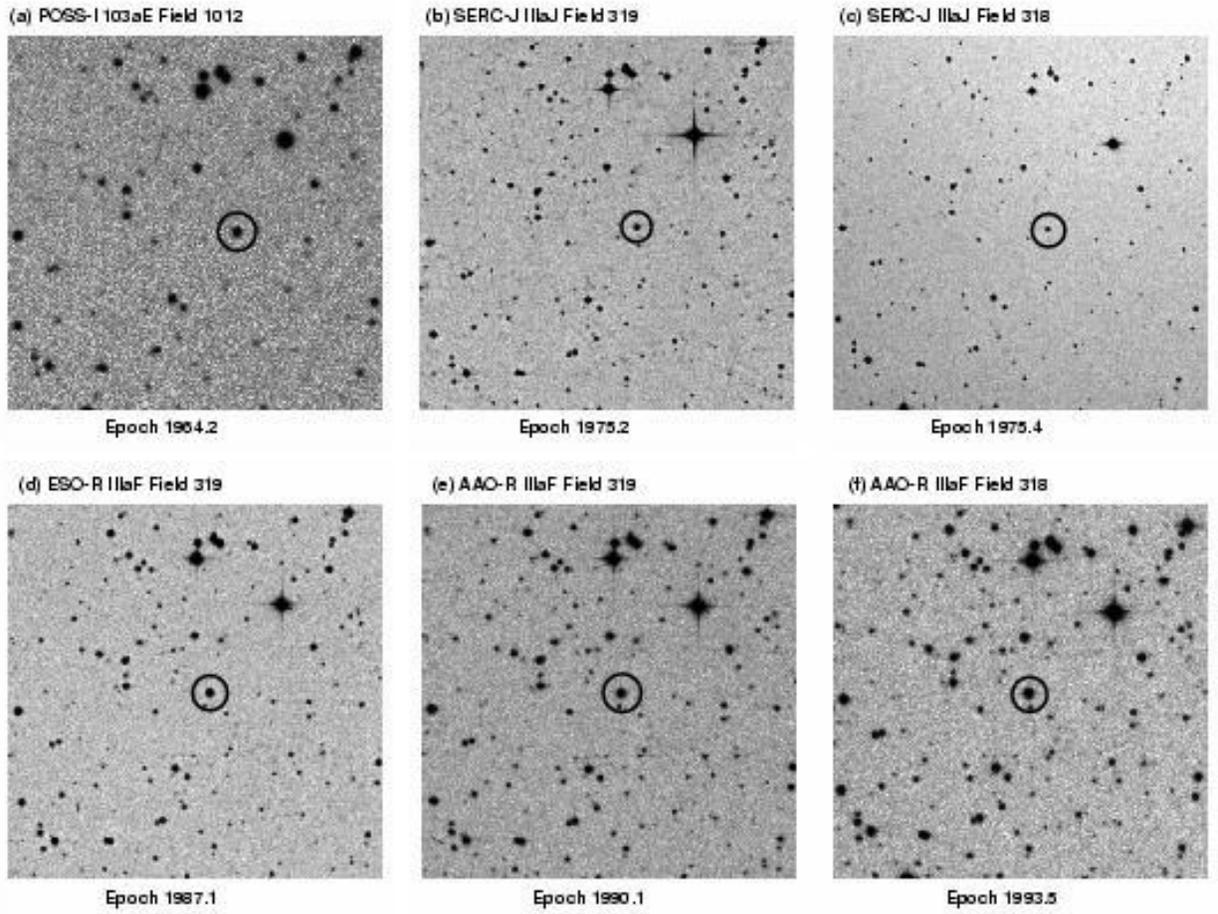
Fig. 4.— Finder charts showing the motion of object USNO-B1 0484-0243338 ($\alpha_{2000} = 11^h07^m55\overset{s}{.}9$, $\delta_{2000} = -41°35'53''$) on the 6 available Schmidt plates. North is up, East is to the right and all images are $6' \times 6'$ in size.
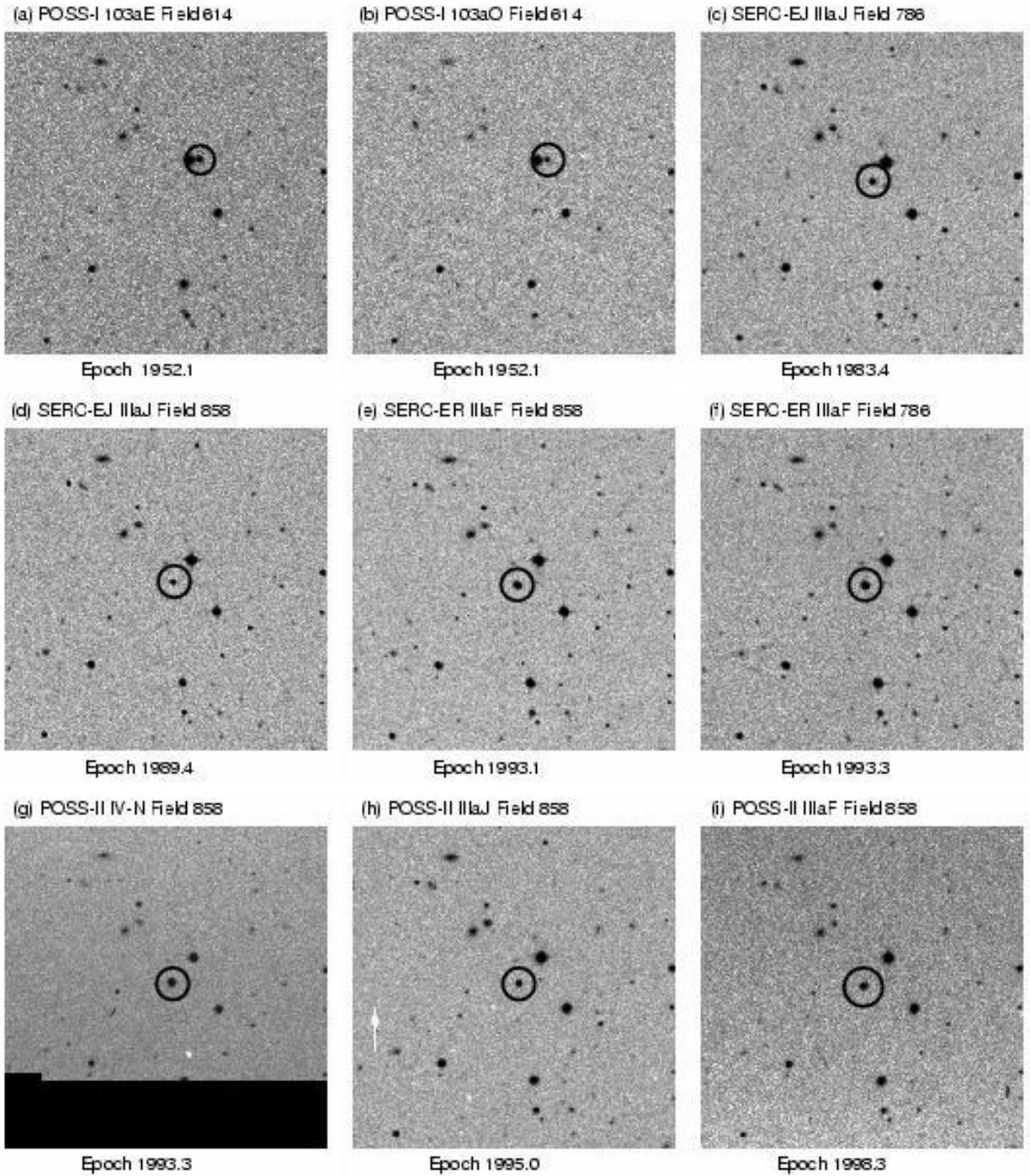
Fig. 5.— Finder charts showing the motion of object USNO-B1 0867-0249298 ($\alpha_{2000} = 11^{\mathrm{h}}37^{\mathrm{m}}16\overset{\mathrm{s}}{.}6$, $\delta_{2000} = -03°17'37''$) on the 9 available Schmidt plates. North is up, East is to the right and all images are $6' \times 6'$ in size.
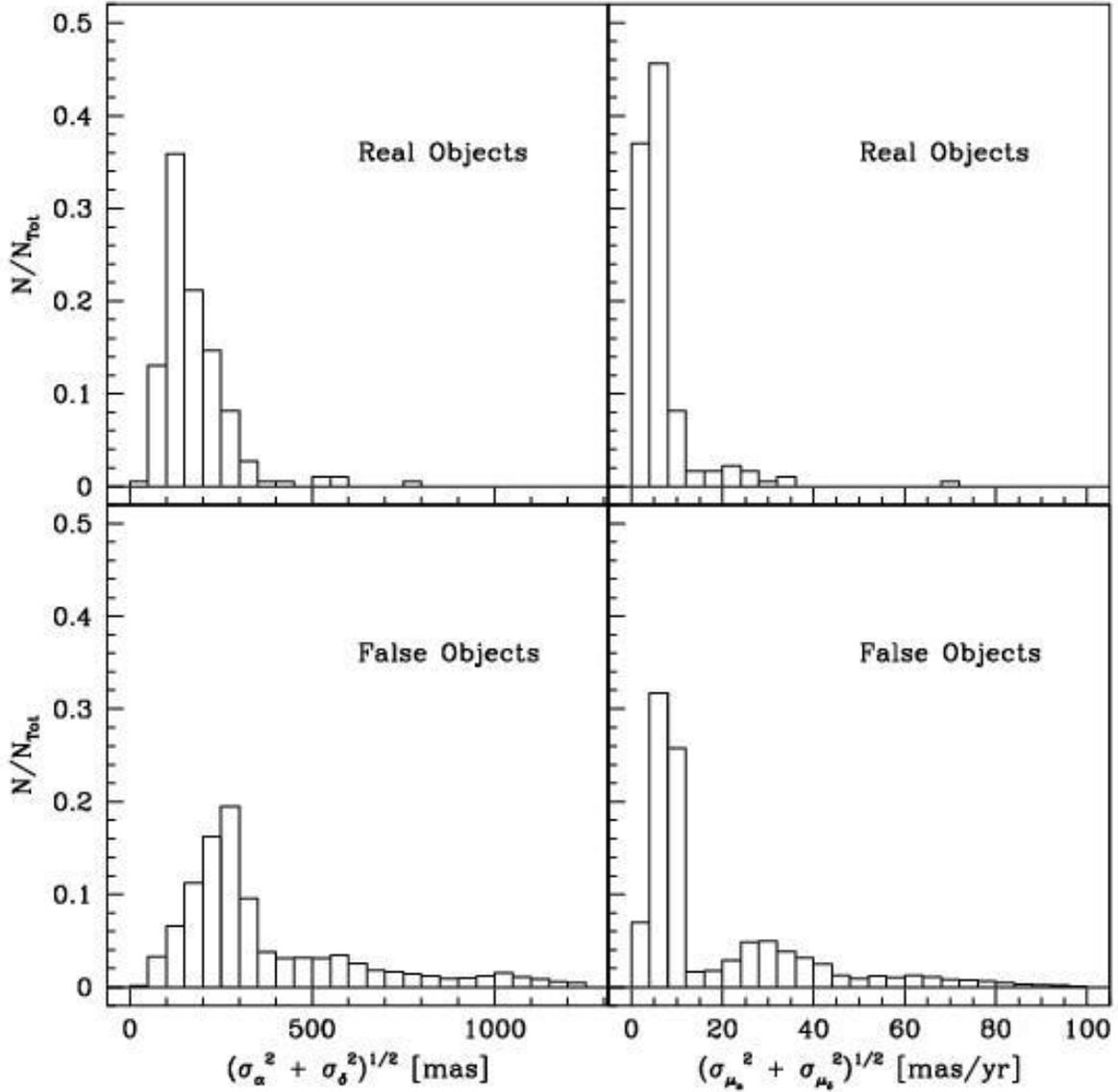
Fig. 6.— Histograms of the errors for the positions (*left column*) and motions (*right column*) for the real (*top row*) and false (*bottom row*) high motion objects. This is for the sub-sample of 3,348 possible objects where the catalogue based finders were reviewed by eye.
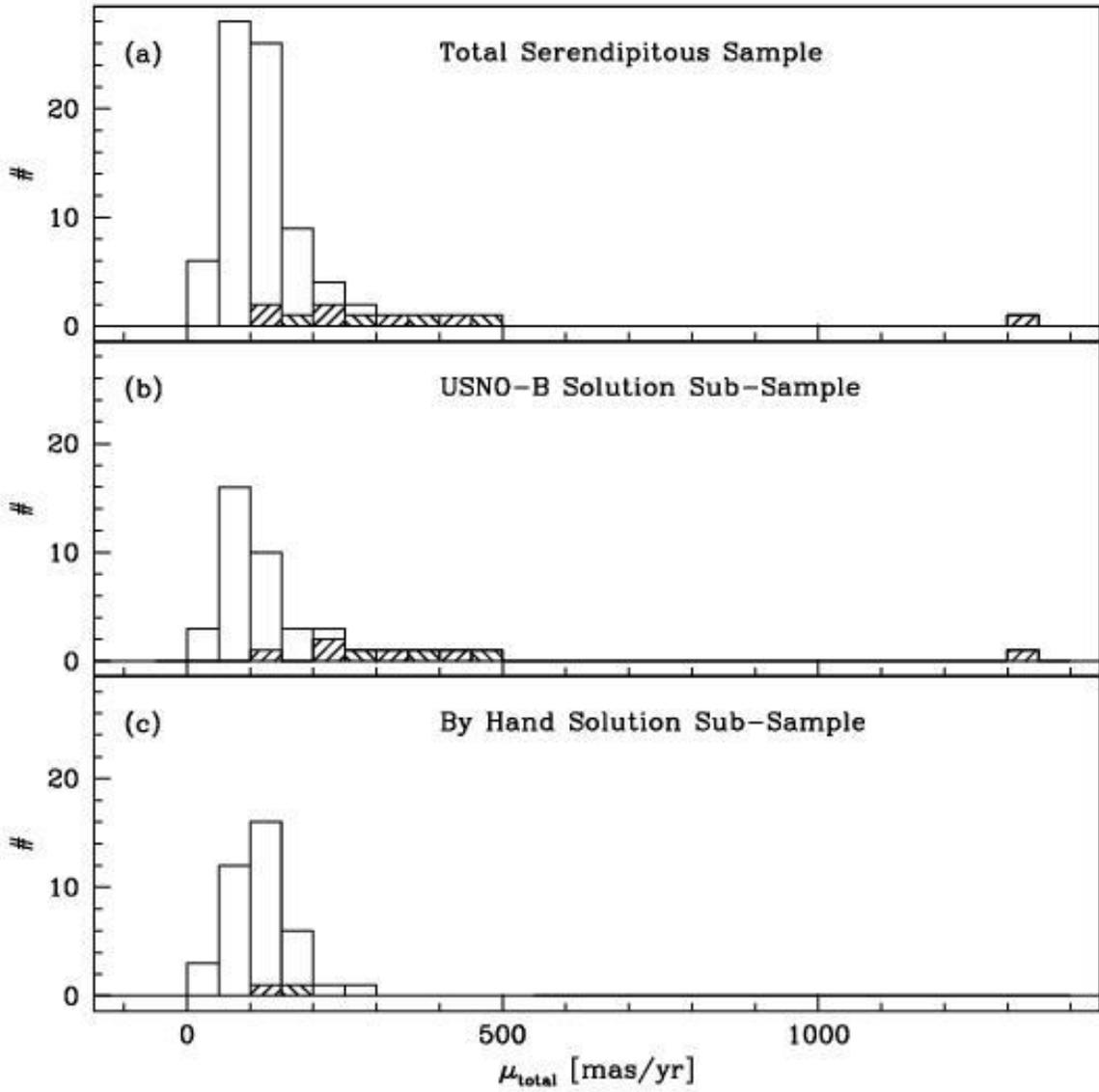
Fig. 7.— Histograms of the total proper motions of the serendipitous objects. The shaded histograms are of the known objects, while the outline histograms show the combined new and known. Panel (a) is the total set of serendipitous objects. (b) is the distribution of objects with good solutions in USNO-B1. (c) is the set of objects with solutions done by hand.
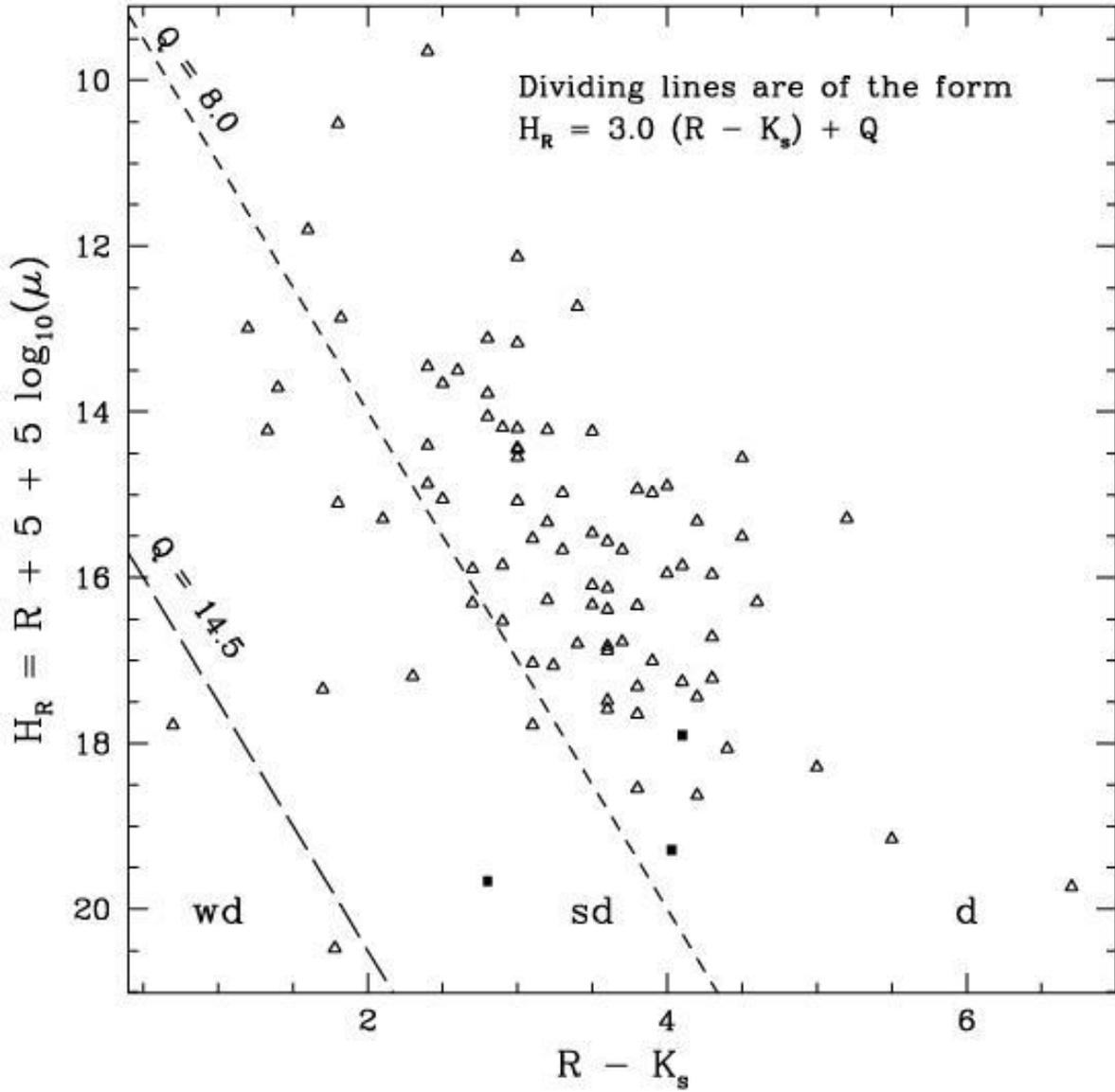
Fig. 8.— Reduced proper motion diagram for the objects listed in Tables 3 through 6. The reduced proper motion is $H_R = R + 5 + 5\log(\mu[\mathrm{arcsec\,yr^{-1}}])$. The lines dividing the space into regions occupied by dwarfs (d), sub-dwarfs (sd) and white dwarfs (wd) are based on the work of Lépine et al. (2003a,b), and Lépine (2005), and give a rough guide to likely stellar type. Objects with motions larger that $1\,\mathrm{arcsec\,yr^{-1}}$ are marked with filled squares.

(a) POSS-I 103aE Field 954
Epoch 1963.9

(b) POSS-I 103aE Field 955
Epoch 1963.9

(c) SERC-J IIIaJ Field 368
Epoch 1977.1

(d) ESO-R IIIaF Field 368
Epoch 1985.1

(e) AAO-R IIIaF Field 368
Epoch 1991.9
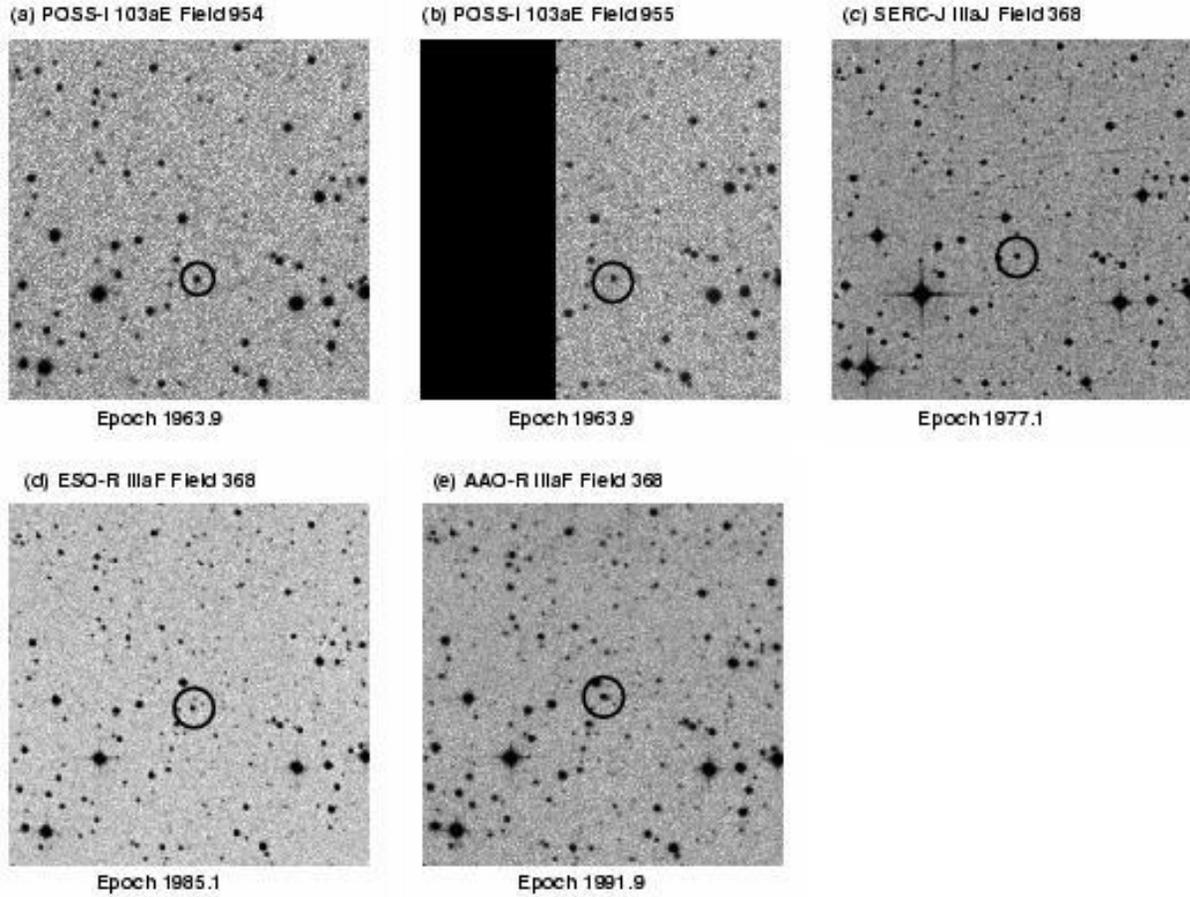
Fig. 9.— Finder charts showing the motion of object LHS 237a (USNO-B1 0560-0118956) ($\alpha_{2000} = 07^{\mathrm{h}}45^{\mathrm{m}}38\overset{\mathrm{s}}{.}5$, $\delta_{2000} = -33°55'52''$) on the 5 available Schmidt plates. North is up, East is to the right and all images are $6' \times 6'$ in size.
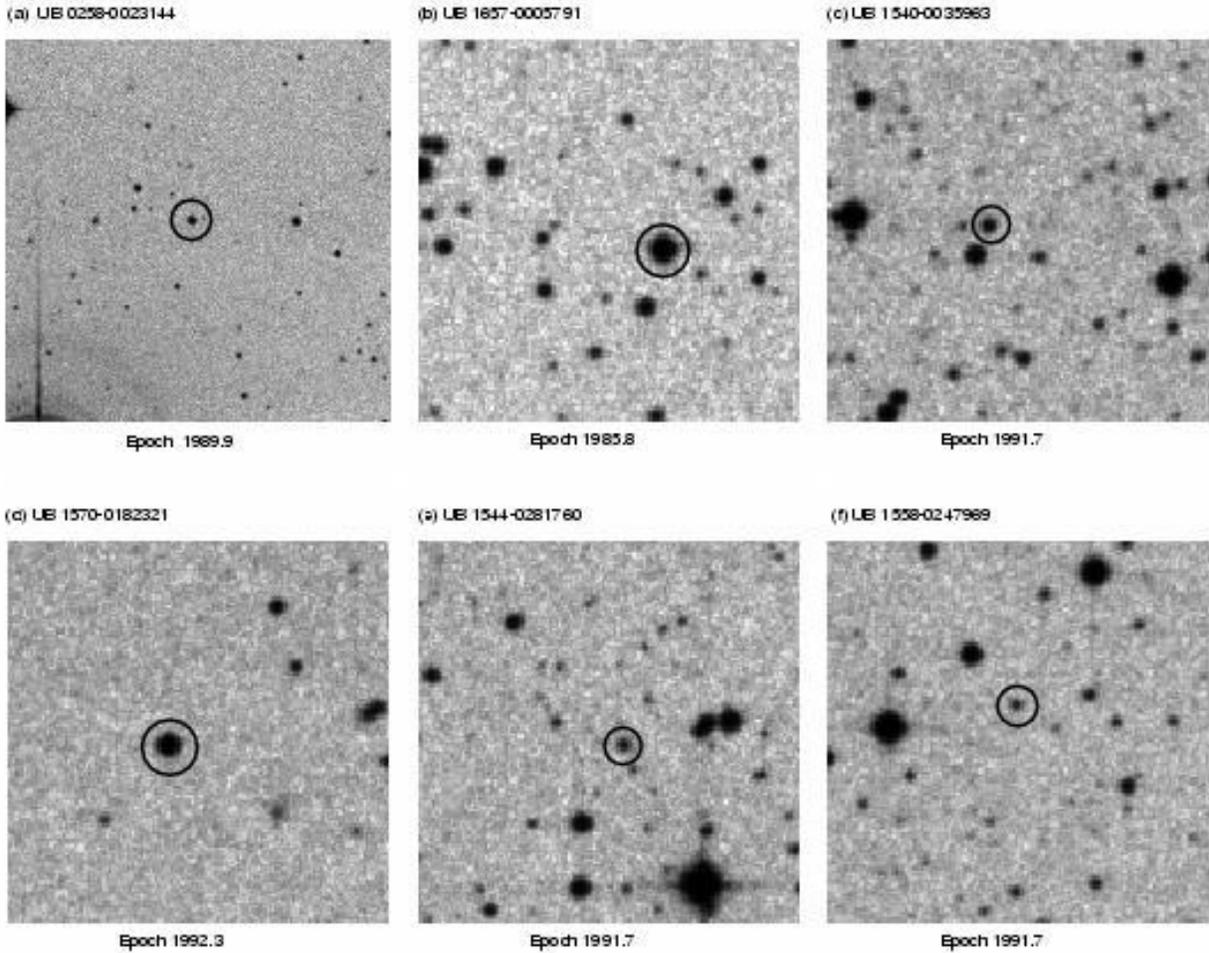
Fig. 10.— Finder charts showing the 6 objects with large relative μ_b. Image (a) is $6'$ square, and images (b) - (f) are $2'$ square. North is up, East is to the right. Image (a) is from an AAO-R IIIaF plate and images (b)–(f) are from POSS-II IIIaF plates. (a) USNO-B1 0258-0023144, (b) USNO-B 1657-0005791, (c) USNO-B 1540-0035963 (d) USNO-B 1570-0182321, (e) USNO-B 1544-0281760 (f) USNO-B 1558-0247969.
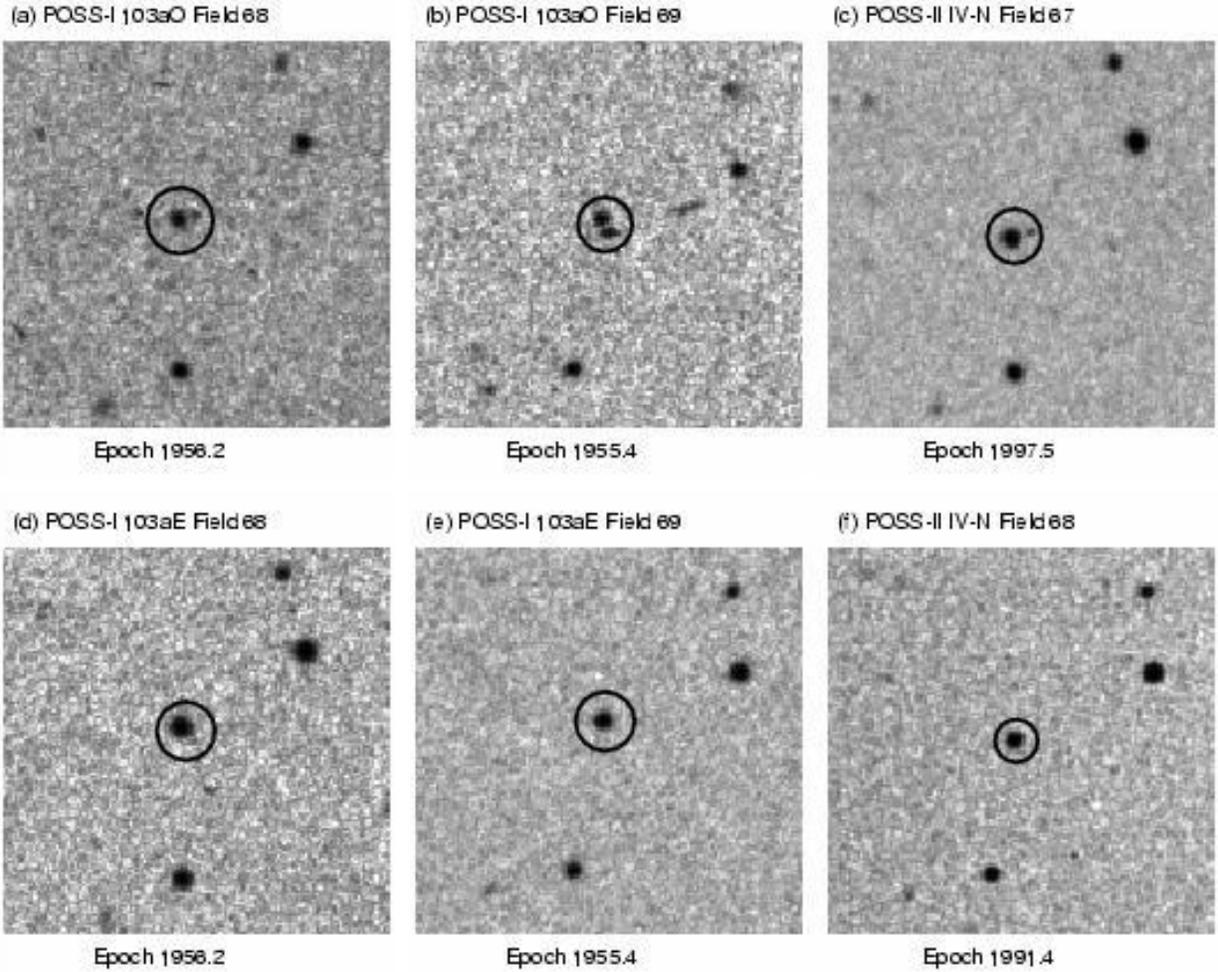
Fig. 11.— The region around MUSR 40 (marked with a circle). All images are $2'$ square. Images
(a)–(c) show more than one object within the circle around MUSR 40. Images (d)–(f) show only
MUSR 40 within the circle. Images (a) and (d) are from the POSS-I 103aO and 103aE images
of field 68 respectively. (b) and (e) are from the POSS-I 103aO and 103aE images of field 69
respectively. (c) and (f) are from the POSS-II IV-N images of fields 67 and 68 respectively. North
is up, and East is to the right.
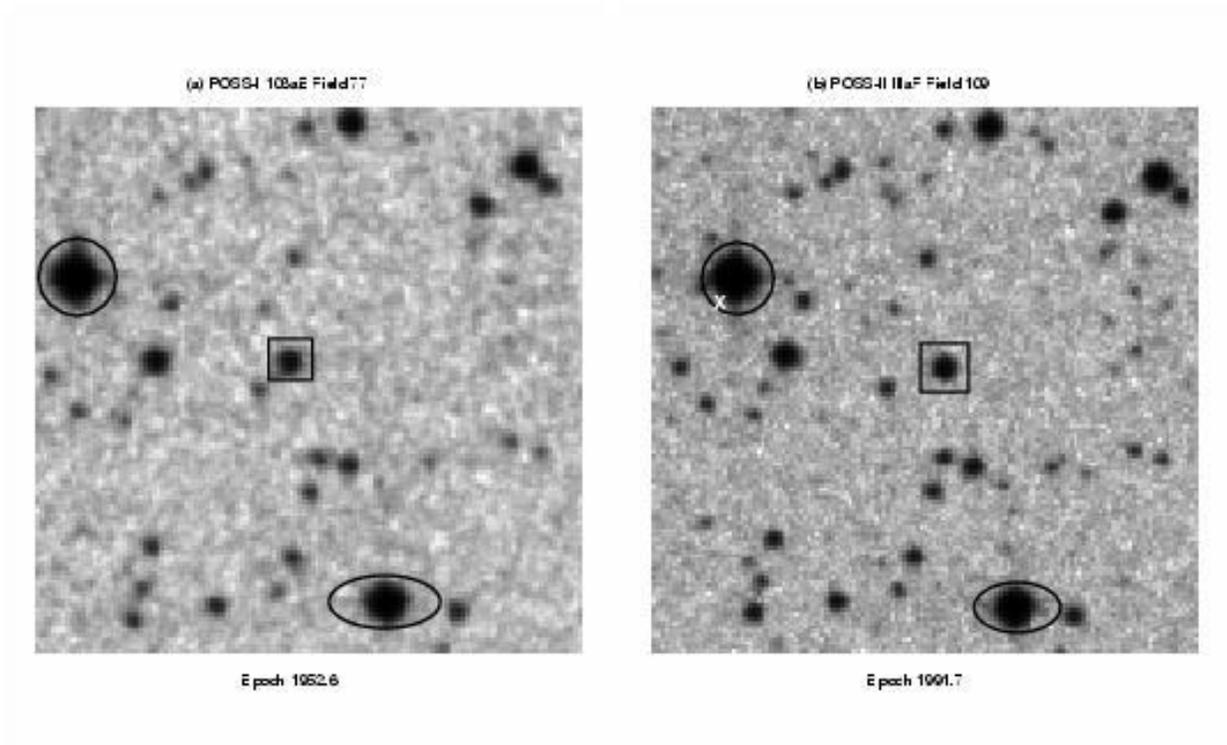
Fig. 12.— The region around LDS 4990 (MUSR 56 - marked with a circle), USNO-B1 1543-0282460 (MUSR 57 - marked with a square) and USNO-B1 1543-0282475 (MUSR 58 - marked with an ellipse). The position of 1RXS J224000.2+642310 is marked with a white X in (b). Both images are $2'$ square. (a) is from the POSS-I 103aE image of field 77. (b) is from the POSS-II IIIaF image of field 109. North is up, and East is to the right.
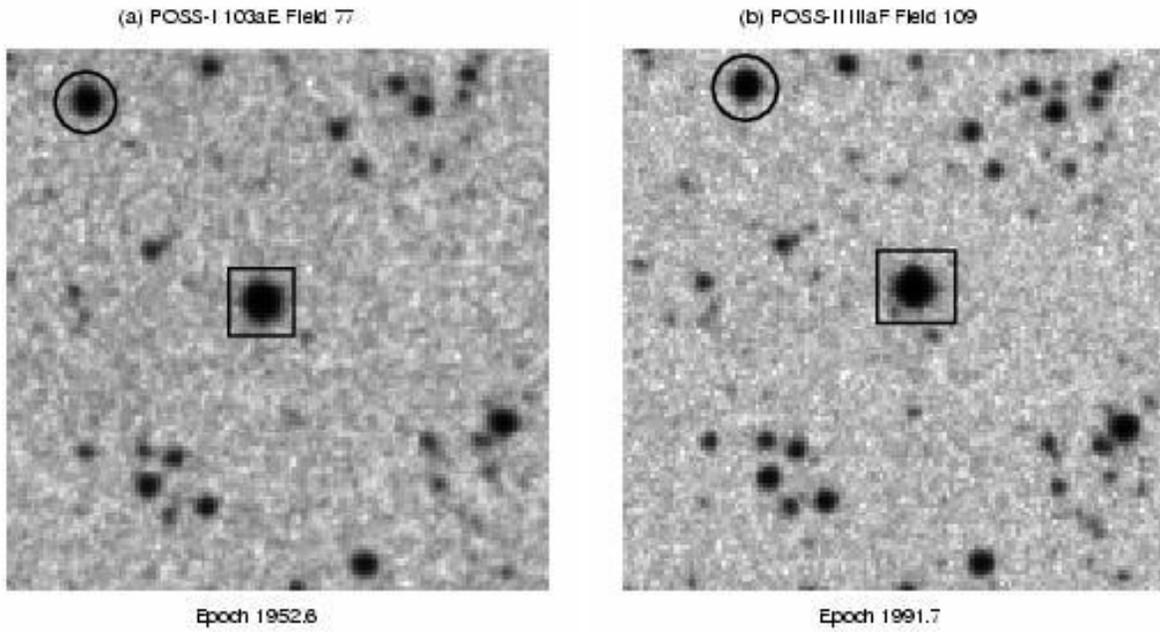
Fig. 13.— The region around MUSR 61 (marked with a circle), and MUSR 62 (marked with a square). Both images are 2′ square. (a) is from the POSS-I 103aE image of field 77. (b) is from the POSS-II IIIaF image of field 109. North is up, and East is to the right.
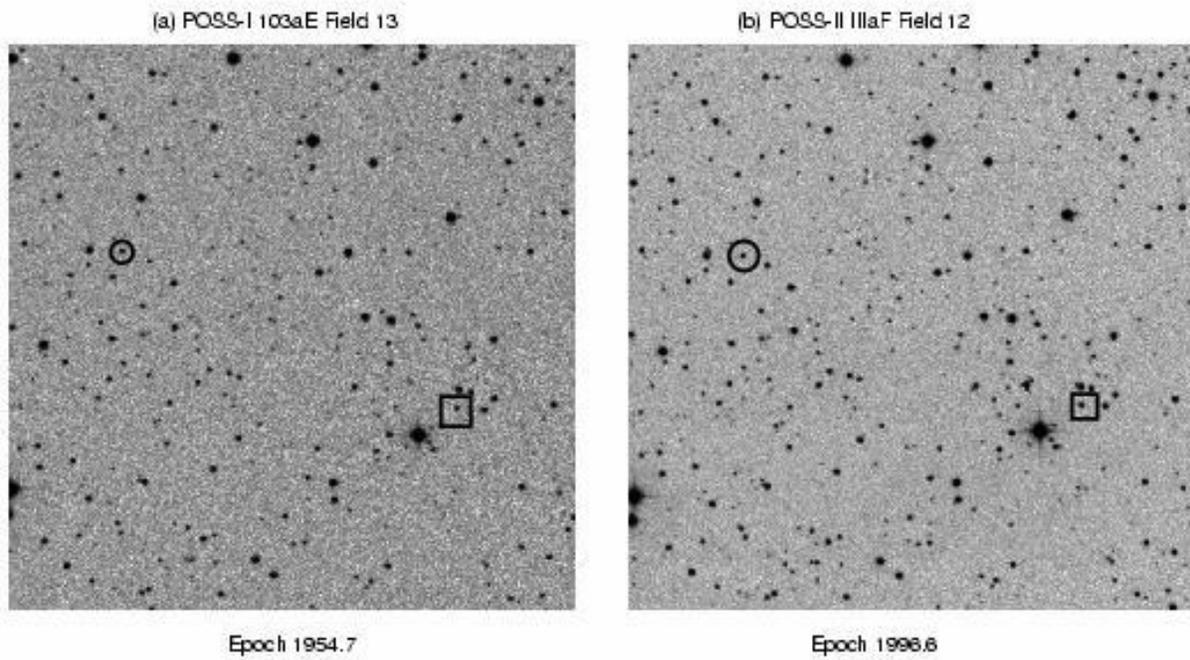
Fig. 14.— The region around MUSR 76 (marked with a circle), and MUSR 77 (marked with a square). Both images are $10'$ square. (a) is from the POSS-I 103aE image of field 13. (b) is from the POSS-II IIIaF image of field 12. North is up, and East is to the right.
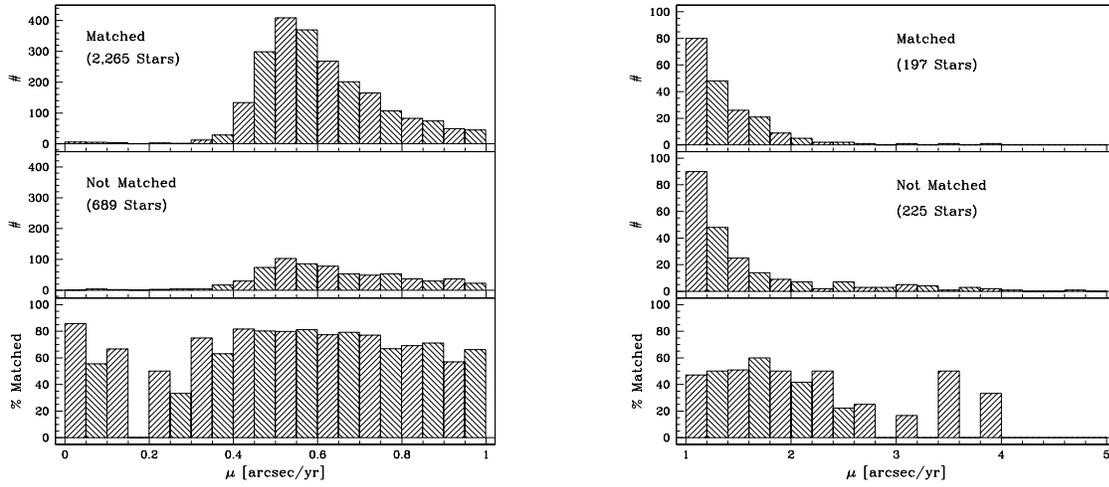
Fig. 15.— Histograms of the number of rLHS objects matched (upper panels) and not matched (middle panels) with objects in USNO-B1. The percent of objects matched is shown in the lower panels as a function of proper motion. The left side shows the statistics for those objects with motions between 0 and 1 $\mathrm{arcsec\,yr^{-1}}$, and the right side shows the data for those objects with motions between 1 and 5 $\mathrm{arcsec\,yr^{-1}}$.
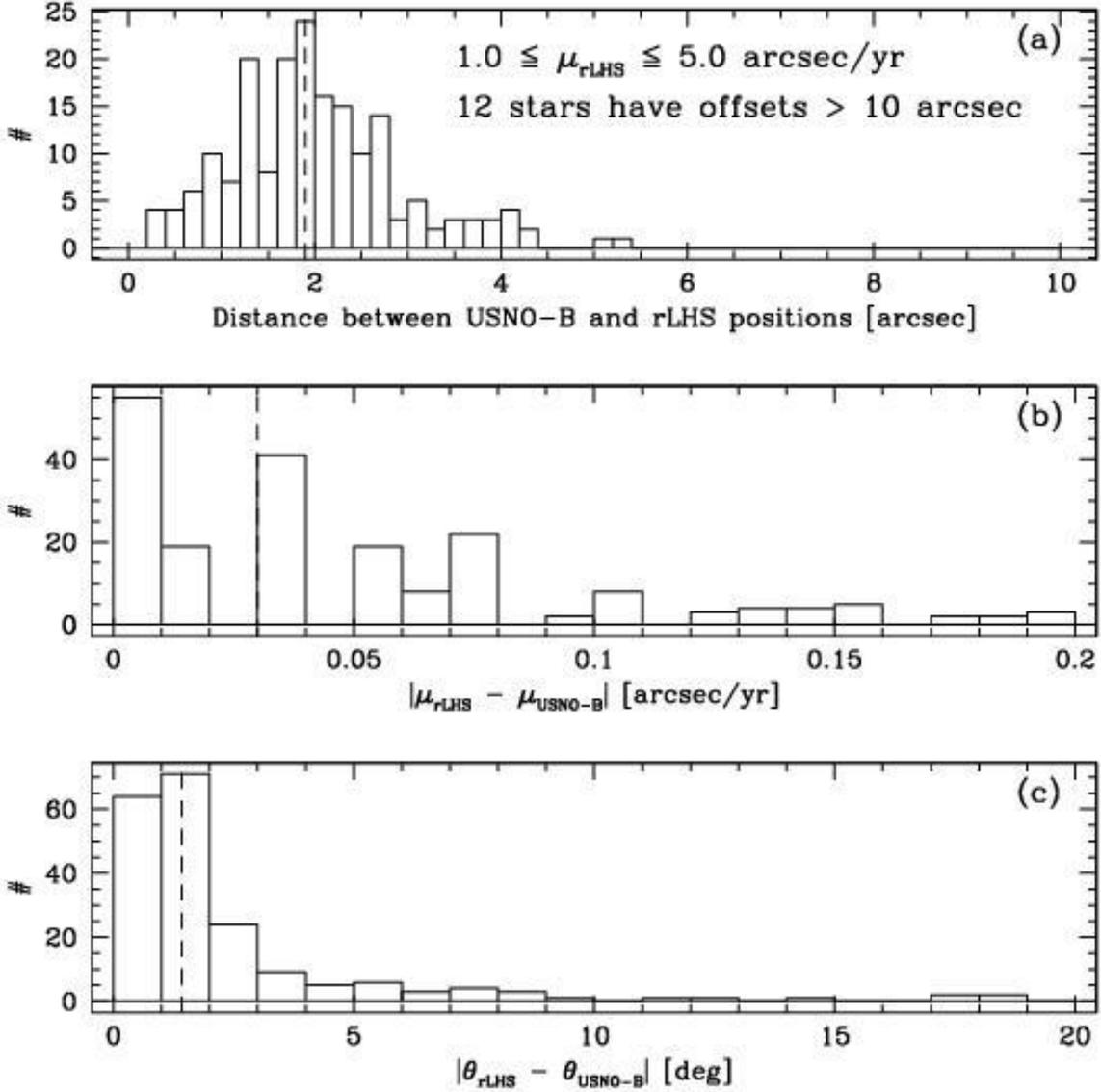
Fig. 16.— Histograms showing the difference between rLHS objects that have been matched up to an object in USNO-B1. Tycho-2 objects have been removed. Panel (a) shows the mismatch in the position between USNO-B1 and rLHS for objects objects in USNO-B1 that matched high motion objects in the rLHS. 12 objects have position differences greater than 10 arcseconds. Panel (b) shows the difference in magnitude of the proper motion, and (c) shows the difference in position angle. These are effectively truncated at $\delta\mu < 0.2\,\mathrm{arcsec\,yr^{-1}}$ and $\delta\theta < 20°$ respectively by the initial matching search. In all three panels, the median offset is marked by the dashed line.