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A *SPITZER* SURVEY FOR WIDE SUBSTELLAR COMPANIONS TO NEARBY STARS

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Abstract

We present search for brown dwarf companions to 135 nearby stars white dwarfs, and brown dwarfs with the *Spitzer Space Telescope* based on common proper motions. Included in this survey are the brown dwarfs WISE 1049−5319 A and B and WISE 0855−0714, which were recently discovered as the third and fourth closest systems to the Sun, respectively. We report the discovery of one new M dwarf companion to the white dwarf WD 1257-032, and we recover previously known companions to three other target stars. We do not find any companions in our images of WISE 1049−5319 A and B and WISE 0855−0714, which are capable of detecting objects as small as $1\mathrm{M_{jup}}$ at an age of 1 Gyr.

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Acknowledgements

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Chapter 1

Introduction

Brown dwarfs are objects that fall bellow the hydrogen mass burning limit ($\sim 0.075\mathrm{M}_{\odot}$) (Burrows et al.1997). Although brown dwarfs are too small to ignite hydrogen in their cores, they are still able to generate their own energy and emit light in the infrared via two processes. If a brown dwarf is more massive than $\sim 0.012\mathrm{M}_{\odot}$, it is able to radiate by briefly fusing deuterium soon after birth (Chabrier et al. 2000). Brown dwarfs that are too small to fuse deuterium can still radiate by contracting under the force of gravity, a mechanism that is also exhibited in large planets. Since brown dwarfs are unable to sustain energy generation for very long via these two processes, they cool indefinitely as they age, fading away and eventually becoming undetectable.

We classify brown dwarfs by collecting spectra, sorting them into three main spectral types: L, T, and Y. These classifications are a reflection of an object's temperature, which in turn are determined by the object's mass and age. Ideally, we would fit model atmospheres to the spectra of these objects to determine these three properties. However, gravity, atmospheric dust, and metallically each have a complicated influence on the observed spectral features (Day-Jones et al. 2008). We need to study systems with previous constraints on many of the unknown parameters in order to understand the atmospheres of these objects and derive accurate models. Brown dwarfs in binary systems with nearby stars are the perfect solution to this problem. Since the discovery of the first confirmed brown dwarf GL 229B (Nakajima et al.1995), it has become well known that brown dwarfs can be found as members of binary systems, and many low-mass companions have been observed orbiting nearby stars (Luhman et al. 2012). These binary systems co-evolve, allowing us to assume that both the well-studied primary star and the more elusive brown dwarf have similar ages and metalicities. With these assumptions, we can simplify the modeling process.

Binary systems with very low temperature brown dwarf companions are especially valuable because they serve as benchmark objects for modeling unexplored temperature regimes. The search for cooler and cooler brown dwarfs has uncovered a new spectral class known as Y dwarfs. The recently discovered brown dwarf WISE 0855-0714 is a perfect example of a planetary mass brown dwarf bellow the temperature range of of known T dwarfs (Luhman 2014). With an effective temperature of < 300 K, WISE 0855-0714 is similar in temperature to the Earth, and its mass is expected to be 3-10 Jupiter masses ($\mathrm{M_{jup}}$). Due to their ultra cool temperatures, atmospheric models created for T and Y dwarfs can be applied to understanding the spectra of planetary atmospheres.

Binary brown dwarfs are also advantageous laboratories for studying the detailed mechanisms of star formation. Larger stars, like our Sun, are formed when a cloud of dust and gas reaches critical mass and collapses. However, a cloud with just enough mass to form a brown dwarf should be too small to be unstable to gravitational collapse. This problem has inspired the development of many competing models to explain the formation of brown dwarfs. The majority of these theories begin with the idea that brown dwarfs are formed from a larger cloud that fragments into smaller stars as it collapses. During this fragmentation process, brown dwarfs must stop accreting matter before they become too large, and the mechanism responsible for halting accretion is widely debated.

For example, one theory maintains that brown dwarfs exhibit such low masses because they were ejected from a system of multiple stars before they were fully formed (Reipurth et al. 2001). This ejection is thought to be caused by dynamical interactions between multiple stars forming in the same cloud. However, other simulations have managed to produce brown dwarfs without the need for ejection. These simulations also have brown dwarfs forming in large fragmented clouds of gas, but they introduce sheering forces within the cloud that limit the flow of gas onto the forming stars, keeping them substellar (Bonnell et al. 2008). It has also been suggested that brown dwarfs could form in a manner more akin to planets than stars. Namely, it is possible that brown dwarfs are not formed in cloud collapse, and are instead formed in the fragmentation of circumstellar disks around existing stars (Bate et al. 2002).

Through observation, we can test the plausibility of each theory and explore the possibility that there may be multiple channels through which brown dwarfs form. Each theory would result in different populations of brown dwarfs, and many of these formation methods drastically influence the prevalence of brown dwarfs in binary or multiple systems.The discovery of brown dwarfs in widely separated binary systems is particularly illuminating because such systems are loosely bound and are not likely to be formed in chaotic environments involving dynamical forces and ejection from a larger cloud. These widely separated companions are also unlikely to have been formed in circumstellar disks, which do not extend beyond > 100 AU from their host star.

We present a survey in which we search for widely separated, low mass companions to 135 nearby stars. Any brown dwarf companions to these target stars would be excellent resources for furthering our understanding of low mass star formation and atmospheric modeling. This survey includes observations of the recently discovered systems WISE J104915.57$-$531906.1 A and B (Luhman 2013) and WISE J085510.83$-$071442.5 (Luhman 2014). With distances of ~ 2 pc, WISE J104915.57$-$531906.1 A and B (hereafter WISE 1049$-$5319 A and B (Luhman 2013)) and WISE J085510.83$-$071442.5 (hereafter WISE 0855$-$0714 (Luhman 2014)) are the closest known L, T, and Y dwarfs, respectively, and the nearest solar neighbors discovered in almost a century. Due to their proximity, these systems are ideal targets for a direct imaging search for companions at very low luminosities and temperatures that reach well into the regime of extrasolar planets.

Chapter 2

Observational Methods

The method of direct imaging has led to the successful detection of many substellar companions, especially at large separations when it is easy to resolve both components. If two stars form a binary system, they should be moving across the sky with the same velocity, and they can be identified as co-moving companions via their common proper motions. Proper motion surveys target nearby star systems because they have well-measured velocities, resulting in displacements that are large enough to be detected over short time spans. To search for companions at wide separations ($> 5''$, > 10 AU) from our target stars, the *Spitzer Space Telescope* (Werner et al. 2004) is the best available instrument because it offers exceptional mid-IR sensitivity, which is the wavelength range where brown dwarfs are brightest. Our 135 target stars were chosen because they were previously observed with the *Spitzer Space Telescope* and have high enough proper motions to show detectable motions in a new set of images. We also included two newly discovered brown dwarfs that had not been previously observed with *Spitzer*, namely WISE 1049−5319 A and B and WISE 0855−0714.

Spitzer is an infrared space observatory that trails the Earth in its orbit around the Sun. This orbit allows the telescope to escape the heat of the Earth and maximizes its field of view. All of the images in this survey were taken with the Infrared Array Camera (IRAC) (Fazio et al. 2004) onboard the *Spitzer Space Telescope*. IRAC has a plate scale of $1.2''$ and a field of view of $5.2' \times 5.2'$. It also has multiple channels (3.6 and 4.5 μm) for detecting light at different wavelengths in the infrared.

To search for co-moving companions in wide orbits, we analyzed multi-epoch images of the field surrounding each target star. For most of our target stars, the first epoch was mined from previous Spitzer cycles, and the second epoch was obtained in our current cycle. Since WISE 1049−5319 A and B and WISE 0855−0714 were only recently discovered, we imaged both epochs for these targets. Our observations employed both the 3.6 and 4.5 μm filters; however, only the 4.5

μm filter was centered on the target star because it provides the optimum sensitivity for detecting cool brown dwarf companions. We used a single pointing for the majority of the targets, capturing a $5.2' \times 5.2'$ field of view in each channel.In our observations of WISE 1049$-$5319 A and B and WISE 0855$-$0714, however, we collected wide-field images. For each of two epochs and for each filter we obtained images in a 3$\times$3 grid of pointings separated by $260''$. At each of the nine positions of in the map, we collected five dithered images with exposure times of 23.6 and 26.8 sec at 3.6 and 4.5 μm respectively. This mapping extends out to $\sim$ 1000 AU from the primary target star; all known brown dwarf binary systems have orbital separations less than $\sim$ 1000 AU. The resulting areas imaged with this mapping can be viewed in Figures 6.1 and 7.1.

Chapter 3

Proper Motion Analysis

The search for low mass companions was only performed in regions that were imaged twice. Although all of our observations centered the target star in the 4.5 μm channel, the first epoch observations were taken from previous *Spitzer* cycles where this was not necessarily the convention. Therefore, regions of overlap could occur between any combination of channels. In our analysis, channel 1 corresponds to 3.6 μm, channel 2 corresponds to 4.5 μm, and the two different epochs are denoted a and b. Accordingly, the possible combinations are channel 1a with 1b, 2a with 2b, 1a with 2b, and 2a with 1b. The overlapping channels were determined by visual inspection. We used the starfind package in IRAF to generate a file of coordinates for all the detected stars in each individual image. For each pair of images, we calculated the difference in the equatorial coordinates of all the sources detected in both epochs. These distances were then plotted on a proper motion diagram such as the plot seen in Figure 4.1. We searched for stars with proper motions similar to the known proper motion of the primary, often recovering the primary star in the process.

After finding stars with similar proper motions to the primary, we output a list possible companions. Our algorithm matches the sources detected in the first epoch to those detected in the second epoch by pairing the sources with the closest coordinates. This method occasionally produces false companions. For example, it might detect spurious motion in the diffraction spikes of a bright star or when multiple sources are very close together. We inspected each companion by eye to reject these false detections.

In cases where the primary star saturated a large fraction of the image, we performed a PSF subtraction. This revealed sources that were previously hidden by the glare of the primary, allowing us to probe for companions at closer separations.

Chapter 4

Recovered Companions

Some of the target stars imaged in this survey had low mass companions that were previously discovered and published in other papers. These systems allowed us to test our procedure, confirming that we could re-discover these objects in our own analysis. Using our methods, we re-discovered low mass companions to the stars GJ 1048, WD 1241-010, and G 124-62. As described in Chapter 3, we identified these companions using proper motion plots. The proper motion plots for each of these three cases are shown in the subsections below. These plots were created by measuring the motion of the sources detected in the overlapping epochs 2a and 2b. On the y-axis, we plot the measured displacement in the declination coordinates. Similarly, the x-axis we plot the measured displacement in the right accession coordinates. In each plot, the motion of the primary is graphed as an open circle, and the motion of the known companion is plotted as an unfilled star shape. The majority of the background stars appear in a cluster around the origin. Since the background stars are much farther away than primary star and its companion, they move much less between epochs.

4.0.1 GJ 1048

In 2001, Gizis et. al. discovered a low mass companion to the nearby K2 dwarf GJ 1048 (Gizis et al. 2001). The primary star was then designated GJ 1048A, and the companion was labeled GJ 1048B. Both the primary and the companion are located at a distance of ~ 21 pc from our Sun, and they are separated from each other by ~ 250 AU. GJ 1048B is categorized as an L1 dwarf with a mass of $\sim 0.076\mathrm{M}_{\odot}$. This mass, is derived from models that estimate that the companion falls within an age range of 0.6 - 2 Gyr. If GJ 1048 is older than expected, it could actually be massive enough to fuse hydrogen in its core. Otherwise, it is a high mass brown dwarf. As seen in Figure 4.1, GJ 1048 A and B exhibit the same motion between epochs, confirming their likely companionship.

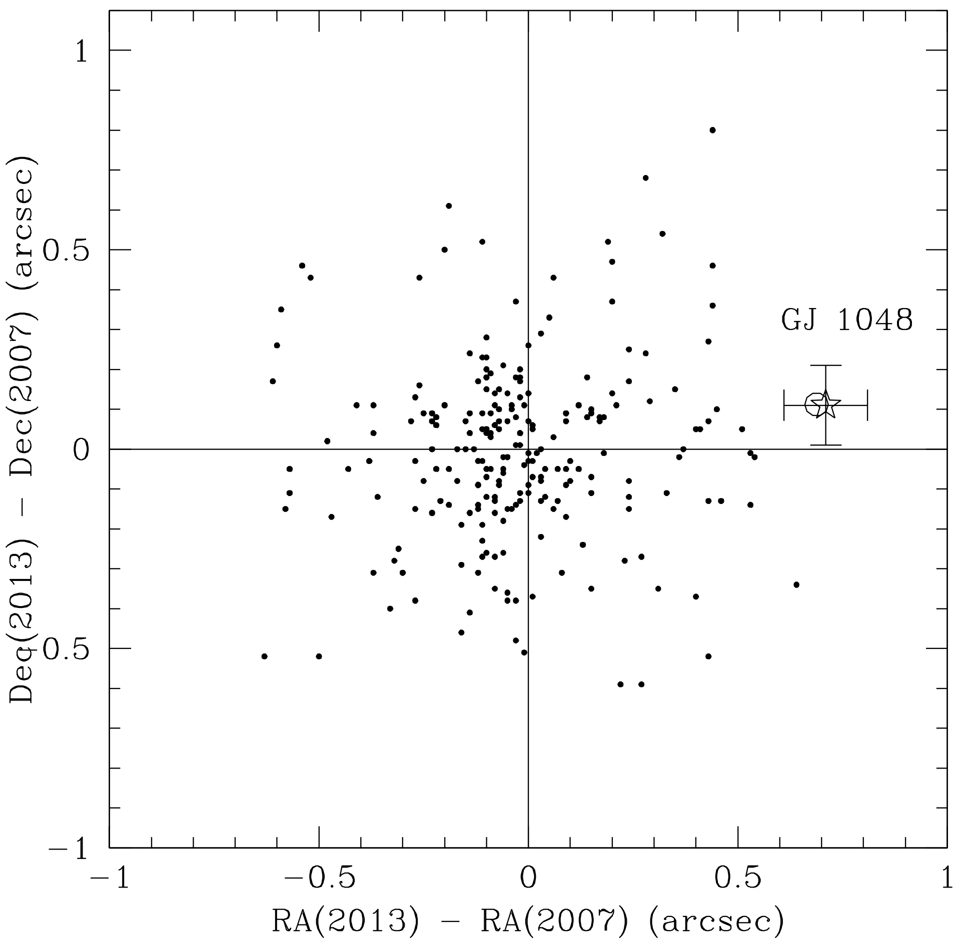

Figure 4.1: Proper motion plot for GJ 1048 constructed by measuring differences in the coordinates of starfind sources between two epochs of IRAC images. The motion of the primary is plotted as an open circle, the motion of the known companion is plotted as an open star shape, and the stationary background stars are clustered at the origin.

4.0.2 WD 1241-010

WD 1241-010 consists of a white dwarf in binary with an M9 brown dwarf. When this companion was discovered in 2008 (Day-Jones et al. 2008), WD 1241-010 became the widest known brown dwarf-white dwarf binary. WD 1241-010 is located about 41-59 pc from the Sun and the components are separated by 3650-5250 AU. The mass of the companion is though to be between 0.07 and 0.08 $M_\odot$, which is near the upper mass limit for brown dwarfs. The effective temperature of the companion is estimated to be between 2000-2400 K, and the age ($>$ 1.94 Gyr) is derived age of the white dwarf primary. This system was originally discovered in a proper motion survey similar to our survey. Figure 4.2 shows the proper motion plot created in our analysis of this system. The primary and companion exhibit similar motion, confirming their previously discovered companionship.

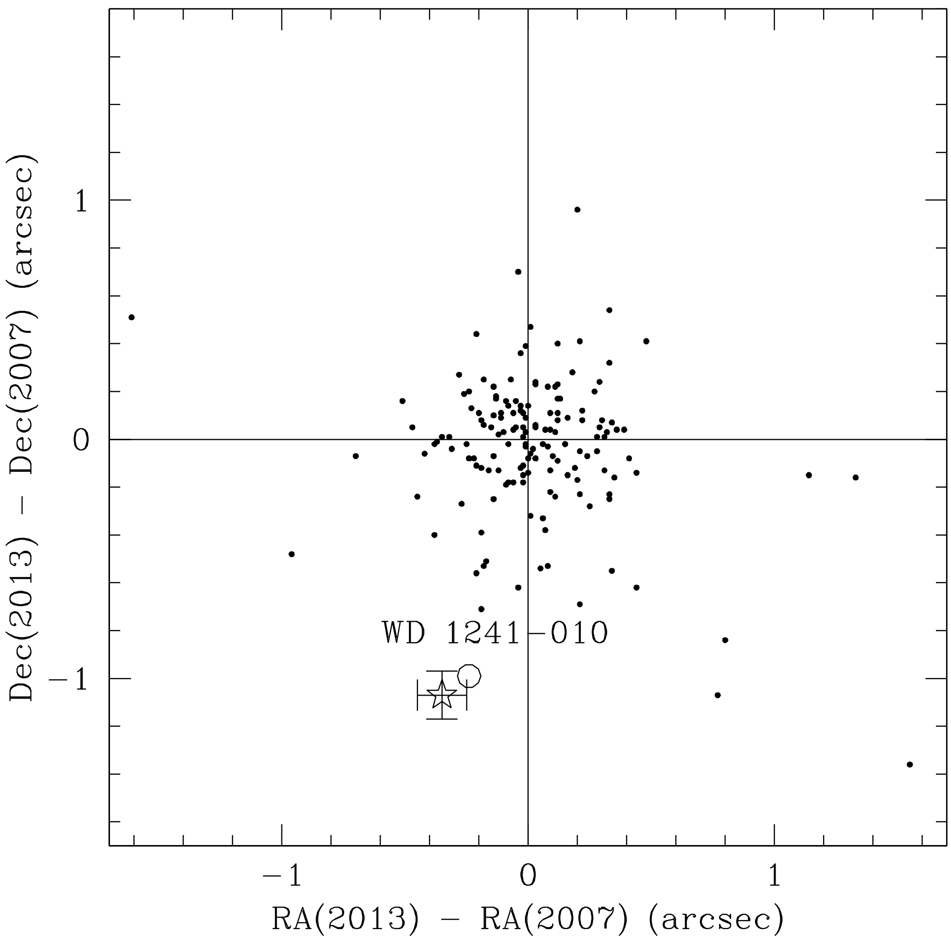

Figure 4.2: Proper motion plot for WD 1241-010 constructed by measuring differences in the coordinates of starfind sources between two epochs of IRAC images. The motion of the primary is plotted as an open circle, the motion of the known companion is plotted as an open star shape, and the stationary background stars are clustered at the origin.

4.0.3 G 124-62

G 124-62 is part of a triple system at a distance of 34 ± 7 pc (Radigan et al. 2013). Originally it appears that G 124-62 has one companion (G 124-62B), as was recovered in our proper motion analysis in Figure 4.3. However, the recovered companion is actually a binary system itself, consisting of two L1 dwarf components G 124-62Ba and G 124-62Bb. Each companion has a mass of $\sim 0.072 M_\odot$, putting them close to the hydrogen burning limit. Although we are unable to resolve the binary nature of the companion, we confirm that G 124-62 and its companion stars form a proper motion pair.

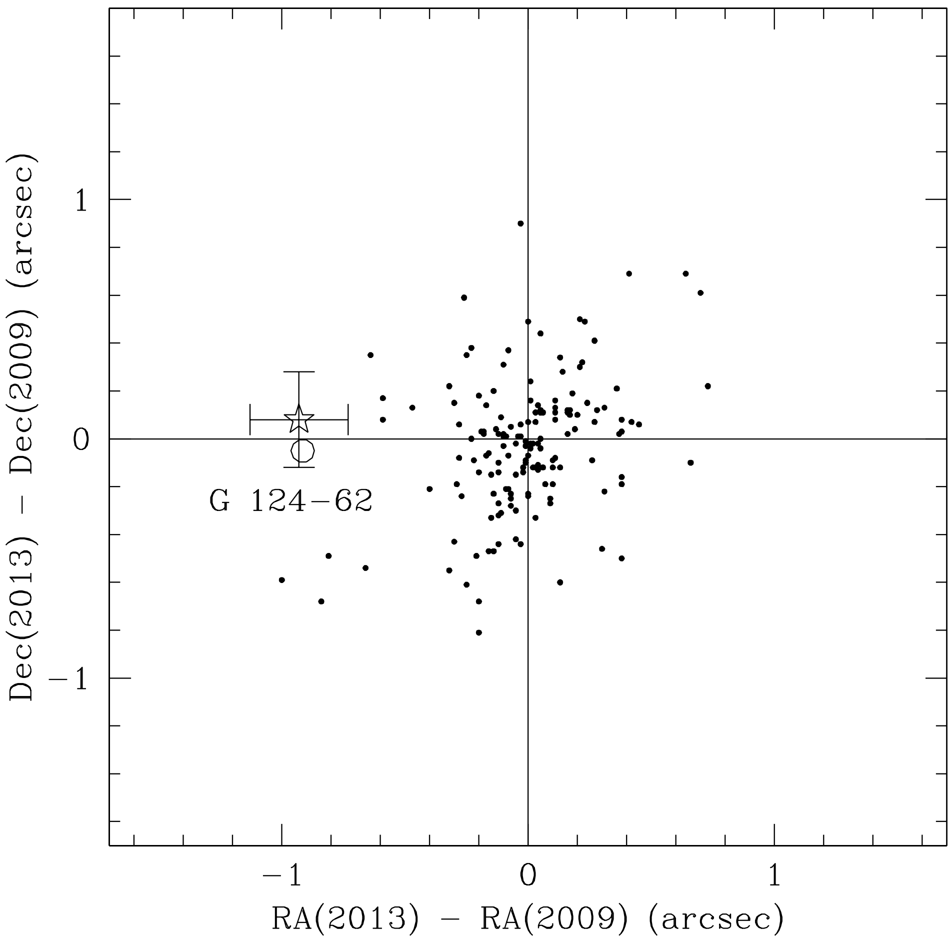

Figure 4.3: Proper motion plot for G 124-62 constructed by measuring differences in the coordinates of starfind sources between two epochs of IRAC images. The motion of the primary is plotted as an open circle, the motion of the possible companion is plotted as an open star shape, and the stationary background stars are clustered at the origin.

Chapter 5

New Companion

WD 1257+032 is listed in the Simbad database as a white dwarf at a distance of 96 pc. It has a proper motion of $\mu_\alpha \cos\delta = -0.090\ ''\mathrm{yr}^{-1}$ and $\mu_\delta = 0.032\ ''\mathrm{yr}^{-1}$, which correspond to an RA shift of $0.163''$ and a Dec shift of $-0.619''$ between our observations. Through our analysis of the IRAC images we found a new proper motion companion to WD 1257+032. Figure 5.1 shows the expected motion of the primary plotted as an open circle and the measured motion of the companion plotted as a star shape. The companion's displacements in right ascension and declination are 0.29σ and 1.33σ, respectively, from the expected motion of the primary.

The error bars plotted around the companion represent the astrometric uncertainty, and they were derived from Figure 5.2. Our ability to accurately measure a source's position depends on the magnitude of the source. To determine this uncertainty, we plotted the magnitude vs. displacement of all of the sources detected in both images. The background stars, which should be stationary, form a gaussian around the origin with the greatest uncertainty in the displacement of the faintest objects. Any motion that falls within this envelope is indiscernible form zero. We estimate the uncertainty in our displacement measurements to be the standard deviations in the component displacements of the background stars to within ± 1 of the companion's magnitude. In Figure 5.2, the companion is plotted as a star shape and the motion of the primary is plotted as a dashed vertical line. At the magnitude of the companion (~ 14) the spread in the uncertainty of both the RA and Dec displacements is $\pm 0.1''$.

We confirm that motion of the proposed companion truly matches the motion of the primary by comparing our most recent epoch with images of this same field taken by older all sky surveys such as the Digitized Sky Survey. Using older images as the first epoch allows WD 1257+032 and its companion to undergo a larger displacement between epochs, which we can measure with greater accuracy. In our images, the dwarf companion and the primary star are separated by $\sim 79''$, which is $\sim 7,584$ AU at a distance of 96 pc. Based in the infrared colors of the companion, we expect that it is an M dwarf.

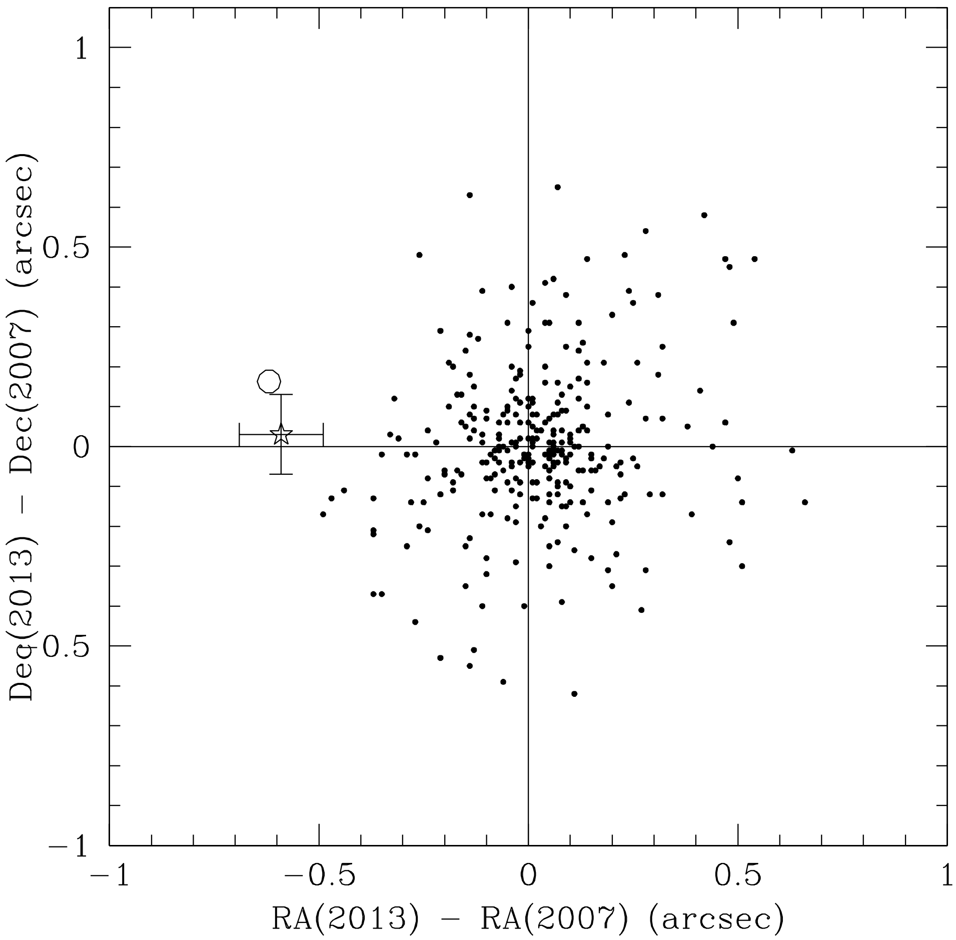

Figure 5.1: Proper motion plot for WD 1257+032 constructed by measuring differences in the coordinates of sources between two epochs of IRAC images. The expected motion of the primary is plotted as an open circle, the motion of the possible companion is plotted as an open star shape, and the stationary background stars are clustered at the origin.

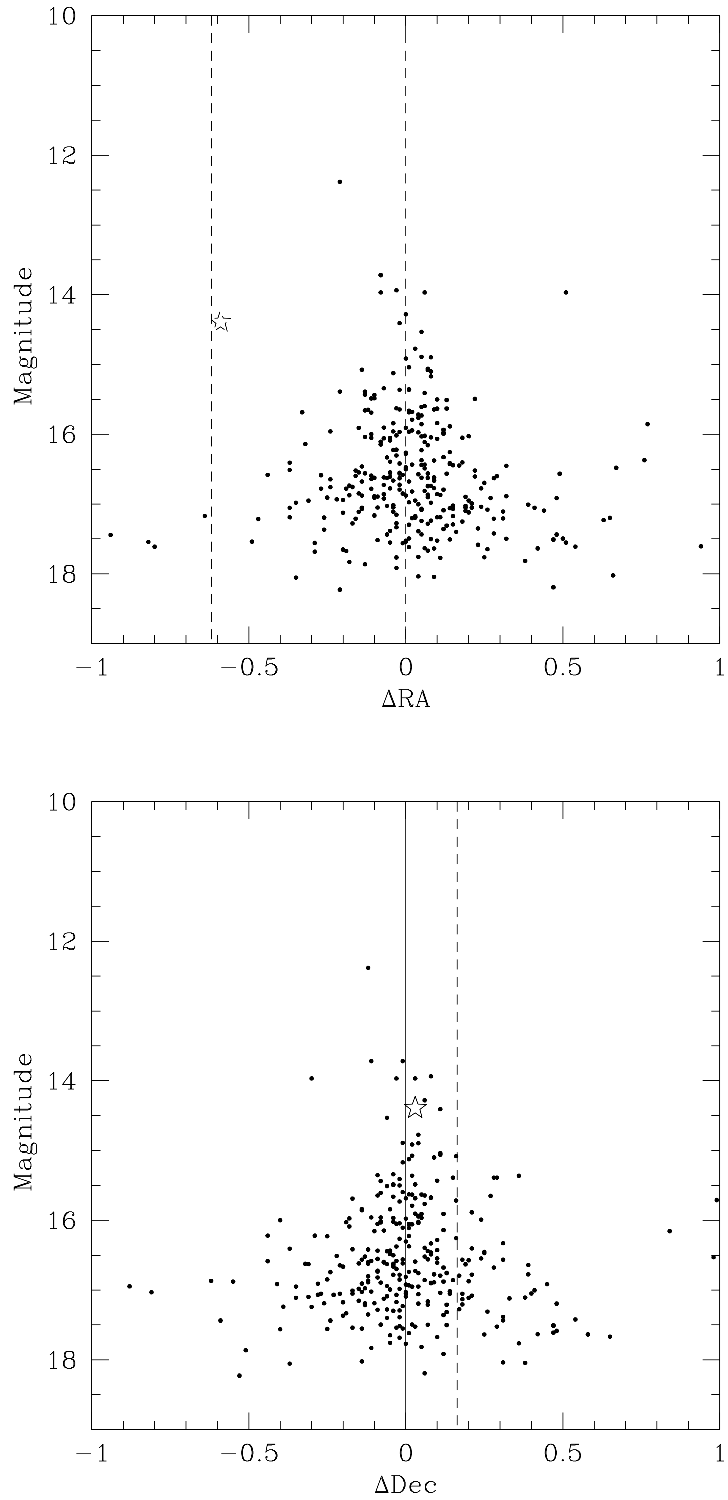

Figure 5.2: This plot is used to determine the astrometric uncertainty in our RA and Dec measurements. The background stars, which should be stationary, form a gaussian around the origin with the greatest uncertainty in the displacement of the faintest objects. Any motion that falls within this envelope is indiscernible form zero. We estimate the uncertainty in our displacement measurements to be the standard deviations in component displacements of the background stars to within ±1 of the companion's magnitude. The companion is plotted as a star shape and the motion of the primary is plotted as a dashed vertical line.

Chapter 6

WISE 1049-5319

WISE 1049-5319 is a binary system consisting of two brown dwarfs. Spectra have revealed that the primary component is an L7.5 $\pm$ 1 dwarf, and the secondary component is classified as a T0.5 $\pm$ 1 dwarf (Burgasser et al. 2013). This system is located at a mere distance of 2.0 $\pm$ 0.15 pc, making it the Sun's third closest neighbor. Despite its unbelievably close proximity, WISE 1049-5319 managed to remain undiscovered until 2013, when it was identified with the Wide Field Infrared Survey Explorer (Luhman 2013). WISE 1049-5319 has likely gone undetected for so long because it is close to the galactic plane, at a latitude that is not commonly imaged in brown dwarf surveys. Naturally this object has become a target of great public and scientific interest. Because it is so close, WISE 1049-5319 is especially well suited for direct imaging observations. The closest star systems allow us to search for very low mass, cool companions that would be too faint to detect around farther systems.

Our observations of WISE 1049$-$5319 A and B were performed on 2013 May 3 and 2013 September 29, during which the primary and any co-moving companions would move $\sim$1.1$''$ between epochs given its proper motion and parallax (Luhman 2013). Since WISE 1049-5319 is such a close target, we only needed a few months between epochs to ensure that the motion of the primary and any possible companions would be easily detectable. A mapping of the imaged fields and their overlap can be viewed in Figure 6.1. Note that the binary brown dwarfs are unresolved. Following the procedure outlined in Chapter 3, we searched for co-moving companions to the WISE 1049-5319 system. Figure 6.2 shows the proper motion plot for the detected objects in this field. Unlike the previous proper motion plots, this plot includes sources from all overlapping channels, not just 2a and 2b. We recover the binary system with its expected proper motion, but we do not detect any co-moving companions.

The detection limits of the *Spitzer Space Telescope* for WISE 1049-5319 are shown in red in Figure 6.3. We assume that any brown dwarf companions have a typical age range of 1-10 Gyr, and we use evolutionary models to plot these two extremes (Burrows et al. 2003). At 2 pc we should be able to detect 1 Gyr old companions down to a mass of 1 $\mathrm{M_{jup}}$ at a minimum orbital separation of $\sim$ 40 AU. We can detect older brown dwarf companions ($\sim$ 10 Gyr) with masses as small as 10 $\mathrm{M_{jup}}$ and at a minimum separation of $\sim$ 20 AU. The mass detection limits increase with age because brown dwarfs become fainter over time. Smaller companions can only be discovered at larger orbital separations because they are fainter and more easily overcome by the glare of the primary.

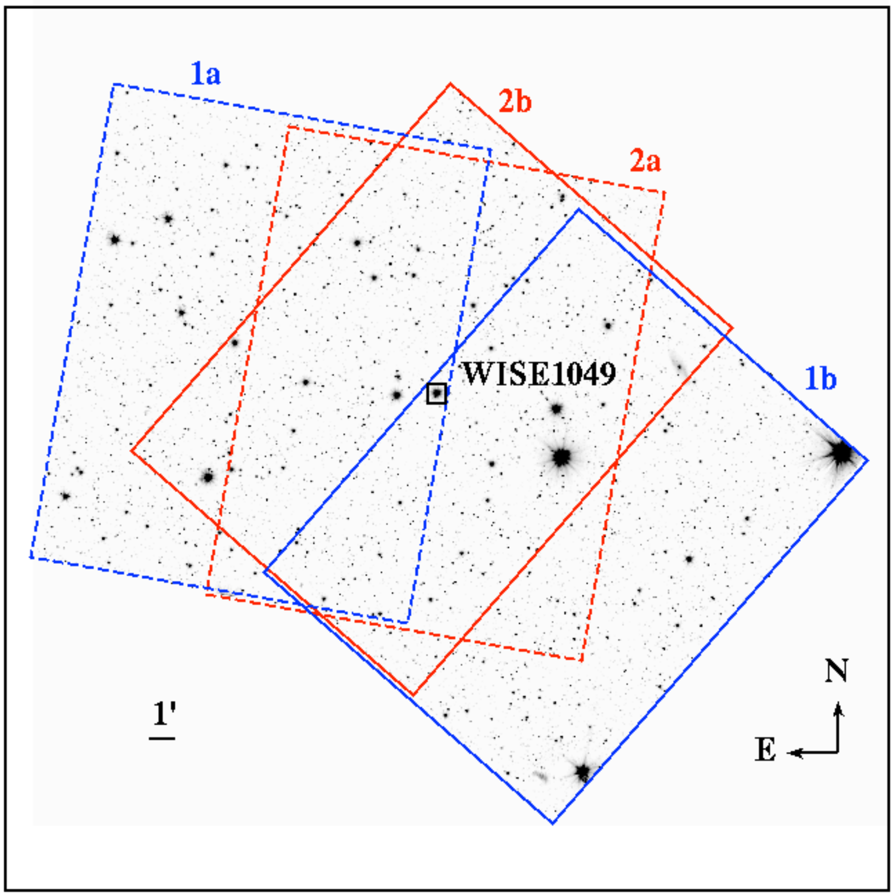

Figure 6.1: The overlapping WISE J104915.57 fields observed with *Spitzer*. These observations employed both the 3.6 (CH1) and 4.5 (CH2) μm filters. Each image consists of a 3x3 grid of exposures with perimeter dimensions $830'' \times 1238''$ (1660 AU x 2476 AU) . The a and b epochs were taken approximately five months apart (May 3, 2013 - September 29, 2013).

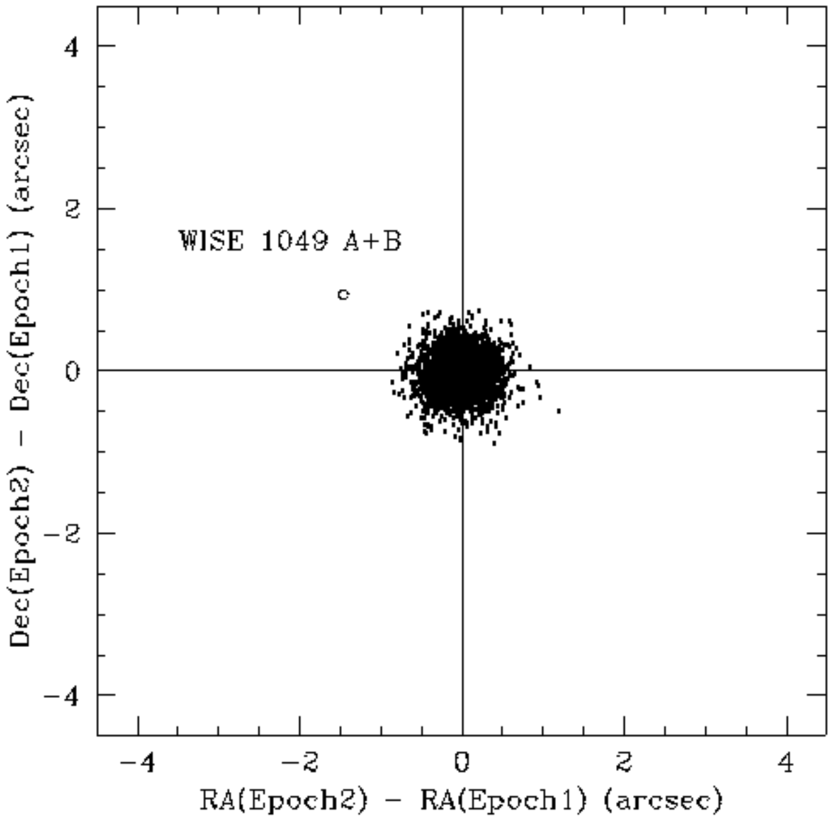

Figure 6.2: Proper motion plot for WISE 1049-5319 constructed by measuring differences in the coordinates of starfind sources between two epochs of IRAC images. The motion of the primary is plotted as an open circle, and the stationary background stars are clustered at the origin.

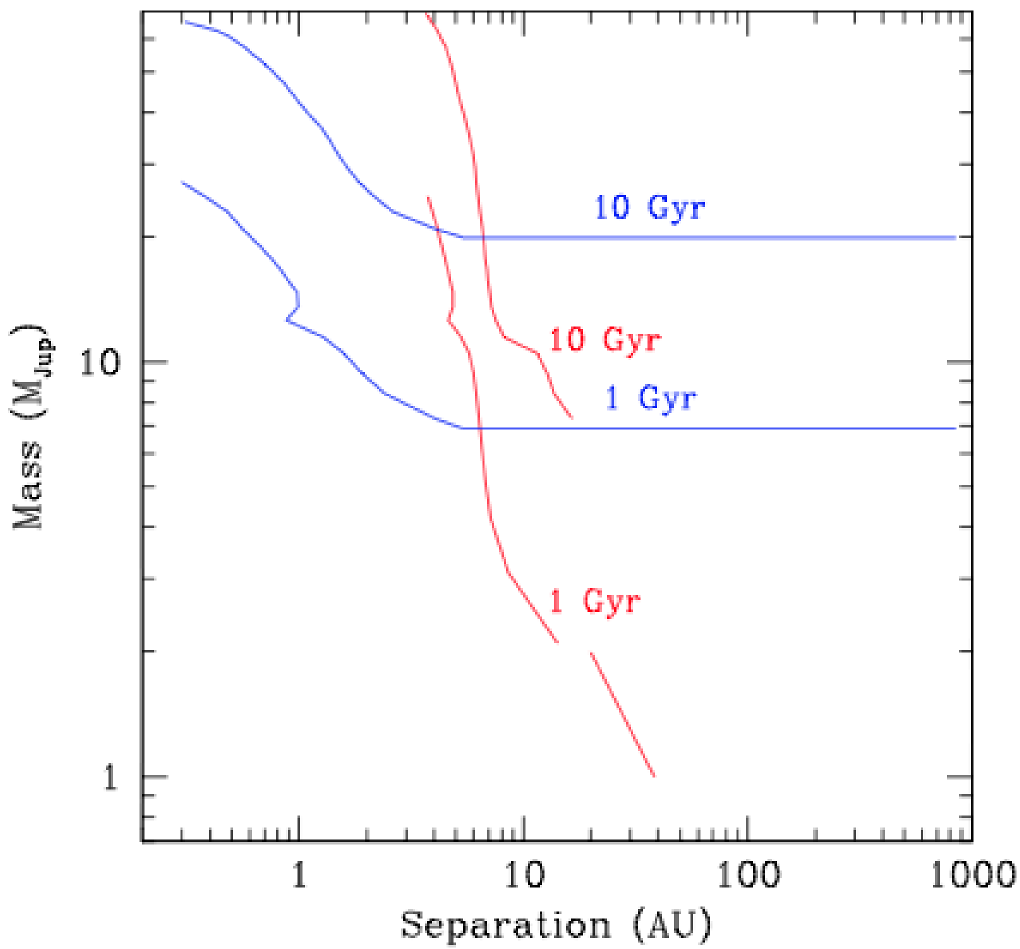

Figure 6.3: The detection limits of our observations at a distance of $\sim$ 2 pc from the Sun. We assume that any brown dwarf companions have a age range of 1-10 Gyr, which is typical of most stars in the galaxy. We plot the extremes of this range, showing the *Spitzer* detection limits in red and the VLT adaptive optics images in blue. At 2 pc *Spitzer* should be able to detect 1 Gyr old companions down to a mass of 1 M_{jup} at a minimum orbital separation of $\sim$ 40 AU. We can detect older brown dwarf companions $\sim$ 10 Gyr with masses as small as 10 M_{jup} and at a minimum separation of $\sim$ 20 AU. Adaptive optics allow us to probe smaller separations but with less sensitivity.

Chapter 7

WISE 0855-0714

WISE 0855-0714 is the fourth closest neighbor to our Sun (Luhman 2014). It was discovered less than a year after the discovery of WISE 1049-5319, and it is located just slightly beyond WISE 1049-5319 at a distance of 2.31 ± 0.08 pc (Luhman & Esplin 2014). Assuming an age range of 1-10 Gyr, WISE 0855 has an estimated mass of 3-10 Jupiter masses and an unprecedented effective temperature in the range 225-260 K. At this temperature, it is the coldest known brown dwarf.

While WISE 0855-0714 itself is a benchmark for testing models of ultra cool brown dwarfs, it is also ideal place to search for very low mass, ultra cool companions. WISE 0855 has a very high proper motion ($\mu = 8.1'' \text{ yr}^{-1}$), so proper motion measurements require very little time between epochs. In our survey, we made two observations of WISE 0855$-$0714 on 2014 July, 1 and 2015 January, 29. This baseline corresponds to a motion of $\sim 4.7''$ given the proper motion and parallax of the primary (Luhman 2014). As described in Section 2, each image maps a wide field of view surrounding the primary star. These mappings and the overlapping channels can be seen in Figure 7.1. Our analysis of these images resulted in the proper motion plot in Figure 6.2. Again, we recovered the primary star (plotted as a circle) with its expected motion, but we did not identify any additional co-moving companions to this brown dwarf. Since WISE 0855-0714 is cool and dim, the faintest and lowest mass detection limits for WISE 1049-5319 (Figure 6.3) are reached at closer separations from the primary binary brown dwarfs. Therefore, if WISE 0855-0714 had very faint, low mass companions, we should be able to detect them down to orbital separations of $\sim 5''$.

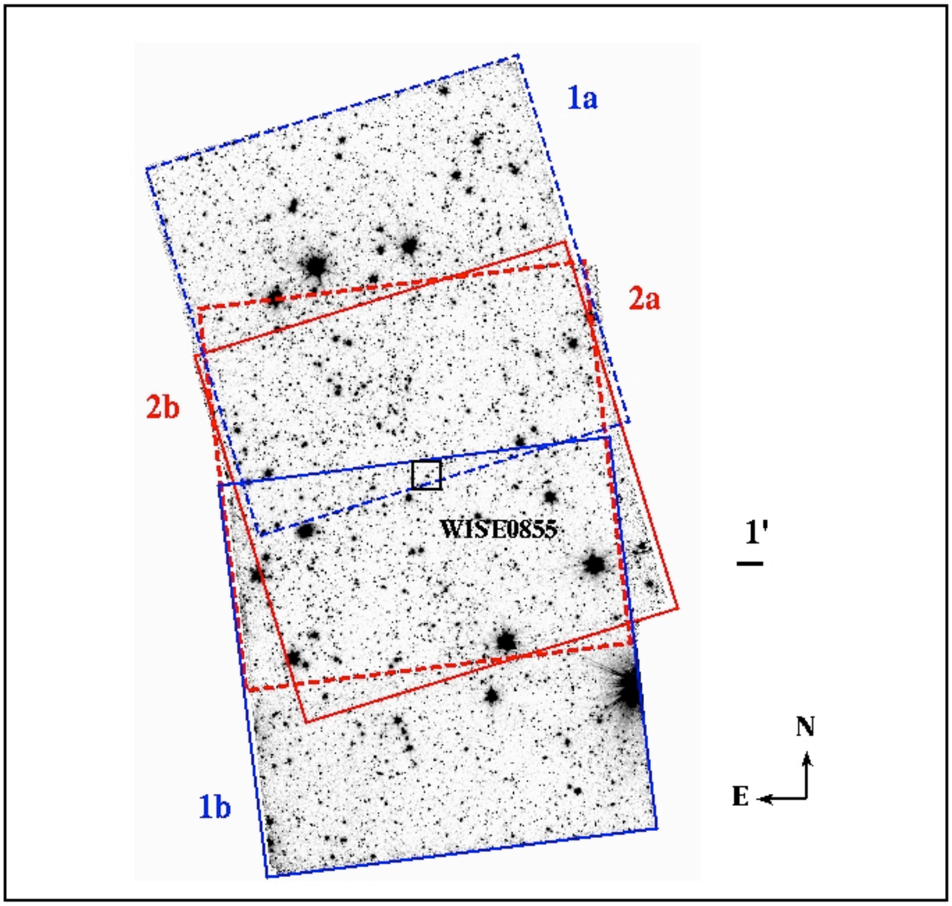

Figure 7.1: The overlapping WISE 0855-0714 fields observed with *Spitzer*. These observations employed both the 3.6 (CH1) and 4.5 (CH2) μm filters. Each image consists of a 3x3 grid of exposures with perimeter dimensions $830'' \times 1238''$ (1660 AU x 2476 AU) . The a and b epochs were taken approximately six months apart (July 1, 2014 - January 29, 2015).

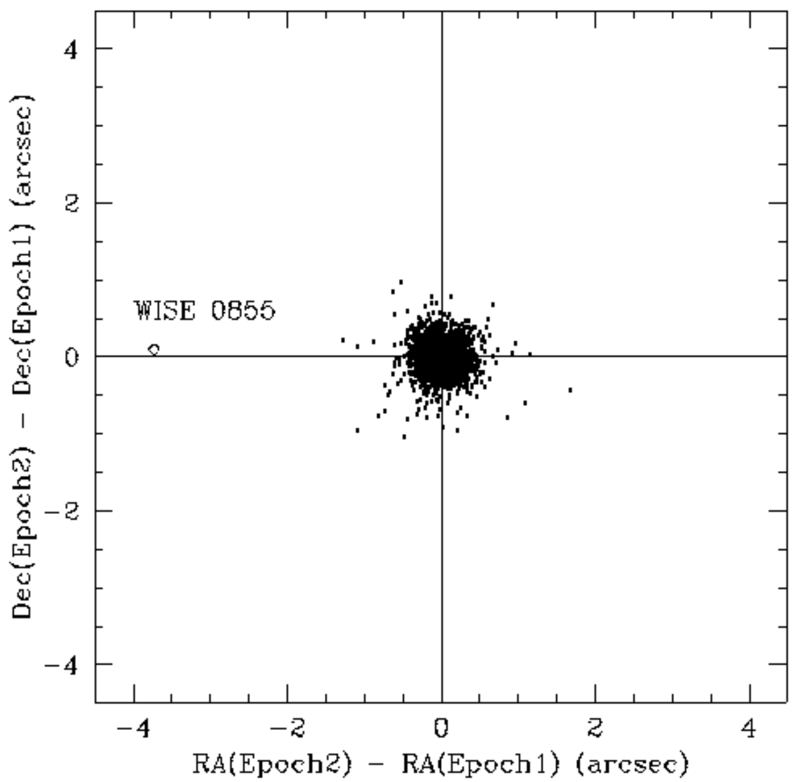

Figure 7.2: Proper motion plot for WISE 0855 constructed by measuring differences in the coordinates of starfind sources between two epochs of IRAC images. The motion of the primary is plotted as an open circle, and the stationary background stars are clustered at the origin.

Chapter 8

Discussion

We have searched 135 nearby stars and brown dwarfs for substellar companions in wide binary systems, discovering one new M dwarf companion to the target WD 1257-032 and recovering previously known companions to three other target stars. Recalling our original motivation, we search for substellar companions in wide binary systems to both test theories of low mass star formation and model the atmospheres of very low temperature T and Y dwarfs. Since the companion to WD 1257-032 is likely and M dwarf, it is not an ultra cool companion, and therefore not an ideal candidate for spectral analysis and atmospheric modeling. However, this system does exhibit a very wide orbital separation of $\sim 7,584$ AU, which allows us to rule out certain formation theories. For example, since wide binaries are loosely gravitationally bound, it is unlikely that WD 1257-032 and its companion dwarf would have survived dynamical expulsion from its cloud of origin. It is also not possible for this companion to have been formed in a circumstellar disk, since these disks have not been observed to extend beyond 100 AU from their host stars. As mentioned above, we also re-discovered brown dwarf companions to the target stars GJ 1048, WD 1241-010, and G124. We confirm the companionship of these objects, affirming that our methods are consistent with those used in previous proper motion surveys.

In addition, we searched for substellar companions to our newest solar neighbors, WISE 1049$-$5319 A and B and WISE 0855$-$0714. Our detection limits allowed us to probe for objects as small as 1-10 Jupiter masses, and our wide-field images extended to ~ 1000 AU from the brown dwarfs. We do not detect any companions to either system within these limits. However, it is possible that companions that fall bellow a few Jupiter masses or exist at separations beyond our field of view remain undetected.

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Wright, E. L., Mainzer, A., Kirkpatrick, J. D., et al. 2014, AJ, 148, 82

Academic Vita

Nicole D. Melso

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ACADEMIC BACKGROUND

The Pennsylvania State University
Schreyer Honors College; Eberly College of Science
BS Astronomy & Astrophysics; BS Physics; Mathematics Minor

RESEARCH EXPERIENCE

Undergraduate Research
Spring 2013 - Present
Department of Astronomy & Astrophysics (Advisor: Dr. Kevin Luhman)

- Searched for substellar objects in wide multiple systems with nearby stars
- Worked with multi-epoch data from the Spitzer Space Telescope, the Wide-field Infrared Survey Explorer (WISE) and the Two Micron All Sky Survey (2MASS)
- Analyzed candidates via common proper motion plots and color-magnitude diagrams
- Identified candidates for spectral analysis and publication (Luhman et al. 2012)

REU Experience
Summer 2014
Harvard-Smithsonian Center for Astrophysics
(Advisors: Dr. Suzanne Romaine & Dr. Jaesub Hong)

- Worked on optimizing miniature X-Ray focusing optics for use in Planetary Science Applications
- Explored multiple configurations and geometries to maximize the telescope's effective area and field of view while meeting practical mass and volume requirements
- Wrote analytic optimization codes in IDL and modified the Suzaku ray tracing simulation (XISSIM) for simulation of X-Ray optics with small-scale mirror geometry

Cerro Tololo Inter-American Observatory
Summer 2013
Data collection and telescope experience

- Selected from my research group to travel to CTIO for three nights of observation
- Collected spectra for substellar candidates in Upper Scorpius using SOAR+Goodman

Independent Research

Fall 2008 – Spring 2011

Presented at County/State competitions and Intel International Science and Engineering Fair

- Explored methods of predicting Cataclysmic Variable Star outbursts in the dwarf novae SS Cygni and U Gem
- Collected data by remotely operating telescopes located at the New Mexico Skies Observatory
- Analyzed photometric data from my own telescope runs as well as the AAVSO database by using Peranso and plotting the observed frequency
- Identified the appearance of high frequency peaks as a possible precursor to non-eclipsing dwarf novae outbursts

COMPUTATIONAL EXPERIANCE

Platforms: Mac, Windows, Linux
Tools: IDL, C++, Perl, Iraf, Ds9, MATLAB, SuperMongo, LaTeX, Microsoft Office Products

PRESENTATIONS/PUBLICATIONS

Refereed Articles

Luhman, K. L., Loutrel, N.P., McCurdy, N. S., Mace, G.N., **Melso, N. D**., Star, K. M., Young, M. D., Terrien, R. C., McLean, I.S., Kirkpatrick, J.D., & Rhode, K.L. 2012, *New M, L, and T Dwarf Companions to Nearby Stars from the Wide-field Infrared Survey Explorer* ApJ, 760, 152

Conferences

Melso, N., Romaine, S., Hong, J., Controneo, V. 2015, *Optimizing X-Ray Optics for Planetary Science Applications*, Upcoming AAS Meeting # 225, #338.37

Melso, N. D., Kaldon, K. M., Luhman, K. L. 2014, *A Spitzer Survey for Wide Substellar Companions to Nearby Stars,* American Astronomical Society, AAS Meeting #223, #441.08

In Preparation

Presently drafting a first author paper on the results of our most recent Spitzer cycle

HONORS/AWARDS

Pennsylvania Space Grant Fellow (2013 – 2014)
Schreyer Honors College Academic Scholarship (2011 – Present)
Eberly College of Science Academic Scholarship (2011 – Present)
National Merit Scholarship (2011 – Present)

OUTREACH/SERVICE

Pennsylvania Junior Academy of Science

Judge and project mentor for regional and state science fair competitions (grades 7-12)

Penn State AstroFest /Exploration U

Volunteer for the department public open house events/ Mentor for STEM activity days

Undergraduate Recruitment/Advising

Upperclassman representative for freshman seminar panel and Penn State recruitment events

CLUBS/ACTIVITIES

Student Pilot – University Park Airport
Eberly College of Science Student Ambassador (Science Lion Pride)
Penn State Astronomy Club
Penn State Dance Marathon Apollo Fundraising Organization Member
Penn State Sign Language Organization Member