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A Survey of Stellar Families: Multiplicity Among Solar-type Stars

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Abstract. Stellar multiplicity is a fundamental astrophysical property. In addition to being the only physical basis for accurate mass determination, this parameter is believed to influence important aspects such as planet formation and stability. Contrary to earlier expectations, recent studies have shown that even against selection biases, as many as 23% of the planetary systems reside in multiple star systems (Raghavan *et al.* 2006). Leveraging recent efforts in identifying stellar and substellar companions to solar-type stars, and augmenting them with targeted observations, we are conducting a comprehensive survey, aimed at providing a modern update to the seminal work of Duquennoy & Mayor (1991). The details of our sample, survey methods, and some preliminary results are presented here.

Keywords. binaries (including multiples), planetary systems, surveys

1. Introduction

The primary motivation of this effort is to better understand the variety of environments inhabited and fostered by solar-type stars in our Galaxy. We hope to accomplish this via a comprehensive multiplicity survey of solar-type stars in the solar neighborhood. Since the seminal work of Duquennoy & Mayor (1991, hereafter DM), our understanding of solar-type stars has grown substantially. The DM survey predated the *Hipparcos Catalog* (ESA 1997) and hence could not leverage its accurate parallaxes in defining the volume-limited sample. Since DM, several high-precision radial velocity surveys (e.g., Nidever *et al.* 2002, Mayor *et al.* 2004, Marcy *et al.* 2005) have identified companions from stars down to planets. Astrometric efforts such as speckle interferometry (Mason *et al.* 2004), adaptive optics (Luhman & Jayawardhana 2002), and long-baseline interferometry (Bagnuolo *et al.* 2006) have been very useful in identifying and characterizing orbits of binary stars. Multi-epoch archival images from the *Digitized Sky Survey*† (DSS) and the *SuperCOSMOS Sky Survey* (SSS; Hambly *et al.* 2001) allow us to unearth wide Common Proper Motion (CPM) pairs. This work leverages these prior efforts and augments them with new observations with speckle and long-baseline interferometry.

2. The Sample of Solar-Type Stars

We have extracted an unbiased volume-limited sample of 455 primary stars (including our Sun) as representatives of solar-type stars in the Galaxy. Our sample includes stars with a Hipparcos parallax of 40 mas or larger, with an error less than 5%. We further restrict our targets to a proximity band of 2.0 magnitudes above or 1.5 magnitudes below an iterative best-fit main sequence, resulting in the inclusion of luminosity classes IV, V,

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† See `http://stdatu.stsci.edu/cgi-bin/dss_form`.

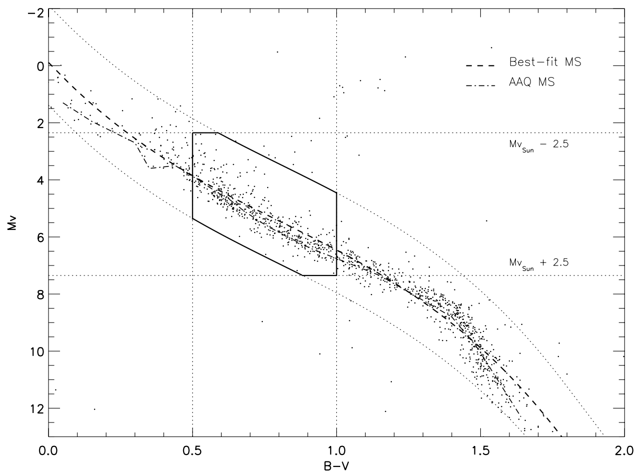

Figure 1. Target list of 455 solar-type stars within 25 pc from Hipparcos. AAQ refers to Allen's *Astrophysical Quantities* (2000).

and VI. The larger band above the main sequence allows for the inclusion of multiple star systems. Finally, we limit targets to $0.5 \leqslant B-V \leqslant 1.0$ in order to select solar-type stars. The above criteria result in the selection of all stars with V–band flux in the range of 0.1–10.0 times the Solar value (see Figure 1), giving us a physical basis for our definition of "solar-type".

2.1. *Comparison with Duquennoy & Mayor (1991)*

This effort is an update to the DM multiplicity survey of solar-type stars. DM used a volume-limited sample of 164 primary stars, selected from Gliese (1969). However, as pointed out in Halbwachs *et al.* (2003), there are substantial differences between a sample selected from Gliese (1969) and the more accurate *Hipparcos Catalog*. We applied the DM selection criteria of spectral types F7 to G9, luminosity classes IV, V, and VI, declination above $-15°$, and parallax greater than 45 mas to the *Hipparcos Catalog*, resulting in the selection of 148 primary stars. Moreover, only 92 of these stars overlap with the DM sample. This implies that 44% of DM's targets are now known to fall outside their parameter space, and their study excluded 38% of the targets now recognized to match their selection criteria. Our sample of 455 primary stars includes 106 of the DM stars. With current information and a larger sample, we hope to present updated multiplicity statistics of better accuracy and precision.

3. Sources Leveraged in the Survey

Every star in our target list is checked against known stellar multiplicity studies. First, we extract information on each target from available catalogs. The *Washington Double Star Catalog* (WDS) is an excellent resource for astrometric pairs. However, it is a catalog of doubles, and hence contains many listings of optical pairs, so we investigate each entry to verify its validity as a gravitationally bound companion. We also polled the *Sixth Catalog of Orbits of Visual Binary Stars* (VB6), the *9th Catalog of Spectroscopic Binary Orbits* (SB9), and the *Hipparcos Catalog*. The *Fourth Catalog of Interferometric Measurements of Binary Stars* (4IF) contains high resolution measures from speckle, adaptive optics (AO) and long-baseline interferometry, and while it substantially overlaps

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with the WDS, it has a few additional companions (such as lunar occultation measures), and importantly, also includes null results. Finally, we search individual publications to ensure completeness and to identify null results that are not included in the catalogs. The lack of published null results is one frustrating aspect of this search, but we are actively pursuing them, both in publications (e.g., Nidever *et al.* 2002, Luhman & Jayawardhana 2002), as well as through collaborations.

4. Observations

Even with the wealth of available observations, significant gaps exist. Some of these are due to the newness of advanced techniques such as adaptive optics and long-baseline interferometry, while others are simply due to incomplete coverage of prior efforts for our targets. Our observations center around three primary areas. First, we use multi-epoch archival images from the DSS and SSS to blink an area of the sky around each primary to identify wide CPM companions. These are then confirmed or refuted by comparing a photometric distance estimate of the companion to the Hipparcos distance of the primary. Second, we are collecting new speckle observations to help confirm candidates, or identify new ones for unobserved systems. Finally, we plan targeted observations using the CHARA Array's long-baseline interferometric capabilities to discover new companions and more fully characterize known spectroscopic orbits.

5. Preliminary Results & Future Work

We have completed a first pass in assimilating companion information from the WDS, SB9, VB6, 4IF, DM, and Hipparcos catalogs into a central database. We have also blinked the DSS and SSS images to identify CPM companions and to verify the physicality of WDS entries. The WDS lists 459 pairs for 205 of our target stars. We have confirmed 131 (29%) of these to be gravitationally bound companions based on the availability of visual or spectroscopic orbits, or because of matching parallax and proper motions. An additional 52 (11%) remain candidate companions, while 276 (60%) have been confirmed to be optical pairs, based on relative motion between the two stars. Upon blinking archival images, 368 of our 455 targets exhibited detectable proper motions, allowing us to search for CPM candidates, and an additional 43 exhibited a marginal proper motion. We confirmed 52 systems with known CPM companions, two of which are triples. Including candidates, there are 66 systems with CPM candidate companions, 5 of which are triples. Six of the CPM companions detected are potentially new discoveries. Overall, our current percentage of single:double:triple:quadruple is 69:26:4:1. If all of our candidates were to be confirmed, the percentages would be 56:33:9:2, including one possibly sextuple system. In comparison, the DM results were 57:38:4:1 for multiples with orbits, and 51:40:7:2 including candidates. While the larger fraction of singles found in our sample is consistent with the studies of M dwarfs (Henry & McCarthy 1990, Fischer & Marcy 1992), it is too early to jump to that conclusion, because the multiplicity search for our targets is as of yet incomplete, and hence our percentage of singles is an upper limit. Finally, of the 162 planetary systems discovered as of July 2006, 32 (20%) are in our target list. The ratios for this subsample are 78:22:0:0 for confirmed companions, and 69:28:0:3 including candidates. The larger fraction of singles among exoplanet systems is not surprising because planet search programs do not target known binaries. Nascent efforts targeting binaries for planet search (e.g., Konacki 2005) might reveal the answer to this question. Stay tuned!

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