Astrometric Binaries in the Age of the Next Generation of Large (Space) Telescopes

Rob P. Olling\textsuperscript{1,2}
\textsuperscript{1}Dept. of the Navy, US Naval Observatory 3450 Massachusetts Ave NW, Washington DC, Washington DC 20392-5420
\textsuperscript{2}Universities Space Research Association

Abstract. I analyze several catalogs of known visual and spectroscopic binaries and conclude that a large number of binaries is missing in current catalogs. Samples of the best studied (nearby and bright) stars indicate that the true binary fraction may be as high as 95%. A preliminary analysis indicates that these binaries can affect the astrometry significantly.

1. Binarity: Past Present & Future

\textbf{Duquennoy & Mayor} (1991, hereafter referred to as DM1991) established the multiplicity of G-type stars within about 22 pc. Their observational dataset consists of thirteen years of radial velocity monitoring, in combination with astrometric, visual and eclipsing binaries, for 164 G-type stars.

However, the pre-Hipparcos lists of wide binaries were rather incomplete. Currently, the number of known binaries is about three times larger. In fact, an analysis of the currently available binarity and multiplicity data of nearby Hipparcos-selected G-type stars indicates that as many as 95% of primaries have a cataloged companion. This binary fraction is almost twice as large as reported by DM1991. In the remainder of this paper I will use the term binarity loosely to mean binarity or multiplicity, where the companion can be a star, a brown dwarf or a planet.

1.1. Binarity: Present

After the publications of the Hipparcos catalogs [\textsuperscript{ESA}1997], several new sources of binarity have become available, which are included in this paper. Specifically, the following (compilation) catalogs are used: HIP [the Hipparcos catalog [\textsuperscript{ESA}1997]], TY2 [The Tycho-2 catalog [Högb et al. 2000]], TDS [the Tycho Double Star catalog [Fabricius et al. 2002]], SB9 [the 9\textsuperscript{th} catalog of spectroscopic binaries [Pourbaix et al. 2004]], EXOP [the catalog of confirmed extra-solar planets [California/Carnegie Planet Search Compilation 2003]], INT4 [the 4\textsuperscript{th} Catalog of Interferometric Measurements of Binary Stars [Hartkopf et al. 2004]], and GCSN [the Geneva-Copenhagen Solar Neighborhood Radial Velocity Survey [Nordström et al. 2004]]. This combined catalog contains 37,341 binaries, or more than twice the number of Hipparcos multiples. Angular separations are available for 11,101 entries for the Hipparcos-only data, and for almost three times as many (29,769) stars in the combined catalog.
In figure 1 I present, as a function of distance, the binary separation in arcseconds (top) and AU (bottom). The binaries included in the Hipparcos catalog [the combined catalog] are plotted in the left-hand [right-hand] columns. In the bottom row, the selection effect due to the distance of the stars are apparent: at small distances, the large-separation binaries are absent, while at large distances, the binaries with short semi-major axes are missing.

Figure 1. Binary separations as recorded in the Hipparcos catalog (left column) and the combined catalog (right column). The top row presents the separations in arcsec, the bottom row in AU. Many of the INT4 binaries (plotted as crosses) are still unresolved. Most of the objects in the INT4 (crosses) at 0.1 arcsec separation are doubles at the Hipparcos resolution limit. The total number of binaries with a parallax accuracy better than 10% and with a measured value for the separation are: 1491, 2316, 1292 and 5099, for Hipparcos-only binaries, TDS binaries, INT4 binaries and the sum of the three catalogs, respectively.

Since the secondaries are drawn from the IMF (DM1991), one expects the secondaries to be much fainter than the primaries, while faint companions should outnumber the bright ones. However, since it is hard to detect faint stars, the apparent binary frequency ($\beta$) might be influenced by magnitude-based selection
effects. Also, $\beta$ is likely to drop with distance since companions of the same physical separation are no longer resolved. Distant double stars are doubly hard to detect: 1) because the are fainter, 2) because they are less easily resolved.

Figure 2 shows that these selection effects are clearly present in the data. The left-hand panels show $\beta$ decreasing rapidly with distance, and that the brighter stars have higher average $\beta$'s, exactly as expected. Also striking is the steep magnitude dependence of $\beta$ (right-hand column).

I also created a G-star sample similar to the one of DM1991 by selecting from the Hipparcos catalog all 204 GV stars closer than 22 pc that are cataloged as primaries. The behavior of $\beta$ (not shown) for this sample is very similar to that of the full sample, except that overall multiplicity level is increased, and that the peak multiplicity reaches 95%, while the minimum level is 65%.

A proper analysis of this data in terms of the multiplicity of field stars is beyond the scope of this paper. Even so, there is significant evidence that $\beta$ is substantially larger than hitherto determined. Because the most complete catalogs of binarity indicate that $\beta$ is close to 100% for the closest and brightest stars, I surmise that the steep drop-offs towards larger distances and fainter magnitudes are unphysical and in fact the result of selection effects. Given that the sample most favorable for the detection of companions has a multiplicity fraction of 95%, I suggest that in fact all stars are part of a multiple system.

2. Astrometry of Binary Systems

Starting with a sample of well-measured Hipparcos stars and the period distribution of DM1991, I generate a fake star catalog of the Solar neighborhood. I estimate the masses of the systems based on the observed color, and apply corrections based on the sample of measured masses from the 6th Orbit Catalog. Positions along the orbits are generated for these orbits, that roughly correspond to various planned astrometric missions. The scatter incurred as a result of these orbital motions are substantial and will contribute to the error budget of a significant fraction of the stars.

References

California/Carnegie Planet Search Compilation. Extracted on 2003-09-09 from http://exoplanets.org/planet_table.shtml

Duquennoy, A. & Mayor, M. 1991, A&A, 248, 485 (DM1991)

ESA, 1997, The Hipparcos and Tycho Catalogues, ESA Publ. Division, ESTEC, the Netherlands

Høg E. et al., 2000, A&A, 357, 367

Fabricius, C. et al., 002, A&A, 384, 180

Fabricius, C. et al., http://ad.usno.navy.mil/wds/int4.html

Nordström, B., et al., 2004, A&A, 418, 989

Pourbaix, D., et al., 2004, A&A, 424, 727 http://sb9.astro.ulb.ac.be/intro.html#Ack
Figure 2. Multiplicity fraction as a function of distance (left-hand panels) and apparent magnitude (right-hand panel) for the Hipparcos stars that have parallax errors less or equal than 10%. The extrasolar planets contribute about 5% to the nearest/brightest bins. The magnitude ranges for the left-hand panels are chosen to have an equal number of stars in each magnitude range. Plotted symbols correspond to a fixed number of stars. The averaged dependencies (as determined from the HIP+TY2+TDS sample) for the three magnitude intervals are plotted (drawn lines) in each of the left-hand panels. The main-sequence stars and the RGB stars behave in approximately the same manner.