CENSUS OF BINARIES - THE BIG PICTURE

Staffan Söderhjelm

Lund Observatory, 22100 Lund, Sweden

ABSTRACT

Gaia will observe huge numbers of binaries with a large range of periods. The present contribution tries to present some estimates of the expected number of detections and/or orbit determinations, based on simplified but large-scale simulations. The simulations have to model both a Galaxy with binaries, the instrument and observations, and the reduction programs. As in previous studies, there are marked distance-effects, with the solar neighbourhood (within a few hundred pc) much more completely sampled than more typical (few kpc) Gaia distances. The large number of simulated solutions allows also a study of some systematic effects in the astrometry of undetected binaries.

Key words: Gaia; Binary stars; Galaxy model; Statistical distributions; Gaia reductions.

1. INTRODUCTION

Inspired by the successful Hipparcos mission, Gaia is based on similar principles, with continous scanning and simultaneous observation in two widely separated fields of view. The most important difference is the large-scale use of CCD detectors, enabling simultaneous observation of large numbers of stars. Even if the measurements are still largely one-dimensional, there is some resolution also in the across-scan direction, which can be used in the detection-phase of the observations. By reason of the limited data-rate available, most of the 'observation-windows' read out from the astrometric CCDs will however only be large enough to ensure good coverage of a single-star image, and many unrecognized binaries will be incompletely observed in some scan-directions. For the detailed (MBP) multi-band photometry, the windows are much larger, with crowding problems instead. For the brightest stars ($V < 15$), epoch radial velocities will also be available.

The by now uncontroversial statement that most stars are binaries has to be qualified by noting that these binaries are found at all periods, from minutes to millions of years, and with mass-ratios from a few parts in a hundred to unity. Most of them will not be seen as binaries with any instrument, and 'observed' duplicity fractions are often well below 50 % (cf. Mermilliod 2001). With Gaia, binaries can be detected in several complementary ways, allowing in fact a unique possibility to characterize their distribution over a large part of the P/q-plane. This contribution aims to make some quantitative estimates of the number of binaries detected, as a function of period, distance and apparent magnitude. This is done by large-scale simulations of the Galaxy, of the Gaia observations and of the Gaia reductions. There are large uncertainties in all three steps, and the results are therefore to be taken mostly as order-of-magnitude estimates. The work can be seen as an extension of two previous studies (Söderhjelm 2003, 2004), with particular emphasis on the short-period population.

2. BINARIES: PROBLEM OR BONUS?

The scientific goals of the Gaia mission are described e.g., in the basic 'Concepts and Technology Study Report' (ESA 2000), or in more recent summaries given e.g., by Perryman (2003) or Mignard (2005). The key questions to be answered by Gaia are in the realm of galactic dynamics, and in this case, binary or multiple stars are clearly mostly problematic. An observed proper motion or radial velocity may pertain to the photocentre of an undetected binary, and the motion may have an unmodelled orbital component. Similarly, the observed multi-colour magnitudes may have contributions from a secondary component, and mass-estimates may be seriously wrong if the contribution from invisible components is neglected. If only for these reasons, effective methods to detect duplicity are clearly important. For some of the systematic effects, see Section 7 below.

But the binaries are clearly also well worth a more detailed study. As natural test-beds, they offer the only fundamental route for stellar mass-determinations. Gaia will observe large numbers of resolved, orbital systems as well as even larger numbers of double-lined spectroscopic systems, with inclinations fixed by astrometry or eclipses. In either case, high-precision masses can be determined for unprecedented numbers of systems.

The main emphasis in the present study is however on the binaries as such, and how the Gaia results may help to clarify the origin and evolution of these basic building blocks of our Galaxy. Here, the distributions of periods, mass-ratios and eccentricities give important clues, when they may now for the first time be observed in detail. In order to correct for the complex selection effects in such statistics, the actual limits of detectability for different types of binaries have to be studied carefully, by making more and more refined simulations of the Gaia observations and reductions. The present study may be seen as a first such step clarifying Gaia's sensitivity for different kinds of binarity. As an important by-product of the 'stellar' binary studies, Gaia will also characterize many of the nearby extra-solar planetary systems (cf. Lattanzi 2005).

The data reductions for Gaia are exceedingly complex even for well-behaved single objects. In order both to detect, and even more so to derive orbital and other characteristics for binary and multiple stars, still more complex reductions have to be devised (cf. Arenou & Söderhjelm 2005). The choice of methods can again be greatly helped by realistic simulations. Only some major classes of systems can probably be treated in the first round of reductions, while large numbers of more complicated systems will be left at least partially unsolved. All the basic observations (suitably calibrated) will be kept available, however, and arbitrarily complex models can be tried later for interpreting individual systems.

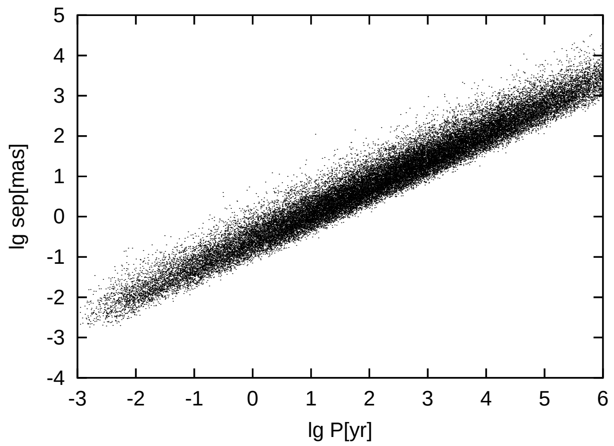

Figure 1. The close relation between orbital period and angular separation on the sky. (Each barely visible dot corresponds to some 10 000 binaries).

3. SIMULATION OF THE GALAXY

An important insight for the observation of binaries with Gaia is that a clear astrometric signature (non-linear proper motion) may be observable even for systems with a photometrically totally insignificant component at a Δm of 15 or 20. (Even a Jupiter-mass planet gives a photocentric orbit as large as 0.001 times the real one). Few of these systems with low-mass or degenerate components are known observationally, and to estimate their numbers, I have used instead a basic galactic disc model with stellar evolution starting from some simple initial mass-distributions. When this model predicts reasonable

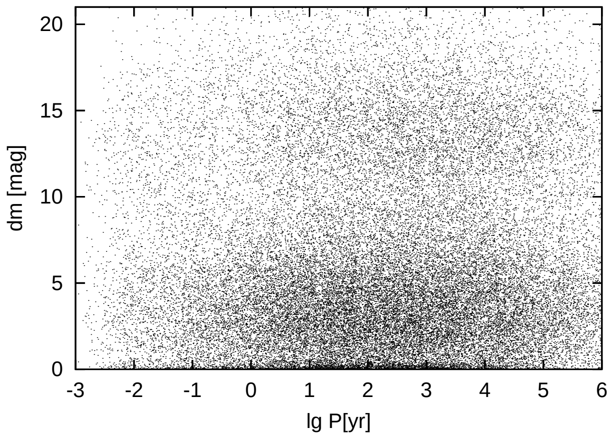

Figure 2. Because of the many faint white- and brown-dwarf components, the period/Δm-plane is rather uniformly filled. (Each barely visible dot corresponds to some 10 000 binaries).

numbers of 'low-Δm' binaries, the idea is that the numbers of invisible high-Δm systems should be of the correct order of magnitude.

So far, the model consists only of a thin disc and a thick disc, since it was originally created to provide a reasonable fit to the Hipparcos and Tycho data. In the present runs, I use a constant Star Formation Rate (0 – 12 Gyr) and a time-independent IMF (Kroupa 2001) plus a wide and almost age-independent metallicity-distribution (cf. Feltzing et al. 2001). One fourth of the 'objects' produced by this IMF are accepted as single stars, while 75% are made into binaries with a single q-distribution function valid at all masses. The f(q) is an ad hoc compromise between the gaussian given by Duquennoy & Mayor (1991), and the more constant one given by Goldberg et al. (2003), and with a narrow peak close to 1.0 (cf. Söderhjelm 2000; Halbwachs et al 2003). The distribution of the semi-major axes of the binaries is again close to that given by Duquennoy & Mayor (1991), [N(1.5,1.5) in log a(AU), with cutoffs above 5 and below -3]. For the eccentricities, an $f(e) \sim e$ is used at large periods, with rapid circularization below some 10 days.

An important improvement relative to the earlier studies is that the close binary evolution with mass-transfer, common-envelope phases and so on, is now accounted for. This is possible by the use of the 'BSE' code (Hurley et al. 2002), based as its single-star predecessor (Hurley et al. 2000) on analytical interpolations among realistic evolutionary models. To go to the 'observed' M_V and V–I very simplified calibrations are used, which certainly needs some corrections at cooler temperatures. The unfiltered passband for Gaia's main astrometric CCDs peaks around 700 nm, and one may use a G(aia) magnitude, defined by the approximate relation $G = V - 0.38 \times (V - I) - 0.12 \times (V - I)^2$. The Hurley et al. models are only valid for *b*ona fide stars with masses above some 0.08 $M_\odot$, and I have added (work by J. Dischler) a brown dwarf extension down to 0.03 $M_\odot$ based on models by Baraffe et al. (1998).

Although Gaia will observe stars with distances from a few pc to several tens of kpc (Magellanic Clouds), it is very apparent from all Galaxy modellings that a large majority will be at around 2–10 kpc. Coupled with the very large range of binary periods, this gives an apparent 'one-to-one' relation between the period and the angular size of the binary orbits, as shown in Figure 1. In Figure 2 the existence of large numbers of high-Δm pairs is emphasized. These look 'single' in most respects, but may show up as astrometric pairs for Gaia. In line with Figure 1, a plot with the angular separation instead of the period as abscissa will look very similar.

This model is certainly too simplified. One should allow for variations with mass in both duplicity rate and distribution functions, possibly also with place in the Galaxy. The SFR has not been constant with time, the thick-disc and bulge are different from the thin disc, and so on and so on forth. The fit to the existing observational data is limited to a very crude comparison with Hipparcos visual binaries and the Tycho star counts, and one should certainly go on to try fitting at least the GSCII star counts. So far, as a sanity check, I have verified that the all-sky accumulated star-counts reach 4×10^8 at V = 20 or 7×10^8 at G = 20. Because the model lacks a halo and a bulge, this 'low' number of stars is deemed qualitatively OK.

4. SIMULATION OF THE GAIA OBSERVATIONS

The galaxy model gives in each direction a list of binaries, which are then 'observed' by a model Gaia. Each object is scanned a number of times in different position-angles, and at each such epoch, a realistic series of astrometric observations is simulated. Only a 'constant' (2-dimensional) PSF is used, but with its size scaled by a colour-dependent effective wavelength. The actual positions of the binary components are calculated from the orbital elements, and the true light-distribution on the CCD are given by convolution with the (colour-scaled) PSFs. Simulated observations (with Poisson and read-out noise) are derived, normally 6–12 samples per CCD on 10 CCDs per scan, each sample an average over 12 across-scan pixels. For bright or easily resolved binaries, a 12×12 'window' (0.5×1.6 arcsec on the sky) is used, but for fainter stars with undetected duplicity, only a 6×12 window centered on the photocentre is available. (In these cases, secondaries at around 0.5 arcsec separation will of course be poorly observed). At 1+ arcsec separations, the two components will be observed as individual single stars in independent windows.

Because the radial velocity mean errors are so dependent on the detailed spectra, only an illustrative model has been used. The mean radial velocity (RV) uncertainty is taken to vary as a simple product of a magnitude-term and a colour-term, with some degradation from the secondary if it is bright enough. For typical error-levels, I have been guided by investigations like Munari et al. (2003), but again the model is only meant to show the major trends. As an example, a 'best' (K star) single-epoch RV uncertainty is taken to be around 2.7 km s^{-1} at G = 13, 11 km s^{-1} at G = 15.

5. SIMULATED SOLUTION MODELS

The simulated observations are now put through a series of different solution models. So far these are only standard iterative least squares solutions for the various parameter sets. The iterations are always started close to the known correct results, avoiding most problems with local minima and poor convergence. In reality, such models will have to be much more complex in order to be able to find useable start values from automatic searches of large regions of parameter-space. The simplified solutions do illustrate the basic principles, however, and may provide some upper limits to the real solution-efficiencies. The so far implemented models are listed here together with proposed further additions (in parentheses), in order of decreasing binary period.

(Common proper motion pairs.) When the component separation is above some 2 arcsec, they will be observed as separate single stars, and no special reduction methods will have to be applied. When the final data are available, it is however an important task to try to find the physically related 'CPM' components (defining the large-separation tail of the f(a) distribution, as continually depleted through stellar encounters). This will be done by studying the 'nearest neighbours' in 5- or 6-dimensional astrometric parameter space, so far not attempted in more than very primitive experiments.

Resolved doubles. For the 'medium wide' pairs (around 10–1000 mas separation), an astrometric detection of both components is attempted. The 1-dimensional ('x') pixel-counts at each scan are fitted in a global model which gives also the (poorly observed) 'y'-coordinates, enabling a correction for the excluded parts of the PSF. The standard model has 5 astrometric parameters plus a magnitude for each component, 12 parameters in all.

(Resolved doubles with orbital motion.) For the important subset of nearby dwarfs with periods below 10 years and still 'resolvable' separations, a full orbital solution should be attempted (giving in the end also fundamental masses for the two components). The model would have 5(astrometric) + 2(magnitudes) + 7(orbit) + 1(mass-ratio) parameters, and in practice, the determination of a preliminary orbit would be the difficult step, with the final LS refinement more or less trivial.

Curved photocentre motions. For unresolved binaries with periods around 10–30 years, even a small photocentre semi-major axis can give a measurable curvature in the position observations. It is easy to solve for additional quadratic and cubic terms in the proper motions, giving 9 instead of 5 astrometric parameters in a 'single-star' solution.

Orbit solutions without RV. For periods shorter than 10 years, one may try to determine the full orbit for the photocentre. There are 5 astrometric parameters plus a magnitude for the centre of gravity, plus 7 standard orbital elements. The full knowledge of good starting parameters simplifies the problem very much, and the number of good orbits is certainly overestimated.

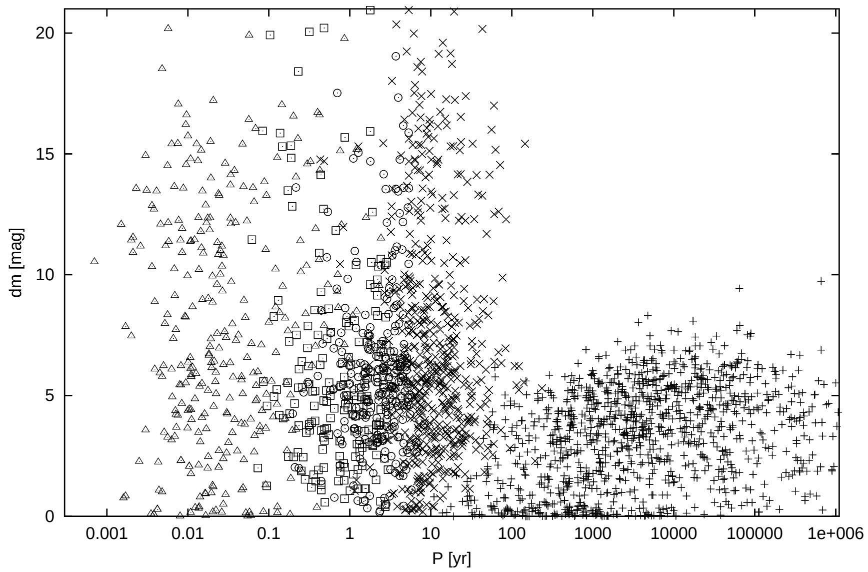

Figure 3. 'Acceptable' solutions as obtained with different solution models for the brightest stars (G = 10.0−15.5). The [+]-crosses are resolved pairs, the [x]-crosses pairs with non-linear photocentre motion. The open circles are photocentre orbits, the squares photocentre orbits with also a RV amplitude. Finally, the triangles signify pure radial velocity orbits with imperceptible astrometric deviations. Each symbol corresponds to some 5000 systems if scaled to the full Gaia mission.

Orbit solutions with RV. Using also the RV observations, an attempt is made to solve for the full astrometric orbit as above, plus the radial velocity amplitude and the system velocity, 15 parameters in all.

RV orbits. At even shorter periods, the photocentre orbit is imperceptibly small, but a pure 5-element spectroscopic orbit may still be derived in addition to the 'single star' (=systemic) astrometric solution.

(Eclipsing binary light-curve solutions.) At the shortest periods, there are sometimes eclipses. Below are given some number-estimates, but it would of course also be interesting to try to solve the simulated light-curves, with methods as used e.g., by Prša (2003). For mass-determinations, the important systems are the bright ones with 2 spectra visible, cf. Zwitter (2003).

Using an input list of binaries from the Galaxy model, the 'bigsim' program tries first a standard single-star solution, then successively five different double star solution models for each system, choosing the one with the best χ^2 fit to the observations. Because the systems are simulated, we know the true parameters, and the solution can be classified as 'acceptable' according to some criteria. In order not to give overly optimistic figures, the acceptance criteria have been adjusted to keep the fraction of false positives below one or two per cent. As an example, Figure 3 shows successful solutions from the five different DS models for an all-sky sample of bright stars (G < 15.5). The data are plotted in the log P(eriod) vs Δm plane, showing the resolved pairs to the right always with $\Delta m <$ 7-8, but with many of the photocentre orbits obtained for systems with invisible white or brown dwarf components.

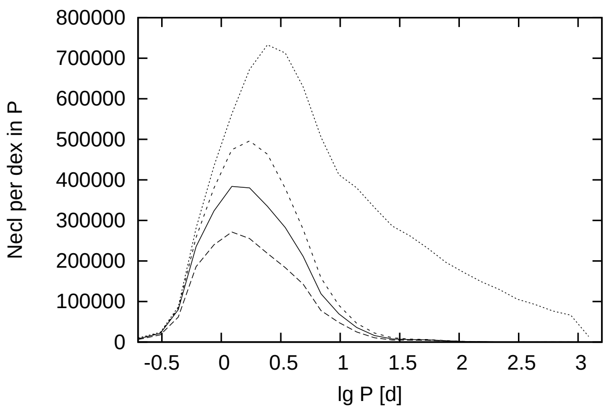

Figure 4. Estimated 'real' number (upper dotted curve) of eclipsing binaries observed by Gaia, and three different estimates of the numbers actually detected (lower three curves). Each is a '3σ'-criterion, but with the photometric σ increased or decreased by a factor two relative to the middle one.

5.1. Eclipsing Binaries

With the BSE code, close binaries are realistically simulated, and it is possible to estimate the observed numbers of eclipsing binaries. This has been done first by directly calculating for each pair the probability of an eclipse of a specified maximum depth, assuming a simplistic spherical model without limb-darkening. (Basically, a depth larger than Δm needs an inclination larger than some

Table 1. Rough estimates of the expected numbers of eclipsing binaries of different depth and apparent magnitude detected by Gaia.

	G < 16.5	16.5–18.5	18.5–19.5	19.5–20.0
0.1-0.2	28 000	40 000	19 000	5400
0.2-0.4	30 000	58 000	39 000	20 000
0.4-0.8	21 000	46 000	40 000	27 000
>0.8	2000	3100	2300	600

$i(\Delta m)$, as calculated from the relative radii and luminosities. For random orientation, the probability for this is simply $\cos(i(\Delta m))$).

Such probabilities are then added to give the expected 'real' numbers of eclipsing binaries. Many low-amplitude or narrow eclipses will however not be detected, and I have added a simplistic 'detectability criterion', requiring that 5% of (randomly phased) observations shall show a Δm more than 3σ from the outside-eclipse value. With three different assumptions about the photometric precision (σ around 0.08, 0.04, 0.02 mag at G = 20), Figure 4 shows the all-mission total numbers (per dex in log P). The 5% limit excludes most long-period systems, while at short periods the photometric accuracy plays the key role (especially for low-Δm systems. The total numbers (from the 'middle' detection criterion) are given in Table 1.

An alternative route to derive these numbers starts from large-scale population synthesis experiments by Söderhjelm & Dischler (2005). As described by Dischler & Söderhjelm (2005), this independent investigation gives comparable numbers and P/Δm-distributions, and we are confident that the basic steps are handled correctly. (Because no apparent magnitudes are involved, a fixed 0.10 mag detection limit is used, giving understandably somewhat smaller numbers than Figure 4 or Table 1).

The bottom line seems to be however that our present estimates of the number of eclipsing binaries observable by Gaia are almost an order of magnitude smaller than the ones given by Söderhjelm (2004). In particular, our present model predicts few deep eclipses (that is few 'Algol-type' post mass-transfer systems). Admittedly, these 'theoretical' estimates are based on a lot of *a*d hoc assumptions, and they have to be checked more carefully against observations. The comparison with Hipparcos data (cf. Dischler & Söderhjelm 2005 and Söderhjelm & Dischler 2005) shows a fair agreement however, and most of the factor-ten reduction should be due to the improved modelling of close binaries with the BSE code. Contrary to the expectations in Söderhjelm (2004), the BSE code gives fewer deep eclipses than a single+single model.

6. CENSUS OF BINARIES

An obvious first question is how many and what types of binaries may be detected by Gaia. As described in Section 5, the simulations can give lists of accepted solutions, but if we want significant numbers at all magnitudes and in all distance ranges, a lot of trials are needed. I have made literally millions of least-squares solutions trying to explore this whole parameter space, and it is only necessary to keep a record of the 'scaling factors' to be used when comparing to a full Gaia mission. Figure 5 shows the 'grand total' figures for the five different solutions, as a function of period. Comparing with the uppermost curve of 'real' numbers, we see that most of the binaries are still undetected. It is also apparent, however, that Gaia samples all periods, with a generally good overlap between the different solutions. With its 5-year observation span and extreme astrometric precision, Gaia is however particularly suited to detect astrometric pairs (including extra-solar planets) with 2 to 10 year periods, providing full orbits for a few million of them. Unlike the resolved binaries to the right and the spectroscopic binaries to the left, which can be observed equally well from the ground, this unique feature may perhaps be called the 'Gaia peak'. For this particular range of periods, Gaia will provide new information on stellar binarity that will otherwise be difficult to come by.

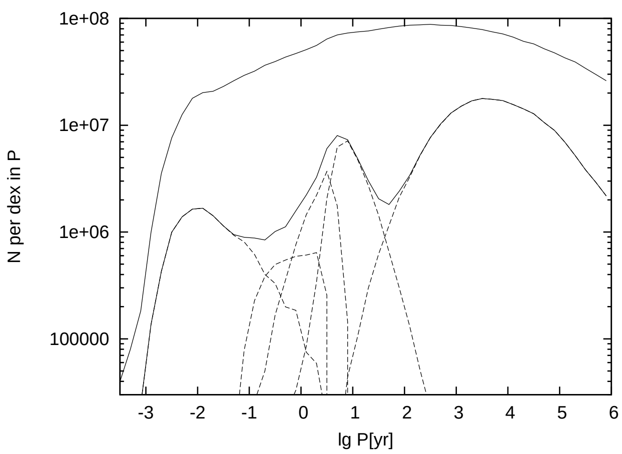

Figure 5. Total number of binaries (upper full curve), and total number of solutions (lower full curve) by any of five different individual methods. These are indicate by dashed lines (from left to right RV orbits, RV+astrometric, astrometric orbits, curved proper motions, and actually resolved binaries).

The overall curves in Figure 5 of course do not tell the whole truth. As expected, both the distance from the Sun and the apparent magnitude plays an important role for the different detections/solutions. As in the previous reports, I have done separate studies in a series of concentric shells, with limits at successive factors 2.5 in distance from the Sun. (The innermost one thus covers distances 62–160 pc, the next 160–400 pc, and so on to 6.25–15.62 kpc, each one with an absorption-free m–M larger by 2 mag). Naturally, because of the dominance of thin-

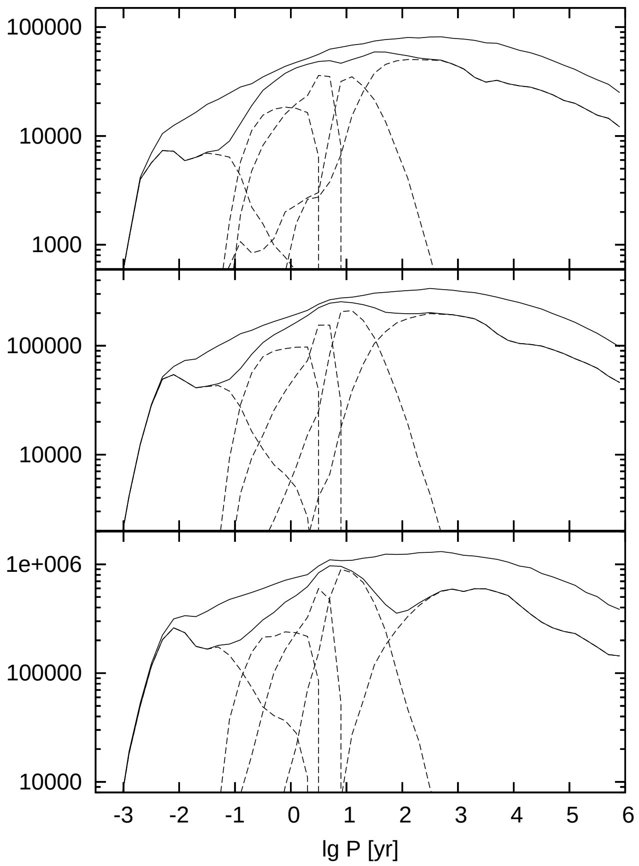

Figure 6. Full-mission number of bright-star (G < 15.5) solutions in the distance intervals 64–160 pc (upper), 160–400 pc (middle) and 400–1000 pc (lower). The five solution methods of Figure 5 are indicated by dashed lines.

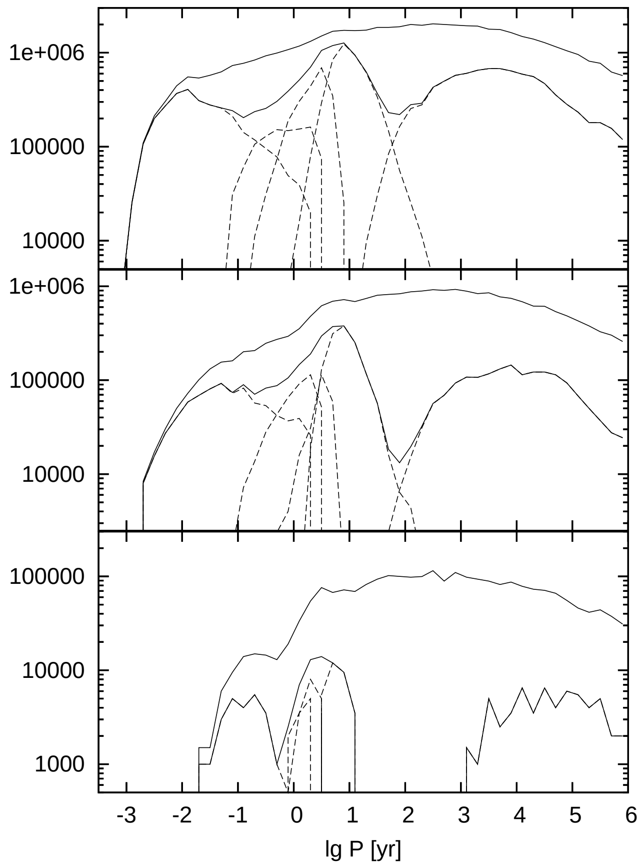

Figure 7. Full-mission number of bright-star (G < 15.5) solutions in the distance intervals 1.0–2.5 kpc (upper), 2.5–6.25 kpc (middle) and 6.25–15.6 kpc (lower). The 'ragged' curves for the largest distances are due to numerical noise (few simulated solutions).

disc' stars, the effective volumes are more ring-like than spherical, highlighting the distance-effects in the plane.

Figures 6 and 7 give the solution numbers separately for each of these distance-shells. By comparing with the true number of binaries, it is easy to interpret these curves also as measuring the 'success-rate' (as given in Söderhjelm 2003, 2004) of each kind of solution. For systems close to the Sun, orbit sizes and/or separations are large, and the success-rates are generally high. Naturally, the resolved systems have larger and larger periods (at the same angular separation) as the distances increase, which tends to give in the end a 'gap' around 100 year period where few binaries can be detected. (See Section 7 for some consequences for the proper motions). The radial velocities are distance-independent, and pure RV orbits are solved equally well at all distances. Because the largest distance-intervals sample mainly OB-stars, with broad lines and large RV errors, there are however fewer long-period spectroscopic binaries detected, creating another 'gap' around 0.5 year period.

The similar plots for the faintest systems (G = 18.5–20.0) in Figure 8 show drastically smaller success-rates in the 'Gaia peak', both because of the smaller orbits for larger distances and because of the increased astrometric errors. Several million long-period systems will be detected, but no spectroscopic binaries (because no radial velocities will be obtained at these faint magnitudes). Interestingly, because the eclipse probabilities increase with increasing absolute magnitude (=increasing distances), a significant number of eclipsing binaries will be observed even at the largest distances. These pairs are interesting both as the only sampling of the short-period binary population, and as a means of mass- and radius-determinations (with radial velocities from the ground).

7. UNWANTED BINARY STAR SIGNATURES

Returning to the view of the Galactic dynamicist, we can ask how large are the 'disturbing' effects of undetected binarity (cf. Bastian 2005). The above large-scale simulations give some unique means of answering such questions, because (unlike in reality), we know the true binary parameters for every solution attempted. Apart from estimated parameters and mean errors, the simulated solutions give the actual offsets of each parameter with re-

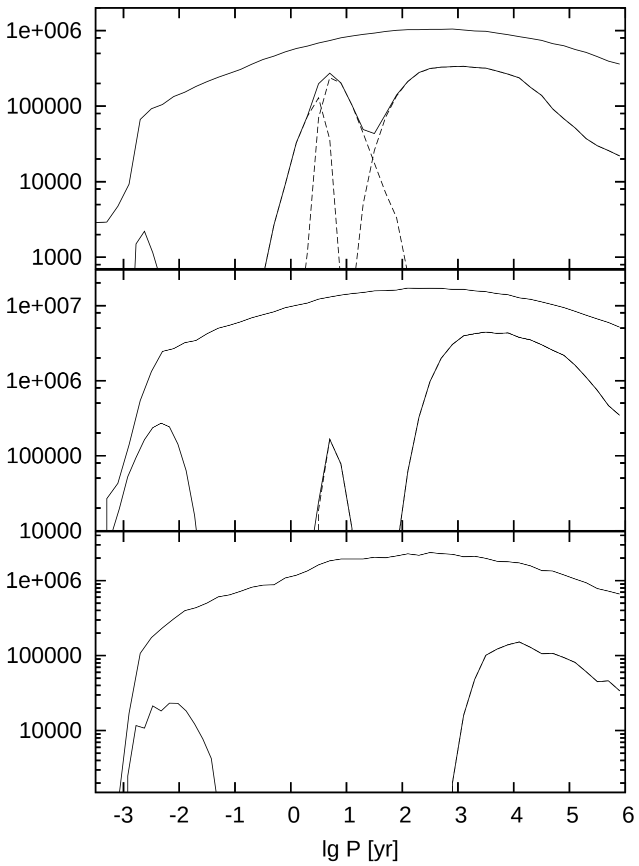

Figure 8. Full-mission number of faint-star (G = 18.5–20.0) solutions in the distance intervals 160–400 pc (upper), 1.0–2.5 kpc (middle) and 6.25–15.62 kpc (lower). Note that the short-period systems to the left are all eclipsing.

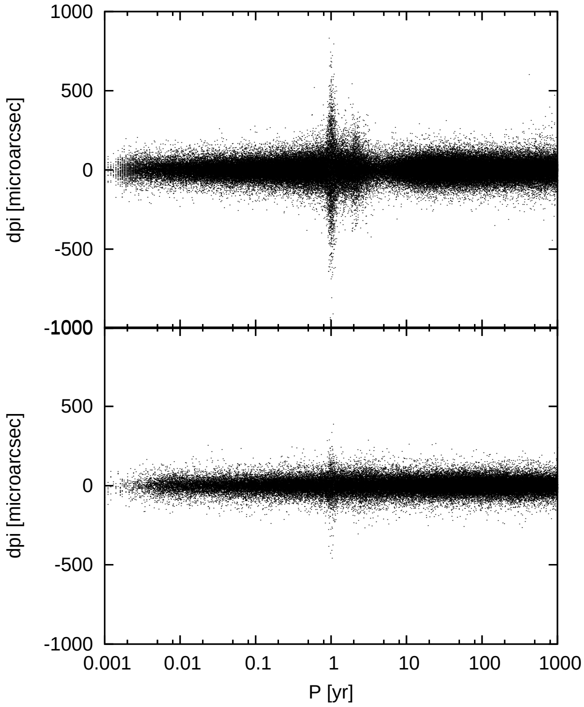

Figure 9. Actual parallax-errors for 'single-star' solutions of binaries with apparent magnitude G = 15.5–18.0, showing the expected disturbance for 1-year period orbits. The upper diagram is for the distance-interval 160–400 pc, the lower for 1000–2500 pc. For the nearby systems, there is even some disturbance for 2-year periods.

spect to its true value. We may thus analyze any deviations with respect to e.g., the binary periods, instead of having just a smeared out 'extra noise'.

A key parameter in almost all uses of Gaia data is of course the parallax. This turns out to be very robustly estimated for most types of binaries, and an (erroneous) single-star solution produces normally a good parallax. The only (well-known) problem comes for orbits with exactly 1 year period, but as shown in Figure 9, the effect diminishes with distance from the sun. At typical (even larger) Gaia distances, the 1-year effect is still less apparent. In the upper figure, one sees a hint of a signal also at 2 years period, as predicted Bastian: ("*The spatial motion on an eccentric 2-year orbit has a strong second harmonic at 1 year period which may mimic a parallax motion as nicely as the fundamental harmonic of a 1-year orbit.*")

As shown above, the binaries with around 100 year period are hard to detect at large distances from the sun. This gives an orbital contribution to the proper motions that is large compared to the observational precision for the brighter stars. Figure 10 shows large deviations for bright stars, but almost imperceptible ones at more typical Gaia magnitudes. These plots are for typical distances (2.5–6.25 kpc), and closer to the Sun, it will obviously *look* worse. Because the deviations are produced by orbital motion, the deviations in the transversal velocities are however independent of distance, producing typical diagrams like Figure 11.

8. CONCLUSIONS AND PROSPECTS FOR FURTHER WORK

The simulations presented illustrate a few well-known points. The census of binaries with Gaia will be very complete in regions within a few hundred pc from the Sun, where binaries at all periods from less than a day (eclipsing) to millions of years (CPM-pairs) will be detected. The completeness diminishes with distance and with faintness, and there will be period-intervals with poor or no coverage. All statistical binary star studies will have to study the selection effects carefully, and further simulations along the present lines can be used to gain valuable insights.

There is much more work to be done in all three parts of the simulations. For the Galaxy model, a natural next step is to vary the input $a-$ and $q-$distributions to see how this influences the observed distributions. Another

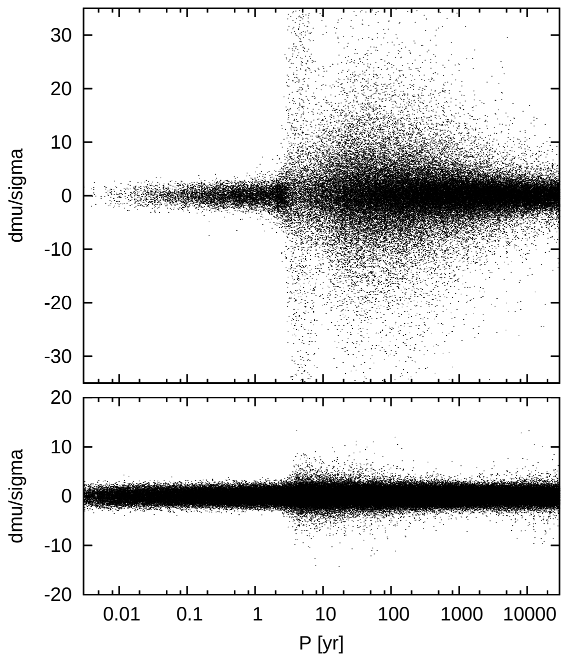

Figure 10. Differences between the observed proper motion components (in α and δ) and the barycentre values, divided by their mean errors. The upper figure is for bright stars (G $<$ 15.5), the lower for G $=$ 18.0–20.0, in both cases for binaries 2.5–6.25 kpc from the sun.

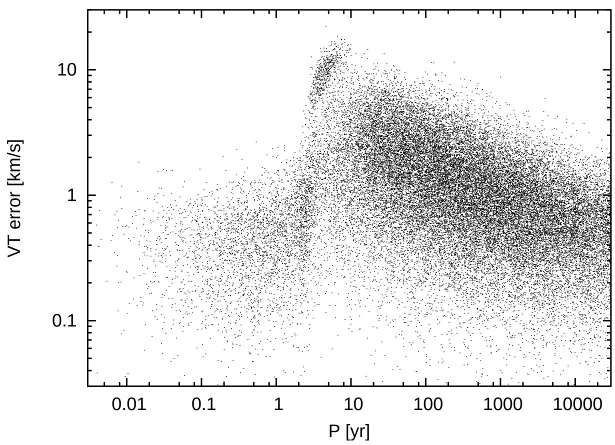

Figure 11. The total transverse velocity-deviations (observed minus barycentre values) as a function of the (in reality unknown) orbital periods. Data for bright stars (G $<$ 15.5) at 2.5–6.25 kpc.

important (but difficult) step is to introduce new distribution functions producing the typical hierarchical multiplicity where a binary component on one level is often in itself a closer binary. In the instrument modelling, one may increase the realism arbitrarily, especially as regards the spectroscopic and photometric details. The not yet implemented reduction models on the list above should be introduced, and perhaps some more realistic 'pre-LS' stage of some of the others.

In fact, a very important goal of the reduction simulations is to get a feeling for how to proceed with the 'real' reduction methods. As outlined by Arenou & Söderhjelm (2005), a long list of reduction algorithms have to be constructed. Even in their first versions for a very simplified model of the Gaia reductions, these algorithms have to be much more complicated than those of the present paper. In practice, an ever changing cycle of simulation/reduction experiments will continue to evolve all the time until the launch of Gaia, and the estimates of what can be expected will hopefully also get more realistic with time.

ACKNOWLEDGEMENTS

This work is partly supported by the Swedish National Space Board.

REFERENCES

Arenou, F., Söderhjelm, S., 2005, ESA SP-576, this volume

Baraffe, I., Chabrier, G., Allard, F., Hausschildt, P.H. 1998, A&A, 337, 403

Bastian, U,. 2005, ESA SP-576, this volume

Dischler, J., Söderhjelm, S., 2005, ESA SP-576, this volume

Duquennoy, A., Mayor, M. 1991, A&A, 248, 485

ESA, 2000, Gaia, Composition, Formation and Evolution of the Galaxy, ESA-SCI(2000)4

Feltzing, S., Holmberg, J., Hurley, J.R. 2001 A&A, 377, 911

Goldberg, D., Mazeh, T., Latham, D.W. 2003, ApJ, 591,397

Halbwachs, J.L., Mayor, M., Udry, S., Arenou, F. 2003, A&A,397,159

Hurley, J.R., Pols, O.R., Tout, C.A. 2000, MNRAS, 315, 543

Hurley, J.R., Tout, C.A., Pols, O.R. 2002, MNRAS, 329, 897

Kroupa, P. 2001, MNRAS, 322, 231

Lattanzi, M.G. 2005, ESA SP-576, this volume

Mermilliod, J-C. 2001, in VanBeveren, D. (ed), ASSL 264, 3

Mignard, F. 2005, ESA SP-576, this volume

Munari, U., Zwitter, T., Katz, D., Cropper, M. 2003, in Munari, U. (ed), ASP Conf. Ser. 298, 275

Perryman, M.A.C. 2003, in Munari, U. (ed), ASP Conf. Ser. 298, 3

Prša, A. 2003, in Munari, U. (ed), ASP Conf. Ser. 298, 457

Söderhjelm, S. 2000, AN 321,165

Söderhjelm, S. 2003, in Munari, U. (ed), ASP Conf. Ser. 298, 351

Söderhjelm, S. 2004, in Hilditch, R.W., Hensberge, H.,Pavlovski, K. (eds), ASP Conf. Ser 318, 413

Söderhjelm, S., Dischler, J. 2005, A&A (in preparation)

Zwitter, T. 2003, in Munari, U. (ed), ASP Conf. ser. 298, 329