HIPPARCOS ASTROMETRIC BINARIES IN THE NINTH CATALOGUE OF SPECTROSCOPIC BINARY ORBITS: A TESTBENCH FOR THE DETECTION OF ASTROMETRIC BINARIES WITH GAIA

S. Jancart, A. Jorissen,*, D. Pourbaix**

Institut d'Astronomie et d'Astrophysique, Université Libre de Bruxelles, Belgium

ABSTRACT

The Ninth Catalogue of Spectroscopic Binary Orbits[1] and the Hipparcos Intermediate Astrometric Data (IAD) are used to retrieve astrometric binaries from the Hipparcos data. It is found that basically all (non-SB2) systems with periods larger than about 100 d, and parallaxes larger than 5–10 mas exhibit an astrometric orbital motion which can be extracted from the IAD. The lessons learned from this kind of approach will be very valuable for the design of the Gaia reduction pipeline.

Key words: Astrometric and spectroscopic binaries: detection, orbit determination; Hipparcos data.

1. INTRODUCTION

The fit of the IAD, via an orbital model, is performed by adopting the eccentricity e, the period P and one epoch of periastron passage T_0 from the spectroscopic orbits given in S_{B^9}, the Ninth Catalogue of Spectroscopic Binary Orbits (Pourbaix et al. 2004). Of course, the binarity is a necessary condition for applying the orbital model but it is not a sufficient one (Pourbaix & Arenou 2001). In this paper, we first present the Hipparcos data and the model used to achieve the fit. Then, we describe the sample and the criteria used to detect an orbital signal in the IAD. Finally, a new criterion to assess the reliability of the astrometric orbital elements is proposed and applied.

2. THE HIPPARCOS DATA

For each observed star and during 3 years, Hipparcos (ESA 1997) measured tens of abscissae, i.e., 1-dimensional quantities, along a precessing great circle. Several corrections were applied to these abscissae (chromaticity effects, attitude, ...). It was decided that the residuals (Δv) of these corrected abscissae would be released together with the catalogue. In order to make the interpretation of these residuals unique, the released values were all derived with the single-star model, whether or not that model was used for that entry in the catalogue. This makes it possible for anybody to fit any model, thus looking for further reduction of the residuals.

The fit is achieved through a χ^2 minimization. For instance, in the case of an orbital model, it may be written as:

$$\begin{aligned}\chi^2 &= (\Delta v - \sum_k \frac{\partial v}{\partial p_k}\Delta p_k - \sum_i \frac{\partial v}{\partial o_i} o_i)^{\mathrm{t}} \\ &\quad \mathbf{V}^{-1}(\Delta v - \sum_k \frac{\partial v}{\partial p_k}\Delta p_k - \sum_i \frac{\partial v}{\partial o_i} o_i)\end{aligned} \quad (1)$$

where Δp_k is the correction with respect to the original parameter p_k, o_i are the orbital parameters and $\mathbf{V}$ is the covariance matrix of the data. $\Delta v_j, \partial v_j/\partial p_k$, and $\mathbf{V}$ ($j = 1, \ldots, n; k = 1, \ldots, 5$) and the Main Hipparcos solution are provided, n is the number of IAD available for the considered star (see van Leeuwen & Evans 1998, for details). Equation 1 thus reduces to

$$\begin{aligned}\chi^2 &= (\Delta v - \sum_k \frac{\partial v}{\partial p_k}\Delta p_k - y\frac{\partial v}{\partial p_1} - x\frac{\partial v}{\partial p_2})^{\mathrm{t}} \\ &\quad \mathbf{V}^{-1}(\Delta v - \sum_k \frac{\partial v}{\partial p_k}\Delta p_k - y\frac{\partial v}{\partial p_1} - x\frac{\partial v}{\partial p_2})\end{aligned} \quad (2)$$

where (x,y) is the relative position of the photocentre with respect to the barycentre of the binary system given by

$$\begin{aligned} x &= AX + FY \\ y &= BX + GY \end{aligned}$$

with

$$\begin{aligned} X &= \cos E - e \\ Y &= \sqrt{1-e^2}\sin E. \end{aligned}$$

A, B, F, G are the Thiele-Innes constant and E the eccentric anomaly.

*Senior Research Associate, F.N.R.S., Belgium
**Research Associate, F.N.R.S., Belgium
[1] http://sb9.astro.ulb.ac.be

3. THE SAMPLE

The sample is composed of 1385 HIP-S_{B^9} entries, taking into account the fact that the DMSA/C stars (i.e., resolved binaries) had to be removed since their IAD are not suited for IAD processing. The sample covers an extensive period and eccentricity range (see Figures 1 and 2).

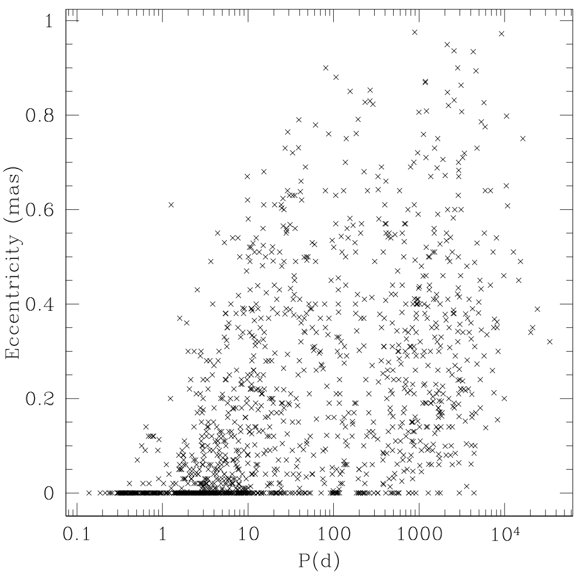

Figure 1. Period-eccentricity diagram for the selected S_{B^9} objects with a HIP entry.

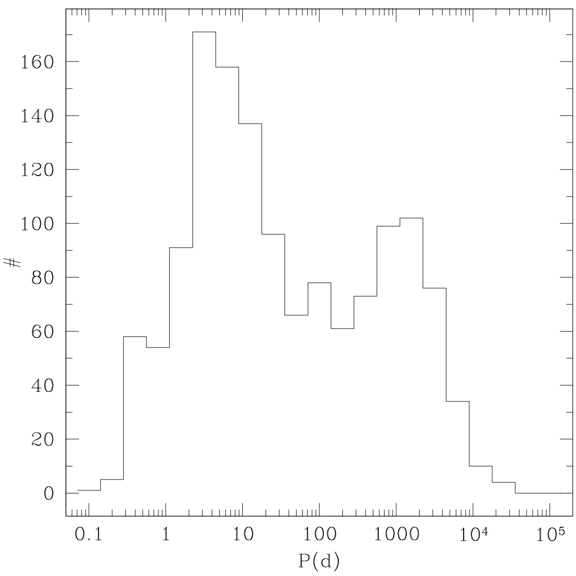

Figure 2. Distribution of the period for the selected S_{B^9} objects with a HIP entry.

4. ASTROMETRIC WOBBLE DETECTION

For the orbit fitting, we check whether the IAD (observations) do hide an orbital signal using two mathematically equivalent methods of orbit determination: Thiele-Innes and Campbell[2] approaches. In fact, we quantify the likelihood of the fit with an F-test measuring the decrease of the χ^2 for the fit of the n IAD with an orbital model (χ^2_T) compared to the fit with the single-star model (χ^2_S) (Pourbaix & Arenou 2001). The combinations of three statistical indicators allow us to keep or discard a solution:

- A decrease of the χ^2 is necessarily obtained when adding 4 supplementary parameters (the Thiele-Innes constants). The criterion is expressed through an F-test:

$$Pr_2 = Pr(\hat{F} > F(4, n-9)), \tag{3}$$

  where $\hat{F} = \frac{n-9}{4}\frac{\chi^2_S - \chi^2_T}{\chi^2_T}$. Pr_2 is thus the first kind risk associated with the rejection of the null hypothesis: "*there is no orbital wobble present in the data*".

- Pr_1 represents the analogous probability obtained by Pourbaix (2001) for the Campbell approach.

- Getting a substantial reduction of the χ^2 with the Thiele-Innes model does not necessarily imply that the four Thiele-Innes constants are significantly different from 0. The first kind risk associated with the rejection of the null hypothesis "*the orbital semi-major axis is equal to zero*" may be expressed as

$$Pr_3 = Pr(\chi^2_{ABFG} > \chi^2_4), \tag{4}$$

  where $\chi^2_{ABFG} = \mathbf{X}^{\mathbf{t}}\mathbf{C}^{-1}\mathbf{X}$ and χ^2_4 is the abscissa of the χ^2 distribution with 4 degrees of freedom. $\mathbf{X}$ is the vector of components A, B, F, G and $\mathbf{C}$ is its covariance matrix.

Among the sample, 300 stars satisfy the criteria at the 5% level ($Pr_1, Pr_2, Pr_3 < 0.05$) and are thus flagged as astrometric binaries (Jancart et al 2005). We present the detection rate as a function of the period and the parallax in Table 1 and Figure 3. All the undetected binaries have been identified as either stars with composite spectrum, SB2 stars (since these stars could have two components of the same brightness, no motion of the photocentre could have been detected) or with a poor quality spectroscopic orbit. If we remove these entries from the sample, the detection rate is close to 100%.

Regarding the orbital parameters and in particular the inclinations (Figure 4) obtained by the two methods (Thiele-Innes and Campbell), not all 300 stars yield consistent values, although the two orbit determination methods should lead to the same results.

In the next section, a preliminary criterion to evaluate the consistency between them is proposed. Pourbaix & Arenou (2001) proposed 6 criteria but they were designed to show that the Hipparcos data were not precise enough to detect the astrometric wobble of planetary candidates. Our purpose being the detection of astrometric wobble caused by known spectroscopic binaries, we could use the first 3 criteria while the last 3 ones did not bring any complementary information for us.

[2]The Campbell elements are a, i, ω, Ω

Table 1. Detection rate in percentage as a function of the period and the parallax. The percentage is given with the poissonian error and the total number of stars in the bin is listed between parentheses. The detection rate is close to 100% if we remove the SB2 stars, the stars with composite spectra and those with a poor spectroscopic orbit.

		Period range (d)				
		0-100	100-2000	2000-3000	3000-5000	$\forall P$
parallax (mas)	$\varpi > 15$	16± 3 (178)	74± 9 (81)	66± 24 (12)	77± 24 (13)	37± 4 (293)
	$\varpi > 10$	14± 2 (285)	73± 8 (123)	70± 20 (17)	58 ± 19 (17)	34± 4 (456)
	$\varpi > 5$	11± 2 (518)	66± 6 (197)	67± 14 (34)	50± 14 (22)	29± 2 (793)
	$\forall\varpi$	8± 1 (875)	47± 4 (368)	41± 8 (59)	27± 8 (44)	22± 1 (1385)

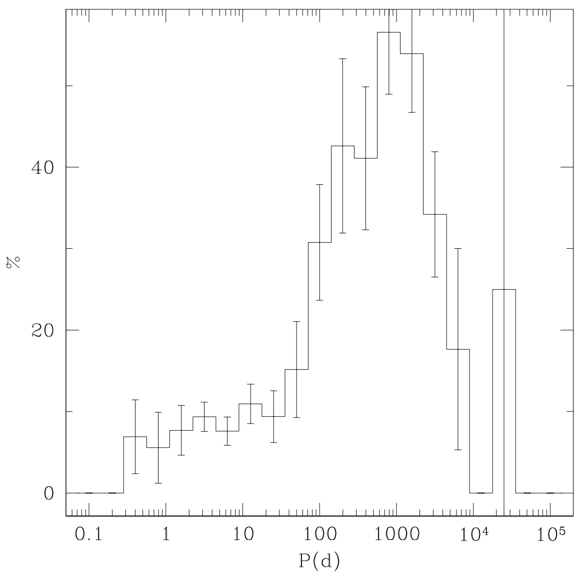

Figure 3. Percentage of S_{B^9} stars detected as astrometric binaries as a function of the period.

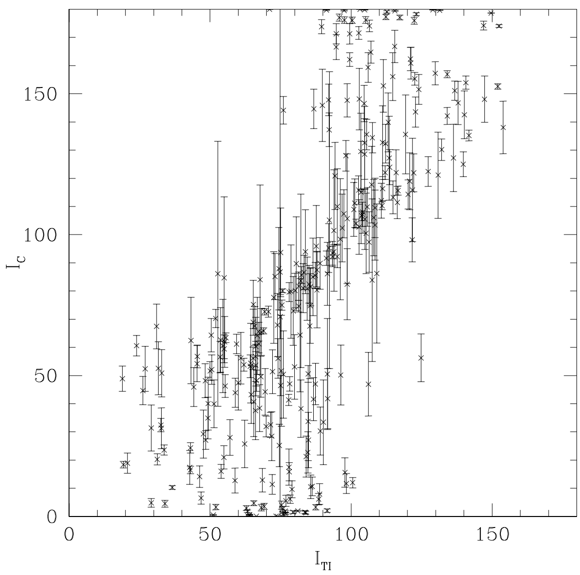

Figure 4. Orbital inclinations derived with two independent methods. These stars comply with the 3 criteria for binary detection.

5. ORBIT ASSESSMENT

The consistency between the Thiele-Innes and Campbell approaches is assessed using a new criterion which test the null hypothesis "*Thieles-Innes and Campbell's approaches yield consistent solutions*". The criterion is based on the distance between the two confidence ellipsoids obtained for each approach. More details and analytic expressions will be published in Jancart et al (2005). As preliminary results, we end up with 56 binaries with a reliable orbit. Among them 28 were flagged as single stars in the Hipparcos catalogue, 16 as DMSA/O (orbital solutions), 6 as DMSA/G with 7 parameters, 4 as DMSA/G with 9 parameters and 2 as DMSA/X. The inclinations derived by the two approaches for the 56 systems are plotted in Figure 5.

6. CONCLUSIONS

We have evaluated the capacity of the method to detect the astrometric wobble of known spectroscopic binaries as a function of their period and parallax.

Among the 56 binaries satisfying the 4 criteria, only 16 of them were flagged as DMSA/O in the Hipparcos catalogue. Although the criterion seems to be an efficient tool and advantageously replaces three criteria of Pourbaix & Arenou (2001), we are still looking for an analytic expression which would take into account the correlation between the Thiele-Innes and Campbell solutions.

ACKNOWLEDGMENTS

This research was supported in part by the ESA/PRODEX Research Grants 90078 and 15152/01/NL/SFe.

REFERENCES

ESA, 1997, The Hipparcos and Tycho Catalogues, ESA SP-1200

Jancart, S., Jorissen, A., Babusiaux, C. et al., 2005, Orbit determination for S_{B^9} stars, A&A, in prep.

Pourbaix, D., Arenou, F., 2001 A&A 372, 935

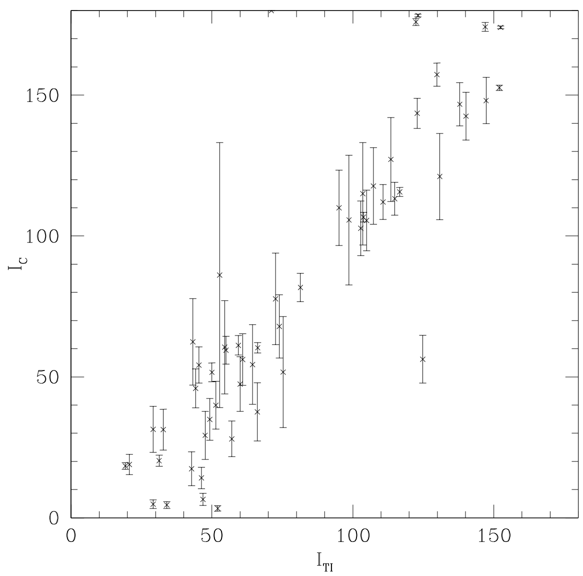

Figure 5. Comparison of the inclinations derived from the Thiele-Innes constants and the Campbell elements for the 56 accepted systems. Same as Figure 4 with the consistency criterion further imposed.

Pourbaix, D., 2001 A&A 369, L22

Pourbaix, D., Tokovinin, A. A., Batten, A. H. et al., 2004, A&A 424, 72.

van Leeuwen, F., Evans, D.W., 1998, A&AS, 130, 157