Orbit Determination of Single-lined Spectroscopic Binaries by Using the Revised Hipparcos Intermediate Astrometric Data

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Abstract: By fitting the revised Hipparcos intermediate astrometric data (IAD), we obtain the photocentric orbital solutions of some single-lined spectroscopic binaries (SB1s) in the 9th Catalogue of Orbits of Spectroscopic Binaries (SB9). The determination of the full orbital solutions of these binaries is discussed.

Notations:
a_0: angular semi major axis of the photocentric orbit;
a_1: angular semi major axis of the primary's orbit;
e: eccentricity;
P: period;
T: the time of passage at periastron;
ω: the argument of the periastron;
Ω: the latitude of the ascending node;
i: inclination;
M_1 and M_2 : component masses;
$\kappa = M_2/(M_1+M_2)$;
△Hp: Hipparcos magnitude difference between primary and secondary;
$\beta = 1/(1+10^{0.4\Delta Hp})$.

Introduction: Assuming $a_0 = a_1$, Jancart et al obtained the orbital solutions of 70 SB1s in SB9 by fitting the Hipparcos IAD. Their assumption would become inappropriate with more precise observational data such as those from Gaia, and it can be dropped without introducing intrinsic difficulties in the orbital determination. Therefore, we determine the photocentric orbital solutions of some SB1s in the SB9 by using the revised Hipparcos IAD. In the case of an SB1 composed of main sequence stars, it's possible for us to give further a preliminary full orbital solution with the help of the color-magnitude relation and the mass-luminosity relation known for these stars.

As an example, we report our results on HIP 113860 (P=178.3177 days, e=0.53, ω=2.6°, F0V).

Photocentric orbit: The photocentric orbital solution is obtained by determining a_0, i, and Ω from the revised Hipparcos IAD, keeping the spectroscopic orbital elements (e, P, T, and ω) unchanged. More details on the fitting and the assessment processes can be found in Ren&Fu 2010.

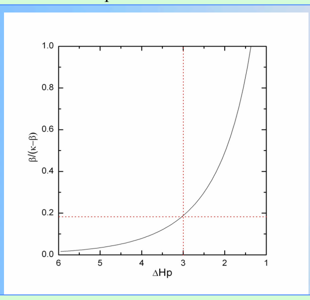

Fig 1. The relation between the Hipparcos magnitude difference △Hp and $\beta/(\kappa-\beta)$.

There are two main differences between our and Jancart et al.'s fitting methods.

One is that a_0 is assumed to be a_1 in Jancart et al., but here it is a normal adjustable parameter. Indeed, the difference between a_0 and a_1 can be quite large for an SB1 with relatively small △Hp. This difference can be quantified as $\frac{a_1-a_0}{a_0}=\frac{\beta}{\kappa-\beta}$, and for SB1s composed of two main sequence stars, its relation with △Hp is shown in fig.1. From this fig., we see that the difference is ~ 20% when △Hp=3^m.

The other is that the number of nonlinear model parameters is reduced by replacing i ($i \in (0^\circ,180^\circ)$) by the linear parameter $\psi = \cos i$ ($\psi \in (-1,1)$). In this way, the fitting efficiency is significantly improved.

By fitting the revised Hipparcos IAD, photocentric orbital solution of HIP 113860 is obtained with a_0=5.9±0.2 mas, i=49°.3±4°.1, Ω=269°.7±3°.7.

Component masses: Because the primary is a main sequence star, we can estimate its mass, ~ $1.56M_{sun}$, by using the color-magnitude relation and the mass-luminosity relation of main sequence stars. Then, the mass of the secondary is estimated as about $1.26M_{sun}$.

A preliminary full orbital solution: If the secondary of HIP 113860 is assumed to be a main sequence star, the magnitude difference of the two components is estimated by virtue of the mass-luminosity relation: △Hp ~1.25^m, and in V-band we have △V~1.16^m.

Then, there are two ways to obtain the value of $\frac{\beta}{\kappa-\beta}$:

$$\frac{\beta}{\kappa-\beta}=\frac{\frac{1}{1+\log(0.4\Delta Hp)}}{\frac{M_2}{M_1+M_2}-\frac{1}{1+\log(0.4\Delta Hp)}}=0.53$$

and

$$\frac{\beta}{\kappa-\beta}=\frac{a_1-a_0}{a_0}=0.56$$

The closeness of these two resulting values shows the internal consistency of our process leading to the full orbital solution.

In order to facilitate planning for future observations, we present the relative orbit (the left panel of fig.2), the phase-dependent radial velocities (the right panel of fig.2), and the ephemeris (table 1).

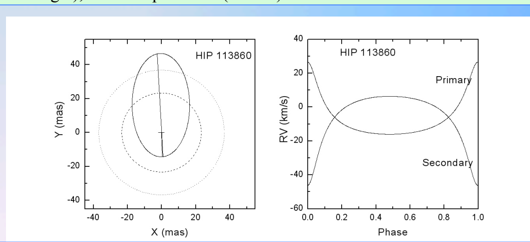

Fig 2. The left panel shows the relative orbit of HIP 113860. The dash circle and the dotted circle indicate the V band Rayleigh limits of the 4 meter and 6 meter telescopes. The right panel shows the radial velocity curves of the primary and the secondary of HIP 113860.

Table 1. Ephemeris of HIP 113860.

Phase	ρ (mas)	θ (deg)	RV_1 (km/s)	RV_2 (km/s)
0.0	23.5	45.4	-6.6	-5.3
0.1	35.4	67.2	-12.7	2.3
0.2	43.1	79.1	-15.2	5.4
0.3	46.5	88.2	-16.0	6.4
0.4	45.7	96.8	-15.6	5.9
0.5	40.7	106.6	-14.0	3.9
0.6	31.6	120.7	-10.4	-0.6
0.7	19.2	150.9	-1.9	-11.0
0.8	13.6	236.9	20.4	-38.6
0.9	12.8	336.1	11.1	-27.1

Discussion: The ultimate goal of binary orbit determination is to obtain the full orbital solution and the component masses. For many double-lined spectroscopic binaries, this goal can be achieved by fitting the coming Gaia astrometric data. But this is not the case for an SB1. Recently, some advanced spectral separation techniques, e.g., Doppler tomography, spectral disentangling and two-dimensional correlation techniques are developed. As pointed out by Taylor et al., SB1s with component magnitude difference less than 3^m can easily be turned into SB2. And we believe that these techniques will become more efficient if they are incorporated with orbital determination. Therefore, it is concluded that the Gaia mission will be helpful in binary full orbit determination of more systems than what was thought to be.

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