Recent results on the hierarchical triple system HD 150136

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Abstract: HD 150136 is a hierarchical triple system, non-thermal radio emitter, made of three O stars totalling some 130 solar masses. The 2.67-day inner orbit is rather well-known. Recent works derived a good approximation for the outer orbit with a period of 3000 days. We report here on interferometric observations that allow us to angularly resolve the outer orbit. First evidences for an astrometric displacement are given. The determination of the outer system orbit gives access to the inclinations of the systems and to the masses, including the one of the O3-O3.5 primary star.

1. Introduction

HD 150136 is one of the two bright stars separated by 10" and hosted in the centre of the young open cluster NGC 6193 in the Ara OB1 association. This object is clearly an early O-type star first classified as O5 in the bright star catalog. Niemela & Gamen (2005, MNRAS, 356, 974) reported on the binarity of HD 150136 and classified the system as O3+O6. They suggested a period of 2.662 d. The estimated distance is about 1.32 kpc (Herbst & Havlen, 1977, A&AS, 30, 279). More recently, Mahy et al. (2012, A&A, 540, A97) demonstrated that the HeI lines in the spectrum of HD 150136 were exhibiting three components. Mahy et al. (2012) revised the period to 2.67454 d and the classification to O3V((f*))-O3.5V((f+)) + O5.5-6V((f)) (P+S), the corresponding lines being rather broad. Figure 1a shows the corresponding radial velocity (RV) curve with a presumably fixed value for the centre-of-mass radial velocity. Figure 1b shows the corresponding RV curve with the systemic velocity authorized to vary slowly. The dispersion is smaller for the latter figure. Mahy et al. (2012) demonstrated that the centre of mass of the O pair in the 2.67454 d orbit was varying slowly in anticorrelation with the variations of the RVs associated to the third component with narrower lines (O6.5-7V((f)), T for tertiary). The inner system O3-3.5+O5.5-O6 and the third object are forming an outer system that is much larger. Mahy et al. presented a very preliminary orbital solution for the outer system suggesting that, at a distance of 1.32 kpc, the projection of this orbit on the sky plane could be astrometrically resolved using modern interferometric facilities. We continued to monitor the spectral variations of the system and we definitively proved that the outer system has a period around 3000 d and an eccentricity in excess of 0.6 (Sana et al. 2013, A&A, 553, A131). The most complete radial velocity curve is given in Figure 2.

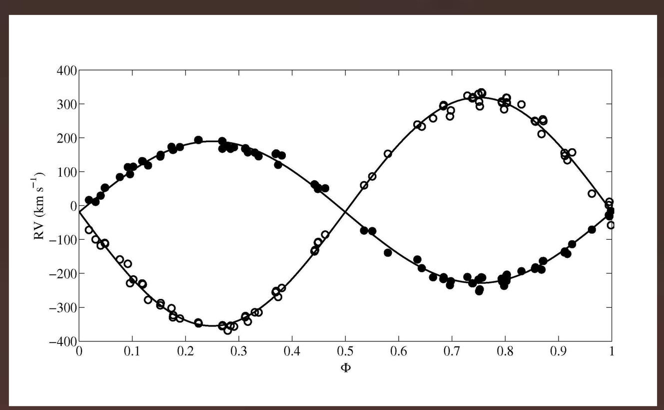

Figure 1a: observed radial velocities and fitted model prediction as a function of phase for the inner P+S system. Primary: filled circles; secondary: open circles. Systemic velocity is constant.

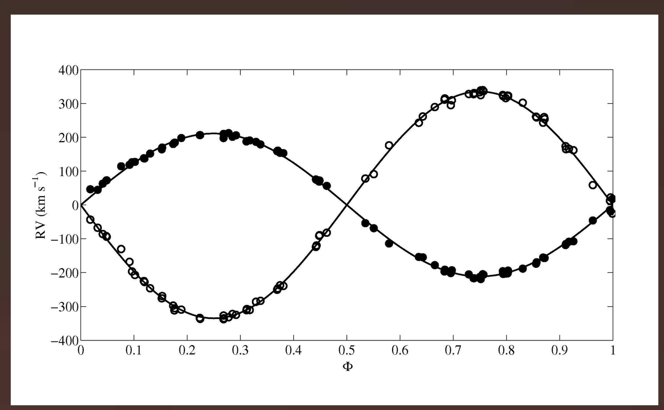

Figure 1b: same as figure 1a but with the systemic velocity allowed to have a long-term drift. Both figures are from Mahy et al. (2012, courtesy A&A).

2. Interest of HD 150136

On the basis of Chandra X-ray observations, Skinner et al. (2005, MNRAS, 361, 191) reported that HD 150136 is one of the X-ray brightest early-star known (log L_X = 33.99 (cgs), $\log(L_X/L_{bol}) = -6.4$). The emission is suggested to occur as a consequence of a radiative colliding-wind interaction. Skinner et al. (2005) also demonstrated that HD 150136 exhibits variations in its X-ray emission. Although established, this variation is not easy to interpret. Although it should be pointed out that the inclinations of both systems were not known before the work described in Section 4.1, making any tentative explanation difficult to prove.

The star is also known as a non-thermal radio emitter (Benaglia et al. 2006, PASA, 23, 50; De Becker 2007, A&ARv, 14, 171). This suggests the idea that there are somewhere in the system relativistic electrons supposed to be accelerated through shocks as those present in colliding wind regions. Our previous work (Mahy et al. 2012) suggests that a non-thermal radio emission originating in the inner system would hardly escape, and the presence of the third object is a unique opportunity to displace the emitting region in the outer system. Since the latter is eccentric, variations in the non-thermal component could occur. The star is worth a radio monitoring. The primary of the triple system is a very early O type star; only very few of them are known in binary systems (particularly in the Galaxy). The constraints on the masses of the O-type stars are worth improving from the observational point of view. Therefore, a determination of the inclinations of both systems would be most welcome. In addition, the possible angle between the planes of both orbits is a rare invaluable information that could bring information on the formation process of the whole system.

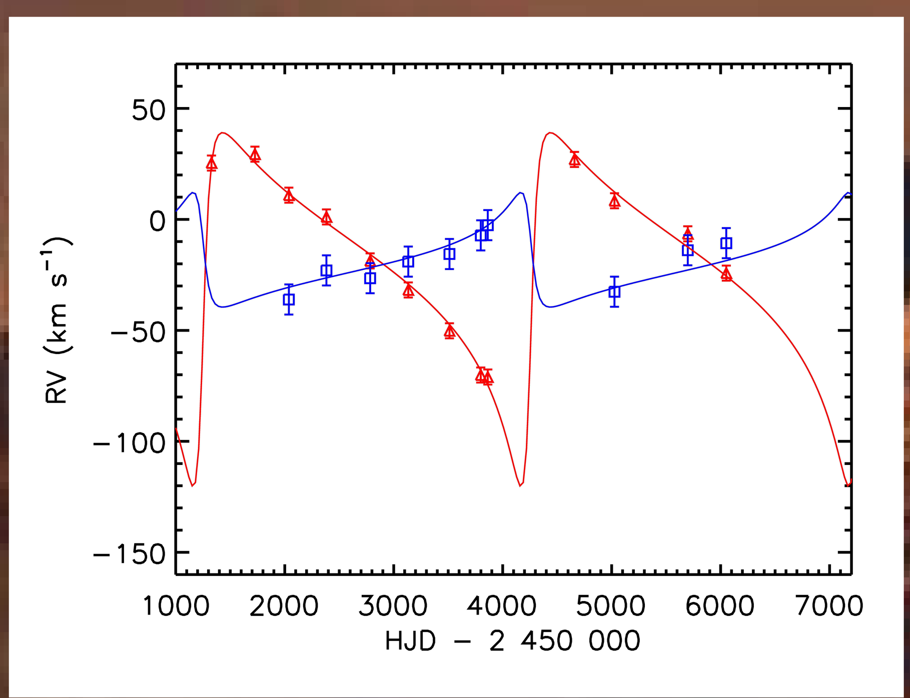

Figure 2: observed radial velocities for the inner-orbit centre of mass (blue squares) and for the tertiary component (red triangles), both forming the outer system, along with the best-fit model prediction and as a function of time. The 3000 d period is obvious.

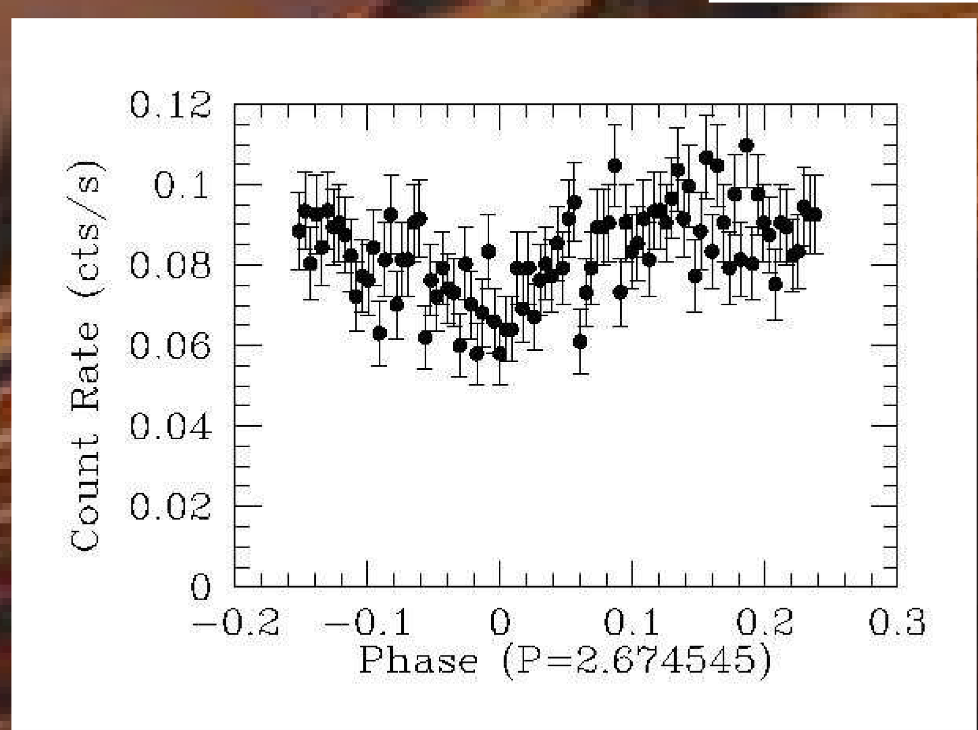

Figure 3: variation of the Chandra count rate of the X-ray emission of the star HD150136. The lightcurve is binned at 1 ks and corresponds to the energy range 0.5-5.0 keV. It is given as a function of the phase of the inner system (from Mahy et al. 2012). Phase zero corresponds to the conjunction with the primary in front.

3. The X-ray lightcurve

The variability in the X-ray domain reported by Skinner et al. (2005) is visible in Figure 3 where we exhibit the lightcurve in count rate as a function of the phase of the inner system (see Figure 1). With the new ephemeris, the minimum of emission corresponds to phase zero, i.e. to conjunction with the primary in front of the secondary. This allows to consider the more classical explanation that the X-ray emission from the apex of the colliding wind shock region is slightly extended and partly occulted. This interpretation agrees with the estimated inclination around 49º (excluding eclipses).

4. Interferometric observations

4.1 First results (published in Sana et al. 2013)

Since the separation of the Primary+Secondary and Tertiary in the outer system should project on the sky plan with an apparent separation of a very few tens of milli-arcsec, we decided to observe this star in interferometric mode. In addition, the star was a target of the ESO Large Program of Sana et al. on the probability of binarity among massive stars. Therefore, we tried to detect the astrometric variations of the outer system. The simultaneous knowledge of the outer orbit RV variations and of the corresponding astrometric orbit will give access to the inclination of the outer orbit and to absolute masses both for the total P+S inner system, and for the tertiary object T. From the RV solution of the inner system, we have a precise mass ratio P/S. Therefore, we will subsequently determine the absolute masses and the inclination of the inner system.

HD 150136 has been observed with the VLTI made of four Auxiliary Telescopes (ATs) located in a configuration A1-G1-K0-I1. The pattern provides six projected baselines ranging from 30 to 120m. The four signals were combined with PIONIER (Le Bouquin et al. 2011, A&A, 535, A67). First observation took place in June 2012 and has been confirmed by an additional one in August 2012. At both dates, HD 150136 appears as a binary system (as expected) with the assumed tertiary object situated some 9 milli-arcsec SW relatively to the inner system that obviously remains unresolved. The positions are given in Table 1 (columns 3 and 4). The separation at a supposed distance of 1.32 kpc corresponds to 12 AUs. The detection of such a companion by chance alignment is low and it is assumed that the identification of the detected pair with the outer system allow a determination of the dynamical masses and inclinations: $M_{P+S} = 102 \pm 16\ M_{sol}$, $M_T = 33 \pm 12\ M_{sol}$ and $i_{out} = 107º.9 \pm 3º.0$. This implies for the inner system $i_{in} = 49º.6 \pm 3º.6$, $M_P = 62.6 \pm 10.0\ M_{sol}$ and $M_S = 39.5 \pm 6.3\ M_{sol}$. The agreement with the expected masses from the Mahy et al. calibration on the basis of CMFGEN computations is very good. The concordance of these masses with the evolutionary masses deduced from the positions in the HR diagram is good too, although the derived ages for the massive objects are smaller than for the other components (see also Martins et al. 2012, A&A, 538, A39). Details are available in Sana et al. (2013).

4.2 New 2013 results

The HD 150136 system was again observed twice in March/April 2013 (see Table 1, columns 5 and 6) in the framework of the belgian VISAS guaranteed time on ATs. Figure 4 illustrates the reduction of the data for one of the runs: the object is still clearly present to the SW of the inner system. However it has moved (see Table 1 and Figure 5). Therefore, the new measurements confirm (if necessary) the presence of an object close to the inner system. More importantly, the latter has moved by several degrees in anomaly and this definitively demonstrates that the object is fully associated to the tertiary discovered through the RV solution. These observations are in good agreement with an independent measurement by Sanchez-Bermudez et al. (2013, arXiv:1305.3431). The star was again observed in May 2013 with the UTs (Table 1, column 7). The positions given by the 2013 observations are well located on the astrometric orbit derived by Sana et al. (2013), see Figure 5, and are thus not changing the above-mentioned results by large amounts but strongly endorse them. These new measurements have a benefic impact on the error-bars which are decreased by some 10-15 percent when compared to the preliminary results of Sana et al. (2013).

Table 1: Results of the five observations of HD 150136 performed with the ESO VLTI (+PIONIER). The relative motion of T is clearly seen unveiling the orbit (1-σ error-bars).

Parameter	Unit	Observation date 2012-06-10	2012-08-15	2013-03-25	2013-04-01	2013-05-25
Configuration		A1-G1-K0-I1	A1-G1-K0-I1	D0-G1-H0-(I1)	A1-B2-C1-D0	U1-U2-U3-U4
(f_T / f_{P+S}) at 1.65µ	flux ratio	0.24±0.02	0.24±0.02	—	0.24±0.01	0.27±0.01
δE (EW separation)	(mas)	-7.96±0.16	-6.98±0.14	-2.95±0.15	-2.99±0.11	-2.25±0.06
δN (NS separation)	(mas)	-4.73±0.09	-5.13±0.10	-6.25±0.17	-6.28±0.13	-6.55±0.15
r (polar separation)	(mas)	9.26	8.66	6.91	6.95	6.93
θ (azimuth N to E)	(degree)	239.2	233.7	205.3	205.5	199.0
χ^2_{red}		1.2	1.4	2.4	0.9	1.4

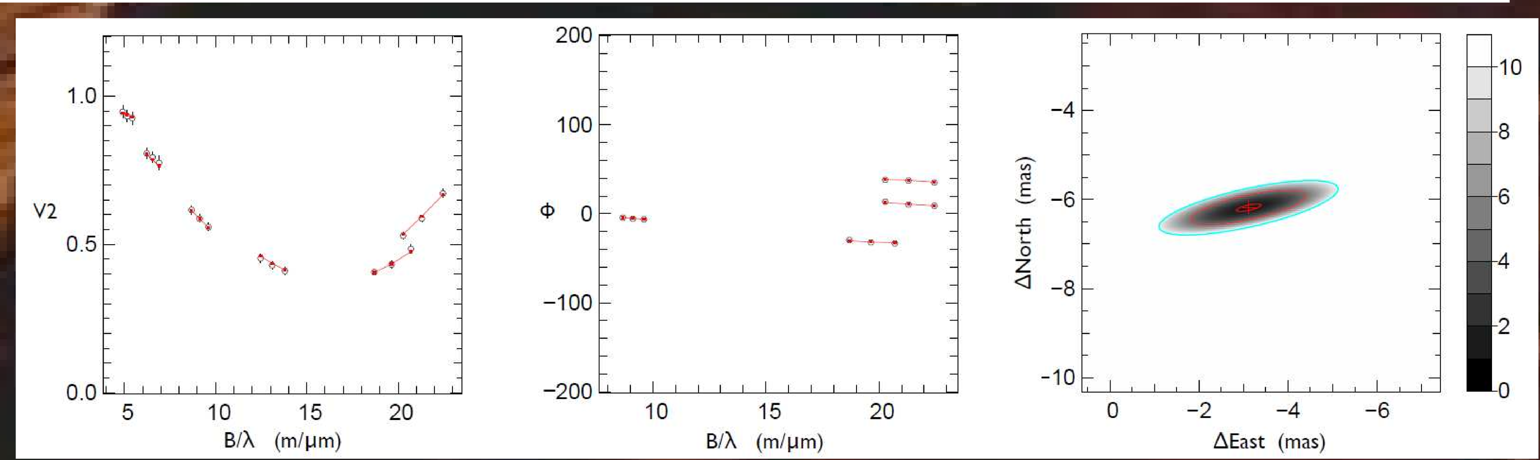

Figure 4: calibrated visibilities (left) and closure phases (middle) for PIONIER observation in April 2013, overlaid with the best-fit binary model (red lines). The right panel exhibits the χ^2 map in the vicinity of the position solution for T.

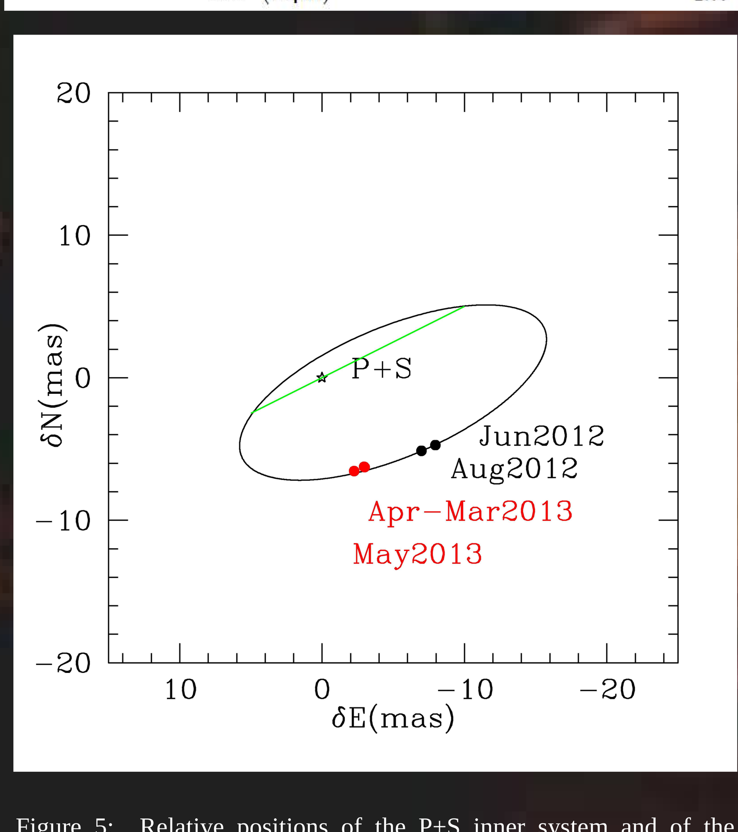

Figure 5: Relative positions of the P+S inner system and of the tertiary object T for the five interferometric measurements performed in the framework of our detailed study of HD 150136.

5. Epilog

All this allow us to conclude that HD 150136 is a very interesting object that deserves that we pursue the monitoring we have initiated. Ultimately, we hope to reach error-bars at the level of a very few percent on the main physical parameters. The total orbit will be covered within 8 years. The next periastron passage occurs in 2015.