ASTROMETRIC ORBITS OF LOW-MASS BINARIES
IS IT POSSIBLE?

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We investigate the possibility of determining astrometric orbits of known low-mass eclipsing detached binaries with the Very Large Telescope Interferometer in H and K bands. For two systems we estimate the possible values of the visibility amplitudes V^2 for various baselines and and various orientations of the orbit and orbital phases. We conclude that, in principal, this kind of measurements is possible with VLTI.

INTRODUCTION:

Observations and modelling of low-mass detached eclipsing binaries (LMDEBs; M<1 M_{sun}) is one of the hot topics in modern stellar astronomy. After we recognised that our evolutionary models do not explain the relations we observe (like the mass-radius relation for the lower Main Sequence), we started to look for new systems in order to collect more observational data and create better models, which include the influence of rotation, metalicity, activity and a more sophisticated approach to convection.

There are about 12 LMDEBs published but not all of them have parameters determined with an accuracy better than 3%, which is required for testing the evolutionary models (Torres et al. 2002). Combining the photometry and radial velocities (RVs) allows us to derive such parameters as the masses, radii and most of the orbital elements but not the ascending node longitude. The distance can be estimated only from the photometric relations between the absolute magnitudes and other parameters. This often implicates large uncertainties, especially if these relations do not account for activity or metalicity. A determination of an astrometric orbit will give an information about Ω, precise magnitude difference between the components and a direct measurement of the distance. In other words, combining all three methods gives us a complete knowledge about a binary.

Astrometry by measuring the fringe pattern visibility (squared), together with precise RVs, was successfully used to determine orbits of many binaries, including over 20 spectroscopic (Quirrenbach 2001). In some cases the derived masses are already at the 1%-2% precision level. Even for separations around 1'', when a system was only partially resolved, interferometry gave quite precise and valuable results (e.g. Konacki and Lane 2004).

THEORY:

Astrometry with interferometers can be done in two ways: by imaging and fringe contrast (visibility squared) measurements. The latter is easier because it uses the basic observable in interferometry, which is the difference between the maximum and minimum in the fringe pattern. V^2 can only have values between 0 and 1. The expected visibility of a binary is given by Equation (1) where V_1, V_2 are the visibility moduli for the two stars alone, r is the apparent brighteness ratio, $\mathbf{B}$ is the baseline vector projected on the plane of the sky in the system's position, and $\mathbf{s}=(\Delta\alpha,\Delta\delta)$ is the separation vector between the two stars (e.g. Boden et al. 1999). V_1 and V_2 can often be approximated by the uniform disk model but in most of cases they can be set to 1.

$$V_{bin}^2 = \frac{V_1^2 + V_2^2 r^2 + 2V_1 V_2 r \cos\left(2\pi \frac{\mathbf{B}\cdot\mathbf{s}}{\lambda}\right)}{(1+r)^2} \quad (1)$$

VLTI+AMBER:

The longest possible baselines of the Very Large Telescope Interferometer are 130m between the Unit Telescopes (UTs) and 200m between the Auxilary Telescopes (ATs). The VLTI uses the AMBER instrument for interferometry in near the infrared (Petrov et al. 2007). The instrument can work in the H (1.65 μm) and K (2.15 μm) bands. The magnitude limits are H<7 and K<7 mag for the UTs and H<5 and K<5 mag for the ATs. These limits exclude most of the LMDEBs due to their low luminosity. Nevertheless, some are still bright enough. The forthcoming instrument PRIMA will be able to observe much fainter stars, thus more of the interesting objects.

CALCULATIONS:

For two eclipsing binaries – ASAS-DEB-003 and CU Cnc – we calculated the visibility in two bands for a range of baseline values and apparent separations between 0 and a. This choice of separations mimics two effects – orbital motion, when the angular separation changes like the cosine function with time, and relative configuration of the vectors $\mathbf{B}$ and $\mathbf{s}$, which varies between the prallel and perpendicular. The baseline is varied between 0 and 200m in order to cover all possible values for VLTI. V^2 varies between 1, when the cosine term in Equation 1 equals 1 (perpendicular vectors or an eclipse: $|\mathbf{s}| = 0$), and $(1-r)^2/(1+r)^2$, when the cosine equals -1 ($\mathbf{B}\cdot\mathbf{s} = \lambda/4$). For both cases the baseline for mimum of V^2 is given (under the assumption of parallel vectors). Figures 1 and 2 show the V^2 variation in given ranges. The color scale is the same in every plot. 0 level is plotted to guide the eye.

ASAS-DEB-003:

ASAS-DEB-003 is a short period (P=1.5285 d) binary. It is quite a bright object (V = 10.24, H = 7.01, K = 6.80 mag; Hipparcos and 2MASS) with the component's masses 0.713 and 0.699 M_{sun} (Hełminiak and Konacki 2008; unpublished). It's eclipsing nature was confirmed by the All Sky Automated Survey (Pojmański 1997). The system has a circular orbit with a semi-major axis a = 0.029640(32) AU (Hełminiak and Konacki 2008). A simple but usefull mass-luminosity relation, given by Henry and McCarthy (1993), gives an absolute magnitude M_K = 3.74 +/- 0.61 mag and a brighteness ration r~0.9 which corresponds to V^2_{min}= 0.0028. This system has an independent distance determination by Hipparcos satelite – the parallax is 20.49 +/- 2.7 mas (d = 48.8 +/- 6.5 pc) which gives M_K = 3.24 +/- 0.31 mag, a value consistent with the previous one. At the given distance, the angular size of a (thus the maximum separation between the stars) reaches 0.60 +/- 0.08 mas. It makes the binary only partialy resolved but still possible to observe.

Assuming parallel vectors, the optimal baseline is $|B| = \lambda/2|s|$ (and $3\lambda/2|s|$). It's values in this case are 283.61m and 369.56m for H and K band respectively. This favours the Auxilary Telescopes which are, unfortunately, too small to observe this system. Nevertheless, 130m baseline gives the smallest values of V^2 = 0.5661 in H and 0.7251 in K which still makes ASAS-DEB-003 possible to observe.

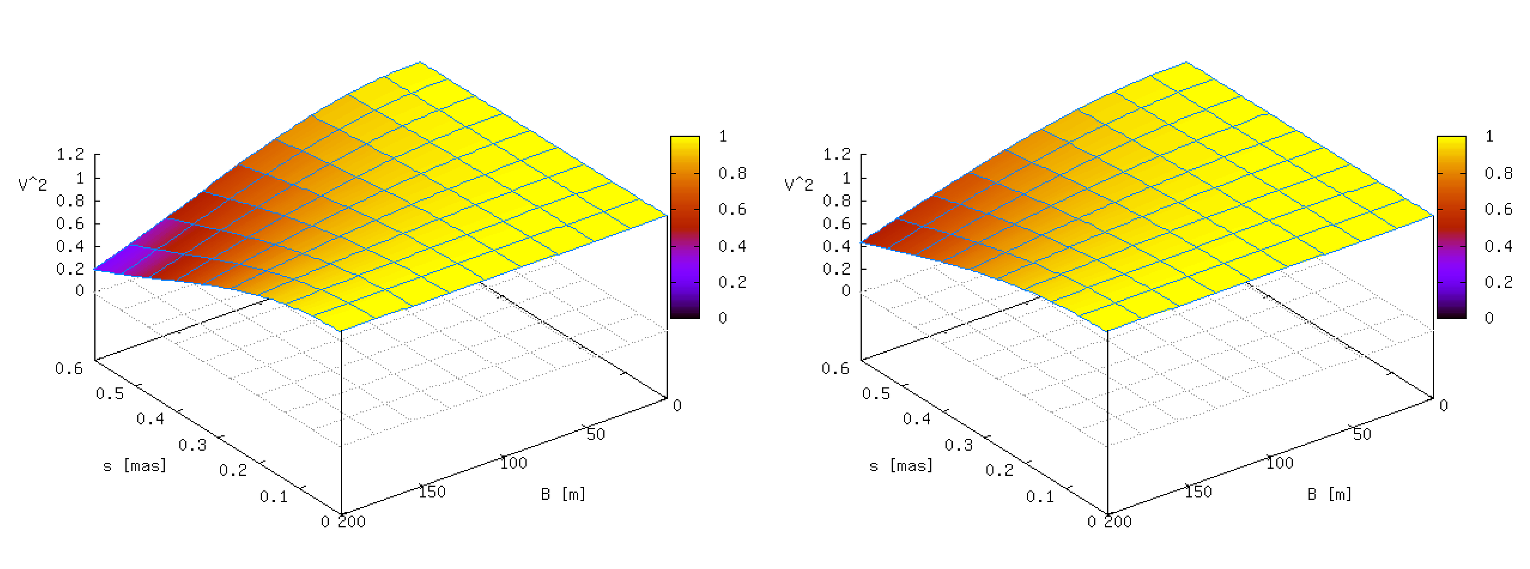

Fig. 1: V^2 variation in case of ASAS-DEB-003 in H (left) and K bands (right).

CU CNC:

CU Cnc (GJ 2069A) was a third known LMDEB. It also has a short period (P =2.7715 d). It's eclipses were reported by Delfosse et al. (1999) who gave the first values of it's physical parameters which were updated later by Ribas (2003). It's component's masses are 0.4317 and 0.3908 M_{sun} (Ribas 2003). This system is redder (V = 11.09, H = 6.89, K = 6.60 mag; *Hipparcos* and 2MASS) and closer (π = 78.05 +/- 5.69 mas, d = 12.81 +/ 0.93 pc; *Hipparcos*) than ASAS-DEB-003. This should make it an easier target for VLTI. The absolute semi-major axis value, a = 0.03628(6) AU (Delfosse et al. 1999), corresponds to the maximum angular size of 2.83 +/- 0.21 mas. The brighteness ratio r, based on the mass-luminosity relation (Henry and McCarthy 1993), is 0.85 which gives V^2_{min}= 0.0066.

CU Cnc is much easier to observe with UTs as the optimal baselines are 60.13m and 180.39m for the H and 78.35m and 235.05m for the K band. It is also bright enough to be visible in both bands operated by AMBER.

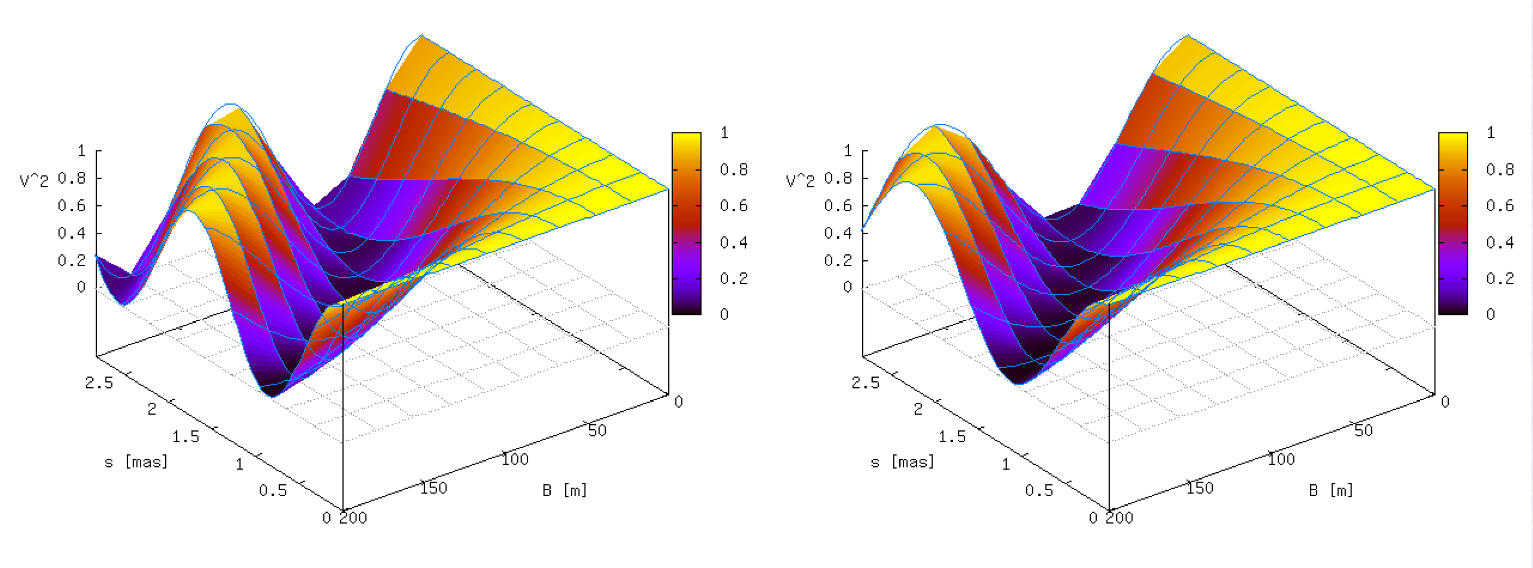

Fig. 2: The same as in Fig. 1 but for CU Cnc.

CONCLUSIONS:

We investigated the possibility of determining an astrometric orbit of two known low-mass detached eclipsing binaries with VLTI + AMBER. We have shown that, using this instrument and Unit Telescopes, it would be possible to determine the orbits in both cases, nevertheless for ASAS-DEB-003 it would be more difficult and probably could be done only in the K band.

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