The VLTI as a tool to study eclipsing binaries for an improved distance scale

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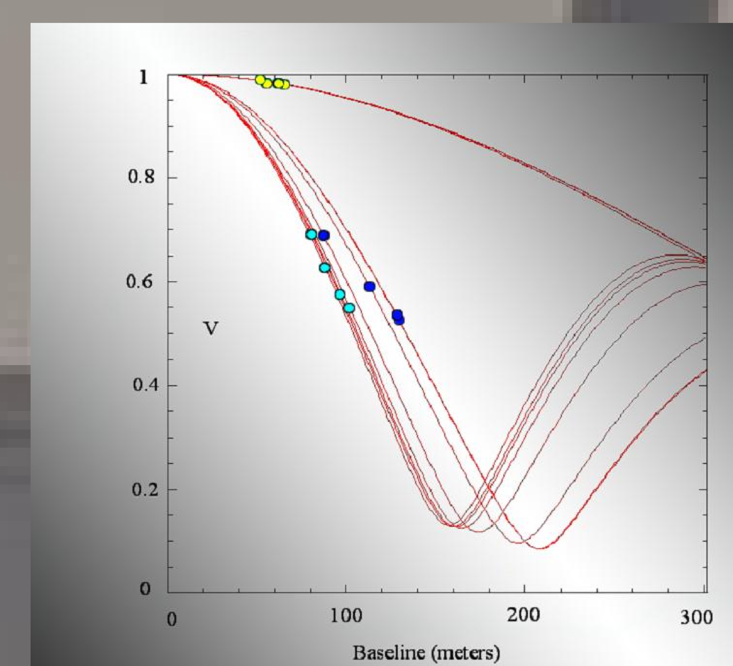
† Bohdan's genius and enthusiasm were the inspiration for this project. R.I.P.

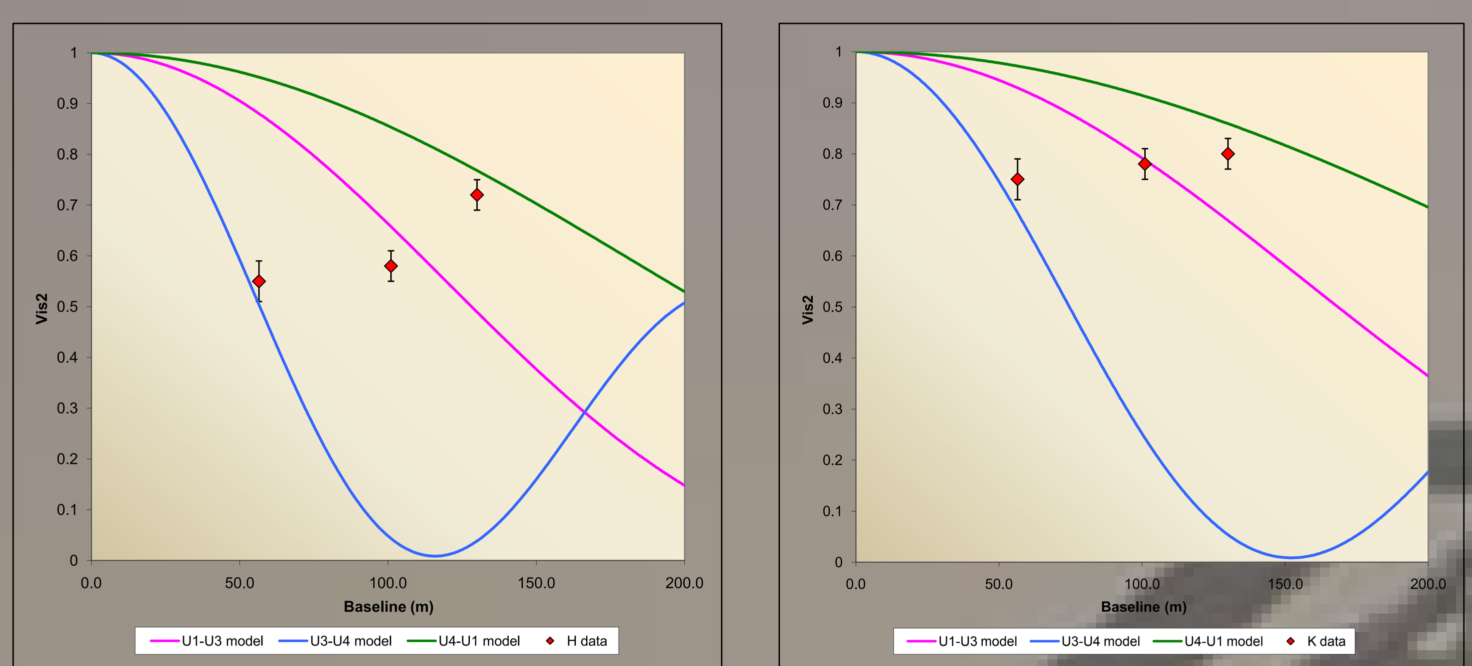
Even in the ELT era, angular resolution in the range of milliarcsecond and less will remain the prerogative of long-baseline interferometers. One area in which milliarcsecond capability is essential is the study of eclipsing binaries, for which the VLTI has already started to produce valuable results and for which we foresee an increase in the statistics as fainter and fainter magnitudes become possible with the introduction of facilities such as FINITO and PRIMA. In the special case of double-lined eclipsing binaries with well-detached components, from radial velocity and light curves it is possible to obtain a full solution of all orbital and stellar parameters, with the exception of the effective temperature of one star, which is normally estimated from spectral type or derived from atmospheric analysis of the spectrum or reddening-corrected photometric colors. Long-baseline interferometry at facilities such as the ESO VLTI is beginning to have the capability to measure directly the angular separation and the angular diameter of some selected eclipsing binary systems, and we have begun to carry out such observations with the AMBER instrument. In particular, we aim at deriving directly the effective temperature of at least one of the components in the proposed system, thereby avoiding any assumptions in the global solution through the Wilson-Devinney method. We have obtained an independent check of the results of this latter method for what concerning the distance to the system. This represents the first step toward a global calibration of eclipsing binaries as distance indicators. Our results will also contribute to the effective temperature scale for hot stars. The extension of this approach to a wider sample of eclipsing binaries could provide an independent method to assess the distance to the LMC. This can only be achieved by the VLTI, as the ELT will not have the required angular resolution.

The angular semi-major axis and the angular diameters a, $\theta 1$, $\theta 2$ are measured with AMBER at the VLTI using baselines of <100 m in the near-infrared provided they are close to the milliarcsecond (mas) scale. Our goal is to measure a restricted number of EB systems with a in the range 1-5 mas, and $\theta 1$, $\theta 2$ 0.4-1.2 mas. This will be accomplished by observing each system at least four times, at precise separated phase of the orbital period P corresponding to maximum separation. Time has been granted to observe δ Ori, a = 1.4, $\theta 1$ = 0.98, $\theta 2$ = 0.55, P = 5.73d (distance 280pc), in the ESO Period 78, unfortunately only two observational runs have been successfully accomplished in December 2006 and March 2007, the rest two runs have been shifted to the Period 80. Also four additional observations of δ Ori has been granted for the Period 80, as well as the time for the observations of η Ori, a = 1.7, $\theta 1$ = 0.84, $\theta 2$ = 0.7, P = 7.98d, and R CMa, a = 1.1, $\theta 1$ = 0.65, $\theta 2$ = 0.5, P = 1.13d.

We are using AMBER, currently offered on UTs in JHK range, in the combination that provides the highest angular resolution, i.e. triplets which include the UT1-UT4 baseline and the low-resolution LR-HK mode. This mode provides dispersed visibilities over the 1.5-2.4 microns range: the shorter wavelengths will provide the best angular resolution for the individual diameters, but the whole range can be used for the angular separation and also to provide a solid estimation of the brightness ratio as a function of the wavelength. This mode also provides the best SNR: although the candidate EB systems are sufficiently bright and we have provided comparably bright calibrators, a good SNR is essential to ensure sufficient quality of the results.



Simulations of the visibilities of δ Ori, to be observed with AMBER UT1-UT3-UT4, two circular disk model. Each dot color corresponds to a different baseline, and four triplets (one per observation) are present. All triplets refer to the same orbital phase.

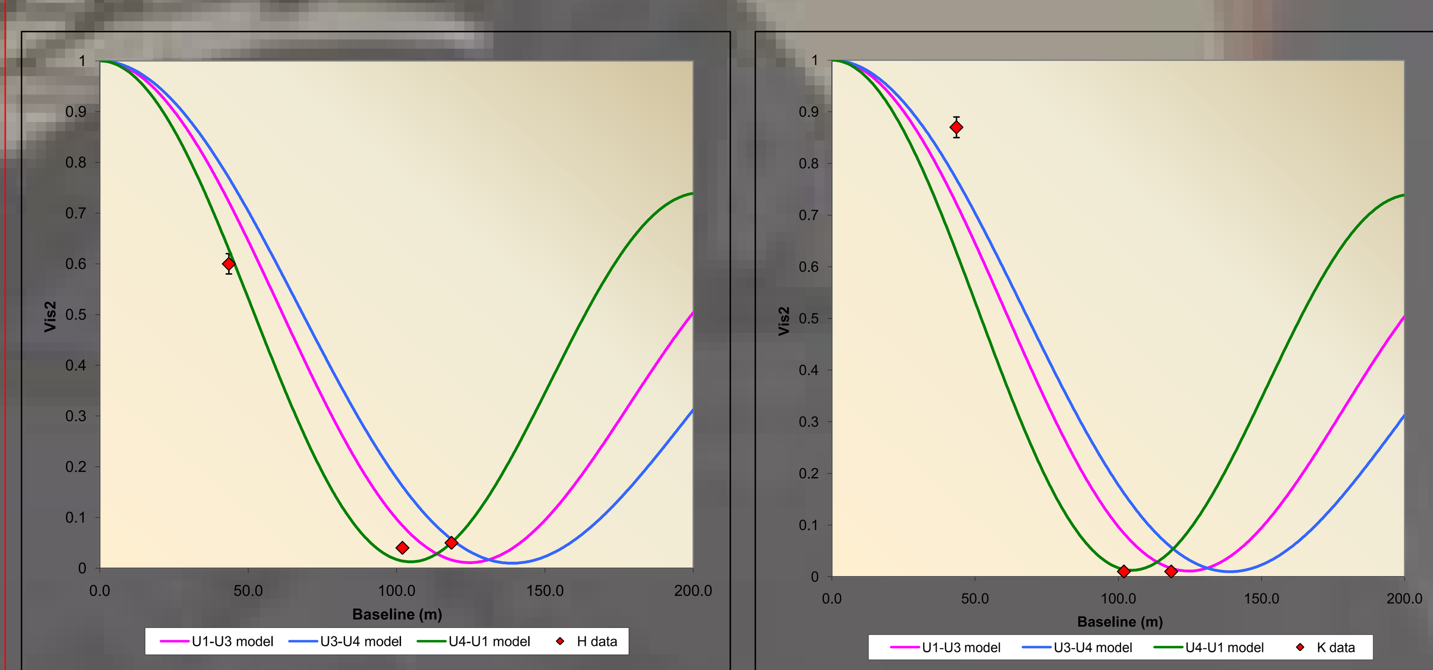


Averaged H- and K-band squared visibilities of δ Ori, observed on 31.12.2006 with AMBER UT1-UT3-UT4. The model fit: separation 1.9 mas, P.A.=149 degrees, brightness ratio 1.3, diameters of 0.9 and 0.6 mas respectively.

Each observation gives us 3 visibilities and one closure phase for the system. These values allow us to determine the separation and the orientation of the system. We observe the systems at the time of maximum separation, at the opposite orbital phases. In order to improve the precision of the observed quantities, the observation of each EB is necessary to repeat four times (i.e., two times at opposite phases), thus providing a reduction of about a factor of two on the final errors with respect to a single measurement. At the end of the four separate observations, we are going to have 12 visibilities and 4 closure phases. The quantities to be fitted are the (fixed) angular diameters, the (fixed) brightness ratio, and four pairs of angular separation and position angle values. Also note that we already have the estimates for each of these parameters, and that the period and photometric phases are very well known. The results of the preliminary simulations, made with ASPRO, are shown at the plot on the left side of the poster.

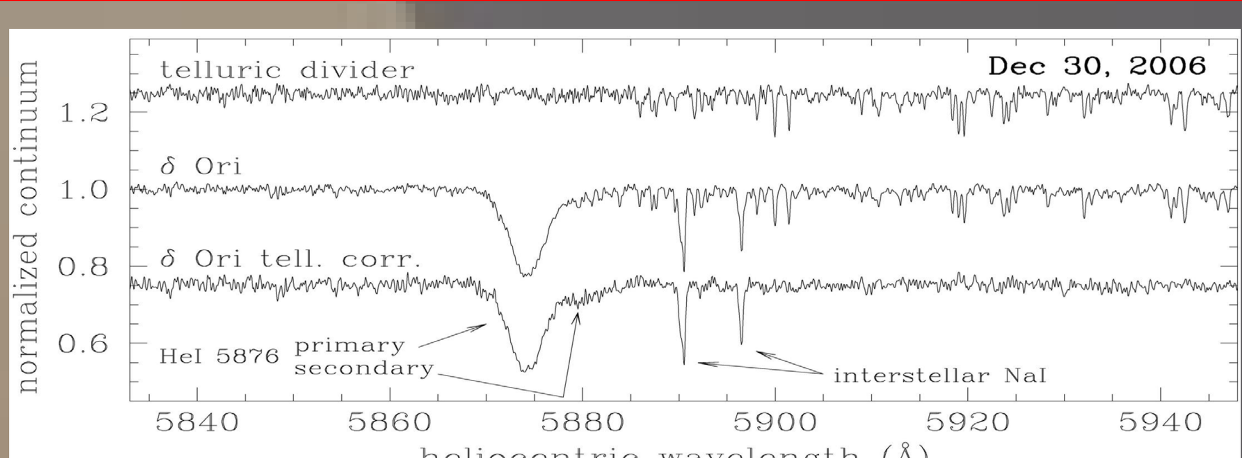
The figure above shows the averaged squared visibilities of δ Ori observed by AMBER UT1-UT3-UT4 at 31.12.06 in H and K band. The data obtained on 07.03.07 are shown below. Please note, that the two observations have been performed at the opposite phases of the orbit, therefore it explains the difference in the fitted parameters. However, since some visibilities within the second run are close to zero and SNR at the longest baselines does not exceed 2, it is not possible to make any reliable conclusion until all the observational runs would be available.

The symbols are the squared visibilities averaged over the wavelengths, H-band ~ 1.72 and K-band ~ 2.26 microns, in reality we have 16 channels in the K and 11 channels in H band. The solid curves in both figures represent the (preliminary) best fit to the data of the separation and position angle of the binary, with respect to the length and position angle of the baselines. The figures show a good match between the model and observed visibilities. Not all parameters used in the fit are available from the literature, and in addition there is a wide scatter of values. However, we note a general agreement with the results of our preliminary fit.



Averaged H- and K-band squared visibilities of δ Ori, observed on 07.03.2007 with AMBER UT1-UT3-UT4. The model fit: separation 1.9 mas, P.A.=75 degrees, brightness ratio 1.3, diameters of 0.9 and 0.6 mas respectively.

All the chosen systems are relatively close to the celestial equator in order to take advantage of the possibility offered by the Asiago observational facilities for obtaining the accurate determinations of photometric and radial velocity curves able to provide uncertainties 1% on masses, radii and semi-major axes for the selected systems. Support high quality radial velocity and photometric light-curve for the proposed targets are currently being collected at Asiago Observatory. 49 high resolution Asiago Echelle spectra of δ Ori have been already collected in 10 different nights during the time interval of ESO period 78. The spectra cover from 3800 to 7300 °A at a resolving power 30 000, and we achieved a S/N per pixel on the extracted spectrum in excess of 150.



A part of Echelle spectrum of δ Ori, secured within a few hour of the AMBER observationes of 31.12.06.

As an example of the type of collected data, we show in the figure above a part of a high SNR (>150) Asiago Echelle spectrum of δ Ori recorded within a few hours of the VLTI observations of 31.12.06. The displayed order covers the HeI 5876 line, the interstellar NaI D1,2 lines and a good number of sharp telluric H2O lines. The HeI absorption lines with their simple, gaussianlike profiles are the best suited to provide accurate radial velocities in earliest type stars, while interstellar NaI D1,2 lines allows accurate determination of the interstellar reddening (Munari and Zwitter 1997, A&A 318, 269) and the telluric H2O lines provide an accurate monitoring of the zero point of the radial velocities (to within 0.1 km/sec). The heliocentric radial velocity of the primary and secondary stars measured on this spectrum are -81 and +204 km/sec, respectively.

In addition, accurate B,V photoelectric photometry has been collected in 12 separate nights to map the eclipse lightcurve. Also note, that test spectra of the two additional proposed targets have been already secured with the Asiago Echelle under conditions similar to those of delta Ori, and proved to be able to deliver equally good results.

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