# Binary stars and the VLTI: research prospects

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## ABSTRACT

Binary star research is one of the oldest fields of astronomy, and yet also one of the most active. In fact, the majority of stars happens to be part of a binary or multiple system, and consequently binary star research covers most areas of stellar astronomy: from the youngest objects to the most evolved ones, from the least to the most massive. From the observational point of view, binary star research has always been strongly linked to the techniques available to push the limits of angular resolution and sensitivity. Significant steps ahead have occurred with the introduction of speckle interferometry, of lunar occultations, of adaptive optics. It is easy to predict that, thanks to its long and flexible baselines and to the large photon-gathering power, the VLTI will create the opportunity for another step ahead in this field. We investigate the potential applications of VLTI for binary star research, in particular with respect to studies of a) T Tauri stars and associated star-formation mechanisms, and b) dynamical mass determinations of low-mass stars. We present some recent results obtained by speckle interferometry and lunar occultations in these two areas, and discuss the follow-up studies which will become feasible with the VLTI.

**Keywords:** VLTI, binary stars, T Tauri stars, brown dwarfs

## 1. INTRODUCTION

The study of binary stars constitutes one of the most wide and diverse fields of astronomy. From the visual systems studied already for more than a century, to the newest ones being discovered and studied with the most modern techniques from the ground as well as from space, this area includes topics that go from the classical binary system comprising two well-detached main sequence stars, to systems having companions with very different masses or ages, to those exhibiting mass transfer phenomena, to contact systems, to binary stars including a white dwarf or a pulsar. The list is even larger when we include multiple systems, stars with sub-stellar companions and exoplanets, and stars in the process of being formed. As a result of this diversity in conditions, the number of physical phenomena that can be studied is very large and touches on fields such as distance and mass determinations, astrometry and celestial mechanics, stellar evolution, star and planet formation, atmospheres and chemical abundances, properties of gas and dust, hydrodynamics and magnetism, high energy physics, relativity, to name some. For all these reasons, binary stars have always attracted the interest of astronomers and continue to do so at present, as innovations in the facilities and techniques permit to obtain ever new types of measurements.

In particular, the introduction of large interferometric facilities, with baselines of 100 meters or more and the combination of very large mirrors for light collection, is going to stimulate many new observing programs in the area of binary stars. It is of course impossible to examine even superficially the implications in all areas of binary star research. In this contribution, we describe in general the kind of measurements permitted by a facility such as the VLT Interferometer (VLTI), which is going to be by far the most powerful interferometer in the southern hemisphere and one of the largest in the world. Subsequently, we turn our attention to two areas of binary star research which can benefit substantially from the VLTI, namely studies of binaries among young stars and low mass stars.

## 2. BINARY STARS AND THE VLTI

The VLTI will offer unique characteristics for binary stars studies, combining very high angular resolution with excellent sensitivity. The characteristics of the interferometer are described in these proceedings by Glindemann et al.[1,2], while those

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of the first generation instruments VINCI, AMBER and MIDI are described in the contributions by Kervella et al.[3], Leinert et al.[4] and Petrov et al.[5]. An overview of some key scientific opportunities with MIDI and AMBER is presented in the contributions by Lopez et al.[6] and Richichi et al.[7] In this section we present some considerations on the general use of interferometers for binary stars studies, and in particular on the performance of the VLTI in terms of angular resolution, baseline coverage, and sensitivity.

An excellent review in this sense has been provided recently by Davis[8], who in particular described in some mathematical and graphical detail the response of an interferometer to a binary star signal. The modulus of the complex visibility of a binary star has a simple mathematical formula, and in the left upper panel of Figure 1 we show the familiar case of two unresolved stars with similar brightness. Under such conditions, it is sufficient to measure very few points along the visibility curve to infer the fundamental parameters of the system: the brightness ratio $R$ and separation $\rho$. For a single baseline, this latter will be the projected value only, and one additional measurement along a baseline in a different direction will be necessary to obtain the actual separation, and the position angle $\theta$ in the sky.

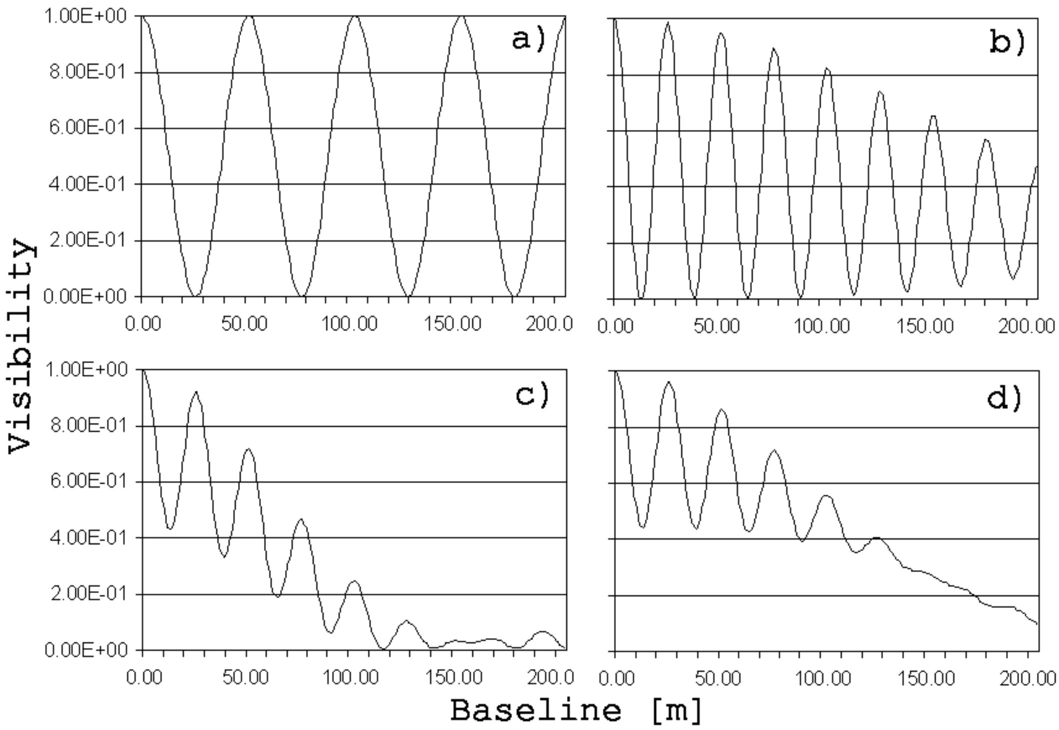


**Figure 1. Examples of binary star visibilities for different values of brightness ratio *R*, separation $\rho$, and angular diameters $\varphi_1$ and $\varphi_2$ of the two components (in mas). For the four panels the values are *a)*: 1, 5, 0, 0; case *b)*: 1, 10, 1, 0; case *c)*: 0.2, 10, 2, 0; case *d)*: 0.2, 10, 1, 2. All curves are computed for the J band, $\lambda$=1.25 $\mu$m.**

This simple situation however can become substantially more complicated, as soon as the angular diameters $\varphi_1$,$\varphi_2$ of the two component stars begin to be resolved even partially by the interferometer baseline. At least in the near-IR, this is going to be a common situation with the longest baselines of the VLTI, which can reach up to 200 m. Significant deviations from the simple cosine-law well known to astronomers working with speckle interferometry and with interferometers with moderate baselines, will become apparent. Some examples are given in the other panels of Figure 1. In the case of resolved components, the increased number of parameters, as well as the more complex behaviour of the visibility, impose more stringent requirements on the accuracy of the measurements, and in general the acquisition of more points in the *u-v* plane. As illustrated by a comparison of panels c-d in Figure 1, the key to distinguish between different models can be provided by the longer baselines.

The case of even more complex systems, such as for instance a triple star (an example of which is given in Sect. 3.2), or of stars with substantial limb-darkening, underline even more the need for highly accurate measurements, at a sufficiently large number of baselines and with high resolution. Therefore, while on one side the VLTI will provide the means to increase the potential for binary star research substantially, by investigating systems which could not be tackled up to present, on the other side these studies will prove more demanding in terms of interferometer time than it has been the case for similar instruments up to now.

A substantial boost to the efficiency of binary stars observations can be provided by the simultaneous observation of more than one baseline. One of the VLTI instruments will permit the combination of 3 beams, thus providing 3 independent baselines which can be used not only to add more points on the visibility plots, but also to derive the actual position angle of the system with one configuration.

**Table 1. AMBER K magnitude limits for various configurations.**

| Mode | Int. time | Disp. | 2UT | 2AT |
|---|---|---|---|---|
| High precision | 0.01s | $R$=5 | 11.3 | 8.0 |
| High sensitivity | 0.1s | $R$=5 | 13.2 | 9.9 |
| Fringe Tracking | 4h | $R$=5 | 17.0 | 12.1 |

Finally, for what concerns the limits in sensitivity, these depend on a large number of factors. Some of these are relatively well identified by the design of AMBER (for instance, transmission efficiency, fiber coupling, detector characteristics etc.), while many others are more difficult to characterize at this time: for instance the quality of fringe tracking and adaptive optics correction. Here we restrict ourselves to presenting a summary of some key numbers in Table 1, derived for the AMBER instrument operating in the K band[7].

Perhaps more important than sensitivity, in the case of binary studies is the accuracy in the calibrated visibilities. This is the key not only to obtain accurate separation measurements, but also to detect separation changes which fall beyond the theoretical diffraction limit of the interferometer. This in turn would permit to study orbital variations for short-period binaries, where the separations are generally small, or in long-period binaries where the separations are more favorable but changes in the position of the secondary are slow. The fundamental importance of visual orbit determinations is stressed in both case studies examined in Sect. 3. In particular, we present a graphical illustration of the VLTI potential in this field in Sect. 3.2. A detailed analysis of the visibility accuracy predicted for the VLTI is at present still in progress, and complicated by the fact that each of its instruments will have different characteristics and performance. At present, we can note that both VINCI and AMBER are based on the FLUOR[9] recombination design, based on optical fibers, already operational at the IOTA[10] interferometer. Recent results with that instrument have shown that absolute accuracies of $\leq 10^{-3}$ (P. Kervella, priv. comm.) can be obtained in a routine fashion, and similar or better results can be expected for the VLTI.

## 3. TWO CASE STUDIES

In the following, we examine separately the current research status and the prospects opened up by the VLTI in two important areas of binary star research, namely young stars and low mass stars. These subjects are sufficiently different in their characteristics to provide an illustration of the wide range of applications possible with the VLTI. At the same time, they are both stimulating topics, which have attracted general attention in the astronomical community in the recent years. The goal is to increase the volume of observational data regarding not only the number of binaries, but also their fundamental parameters such as period and masses, which in turn provide a fundamental check of theoretical models and a better understanding, in the two cases respectively, of *a)* the processes of star formation (with important implications on the formation of protoplanetary disks and planets), and *b)* the formation and evolution of objects at the boundary limit between stars and planets. An overview of the observable quantities in different types of binary systems and the types of fundamental quantities that can be derived from their observation has been given by Davis[8].

### 3.1. Binaries among young stars

Star-forming regions (SFRs) offer a unique opportunity to investigate the early evolutionary stages of stars and their surrounding environment, with important implications on our understanding of the subsequent evolution on the main sequence. Among the many physical phenomena which are observed in SFRs, an important role is played by the presence of binary stars. A comprehensive review of this topic has been given recently by Mathieu[11], and here we provide only a summary of the main issues of this important research area. In particular, we restrict ourselves for the moment to low-mass young stars, with masses around or below $1M_\odot$ (T Tauri stars). Note that we use the term binary also for those systems which are in fact multiple: in fact, it is observed that most multiple systems are hierarchical. A more in-depth discussion of this issue can be found for instance in the review by Mathieu[11].

This field is relatively new: although the first binaries among T Tauri objects were discovered already more than 50 years ago alongside with the first observations of this class of stars, their number has remained sufficiently small for many decades, that theoreticians did not pay too much attention to the phenomenon, and models of star formation mechanisms were usually developed having in mind a single star as the final product. The situation has changed considerably in the last decade, as IR array detectors have come into play[12], allowing to reveal sources which would be difficult or impossible for visual observations, and especially methods of high angular resolution such as lunar occultations (LO) and speckle interferometry (SI). The pioneering LO observations by Simon et al.[13,18] began to reveal a large number of binaries in the Tau-Aur and in the Oph-Sco SFRs, two regions which happen to be covered by the orbit of the Moon and which at the same time are among the closest and richest in T Tau stars. Subsequent more systematic surveys by SI, mainly by Ghez et al.[14] and Leinert et al.[15], although with lower resolution, confirmed this result.

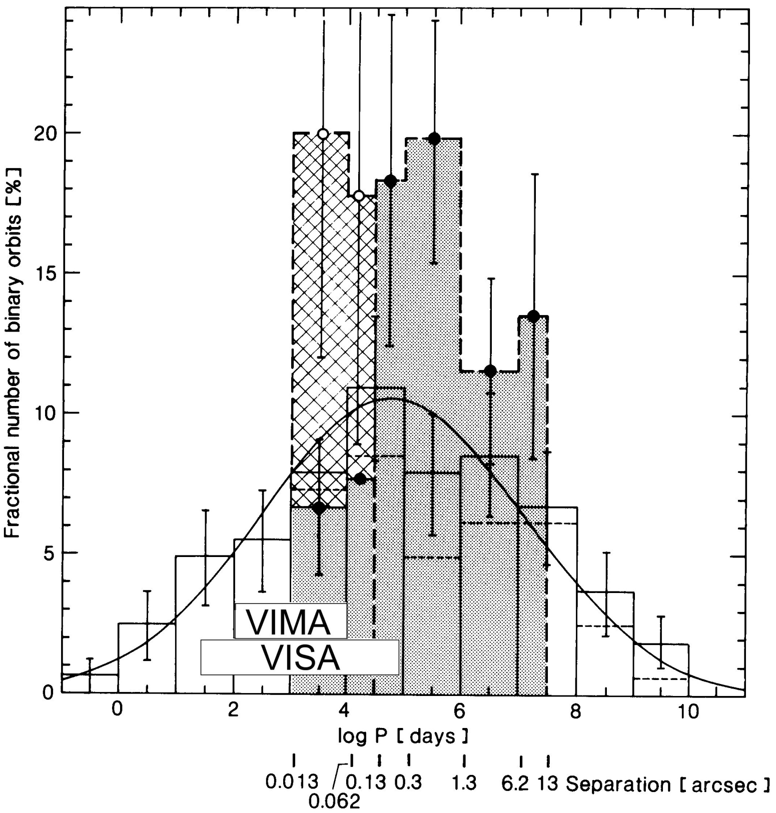


**Figure 2. Binary frequency in the Tau-Aur star-forming region, adapted from Richichi et al[16]. See text for details.**

The picture that emerged was that, at least in the case of the Tau-Aur SFR, there is a higher frequency of binaries than observed on the main sequence in the same period range. The situation was summarized by Richichi[16], from which we draw the graph shown in Figure 2. In the figure, the solid line represents the observed binary frequency for solar-type stars in the solar neighborhood, as derived by Duquennoy & Mayor[17] by means of a statistically complete survey using radial velocities. The shaded areas represent the binary frequency observed by LO (cross pattern) and speckle interferometry (gray) among T Tau stars in the Tau-Aur SFR. An excess with respect to the main sequence is evident. A detailed statistical significance is discussed by Simon et al.[18] It is noteworthy to stress that some spectroscopic binaries are also known, with periods in the ≈1-1000$^d$ range. These kind of observations are particularly challenging, and a total of only 25 spectroscopic binaries are known or suspected over all SFRs, of which only a fraction has a confirmed solution[11].

This evidence has pushed theoreticians to improve models, or produce new ones, in order to reproduce the observed binary frequency. Many ideas have been developed for star formation mechanisms, such as capture, fission of a protostar, independent condensations, fragmentation of the protostellar cloud or of the disk. A brief review and references for the main papers in this area are given by Mathieu[11]. Some of these models seem to hold enough potential for a realistic approximation of the observed binary frequency, however there is a wide range of parameters that needs to be constrained. For this reason, several quantities would be needed from observations. Among them:

- the frequency of binary systems with period
- the distribution of eccentricities
- the distribution of secondary masses
- the presence of accretion disks and their correlation with the binary characteristics

An example of the binary frequency in a special SFR has just been presented, however there are many caveats. For instance, the main sequence data are plotted against period, while the high angular resolution data are plotted against apparent separation: the conversion between these two scales rests on a few hypotheses[15], which are correct only in a wide statistical sense. Eccentricities can be derived today only for spectroscopic binaries. For what concerns the masses of the companions, there are no direct determinations, given the lack of systems with a visual orbit; at present, masses are inferred from the luminosity, a model-dependent step. Finally, the presence of circumstellar disks has been surveyed typically by means of mm-wavelength observations[19]. However, such surveys are sensitive only to the outer, colder parts of large circumstellar disks, and the completeness is far from satisfactory for smaller disks. Observations by high angular resolution methods including LO, speckle and adaptive optics are also available[20,21,22], but the performance of each technique is lacking under one or more respects to provide a complete picture. The situation is further complicated by the possibility of multiple disks (circumprimary, circumsecondary or properly circumbinary ones), which can be hard to disentangle without the necessary resolution, dynamic range or wavelength coverage.

The main difficulty in extracting useful constraints for the current theoretical models from the available observations is in the limited database available. Only for Tau-Aur, the nearest (140 pc) among the relatively rich SFRs and the best studied one, is there a sample with a significant statistical basis[15]. Already in the second best-studied case, the Sco-Oph SFR at 160 pc, the available numbers are smaller and they become practically insufficient, either in terms of resolution achieved and/or of star sample, for all other SFRs. Simon et al.[18] have discussed the statistical significance of the results of Figure 2 for the Tau-Aur and Sco-Oph SFRs, and the result is that wider samples are needed to draw firmer conclusions about the reality of the observed binary excess. In particular, also for Taurus where the result seems more certain, it is difficult at present to ascertain whether the excess extends over the whole period range or not. The frequency of the spectroscopic binaries, which fall in the leftmost part of the histogram of Figure 2 (not shown), seem consistent with that observed on the main sequence, but the statistics is too small to put a significant constraint.

The situation is complicated by the fact that in other SFR, notably the Orion association, current surveys provide a binary frequency which is fully consistent, in the measured separation/period range, with that on the main sequence[23]. Whether this is due to a difference in the star-formation mechanisms at work in different SFRs, and whether there is a correlation with the physical properties of the individual SFRs (for instance, the stellar density or the presence of winds from hot OB stars), is an intriguing question that needs more data and from more SFRs to be answered.

Can the VLTI help, and how? The answer is yes, and for the following reasons:

1. The VLTI will combine long baselines with large mirrors. The VLTI maximum baselines will provide an angular resolution close to 1 mas. This is equivalent to 0.14 AU at the distance of the Tau-Aur SFR, making a significant step towards bridging the gap between the resolution currently available from high angular resolution methods, and the range of the spectroscopic binaries. The ranges which can be covered by the VLTI in the VISA/VIMA configurations is reported schematically in Figure 2. At the same time, the sensitivity provided even by just the ATs (see Table 1) should be sufficient to cover the entire T Tau population in the Tau-Aur SFR.

2. The boost in angular resolution compared to what is currently available will permit to extend this kind of studies to other, more distant SFRs. An additional step of one decade in the separation/period range, means that histograms similar to those of Figure 2 can be produced for SFRs which are 10 times more distant than Tau-Aur, i.e. out to 1-2Kpc. In turn, this means an improvement in the statistical basis of $\approx 10^2$ (including the effect of the galactic disk thickness and disregarding density effects within it). The apparent decrease in brightness of the T Tau stars in more distant SFRs should be largely balanced by using the UTs in place of the ATs.
3. The possibility to cover a wide wavelength range, at least for the relatively nearby SFRs, from 1 to 10μm, as well as the possibility to investigate the sources with a choice of several spectral resolutions, will open the possibility to study in more detail and with a wider statistical significance the presence of infrared companions and circumstellar disks.
4. The availability of many baselines will permit a quick access to complete solutions for binary pairs, and to investigations of complex structures such as disks. In particular, the possibility to combine the light from three telescopes at a time included for instance in the AMBER instrument[5] will speed up the time required to complete surveys of binary stars, doing away with the need to relocate telescopes to obtain independent baseline projections.
5. The increased angular resolution will permit to measure actual orbital motions, at least in the most favorable cases. At the distance of the Tau-Aur SFR, an orbital period of one year corresponds to an orbit diameter of about 0.014", and significant changes of the companion's position should be detectable in a matter of few days. Alternatively, it will be possible to detect orbital motions for much wider systems on time scales of months. The key to this is the high accuracy permitted by instruments such as VINCI and AMBER, which are based on a design that has already achieved relative precisions at $\leq 10^{-3}$ in the visibilities (P. Kervella, priv. comm.). With reference to the examples given in Figure 1, this will permit to extend the actual resolution well beyond the theoretical diffraction limit of the baseline. This issue is discussed more at length in Sect. 3.2.We note that the determination of visual orbital solutions is the key to refine the assumptions in the period/separation hypothesis, and to derive masses in those cases for which a parallax determination is also available, as is the case for most SFRs.
6. At least for the nearest SFRs, T Tau stars will always be sufficiently bright to permit fringe tracking and to serve as natural guide stars for the AO systems. At the same time, SFR provide a wealth of calibrator sources either within the region itself, or in the immediate vicinity thanks to the presence of galactic disk stars.

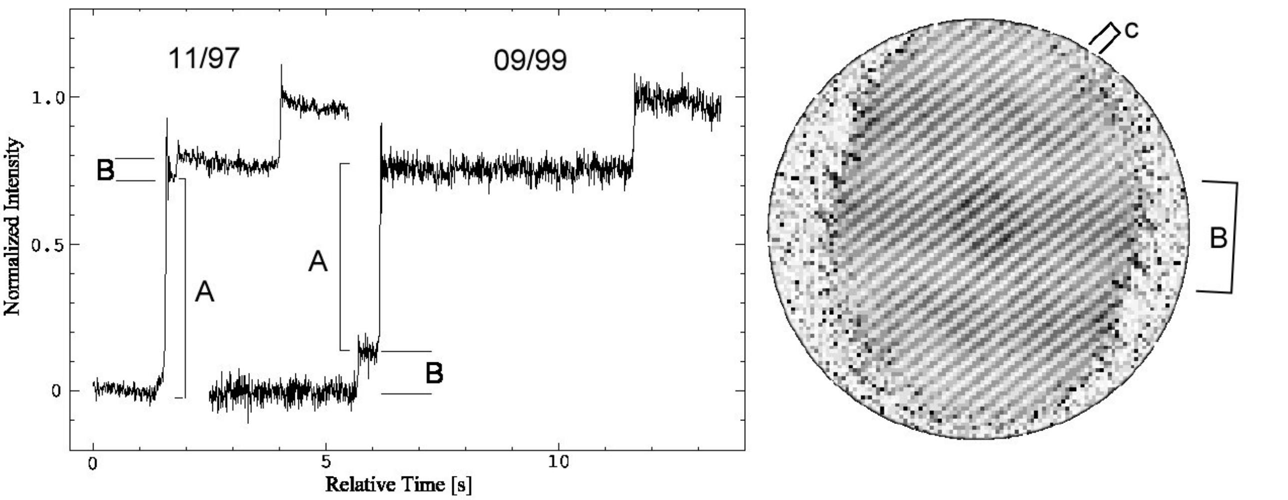


**Figure 3. Observations of Haro 6-37. Left: LO discovery of the B companion and its brightness variation. Right: the visibility of the system as measured by speckle interferometry (partly adapted from Richichi et al.[24])**

Finally it should be stressed that the VLTI will be located in a favorable position to investigate all southern SFRs, for which observations by high angular resolution methods have been comparatively lacking so far. A key to the success of a VLTI program for observations of young binaries will be the fact that such observations are relatively easy, fast and with a well-defined data analysis procedure (see points 4 and 6 above). This should permit, in addition to establishing the constraints on the frequency and characteristics of the binary systems which are needed to improve the theoretical models of star formation processes, to follow also phenomena such as time variability. For example, it is known that the brightness of the components in a young binary system can change significantly, on time scales of one year or less. Such changes can be similar in the two components, or be independent of each other. An example is given in Figure 3. Explanations include the effects of surrounding remnant dust or of differential accretion, but detailed investigations are needed in each case. The ability to carry out frequent monitoring with the VLTI, especially in its VISA configuration, is a key to understanding the physics of such phenomena.

### 3.2. Binaries among low mass stars

There is general agreement that the minimum stellar mass necessary for stable hydrogen burning is ≈0.08 $M_{\odot}$, while the minimum mass required for a molecular cloud core to collapse has been estimated at ≈0.01 $M_{\odot}$[25]. The existence of substellar objects, or brown dwarfs (BD), is thus expected. Besides being interesting new objects of their own, they would play an important role for the knowledge of the initial mass function and of the missing mass in the galactic halo. However, so far they have eluded definitive detection. One of the main problems is the fact that mass estimates are possible, in the case of isolated BDs, only by means of model predictions on the basis of their luminosity[26]. This approach suffers from uncertainties in the distance, and of course in the assumed models. The direct determination of the stellar mass of a BD candidate is only possible if this latter is a member of a binary system, for which both the visual orbit and the parallax are known (we do not linger on the rare possibility of BD which are members of eclipsing binaries).

Brown dwarfs have been searched for as companions to white dwarfs (where they would show well because of their very different red color), as companions to red dwarfs (where the primary already has low mass and luminosity to begin with), in young clusters (where they would still be comparatively luminous), and in astrometric and radial velocity surveys of nearby stars (where the observed effect is not reduced by their low luminosity). Among the identified candidates, the white dwarf companion GD 165 B presents the strongest case; this companion was interpreted as an object in the transition region from stellar to substellar masses and its mass was estimated to be ≈0.075 $M_{\odot}$[27]. The M dwarf with the lowest measured mass is GJ 1245 C with 0.074±0.013 $M_{\odot}$[26].

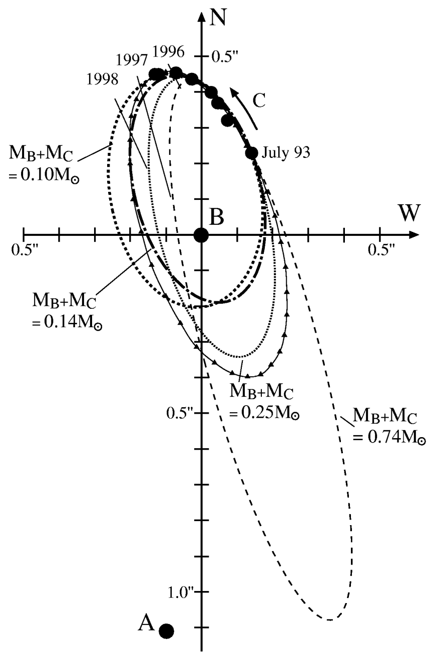


**Figure 4. Orbital motion of the pair LHS 1070 B/C. Adapted from Leinert et al.[33]**

In addition to the exciting topic of direct mass determinations of BD candidates, binary searches among M dwarfs aim also at a better definition of the luminosity function and the initial mass function for the low end of the main sequence, which still is very much needed[28], and at a comparison of duplicity with stellar groups of different mass and age, a topic which recently gained high interest because of advances in observation and because of its close connection to the questions of star formation which we have examined in Sect 3.1 above.

As an example of low mass stars in a multiple system, we take the case of LHS 1070. For a long time, this has been the only such system for which orbital determinations were possible. The statistics has recently increased with the addition of the system GL 569B[29]. The LHS 1070 system has been studied in detail by Leinert et al.[30,31], who have resolved three very red, low mass components, obtained their photometry and spectroscopy, and followed their relative orbital motion for a period of a few years by means of ground and space observations. A preliminary orbit for the system is shown in Figure 4, while the basic data are summarized in Table 2. The existence of a fourth component has been discovered by means of observations with the HST Fine Guidance sensors[32], with the companion being very close to the main component and not resolved by single-mirror, ground based observations. The distance estimates for LHS 1070 vary between 7.4 and 8.8 pc, and the age of the system is estimated at ≈5 Gyr.

A system like LHS 1070 offers the possibility to investigate many topics of interest to low mass star research: from models of atmospheres of such cool stars, to their chemical abundances, to their ages and their evolution. Although the masses of the components appear to be just at or slightly above the brown dwarf limit, we can still take it as a good example of the kind of targets that will be presented to an interferometer aimed at direct determinations of the masses of BD candidates. The orbits of the B and C components have been studied by means of near-IR speckle interferometry by Leinert and collaborators. The preliminary result is shown in Figure 4, where it can be seen that the system has been discovered with the secondary components close to periastron. This fortunate situation has resulted in an orbital motion of ≈45° in just three years, with separations that are within the feasibility limits for a large telescope in the near-IR[1]. However, the orbits are very inclined and the total period is of a few tens of years. In general, a system like LHS 1070 would require monitoring over many years with speckle interferometry, to achieve a reliable orbit determination. At the same time, currently available near-IR interferometers do not have the necessary sensitivity to detect this system.

**Table 2. Basic parameters for the LHS 1070 system[30,31,33].**

| LHS 1070 | V | R | I | J | K | Spectrum | $T_{eff}$(K) | Mass($M_\odot$) |
|---|---|---|---|---|---|---|---|---|
| A | 15.35 | 13.63 | 11.66 | 9.00 | 8.65 | M6.3 | 2950 | 0.098-0.109 |
| B | 18.68 | 16.30 | 14.01 | 10.95 | 9.85 | M9.4 | 2400 | 0.080-0.083 |
| C | 19.07 | 16.65 | 14.43 | 11.41 | 10.20 | M9.6 | 2300 | 0.079-0.080 |

Can the VLTI help, and how? Also in this case, the answer is a yes, and the points made in Sect. 3.1 apply also here. In particular, the VLTI, by combining long baselines and large mirrors, can easily detect a system like LHS 1070, and also fringe-track on it. We also note that, at $\delta=-27°$, LHS 1070 is a difficult target for Keck, while it is ideally situated for the VLTI. A possible problem is the fact that the angular extent of the system is rather large. Although it would fit into the 2" nominal field of view of the interferometer, some instrumental modes foresee to use only the Airy disk of the single telescopes, and in this case it would be difficult to fit the three components into the AT Airy disks, let alone that of the UTs. An additional possibility would be given by the availability of the PRIMA astrometric instrument[34], with its dual feed capability, although the minimum separation between the two beams is still subject to definition.

However, the interest of the VLTI is that it will make it possible to determine orbits, and hence masses, for low mass stars in binary or multiple systems farther away than LHS 1070. A comparison of Table 1 and Table 2 shows that an instrument like AMBER would be able to fringe-track on the main component of a system like LHS 1070, if it were ≈3.5 mag fainter. In other words, the VLTI could detect and study systems like this one, out to ≈50 pc.

Of course, the apparent separations would be up to 5 times smaller, but still comfortably within the angular resolution provided by the VLTI. What is more interesting, is that the VLTI would permit to speed up considerably the times needed for an orbit determination, i.e. to derive the masses of the components. This comes from the fact that, provided sufficient SNR and visibility accuracy are secured, the interferometer will be able to detect changes in the separation of a binary star which are potentially much smaller than its diffraction limit.

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[1] Fits that include additional, more recent data start converging towards a semimajor axis of about 0.45" and a period of about 16 years (work in preparation).

In Figure 5 we show the visibility curves for various sets of binary simulations. The differences in the two curves of each panel are small (note the expanded vertical axis), but detectable under conditions of good SNR, and especially of good and stable visibility calibration. Although at present we cannot quantify in detail the behaviour of the visibility accuracy as a function of source luminosity, we note that for bright sources the fiber-based recombination scheme to be employed in VINCI and AMBER has already been operating for some time at the IOTA/FLUOR interferometer[9,10], where it has achieved visibility accuracies below the $10^{-3}$ level. By comparison, the differences at the maximum baseline separation between the visibility curves of Figure 5 are 0.038, 0.008, 0.07, 0.012 in panels from *a)* to *d)* respectively. This result shows that determinations of orbital motions will be possible with the VLTI even at levels of 0.1 or 0.01 milliseconds of arc.

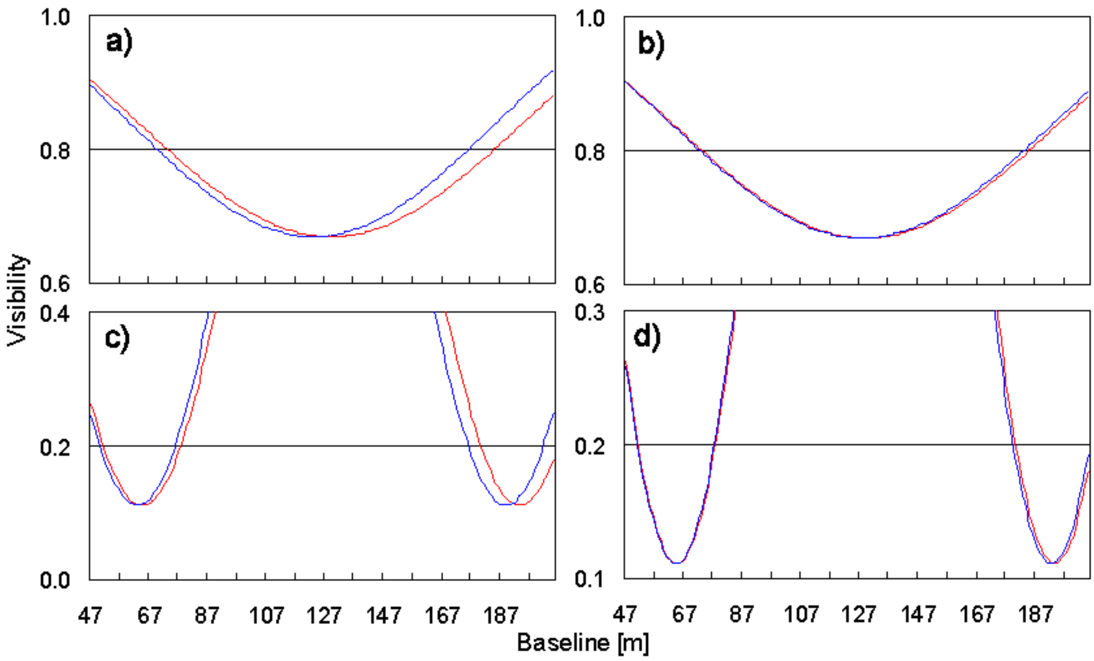


**Figure 5. Examples of simulated binary detections, that illustrate the possibility of detecting orbital motion at levels beyond the theoretical diffraction limit of the VLTI, under conditions of good visibility accuracy. In each panel, the two curves represent the visibilities for a binary with slightly different angular separations: *a)* ρ=1.00, 1.05; *b)* ρ=1.00, 1.01; *c)* ρ=2.00, 2.05; *d)* ρ=2.00, 2.01 (in milliarcseconds). In all cases, the angular diameters are $\varphi_1$,$\varphi_2$ =0, and the observing wavelength is 1.25µm (monochromatic). The top panels are for a brightness ratio *R*=0.10, and the bottom ones for *R*=0.50. The range of baselines between the minimum VIMA and the maximum VISA configurations are shown.**

Such precision is sufficient to obtain observations of the quality shown in Figure 4, in a matter of few weeks or few months, depending on the distance of the object and the actual eccentricity of the orbit. While it would still be necessary to wait for the total orbit completion in order to derive the most accurate determination possible, this feature would permit to assess in a preliminary way the masses already in a relatively short time, and to select those candidates which fall in the brown dwarf limit.

## 4. CONCLUSIONS

We have examined the general properties of the VLTI as a tool to study binary stars, and concentrated on two case studies, namely investigations of binaries in star forming regions, and of low mass stars in binary systems. The prospects opened up by the VLTI in these fields are very encouraging.

For what concerns binaries in SFRs, the VLTI should make it possible to assess the frequency of binary systems in a complete way for the nearest regions, largely covering the gap which exists at present between high angular resolution and spectroscopic detections. For more distant regions, up to about 1.5 kpc, the VLTI should still be able to produce satisfactory surveys that will constrain in a significant way the frequency of binaries. The available statistical basis should be boosted by a factor $\approx 10^2$ with respect with present, allowing us to understand in a more complete way the nature of the star formation mechanisms at play, their relationship to the conditions in the parent cloud, and other characteristics such as the presence of circumstellar and/or protoplanetary disks.

For what concerns studies of low mass stars in binary systems, the VLTI should be able not only to obtain more accurate results on the very few, relatively nearby ones known today, but also to extend the possibility of direct orbit determinations to systems which are further away. This will boost the available statistical basis, with fundamental advantages for our theoretical understanding of this class of objects.

## REFERENCES


1. A. Glindemann et al. 1999, *The ESO Messenger*, 98, 2.
2. A. Glindemann et al. 2000, SPIE Proc. 4006-01
3. P. Kervella et al. 2000, SPIE Proc. 4006-04
4. C. Leinert et al. 2000, SPIE Proc. 4006-05
5. R.G. Petrov et al. 2000, SPIE Proc. 4006-07
6. B. Lopez et al. 2000, SPIE Proc. 4006-06
7. A. Richichi et al. 2000, SPIE Proc. 4006-08
8. J. Davis, ESO Workhsop on "*Science with the VLT Interferometer*", F. Paresce (ed.), Springer, 1997, p. 143
9. Coude Du Foresto V. et al. 1998, SPIE 3350, p. 856
10. Traub W.A. 1998, SPIE 3350, p. 848
11. R.D. Mathieu, Annual Review of Astronomy and Astrophysics, 1994, 32, 465.
12. Moneti A., Zinnecker H. 1991, A&A, 242, 428
13. Simon M., Howell R.R., Longmore A.J., Wilking B.A., Peterson D.M., Chen W.P. 1987, ApJ, 320, 344
14. Ghez A., Neugebauer G., Matthews K. 1993, AJ, 106, 2005
15. Leinert Ch. et al. 1993, A&A, 278, 129
16. Richichi A., Leinert Ch., Jameson, R., Zinnecker H. 1994, A&A 287, 145
17. Duquennoy, Mayor 1991, A&A, 248, 455
18. Simon, M. et al. 1995, ApJ, 443, 625
19. Beckwith S.V.W., Sargent A.I., Chini R.S., Guesten R. 1990, 1990 AJ 99, 924
20. Leinert Ch., Haas M., Richichi A., Zinnecker H., Mundt R. 1991, A&A, 250, 407
21. Haas M., Leinert Ch., Richichi A. 1997 A&A, 326, 1076
22. Roddier C., Roddier F., Northcott M.J., Graves J.E., Jim K. 1996 ApJ 463, 326
23. Prosser et al. 1994, ApJ 421, 517
24. Richichi A., Köhler R., Woitas J., Leinert Ch. 1999, A&A 346, 501
25. Silk J. 1977, Apj 214, 152
26. Henry T.J., McCarthy Jr. D.W. 1993, AJ 106, 773
27. Zuckerman B., Becklin E.E. 1992, ApJ 386, 260
28. Bessel M.S., Stringfellow G.S. 1993, ARA&A, 31 433
29. Martín E. L., Koresko C. D., Kulkarni S. R., Lane B. F., Wizinowich P. L 2000, Apj 529, L37
30. Leinert Ch., Weitzel N., Richichi A., Eckart A., Tacconi-Garman L.E. 1994, A&A 291, L47
31. Leinert Ch., Allard F., Richichi A. , Hausschildt P.H. 2000, A&A 353, 691
32. Henry T.J., Franz O.J., Wassermann L.H.n et al. 1999, ApJ 512, 864
33. Leinert Ch., et al. ASP Conf. Series 134, Rebolo, Martin, Zapatero Osorio (eds), p. 203
34. Delplancke F., Leveque S.A., Glindemann A., SPIE Conference 4006-41, 2000