Young Stars Near Earth: Progress and Prospects
ASP Conference Series, Vol. ???, 2001
Ray Jayawardhana and Thomas Greene, eds.

The ESO Very Large Telescope Interferometer as a machine to study young stars

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Abstract. From basic considerations, it appears that interferometry will be a necessary tool to study star formation and young stars in the near future. The ESO Very Large Telescope Interferometer is one of the largest interferometric facilities to be used for such studies. We describe briefly the current status of the project, and the additional developments that will take place in the next few years in the course of a progressive implementation plan. Upon final completion, the VLTI will have the ability to perform measurements on sources as faint as K≈20 mag with accuracies as good as 10-50μarcsec. We illustrate some of the observations planned with respect to the field of young stars.

1. Introduction

High angular resolution is one of the key factors needed to advance our knowledge of the formation of stars, and of their evolution. In conventional imaging, angular resolution is usually limited by seeing to about 0.5 arcsec at the best sites; in the case of telescopes equipped with adaptive optics or in space, diffraction sets a limit of about 0.2 arcsec λ/D, where λ is the wavelength expressed in μm and D the diameter expressed in meters. This should be compared to the typical values of a few characteristic physical quantities that must be investigated in this field.

For example, we know that a large number of stars are formed as members of binary or multiple systems, with a median separation $\lesssim$ 50 AU. Masses of young stars are one of the fundamental quantities which are still largely assumed rather than determined. Their direct measurement requires to determine orbital motions in binary systems. For this, the best candidates are those with short periods, i.e. one would like to study those systems with separations much shorter than the value just mentioned.

Another important physical quantity that cannot yet be measured directly is the effective temperature of young stars, which is a key to study their location in the HR diagram and hence their age and their evolution. For this, measurements of their angular diameter are needed. Even considering that in young stars, which are dominated by convection, stellar radii are a few times larger than on the main sequence, this implies linear diameters $\ll$ 0.1 AU. Additionally, the surfaces of young stars are thought to be covered by (very) large spots. One would like to investigate also the inner regions of the circumstellar disks and envelopes which are often the residual of the star forming process, and which extend to a few stellar radii. Similarly, the undestanding of the origin, kinematics and stability of stellar jets require a similar level of detail.

Until recently, the nearest known star forming regions were Taurus/Auriga and Ophiuchus/Scorpius, both at about 150 pc. At this distance, the above mentioned linear sizes imply the need for angular resolution at the level of 0.1-1 milliarcsecond (mas), which constitutes a formidable observational challenge. The recent discoveries of several considerably closer star forming regions has relatively improved the situation, and it is clear that regions such as that of TW Hya offer now realistic prospects of measuring directly important parameters such as masses and temperatures of young stars.

2. The role of interferometry

From the arguments exposed above, it follows that many important measurements needed to understand the physical characteristics of young stars, can only be obtained with angular resolutions significantly better than the performance allowed by a single telescope.

With the possible exception of lunar occultations, which deliver a very good angular resolution but are limited in application by several constraints, it is then natural to resort to the interferometric combination of two or more telescopes to increase the level of angular detail.

However, interferometry differs considerably from conventional imaging. It is worthy to stress that what interferometry measures is the coherence factor of a source as a function of the baseline between the telescopes. This is often expressed in terms of the so-called visibility. Being related to the Fourier transform of the source image, which is a real 2-D function, this is in general a complex hermitian 2-D function. Ideally, if one could measure the complex visibility for all possible baseline separations from b to B, an image could be recovered with angular scale and angular resolution equal to λ/b and λ/B, respectively.

Due to the physics of the detection process in the visible and near-IR range, interferometers operating in this range in practice measure only the modulus of the source visibility, a real (positive) quantity which is often normalized by measuring the visibility of a known reference source with the same instrumental setup. Only in the special case in which 3 or more telescopes can be combined, visible and near-IR interferometers can measure the so-called closure phase which opens up the possibility to add some phase information. We will not enter this aspect in detail, although several modern interferometers are designed with this mode of operation in mind (Colavita & Wizinowich 2000; Glindemann et al. 2000; McAlister et al. 2000; ten Brummelaar et al. 2000; Young et al. 2000).

Furthermore, interferometers have a limited number of baselines and can measure only a few points in the so-called u,v plane. As a result, interferometers operating at visible and near-IR wavelengths have only a very limited imaging capability. Instead of images, one should think in terms of visibility functions.

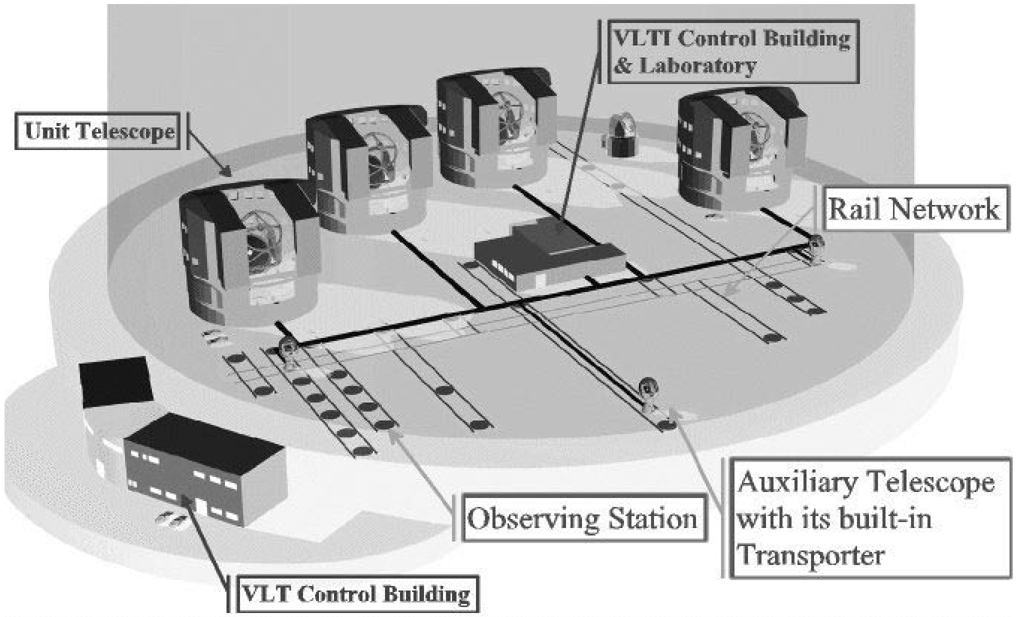

Figure 1. Scheme of the Very Large Telescope Interferometer

3. VLTI: concept, status and development

The ESO Very Large Telescope Interferometer (VLTI) is located on Cerro Paranal, in northern Chile. This facility consists of the four (fixed) 8.2 m Unit Telescopes (UT), and of a number of 1.8 m Auxiliary Telescopes (AT) which can be moved over an array of 30 stations.

All these stations, as well as the UTs, are connected by a network of underground light ducts. Central to the facility is the delay line tunnel, where optical path differences are continually adjusted to correct for both long range effects (such as those due to sidereal motion) and fast, short range variations such as those due to differential atmospheric piston. Finally, in a central laboratory the beams from two or more chosen telescopes are brought together and combined interferometrically (see Fig. 1). More details can be found in Glindemann et al. (2000).

Several instruments have been designed for the VLTI, and partly completed. These include VINCI (Kervella et al. 2000), AMBER (Petrov et al. 2000), and MIDI (Leinert et al. 2000). First fringes have been achieved in March 2001 (see ESO PR 06/01, 2001). The VLTI is following an implementation plan that is characterized by the progressive introduction of several subsystems, including a fringe-tracker (FINITO), an adaptive optics system (MACAO) and a dual feed facility (PRIMA). Details and schedules are provided by Richichi et al. (2001). At the end of this implementation plan, it is expected to reach K≈20.

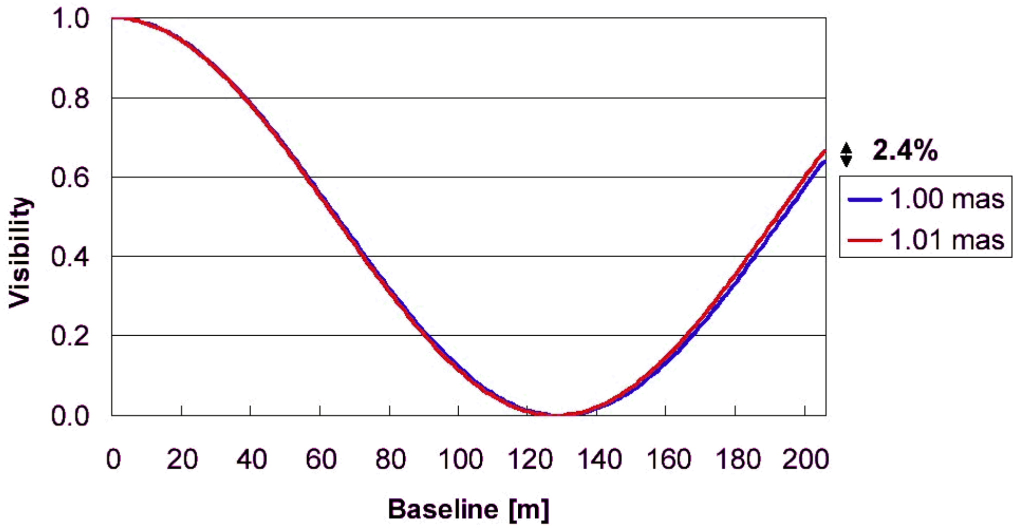

Figure 2. Detection of orbital motion by accurate visibility measurements

4. Applications

It is impossible to provide a full description of the potential of the completed VLTI for research in the area of young stars in this limited space. In the following, we present two examples of how the VLTI can be used to obtain high angular measurements.

It is often assumed that the limiting angular resolution of an interferometer with maximum baseline B is λ/B. This is due to the fact that no spatial frequencies above this limit are transmitted. However, even with this frequency cut-off, details smaller than λ/B can be measured provided that sufficient accuracy is achieved on the visibility measurements.

In Fig. 2 we show an example of the visibility of a binary system, where the separation between the components is varied by amounts much smaller than λ/B. With an accuracy goal of 10^{-3}-10^{-4}, such variations could be easily measured by the VLTI. An application would be to measure orbital motions in binary systems, on time scales much shorter than what is currently needed by diffraction-limited observations on large telescopes. This is the key to derive accurate masses.

A second way to obtain the same results, would be to use accurate (narrow-angle) astrometry of one of the components in the binary system, with respect to a nearby bright reference star. This is illustrated in Fig. 3. In the case of the VLTI, this mode of operation will be made possible by the PRIMA dual-feed facility (Delplancke et al. 2000). Accuracies of 10 μas will be possible, under favorable conditions, for distances $\lesssim$30 arcsec. Taking as an example a (young) binary with 10 AU separation at 50 pc (equivalent to 0.2 arcsec), this would permit to detect and measure orbital motion in the space of one night. The method has a clear potential to detect systems with (very) low mass components.

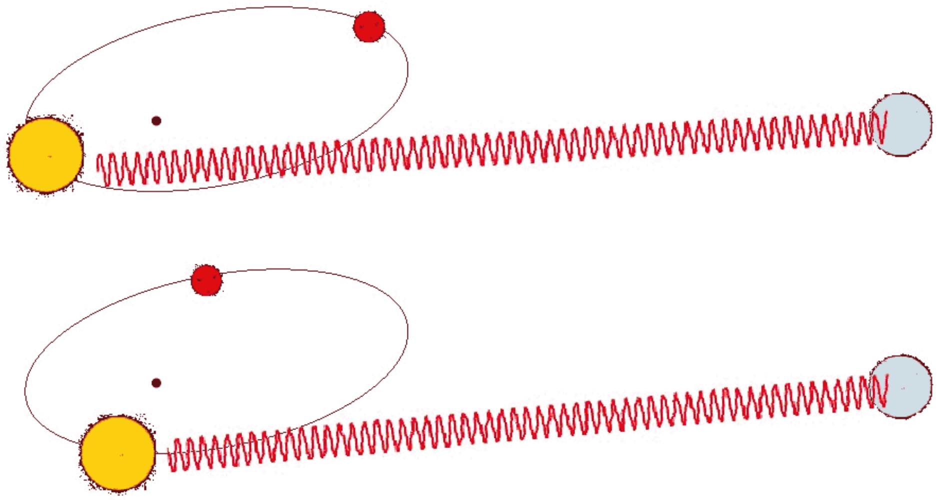

Figure 3. Detection of orbital motions by phase referencing.

References

Colavita, M.M., & Wizinowich, P.L., 2000 in SPIE Proc. Vol. 4006, Interferometry in Optical Astronomy, ed. P. Lèna & A. Quirrenbach, p. 310

Delplancke, F., et al. 2000 in SPIE Proc. Vol. 4006, Interferometry in Optical Astronomy, ed. P. Lèna & A. Quirrenbach, p. 465

ESO PR 06/01 2001, http://www.eso.org/outreach/press-rel/pr-2001/pr-06-01.html

Glindemann, A., et al., 2000 in SPIE Proc. Vol. 4006, Interferometry in Optical Astronomy, ed. P. Lèna & A. Quirrenbach, p. 2

Kervella, P., et al. 2000 in SPIE Proc. Vol. 4006, Interferometry in Optical Astronomy, ed. P. Lèna & A. Quirrenbach, p. 31

Leinert, C., et al. 2000 in SPIE Proc. Vol. 4006, Interferometry in Optical Astronomy, ed. P. Lèna & A. Quirrenbach, p. 43

McAlister, H.A., et al., 2000 in SPIE Proc. Vol. 4006, Interferometry in Optical Astronomy, ed. P. Lèna & A. Quirrenbach, p. 465

Petrov, R., et al. 2000 in SPIE Proc. Vol. 4006, Interferometry in Optical Astronomy, ed. P. Lèna & A. Quirrenbach, p. 68

Richichi, A., et al. 2001, in The Origins of Stars and Planets: the VLTI View, ed. J. Alves & M. McCaughrean, in preparation.

ten Brummelaar, T.A., et al., 2000 in SPIE Proc. Vol. 4006, Interferometry in Optical Astronomy, ed. P. Lèna & A. Quirrenbach, p. 564

Young, J.S., et al., 2000 in SPIE Proc. Vol. 4006, Interferometry in Optical Astronomy, ed. P. Lèna & A. Quirrenbach, p. 472