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Optical Interferometry at the VLTI: Italy's contribution and the latest advancements in understanding the circumstellar environment of young stars

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Abstract. The Very Large Telescope Interferometer (VLTI) at Cerro Paranal is currently the larger facility for optical interferometry open to astronomers. In this paper I will briefly review the Italian contribution to VLTI and the most important results obtained by Italian astronomers in the field of young stars through VLTI observations.

Key words. Techniques: interferometric – Instrumentation: interferometers – Infrared: stars – Stars: circumstellar matter – Stars: pre-main sequence

1. Introduction

The development of optical/Near-Infrared interferometry (hereafter just optical interferometry) at ESO is deeply linked to the concept of Very Large Telescope (VLT) itself. The sequence of events leading to the VLT Interferometer can be followed throughout the various reports published in the ESO Messenger from the late 70s on.

In December 1977, the "ESO Conference on Optical Telescopes of the Future" took place in Geneva and first planted the seeds of a 16-m Very Large Telescope. The concept was further discussed in 1983 at a workshop in Cargese and, in November 1983 an ESOs Scientific and Technological meeting recommended an array of 8-10 m elements. This would have allowed optical interferometry to be carried out, as well. The Final Report n. 49 of the VLT Interferometry Working Group (June 1986) recommended that optical interferometry should be implemented at VLT. In the end, the ESO Council gave the green light to VLT on December 1987.

In 1990, the ESO VLT Interferometry Panel recommended: to adopt a trapezium configuration for the telescope array, to perform beam combination in air and to built a sub-array of 2 smaller movable telescopes. But in 1993, financial problems forced ESO to postpone the implementation of VLTI and the sub-array of movable telescopes. The development of interferometry was resumed in 1996 with an agreement between MPG (German), CNRS (France) and ESO.

Currently, VLTI[1] consists of the four 8.2-m telescopes (called UTs; first lights in 1998–

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[1] `http://www.eso.org/sci/facilities/paranal/telescopes/vlti/`

2000) and a subarray of four 1.8-m movable telescopes (called ATs; first lights 2004–2006). The four ATs are only used for interferometry. The first interferometric fringes with the UTs were obtained on Achenar in the *K* band on October 30, 2001, using 2 UTs.

2. AMBER and Italy's contribution to VLTI instrumentation

Italian institutes directly took part in two forefront technological programmes: the development of the fringe tracker FINITO (a collaboration between Osservatorio Astronomico di Torino and ESO; Gai et al. 2003), and the AMBER project for a focal-plane beam combiner operating in the Near-Infrared (Petrov et al. 2007). In this paper, I will only discuss the Italian role in the AMBER projects, where I was directly involved.

First ideas for developing a beam combiner for VLTI came up in France in 1996. On January 26, 2001, ESO and five European institutes (including Osservatorio Astrofisico di Arcetri) signed an agreement for designing and building the beam combiner, which was called AMBER[2]. In particular, AMBER is equipped with a spectrometer which was designed and built in Arcetri. AMBER was shipped to Paranal in 2004 and has been open to observations since the second half of 2005.

3. Scientific programmes based on VLTI observations

The development of AMBER entitled the institutes of the AMBER consortium ~ 1200 hrs of guaranteed time on VLTI (with the ATs), of which Arcetri had ~ 200 hrs. On the other hand, INAF (the Italian National Institute for Astrophysics) gained guaranteed time on VLTI due to Italy funding of the ATs. From P80 to P90, ~ 93 hrs of this GTO were used by Italian astronomers (mostly with AMBER). Guaranteed time was also obtained by Osservatorio Astronomico di Torino as a reward for the development of FINITO. In P90, 24 hrs of the latter GTO were used by Italian astronomers. Most of this time has been spent on studies of circumstellar disks around young stars and stellar evolution.

The scientific impact of VLTI on optical interferometry can be fully appreciated by comparing the number of publications per year based on VLTI observations, and the number of publications per year based on observations with any optical interferometer. This is shown in Fig. 1 using data from OLBIN[3]. After a slow rise in the number of publications discussing results of optical interferometric observations from 1980 to 2003, these have increased significantly and nearly half of the most recent papers are based (or also based) on VLTI data. On average, 40–50 refereed papers per year have discussed optical interferometric observations since 2006. Out of these, about 10 papers per year have also been based on AMBER data.

In the context of the present paper, it is useful to evaluate how Italian astronomers have used VLTI data. Figure 2 shows the number of refereed papers per year with an astronomer affiliated to INAF (Istituto Nazionale di Astrofisica) as the first author, and the number of refereed papers per year with at least one co-author affiliated to INAF. Nearly a quarter of the papers based on VLTI data have had Italian co-authors in the last few years. Also shown in the figure is the number of papers discussing VLTI data obtained either with MIDI (the Mid-Infrared beam-combiner of VLTI, Leinert et al. 2003) or AMBER. Clearly, AMBER is currently the most commonly used beam-combiner at VLTI.

4. Arcetri's programme on young stars

The Arcetri share of AMBER GTO was mainly devoted to an observational study of circumstellar disks around young stars. Circumstellar disks are the leftovers of the parental gaseous cores originating the star. The intense radiation field from the latter sublimates the dust inside a distance called *sublimation radius* (~ 1 AU). This produces a hot inner dust rim which manifests itself as an emission excess at NIR

[2] http://amber.obs.ujf-grenoble.fr

[3] http://olbin.jpl.nasa.gov

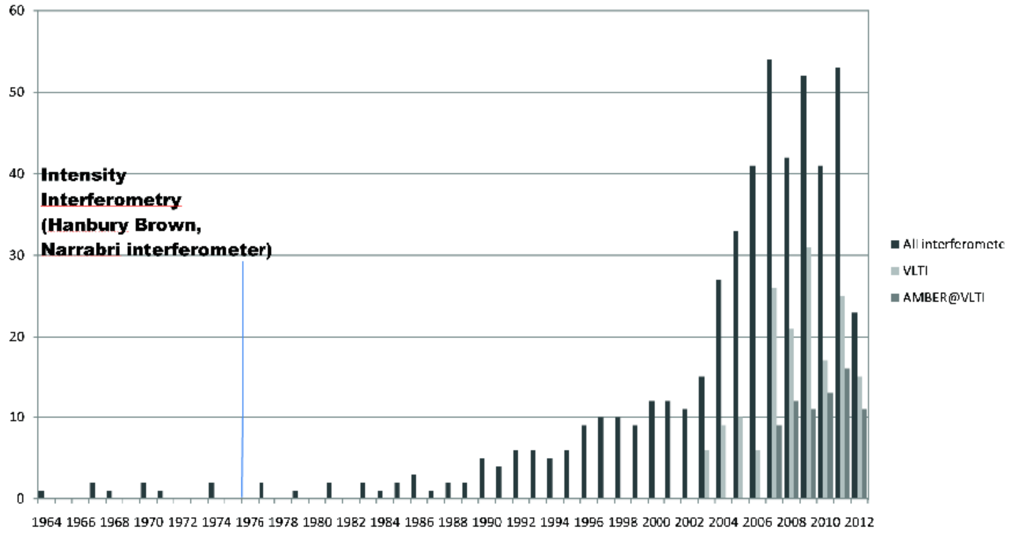

Fig. 1. Number of refereed papers per year discussing results of optical interferometric observations. The number of papers also based on VLTI data, and on AMBER data in particular, are shown as well.

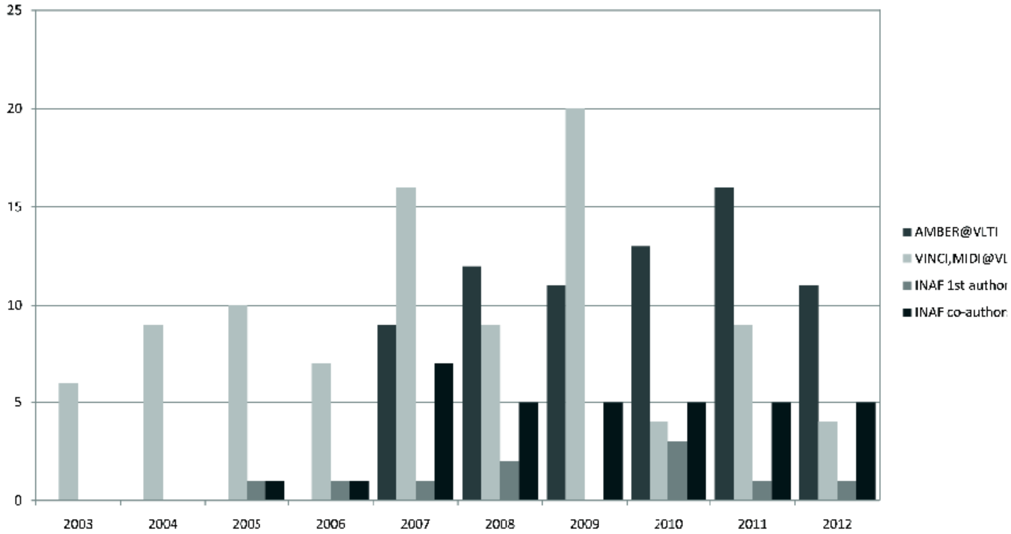

Fig. 2. Number of refereed papers per year discussing results of VLTI observations obtained either with MIDI or with AMBER. The number of papers per year produced by authors including INAF astronomers are also shown.

wavelength in low spatial resolution photometry (Isella & Natta 2005). An optical interferometer is therefore well suited to resolve this inner disk. The VLTI sensitivity forced us to select nearby Herbig Ae/Be (HAeBe) stars as targets, rather than T Tauri stars. These are pre-main sequence stars of intermediate mass ($\sim 2-10 M_{\odot}$), hence the analogues of T Tauri at larger stellar masses. HAeBe stars are brighter and have inner dust rims larger than T-Tauri

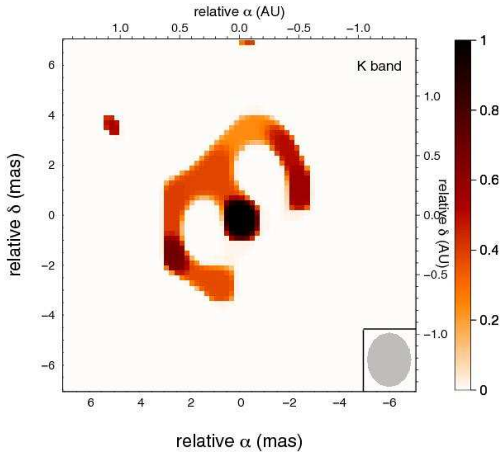

Fig. 3. Reconstructed VLTI image of HR5999 in the *K* band. The bottom right box shows the synthesised beam.

stars (Millan-Gabet et al. 2007), so the nearest ones are more easily observable with an optical interferometer.

Hereby I can only give a brief outline of the results obtained in the framework of Arcetri's programme, and the relevant publications. One has also to consider that other institutes of the AMBER consortium are interested in young stars and full collaboration between them and Arcetri is the rule, leading to an even wider scientific production.

In particular, Arcetri's programme yielded three seminal works in the field of circumstellar environment of young stars. Benisty et al. (2010a) focus on a more compact NIR emission inside the inner disk of the HA star HD163296 ($\sim 2M_\odot$, 4 Myr old, $d \sim 120$ pc). Similar compact emission regions had already been found towards other HAeBe stars (e. g., Kraus et al. 2008), but these authors convincingly show that this cannot arise from a gaseous disk and propose that refractory dust grains can survive inside the sublimation radius. Benisty et al. (2010b) exploited an outburst of the HBe member of the young double system Z CMa (at ~ 1 kpc) to study its nature. They found the outburst to be associated with compact Brγ emission caused by a strong episode of mass outflow. According to a widely-accepted paradigm, Brγ emission from HAeBe stars is produced by accretion, but these observations clearly show that the Brγ emission related to the Z CMa outburst is produced in a wind.

Finally, Benisty et al. (2011) were able to reconstruct an image of the HAe star HR5999 ($3-4M_\odot$, ~ 1 Myr, $d \sim 200$ pc), obtaining the first clear view of the inner rim of a circumstellar disk (see Fig. 3).

5. Conclusions

Optical interferometry appears now as a mature astronomical technique, although still limited to relatively bright sources. Imaging is now possible with modern arrays and VLTI can be considered as the major facility available to astronomers. To assess the Italian contribution to the optical interferometry with VLTI, one has to keep in mind that this is a field of little tradition in the Italian astronomical scenario. Nevertheless, the technological contribution from Italian institutes appears valuable. On the other hand, Italian astronomers have taken part in some milestone observations with VLTI, leading to a few seminal papers in the field of circumstellar disks around young stars. A significant fraction of papers based on VLTI data is co-authored by INAF astronomers, as well.

Acknowledgements. This paper is dedicated to the memory of Sandro Gennari who took active part in the development of AMBER and, in particular, put a lot of effort in setting up the spectrometer.

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