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OPTICAL INTERFEROMETRY OBSERVATIONS OF VARIABLE SOURCES

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RESUMEN

Con las capacidades actuales de los instrumentos de la interferometría óptica, abordar la variabilidad de las fuentes es un desafío. Una de las características de los vientos de estrellas calientes y del ambiente circundante es su variabilidad intrínseca, revelada notablemente por intensivas campañas de monitoreo espectroscópico. La binaridad es también una fuente importante de variabilidad, que tiene que ser considerada puesto que se ha descubierto que muchas fuentes con material circunestelar residen en tales sistemas. Por último pero no menos importante, los acontecimientos explosivos no son raros, y requieren una estrategia específica de observación. Las diferentes escalas de las variaciones para los distintos tipos espectrales serán revisadas, y la adaptación de las observaciones interferométricas discutida. Finalmente, se discutriá el advenimiento de las interesantes capacidades de realización de imágenes en un futuro cercano.

ABSTRACT

With the current capabilities of optical interferometry array, tackling the variability of the sources is a challenge. A characteristic of hot stars winds and close environment is their intrinsic variability, revealed remarkably by intensive spectroscopic monitoring campaigns. Binarity is also an important source of variability that has to be managed since many sources with circumstellar material are discovered to reside in such systems. Last but not least, explosive events are not rare, and require to be monitored a dedicated strategy of observation. The different scales of variations for various spectral types will be reviewed, and the adaptation of the interferometric observations discussed. Finally, the advent of interesting imaging capabilities in a near-future will be discussed.

Key Words: circumstellar matter — stars: mass loss — techniques: interferometric;

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1. VARIABILITY AND OPTICAL INTERFEROMETRY

Many hot stars exhibit variability in various time scales, from minutes to months and years. In order to ensure the consistency of a time monitoring of variable sources, it is necessary to use the same set of filters or similar dispersion laws when spectrophotometers or spectrographs are used. Similarly, different images from various telescopes can better be compared when the telescopes diameters and the filters are as similar as possible. Currently, optical interferometry observations are limited to a few baselines, and the interpretation of the variability of the interferometric observables, such as visibilities and phases, must rely on a careful analysis of the conditions of observation (time of observation, number of baselines, projected lengths, orientation, spectral bands, spectral resolution).

The goal of this article is to give you some insights on the windows opened by the advent of new interferometric instruments for the study of variable phenomena encountered in massive stars. Some examples will be given on the study of Be stars disks (§ 2), the circumstellar environment of BA supergiants (§ 3), the detection companion and the monitoring of the evolution of binary systems (§ 4) and the time monitoring of novae (§ 5). Finally, a brief prospective is proposed in § 6.

2. VARIABILITY OF BE STARS DISKS

Classical Be stars are B-type stars close to the main sequence exhibiting numerous line emission, mostly from hydrogen. The moderate infrared excess is attributed to a circumstellar gaseous disk (Porter & Rivinus 2003). Since the pioneer observations of one-armed oscillations in Be star disks by the GI2T interferometer team (Berio et al. 1999; Vakili et al. 1998), the analysis of this phenomenon has reached an impressive level of details (Carciofi et al. 2009). In particular, the detection of new companions to Be stars (Meilland et al. 2008; Kervella et al. 2008; Chesneau et al. 2005) and their presumed influence on the formation of Be star disks (see in particular the case of δ Sco described by Tycner 2010; Robertson et al. 2010; and also Kanaan et al. 2008; Meilland et al. 2006; Carciofi et al. 2006). Note also that a low-mass white dwarf was discovered around the fast rotating B star Regulus (Gies et al. 2008), suggesting a long

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and complex history of mass-exchanges (Rappaport et al. 2009).

3. THE CIRCUMSTELLAR ENVIRONMENT OF BA SUPERGIANTS

Supergiants of spectral types B and A (BA-type supergiants) are evolved massive stars of typical mass 20 $M_{\odot}$ and high luminosity (above 10^5 $L_{\odot}$. Their luminosity and temperature place them among the visually brightest massive stars. Therefore, they are particularly interesting for extragalactic astronomy. Moreover, a great potential as independent distance indicators lies in the use of the wind momentum luminosity relationship (Kudritzki et al. 2008). As a consequence, the closest representatives of this class are analyzed with the most developed radiative transfer methods of analysis (see for instance Schiller & Przybilla 2008). Yet, the wind sensitive lines like Hα remain difficult to model, and intensive spectroscopic monitoring of these lines has lead to the conclusion that variability in the stellar winds of these supergiant is localized and structured, and rotates around the stars.

The origin of these structures might be patches on the stellar surfaces produced either by non-radial pulsation (NRP) patterns or magnetic surface structures. Optical interferometry could provide precious complementary information in this field (Dessart & Chesneau 2002). BA supergiants, given their large radius, rotate moderately fast ($v \sin\ i$ of about 25–40 km s^{-1}), and the terminal velocity of the wind is about 200–400 km s^{-1}. Spectrally resolving the Balmer lines requires resolving power as high as R=10000. Their large apparent diameter makes them good sources of long baseline optical observations, whereas observing the CIR around main sequence O star or WR stars is more difficult. Two instruments can provide such a high spectral resolution: the near-IR instrument AMBER at the VLTI (R=12000) and the visible instrument VEGA at the CHARA (R=30000). A monitoring of Rigel (B8Iab) was performed during 5 months in 2006–2007 using AMBER and the FEROS spectrograph. A deep visibility decrease is observed in the Brγ line showing that the photospheric absorption line is significantly filled by emission from the wind. The Brγ line forming region is located within a thin shell at 1.3 R_*, and the spectroscopic activity in the Brγ line is clearly correlated to the one seen in the Hα line. The interpretation of the visibility and phases is under way, though the information on the inclination of the rotation axis of the star is badly missing. The diameter of Rigel and Deneb (A2Iae) were measured in the K band with great accuracy by the FLUOR instrument at the CHARA (Aufdenberg et al. 2008). Some evidence that Deneb is a fast rotator were discovered, that provide the inclination and orientation of the sky of the rotation axis. Observations in the Hα line were also secured with the visible recombiner VEGA. The line forming region is (larger than about 1.5 R_*), and the Hα line forming region appears very asymmetrical. This might conjecturally be interpreted as a co-latitude dependent line-forming region, around a fast rotating star.

4. OBSERVATIONS OF BINARY SYSTEMS

Optical interferometry is particularly well suited to detect and study binary systems (see contributions from De Becker et al. 2010; Gies et al. 2010). We focus here on systems in which the stars interact, by their wind, or by exchanging mass.

4.1. *Wind-wind collisions sources*

Observations of early-type binaries provide some fundamental properties of massive stars, but they also represent good laboratories of the interactions of their stellar winds, even able in the most extreme case to generate copious amount of dust (Rauw 2008). The usual picture is that of an interaction zone limited by two hydrodynamic shocks, which follows the orbital motion of the stars. The best system in which a wind-wind collision zone can be studied is γ^2 Velorum (Millour et al. 2009, 2007) . When dust forms, a bright pattern is observable in the infrared, both in the near-IR and mid-IR (Millour et al. 2009). η Car (Weigelt et al. 2007; Chesneau et al. 2005; van Boekel et al. 2003) cannot be omitted in this section. in particular, the AMBER instrument has intensively monitored this star during the periastron passage of the companion.

4.2. *Mass-exchange binaries*

Interacting systems are of particular importance to understand how the fate of the stars can be dramatically affected by mass-loss and mass-exchanges. The case of the B[e] star HD87643 is impressive. AMBER and MIDI observations have revealed that this hot source exhibiting an impressive amount of hot and cold dust is a binary systems, in which two circumstellar disks are observed around the unseen stars (Millour et al. 2009). The orbital motion remains to be monitored, at a scale of several years to tens of years, as the separation of the components is about 40 AU. β Lyrae is an archetypal mass-exchange that was recently revisited by interferometers (Schmitt et al. 2009; Zhao et al. 2008, 2010).

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υ Sgr is also a binary system in which an important mass-transfer occurred in the past, leaving a very hydrogen deficient star as primary (Koubský et al. 2006). This system that, by contrast to β Lyrae, exhibits an important amount of dust, was observed with the mid-IR VLTI instrument MIDI. The dust resides in a disk providing further constraints on the inclination of the system (Netolický et al. 2009).

5. THE OBSERVATION OF NOVAE

A classical nova eruption results from a thermonuclear runaway on the surface of WD that is accreting material from a companion star in a close binary system. The temporal development of the fireball, followed by a dust formation phase or the appearance of many coronal lines can be studied with the VLTI. The detailed geometry of the first phases of novae in outburst remains virtually unexplored. The recent outburst from the recurrent nova RS Oph showed how complex such an ejection can be, as seen in the radio-interferometers and the HST images of the rapidly formed bipolar nebula formed rapidly (Bode et al. 2007; O'Brien et al. 2006). This event was observed by several optical interferometers (Barry et al. 2008; Chesneau et al. 2007; Monnier et al. 2006), and we can cite in particular the monitoring from the Palomar Testbed Interferometer (PTI) reported in Lane et al. (2007).

More recently, the classical nova V1280 Sco was monitored during 4 months, providing the first spatially resolved observations of a (hopefully spherical!) dust forming nova (Chesneau et al. 2008). The data were fitted using a series of dusty shells generated with the DUSTY code. These promising observations represent the first monitoring of a dusty nova using an optical interferometer. Another aspect is the detection, in the best dust forming stars, the cool R CrB stars, of big clumps, such as the one detected around RY Sgr by MIDI (Leão et al. 2007).

6. THE NEAR AND MID-TERM FUTURE

During the meeting, some discussions arose on the potential of the technique for studying non-radial pulsations (NRPs), wind clumping and magnetic fields. Generally speaking, the apparent diameters of hot stars is small, in the range of 0.2–1 mas for the closest objects. As a consequence, for studying these phenomena occurring at or close to the photosphere, interferometers must operate with long baselines, typically larger than 200m in the near-IR, or larger than 50m in the visible. The CHARA array is well suited for such a study. A theoretical study of the potential of spectro-interferometric observation for studying NRPs was presented by Jankov et al. (2001), and differential rotation could also be probed (Domiciano de Souza et al. 2004). The study of these phenomena greatly benefit from the fact that the observable patterns are well-structured in the surface of the star, leading to an interferometric signal that can be isolated. The observation of the wind clumpiness is by far more challenging. To detect such a signal, the clumps distribution of sizes must be peaked to a certain value, preferentially a significant fraction of the star apparent diameter, and the contrast between the wind and the star, must be also favorable. All O-star optical diagnostics originate close to the hydrostatic core radius (below ca. 2–3 R_*) while those of Wolf-Rayet stars (WRs) subsist out to large radii (Dessart & Owocki 2005). However, again, O and WR stars are small, and the good line diagnostics were found historically in the visible, so that long baselines and high spectral resolution in the visible are required. Yet, 'naked' Luminous Blue Variable like P Cygni are good candidates for test observations (Vakili et al. 1997). AG Car or HR Car are also interesting, but we recall that the estimated distance of AG Car is about 6 kpc (Groh et al. 2009). In a near-future, the most promising observations will be on hot stars, particularly those located in Orion, in which magnetic fields were recently discovered (Petit et al. 2008; Bouret et al. 2008). The periodic and stochastic variability of the emission lines from the confined wind could be monitored (Townsend et al. 2007; ud-Doula et al. 2009; ud-Doula 2010).

As demonstrated in § 5, there is a great potential for the study of outbursting novae. I am more skeptical for the potential of observing supernovae, not only because their occurrence is much lower, and their brightness statistically more limited, but also because the ejecta expand much faster, by a factor 4 to 10 compared to the novae. As a consequence, for a given event, the window for the interferometric observations is decreased, and the ejecta can be more rapidly resolved by large 8–10 m telescopes, furthermore by an ELT.

DISCUSSION

Jose Groh: *You said something about matter ejection in Be stars being caused by the periastron passage of a companion. Do you have any estimate on how close the companion has to come in order to trigger matter ejection?* — I would say that we are close to have good estimates for a small number of interesting targets, cited in this talk. These targets are Achernar (B3Ve), whose companion is getting closer to the primary (from 12 AU at discovery to less than 7 AU now), δ Sco also cited here. The periastron passage must be closer to a 1–3 AU or close in both cases. The orbit of β Cep and its close Be star companion is also of great interest (Wheelwright et al. 2009). Let me add also that the primary should exhibit favorable conditions for mass-ejection: fast rotation, and/or non-radial pulsation and/or more...

Gerard van Belle: *In science preparation studies for the Keck Interferometer, we estimated a supernovae rate of well suited targets (angular size-brightness in the Local Group) of about once per 10 years.*

Eugene Trunkovsky: *As for the measurements of the angular sizes of Rigel and Deneb, what do you think about the possibility of some pulsations of these stars.* — The extremely accuracte CHARA/Fluor exclude any significant diameter variations for these stars, but NRPS are good candidate for explaining the wind variability detected in Hα.

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