Prospects for the multiplicity investigation of massive stars with the CARLINA interferometer

Michaël De Becker[1,2], Hervé Le Coroller[2], Julien Dejonghe[2]

[1]Institut d'Astrophysique et de Géophysique, Université de Liège, Belgium

[2]Observatoire de Haute-Provence, 04870 St Michel l'Observatoire, France

Abstract: *The multiwavelength study of massive stars revealed many phenomena that are intimately related to their mutliplicity. Colliding winds in massive binaries play indeed a significant role in thermal X-ray emission, particle acceleration, or even dust formation in such systems. In this context, the identification of binaries and the determination of their orbital parameters is a pivotal issue. We describe first briefly the CARLINA project. The sensitivity and imaging capability of Carlina are perfectly adapted for the study of binary systems. Considering its expected specifications, Carlina will operate in complementarity with ELTs and long baseline interferometers. Then, we will discuss some prospects for the multiplicity investigation of massive stars, on the basis of the expected performances of the prototype currently built at the Observatoire de Haute-Provence (OHP).*

The CARLINA OHP prototype

• The CARLINA design consists in a ***diluted aperture of spherical shape***, with focal optics mounted in a balloon suspended gondola. One of the main advantages of such a design, with respect to other interferomtric systems, is the ***absence of delay lines***. The apertures are anchored on the ground and positioned to constitute parts of a large spherical surface (curvature radius R=71,2 m for the OHP prototype). The light is reflected up to the focal gondola (at R/2, *Fig.1)* that contains the sphericity correctors, densified-pupil *(ref.1)* and photon counting camera *(ref.2)*.

• The stability of the position of the gondola is warranted by a tripod of cables whose the lenght is accurately controlled by computer-controlled winches and a laser monitored system *(ref.3)*. A schematic view of the prototype installed at OHP is shown below *(Fig.2)*.

• A set of three mirrors with a diameter of 25 cm is located on the ground. The 3 baselines have lengths of respectively 5, 9, and 10.5 m *(Fig.3)*.

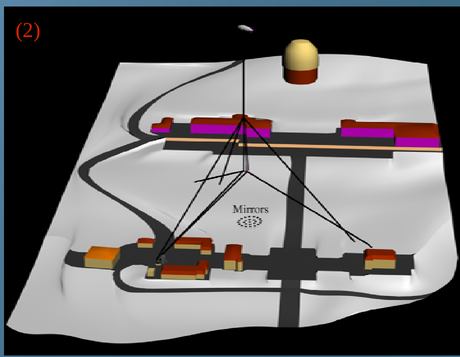
• The beams from the three apertures are then combined in the optics mounted in the gondola, and the detection is performed using a photon counting camera.

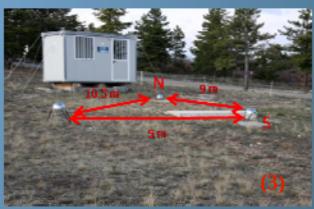
• Four waveband filters (width ~100 nm) will be available, with central wavelengths respectively of 531, 562 ,624 and 692 nm (noted A, B, C, and D, respectively). It is important to emphasize that this prototype operates in the ***visible domain***.

• The optics mounted in the gondola contains several elements whose individual transmissions are taken into account in order to calculate the efficiency of the design, and convert it into an effective sensitivity as briefly illustrated in *Fig.5*.

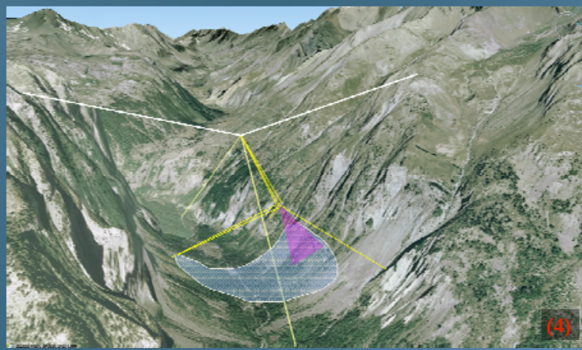
• The present design is still in development. First results for technical demonstration are expected to take place in the forthcoming months, and should be followed by a first science observation in 2011 - 2012.

• In the future, additional mirrors may be installed in order to characterize further the multi-aperture recombination and i ncrease the aperture to 17m.





Design for a 100-200 m class CARLINA interferometer



• Potential sites for future large CARLINA interferometers have already been identified. The selection relies mainly on topographic considerations: typically, a valley oriented in the East-West direction is required, with a nearly hemi-cylindrical shape at the bottom.

• In Fig.4, such a site is represented. The grey area corresponds to the area covered by a large number (100 - 1000) of small apertures. Some sites allow the focal optics to be suspended by cables (white/yellow lines), and not anymore by a balloon. The tracking is equatorial: the orientation of the focal optics follows the motion of the target in the East-West direction. The violet triangle represents the cone of reflected light from the operating apertures. In such a site, most of the sky would be accessible.

The replication of a large number of small apertures is much less expensive than the construction a large pieces of mirror. A diluted aperture design such as a CARLINA interferometer constitutes a alternative architecture for hypertelescopes able to perform high angular resolution observations in the visible domain (at the sub-mas scale), without the caveat of delay-line designs used in present long baseline interferometric facilities. Carlina should be much more sensitive than conventional interferometers and will be able to obtain complex images of fainter objects (mv>12).

Multiplicity investigation of massive stars with CARLINA

The importance of the multiplicity of massive stars

• A very important point to consider in the context of massive binaries is the fact that the stellar winds of the components of the system are likely to collide. This phenomenon is a key point in the physics of massive stars. This ***wind-wind interaction*** is indeed responsible for several physical processes at the front of modern stellar astrophysics research *(ref.4)*, such as copious high energy emission, particle acceleration, and even dust formation.

• In addition, high angular resolution techniques turn out to be very valuable in order to investigate the multiplicity of massives stars. Spectroscopic techniques are indeed generally limited to shorter or medium period systems, and are strongly biased to significantly inclined systems *(ref.5)*. As a complementary technique, interferometry is worth considering by the massive star community to ***detect new multiple systems and determine their orbital parameters***.

Criteria for the selection of targets for the OHP prototype

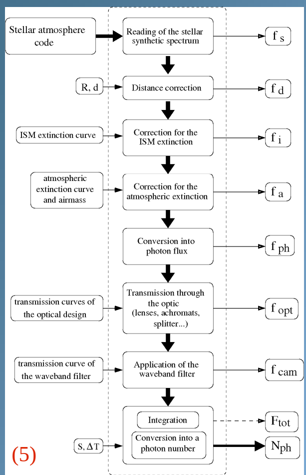
The main goal of the OHP prototype is to test all the optical train of an hypertelescope and to show that Carlina will be more sensitive than conventional interferometers. It is a purely technical demonstrator but it is not impossible that we will be able to make a little science. To fulfill the requirement for the protoype, potential targets have to fulfill 4 criteria:

(1) angular separation: as the resolving capability is derectly related to λ/D (where D is the baseline), the prototype is characterized by a well-established angular resolution. Typically, for the longest baseline, we may expect an angular resolution of the order of 10 mas. This translates into an orbital separation of 10 AU for a target located at 1 kpc. Only long period systems are thus accessible, considering the typical distance to massive stars (typically a few kpc).

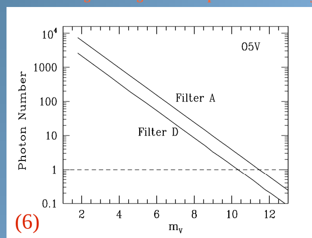
(2) brightness ratio: a secondary star in a binary system should not be too faint, w.r.t. the primary, in order to be detected. The criteria is not yet quantified, but typically in speckle intererometry the contrast should not be larger than 100-1000.

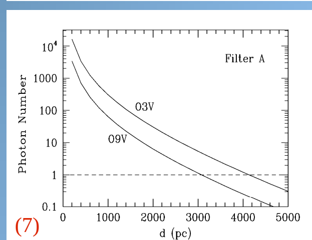
(3) coordinates: with the present fixed apertures, the declination of the targets must lie between +40 and +50 degrees. Such a restriction would of course be lifted in a valley, but the OHP site is flat.

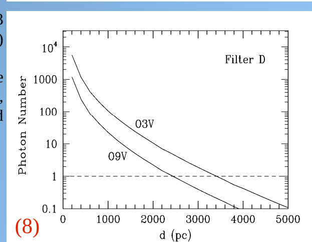
(4) brightness: as a first approach to estimate the sensitivity of the optical design, let us consider that a a target is accessible provided the photon counting camera detects at least one photon in a sub-exposure (typically 0.001 s).



Below: curves computed for the prototype. The sensitivity will be much higher using 100-1000 apertures in a valley,







Estimation of the number of photons detected by the camera

• We estimated the number of photons detected by the camera on the basis of synthetic stellar spectra taken from the Kurucz library *(ref.6)* for a range of spectral type (O3 to O9), using typical fundamental parameters for these stars *(ref.7)*. The stellar spectra were corrected for ISM extinction (assuming 1 magnitude of extinction per kpc) and for atmospheric extinction (assuming mean atmospheric conditions). The complete procedure is summarized in *Fig.5. The aperture diamater considered is 25 cm* .

• Some results are illustrated on the right. *Fig.6* compares the expected results, as a function of the V magnitude of the target, for filters A and D. *Fig.7* and *8* plot the number of photons detected for stars of spectral types O3V and O9V as a function of the distance to the target,for two filters, We see that, in typical extinction conditions, O stars might be detected with the OHP prototype provided their distance is not larger than about 4 kpc (with differences depending on the spetral typde and the waveband filter used). Note that any additional extinction, depending on individual targets, will affect signicantly these limits.

Preliminary studies aiming at using the CARLINA OHP-prototype are in progress, and suggest promising results for the multiplicity investigation of massive stars. Potential targets are already identified and should be observed in the forthcoming years.
The objective of these preliminary studies is to pave the way for 100-m class CARLINA interferometer, opening a new era for high angular resolution observation techniques, in complementarity with ELTs.

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PI of the CARLINA project at OHP : H. Le Coroller (Herve.LeCoroller@oamp.fr)