Science with the Carlina hypertelescope

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Abstract: Studies are currently underway to propose a generation of post-VLTI interferometers (Carlina, OHANA, Keops, etc.). Such interferometers will open new fields of research in astrophysics by imaging the surfaces of supergiant stars, gravitational microlensing, AGN, Hot Jupiters, etc. To achieve these goals, they will have to respond to several criteria: to provide very high angular resolution (baselines > 100 m), to be equipped with a large number of mirrors (rich UV coverage), and to be able to accommodate high tech instrumentation such as an Adaptive Optics system and a coronagraph. We describe the optical Carlina architecture and show that it fulfills all these criteria. We give new results obtained with the prototype of Carlina currently built at Observatoire de Haute-Provence. Considering its expected specifications, Carlina will operate in complementarity with ELTs and very long baseline interferometers.

(1) The Optical CARLINA architecture

Carlina is an optical interferometer configured like a diluted version of the Arecibo radio-telescope (*ref.1*). Above the diluted primary mirror, made of fixed co-spherical segments, a helium balloon, or cables suspended between two mountains, carry a metrology gondola and a focal gondola (Fig. 1). The metrology gondola is positioned at the curvature center of the diluted primary mirror while the focal gondola is at half the distance to the ground mirrors (on the focal sphere). The main advantages of such a design are the absence of delay lines, the simplicity of the optical train, and the possibility of using an internal metrology at the curvature center (metrology gondola) to align the carlina mirrors on the primary sphere.

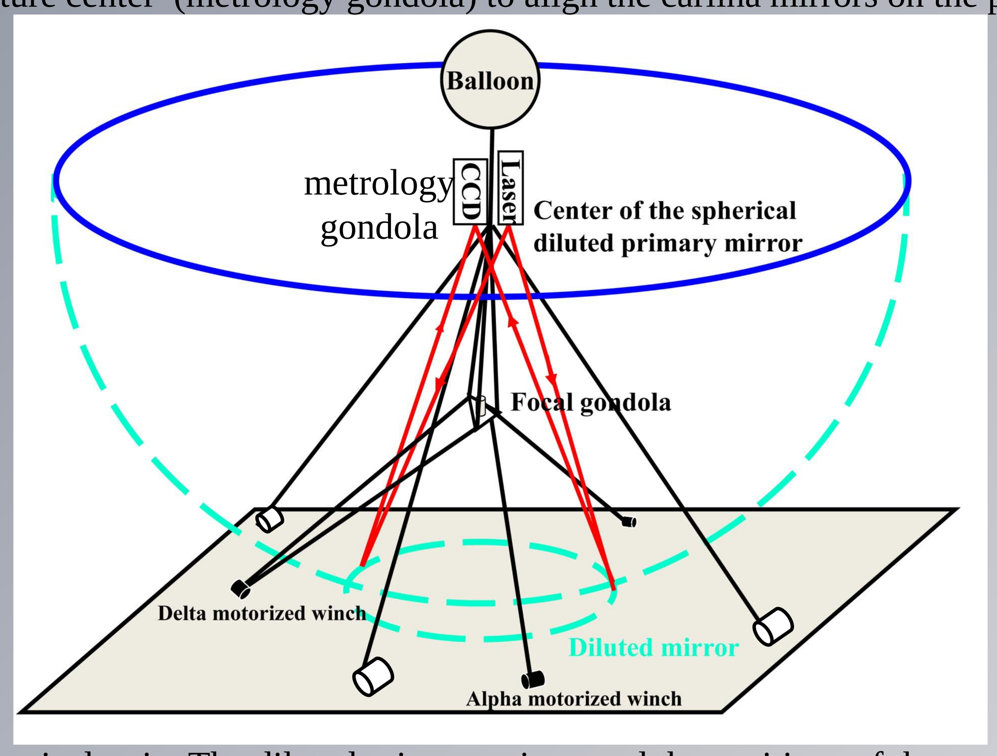

Fig.1 Principle of the Carlina optical train. The diluted primary mirror and the positions of the metrology and focal gondolas are indicated. The latters are attached under a tripod of cables that stabilizes the experiment (see also Fig. 2).

(2) The prototype at Haute-Provence Observatory (OHP)

The CARLINA design at OHP consists of :

- A diluted aperture of spherical shape anchored on the ground and positioned to constitute parts of a large spherical surface (curvature radius R=71.2 m). 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.2*)*.

- The star light is reflected up to the focal gondola (at R/2, Fig.1*)* that contains the Mertz sphericity corrector, densified-pupil *(ref.4)* and photon counting camera working in the visible.

- The stability of the position of the « metrology gondola » is achieved by means of a tripod of cables whose lengths are accurately controlled by computer-controlled winches *(see* Fig.1, 2*)*.

The main goal of the 10 m baseline OHP prototype is to test the whole optical train of an hypertelescope and to show that Carlina will be one of the most sensitive interferometers ever built. The system for stabilizing the "metrology gondola", and the metrology have been recently tested successfully (see right panel). Observation with a focal gondola is scheduled for 2011-2012. It is a purely technical demonstrator but we hope to carry out some interesting science. If any team of interferometrists is interested in performing technical or scientific observations with our demonstrator, we are open for collaboration. It will be possible to add 5-10 mirrors over baselines up to 17m. In this spirit, Michael De Becker has identified interesting massive binary stars that should be observable with our prototype (*ref.3*).

(3) New results obtained in 2010 with the Carlina prototype at OHP

In order to make lighter the "metrology gondola" we have placed all the metrology devices (lasers, CCD, etc.) on the ground. Only a convex mirror is positioned on the "metrology gondola" (see Fig.2). A computer-controlled system is used for stabilizing the "metrology gondola" while a metrology table works with the gondola in order to align the primary mirrors:

1) Three computer-controlled winches stabilize the position of the "metrology gondola" (top of the tripod, i.e. center of the spherical diluted mirror) with an accuracy better than 1mm! This control system works with two small telescopes at the ground level that observe the motions of the "metrology gondola". Then, real-time computing provides the position of the gondola and send orders to the three winches for re-centering the gondola and the metrology mirror when the balloon/cables move due to the wind.

2) A laser (green, or white) on the table of metrology lights up the "metrology mirror" ~70 m above the ground. The "metrology mirror " creates a virtual source for the primaries by lighting them. By following the inverse path, the light comes back on the table. By superimposing the spots coming from the three primary mirrors and by searching the white fringe, we can adjust very accurately the primaries on the sphere.

We obtained in July 2010 first fringes of metrology. We have thus demonstrated that residual vibrations of the cables in the wind do not disturb the metrology fringe detection. Now, there are no more obstacles to get white fringes (using a supercontinumm laser source) in order to adjust the position of the primary mirrors on the sphere within one micron of accuracy. This should be done during the coming months. All these systems will be described in more detail in a forthcoming paper *(ref.2)*.

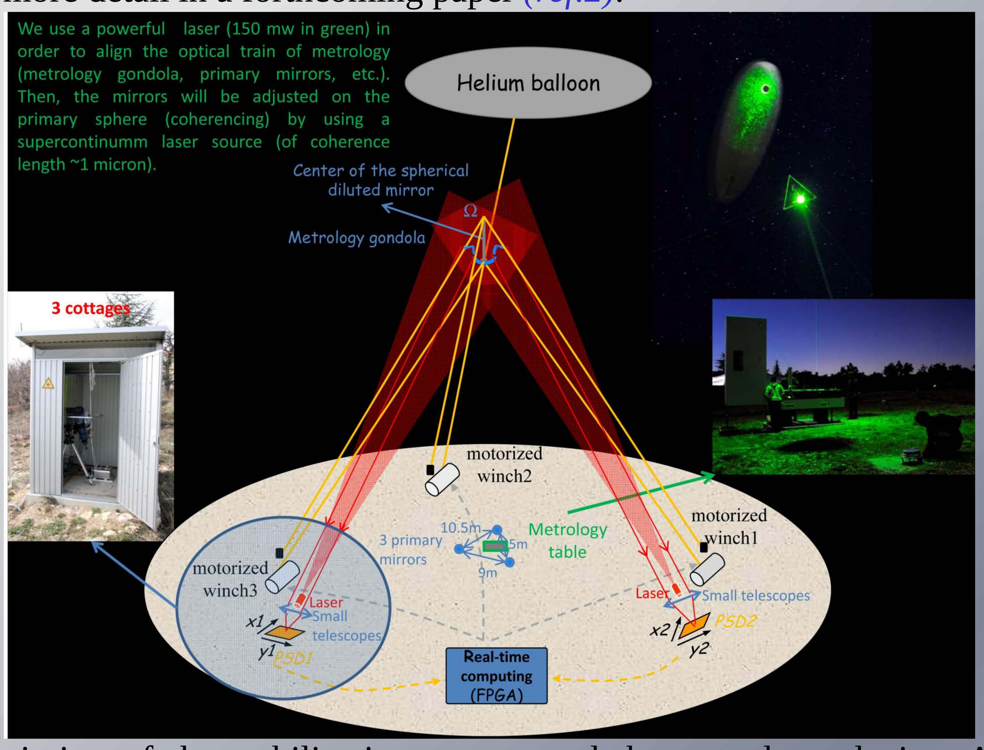

Fig.2 Description of the stabilization system and the metrology device. All these devices currently work at the Haute-Provence Observatory (see pictures). The focal gondola (at half the distance between the ground and the metrology gondola) is not represented for clarity of the figure.

(4) Carlina is for NOW!: We propose to build within the next ten years a scientific demonstrator of Carlina:

4.1 Design for a 100-200 m class CARLINA interferometer

The constraints for a Carlina's site are the same as for any modern telescope: it should be located relatively high-up in the mountains (dry air for IR observations), in a good weather area (weak cloud cover) and with a favorable atmospheric turbulence (seeing< 1", slow turbulence), etc. But, 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.

The price of the project will mainly depend on the site choice to build Carlina. For this reason, we distinguish between two kinds of site:

- The extremely good areas (ex: Paranal site) where we could propose only in a second stage (20-30 years) to build a very large Carlina (~200-700 m aperture).
- The "intermediate" sites (the weather and turbulence are acceptable but generally not the best) are not far from a village; it is relatively easy to access such sites by road and to connect them to the electricity, web, etc:

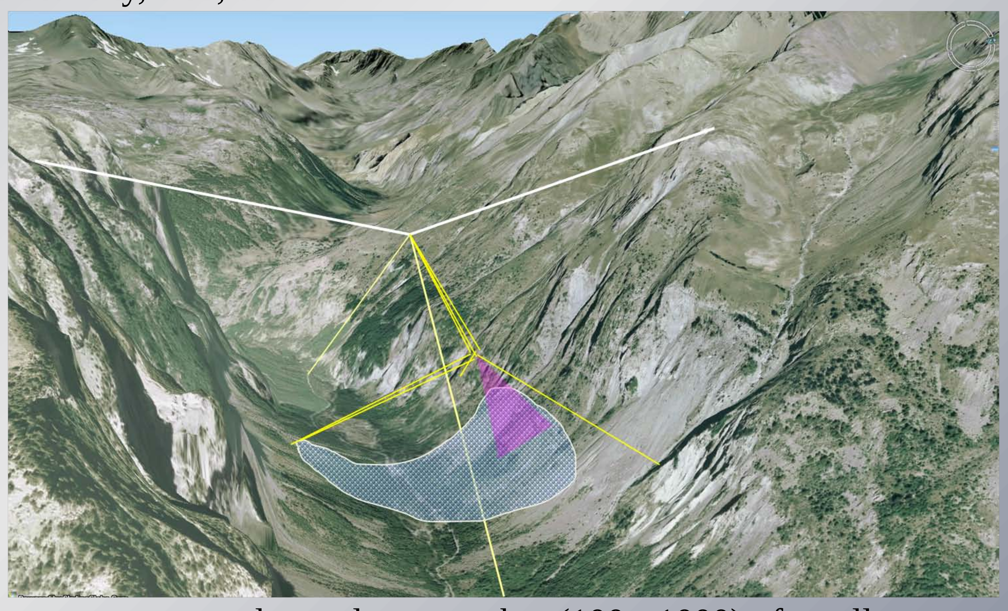

Fig.3 The grey area corresponds to a large number (100 - 1000) of small apertures. The violet circle represents the cone of reflected light from the operating apertures. In a such site, most of the observable sky is accessible by Carlina.

More than 10 potential « intermediate » sites in the Alpes, Pyrénées for a future large CARLINA interferometer have already been identified. We propose to build within the next ten years a scientific demonstrator of Carlina with a ~100 m aperture for such a site. This demonstrator should provide many scientific results complementary to the ELTs, and to the long baseline (~1 km) interferometers. Its imaging capabilities, and sensitivity (mv>15) will be much higher than for conventional interferometers.

4.2 Carlina should be one of the most sensitive interferometers ever built

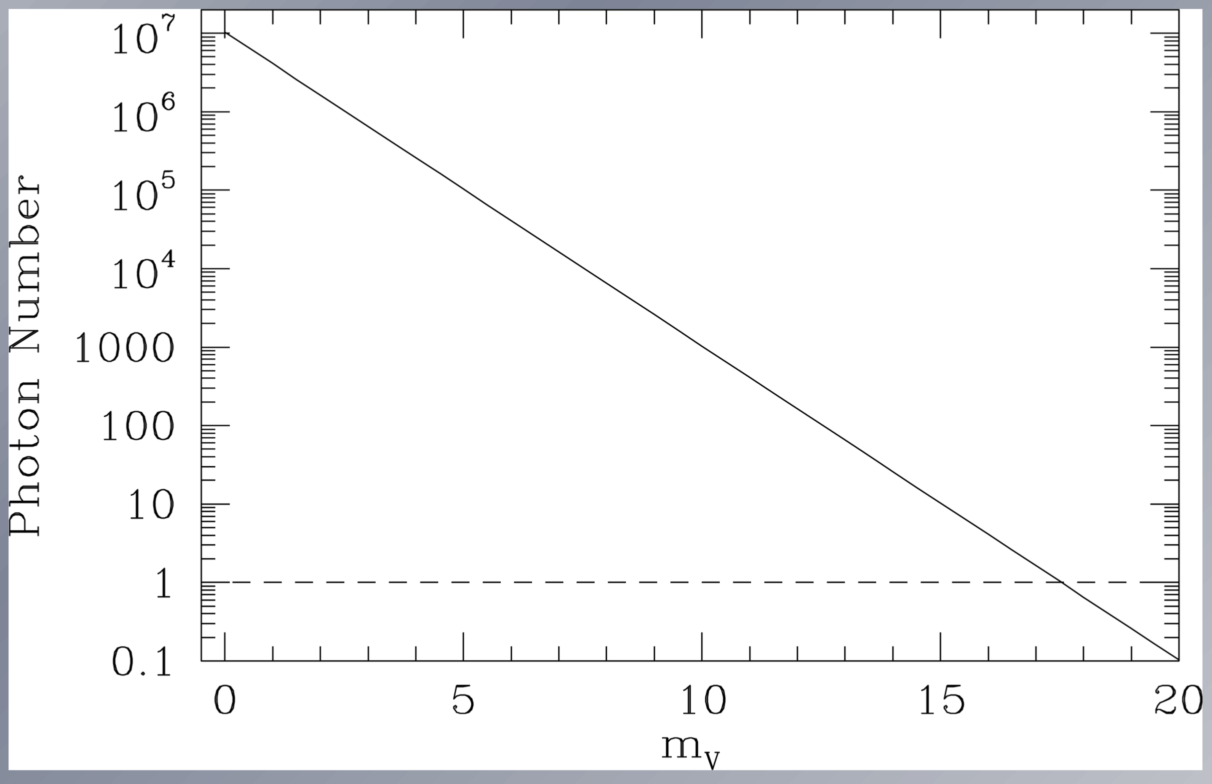

Fig. 4 We have estimated the number of photons detected by the camera as a function of m_v taking into account the whole optical train of Carlina (*ref. 3*). This graph assumes 100 sub-apertures of diameter 25 cm (exposure 0.001 s, filters width ~100 nm).

Conclusion: The objective of these preliminary studies is to pave the way for a 100-m class CARLINA interferometer, opening a new era for high angular resolution observation techniques working without delay-lines, in complementarity with ELTs and very long base line interferometry. Carlina should be very sensitive with a larger field of view (*ref. 5,6*) than conventional interferometers and will be able to obtain complex images (angular resolution ~ 1 milliarcsecond) of faint objects (mv>15). We propose to build a scientific demonstrator of Carlina within the next 10 years. The optical architecture of Carlina is relatively simple (no delay-lines, no large domes, etc.). Thus, Carlina should be cheaper than other interferometers. Carlina can also be built progressively. We could start with several tens of mirrors and finish it using more than 1000 mirrors. For example the OHP prototype costs ~ 500 Keuros.

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