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The Optical Very Large Array project (OVLA): a concept for kilometric ground-based hypertelescopes

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Abstract: The Optical Very Large Array (OVLA) concept initially proposed by Labeyrie in 1987 became a generic concept for kilometric arrays of telescopes, now considered for various projects such as KEOPS (Vakili et al.) or ELSA (Quirrenbach). As the effective aperture of a CARLINA-type hypertelescope seems to be limited to several hectometers, we show here how to combine the advantages of the hypertelescope beam combination with those of OVLA, in order to design large ground-based kilometric hypertelescopes opening new capabilities for analyzing extra-solar planets and faint extragalactic sources.

1 Introduction

Proposed by Labeyrie in 1987, the OVLA project was the first proposal for a giant multi-telescope interferometer with high resolution direct imaging capabilities. The original version of the OVLA concept consists in 27 mobile 1.5-m telescopes arrayed along an ellipse, which is the intersection between the ground plane and a virtual giant parabola pointing towards the star. As the star follows its diurnal path in the sky, the virtual parabola has to track it, so the telescopes are moving continuously on the ground to follow the ellipse distortion. Thus, no delay-line is required.

More recently, another concept was proposed for a giant direct imaging interferometer. Called Carlina Hypertelescope, it is simplified as it does not require mobile telescopes nor delay lines. Its design is analogous to the Arecibo radio telescope, with a diluted aperture, although working in the visible and near infra-red, but has a diluted aperture which is re-arranged in the beam combiner to provide a densified pupil (Labeyrie 1996, Borkowski et al. 2005) .

As the effective aperture of CARLINA-type hypertelescopes will be limited to several hectometers or perhaps 1.5 kilometer by the size of available crater or canyon sites (fig. 1), the OVLA concept remains a good candidate for future ground-based arrays spanning one or several kilometers. Using densified pupil combination together with the telescope mobility, OVLA becomes a unique high-resolution and high-contrast snapshot imager. This configuration is called OVLA Hypertelescope (OVLA-HT).

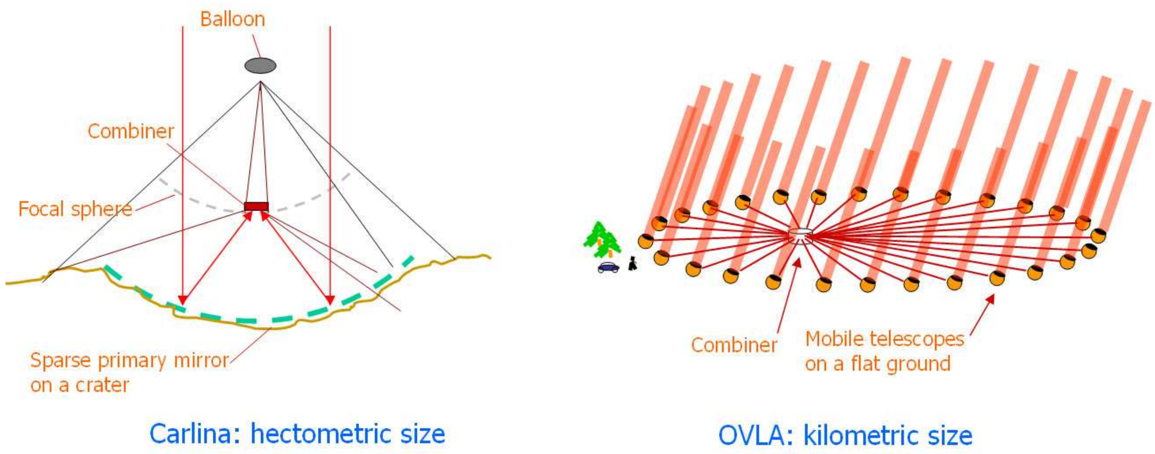

Figure 1: Comparison of the CARLINA and the OVLA concepts. The CARLINA size is limited to a few hundred meters or perhaps 1.5 km by the availability of spherical sites and the stabilization of balloon-borne focal optics. As the moderately flat sites needed for OVLA are available in multi-kilometer sizes, the practical aperture limitation for OVLA, likely to arise from turbulence in the horizontal coudé beams, may reach 10 km for the infrared.

2 The OVLA-HT concept

The densified pupil technique is more valuable if the output pupil is well filled. However, the initial OVLA configuration, consisting in an annular pupil, features a huge central obscuration. To tend towards a monolithic pupil, we can use several concentric rings of telescopes, but it requires one delay-line per ring.

A better solution has been opted for OVLA-HT. It involves a hierarchy of several non-concentric rings of telescopes connected by intermediate beam hubs (one per ring), transporting the clustered beams towards the focal beam combiner (fig. 2). This versatile concept can serve for a 20-40m compact array or a kilometric diluted aperture providing a higher resolution. A fully filled exit pupil, without central obscuration, can be obtained by pupil densification for high dynamic-range imaging (fig. 4).

The OVLA-HT concept is based on the mobility of each element (telescopes, hubs and the combiner) during the observation, which offers three main advantages:

- No delay lines nor huge infrastructure are needed for the beam transportation and combination.
- The array configuration is entirely free and can be optimized for the observed source. In this way, the angular resolution can be chosen freely, as well as the array redundancy. Typically, a non-redundant array will be preferred for observing extended sources, while a redundant array will be better for high-dynamic range imaging on compact sources.
- The entrance pupil shape and orientation seen from the sky can be stabilized (or not) during long-exposure observations (fig. 3). Then, the PSF remains static on the sky as with an equatorial telescope!

The two last capabilities are particularly valuable for exoplanet coronagraphic imaging, making easier dual-imaging techniques, PSF calibrations, deconvolution, etc.

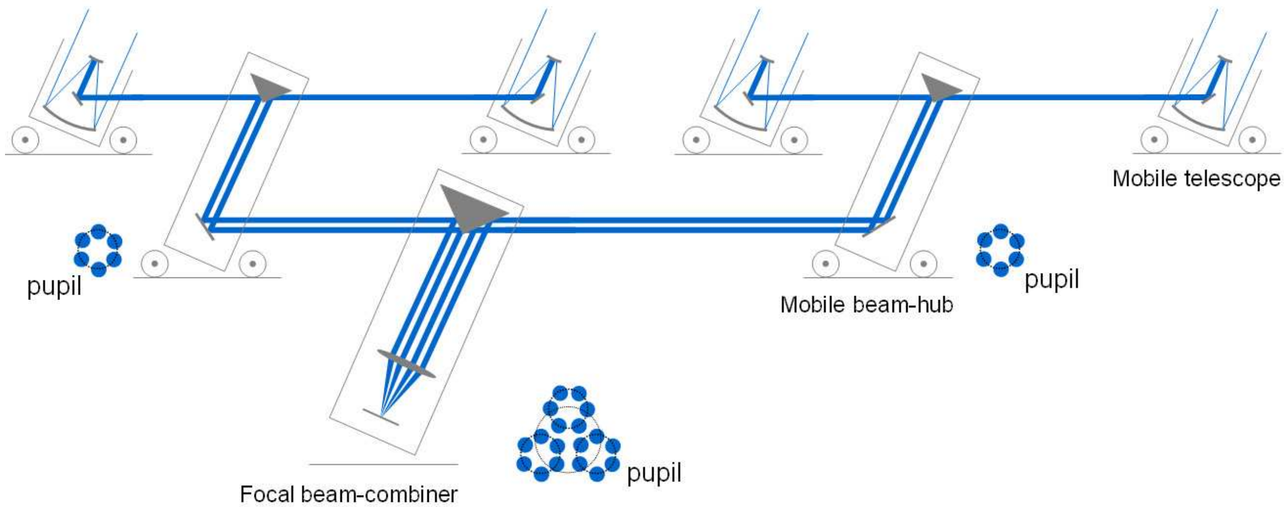

Figure 2: Schematic view of the OVLA-HT hierarchic optical scheme. Collimated beams that come from the telescopes of a same ring are collected by a beam-hub. Then, each hub sends its beams to the focal combiner where a direct image is formed. The focal combiner can be fixed (to accept a bulky instrument) or mobile (to decrease the speed of telescopes and hubs). To avoid delay-lines, each hub is located on the focus of its telescope ellipse, and the combiner is as well located on the focus of the hub ellipse. Lastly, each hub and the focal combiner are pointed to the star in order to automatically remap the pupil as seen from the star, without inducing differential effects between beams (field rotation, polarimetry). A sketch shows an example of pupil configurations seen from a hub and from the combiner for an array involving 3 rings of 6 telescopes each.

Wheels can suffice in principle to move the telescopes if the ground is mostly flat like the dry salt lakes of Central Andes or Dome C in Antarctica. Residual positioning errors can be then corrected by a small and fast delay line embedded on each telescope.

3 The OVLA prototype telescope

Mobile telescopes have to be compact and light-weight. A 1.5-m prototype telescope has been studied and constructed at Observatoire de Haute-Provence (OHP) in 1995-2000 (Dejonghe *et al.*, 1998, Lardière *et al.*, 2000). Its major characteristics are a spherical mount, also serving as a dome, and an active thin primary mirror, made of ordinary glass and supported by 32 actuators (fig. 5). The main difficulties encountered were the reliability of the wavefront measurement to control the active primary, and the funding of an aluminum spherical mount, more rigid than the glass-epoxy composite used for the prototype.

Of course, a spherical mount is not mandatory for the OVLA projet, it was just a compact and elegant solution we have explored, in the following of GI2T development (Mourard *et al.* 1994).

The main key-point remaining to validate is the fringe acquisition from a continuously movable telescope, in order to check the fringe stability and to compare with classical delay lines.

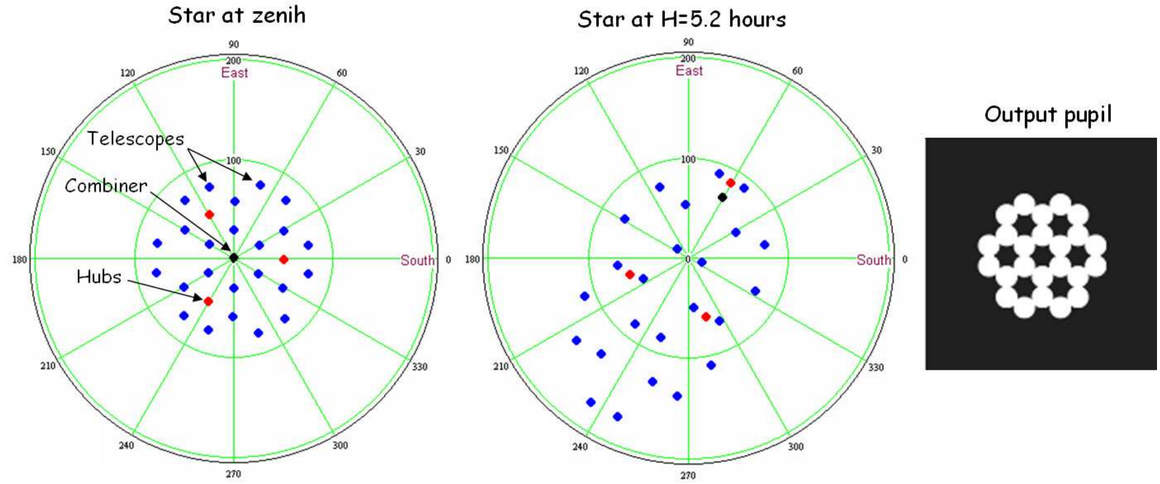

Figure 3: Positions of the telescopes, beam hubs and combiner for different hour angles. The output pupil shape and orientation (and thus the PSF) co-rotates with the sky, allowing long-exposure observations.

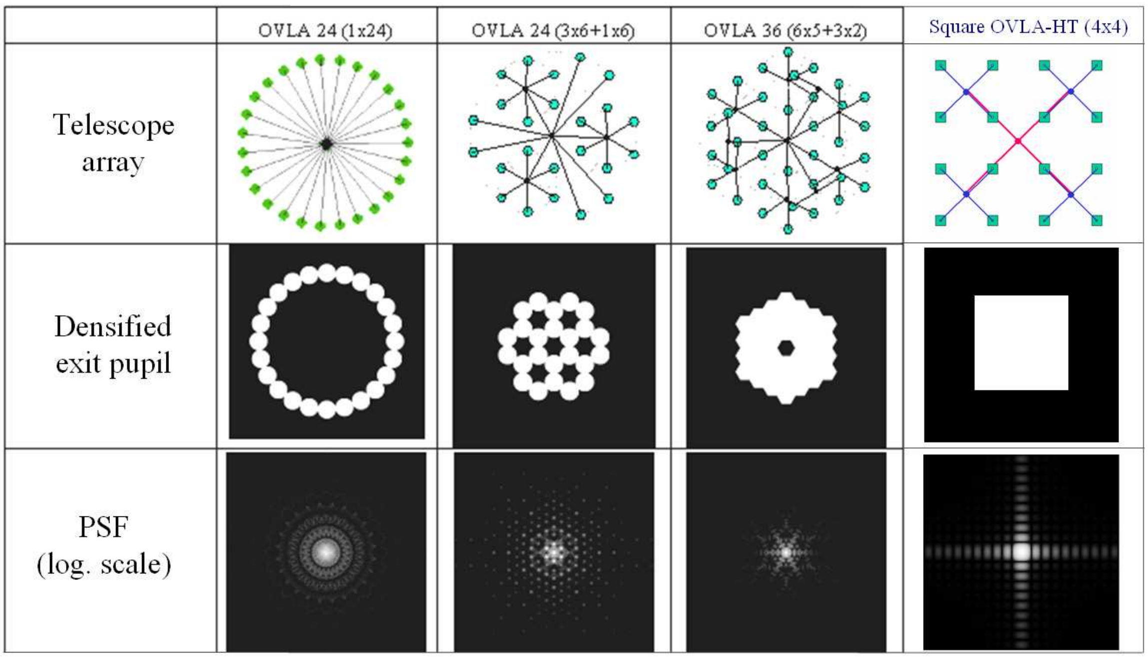

Figure 4: Examples of possible configurations for OVLA-HT. The original version of OVLA consisted in a ring of telescopes. With pupil densification, a hierarchy of rings and beam hubs can provide a Keck-like output pupil or a square fully filled pupil without central obscuration. The latter configuration is particularly valuable for high-contrast imaging.

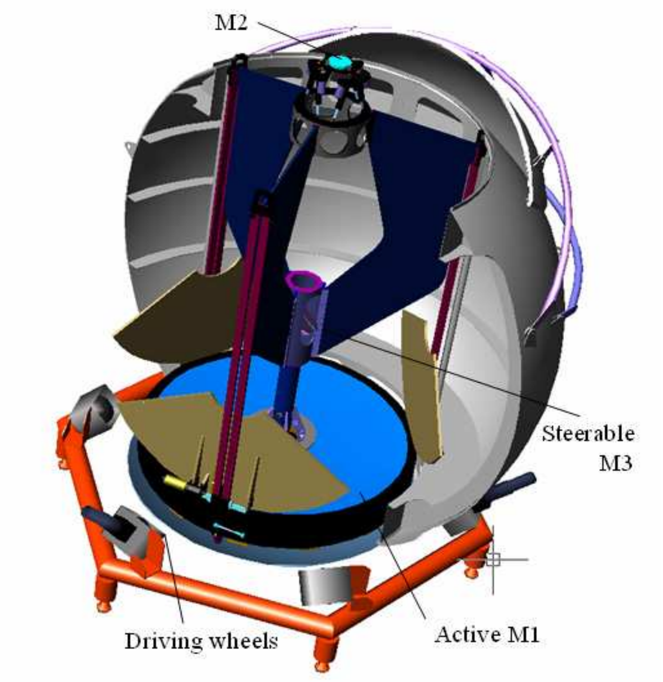

Figure 5: Schematic view and picture of the 1.5-m prototype telescope built at OHP.

4 Conclusions

The generic OVLA concept seems to have inspired new projects for future arrays involving numerous telescopes on kilometric baselines, such as KEOPS (Vakili *et al.*, 2005) or ELSA (Quirrenbach 2005), but numerous long delay lines and a huge infrastructure are required for the beam transportation and the OPD compensation.

An alternative solution is to move the telescopes during the observation and to choose a hierarchic beam transportation. This concept offers also much more versatility and new capabilities for high-contrast and long-exposure imaging.

However, appreciable R&D studies are required to compare the feasibility of kilometric delay lines versus mobile telescopes (i.e. 2D delay lines). A small demonstrator with 2 small mobile telescopes could be a first step. As the telescope mobility problem is very similar to the formation flying problem for future space interferometers, collaborations with space agencies should be possible.

References

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