Possible Designs for Optical Interferometric Array Unit Telescopes

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ABSTRACT

The next generation of optical interferometer arrays will require a large number of unit telescopes in the same manner as the VLA if meaningful scientific objectives are to be achieved. Studies based on the five element COAST array show that something like ten to fifteen telescopes are necessary. For such a project to be viable the unit telescopes must be designed from the outset for this task. The basic criteria are as follows: The wavefront quality and stability should be excellent, with high optical throughput, autonomous automatic operation, high coupling efficiently into the beam transport and combination system, while maintaining acceptable unit cost. To achieve these goals a number of novel designs were considered and are described in this paper. Two of the most suitable designs with low technological risk were studied in more detail by Telescope Technology Ltd., as described in a separate paper.

Keywords: Interferometer, optical array, telescope design

1.INTRODUCTION

The aim of this paper is to formulate the basic design criteria for next generation stellar interferometer unit telescopes and discusses a number of potential design solutions.

An individual telescope forming part of a separated element interferometer array has a number of stringent requirements placed on it as compared to a normal solitary instrument. These can be summarised into the following points.

1. Excellent wave front quality and stability to ensure that the beams from the separate telescopes can be combined to produce high contrast and stable fringe patterns.
2. The output beam from the telescope must efficiently couple into the beam transport system to the central laboratory.
3. High optical efficiency. Interferometers have complicated beam paths that can lead to large losses in the overall system. The number of optical surfaces should be minimised.
4. Reliable, autonomous operation. With an array containing many telescopes reliability and ease of operation are of prime importance to ensure observational efficiency.
5. Reasonable unit cost. To ensure good synthetic aperture filling large numbers of telescopes are required. To maintain realistic budget unit cost must comparatively low.
6. Unit telescopes must be capable of being moved and accurately placed in another position to enable the array to be reconfigured to suit the observation.

The above criteria have been largely formulated from experience gained with the operation of the Cambridge Optical Aperture Synthesis Telescope (COAST). This array has been observing successfully for a number of years and in this paper is considered to be the "benchmark" for any new instrument. An outline of the system follows to enable comparison. COAST has 5 unit telescopes of siderostat design (Baldwin[1]) with a 0.5m flat feeding a fixed 0.4m parabolic mirror. This design is extremely rigid and has only 11 reflections of the starlight to achieve beam combination. The design is also cost effective as a unit telescope complete with control electronics and cover costs approximately $100k. Due to their moderate size the siderostat flat, parabolic and the secondary mirror only contributed $26k towards the total. Even with hindsight the basic design of the unit telescopes is sound and probably would not be changed for a future instrument of a similar aperture. However, to produce worthwhile new scientific results any next generation instrument will require substantially larger apertures compared to COAST. The largest useable aperture is governed by r_0, which is the largest dimension over which there is not a significant phase shift in the incoming wave front during a time t_0. A larger aperture can be utilised on the next generation instrument for the following reasons.

1) Improved seeing on a high altitude site means r_0 effectively larger. (COAST 22m altitude)
2) Instrument will be designed to work further into IR (r_0 proportional to wavelength)
3) Instrument will be designed to accommodate multi-order adaptive optics again effectively increasing the useable r_0.

To summarise it would seem that an aperture in excess of 1m is required to generate significant new scientific results, while 2m might be too large to usable at the wavelengths currently contemplated. Using conventional technology, mirror costs rise exponentially with aperture and dominate the overall cost of any new array. The use of metal, composite or replicated glass mirrors may significantly affect this calculation but at the present time the technological risks seem out weighed by the need to reduce develop time and ensure reliability

In any new instrument reflections and other optical surfaces should be minimised, as interferometers require a substantial amount of additional optics. In theory each reflection of the starlight induces a few percent loss of the beam, however, dirt and corrosion mean much grater losses in practice. Reflection losses of 10% are not uncommon, thus, it can be considered that effective size of the costly primary mirror is reduced by up to 10% per reflection. The figure quoted for various unit telescope designs in this paper is the number of reflections to a horizontal reflection suitable for directing to a central laboratory. Separated aperture interferometers require active mirrors such as those to provide path compensation or to correct for atmospheric fluctuations. Since the use of active optics seems unavoidable it would seem cogent to incorporate them into the heart of the instrument at the design concept stage. If the active mirror can be made to replace a stationary or even perform several tasks simultaneously, the total reflection count can be reduced. This philosophy can be seen in the Alt. Alt. design that requires a mirror that moves at half the tracking rate. This mirror directs the beam back to central laboratory and can also compensate for atmospheric disturbances.

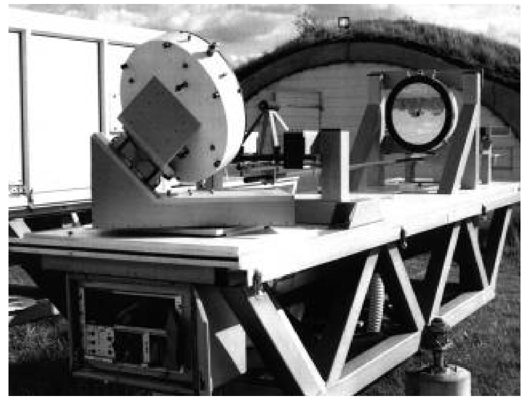
Any new array should, ideally have “snap-shot” capability as in high resolution many objects can exhibit blurring due time dependant behaviour. To overcome this problem the synthetic aperture of the needs to be more densely populated with telescopes. For “snap-shot” operation of the order of ten to fifteen telescopes is required, the number necessary being related to the length of the maximum baseline. Inevitably, such a large number of telescopes will be costly and in order maintain the viability of any new project the unit cost must be maintained at a reasonable level.

2. POSSIBLE TELESCOPE DESIGNS

When scaled up to a size suitable for the next generation instrument, the siderostat system of COAST has the disadvantage of having two, large and potentially expensive optics. For this reason the original, internal, design study was undertaken resulting in a number of novel designs the most promising of which are now described. All the designs have various advantages and disadvantages, which are briefly outlined. Hexapod and Pentapod telescopes were thought at the present time to be too greater technological risk to be considered as elements of an interferometer. However, it is thought that they may have the potential to be scaled up into very large solitary telescopes.

Siderostat

This is a scaled up version of present COAST design (See below). The mirror is mounted at 45^0 the elevation rotation axis which mounted at 45^0 to azimuth axis.



For

- Extremely rigid as it has strong triangulated frame.
- Low moving mass as only the flat moves improving rigidity and easing control problems.
- 3 reflections to output.
- Proven technology.
- Can moved and accurately relocated using kinematic foot system.

Against

- Costs. Two large optics required substantially increasing overall price of array
- Limited sky coverage. It can only observe one hemisphere that is also obstructed by the telescope superstructure surrounding the fixed parabolic mirror.
- Can have vignetting and grazing incidence on flat at high elevations
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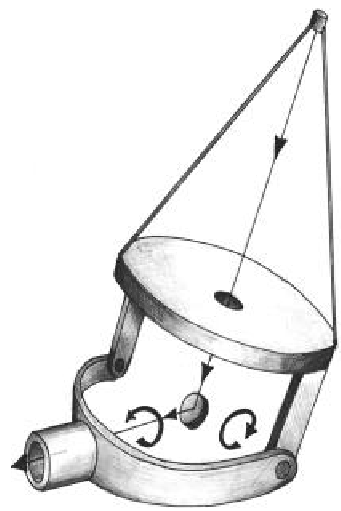
- Large telescope structure. This can effectively prevent the active elements of separate telescopes being placed close together, hence limiting the shortest available baseline.

Alt. Alt.

Both axes of rotation are in the horizontal plane. A tertiary mirror is at the intersection of these axes tracking at half telescope rate and directs the beam horizontally back to the central laboratory. The primary mirror structure is supported in the manner of an equatorial telescope, either on a large yolk as shown here or on a spindle system. The latter is stronger but will further reduce sky coverage.



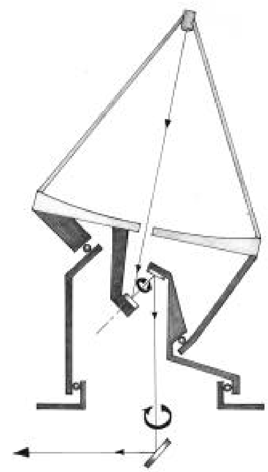
For

- Good sky coverage. This limited by the primary mirror structure either clashing with the yolk or intercepting the output beam.
- 3 reflections to output. The same as siderostat.
- Fairly conventional design that is similar to equatorial mount instruments. Should not present construction problems to commercial telescope manufacturers.

Against

- Tracking tertiary mirror that moves at half telescope rate. This mirror will, almost certainly have to be active. Can double up as fast guiding mirror correcting for atmospheric fluctuations.
- Grazing incidence on tertiary at low elevations. If problematical could be cured with an extra mirror.
- “U” shaped section of sky coverage missing due to position of output beam and yoke
- Large “yoke” type support required. May possibly lead to problems with rigidity compared with siderostat.

Code "Goniometer"



This is based on the COAST siderostat mechanism used as a stand-alone telescope. After the secondary mirror, the light strikes a mirror fixed to the rear of the primary and is reflected along the rotation axis of the altitude bearing. It then strikes another mirror that reflects it down wards precisely along the azimuth rotation axis. The fifth mirror directs the beam horizontally to the central laboratory.

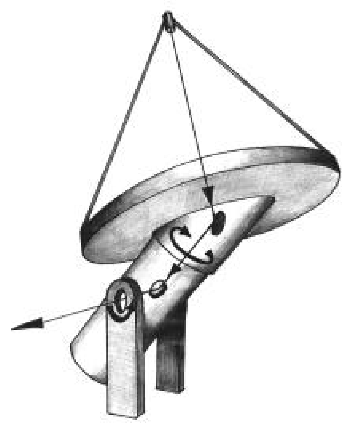
For

- Very rigid. Large diameter bearings required by this design enhance stability.
- Proven motion system as scaled up version of COAST mechanism.
- Almost complete sky coverage. Portion missing is near the horizon and is rarely used for interferometeric observations.
- No grazing incidences on mirrors.
- Lowness of output beam may possibly be and advantage as it would allow underground beam transmission tubes without any extra reflections. Underground beam tubes have the potential advantages of a stable thermal environment and of not suffering wind vibration that can be transmitted into the telescope or central lab.

Against

- 5 reflections to output
- Small area of sky coverage near horizontal elevation lost due to internal mirror mountings clash.

"Inclined" Mirror Telescope



The elevation section of the COAST siderostat mounted on a horizontally pivoting mount. Since both axes can alter the elevation the inclination of the primary mirror need not necessarily be 45^0.

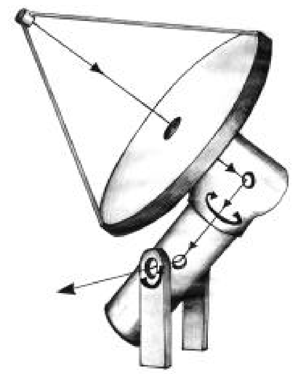
For

- Good sky coverage
- Rigid and compact design
- No tracking mirrors

Against

- 4 reflections to output
- Large counterbalance weights required
- 2 "U" shaped sections of sky coverage missing due to clash between primary mirror structure and side bearing mounts. The position of the blind spots can be arranged to some extent to minimise the problem.
- Grazing incidence on 3rd.mirror

Alt. over Alt. Telescope
The 90^0 case of the inclined telescope to enable full sky coverage.



For
- Full sky coverage
- No tracking mirrors required.
- No grazing reflections.

Against
- 4 reflections to output
- Very large counter balance weights required
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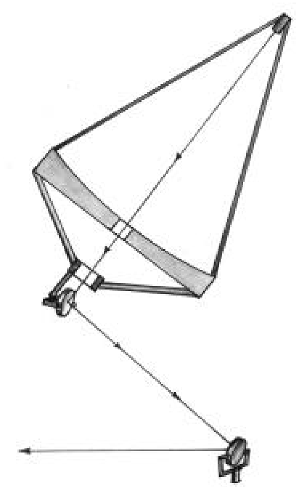
- Rigidity problems possible because of large overhangs from bearings and large counter balance weights.

Rear Siderostat
This consists of a conventional telescope with 2 fully steer able mirrors at the rear of the telescope. One is mounted on the moving part of the telescope and directs the beam onto the second mirror. The latter sits on a non-moving base and directs the beam to the central laboratory.



For
- Can use commercial telescope
- Good sky coverage

Against
- 4 reflections to output
- Complicated control system for mirrors.
- Sky coverage could be limited due obscuration by structure unless telescope designed from outset for this system.
- Grazing incidence on mirrors possible
- Alignment problems possible as both mirrors 3 and 4 will have to be active and therefore have no fixed zero position.

3.CONCLUSIONS

The siderostat arrangement of COAST is a tried and tested design for stellar interferometry and it is felt that a scaled up version would perform equally well. However, the cost of two large mirrors per telescope and the need for many telescopes to provide “snap-shot” imaging would make a new generation array prohibitively expensive. COAST also suffers from insufficient sky coverage. All the other designs discussed in this paper have single mirrors and better sky coverage. The Alt. over Alt. design for instance has complete sky coverage but is a totally new design which may well require considerable development work before it became an suitable unit telescope. The most conventional of the designs is the Alt. Alt. telescope and it probably has the least technological risk. Its construction would probably not present any insurmountable difficulties to a commercial manufacturer. This telescope also has three reflections to output, the same as the siderostat and the least of the new designs. For these reasons the Alt. Alt. seems the most promising design and was chosen for an external design review along with the siderostat by Telescope Technology Ltd. Their findings are discussed in a separate paper in these proceedings. All the proposed designs have strengths and weaknesses and some of the other designs may prove to be a better solution depending on the scientific goals and budget of the interferometer.

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