CHARA Technical Report

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Notes on Using 1.8 meter Telescopes

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1. INTRODUCTION

It has been suggested, by numerous people, that we should try and employ larger apertures in the array in order to try for fainter objects, specifically AGNs. In particular the use of the old MMT 1.8 m mirrors has been put forward by UNM. While larger apertures will supply more photons downstream, increasing the magnitude limit of the array is not simply a matter of increasing aperture size. I will set out a few thoughts on the technical issues as I see them, with little regard to costing restrictions.

The options, as I see it, are

1. Use all six MMT mirrors and have a six element array.
2. Use a mixture of 1m and 1.8 m telescopes to improve the UV coverage as well as the light gathering power.
3. Spend the money purchasing more 1m telescopes to fill out UV coverage.

I will cover each option individually after a short discussion of some general technical issues. An underlying assumption is that the use of larger apertures should not compromise the design of the system or the scientific goals of CHARA. I have also attempted to keep to our original plan of striving for the use of proven techniques and, where ever possible, currently available technology.

Many of the technological problems set out below could be said to be minor and easily fixed with extra optics. Taken together, however, the problems are coupled and their solution is not straight forward. Furthermore it would be disadvantageous to add still more optical components or servo systems to the system thereby reducing throughput and increasing alignment difficulties and cost.

2. TECHNICAL ISSUES

There are a number of problems to be tackled when considering using larger apertures including, diffraction, optical quality, central obscuration size, tip/tilt system, higher order

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AO, fringe tracking and focal ratios. These are all coupled to whether one is using all 1.8 m telescopes or a mixture of both 1 and 1.8 meter.

2.1. Diffraction

Unless the seeing is excellent, or one employs a high Strehl AO system the current output beam size of 12.5 cm will mean that differential diffraction effects will be much greater for 1.8 m than for 1m apertures. Some simulations should be run to see how big this effect may be, but it is my feeling that under normal conditions differential diffraction will result in the loss of almost all coherence. Thus we will either have to stop the apertures down, or use a larger diameter for the beam transport system. It is theoretically possible to use fibers, avoiding this problem altogether, although this would restrict the bandwidth of the instrument to the bandwidth of the fibers chosen, and change the entire downstream design. For example, it is not clear how one would perform pathlength equalization with such a fiber system. The technological risks in using a 'fiber all the way' design are very large. Using a larger beam transport diameter increases the size of all optical elements downstream, including the OPLEs, which would be a major cost driver.

We could get around diffraction effects by re-imaging the apertures in the beam combining rooms just before the beam reducing telescopes. Unfortunately this would required a new servo system employing a variable focal length optic similar to the proposed VLTI. To date this is something that has never been done and again the technological risks are high.

2.2. Optical Quality

The current specification of optical quality for the telescope are

- No greater than 1/5 wave peak to valley over 80% of aperture.
- No greater than 1/4 wave peak to valley over 100% of aperture.
- RMS wavefront error over full aperture of 1/17 wave

at a wavelength of 630 nm. This would mean re-figuring the surface of at least some of the MMT mirrors. Indeed, it would probably be best to reconfigure all the mirrors to use a shorter focal length in order to reduce mounting and housing costs. We should also find out if it is possible to have high quality silver coatings put on these mirrors at reasonable cost.

2.3. Central Obscuration Size

The current design calls for 1 meter apertures and an output beam of 12.5 cm, implying a obscuration to aperture ratio of 1/8. What is the size of the central obscuration of the MMT mirrors? This will mainly be a problem if the mixed aperture size option is used. If the central obscuration is different to that of the 1 m telescopes the aperture with the smallest hole would need to be stopped down so that the re-mapped apertures fully overlap.

2.4. Tip/Tilt System

If the output beam size specification for the array is not changed larger apertures will imply a larger beam reduction ratio. This in term will imply a larger dynamic range of tip/tilt in the beams. The tip/tilt mirrors in the baseline design are already larger than anything commercially available and have a large dynamic range. While it would be possible to increase this specification it will curtainly be a cost driver and will increase the technological risk.

2.5. Higher Order AO

As I showed in a previous memo, no AO system is currently available, or under construction, that would allow us to effectively use a larger aperture in the visible. In the K band it is likely that such system will be forth coming, although they would have to employ Sodium laser guide stars and we must remember that the tip/tilt and fringe tracking signals will still have to be derived from the object itself. In the case of 1 m apertures, it is probably not cost-effective to employ such a system, while it would be essential for a larger aperture. Without high quality AO it would be necessary to simply stop down the apertures.

2.6. Fringe Tracking

Even given an AO system, we must remember that the magnitude limit of the instrument is set by the fringe tracking system which is to operate in the visible band. Even if the K band limit for imaging were increased 1.3 magnitudes we would still require objects bright enough in the visible to perform tip/tilt and fringe tracking. It would be theoretically possible to fringe track in the IR but this would fundamentally change the baseline design of the instrument. No detectors are available in the K band with sufficient quantum efficiency or low enough noise to use the channel spectra for a fringe tracking signal. We would need to switch to a temporal encoding scheme and single pixel detectors for fringe tracking and, as a consequence, imaging. Thus an entirely new back end is required including a completely new imaging scheme. As I set out in the NSF report, temporal encoding is good for only small bandpasses, and for large numbers of apertures, that is more than 3, the necessary non-redundant encoding scheme implies very high modulation frequencies. Again the technological risks are high. Furthermore, this would basically mean the instrument is K band only, totally wiping out a large proportion of the science goals of CHARA.

2.7. Focal Ratios

Apart from being coupled to the diffraction and tip/tilt servo issues the choice of focal ratios becomes important if we are to consider using a mixture of different aperture sizes in the array. Let us assume that to begin with we will not employ an AO system and some of the telescopes in the array are to be 1.8 meters. Is the output beam of 12.5 cm from the 1.8 m telescopes to represent the full aperture or only the equivalent 1 meter aperture? If it is to represent the full aperture the design of the fringe tracking system would need to change since it would not be meaningful to simply overlap beams from different sized apertures. This problem is increased if the central obscurations do not match. Similar problems exists if the focal ratio is chosen such that the entire 1.8 m aperture is represented in the output beam.

3. OPTIONS

Given the technological difficulties presented above we can now consider a number of ways of incorporating the 1.8 m telescopes into the array.

3.1. Six Aperture Array with all 1.8 m Telescopes

This is the option first put forward by UNM. The idea would be to use all six of the MMT mirrors and have a six element array, rather than a five/seven element 1 meter aperture array as things currently stand. It must be possible to use the array without high order AO and to achieve the science goals already set out for the array. There are a number of approaches to doing this:

- Have two sets of secondaries for each of the telescopes. One would produce an output beam representing the equivalent of a 1 meter aperture, the other the full 1.8 meters. In this way the design of the array, or it's science goals, would not be significantly changed and if/when high order AO is available the other secondaries could be used to increase the aperture size.

- As pointed out above, during times of excellent seeing it would also be possible to employ the full aperture in the K-band, effectively making the instrument a K-band only device. However, this would be a fundamental change in direction, not only for the array design and costing but also the scientific agenda and so, I feel, should not seriously be considered.

The fact remains then, that without AO, we would have a set of 1.8 m telescopes stopped down to 1 meter. It will be some years before high Strehl sodium guide star AO systems are available, and longer still before they become affordable. There must be a better way to employ these mirrors in this time interval.

3.2. Mixed Aperture Sizes

By adding two or three 1.8 m telescopes to the five 1 m telescopes currently planned we would achieve the original goals of the proposal and increase UV coverage. As set out above there are many technical issues here, concerning beam transport size, central obscurations and beam combining. Once again we would simply mask the larger telescopes down to 1 meter until a suitable AO system was available and we had the money to buy seven or eight of them. Once we could employ the full aperture of all of the telescopes new problems arise in the beam combiner. The current fringe tracking scheme would need to be extensively modified. No one has combined light in the aperture plane from different sized apertures and only the VLTI plan to do so in the image plane. We should take note of the fact that the VLTI has received strong criticism for this approach. Even with an AO system the improved performance would only be seen on the baselines incorporating one of the larger telescopes and no large improvement in fringe tracking magnitude limit can be expected.

3.3. Buying More 1 m Telescopes

Even with the reduced cost of the MMT optics it is unlikely that the 1.8 m telescopes will be cheaper than the 1 meter telescopes, especially if one takes into account the mounting and housing costs. It would perhaps be better to simply purchase more of the 1 meter telescopes and forget about the MMT mirrors. In this way UV coverage would be increased and the science goals and design of the instrument would be enhanced rather than compromised.

The 1.8 m mirrors of the MMT, while very tempting, would be 'wasted' on the array while the full implementation of the system is under way and longer still while we find money for a, yet to be built and proven, AO system.

4. CONCLUSION

Due principally to differential diffraction, the lack of an existing and affordable AO system, and the fact that the magnitude limit is set by the fringe tracking system, it is not true to say that using larger apertures, especially 1.8 meter, will give us a much better observational magnitude limit. Even if it was true, the increase would only be 1.3 magnitudes. We need to know exactly what new scientific goals would made be possible by employing these larger apertures.

By the time we have exhausted the use of the 1 m apertures, which I feel is at least a decade beyond the commissioning of the device, it would probably be time to strive for apertures much large than 1 meter, rather than only twice as big. If we plan to search for money for the AO systems, we may as well plan to search for money for much larger apertures, and choose the aperture to fit our scientific goals.

It is my opinion that the third option, that of simply buying more 1 meter telescopes, is the best choice, although the second option, a mixed array, comes a close second. In this way it will be possible to employ the MMT mirrors in a series of parallel experiments involving fibers, the CHARA Array OPLES and the K-band, or indeed, to use them separately for more conventional imaging.