Lessons Learned in Array Operations

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Workshop: Future Directions for Interferometry

1 Introduction

If a next generation optical/Infrared Interferometer is to be successful, we must ensure that the operation of this interferometer is well funded and well managed. In an attempt to learn what we can from the current generation of interferometers, we have put together a list of costs and man power currently used, as well as a list of the most troublesome sub-systems. A comparison is also made between the costs of running the existing optical facilities with the known costs of running the mm arrays.

To this end a small questionnaire was sent to a representative of each group and the responses to these questions are summarized below. There is some overlap in this report with the group lead by Rachel Akeson, and so we have tried not to repeat those things set out there.

Our primary conclusion is that a majority of the current facilities are under funded and suffer from a lack of personnel on the mountain. The comparison of the costs of optical/IR arrays and mm arrays is startling.

2 Questionnaire

The following questions were sent to each group:

1. How many full time staff work, or are planned to work, on your array maintenance? Would you like more? How many?

2. What percentage of these are, or need to be, PhDs?

3. How many night assistants are required to run the instrument? Do you run every night?
4. What, and we don't need exact figures here, is the operations budget of your array?
5. How do you allocate, or plan to allocate, observing time?
6. Is the time over subscribed? If so, by how much?
7. How broad is your user base? That is, do you need to be a member of a collaboration to get time on the instrument?
8. Which sub-systems cause the most trouble?
9. Do you have any particular warnings regarding operations to those building new arrays?

In Table 1 we summarize the responses received. Note that these responses have been paraphrased in order to fit them into the table. The full text of the responses can be made available on request[1].

Unfortunately we do not have monetary figures for the two largest, and presumably most costly, arrays: the VLTI and the KI. Furthermore, it is important to note that these facilities also provide science support in addition to array operations. Still, we can draw some conclusions from the data we do have. The final figure for the cost per telescope is over simplistic, being the total budget divided by the number of telescopes and the percentage of time on the sky, but it does help to give us some idea of the current funding levels for array operations. The final costs are, in fact, quite similar representing about \$100k per telescope in the array per year.

For comparison, we compiled similar information on a number of mm arrays as shown in Table 2. Here the final figure is some six times higher. Of course, this figure does not take into account array location or the size of the apertures, and the fact that we are missing figures for VLTI and KI must skew the result. Furthermore, if we factor in the number of papers published and the size of the user community things may seem more equitable. It is still interesting to see such a large difference.

One can also consider the "canonical" figure of having 10% of construction costs per year for maintenance. We don't have all the figures for all the systems, but in the case of CHARA this would be \$1.5M, twice the current funding level. Clearly, we are either working cheap or underfunding our instruments. Most likely both.

[1] Should they be in a appendix?

Table 1: Existing Facilities

Array	FTEs	PhDs	Night	On Sky	Budget	Subs	Trouble	Scopes	$/Scope
CHARA	6	67%	2	100%	$750000	150%	Metrology	6	$125000
SUSI	0.25	50%	0	30%	$50000	50%	Metrology Tiptilt Disp Corr	2	$83333
GI2T	1	10%	1	71%	$62500	125%	Scopes	2	$43750
PTI	0.2	0%	1	71%	$15000	200%	Legacy RT	3	$70000
NPOI	3	50%	3	100%	$800000	125%	Delay Line	6	$133333
Mean									$91083
VLTI	25	0%	2	95%	???	200%	New Sys	4	
Keck V^2	11^2	30%	5	3%	???	110%	AO/CT-Met	2	
Keck Null	11^3	25%	12	6%	???	110%	AO/CT-Met	2	

Table 2: mm Arrays

Array	Budget	Scopes	$/Scope
PdBI	$10000000	6	$1666667
BIMA	$2000000	10	$200000
OVRO	$2000000	6	$333333
SMA	$3000000	7	$428571
Mean			$657143

3 Problem areas

Not surprisingly, each group had different opinions on which subsystems are most problematic. It is, however, interesting to note that delay lines and metrology are mentioned by several groups. For example, at CHARA, the delay line metrology is the system most likely to fail, and requires constant adjustment and realignments. While this does point at design flaws in the system, it seems this is not a unique problem for CHARA. Furthermore, metrology and delay lines are listed as a problem in the groups with the longest metrology propagation path. As we move towards larger baselines and more telescopes, we suspect that metrology will once again be a problem area.

It is also interesting to note that the AO systems are mentioned as a problem area for the KI. As we move towards more and larger telescopes, there is little doubt that AO will play a part, and must be at least as reliable as the other systems in the array.

Another common theme was legacy software and hardware, though this must not be unique to interferometry and we can probably learn how to deal with this from other institutions.

4 Advice and Warnings

The final question had the most interesting, and lengthy, responses. These are set out here, in no particular order:

- Develop an automatic seeing monitor in parallel to the array. The seeing conditions affect interferometers more directly, and more quickly, than more ordinary observations. Being able to monitor and log the relevant seeing statistics can help plan observing strategies, on both the long and short terms.
- Automated data and environment logging. Like seeing, keeping track of an interferometers environment will help observation planning. Also, interferometers can create a large amount of raw data, which should be recorded and logged automatically.
- Plan on full testing and characterization. We are often tempted to move ahead with new systems and observing modes as they start to become operational. In a research facility this makes sense, but for a larger national, or international, facility more careful planing and testing of new hardware and new observing modes is extremely important.
- Make the operation (and array!) as simple as possible - offer a small number of modes but make sure these are reliable. Once a new mode is fully tested and characterized it should be automated as much as possible and made available to the observers. We

have a tendency to continue to tweak these modes, which can lead to break downs and confusion.

- It's also important to provide a mode of operation for more experienced "black belt" interferometry groups. The methods and techniques of interferometry are still very much in an early state of development, certainly as far as imaging is concerned, and it will be essential to provide a PI based mode to allow experimentation and development of new instruments and techniques.

- Implement metrics to follow the health of your systems. There are a large number of subsystems within any array, and it is important to have good metrics on how well they are performing.

- Be very cautious when trying to conduct nightly operations and develop the system at the same time. Engineering experiments and scientific observations don't mix well and there needs to be a clear dividing line between them. This means that we must plan the integration and commissioning of instruments very well.

- Buy critical spares when buying the original parts. It seems common for us to be locked into a piece of hardware, or software, that quickly dates. Spares of critical components should be purchased while these devices are still on the market. This also means we must include a serious, on-going budget for replacement parts in annual budgets.

- It is painful to write adequate documentation while developing a system, but it always pays off later, particularly if key people leave the project.

- It will cost much more than you estimate! Very few of us got the estimates for the costs of running a large array right. We must be prepared to have full year coverage of the technical staff.

- Make everything rock solid so it does not need to be realigned too often. There is a large amount of overhead in making daily, and even more frequent, alignment adjustments. For those systems that can not be made stable, automated alignment systems will be essential.

- Equip your array with pupil and image actuators and monitors. Beam shear and angle errors are two of the main alignment problems in all systems. There must be a way of monitoring both the image and pupil plans, and the ability to adjust them remotely.

- Bid for a realistic amount of operating costs. This is probably the single most important item, we must ensure that we fund the maintenance of any new array as well as the capital costs.

5 Conclusion

Optical/IR Interferometers have an amazingly large number of components and moving parts. If you start to count all the nuts and bolts in delay lines, telescopes, beam samplers and beam combining labs you reach the tens of thousands very quickly. Furthermore, these systems have multiple single point failure modes. These devices are difficult to build and not at all easy to maintain and manage, and as we move to larger facilities with more telescopes it's not going to get any easier.

To quote Finding 2 from the recent NSF senior review:

Major astronomical observatories typically take at least a decade to plan, construct and commission. They are usually operated for several decades. The full costs of operating, maintaining, upgrading, exploiting, and decommissioning them are many times the costs of construction. Realistic life cycle costing for the observatories that are under construction or consideration is an essential part of planning.

It is clear that most existing OI-Interferometry facilities are under funded for operations and long term engineering support, and that we all wish we had more personnel on the ground. The single most important lesson here is that we must ensure that any new facilities are adequately funded for operations on a long term basis.