Flagstaff Interferometry Forum Report
15-16 March 2013
Host: Lowell Observatory, Flagstaff, AZ

Forum Organizers:
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Introduction

The forum was organized around a list of topics – each topic had a moderator and an archivist. Each participant in the forum had one or more assignments – this was not a meeting for passive participation.

The following summaries are a slightly edited version of those notes; conclusions and recommendations are presented at the end of the document.

Friday's Discussions

Forum Concept Presentation and Initial Discussion

Moderator: van Belle
Archivist: Baines

The **Optical Interferometry Forum** was a special opportunity to get together and talk about a technique that is both important to our various areas of expertise, and scientifically productive. The interferometry[1] community has this opportunity only infrequently and incompletely, so having a more focused event with adequate time for discussion was, we felt, important. The attendance for the Forum was solicited from throughout the community and largely self-selecting; the organizers (Steve Ridgway, Gerard van Belle, Theo ten Brummelaar, Guy Perrin) accepted every request for attendance.

The rationale for the Forum can be summed up in two sides to the issue:

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[1] Throughout this report, "interferometry" is intended to refer to long-baseline optical interferometry - eg. Interferometry which operates in the visible and near- to mid-infrared, and principally employs reflecting surfaces and homodyne combination.

We live in a time of **Great Disturbances**: Big things are happening in astronomy that unsettle the status quo and make it challenging to develop and use the technique of optical interferometry. In the United States, this in particular includes the Decadal Review, and even the detailed plans laid out therein aren't quite happening as expected because of funding issues. On the European side, if the need for high spatial resolution is correctly described in the Science Vision document of ASTRONET, its declination in the Infrastructure Roadmap is clearly postponed. Development of JWST and the next generation of large ground-based telescopes require lots of resources, and operating costs of new facilities that are coming online (such as ALMA) have a large impact as well.

We also live in a time of **Great Opportunities**: There will be a time after JWST. The CHARA Array is soldiering along, the NPOI upgrades are poised to revitalize the instrument, VLTI has upgrades under development, there are new efforts in LBTI and MROI, and China is developing Dome A. The scientific productivity of the existing facilities is robust and unique.

All these circumstances inspired the organizers to put this forum together. The intent was to supplement the SPIE meetings (but not to supplant them). The annual CHARA Science Review meetings have been going on for a while and are growing in scope; this idea grew out of those meetings. Future versions of this Forum may grow into an 'official' interferometry meeting.

Since 2000 (and even earlier), the interferometry community set aside special sessions of an hour to a half day in length at other meetings, to have less formal interaction with discussion sessions and overview talks. While those were effective, they are always ad hoc with no set structure. For meetings like these, such as the SPIE, frequently a substantial portion of our community is somewhere else (eg. sessions on adaptive optics) so the organizers felt having a dedicated meeting would foster interaction and communication.

In defense of SPIE: it can be a drawback for some folks but an advantage for others, so the Forum is not intended to be the only gathering. Future Forums could be organized to be adjacent to SPIE to reduce travel. Having it *during* the SPIE is not attractive, because there are those who want to represent interferometry to other elements of the astronomical community in the general SPIE audience.

The questions we aimed to address by the end of the Forum:

- How do we envision this forum as related to other existing structure, such as the IAU, USIC, OLBIN, EII? We shouldn't duplicate those efforts.
- Do we want future meetings? Are they associated with the SPIE or other meetings? Are they combined with the interferometry schools in Europe?
- Do we want proceedings? The answer is probably yes. What are those written products?
- How do we best construct a plan for the future?

Active Plans of Current Facilities

Moderator: Herbst
Archivist: Baron

The Forum began with a review of the current facilities.

The **Very Large Telescope Interferometer** (VLTI) of the European Southern Observatory (ESO) is located on Cerro Paranal in Chile. The current suite of instrumentation for the VLTI includes the 3-way near-infrared AMBER combiner, the 2-way mid-infrared MIDI combiner, the 4-way near-infrared visitor instrument PIONIER, and the dual-beam 2-way astrometer PRIMA. There currently is also a 3-way fringe tracker FINITO that can feed AMBER, and PRIMA can also act as a fringe tracker for MIDI.

Planned instrument changes for VLTI from 2013 to 2018 include AMBER being upgraded to AMBER/PIO++; MIDI will be replaced by the 4-way MATISSE, which will extend wavelength coverage from the N-band down the L-band. The 4-way visitor PIONIER will be replaced by the 4-way GRAVITY instrument.

The VLT Array on the Paranal Mountain

ESO PR Photo 14a/00 (24 May 2000) ©European Southern Observatory

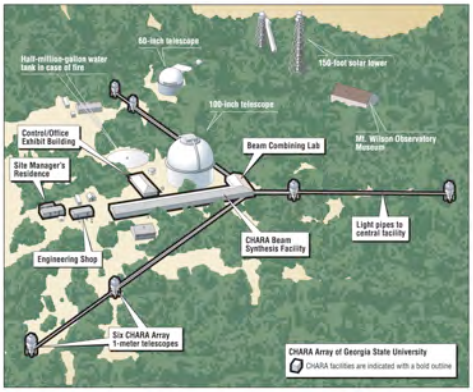
Infrastructure upgrades include the FINITO fringe tracker being upgraded by the second-generation unit 2GFT. Star separators for dual-beam feed to PRIMA will be deployed on all four 1.8m UT telescopes, and all four 8.2m AT telescopes. An adaptive optics system, NAOMI, is under development for the UTs. Longer range plans for the VLTI in the E-ELT era in 2020-2030 are also under development.

The **Navy Precision Optical Interferometer** (NPOI) is a joint activity of the United States Naval Observatory (USNO), the Naval Research Laboratory (NRL), and Lowell Observatory, located on Anderson Mesa near Flagstaff, Arizona. The USNO has recently accepted from CARA the gift of four 1.8m telescopes, originally intended for the Keck Interferometer, but not installed for non-technical reasons; the project currently has a FY2015 start funded to proceed with installing these telescopes. Additionally, there is ongoing development of 1.4m lightweight carbon-fiber reinforced-polymer (CFRP) telescopes. NPOI's use of small imaging stations out to baselines of 79m is being expanded with commissioning of stations for baselines of 98m and 432m in the next 12 months. The Tennessee State University VISION six-way beam combiner has been deployed on site, and on-sky fringes with four telescopes (4T) was demonstrated in January 2013.

The Georgia State University (GSU) **Center for High Angular Resolution Astronomy** (CHARA) **Array** is located on Mount Wilson, near Los Angeles, California. The CHARA Array is currently developing a two-phase adaptive optics program. Phase I involves deployment

of a wave-front sensor (WFS) and static correction, and is fully funded. Phase II will expand upon that infrastructure with deformable mirrors and active correction.

The CHARA Array's beam combiner back end hosts a significant variety of combiners from the visible to the near-infrared. Phase locking and fringe tracking using the CHAMP Beam Combiner is under development, for use with the University of Michigan MIRC combiner. An effort is underway for integration and standardization of beam combiner control systems, along with a telescope secondary mount upgrade. For the Classic and CLIMB combiners, a detector upgrade from NICMOS to HAWAII should improve performance. A delay line control system upgrade is underway, with the longer-term goal being a duplication of the upgraded NPOI system. Improvements to the time standard and time signal distribution should also improve the facility operations.



The **Large Binocular Telescope** (LBT), on Mount Graham in Arizona, is deploying two interferometric back ends. The LBT Interferometer (LBTI) is a 3-10 micron nulling interferometer. Data are collected by the LBTI after dual AO, at 4 and 10 microns; upgrade plans include improvement to 20” FOV for a 3-5 micron detector. The LBT's LINC/NIRVANA combiner is a 1-4 micron Fizeau imager, leveraging the LBT's multi-conjugate adaptive optics (MCAO) capabilities. The planned magnitude limit is 25th with a 1 hour integration time. PATHFINDER development is ongoing until Q2 2014; a planned upgrade is the addition of an integral field unit (IFU).

The **Sydney University Stellar Interferometer** (SUSI) in Narrabri, Australia, has been operating with PAVO as the primary instrument (a copy of PAVO is available as one of the combiners for the CHARA Array as well). A secondary instrument, MUSCA, has goals of planet detection, operating in a manner similar to the previous PHASES experiment at the Palomar Testbed Interferometer (PTI). SUSI is currently unfunded but can still operate due to low overhead; one notable aspect of its operations is that it is fully remotely operable. No upgrades are planned for this facility.

New Mexico Tech's (NMT) **Magdalena Ridge Optical Interferometer** (MROI) continues to undergo construction and development near Socorro, New Mexico. The fringe tracker is being deployed and tested in the lab; delay line and first telescope installation (in a maintenance facility) are expected later in 2013. Funding is being sought to complete

first fringe tests within 3 years. The preliminary design of the SIRCUS NIR imaging beam combiner is nearly complete.

Berkeley's **Infrared Stellar Interferometer** (ISI) on Mount Wilson operates in the mid-infrared with high spectral and high spatial resolution using a digital 3-way spectrometer-correlator backend. The ISI group is participating in a study to image geostationary satellites.

The **Keck Interferometer** (KI) has been formally mothballed due to lack of NASA operations funding. KI data are presently archived at the IPAC website by NExScI.

The **OHANA** (Optical Hawaiian Array for Nanoradian Astronomy) effort had success with an experiment at CFHT; fringes on bright stars were demonstrated. However, it is currently understaffed; a possible future collaboration with John Monnier at CHARA may be possible in the future.

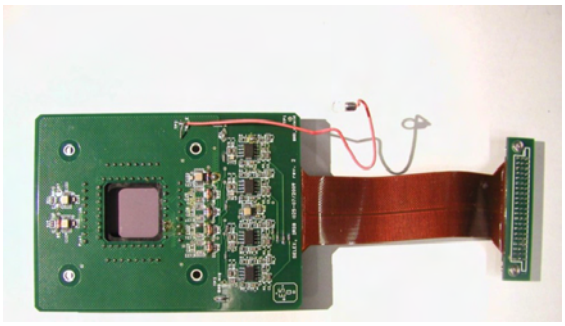
The **Cambridge Optical Aperture Synthetic Telescope** (COAST) has not been used for at least the past 5 years. The Cambridge group is now working on several other projects, including MROI.

Finally, there are several balloon experiments, including Labeyrie's 'hypertelescope' project ongoing in France, and the NASA Goddard's Balloon Experimental Twin Telescope for Infrared Interferometry (**BETTII**) mid-IR telescope, slated for first flight in 2015.

Significant Developments in Technology - Achieved or Needed

Moderator: Buscher
Archivist: Berger

New technology developments should be driven not only by the main scientific requirements but also by what is technically feasible - there is an interactive relationship between the science and the technology. For optical long baseline interferometry the main science necessities are to raise the limiting magnitudes, to improve the imaging capability, to allow for faint companion detection and characterization and to a lesser extent to allow scientific polarimetric measurements and astrometry.



One of the considerable advances in the coming years will be the arrival of new technology detectors such as the SELEX currently being test-developed at ESO in collaboration with other partners. These detectors should provide kHz readout possibilities with sub-electron read noise. In addition to that, all technologies related to improving the wavefront propagation quality (coatings, surface qualities, adaptive optics) have the potential to considerably improve limiting magnitudes. For adaptive optics the constraints are to develop low-cost systems for multi-telescope arrays, possibly with infrared wavefront sensors. To improve the sky coverage low cost laser star guiding

systems would be needed. Finally, multi-telescope phase-tracking systems should enable long integrations.

Pushing the aperture synthesis imaging capability requires more telescopes. The development of low-cost telescopes that are reliable, resistant to vibrations and possibly relocatable would help with this. Beam transportation through fiber optics could be further studied. At the central laboratory multi-telescope combiners will be needed with spatial/modal filtering capabilities and improved calibration capability of temporal effects. Other relevant technologies are integrated optics (2D, 3D), temporal hypertelescopes, and homothetic mapping. Additionally, "non-linear" optical technologies such as squeezed light amplification and parametric up-conversion may be of benefit, but the quantum physics are unfavourable. It seems obvious that all these developments do not only depend on the will of the community and that it is the convergence of all the technology readiness that will trigger the feasibility of large scale, sensitive, aperture synthesis optical facilities.

Funding and Other Practical Matters

Moderator: Wishnow
Archivist: Creech-Eakman

The various interferometry groups reported on current and near-term funding. There is not a surfeit of funding or human resources, particularly for all US-based facilities. The results of the top-level 2010 Astrophysics Decadal report have made it very difficult to obtain operational funding from US funding agencies, except in the case that this funding comes from PI based proposals for scientific experiments or new technologies. While the primary source of funding in the US for present-day interferometric science is NSF, we have previously benefitted (and some still do) from funds garnered via: the Defense Department (ONR, NRL, DARPA), NASA, Federal earmarks, and some state and institutional funds. As a community we have experienced limited success, mainly in the form of funding large pieces of hardware (e.g., telescopes) from philanthropic groups. While it appears that US-based facilities will continue to approach all of the same funding agencies, it is clear that operational support is not something most of these funding agencies are able or are eager to support. Much of this uncertainty in the US is related to the anticipated release of NSF's Midscale program.

In Europe the funding for VLTI is exclusively through ESO, and individual interferometer backends (e.g., beamcombiners and detectors) are provided by the community-funded national organizations or international partnerships. The status of the individual projects is fairly complex in almost all cases, and there is no clear path to medium and long-term funding.

Long Term Perspective on Astronomy Programs - Relation of Interferometry to Other Facilities

Moderator: Mourard
Archivist: Tuthill

The lesson from projects and programs that have been successful in securing resources both for construction and for ongoing science support is that broad based community support is required to drive major investment. It is not clear that the interferometry community has been successful in such community building (or even community

awareness) for the science we do. In order to launch major initiatives, often decades of careful lobbying and awareness raising are required.

The formal process by which this is done is usually through national or transnational planning processes such as the Decadal Plan in the US or the ASTRONET 2020-40 exercise in Europe. Here we take the latter as an example (these exercises usually come up with broadly common science themes which are judged to be top priorities). In general, it was recognized that interferometry was poorly represented in such exercises on both sides of the Atlantic. The onus is on the interferometry community to attempt to make the case for a stronger presence in future exercises of this type.

Analysis of the four main ASTRONET science cases[2] with highlighting of items especially relevant to optical interferometry:

- Do we understand the extremes of the Universe?
  - How did the Universe begin?
  - What is dark matter and dark energy?
  - *Can we observe strong gravity in action?*
  - *How do SN and GRB work?*
  - *How do black hole accretion, jets and outflows operate?*
  - *What do we learn from energetic radiation and particles?*
  - Current facilities: Planck, gravitational wave observatories*, Optical Interferometry, LOFAR*
  - Future facilities : SKA, X-ray survey satellite, ELT, CTA, LISA, sub-mm VLBI, neutrino observatories
- How do galaxies form and evolve?
  - How did the Universe emerge from its Dark Ages?
  - How did the structure of the cosmic web evolve?
  - Where are most of the metals throughout cosmic time ?
  - How were galaxies assembled?
  - How did our galaxy form?
  - Current facilities: LOFAR, PLANCK, 8-10m telescopes, ALMA, Gaia, JWST
  - Future facilities: ELT, SKA, X-ray-UV-IR space missions, far-IR space interferometer
- What is the origin and evolution of stars and planets?
  - *How do stars form?*
  - *Do we understand stellar structure and evolution?*
  - *What is the life-cycle of the Interstellar Medium and Stars?*
  - *How do planetary systems form and evolve?*
  - *What is the diversity of planetary systems in the Galaxy?*
  - *Is there evidence for life on exoplanets?*
  - Current facilities: 8-10m telescopes, HST-JWST, Herschel, ALMA, Gaia
  - Future facilities: *HRA on ELT and beyond*, SKA, *IR interferometer in space*, high spectral resolution
- How do we fit in?
  - What can the Solar System teach us about astrophysical processes?
  - What drives Solar variability on all scales?
  - What is the impact of Solar Activity on life on Earth?
  - What is the dynamical history of the Solar System?

[2] http://www.astronet-eu.org/spip.php?article40

- What can we learn from Solar System exploration?
- Where should we look for life in the Solar System?
- Current facilities: Space and ground solar observatories, Rosetta, ALMA, LOFAR, solar system exploration
- Future facilities: EST/ATST?, UV satellite, earth-based radars, exploration, JWST, ELT

The good news is that interferometry, as presently formulated, does seem directly applicable to large parts of two of the four major themes from ASTRONET. There was discussion (although no consensus) on the question as to whether it is more important to play to those strengths we already do well, or to try to expand to tick more of the boxes with our instruments. In the end this decision may be taken out of our hands by technical arguments - the parts of astronomy we don't contribute to are hard for fundamental detection reasons.

It was recognized that none of the present crop of major instruments could be considered to be fully "mature", and in this sense we can expect a continuing strong growth in science even with no major new investment at the scale of a major facility. This generated debate about whether our focus should be on exploitation of the present instruments or pushing for a visionary new machine with significantly enhanced capabilities in future. Although there was not universal consensus on this point, more of us seemed to think that for now we need to get the most out of existing facilities. Long range planning is of course not excluded by this.

We must be careful that we are not perceived to be in competition with major community investments such as ELTs. There are plenty of opportunities for synergy and cooperation - both VLTI and KI being excellent examples.

We are slowly gaining recognition and traction within the stellar physics community, although more could be done to spread the word more widely. It is still common to encounter astronomers who do not know that stellar diameter measurements are possible. Better engagement with the community is vital for any prospect of growth, or indeed survival.

Next-Generation Interferometric Science - Opportunities and Requirements

Moderator: Berger
Archivist: Petrov

The discussion started by asking the instrument or facility representatives to say a few words about:

- Their scientific drivers
- What kind of trend they see in their use
- Their subjective feeling of success

A broad range of instruments and programs was quoted. The following is an attempt to isolate some key points.

Old and new science goals and trends

- We have evolved from "fundamental parameters" (diameters, masses, distances…) to "general stellar astrophysics"

- There is an (unfinished) evolution from performance to science driven designs. For example GRAVITY is optimized for the observation of the Galactic Center with certain sacrifices.
- We have not delivered all that we initially promised. We have actually delivered much more. For example, we have
    - solved "old" astrophysical problems and modified new ones;
    - provided images on complex objects with unexpected shapes.
- One major field has been abandoned: the direct detection and characterization of extrasolar planets. More precisely, this field has abandoned us: ground and space interferometry are not expected to be a major contributor to this topic any more. This has a major impact on the long term plans for major interferometers.
- There is an open discussion about the real future of extragalactic applications: is it enough to increase the limiting magnitudes; when do we need to move to much larger baselines; is there a major science case beyond AGNs and QSOs?
- Marketing strategy
    - We discussed the need to advertise attractive science goals, with the risk of overselling our potential and being eventually punished for it. Even if we had to abandon some topics, we have not really oversold the potential of interferometry, which has delivered a fair deal of what it promised plus a large sample of unplanned results.
    - Another discussion about our "marketing" strategy is about the necessity to insert our science potential into the large objectives of the ASTRONET or US Decadal prospective. We need to place interferometry in this global landscape if we want to obtain substantial resources. However, by doing so, we might harm some important "basic" science and blind ourselves to new perspectives.
    - These debates about "marketing" are not closed.

Past and present perspective

- Ten years ago, Optical Interferometry was a difficult technique, with very few results, and a grandiose future, with a long term path: the "small interferometers", then VLTI-KI, then DARWIN-SIM, then some kind of OVLA.
- Now, optical interferometry is a difficult technique, with a lot of results, great expectations for the 2015-2020 period, and a dim future. After the 2nd generation VLTI instruments (e.g. GRAVITY) and the completion/extension of the US arrays, the horizon is opaque.
- We need a long term perspective:
    - Our grail could be a super interferometer, imaging very faint targets with dense u-v coverage and kilometric baselines.
    - As this might be overwhelmingly expensive, we could switch to two more "modest" projects:
        - A very good imaging interferometer, with very dense u-v coverage, but relatively less demanding in sensitivity and maybe resolution (a super CHARA or NPOI+ or MROI+)
        - An interferometer shaped for very faint sources at very high angular resolution, with a smaller number of larger apertures (a super VLTI, not necessarily on Paranal).
    - We have the tools to specify and evaluate such concepts, but we need to coordinate this evaluation and to agree on the criteria and the procedure.

Saturday's Discussions

Forum Concept - Discussion Continues

Moderator: ten Brummelaar
Archivist: Schmitt

The general consensus was that, while having a gathering on this topic was productive, a specific set of outcomes from this meeting was necessary. Who are we and why are we here? Is this meeting to plan for more planning meetings? Are we working towards an optical VLA? Towards a space mission? Are we simply trying to stay alive? It seemed that all of these things applied.

What can we do that no one else can do?

Is there a need for a global and unified vision? ESO is "only a small part of our user base"; in the USA the next decadal review already looms large on the horizon. There was broad agreement that a unified global vision is required.

Do we do this under an IAU Banner? Yes. The IAU, not only Commission 54, should take a role in leading and guiding, or at the least coordinating and endorsing, the development of this vision.

How do we best sell ourselves to the community? The potential user base is larger than most people think.

Should there be a publication or written statement from this meeting? Yes; there was broad agreement that we should have a written record of this discussion. The forum chairs will put together an executive summary to be distributed amongst the forum members and published in some manner, on the OLBIN email list at a minimum.

Is this the forum for building a long term science case? Yes; we should think on the time scales ranging from a few years through to the time of the next decadal survey and even longer. A consensus is needed in order to promote a big instrument like an OVLA. ALMA is be a good example. A roadmap for future developments is needed. The US and EU roadmaps are not well coordinated, which should be changed. The IAU C54 Chair should appoint a panel chair to coordinate this work.

In order to prepare for a major facility in the future, it is necessary to do a lot of preparation over many years. In order to make this preparation happen, it is necessary to begin working now or soon.

This forum is not an alternative to the SPIE but offers an opportunity for interaction that has not been achieved at the SPIE. There was a consensus that the forum should be repeated in an annual or biennial pace. Considerations for possible future forum meetings:

- In SPIE years, it is possible to have a Forum meeting separate from but adjacent to the SPIE, or to have a segment of the SPIE meeting devoted to Forum activities.
- What about non-SPIE years? One option is to have it in non-SPIE years, possibly as an additional meeting during the CHARA meetings. The CHARA annual science meeting has developed over the years, and this year includes NPOI. What direction

might it go in the future? Perhaps it could extend its scope to include at least some aspects of activities at other facilities.

Part of the value of this meeting is the relatively small attendance and the resulting intense participation by attendees. Should the meeting size be limited in the future? Should future Forum participation remain self selected?

Interferometry User and Operator Experience

Moderator: Delplancke
Archivist: Stencel

The following topics related to the status of various facilities—the VLTI, Keck-I, CHARA, NPOI, MROI, LBTI and LINC NIRVANA—were addressed:

- Is the facility an open user and/or a proprietary user facility?
- How is the time allocated?
- How organized are the data acquisition and reduction?
- Is user support available?
- Are the data archived? And is the archive publicly available?
- What were the difficult things that went well and what were the easy things that turned out to be difficult?

VLTI instruments each have well-developed data pipelines, user support and training (summer schools), but work within a constrained template system that limits flexibility. Data rights are clearly stated.

VLTI and NPOI found that changes to telescope array baselines were far less frequent than planned, due to complexities of telescope re-alignments after movements.

Proprietary facilities state that they are open to collaborations, but have resource limitations for hosting, training and processing data requested by visitors. CHARA cites its great flexibility in operational modes and their great access by GSU graduate students.

CHARA and its combiners use OIFITS, NPOI does not. CHARA's NOAO access is considered successful in attracting wider interest. SUSI finds OIFITS insufficient for its special parameters. JMMC currently hosts an IAU forum for the design of an OIFITS version 2 document. Both Data Providers and Consumers of OI data participate to this forum: http://www.jmmc.fr/twiki/bin/view/Jmmc/OIFITSTwoProject Encouraging news is that Lowell is rewriting NPOI data pipeline software that can lead to wider use. LBTI is developing pipelines and web-based archives. MROI is planning data reduction software (Level 1) and recognizes the need for data reduction workshops.

At the LBT, the time allocation is essentially proprietary, blocked for the partners. There is the possibility of night exchanges. For LINC-NIRVANA only 24 nights are booked for commissioning. If the commissioning time goes beyond 24 nights, LINC-NIRVANA will have to return one night of community support for each additional commissioning day. There is also a taxation system whereby one partner can bring five nights to get four nights on another instrument.

On LINC-NIRVANA a great deal of effort has been expended in observation preparation and data reduction. They are in advanced state. Standard FITS format is used (direct imaging data). The LBT has a web-based archive in which LN data will be ingested.

Discussion

The advantage of having an open user community or at least to partially opening a facility to all users is the increased the scientific return. Some proprietary facilities are sitting on unreduced data due to lack of available manpower.

The usefulness of OIFITS data format was discussed. The advantages are that imaging data packages are based on that format and that it allows combining observations from different facilities (e.g. CHARA and VLTI). However, in the case of some very specialized instruments, the current format is not enough. We should consider whether improvements to OIFITS are needed and whether its use should continue to be recommended. It is probably important to keep such a standard to give access to interferometric data to a large community (see comments above).

The availability of good data reduction packages, properly supported, is essential if we want to widen our user community. The issue is no longer so much on the imaging data package but in calibrating the data well and assessing their quality. Currently a new user has to sit with an experienced interferometrist to do these first steps properly. A data reduction package will be developed for MATISSE and GRAVITY, but on the US side an equivalent effort is either not present or is present at very low level (NPOI and Oyster development) and is not financially supported for the future.

The language to use for the data reduction was briefly discussed. Opinions were very diverse and will remain so in the future.

Conclusions and Recommendations

To attract external interest, proprietary and new facilities could host an online catalog of observed target and calibrator objects, even if making OIFITS or equivalent data generally available comes (much) later. This will allow archive users to find potentially useful information that we uniquely can provide, and perhaps homogenize access to good calibrators. For example, CHARA+VEGA data are available on VizieR (but only data on which a paper has been published.) Questions to address include: where should these catalogs be hosted? Should they also include data on which no paper has been published? JMMC will open a VO-compliant optical interferomery database (i.e., interoperable with other tools of the Virtual Observatory, allowing Data Discovery from external resources) at the end of 2013. Initially designed for VEGA and PIONIER "reduced" or "published" data, it will be designed to be easily extendable to other instruments or facilities, at no cost.

The US community should consider creating interferometry "webinars" that mirror the European ones and complement what the Michelson Science Center used to offer. A natural opportunity could involve a collaboration among GSU/NAU/NMT - each of which already serves under-represented populations and thus could anticipate NSF training grant funds. They could be bilingual (in Spanish and English) And eventually extend to Central and South American students in similar time zones.

IAU Commission 54 should devise a survey for all facilities. The information collected in this survey could then be posted on OLBIN.

Blue Sky Thinking

Moderator: Eisner
Archivist: Payne

We need to identify high profile science goals that only interferometry can attack. If the science is compelling enough but is out of the reach of current facilities, we may be able to promote a new facility—space- or ground-based, as the science dictates—as a single experiment (e.g., the Event Horizon Telescope). When new facilities are built, they often work well beyond the original science goals.

But we also need to identify science goals that get the most out of current facilities. HST is a good example.

Example science goals that were discussed:

- Precision astrometry in dense fields
- Low-mass exoplanets in clusters
- Star cluster kinematics to explore general relativity, H_0, dark matter, etc.
- High angular resolution imaging and spectroscopy
- AGN disks and black hole masses
- High redshift galaxy kinematics (possibly including merger physics)
- Terrestrial planet formation via disk structure asymmetries
- High contrast imaging
- Planets at very small separations
- Fundamental stellar parameters for a wider range of stellar types, e.g., direct angular diameters of white dwarfs
- Dark matter calibration in a small cluster
- Imaging asymmetric stellar structure
- Constraints on exoplanet hosts
- Asteroid imaging

Science of interest outside astronomy that may yield support

- Wide angle astrometry is of interest to the Navy and should be of interest to NASA (GAIA will not hit the bright stars needed for navigation)
- Imaging GEO satellites is an interest of DARPA; communication satellite companies might also be interested.

Basic limits

- Sensitivity to low surface brightness features (galaxies for example have very low surface brightness, although this may not be as true of emerging galaxies) often requires good u, v coverage.
- Using longer baselines leads to less flux per resolution element, which may drive a need for larger apertures.

Technological possibilities to be explored

- Increasing aperture diameter: bigger is better (modulo AO problems)
- More apertures: improves u,v coverage at the possible cost in sensitivity and the certainty of higher expense
- Baseline extremes of B_{max}, B_{min} to increase angular resolution and dynamic range
- Beam propagation in fibres
- Beam combination using photonics technologies

- Other styles of interferometry, such as heterodyne detection, optical amplification, and intensity interferometry
- Detector requirements: increased sensitivity, increased number of pixels for spectroscopy, fast clocking for precision
- Extending wavelength range to the blue: shorter wavelengths produce higher resolution

Site considerations: High? Cold? Space?

- Explore piggy-backing on existing or planned facilities, such as ELT's or LIGO, which already has mile long vacuum tubes
- Explore mounting small telescopes on a larger one and linking them with fiber, e.g., GBT (Green Bank Telescope) 100 meter off-axis radio telescope, CCAT (25 meter mm-submm telescope)
- Situation in Antarctica
    - Query the status of dome C
    - Dome A
        - Chinese building their own interferometer at a domestic site for testing (in poor seeing conditions)
        - There is a requirement for building an optical interferometer - Zhongwen Hu
        - Already two or three telescopes on site at Dome A, one is a wide field telescope
        - Long discussion on the pros and cons

International Collaborations & Coordination

Moderator: Armstrong
Archivist: Herbst

Hardware Collaboration

Instrumental collaborations are more difficult than observational collaborations. One of the primary obstacles to instrumental collaboration is the perception that, e.g., a proposal to VLTI must have a European PI. In actuality, ESO evaluates proposals without regard to where they come from, but allocation considers PI institution. Being Co-I is the route to follow.

Instrumental collaboration at CHARA has taken the form of outside users, many of them European, bringing instrumentation to CHARA. This approach has worked well in making CHARA scientifically productive.

Observational Collaboration

Our interferometer facilities are complementary in interesting ways. One example is CHARA and NPOI baselines for visible imaging. Another is VLTI and CHARA baselines for near-IR imaging. If multiple facilities can be utilized in coordination to produce better science, it will benefit not just the particular project, but the entire community. It was suggested that CHARA and ESO might coordinate to offer access to both the ESO AT’s and the CHARA Array for proposals which need both.

Another route to observational collaboration is collaboration on data archives, to provide data on when particular targets have been observed by various instruments to users (especially new users), and on educational/instructional information, which currently isn't well served by OLBIN.

Collaboration on Software

Is there a regime between highly instrument-specific data-processing and high-level imaging on which collaboration would be useful? Collaboration could range from exchange of approaches to production of software. An EII collaboration with moderate funding from ESO has started, focused on coordinating image reconstruction algorithms, developing cookbooks and making how they work clearer. The above-mentioned JMMC OI database is partially funded through this EII grant.

The Role of Formal and Informal Community Organizations and Networking

Moderator: Mozurkewich
Archivist: Elias

Communication among the various groups around the world is lacking. Better communication is required for the survival of optical interferometry, successfully funding next generation instruments, and organizing for the next decadal review. Getting together every two years at an SPIE meeting is not sufficient.

OLBIN has been the communications vehicle in the past, but there has been very little recent activity. It was proposed to upgrade OLBIN to a wiki, which is newer technology. It was also proposed to start a Facebook page for more rapid dissemination of relevant information. Both the wiki and the Facebook page would be run under the auspices of IAU Commission 54. Part of OLBIN is hosted at JMMC.

In Europe, EII is the voice of the VLTI community. It makes recommendations to ESO. USIC partially filled that role before the last decadal review, but it has fallen into disuse. It has been proposed to resurrect USIC as the US equivalent to EII to speak on behalf of the optical interferometry community to NSF and the next decadal review. EII runs workshops and schools. Is that possible for USIC? It was also suggested that EII, USIC, and possibly other groups organize for global planning. What do groups have in common, how do their efforts complement each other, and how can we coordinate more effectively to revitalize the field?

Plans for Future Activities

One model: an interferometry science & technology meeting (ISTM)

- The Annual CHARA Science Review has evolved (for 2013) into CHARA-NPOI. Should it evolve further into an ISTM?
- Frequency: annually to every two years? For the latter, the SPIE 'off' years could be when a larger ISTM is held.

Future forum details

- Keeping the attendance modest, to ~20 people, is helpful to streamline discussion & interactions
- Complete or nearly-completely representation from world interferometry groups is desirable

- Such future forums could be adjunct to SPIE or ISTM meetings, just as the 2013 Forum was adjacent on the calendar to the CHARA-NPOI meeting

Interferometry rocket, stages:
1 - Road map
2 - Organize interferometry ('specialist') conferences
3 - Organize scientific conferences to popularize interferometry
4 - Organize meetings to work on potential science cases
5 - Be active in committees planning/defining the future

Conclusions

- Interferometry has gone from an exotic technique with promise, to a demonstrated technique with a steadily growing technical capability, a large and active community, and significant impact on stellar physics.
- Opening access to a wider community has demonstrated benefits. Opening to a wider community is also due to the availability of data preparation, data calibration, data reduction and data interpretation packages, in a word, documented, reliable and well behaved user-friendly software.
- Funding
  - In Europe, VLTI funding, including some development, is currently stable. France, through its funding by INSU of, e.g., JMMC, plays a supportive role for OI interferometry well beyond its contribution to ESO funding. Positive feedback is needed for this effort to be considered worthwhile by the funding agencies.
  - Interferometry in the U.S. is not strongly supported by the Decadal report, and there are reduced opportunities at NSF but there is a possible future "mid-scale" funding opportunity.
  - In the next 10+ years, the interferometry community must make the most of existing facilities and their obvious extensions.
- Possible facility options for the future on the decade+ time-scale include:
  - Moderate development from existing facilities to much enhanced imaging capability
  - Moderate development to fainter target capability
- Possible options on the decade++ time-scale include:
  - Major development of a super-facility
  - Not in sight at present
  - Now is the time to build a consensus for the next major development.
- The meeting was a success.
- An International Interferometry Forum is needed and has numerous important roles.

Recommendations

- The Forum should have both on-going and annual activities.
- The Forum should develop a charter.
- The Forum should use the IAU banner as a Commission 54 activity.
- The Forum should engage IAU officers and members in Forum work.
- The Forum should hold annual meetings:
  - Adjacent to SPIE in SPIE years.
  - In alternate years adjacent to CHARA-NPOI meetings or schools.
- The Forum should publish Forum reports, including from this meeting.
- The Forum should foster long-term development of interferometry science directions.
- Roadmaps are needed – including U.S.-Europe coordination of roadmaps – which requires U.S. entity to develop roadmap.
- USIC should be revived, to develop a national consensus and to represent the U.S. to Europe.
- We encourage making catalogs of observed targets available.
- We encourage improved archive access.

- The U.S. community should consider "webinars" as a low-cost implementation of interferometry schools.
- U.S. PI's should be encouraged to propose to VLTI.
- Joint facility access – CHARA-VLTI, CHARA-NPOI, NPOI-VLTI – should be studied.
- The scope of the CHARA-NPOI meetings should be expanded, at least in SPIE off-years.
- OLBIN should be rebuilt in a supportable form, perhaps as a wiki.
- The community should make use of social media, including starting and maintaining an interferometry Facebook page.

Draft Forum "Charter"

The International Interferometry Forum

The Forum will organize occasions and channels for communication, facilitate coordination in planning, and encourage and promote opportunities for technical and scientific collaboration, both within and beyond the interferometry community.

The Forum will operate as an element of IAU Commission 54. The commission officers will take initiative and personal responsibility for ensuring some Forum activities. Initially, these will include: organizing annual Forum gatherings, continuation of the online OLBIN functionality in a more sustainable incarnation, and implementation of social media networking opportunities, such as an IAU C54 Facebook page.

Forum participation will be open to the community. The IAU officers will call on and benefit from the support of Forum participants in carrying out their Forum responsibilities.

Forum Participants

Tom Armstrong (NRL)
Jean-Philippe Berger (ESO)
Fabien Baron (UMich / GSU)
Jim Benson (USNO-FS)
David Buscher (Univ. Cambridge)
Michelle Creech-Eakman (NMT)
Francoise Delplancke (ESO)
Joshua Eisner (U. Arizona)
Nicholas Elias (OAMS)
Tom Herbst (MPIA-Heidelberg)
Don Hutter (USNO-FS)
Fabien Malbet (Grenoble)
Denis Mourard (OCA)
David Mozurkewich (Seabrook Engineering)
Ifan Payne (NMT)
Guy Perrin (Paris-Meudon)
Romain Petrov (U. Nice)
Steve Ridgway (NOAO)
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