THE BIG OPTICAL ARRAY

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ABSTRACT. The Naval Research Laboratory and the US Naval Observatory are building a phase tracking optical interferometer for high resolution imaging and astrometry. This instrument will be a six element interferometer capable of true imaging using interferometric amplitudes and closure phases. This talk will describe the instrument, with an emphasis on those aspects of the array related to high resolution imaging. The status of the project will be presented. First light is planned for October 1993, with 6 element imaging beginning in 1994.

1. Background

The Mark III Optical Interferometer is operated by the Naval Research Laboratory on Mt. Wilson, CA. Using active fringe tracking and baselines ranging from 3 to 31 meters in length, the instrument observes stars and stellar systems with a resolution down to a few milliarcseconds at visual wavelengths. Results from recent observations with the Mark III Interferometer are presented in papers at this meeting by Andreas Quirrenbach, J. T. Armstrong, and C.A. Hummel. Highlights of these results include: Diameter measurements of Nova Cygni 1992; Diameter measurements of stars in the TiO band compared to the continuum, revealing the extent of TiO surrounding the star; Resolution of the hydrogen disks surrounding Be stars using observations in the Hydrogen alpha line; Observations of Alpha Bootes confirming the presence of substantial limb darkening for the star; Extensive results on binary star orbits, with determined orbits for more than 20 spectroscopic systems; and high precision wide-angle astrometry.

Experience with the Mark III Interferometer led to a collaborative effort at the Naval Research Laboratory and the US Naval Observatory to develop new interferometric instruments for imaging optical interferometry and high precision stellar astrometry. Subsequently, the instruments have been combined into a single interferometer which is being built with collaboration of the Lowell Observatory, on Anderson Mesa near Flagstaff, Arizona. The official title of the instrument is The Navy Prototype Optical Interferometer at Lowell Observatory; The Big Optical Array is the part of the project aimed specifically at high resolution imaging. This paper describes the capabilities and current status of The Big Optical Array. The USNO Astrometric Interferometer is the part of the project aimed at astrometry, as is described in papers by Don Hutter and N. Elias in other papers presented at this meeting.

2. The Big Optical Array: Instrument Description

BOA will be a multi-element imaging interferometer, located near Flagstaff, Arizona on the Lowell Observatory site. It will operate in two modes: the first for imaging, described here, and the second for astrometry (described by D. Hutter and a

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related paper by N. Elias in this volume). Key features of the instrument are summarized in Table 1 below. Details of the control system for BOA were presented by K. Buchanan in this volume. Several features of the instrument are especially noteworthy:

2.1 BEAM TRANSPORT AND PATH DELAY

The siderostats in BOA will direct star light into the feed beam system through a window. The light will then move through evacuated pipes to the vacuum delay lines. This approach has two principle advantages. First, the feed pipes protect the wave front from degradation by turbulence near the ground; this will be especially important on long baselines, where path lengths near the ground may be several hundred meters long. Second, the use of vacuum delay lines minimizes the effects of differential atmospheric dispersion and allows the use of detector-limited bandwidths. Other approaches, such as using selected glass compensator plates, are being used by other groups (for example, see the description of the SUSI instrument by John Davis in this volume). The advantage of air delay lines is reduced cost and reduced complexity of the delay line, at a cost of a significant reduction in bandwidth and sensitivity. Since sensitivity is a crucial consideration for BOA, and since astrometry precludes the use of variable dispersion compensation, BOA will be using vacuum delay lines.

2.2 MULTIPLE BEAM COMBINATION

Interferometric imaging requires observing the complex fringe visibility for an object on a variety of baselines, ranging from those which provide partial resolution of the object to baselines on which the object is heavily resolved. For the latter, direct detection of the interference fringes will not be feasible, since the low fringe visibility

Table 1: NRL / USNO Optical Interferometer Key Technical Features

6 Elements (0.5m siderostats)	**Active fringe tracking**
0.35m clear aperture	Multi-channel dispersed fringe det.
Vacuum beam transport	Fiber-fed APD arrays
Vacuum Optical Path Delay	"Phase bootstrap" on long baselines
Minimize dispersion	**Full phase closure for imaging**
Maximum possible bandwidth	Goal: ±0.1°
2μ IR capability (future)	Internal metrology in combiner
3, 4, & 6-way beam combination	**Large Optics Lab**
4 fixed Astrometric siderostats	Multiple experiment configurations
6 movable Imaging siderostats	Future upgrades
Initial configuration: 5 to 60m	**Fully automated operation**
Ultimate configuration: to 470m	Reliable calibration
Y-shaped layout, reconfigurable	Efficient observation
Full metrology	**High Sensitivity**
End to end delay, continuously	~10-12th Mag. (or more?)
Siderostats to bedrock	~4-5th Mag. when imaging
Full baseline monitoring	

reduces the SNR, roughly as (Visibility)^2. Thus, we have adopted a "phase-bootstrap" approach that uses a partially redundant arrangement of baselines. In the "phase-bootstrap" method, all elements of the array are arranged with roughly equal separations, so that each array element is connected to another via a short baseline (which will presumably have high fringe visibility). Fringes can be detected and tracked on these short baselines, with active compensation for variable path delays caused by atmospheric turbulence. The instrument is thus co-phased, allowing longer coherent integration to measure fringe visibilities on the long baselines where fringes are weak. For this procedure to work, all of the baselines in the array must be observed simultaneously, requiring multi-beam beam combination. D. Mozurkewich presents the details of the beam combination approach we have adopted for the initial 3-way beam combiner in this volume. Four-way and six-way beam combination can use a similar approach, although the complexity of the required optics may make alternative approaches attractive.

2.3 SENSITIVITY

The limiting magnitude for BOA is determined by the maximum usable aperture, the usable bandwidth, the atmospheric coherence time, and the stellar fringe visibility. The active fringe tracking algorithm requires ~100-200 photons detected across all the spectral bands being used for successful fringe tracking. For an unresolved star, with typical conditions of ~10cm r_0 and ~10ms coherence time, and an observing band of roughly 450-800nm, we estimate that fringe tracking will work down to about m_V~10. Active fringe tracking may be possible for stars fainter than this, under unusually good seeing conditions.

The limiting sensitivity for imaging is greatly reduced. Fringes must be recorded on 15 baselines simultaneously (for a six element interferometer). In this manner, the strong fringes on short baselines can be used to co-phase the array elements and allow coherent integration of fringes on the longest baselines where the fringes are weakest. We estimate that for a six element array like BOA, imaging sources with 10 resolution elements across the source will require stars with m_V~4-5.

Several future enhancements are possible to improve the sensitivity, such as near-IR operation, adaptive optics, and eventually artificial laser guide stars. M. Colavita discusses the ultimate limits to ground based interferometry in this volume.

3. Project Status

The Optical Interferometer project is currently in its busiest phase, with site preparation in full swing in Arizona while fabrication of the major optical, mechanical, electronic, and software systems takes place in Washington, DC. Prototypes of most of the major mechanical, optical, and electronic subsystems required for initial operations have been prototyped and tested (including the siderostats, vacuum delay lines, feed system hardware, 3-way beam combiner, APD detectors, laser metrology systems, and star acquisition and tracking systems). The control building on site is completed, while the main optics lab is under construction. Final integration on site will begin in Summer 1993. First light with three elements is scheduled for Fall 1993, with full operations and imaging using six elements for imaging to begin in 1994.

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