



## National Optical Astronomy Observatory

### ADAPTIVE OPTICS DEVELOPMENT PROGRAM (AODP) FY 2003 PROPOSAL CYCLE

See: <http://www.noao.edu/system/aodp/>

#### ANNOUNCEMENT OF AODP AWARDS FOR 2003

Issued March 26, 2004

The 2003 AODP grants competition received 17 proposals covering the full range of adaptive optics technology. A community-based review panel recommended funding of six proposals in the areas of laser beacon technology, detectors, deformable mirrors, and algorithms. As formal funding agreements are concluded, the approved and funded projects will be listed here.

The recommended awards total \$2.56M in 2004. Five of the programs are multi-year programs, and the total run-out cost, if all programs are continued to planned completion, will be \$7.7M.

- *Development of the Next Generation Optical Detectors for Wavefront Sensing* (PI James W. Beletic, California Association For Research In Astronomy).

This project will implement a major advance in the performance of Adaptive Optics (AO) systems by developing significantly improved optical wavefront sensor detectors.

Remarkably, the readout noise of AO CCDs has not improved in nearly 10 years. It is time to do something about this, and to push the technology of optical wavefront sensor detectors to the next level. We will address the readout noise performance issue in two ways:

1. Develop lower noise amplifiers. We will test a new amplifier technology, the planar JFET, which has the potential to significantly reduce noise.
2. Put many of the lowest noise amplifiers on a single CCD. Since readout noise decreases with decreasing readout rate, more amplifiers is a certain path to producing wavefront detectors that will be significantly better than those currently in use on astronomical telescopes. We propose a CCD with 20 amplifiers, a fivefold increase over the 4 amplifier CCDs now used for wavefront sensing at the Gemini and Keck telescopes. At the same time, we will provide 8x8 pixels per Shack- Hartmann subaperture, a significant advantage over the quad cells in use today at Keck and Gemini. This development approach will significantly benefit today's systems, while developing technology for the ELT era.

In addition, the full utility of AO will only be achieved when broad sky coverage is possible. The laser guide star (LGS) has begun to demonstrate the potential for AO over more of the sky, but very little work has been done to optimize wavefront sensor detectors for operation with LGS systems. We believe that a combination of pulsed laser

operation and a detector with a novel pixel layout designed to track the laser pulse through the sodium layer will improve LGS system performance and make it possible to produce photon-noise-limited detectors for ELT LGS systems.

- *Compact, Modular Scalable Versatile LGS Architecture For 8-100-M Telescopes* (PI Allen Hankla, Coherent Technologies, Inc.).

CTI proposes a new and unique solid-state architecture for sodium laser guide stars (LGS). The proposed architecture is based on a set of requirements that has been determined after extensive discussions with the astronomy adaptive optics community. These are:

- Compact, robust, reliable, low-maintenance and affordable laser system;
- Compatible with observatory environmental conditions – either direct telescope mounting or via fiber transport from a nearby room;
- Manufacturable system (simple with low-parts count) that can be reproduced at moderate cost;
- Near diffraction-limited laser output power, intensity and polarization that can be optimized with only minor modifications for AO systems based on: single laser beacons on 8-10 m telescopes; multi-conjugate adaptive optics (MCAO) on 8-10 m telescopes or on future 30-100 m extra-large telescopes;
- Laser temporal format optimizable for efficient sodium layer interaction for each telescope/ AO system with mitigation of parasitic effects such as parasitic Rayleigh or cirrus cloud scatter of adjacent beacon light in MCAO; and spot elongation in the sodium layer from off-axis light launch in an ELT;
- Modular laser architecture that is readily scaled to kW average power levels.

Our proposed solution is based on two critical components: (1) a versatile-waveform low-power master oscillator based on CTI's ultrastable COTS laser modulated by a telecom heritage COTS fiber-modulator to generate a temporal and spectral format tailored to the sodium interaction; and (2) compact amplifier chains that implement patent-pending self-imaging waveguide technology to achieve the necessary high gain without significant noise or beam/ waveform distortion, but with high efficiency and near diffraction-limited beam quality in a small footprint. Through interactions with fiber vendors, the program will also evaluate high power ELT-format 589 nm beam transmission through the new generation of large mode area photonic crystal or double-clad fibers. A three phase program is proposed in order to provide NOAO with funding

flexibility and go/ no-go decision points. Phase I will develop a compact breadboard 20 W 589 nm LGS based on the new technology, and Phase II scales the 589 nm output power to 100 W ( $5 \times 20$  W). Beam transport through large mode area photonic crystal and double-clad fibers will be assessed in each program phase. Phase III will develop a fieldable breadboard version of the Phase II hardware that can be deployed and tested at a suitable observatory.

- *Practical and Analytical Assessment of Adaptive Optics concepts Required to Provide Atmospheric Compensation for the Next Generation of Large Ground-Based Telescopes* (PI Glenn A. Tyler, The Optical Sciences Company).

At this point in time, it is anticipated that sodium-Rayleigh laser guide star constellations will be required to compensate the turbulence induced aberrations present in a very large diameter ground based telescope. The work conducted during the proposal phase of this activity has illustrated that such hybrid guide star techniques provide an important match with multigrid mathematical techniques and result in efficient wavefront reconstruction algorithms.

The major issues include physics issues and practicality issues. The physics issues are concerned with the low spatial frequency aberration distortion that may prohibit accurate combination of laser guide star data over very large diameters. The practical aspects of the problem are concerned with the development of algorithms that can be used to take the data from a large number of wavefront sensors and combine the data in an appropriate manner to reconstruct the wavefront in a time that is short enough to allow the computed wavefront correction to keep up with the temporal dependence of the atmosphere.

The purpose of work performed is to develop and assess advanced concepts that show promise in this application. The work may include but will not be limited to hybrid sodium and Rayleigh laser guide star concepts, natural guide stars, multigrid techniques, exponential class reconstructors, and piston phasing concepts that are thought capable of combining multiple patches of compensated wavefront distortion present in the aperture. Hybrid sodium-Rayleigh laser guide star concepts using multigrid wavefront reconstruction algorithms will be used as a baseline for comparison with other concepts.

- *A Noiseless Imaging Detector for Adaptive Optics with KiloHertz Frame Rates*, (J. Vallergera, PI, University of California, Berkeley, Space Sciences Laboratory)

The white paper entitled “A Road Map for the Development of Astronomical Adaptive Optics” spells out the desired properties for the next generation of detectors for

wavefront sensing: very fast, very low noise, and many pixel elements. Specific goals cited were 512 x 512 arrays with 1 kHz frame rates, 1-3 electrons noise per pixel and optical/IR quantum efficiencies (QE) > 80%. Currently, most array-based wavefront sensor (WFS) detectors are silicon charge coupled devices (CCDs) which can achieve the QE goal but currently have readout schemes that are incapable of simultaneously achieving fast frame rates and low readout noise. For example, the Palomar AO wavefront sensor detector (EEV39 CCD 64x64 pixels) can run at 1100 Hz at 7.5 e- rms or 50 Hz at 3e- rms [DuVarney, 2001].

We propose a novel detector scheme that can achieve the first three of the specific goals listed above with QEs approaching 40%. The detector (Fig. 1) is a microchannel plate (MCP) image tube with a gallium arsenide (GaAs) photocathode and a new pixelated CMOS readout chip called the "Medipix2". Photons interacting with the photocathode release a photoelectron that is proximity focused to the MCP input face. The MCP amplifies this single photoelectron with a gain on the order of 104. The resultant charge cloud exits the MCP and lands on the input pad of a Medipix2 pixel. Each pixel in the Medipix2 has an amplifier, discriminator and counter so each detected photon event will be counted as 1 event. The counter will integrate until it is read out in a digital, noiseless process. Also, because the data is digital, it can be read out at ~246 MHz pixel rates, which corresponds to a frame readout time of 266  $\mu$ s for the current Medipix2 chip (256x $\times$ 256)[Llopert, 2002].

- *Development of Large Deformable Mirrors Based on Dense Actuation of Nano-Laminate Membranes* (Scot Olivier and Troy Barbee, PI, Lawrence Livermore National Laboratory)

This proposal addresses the development of large deformable mirrors (DMs) applicable to adaptive optics for Giant Segmented Mirror Telescopes, both in terms of the clear aperture (i.e., >130 cm) and in terms of the number of actuators (i.e., >14096). These DMs will be based on actuation of nano-laminate membranes, which are manmade, flexible, robust metal nano-structures applicable to high-quality optical systems. These foils, developed at Lawrence Livermore National Laboratory (LLNL), represent a revolutionary breakthrough in optical technology. Nano-laminate membranes fabricated at LLNL have been demonstrated to have high tensile strength, ultra-low internal stress and super-smooth ( $\sigma < 0.5$ nm rms) optical surface quality. Ongoing development of this nano-structure metal membrane technology is currently supported by government agencies for application to large lightweight optics for space telescope applications. We propose to investigate the combination of nano-laminate membranes with dense actuator arrays based on micro-electromechanical systems (MEMS). The structural/mechanical properties of the nano-laminates are expected to facilitate actuation by these methods, resulting in a new paradigm for DM technology. The proposed program will be strongly

supported and leveraged by LLNL's long term effort in nanolaminate science and technology and by the MEMS development consortium coordinated through the NSF Center for Adaptive Optics which has produced state-of-the-art MEMS devices.

The specific technical goal of this project will be to fabricate a nano-laminate mirror with a clear aperture of 10 cm and ~1000 MEMS actuators with appropriate characteristics discussed in more details in the proposal text. The objective is, however, to produce this mirror using an fabrication, packaging and integration strategies that are plausibly scalable to a 50 cm mirror with ~20,000 MEMS actuators. The completed mirror will also be characterized to determine its electro-mechanical and optical properties.

- *Compact, High Power Pulsed Fiber-Based Sodium Guide Star Lasers* (D. Pennington, PI, Lawrence Livermore National Laboratory)

Laser guide stars are crucial to the broad use of adaptive optics, because they facilitate access to a large fraction of possible locations on the sky. In particular, lasers tuned to the 589 nm resonance line of atomic sodium can be used to create an artificial beacon at altitudes of 95-105 km, thus coming as close as possible to reproducing the light path of starlight. To realize the potential of adaptive optics (AO) on extremely large telescopes (ELTs), however, new laser and beam projection concepts must be developed with performance characteristics well beyond the current generation of systems. These innovations are needed to defeat the guide star elongation problem induced by the depth of the sodium layer, and to mitigate fratricide of multiple laser signals.

Approaches proposed to date include solid-state laser media, significantly higher-power laser systems, innovative pulse formats, and/or a multiplicity of launch telescopes for each guide star location. Progress in fiber lasers and beam transport systems can help reduce system costs and improve reliability for AO systems on extremely large telescopes, as well as for all other current and future observatories. We are developing a versatile laser technology based on diode pumped fiber lasers which are sum frequency mixed in periodically poled materials to provide 589 nm light for laser guided adaptive optics. This technology will provide a compact, efficient, robust, turnkey laser source, to replace the cumbersome dye lasers currently used in several existing guide star laser systems.

To date our prototype fiber laser functions in continuous wave (CW) mode. However, the technology is also capable of operating in pulsed format, and can be scaled to high CW power. Improvements in laser power will also enable brighter guide stars and higher-resolution wavefront sensing, as will be needed to transition astronomical laser guide star (LGS) AO into visible wavelength applications. In addition to meeting

technical specifications, next generation laser systems must be sufficiently reliable to enable routine operation in remote, somewhat hostile observatory environments. Prototyping and experience is needed for low-cost, reliable, properly qualified laser systems, laser beam handling and launch.

This proposal will address the development and prototyping of the laser technologies and delivery systems required to realize the potential of laser guided adaptive optics of next generation ELTs. In particular, we propose to develop pulsed format and higher powers for our fiber laser, to mitigate the spot elongation problem for ELTs of the future. The end goal of this research is to prototype a fully operational 589nm laser system capable of generating any arbitrary pulse format with a duty cycle greater than 1% and a repetition rate greater than 2 kHz. We will also study hollow core fibers to enable easy delivery of these pulse laser beacons.