Project Summary

Adaptive Optics (AO) is a key enabling technology in astronomy for high resolution imaging and spectroscopy, and is an essential scientific tool for current large aperture telescopes and the next-generation of telescopes incuding the Giant Magellan Telescope (GMT) where Arizona is a major partner. The MMT AO system, based on the world’s first adaptive secondary mirror, was a “game-changer” a decade ago in demonstrating how an AO system can be integrated into the telescope, without requiring additional optics before the corrected focus. We propose to upgrade the MMT system by implementing a Faint guide-star AO System Tool (FAST), which will build on existing MMT optics and leverage major electronics advances of the last decade to improve performance. We will couple a greatly improved adaptive secondary with a pyramid-based wavefront sensor and the first commercially available EMCCD (essentially noise-free) detector to reach fainter limiting reference star magnitudes and hence achieve broader sky coverage. Finally, we will couple the AO system with the infrared imager/spectrometer ARIES, upgraded with a state-of-the-art Teledyne HgCdTe 1-5 μm detector (provided by Steward Observatory), to extend the wavelength range for high spatial and spectral resolution observations at the MMT into the important near-thermal infrared range. FAST will provide a wide community of MMT users with unique capabilities for high resolution imaging and spectroscopy (up to R~50,000) with high sensitivity and low thermal background in the 3-5 μm range and a dramatic improvement in performance from 1-2.5 μm.

**Intellectual Merit:** The technical improvements, coupled with the large fraction (44%) of observing time available on a large and efficient telescope, will enable time-domain science not routinely available at other facilities. FAST’s 10x improvement in sensitivity and 3x in field-of-view will also expand the accessible sky coverage for guide stars. Thus, combined with unprecedented sensitivity and wavelength coverage, we can conduct wide-area surveys for exoplanets and monitor temporal variability in regions undergoing rapid change related to star/planet formation. For examples, we intend to use FAST to carry out an ambitious high-contrast imaging survey for giant planets that will surpass any existing survey in number of targets, sensitivity, and number of nights and will provide detailed statistical assessment of planet frequency. Due to the larger amount of time available we also intend to carry out time-domain monitoring of variability, for example using the high spectral resolution capability, to measure and understand variations in exoplanet atmospheres. Planet formation can also be probed with FAST. Planets are formed from circumstellar disks around newborn stars, which in turn are formed from dark molecular clouds. Yet, fundamental aspects of these formation processes remain shrouded in mystery. While the massive NSF-funded Atacama Large Millimeter Array (ALMA) promises to address these topics, many of the most important diagnostics of these environments (H2O, CH4, H2, H3+) have no accessible radio spectral features and can only be studied at infrared wavelengths. FAST provides a *unique* blend of high angular and spectral resolution with broad spectral coverage in the infrared that makes it the ideal counterpart to ALMA. Precision spectro-astrometry of circumstellar disks will provide unprecedented knowledge of the chemistry and spatial kinematics of planet-forming environments. Similarly, absorption line spectroscopy of star forming molecular clouds using FAST will provide the first direct, unbiased views of their physical structure and chemistry. Such measurements are essential to understand the origin of planets and the mass distribution of stars that form in molecular clouds, and represent important tests of theoretical models. FAST will also be exploited to address problems in extragalactic astronomy including gravitational lens monitoring and probing the centers of galaxies with central black holes. Theoretical interpretation of such fundamental observations is a strength of newly hired University faculty in Astronomy, Planetary Science, and the interdisciplinary Theoretical Astrophysics Program.

**Broader Impacts:** The improved MMT AO system will be available to astronomers and students at the three Arizona state universities as well as to the Harvard/ Smithsonian Center for Astrophysics and to guest observers. Besides its unique scientific impact, this system will also serve as a prototype for the AO system being planned for the GMT. We will continue our rich tradition of involving undergraduates, graduate students, and postdocs in its development and operation, growing the community of astronomers and optical engineers familiar with AO techniques, an important need in the era of the future Extremely Large Telescopes such as the GMT. The 2008 NSF AO roadmap states that “to gain critical quantitative understanding of new concepts and architectures, priority should be placed upon well-controlled laboratory and on-sky AO experiments having proportional impact on science capabilities.“ FAST fulfills this need and continues the tradition of such efforts at Steward Observatory’s Center for Astronomical Adaptive Optics.

**Facilities and Equipment**

**THE UNIVERSITY OF ARIZONA** – A leading research institution in the fields of

Astrophysics and Planetary Science, the University has committed a wide array of resources for the successful implementation, execution, and conclusion of this scientific effort. All the infrastructure of the university is accessible to the project team members including classrooms, office and laboratory space, and powerful, world class, research facilities. The University of Arizona maintains and operates several state of the art instruments ideally suited to leverage the improvements to the Adaptive Optics system.

**MMT FACILITY -** The research facility used for FAST will be the MMT located 40 miles south of Tucson. This 6.5 meter telescope facility is jointly operated by The University of Arizona and the Smithsonian Astrophysical Observatory (SAO). The telescope recently completed a $30 million upgrade and serves as the work horse for astrophysical research community at Steward Observatory. Through the standard proposal process Arizona researchers have access to 44% of the observing time on the telescopeand can collaborate with SAO astronomers to augment available time.

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**ADAPTIVE SECONDARY MIRROR** - The MMT’s adaptive optics secondary mirror is the key existing equipment enabling the FAST development. The ASM was developed at UA for approximately $10 million and is now a part of the MMT facility with maintenance shared between MMT and Steward’s Center for Astronomical Adaptive Optics (CAAO). The adaptive secondary delivers diffraction limited imaging from 1.5-10 μm.

Salient Features:

* 0.64 meter diameter
* 336 actuators
* 2mm shell thickness
* f/15
* 0.5 kHz closed loop operation

**ARIZONA INFRARED IMAGER AND ECHELLE SPECTROMETER (ARIES) -**

The ARIES instrument is a 1-5 μm camera/spectrometer located at the MMT. It is designed to capitalize on the exceptionally low thermal background and high optical throughput offered by the MMT’s f/15 adaptive secondary system. With two state-of-the-art IR arrays, ARIES provides diffraction-limited imaging in the JHKLM atmospheric windows and also echelle, long-slit spectroscopy at resolutions of 2,000 and 30-50,000. ARIES is capable of supplying global wavefront tip/tilt information to the adaptive system using a cryogenic pick-off mirror to access field stars over a 100 arcsecond diameter field at wavelengths from 1-2 μm.

**LABORATORY FACILITIES** - The team possesses well-equipped laboratories for the support of the tasks described within this proposal. The labs themselves provide the necessary infrastructure for the proposed development. In addition, most of the testing and verification equipment components required are already in place, including logic analyzers, oscilloscopes, lock-in amplifiers, optical benches, etc.