PROCEEDINGS OF SPIE

SPIEDigitalLibrary.org/conference-proceedings-of-spie

Status update for MAPS, the MMT AO exoPlanet characterization System

Manny Montoya, Katie Morzinski, Olivier Durney, Andrew Gardner, Emily Mailhot, et al.

Manny Montoya, Katie M. Morzinski, Olivier Durney, Andrew Gardner, Emily Mailhot, Dan Vargas, Amali Vaz, Grant West, Jenny Patience, Buell T. Jannuzi, Narsireddy Anugu, Jared Carlson, Kim Chapman, Shaojie Chen, Chuck Fellows, Lori Harrison, Terry Jones, Craig Kulesa, Masen Lamb, Siqi Liu, Don McCarthy, Suresh Sivanandam, Jacob Taylor, "Status update for MAPS, the MMT AO exoPlanet characterization System," Proc. SPIE 12185, Adaptive Optics Systems VIII, 121856S (29 August 2022); doi: 10.1117/12.2619434

Event: SPIE Astronomical Telescopes + Instrumentation, 2022, Montréal, Québec, Canada

Status update for MAPS, the MMT AO exoPlanet characterization System

Manny Montoya[*a], Katie M. Morzinski[a], Olivier Durney[a], Andrew Gardner[a], Emily Mailhot[a], Dan Vargas[a], Amali Vaz[a], Grant West[a] , Jenny Patience[b], Buell T. Jannuzi[a], Narsireddy Anugu[ac], Jared Carlson[a], Kim Chapman[a], Shaojie Chen[d], Chuck Fellows[a], Lori Harrison[a], Terry Jones[e], Craig Kulesa[a], Masen Lamb[d], Siqi Liu[e], Don McCarthy[a], Suresh Sivanandam[d], Jacob Taylor[d]

[a]Steward Observatory, 933 N. Cherry Ave., University of Arizona, Tucson AZ 85721, USA
[b]School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85281, USA
[c]The CHARA Array of Georgia State University, Mount Wilson Observatory, Mount Wilson, CA
[d]Dunlap Institute for Astronomy and Astrophysics, University of Toronto, 50 St. George St, Toronto, ON, Canada [e]Minnesota Institute for Astrophysics, 116 Church St. SE, Minneapolis MN, 55455, USA

ABSTRACT

The MMT Adaptive optics exoPlanet characterization System (MAPS) is an exoplanet characterization program that encompasses instrument development, observational science, and education. The instrument we are developing for the 6.5m MMT observatory is multi-faceted, including a refurbished 336-actuator adaptive secondary mirror (ASM); two pyramid wavefront sensors (PyWFS's); a 1-kHz adaptive optics (AO) control loop; a high-resolution and long-wavelength upgrade to the Arizona infraRed Imager and Echelle Spectrograph (ARIES); and a new-AO-optimized upgrade to the MMT-sensitive polarimeter (MMT-Pol). With the completed MAPS instrument, we will execute a 60-night science program to characterize the atmospheric composition and dynamics of ~50-100 planets around other stars. The project is approaching first light, anticipated for Summer/Fall of 2022. With the electrical and optical tests complete and passing the review milestone for the ASM's development, it is currently being tuned. The PyWFS's are being built and integrated in their respective labs: the visible-light PyWFS at the University of Arizona (UA), and the infrared PyWFS at the University of Toronto (UT). The top-level AO control software is being developed at UA, with an on-sky calibration algorithm being developed at UT. ARIES development continues at UA, and MMT-Pol development is at the University of Minnesota. The science and education programs are in planning and preparation. We will present the design and development of the entire MAPS instrument and project, including an overview of lab results and next steps.

Keywords: Adaptive optics, Adaptive secondary mirror, Pyramid wavefront sensor, High-resolution spectroscopy, Exoplanets, Infrared wavefront sensing

1. INTRODUCTION

The MMT Adaptive optics exoPlanet characterization System (MAPS) encompasses instrument development, observational science, and education. The instrument includes a refurbished 336-actuator adaptive secondary mirror (ASM); two pyramid wavefront sensors (PyWFS's); a 1-kHz adaptive optics (AO) control loop; a high-resolution and long-wavelength upgrade to the Arizona infraRed Imager and Echelle Spectrograph (ARIES); and a new-AO-optimized upgrade to the MMT-sensitive polarimeter (MMT-Pol). With the completed MAPS instrument, we will characterize ~50-100 exoplanets on the 6.5-m MMT telescope. First-light is anticipated for Summer/Fall of 2022.

Adaptive Optics Systems VIII, edited by Laura Schreiber, Dirk Schmidt, Elise Vernet,
Proc. of SPIE Vol. 12185, 121856S · © 2022 SPIE
0277-786X · doi: 10.1117/12.2619434

2. ASM DEVELOPMENT

2.1 Adaptive Secondary Test Stand Improvements.

To better understand the ASM and the optical characteristics an optical test stand was used to be able to image the optical mirror of the secondary. This was done using an Adaptive secondary Mirror (ASM) Test stand that had been upgraded with a new camera called a Phasics-based wavefront sensor. Along with other improvements a system that can be used to better quantify the optical performance of the ASM.

- Test stand achieved a resolution of 20 nm RMS in differential mode
- ASM achieved Re-alignment of aspheric shell on the Test Stand complete (~1 wave RMS residual error)
- A more LED stable source was bought and installed to cut down on fluctuation of the light through the system
- The test stand was isolated from the floor to better isolate vibrations being transmitted through the floor
- The test stand itself had structural tubes that had natural resonance frequencies and damping material cut down those resonate modes
- The ASM alignment mechanism was improved so that a true x-y translation providing better resolution so that the test stand could be better aligned to the ASM and cut down on the amount of work that was needed to align the system

2.2 Adaptative Secondary Work

The initial work on the Adaptive secondary found that there were problems with excess noise. The noise was greater than 15 nm of rms and hindered the ability to get proper calibration results out of the mirror. The specification for this mirror with the old electronics was below 10 nm rms of error. A few items addressed that helped mitigate some of the issues when it came to noise. This both addressed the problems with noise and after the improvements below the mirror is not running below 10 nm rms of noise and it allows for better calibration of the ASM while it is on the test stand.

- Re-cabling of actuators using shorter USB cables wherever possible
- Installation of thicker vibration-damping pads under test-bench legs
- New ASM power cables and better shielding
- Replacing power distribution board
- Better grounding of reference signal

Along with the work to cut down noise there were an improvement to the calibration and the actual use of the mirror.

- new method to generate a "forces-flat" shape
- acquisition of "forces-flats" at gaps from 35um to 50um, confirming shell ability and range
- new loop tuning procedure

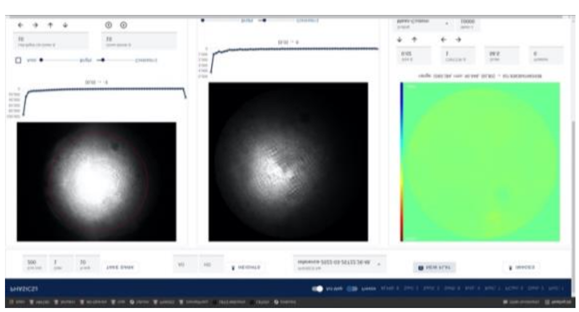

Figure 1. New user interface showing the range 1um rms 90nm. Shown under the phase map on the right side.

3. WAVE FRONT SENSOR

3.1 Bread Board and Optical Mechanical Build Up.

The final design for the wave front sensor was completed in the fall of 2021 and the build of optical/mechanical components began in January of 2022. These included entrance optics to the Wave Front Sensor (WFS), Atmospheric Dispersion Corrector (ADC), Fast Steering Mirror (FSM) Modulator, K-Mirror, Pyramid, Camera Lens, bread board to mount all the components on, calibration source slide, Periscope assemblies. The WFS will have two cameras, an IR Camera and a Visible Camera, each with its own Pyramid and camera lens. All other components will be shared between the two channels in order to reduce cost and the amount of work that would be needed to align the system. COTS items were procured and modified to work in the telescope environment, for items that were more critical custom mounts were manufactured.

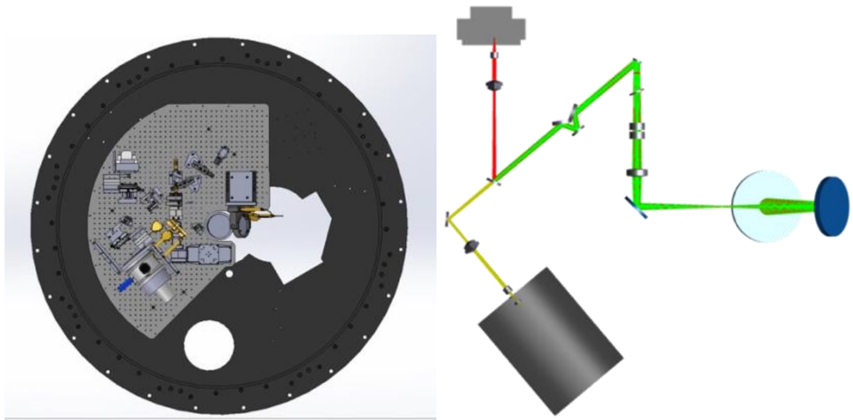

Figure 2. On the left is the CAD model and on the right is the optical model. On the bottom left of each image is the IR Pyramid Wave Front Camera and the upper left is the Vis Pyramid Wavefront Camera

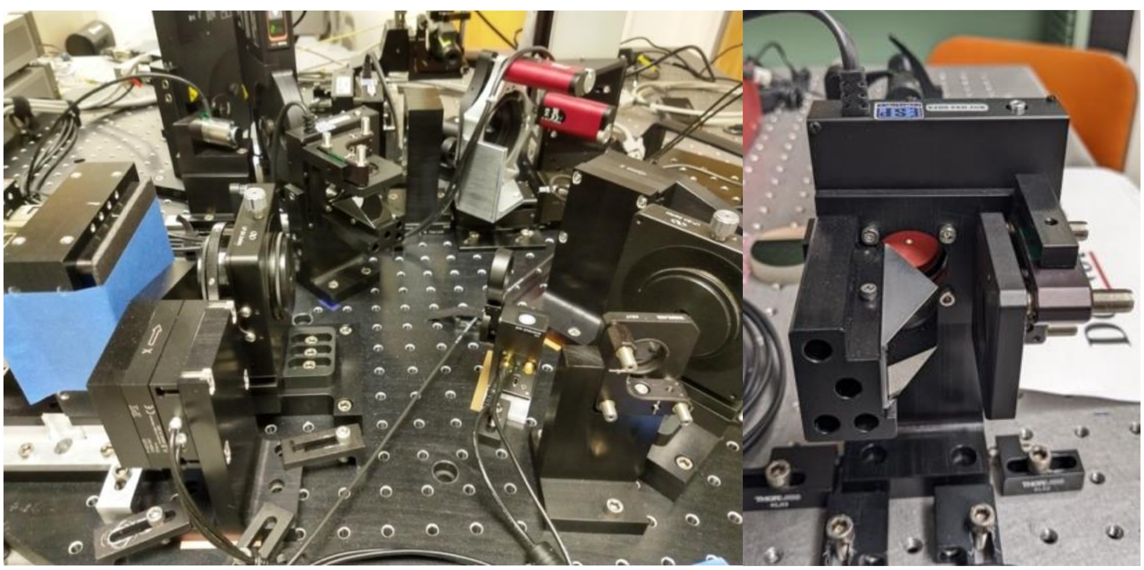

Figure 3. On the right is the wave front sensor bread board full assembly. The left image is the K-mirror with both custom and COTS parts to solve the problem of aligning and assembly.

3.2 Optical alignment

The optical alignment has a full through put and has initial pupils being illuminated on the Visible Wave Front Sensor. The pupil centers pupils are currently separated by 43 pixels and the diameter size of each pupil is 35 pixels. This is the first rough alignment of the pupils on the visible wave front sensor and the refinement to a goal of 40 & 30.8 pixels refinement is ongoing.

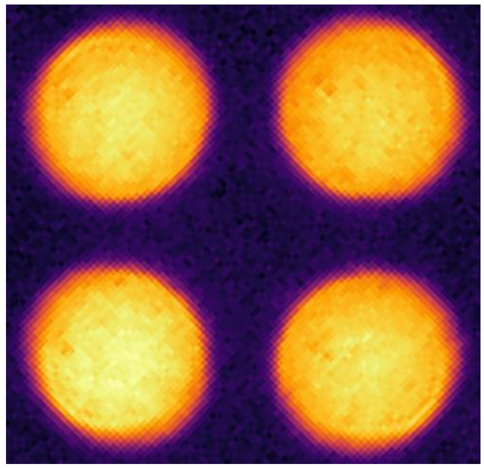

Figure 4. First image of Visible Wave Front Sensor. Modulation amplitude control is in preliminary stages - this figure shows a small amplitude modulation at 100hz.

The University of Toronto built the IR Wavefront Wave Front Sensor is rough aligned with a pyramid and is reading out the pupils. The pupils are 24 pixels in diameter. These are the first images and is a rough alignment. This will be closed on the University of Toronto's AO bench and then integrated in the Wave Front Sensor board in Tucson in late June.

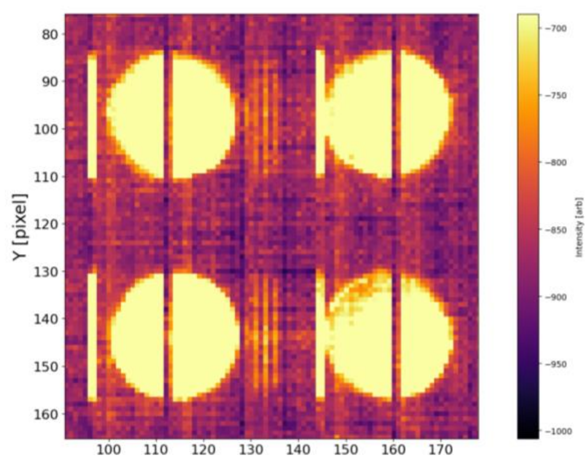

Figure 5. First image of IR Wavefront Sensor (very rough) 80X80 pixel region of the array. This is an image taken by the SAPHIRA using a 1.31um laser. The pupils are 24 pixels in diameter as expected. There is still some electronic read out items to resolve.

4. AO SYSTEM

4.1 System Architecture

Planning continues on four major components to work on- sky and be functional for the full AO system. These components include the Wave Front Sensor, PC Re-Constructor, ASM, and the Science Camera. For the different components that are being used it has been decided to leverage other open-source work that has been produced at the University of Arizona to not only to not re-invent the wheel, but to leverage the lessons learned from other AO Systems and success that have been demonstrated within the UArizona.

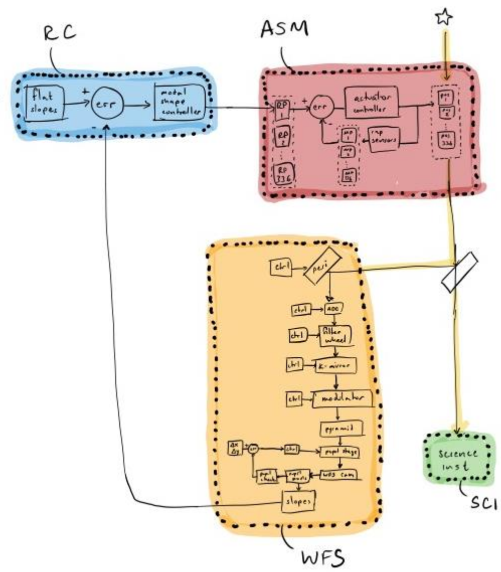

Figure 6. A system level diagram with the four pieces shown for Re-constructor (RC), Wave Front Sensor (WFS), Adaptive Secondary (ASM), and Science Camera (SCI).

4.2 System Software

There are a few software packages that are being leveraged to allow for a better performing system and implementation of already the ease of using the ease of using tested on sky software. The first one was called Astrolabe CHAI a desktop application composed of plugins in a NetBeans platform application. Astrolabe is derived from the science operations tools developed at LPL for OSIRIS-REx called JPlanner.

Key benefits. Fast turn-around on changes and bug fixes, very robust and well-understood testing infrastructure, well-understood by the developer.

Status. Development started in January of 2022, now at 75% of feature set of mmtao-web. Development started in January of 2022, now at 75% of feature set of mmtao-web.

Next steps. Integrate new capabilities to test CHAI.

The next piece of software being implemented is what we are colling CHAI. CHAI is a real-time server application composed of plugins to the Modular Image processing ToolKit (MILK) framework by Olivier Guyon, et. al., at Steward. Plugins are written in C++ with packages from vcpkg. Real-time communication is accomplished with MILK ImageStreamIO and shared memory. Non-real-time communication is done through gRPC.

Key benefits. Software architecture makes unit and integration tests much easier to develop/perform. gRPC is significantly more robust and efficient than INDI. Build and startup are clearer and less obfuscated.

Status. Acquisition camera integrated with visible WFS sensor next week. Infrastructure in place to support ASM integration within two weeks.

Next steps. Finish integration of the CCID75 and modulator, then move down to the lab on 2 to begin integrating with the ASM.

5. FURTHER DEVELOPMENT

5.1 Commissioning

The MAPS is finishing up the hardware and initial alignment of the system and starting the process of moving the hardware to the mountain. To minimize the complexity of having to commission an AO system and a science camera, the camera ARIES will not be part of the initial commissioning, but in the process of determining what camera would be best to be able to quantify the viability of the system. These include a few instruments that have been on the MMT to include MIRAC/BLINC, PICES, and CLIO.

A total of 10-12 nights have been requested to start the commissioning of the system and with the goal to minimize complexities the below steps have been started and are being worked on with the team in UToronto.

Steps:

1. Develop realistic end-to-end MMTAO simulation tools (Done)
2. Derive synthetic interaction matrix for AO system (Done)
3. Develop on-sky technique to measure misregistration's (In Progress)
4. Understand ASM properties and WFS response in the lab (In Progress)
5. On-sky measurements to derive final pseudo-synthetic interaction matrix (separately for VisWFS and IRWFS)
6. Validate AO performance on Science Camera across guide-star different field angles and elevations
7. Update interaction matrix as necessary with Step 5

5.2 Summer/Fall 2022 and Spring 2024

The summer of 2022 is being used to do the final fine alignment on the Wave Front Sensors and put the necessary calibrations on the adaptive secondary. In late July and August, the Wave Front Sensor bread board will be integrated into the Top box at the telescope and all the mechanical and electrical test will be done. The ASM and the WFS will use the summer shut down to test fit items and come up with the necessary procedures so that valuable nighttime activities can be properly utilized. This is an ongoing coordination between the MAPS staff and the MMT mountain staff. This will benefit in two ways one it will familiarize the MMT staff with the system and help with the integration into the telescope. It will also allow the MAPS team to have a dry run installation of the instrument onto the telescope and have a proper procedure in place.

6. SUMMARY

The MAPS system is to be finally ready to go to the telescope and achieve its "first light". The improvements which include the upgrade to the ASM electronics, two new independent wave front cameras one using a CCID75 SciMeasure camera and the second camera using a Saphira IR array. The combination of these two cameras will give us the ability to both test the system, but also give us options when it comes to the science availability. The IR system allows the system to correct near actual functioning wavelength of the science camera. It also gives the system the ability to us less than 1 micron as natural guide stars. The complete system will not only be used to get spectrograph information but has the possibility to be able to be use with multiple cameras systems that were used on the previous system. These are to include MIRAC/BLINC, CLIO, MMT-Pols, PICES, and ARIES direct imager and spectrograph. It will be an upgrade that will be a lot easier to maintain and an upgrade path in place to future proof for implementation of more efficient tools as they become available.

7. ACKNOWLEDGMENTS

The MAPS project is primarily funded through the NSF Mid-Scale Innovations Program, programs AST-1636647 and AST-1836008. This research has made use of NASA's Astrophysics Data System. The University of Arizona sits on the original homelands of Indigenous Peoples who have stewarded this Land since time immemorial. Aligning with the university's core value of a diverse and inclusive community, it is an institutional responsibility to recognize and acknowledge the People, culture, and history that make up the Wildcat community. At the institutional level, it is important to be proactive in broadening awareness throughout campus to ensure our students feel represented and valued.

8. REFERENCES

[1] Wildi, F. P., Brusa, G., Lloyd-Hart, M., Close, L. M., and Riccardi, A., "First light of the 6.5-m MMT adaptive optics system," in [Astronomical Adaptive Optics Systems and Applications], Tyson, R. K. and Lloyd-Hart, M., eds., Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series 5169, 17–25 (Dec. 2003).

[2] Anugu, N., Durney, O., Morzinski, K. M., Hinz, P., Sivanandam, S., Males, J., Gardner, A., Fellows, C., Montoya, M., West, G., Vaz, A., Mailhot, E., Carlson, J., Chen, S., Lamb, M., Butko, A., Downey, E., Tyler, J., and Jannuzi, B., "Design and development of a high-speed visible pyramid wavefront sensor for the MMT AO system," in [This Proceedings], Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series 11448, 11448–332 (2020).

[3] Vaz, A., Morzinski, K. M., Montoya, M., Fellows, C., Ford, J., Gardner, A., Durney, O., West, G., Harrison, L., Gacon, F., Downey, E., Carlson, J., Mailhot, E., Anugu, N., Jannuzi, B., and Hinz, P., "Status of the upgraded MMT adaptive secondary mirror: preparing for telescope integration" in [This Proceedings], Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series 11448, 11448–331 (2022).

[4] Vaz, A., Morzinski, K. M., Montoya, M., Fellows, C., Ford, J., Gardner, A., Durney, O., West, G., Harrison, L., Gacon, F., Downey, E., Carlson, J., Mailhot, E., Anugu, N., Jannuzi, B., and Hinz, P., "Laboratory testing and calibration of the upgraded MMT adaptive secondary mirror," Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series 11448, 11448–331 (2020).

[5] Lloyd-Hart, M., Wildi, F. P., Martin, B., McGuire, P. C., Kenworthy, M. A., Johnson, R. L., Fitz-Patrick, B. C., Angeli, G. Z., Miller, S. M., and Angel, J. R. P., "Adaptive optics for the 6.5-m MMT," in [Adaptive Optical Systems Technology], Wizinowich, P. L., ed., Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series 4007, 167–174 (July 2000).

[6] Brusa, G., Riccardi, A., Salinari, P., Wildi, F. P., Lloyd-Hart, M., Martin, H. M., Allen, R., Fisher, D., Miller, D. L., Biasi, R., Gallieni, D., and Zocchi, F., "MMT adaptive secondary: performance evaluation" "and field testing," in [Adaptive Optical System Technologies II], Wizinowich, P. L. and Bonaccini, D., eds., Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series 4839, 691–702 (Feb. 2003).

[7] Powell, K. B., Next generation wavefront controller for the MMT adaptive optics system: Algorithms and techniques for mitigating dynamic wavefront aberrations, PhD thesis, The University of Arizona (Jan. 2012).

[8] Pinna, E., Esposito, S., Hinz, P., Agapito, G., Bonaglia, M., Puglisi, A., Xompero, M., Riccardi, A., Briguglio, R., Arcidiacono, C., Carbonaro, L., Fini, L., Montoya, M., and Durney, O., "SOUL: the Single conjugated adaptive Optics Upgrade for LBT," in [Adaptive Optics Systems V], Marchetti, E., Close, L. M., and V´eran, J.-P., eds., Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series 9909, 99093V (July 2016).

[9] Morzinski, K. M., Close, L. M., Males, J. R., Kopon, D., Hinz, P. M., Esposito, S., Riccardi, A., Puglisi, A., Pinna, E., Briguglio, R., et al., "Magao: Status and on-sky performance of the magellan adaptive optics system," in [Adaptive Optics Systems IV], 9148, 914804, International Society for Optics and Photonics (2014).

[10] Jovanovic, N., Martinache, F., Guyon, O., Clergeon, C., Singh, G., Kudo, T., Garrel, V., Newman, K., Doughty, D., Lozi, J., et al., "The subaru coronagraphic extreme adaptive optics system: enabling high-contrast imaging on solar-system scales," Publications of the Astronomical Society of the Pacific 127(955), 890 (2015).

[11] Bond, C. Z., Wizinowich, P., Chun, M., Mawet, D., Lilley, S., Cetre, S., Jovanovic, N., Delorme, J.-R., Wetherell, E., Jacobson, S., et al., “Adaptive optics with an infrared pyramid wavefront sensor,” in [Adaptive Optics Systems VI], 10703, 107031Z, International Society for Optics and Photonics (2018).
[12] Riccardi, A., Brusa, G., Salinari, P., Gallieni, D., Biasi, R., Andrighettoni, M., and Martin, H. M., “Adaptive secondary mirrors for the Large Binocular Telescope,” in [Adaptive Optical System Technologies II], Wizinowich, P. L. and Bonaccini, D., eds., Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series 4839, 721–732 (Feb. 2003).
[13] Hinz, P. M., Downey, E., Montoya, O. M., Ford, J., Powell, K., and Hill, R., “Developing new adaptive secondary electronics for the MAPS project,” in [Adaptive Optics Systems VI], Close, L. M., Schreiber, L., and Schmidt, D., eds., Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series 10703, 1070369 (July 2018).
[14] Liu, S., Sivanandam, S., Chen, S., Lamb, M., Butko, A., Veran, J.-P., Hinz, P., Mieda, E., Hardy, T., Lardiere, O., and Shore, E., “Upgrading the MMT AO system with a near-infrared pyramid wavefront sensor,” in [Adaptive Optics Systems VI], Close, L. M., Schreiber, L., and Schmidt, D., eds., Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series 10703, 107032K (July 2018).
[15] Shelton, J. C., Lloyd-Hart, M., Angel, J. R. P., and Sandler, D. G., “6.5-m MMT laser-guided adaptive optics system: overview and progress report II [3126-01],” in [Adaptive Optics and Applications], Tyson, R. K. and Fugate, R. Q., eds., Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series 3126, 2 (Oct. 1997).
[16] McCarthy, D. W., Burge, J. H., Angel, J. R. P., Ge, J., Sarlot, R. J., Fitz-Patrick, B. C., and Hinz, J. L., “ARIES: Arizona infrared imager and echelle spectrograph,” in [Infrared Astronomical Instrumentation], Fowler, A. M., ed., Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series 3354, 750–754 (Aug. 1998).
[17] Packham, C., Jones, T. J., Warner, C., Krejny, M., Shenoy, D., Vonderharr, T., Lopez-Rodriguez, E., and DeWahl, K., “Commissioning results of MMT-POL: the 1-5um imaging polarimeter leveraged from the AO secondary of the 6.5m MMT,” in [Ground-based and Airborne Instrumentation for Astronomy IV], McLean, I. S., Ramsay, S. K., and Takami, H., eds., Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series 8446, 84463R (Sept. 2012)."