ALIEN EARTHS

Recent Publications

MagAO-X: current status and plans for Phase II

The Optical and Mechanical Design for the 21,000 Actuator ExAO System for the Giant Magellan Telescope: GMagAO-X

Visible extreme adaptive optics for GMagAO-X with the triple-stage AO architecture (TSAO)

A Novel Hexpyramid Pupil Slicer for an ExAO Parallel DM for the Giant Magellan Telescope

The conceptual design of GMagAO-X: visible wavelength high contrast imaging with GMT.

Earths in Other Solar Systems and **Alien Earths** are part of NASA's Nexus for Exoplanetary System Science program, which carries out coordinated research toward the goal of searching for and determining the frequency of habitable extrasolar planets with atmospheric biosignatures in the Solar neighborhood.

Our interdisciplinary teams includes astrophysicists, planetary scientists, cosmochemists, material scientists, chemists, biologists, and physicists.

The Principal Investigator of Project EOS and Alien Earths is Daniel Apai (University of Arizona). The projects' lead institutions are The University of Arizona's Steward Observatory and Lunar and Planetary Laboratory.

For a complete list of publications, please visit the **AE Library** on the SAO/NASA Astrophysics Data System.

Origins Seminar

The **Origins Seminar** series brings together ISM, star and planet formation people, exoplanets experts, planetary scientists and astrobiologists. Topics range from molecular clouds through star and planet formation to exoplanets detection and characterization and astrobiology.

The seminar series is organized by Serena Kim (SO), Sebastiaan Haffert (SO), and Chenliang Huang (LPL) from Steward Observatory/Dept. of Astronomy and Dept. of Planetary Sciences (LPL) at the University of Arizona. The Origins Seminar series is partly supported by the Earths in Other Solar Systems NExSS team.

Talks take place **12:00 – 1:00pm (MST) on Mondays**. To receive weekly updates and advertisements for talks, please subscribe to the **mailing list**. If you are interested in presenting your work during one of the open slots, feel free to contact **the organizers**.

During the Fall semester 2021 and Spring 2022, the Origins seminar will meet via Zoom or in Hybrid (in-person + zoom) due to the Covid-19 Pandemic. The Zoom information is sent via email, and the Origins seminar talks are recorded. The talk videos can be viewed from the Origins youtube channel.

OriginsSeminars

Origins Seminars YouTube Channel

MagAO-X: current status and plans for Phase II

Jared R. Males, Laird M. Close, Sebastiaan Haffert, Joseph D. Long, Alexander D. Hedglen, Logan Pearce, Alycia J. Weinberger, Olivier Guyon, Justin M. Knight, Avalon McLeod, Maggie Kautz, Kyle Van Gorkom, Jennifer Lumbres, Lauren Schatz, Alex Rodack, Victor Gasho, Jay Kueny, Warren Foster

arXiv, August 2022

We present a status update for MagAO-X, a 2000 actuator, 3.6 kHz adaptive optics and coronagraph system for the Magellan Clay 6.5 m telescope. MagAO-X is optimized for high contrast imaging at visible wavelengths. Our primary science goals are detection and characterization of Solar System-like exoplanets, ranging from very young, still-accreting planets detected at H-alpha, to older temperate planets which will be characterized using reflected starlight. First light was in Dec, 2019, but subsequent commissioning runs were canceled due to COVID-19. In the interim, MagAO-X has served as a lab testbed. Highlights include implementation of several focal plane and low-order wavefront sensing algorithms, development of a new predictive control algorithm, and the addition of an IFU module. MagAO-X also serves as the AO system for the Giant Magellan Telescope High Contrast Adaptive Optics Testbed. We will provide an overview of these projects, and report the results of our commissioning and science run in April, 2022. Finally, we will present the status of a comprehensive upgrade to MagAO-X to enable extreme-contrast characterization of exoplanets in reflected light. These upgrades include a new post-AO 1000-actuator deformable mirror inside the coronagraph, latest generation sCMOS detectors for wavefront sensing, optimized PIAACMC coronagraphs, and computing system upgrades. When these Phase II upgrades are complete we plan to conduct a survey of nearby exoplanets in reflected light.

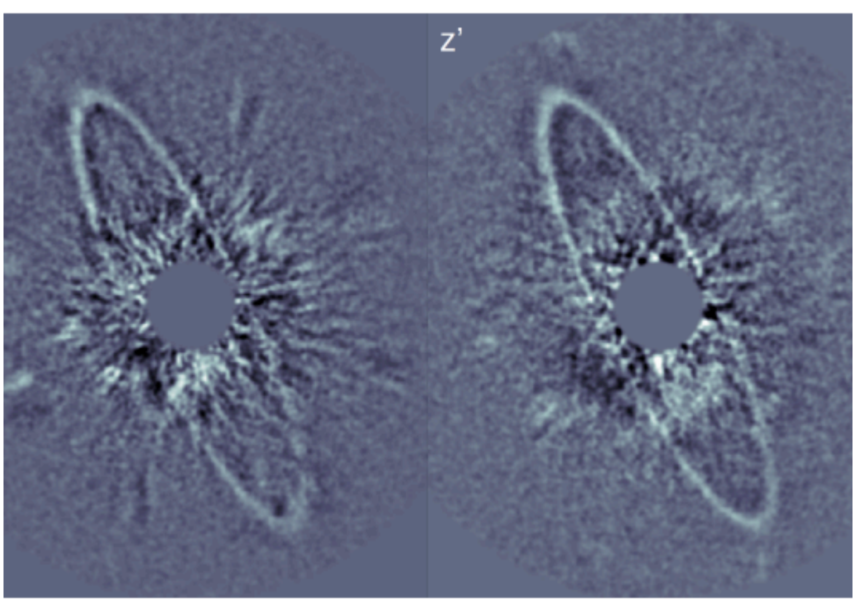

Figure 6. The well known debris disk around HR 4796 A, observed with the Lyot coronagraphs of MagAO-X. Weinberger et al., in prep.

The Optical and Mechanical Design for the 21,000 Actuator ExAO System for the Giant Magellan Telescope: GMagAO-X

Laird M. Close, Jared R. Males, Olivier Durney, Fernando Coronado, Sebastiaan Y. Haffert, Victor Gasho, Alexander Hedglen, Maggie Y. Kautz, Tom E. Connors, Mark Sullivan, Olivier Guyon, Jamison Noenickx

arXiv, August 2022

GMagAO-X is the near first light ExAO coronagraphic instrument for the 25.4m GMT. It is designed for a slot on the folded port of the GMT. To meet the strict ExAO fitting and servo error requirement (<90nm rms WFE), GMagAO-X must have 21,000 actuator DM capable of >2KHz correction speeds. To minimize wavefront/segment piston error GMagAO-X has an interferometric beam combiner on a vibration isolated table, as part of this "21,000 actuator parallel DM". Piston errors are sensed by a Holographic Dispersed Fringe Sensor (HDFS). In addition to a coronagraph, it has a post-coronagraphic Lyot Low Order WFS (LLOWFS) to sense non-common path (NCP) errors. The LLOWFS drives a non-common path DM (NCP DM) to correct those NCP errors. GMagAO-X obtains high-contrast science and wavefront sensing in the visible and/or the NIR. Here we present our successful externally reviewed (Sept. 2021) CoDR optical-mechanical design that satisfies GMagAO-X's top-level science requirements and is compliant with the GMT instrument requirements and only requires COTS parts.

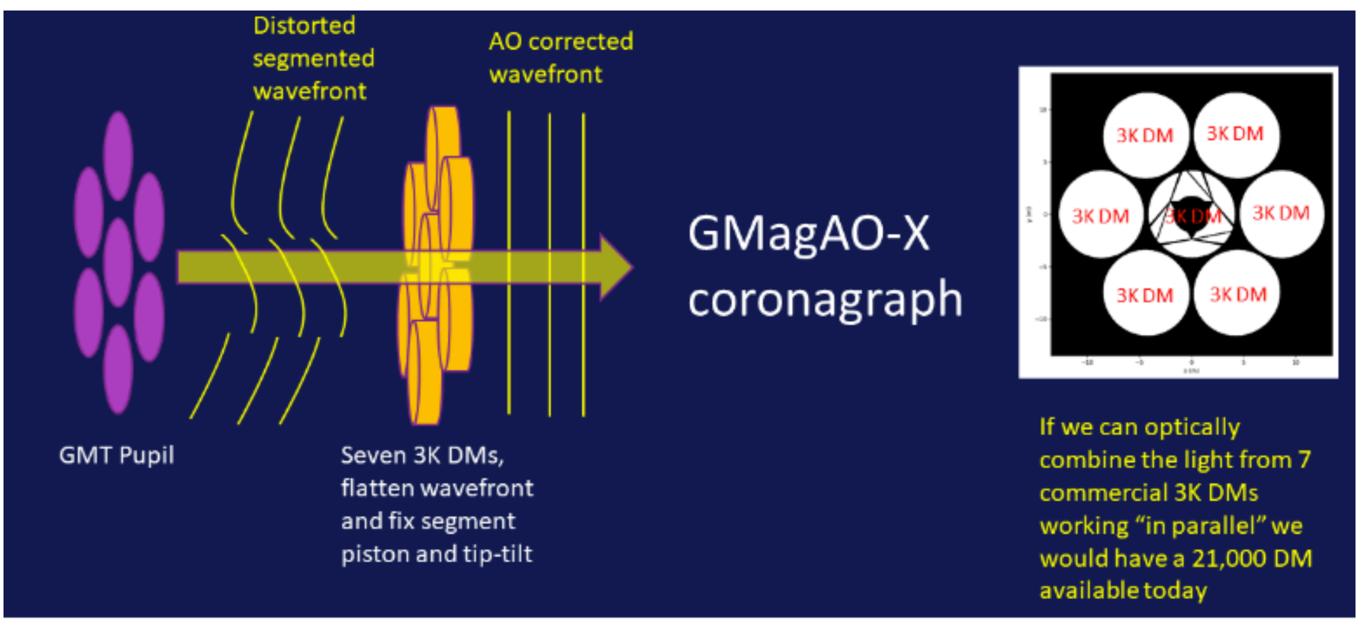

Figure 1: A cartoon motivating the parallel DM concept. Note that the parallel DM geometry is naturally well suited to fix segment piston and tip-tilt).

Visible extreme adaptive optics for GMagAO-X with the triple-stage AO architecture (TSAO)

Sebastiaan Y. Haffert, Jared R. Males, Laird M. Close, Olivier Guyon, Alexander Hedglen, Maggie Kautz

→ arXiv, August 2022

The Extremely Large Telescopes will require hundreds of actuators across the pupil for high Strehl in the visible. We envision a triple-stage AO (TSAO) system for GMT/GMagAO-X to achieve this. The first stage is a 4K DM controlled by an IR pyramid wavefront sensor that provides the first order correction. The second stage contains the high-order parallel DM of GMagAO-X that has 21000 actuators and contains an interferometric delay line for phasing of each mirror segment. This stage uses a Zernike wavefront sensor for high-order modes and a Holographic Dispersed Fringe Sensor for segment piston control. Finally, the third stage uses a dedicated 3K dm for non-common path aberration control and the coronagraphic wavefront control by using focal plane wavefront sensing and control. The triple stage architecture has been chosen to create simpler decoupled control loops. This work describes the performance of the proposed triple-stage AO architecture for ExAO with GMagAO-X.

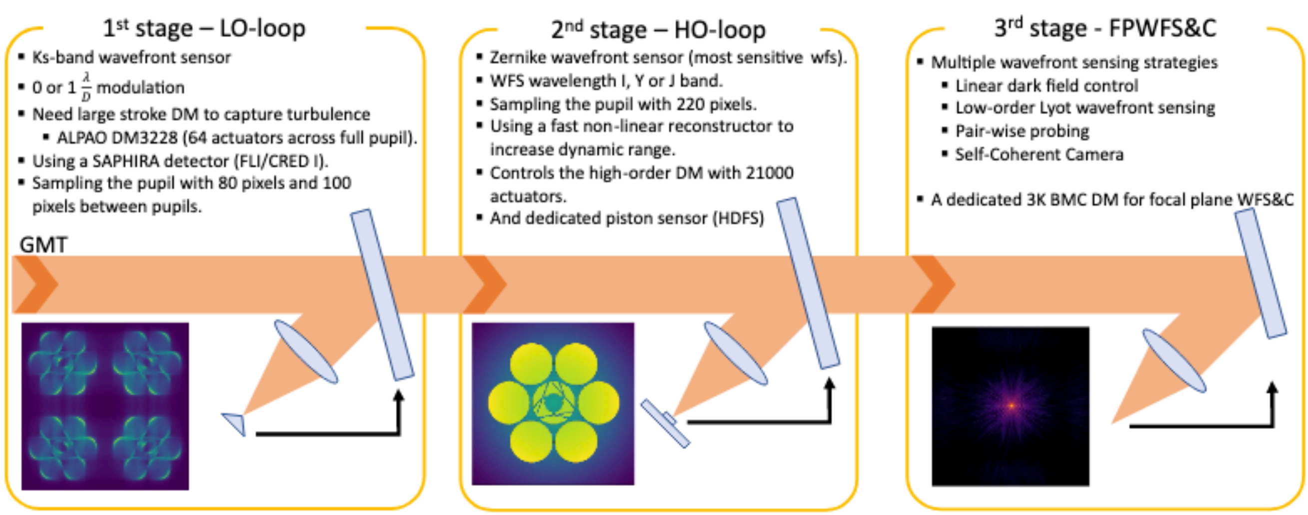

Figure 1. An overview of the triple stage AO system that is envisioned for GMagAO-X. It starts with a low-order loop that has a pyramid wavefront sensor driving the 3228 actuator woofer. A second stage with a Zernike wavefront sensor and the high-order 21K DM is used to achieve very high Strehl. The well corrected wavefront is then send into the coronagraph that has multiple wavefront to control non-common path aberrations and create dark holes around the star.

A Novel Hexpyramid Pupil Slicer for an ExAO Parallel DM for the Giant Magellan Telescope

Maggie Kautz, Laird M. Close, Alex Hedglen, Sebastiaan Haffert, Jared R. Males, Fernando Coronado

arXiv, August 2022

The 25.4m Giant Magellan Telescope (GMT) will be amongst the first in a new series of segmented extremely large telescopes (ELTs). The 25.4 m pupil is segmented into seven 8.4 m circular segments in a flower petal pattern. At the University of Arizona we have developed a novel pupil slicer that will be used for ELT extreme adaptive optics (ExAO) on the up and coming ExAO instrument, GMagAO-X. This comes in the form of a six-sided reflective pyramid with a hole through the center known as a "hexpyramid". By passing the GMT pupil onto this reflective optic, the six outer petals will be sent outward in six different directions while the central segment passes through the center. Each segment will travel to its own polarization independent flat fold mirror mounted on a piezoelectric piston/tip/tilt controller then onto its own commercial 3,000 actuator deformable mirror (DM) that will be employed for extreme wavefront control. This scheme of seven DMs working in parallel to produce a 21,000 actuator DM is a new ExAO architecture that we named a "parallel DM," in which the hexpyramid is a key optical component. This significantly surpasses any current or near future actuator count for any monolithic DM architecture. The optical system is designed for high-quality wavefront (lambda/10 surface PV) with no polarization errors and no vignetting. The design and fabrication of the invar mechanical mounting structure for this complex optical system is described in this paper.

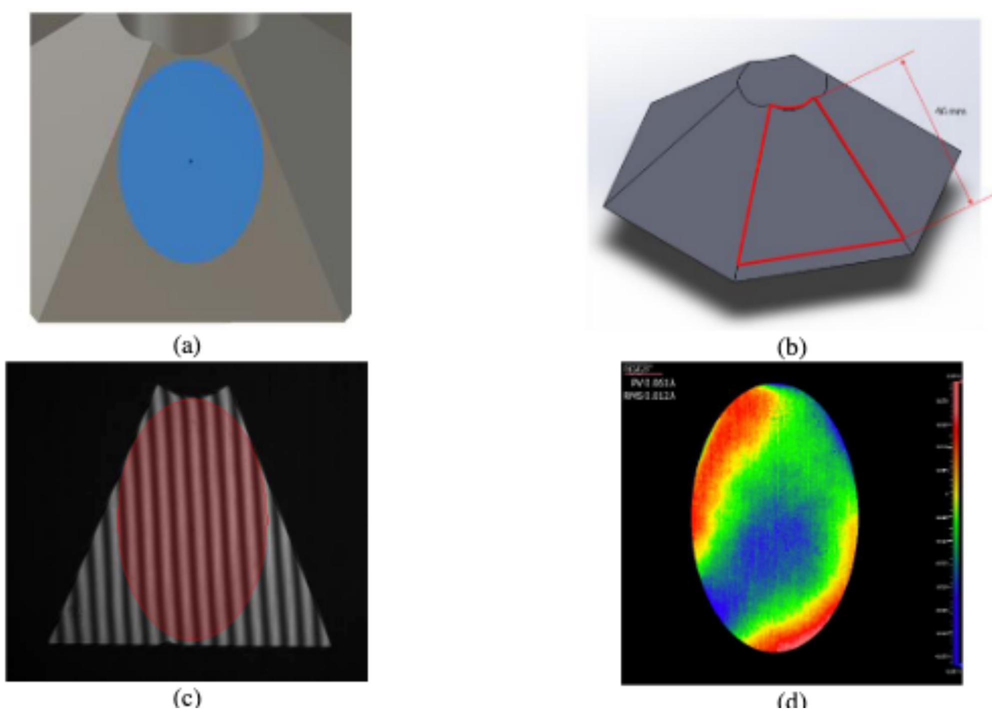

Figure 6.
(a) Beam footprint
(b) Clear aperture
(c) Circular mask
(d) Zygo® measurement

The conceptual design of GMagAO-X: visible wavelength high contrast imaging with GMT

Jared R. Males, Laird M. Close, Sebastiaan Y. Haffert, Olivier Guyon, Victor Gasho, Fernando Coronado, Olivier Durney, Alexander Hedglen, Maggie Kautz, Jamison Noenickx, John Ford, Tom Connors, Doug Kelly

➔ arXiv, August 2022

We present the conceptual design of GMagAO-X, an extreme adaptive optics system for the 25 m Giant Magellan Telescope (GMT). We are developing GMagAO-X to be available at or shortly after first-light of the GMT, to enable early high contrast exoplanet science in response to the Astro2020 recommendations. A key science goal is the characterization of nearby potentially habitable terrestrial worlds. GMagAO-Xis a woofer-tweeter system, with integrated segment phasing control. The tweeter is a 21,000 actuator segmented deformable mirror, composed of seven 3000 actuator segments. A multi-stage wavefront sensing system provides for bootstrapping, phasing, and high order sensing. The entire instrument is mounted in a rotator to provide gravity invariance. After the main AO system, visible (g to y) and near-IR (Y to H) science channels contain integrated coronagraphic wavefront control systems. The fully corrected and, optionally, coronagraphically filtered beams will then be fed to a suite of focal plane instrumentation including imagers and spectrographs. This will include existing facility instruments at GMT via fiber feeds. To assess the design we have developed an end-to-end frequency-domain modeling framework for assessing the performance of GMagAO-X. The dynamics of the many closed-loop feedback control systems are then modeled. Finally, we employ a frequency-domain model of post-processing algorithms to analyze the final post-processed sensitivity. The CoDR for GMagAO-X was held in September, 2021. Here we present an overview of the science cases, instrument design, expected performance, and concept of operations for GMagAO-X.

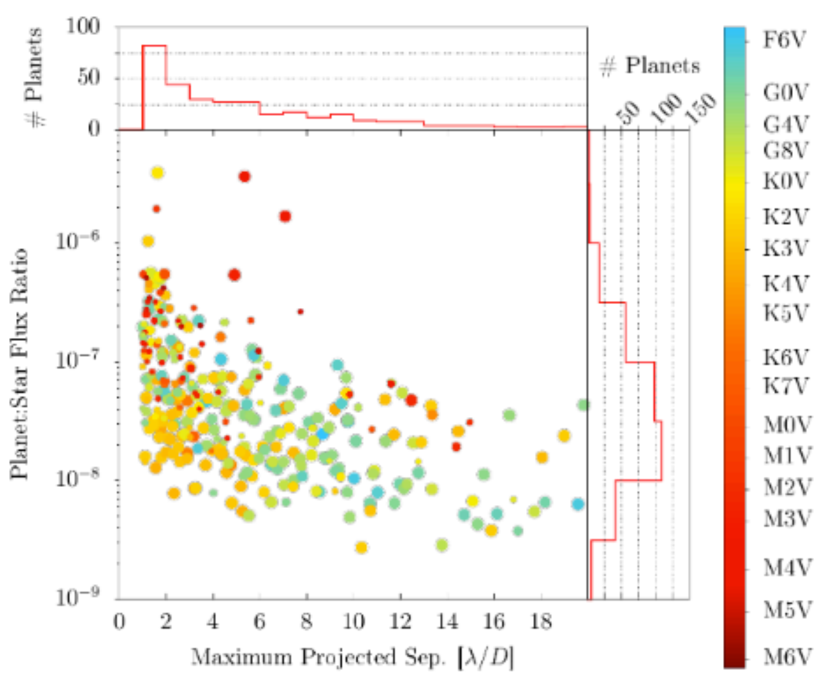

Figure 8. Planet:Star flux ratio vs. separation in λ/D at 800 nm for the GMagAO-X RV-detected planet sample.