# The 21,000 Actuator GMagAO-X Parallel DM for the Giant Magellan Telescope: First HCAT Testbed Results with Segment/Petal phasing/AO control of Seven GMT Segments

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**Abstract**

A key scientific reason we are pursuing the very difficult effort of construction of ELT-class telescopes is for the characterization of habitable exoplanets. Indeed, the recent *Astro2020* decadal survey listed this as the number one science goal for the "Worlds and Suns in Context" over the next decade. Currently this goal is extremely difficult with the current generation of D=6.5-10m telescopes (on the ground or in space) but the problem becomes more tractable with ELT-class telescopes. If we enable very high-contrast AO at _˜0.8microns on a D=25-38m ELTs then, for example, the habitable planet Proxima Centauri b becomes a reasonable 6-9 lambda/D resolution elements from its star (with a challenging, but theoretically achievable, contrast of _˜10 million).
The GMagAO-X instrument is motivated by this reflected light direct imaging exoplanet science. GMagAO-X is a first light ExAO coronagraphic instrument for the 25.4m GMT. It is designed for the folded port "D" of the GMT. To meet the strict ExAO fitting and servo error requirement for visible light ExAO (less than 90nm rms WFE), GMagAO-X must have a very high authority 21,000 actuator DM (yielding a sampling of _˜14cm on the primary/actuator) capable of ≥2KHz correction speeds. Moreover, the GMT (and likely all ELTs) will suffer from low wind effect, and petal phasing/piston errors. To minimize this wavefront/segment piston error GMagAO-X has a novel seven arm interferometric beam combiner on a vibration isolated table. As well this DM has seven 3,000 actuator MEMS DMs that work in parallel. We call this DM/beam combiner the "21,000 actuator parallel DM" and it is at the heart of the GMagAO-X instrument.

Due to the challenges of piston sensing and AO control we have developed a GMT AO testbed called HCAT at the University of Arizona, Center for Adaptive Optics (CAAO) in partnership with the NSF/AURA and the GMT. Piston errors are sensed by a Holographic Dispersed Fringe Sensor (HDFS), a device invented at CAAO and tested in our HCAT testbed. In this talk we will highlight the exciting new HCAT testbed results from the fully phased parallel DM with all seven GMT segments actively co-phased. We will also report on the first testbed results of feeding this seven segment GMT pupil from the HCAT testbed

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into the MagAO-X ExAO instrument. This HCAT optical feed effectively makes MagAO-X "believe" it is at the GMT and so we can easily utilize MagAO-X's PyWFS and HDFS to close the AO loop on the GMT pupil. We will report on the current phasing accuracy of the HDFS and the parallel DM on the GMT pupil, and on lessons learned about ELT AO issues with segmented primary mirrors with real hardware.
In addition to these exciting testbed results, we will also briefly present our current (post-CoDR) optical-mechanical design for GMagAO-X that satisfies GMagAO-X's top-level science requirements and is compliant with the GMT instrument requirements.

**Keywords:** adaptive optics, wavefront sensing, coronagraphs, high, contrast imaging, exoplanets, deformable mirrors