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GPI 2.0: Pyramid Wavefront Sensor Status

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ABSTRACT

The Gemini Planet Imager (GPI) is a high contrast imaging instrument designed to directly detect and characterize young Jupiter-mass exoplanets. After six years of operation at Gemini South in Chile, the instrument is being upgraded and moved to Gemini North in Hawaii as GPI 2.0. As part of this upgrade, several improvements will be made to the adaptive optics (AO) system. This includes replacing the current Shack-Hartmann wavefront sensor (WFS) with a pyramid wavefront sensor (PWFS) and a custom EMCCD. These changes are expected to increase GPI's sky coverage by accessing fainter targets, improving corrections on fainter stars and allowing faster and ultra-low latency operations on brighter targets. The PWFS subsystem is being independently built and tested to verify its performance before its integration into the GPI 2.0 instrument. In this paper, we will present the design and pre-integration test plan of the PWFS.

Keywords: Adaptive Optics, Pyramid Wavefront Sensor Wavefront Sensing, Gemini Planet Imager

1. INTRODUCTION

For six years the Gemini Planet Imager (GPI) successfully operated at the Gemini South telescope, located in Chile, until its decommissioning in August 2020. GPI was tasked with observing wide orbit (> 10 AU) Jupiter-mass exoplanets and resolving circumstellar material around young, nearby stars.[1] The decision to move GPI to the Gemini North telescope presented an opportunity to envisage new scientific goals, and assess how

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these would translate to the instrument upgrade to become GPI2.0. As GPI2.0 moves to improve sensitivity for fainter planets and circumstellar disks at smaller inner working angles, upgrades to the adaptive optics (AO) system, calibration unit (CAL) and integral field spectrograph (IFS) will be needed.[2] The major upgrades to the AO system include; (i) replacing the current Shack-Hartmann wavefront sensor (WFS) with a pyramid WFS (PWFS) (ii) replacing the current CCD with a custom Nüvü EMCCD and (iii) updating the current real-time controller software to the Herzberg Extensible Adaptive Real-time Toolkit (HEART).[3] The subject of this paper is the PWFS, which will enable access to fainter WFS targets (I band magnitude of 14) whilst also providing more stable operations on brighter targets. GPI2.0's PWFS has benefited from the research and design of the Thirty Meter Telescope (TMT) Narrow Field InfraRed Adaptive Optics System (NFIRAOS),[4] using many of the same components. In this paper, an overview of the design and the outline of the pre-integration tests will be presented.

2. DESIGN

In this section the design and manufacturing of the PWFS will be presented, for a complete description see Fitzsimmons et al. (2020).[5] Since the PWFS will replace the Shack-Hartmann WFS, there is a narrow space envelope to add the new PWFS bench. The placement of the PWFS bench, which includes the new EMCCD, is shown i m reflected from the G

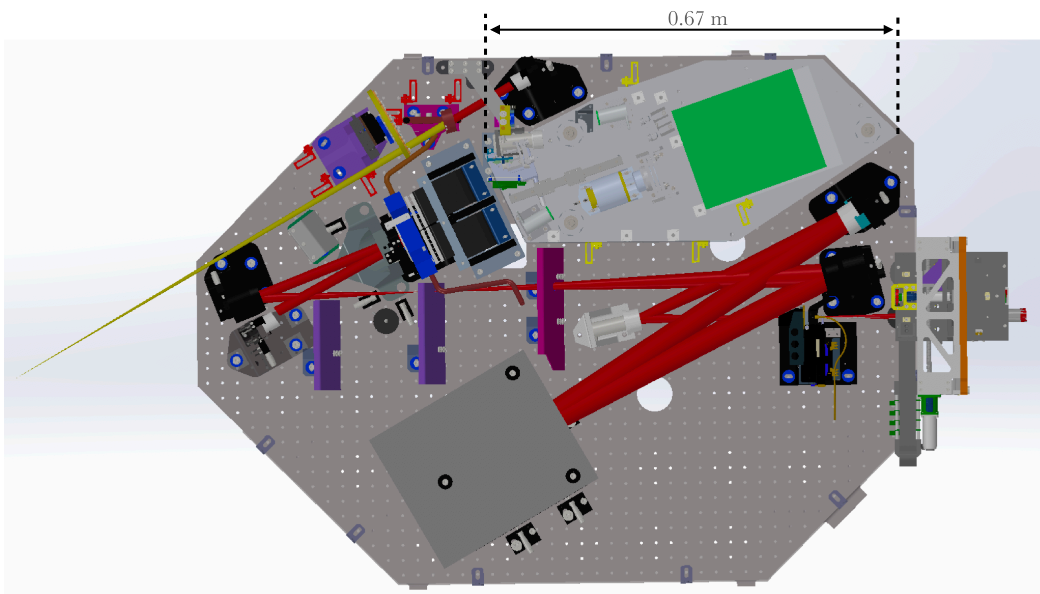

Figure 1. AutoCAD of where the PWFS bench (light grey outline) sits on the GPI bench. The red and yellow beams are the AO relay and coronagraph path respectively.

The PWFS employs two fast steering mirrors (FSM) each mounted on a Physik Instrumente (PI) S-331.5SL actuator stage; FSM1 will modulate and dither the focused spot around the tip of the pyramid, and FSM2 will be used for alignment. In addition, there are two fold mirrors (FM), one of which is mounted on a PI M-111.1DG1 focus stage. These mirrors were manufactured by Coastline Optics and will be discussed further in section 3.1. The pyramid optic is a four sided double-pyramid comprised of two different class materials combined along their base, identical to that used by NFIRAOS and manufactured by BMV Optical Technologies. The pyramid splits the light into four channels, each propagating through a triplet (camera) lens (manufactured by BMV Optical Technologies) to image the telescope pupil onto the EMCCD, each with a diameter of 60 subapertures. The EMCCD is a Nüvü custom camera with near-zero noise, high quantum efficiency and fast readout, and will operate at frequencies up to 2 kHz (though capable of 3 kHz). The typical radius of the modulation circle, produced by FSM1, will be $3\lambda/D$ and must evenly illuminate the four quadrants of the pyramid. Therefore it will require an integer number of circles during the integration time of the detector. To reduce background noise and

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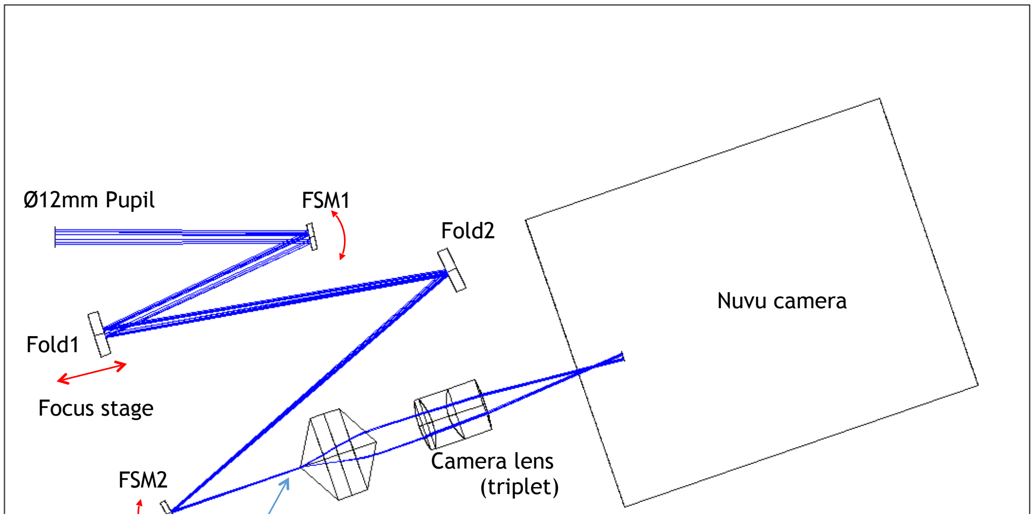

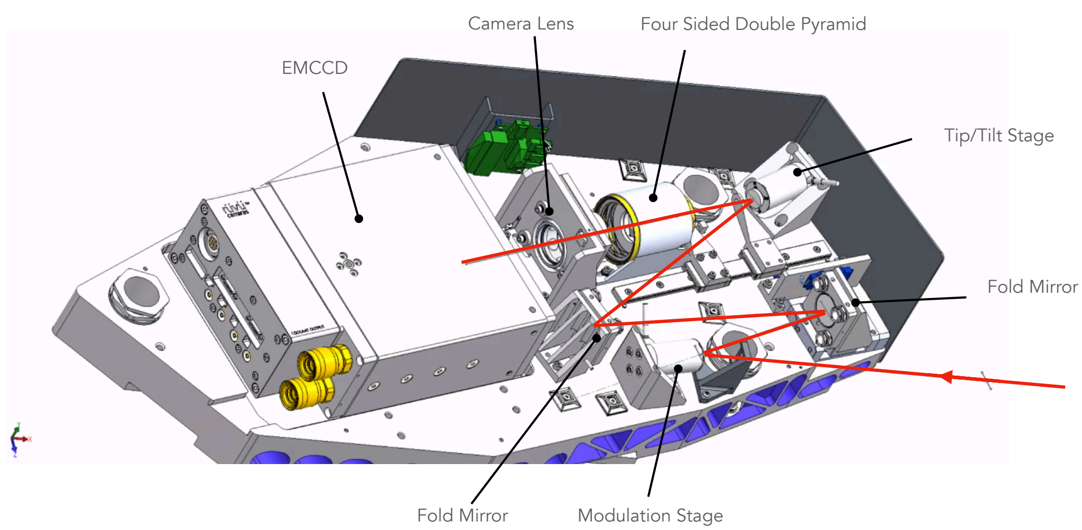

Figure 3. AutoCAD drawing of the PWFS bench, with the light path illustrated by the red line.

3. CURRENT STATUS

Figure 4 shows the current pre-integration laboratory test plan, which was based on the TMT NFIRAOS PWFS test plan. The sequence is divided into three distinct test regimes: component, intermediary and end-to-end.

Figure 5 shows the PWFS bench with all optical components. All machined parts including the optomechanical components were provided by Opto-Mécanique de Précision (OMP). Component testing to assess the manufacturing has been completed on all procured parts. This includes confirming dimensions and mass, assessing the surface quality of the mirrors and measuring the transmission and reflectivity of the optical components. For initial alignment, a laser jig that sits at the entrance of the PWFS will be used, as shown in figure 5. For

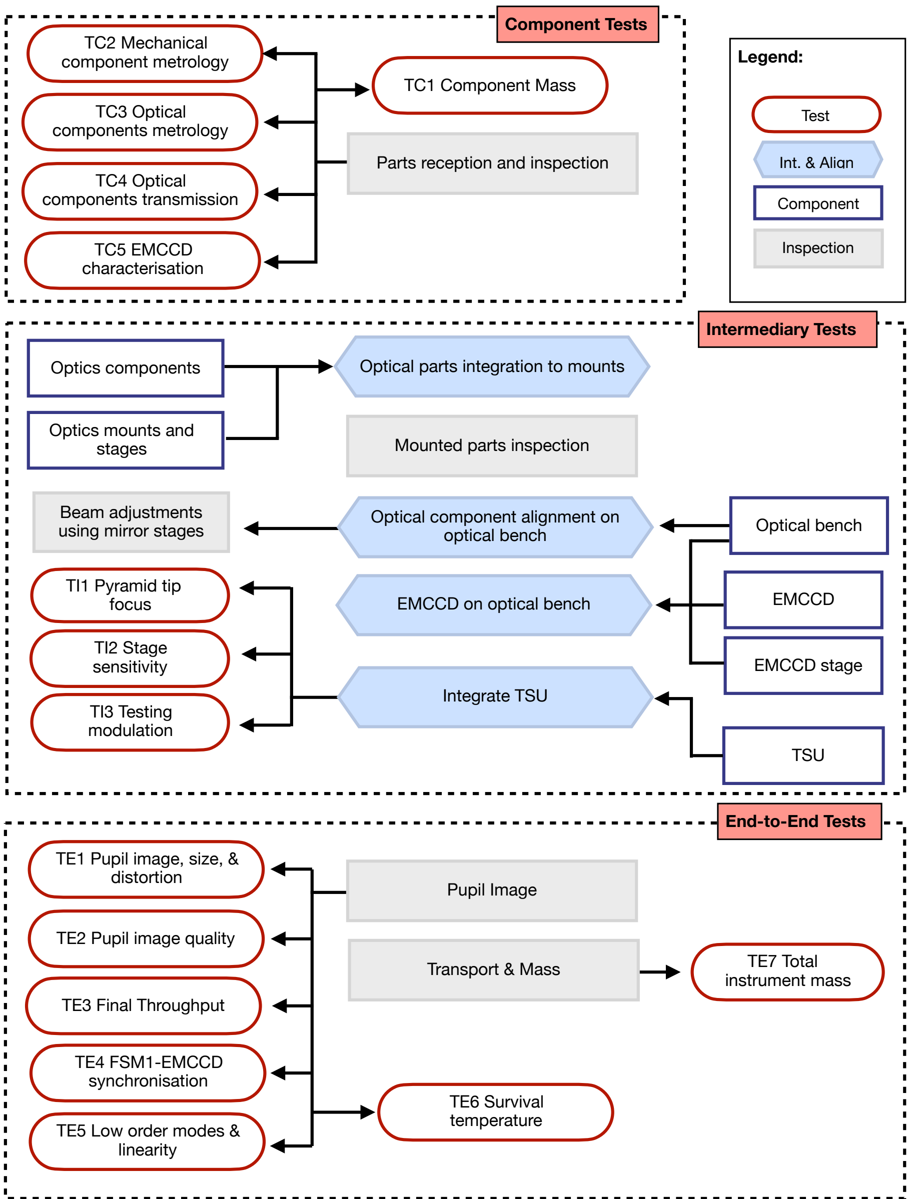

Figure 4. PWFS verification flow chart.

laboratory pre-integration testing a telescope simulator unit (TSU) was designed and built to provide an f/64 beam, which will replace the laser jig. The wavelength of the light source used for testing is 635 nm.

3.1 MIRRORS

The PWFS utilises four mirrors; two FSMs and two fold mirrors. Prior to mounting the mirrors onto their respective stages, the surface flatness and quality of the mirrors were assessed by using a Zygo interferometer. Measurements were taken over two days. With 24 hours apart, the surface flatness RMS had more than halved. This is most likely due to temperature variations (since the environmental conditions of the mirrors had changed). The effects of temperature on the performance of the PWFS will be further investigated. The mounting procedure of the mirrors was designed by OMP and is described here.

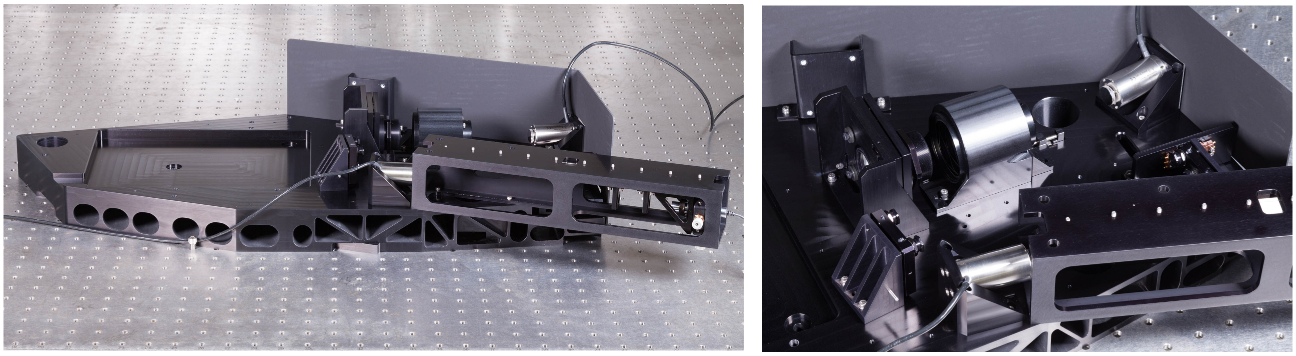

Figure 5. Images of the PWFS bench with laser jig in the laboratory.

Fold Mirror Mounting

The diameter and thickness of the fold mirrors are 25.4 mm and 6.0 mm respectively. Each mirror was mounted by using an o-ring and alignment circle, which applies slight pressure to seal the mirror. Injection holes were located on the sides of the mount to evenly fill the inner edge of the mount to the outer edge of the mirror with adhesive. The adhesive used was DC 732. Figure 6 shows the mounting of one of the fold mirrors, as well as the masked surface height map of one of the fold mirrors before and after mounting. The diffraction circles present in the image are not from the mirror but the Zygo interferometer. After mounting, there was a 6 and 1 % increase in the surface flatness RMS for the two fold mirrors.

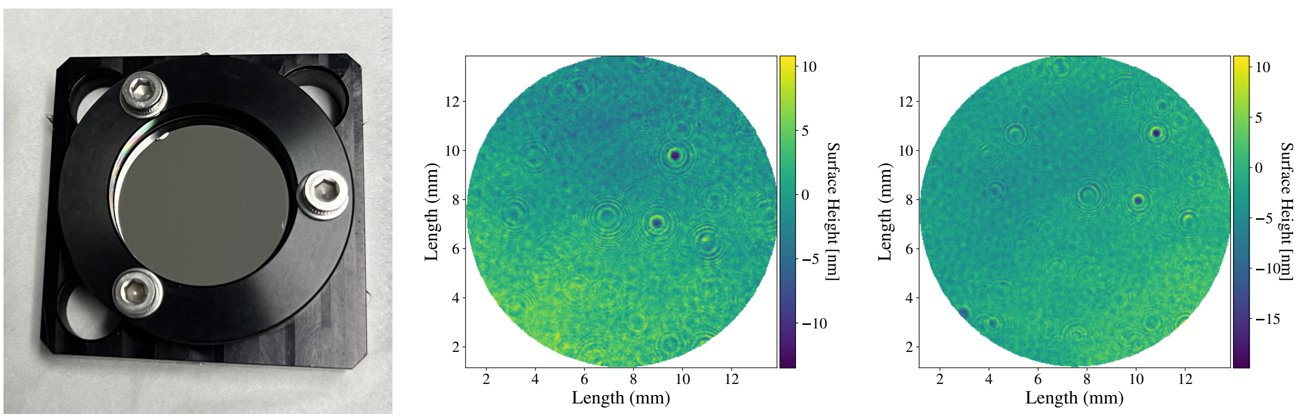

Figure 6. (Left) Mounted fold mirror with alignment o-ring under the alignment circle. (Middle & Right) Masked surface height map of one of the fold mirrors before and after mounting respectively, with piston and tip/tilt subtraction.

Fast Steering Mirror 1 Mounting

The diameter and thickness of the FSMs are 15 mm and 3 mm respectively. Only FSM1 required mounting, as FSM2 had previously been mounted by PI. The mounting of FSM1 onto the PI S-331.5SL modulation stage was facilitated by a 3D printed alignment ring, as shown in figure 7. The adhesive used was Epoxy Adhesive DP 2216 Gray. To reduce the possibility of trefoil on the mirror, six small dots of glue were placed onto the stage. Figure 7 also shows the masked surface height map of FSM1 after mounting. The surface flatness of FSM1 appeared to improve by 8 %, this is likely due to the difference in the mounts when using the Zygo interferometer.

4. CONCLUSION & FUTURE WORK

The upgrade of the GPI AO system will provide significant improvement to the performance of GPI 2.0, as it accesses fainter WFS targets and provides better performance on bright targets. All optical and optomechanical parts have been procured, and an extensive plan for aligning and testing the PWFS has been made to ensure

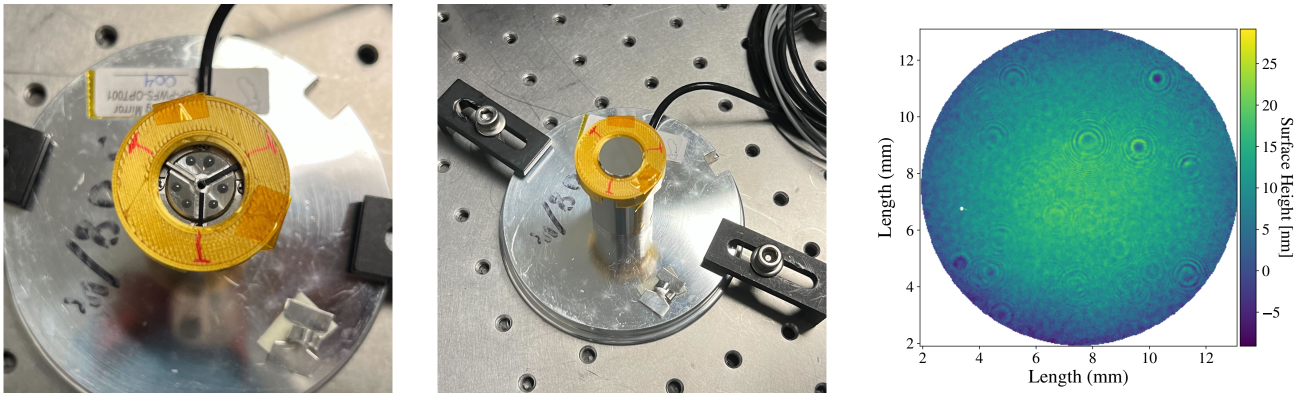

Figure 7. (Left) Modulation stage with 6 dots of glue, shims to stop glue falling into the grooves of the stage as well as the 3D printed alignment ring. (Middle) Mirror for FSM1 on the PI S-331.5SL modulation stage. (Right) Masked surface height map of the mirror for FSM1 after mounting, with piston and tip/tilt subtraction.

performance requirements are met. Optical component tests have been completed and the next steps will include characterisation of the EMCCD, alignment and modulation tests to ensure integer number modulations for single exposures, as well as assessing the throughput, pupil image quality and linearity. In addition, as seen by the surface flatness RMS variations, further testing of the effects of temperature on the PWFS performance is needed and will be completed using an environment chamber. These performance validations will take place before the PWFS integration into the GPI2.0 instrument.

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