GPI 2.0: Upgrade Status of the Gemini Planet Imager

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ABSTRACT

The Gemini Planet Imager (GPI) is a dedicated high-contrast imaging facility instrument. After six years, GPI has helped establish that the occurrence rate of Jovian planets peaks near the snow. GPI 2.0 is expected to achieve deeper contrasts, especially at small inner working angles, to extend GPI's operating range to fainter stars, and to broaden its scientific capabilities. GPI shipped from Gemini South in 2022 and is undergoing an upgrade as part of a relocation to Gemini North. We present the status of the upgrades including replacing the

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current wavefront sensor with an EMCCD-based pyramid wavefront sensor, adding a broadband low spectral resolution prism, new apodized-pupil Lyot coronagraph designs, upgrades of the calibration wavefront sensor and increased queue operability. Further we discuss the progress of reintegrating these components into the new system and the expected performance improvements in the context of GPI 2.0's enhanced science capabilities.

Keywords: Adaptive optics; extrasolar planets; coronagraphy; integral field spectrograph

1. INTRODUCTION

The search for and discovery of extrasolar planets has profoundly transformed our understanding of planetary formation and our solar system's place among other systems in the galaxy. Thousands of exoplanets have been identified, showcasing a vast diversity of planetary system configurations. However, only a few of the largest or most widely separated exoplanets have been studied spectroscopically. Direct imaging plays a crucial role in advancing our knowledge of exoplanets. It enables the discovery of planets in solar system-scale orbits, offers new insights into the formation and characteristics of extrasolar systems, and allows for direct spectroscopic observations of their atmospheres.

The Gemini Planet Imager (GPI) is a facility class instrument designed to address the fundamental goal of directly imaging exoplanets (Figure 1). GPI was designed and built to directly image and spectroscopically characterize young, Jupiter-sized, self-luminous extrasolar planets and search for circumstellar debris disks that are sculpted by planetary systems. The primary motivation for constructing GPI was to measure the frequency and distribution of wide-orbit, giant planets. GPI was installed at Gemini South in the fall of 2013[1] and operated as part of the general suite of facility instruments until the fall of 2020.

1.1 Overview of exoplanet science with GPI

GPI 1.0 consisted of seven major subsystems: an adaptive optics (AO) system, apodized-pupil Lyot coronograph (APLC), a precision infrared wavefront sensor (CAL), a near-IR integral field spectrograph (IFS), an opto-mechanical subsystem to hold all of the components together (OMSS), a top-level computer (TLC), and a data reduction pipeline (DRP), written in IDL, to reconstruct raw IFS images into three-dimensional data cubes and provide basic PSF subtraction. The AO system features a 4096-actuator micro-electromechanical (MEMS) deformable mirror, a CILAS 11-actuator diameter piezoelectric DM in a woofer-tweeter configuration, and a Shack-Hartmann wavefront sensor (WFS) with a Lincoln Labs CCID-66 sensor.[1,2] GPI uses an APLC to suppress coherent light from the central star.[3] GPI's science instrument is an IFS with 192x192 spatial pixels dispersed through a prism to provide a resolving power of R=∼30-100 depending upon the band. The GPI IFS has 5 individual filters in Y, J, H, and 2 in K-band (split into overlapping segments). The IFS further incorporates a Wollaston prism to allow for polarization measurements but only in broad band.[4,5]

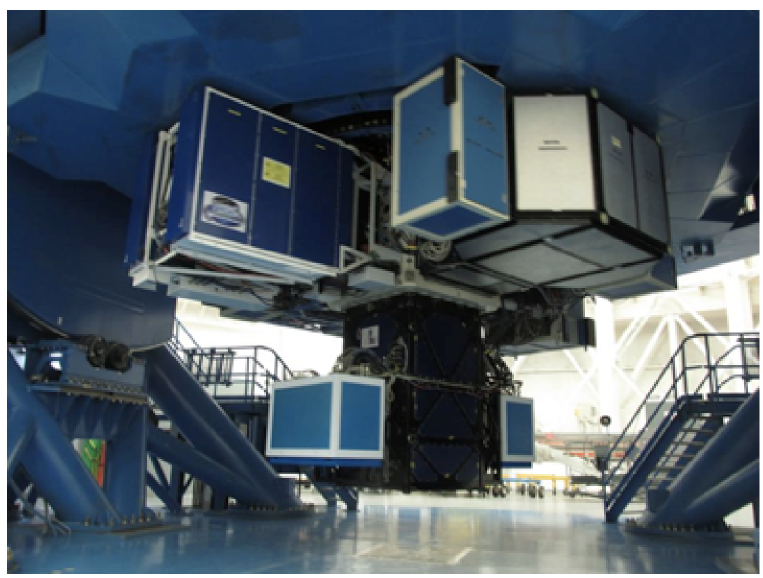

Figure 1: GPI (bottom) mounted on the Cassegrain mount of the Gemini South telescope, Chile.

2. SUMMARY OF GPI 1.0

GPI was shipped to and installed at Gemini South in 2013. It was commissioned during the 2013B and 2014A semesters and began routine science operations in the 2014B semester. More then 58 unique principal investigators used GPI, with about half of the accepted programs being related to exoplanet detection and characterization, while one third utilize GPI's polarimetric capability to study circumstellar material around both young and more evolved stars.

GPI has been scientifically productive with several high-impact results.[6–15] While only on the telescope of a short time, the papers produced by GPI have been cited more then 4300 times (a refereed instrument h-index of greater than 35). One of GPI's main goals was to measure the frequency of wide-orbit (10–100 au) massive (5–13 MJup) planets, finding it to be $8.9^{+4.0}_{-3.6}\%$ for stars over 1.5 $M_{\odot}$.[16] This rate, combined with other data, indicates that giant planet systems are rare.[16]

3. NEXT GENERATION SCIENCE GOALS

In 2018, the Gemini Planet Imager (GPI) was reviewed for a potential relocation from Gemini South to Gemini North. At that time, GPI had been operational since 2013 without any significant overhauls. Since GPI was originally designed to operate at both Gemini North and Gemini South, it met all interface control specifications for both observatories and was expected to function normally at Gemini North. The report recommended a major inspection or overhaul of GPI within the next two to three years to ensure its uptime. It was recognized that relocating from Chile to Hawaii would require significant disassembly of the instrument. Therefore, the report recommended that the timing of the relocation to Gemini North be closely coordinated with the period when GPI would need major servicing. The team proposed using the relocation and maintenance period to upgrade GPI's hardware for next-generation science needs.

Science Goals	**WFS I-magnitude**	**Inner working Angle**	**Contrast Improvements**
Large-scale survey / cold-start planets	10	0.15”	2+ mag
Very young stars + transitional disks	13	0.1”	0
Asteroids & solar system objects	13-14	-	0
Debris Disks	9	0.2”	0
Planet Variability & abundance characterisation	6	0.2”	1% photometry high-res
Evolved Stars	9	0.1”	0
Nearby AGN	14	-	0

Table 1: GPI 2.0's science goals which drove technical requirements for the upgrade.

The GPI 2.0 team used several science goals to design hardware upgrades around. The first is a Large-scale survey with an emphasis on cold-start planets. Models suggest that a modest increase in contrast of 1-2 magnitudes would lead to a significant increase in the area of the mass/semi-major axis phase space that GPI could probe. As seen in Figure 2, while cold start models predict low-luminosity planets, the overlap of models at $\sim 2 \times 10^{-6} L_{\odot}$ means a small increase in achieved contrast around a young star will rapidly switch from no sensitivity to cold start planets to being sensitive to cold start planets between 2 and 10 M_{Jup}. This is a stark difference from hot-start planets, where luminosity increases gradually and monotonically with mass. Additionally, increasing the contrast will allow for searches for higher-mass planets around stars that are somewhat older (300-500 Myr) but that are significantly closer to the Sun (20-30 pc). The proximity of these stars will allow an upgraded GPI to probe separations that are consistent with the location of the peak of the occurrence rate distribution as measured for Solar-type stars from previous radial velocity (RV) surveys.[17]

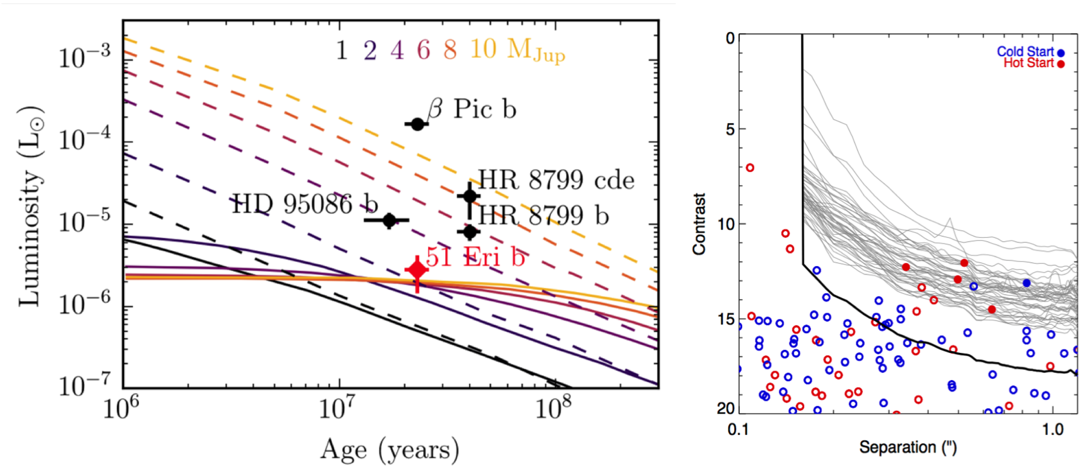

Figure 2: **Left:** Hot-start (dashed) vs cold-start evolutionary models for 1-10M_j with age vs luminosity.[18] Several known planets are indicated. **Right:** In gray are typical GPI contrast curves with the present instrument. In black is a prediction of improving GPI's contrast by 3.2 magnitudes. The planet population is modeled using a distribution of planets consistent with radial velocity and direct imaging surveys. Filled circles represent planets that could be detected with the current observations, open circles would fall below the contrast curve for their particular host star.

Very young stars such as those located in Upper Scorpius (Upper Sco) and Taurus could reveal a number of newly formed planets that can shed light on the distribution and atmospheric properties of targets shortly after formation. By identifying these sources and comparing their demographics with those of the adolescent planets probed by current direct imaging surveys, we can constrain important processes that occur in the early lifetimes of planets, such as migration timescales or atmospheric chemistry evolution. To undertake this science, GPI would need to push its AO system down to 13th or 14th magnitude stars.

While GPI 1.0 hoped to be sensitive to asteroids in our solar system magintude limitations on GPI limited the number of available objects. Increasing the AO system to a limiting magnitude of V=14 would open up $\sim$ 1300 objects for study.

4. GPI 2.0 INSTRUMENT UPGRADE OVERVIEW

In order to achieve the new science goals for GPI 2.0 a number of hardware upgrades to the AO system, the chorongraphs, and the IFS are required. While each of these changes are important, the core capabilities and high quality optics originally designed for GPI are being preserved and reused.

4.1 AO Upgrade: Improving contrast and limiting magnitude

GPI 1.0's adaptive optics (AO) system used a spatially-filtered, Shack-Hartmann wavefront sensor (WFS), designed around a Lincoln Labs CCID-66 sensor, along with a CILAS 95-actuator piezoelectric deformable mirror (DM) and a Boston Micromachines 4096-actuator micro-electro-mechanical (MEMS) DM. The original GPI science case focused on observations of moderate-mass stars in nearby moving groups. The AO system was designed with a limiting magnitude of $I = 9$, with a goal of $I = 10$ due to the brightness of the vast majority of the identified targets GPI would be interested in observing in these moving groups. Further, a conventional CCD detector was used.

Many of the science cases for GPI 2.0 described in Section 3 require GPI to operate at a fainter magnitude of I=13-14. In order for GPI to achieve operations on fainter targets two major changes were undertaken each accounting for approximately half of the magnitude improvement in GPI's capabilities. The first of these is

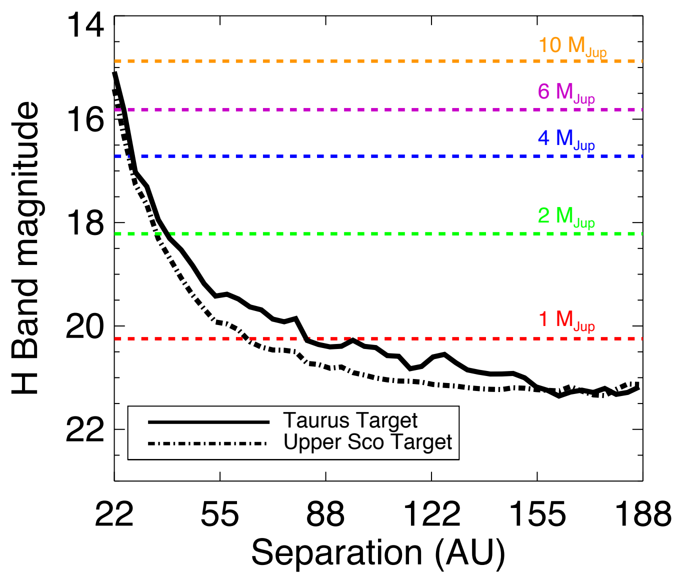

Figure 3: GPI 2.0 sensitivity predictions for very young planets in Upper Sco and Taurus. Contrast curves for two example targets with similar H-band magnitudes but different I band magnitudes are shown. These curves are based on predictions from current GPI performance. The predicted brightnesses of hot-start planets at these ages are shown as dashed colored lines. Note that we will be sensitive to planets as small as 4 M_{Jup} at all separations and down to 1 M_{Jup} at wider separations.

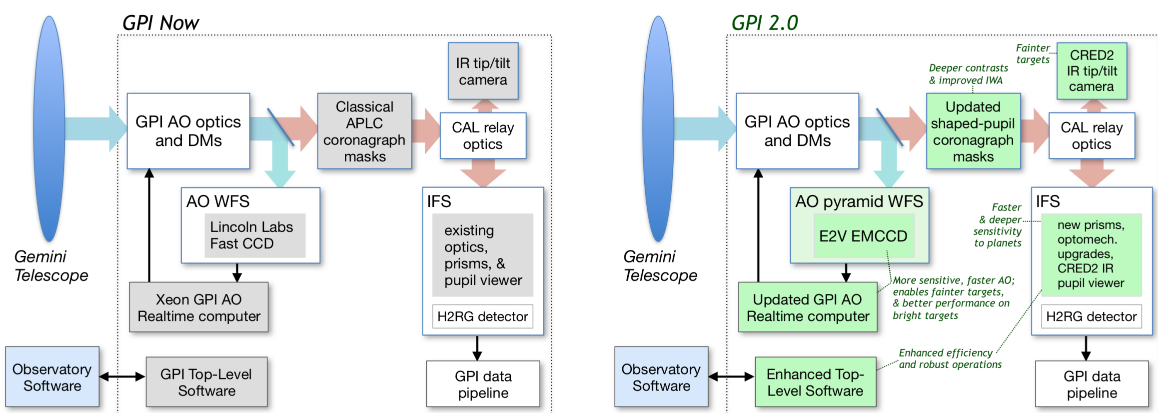

Figure 4: Schematic of GPI subsystems with the original as built system (**Left**) and the upgraded subsystems (**Right**)

moving GPI away from a a conventional CCD detector to a NUVU HNü 240 EMCCD. At the highest gain, the camera is capable of achieving less then $1e^{-}$ of read noise.[19,20]

The second major change is GPI 2.0 will be removing the existing spatially-filtered, Shack-Hartmann wavefront sensor and replacing it with a pyramid WFS. A pyramid WFS for GPI was simulated with PASSATA[21] and desinged by NRC Herzberg Astronomy and Astrophysics.[22] Simulations of a new PYWFS used existing knowledge of GPI's pupil, DM, and science operation goals to estimate performance and confirm that the system will meet requirements. Simulations showed that GPI 2.0 will be able to operate on stars between I=0 and I=14 with performance degrading gracefully for magnitude larger than I=13.[23] Preliminary followup simulations with HCIPy[24] show similar performance results. The GPI RTC is being transitioned to using the HEART architecture.[25]

These upgrades only effect the optical elements in the wavefront sensor path and RTC. GPI will preserve the common light path elements including its optics, CILAS 95-actuator piezoelectric DM and a Boston Micromachines 4096-actuator MEMS.

4.2 Coronagraph Upgrade: Improving inner working angle and contrast

To obtain deeper contrasts, especially close to the star, and to improve performance on fainter stars GPI 2.0 will replace the existing apodized pupil Lyot coronagraph masks[26, 27] with a new generation of designs. This upgrade takes advantage of a decade of technology and concept development since the original GPI coronagraphs were designed. GPI currently uses a set of APLC masks designed to reach a raw contrast of 10^{-7} at 0.2 arcsec in 20% broadband light.

GPI 2.0 will retain the same focal plane masks as the original GPI 1.0 but pair these with new pupil plane masks and lyot stops. The new apodizer and lyot mask combinations have been designed by Russel B. Makidon Optics Laboratory at the Space Telescope Science Institute[28] and manufactured by λ Consulting. The apodizers manufactured by λ Consulting are patterned carbon nanotubes on infrasil substrates.

4.3 CAL 2.0

The GPI CAL will be upgraded in two phases. The first is an upgrade to the low order WFS[29] to improve its operable range to fainter stars of an H-mag of 12 and to improve it accuracy and convergence time as part of improving GPI's efficiency on sky. The second phase of the upgrade is being carried out by NRC Herzberg Astronomy and Astrophysics (HAA). The NRC HAA research centre will replace the high-order WFS sub-system of GPI. CAL 2.0's main focus is the Self Coherent Camera (SCC). The SCC uses a common-path interferometer design to enable focal plane wavefront sensing and control simply by acquiring science camera images showing fringes, which simultaneously allows (i) the measurement of the science focal plane electric field (a standard focal plane imaging science camera only measures intensity), and (ii) the removal of uncorrected stellar noise by post-processing and/or by a feedback loop to the adaptive optics (AO) deformable mirror. The design and overview of CAL 2.0 is discussed in depth in Marois et al.[30–34]

4.4 IFS Upgrade

The GPI IFS[4, 5] is a cryogenic instrument sensitive from $0.95 - 2.4$ μm that measures an image at multiple wavelengths simultaneously. The GPI 2.0 upgrade will modify the prisms inside of the IFS to enable new observing resolutions including a low-spectral-resolution observing mode ($R \sim 10$) and a higher resolution mode in line with GPI's original resolution but with a resolution more even across the filter bands. The design of these prisms, observing modes, and resolutions enabled by GPI are discussed in depth in Limbach et al.[35] and Peng et al.[29] Multiple different designs for prism combinations were considered, and a combination of N-SF66 and CaF_2 was ultimately chosen both for the low resolution prism set and for the replacement higher resolution individual filter band set.

In parallel with adding the low-resolution mode, the high resolution prisms will also be upgraded to enable all of K-band (2-2.4 micron) to be observed simultaneously, reducing the amount of telescope time needed to observe all of K-band by more than 50%. The Y,J, and K-bands are all changing in wavelength coverage from GPI 1.0, though each will still cover the full wavelength band of Y,J,K with some wavelengths outside of the traditional bandpass.[29]

4.5 GPI Operational & Usability Upgrade

Although GPI's reliability has been excellent, and GPI 1.0 was well integrated with Gemini South's computer systems, several improvements have been identified over years of operation to enhance system robustness and user-friendliness. The development of the observing checklist for GPI 1.0 resulted in approximately ten discrete user actions, depending on the type of observations. These steps can be streamlined and reduced to one or two via software improvements. Additional error checking in the alignment and calibration process will reduce the number of steps and eliminate multiple human interventions required in case of an alignment failure. Furthermore,

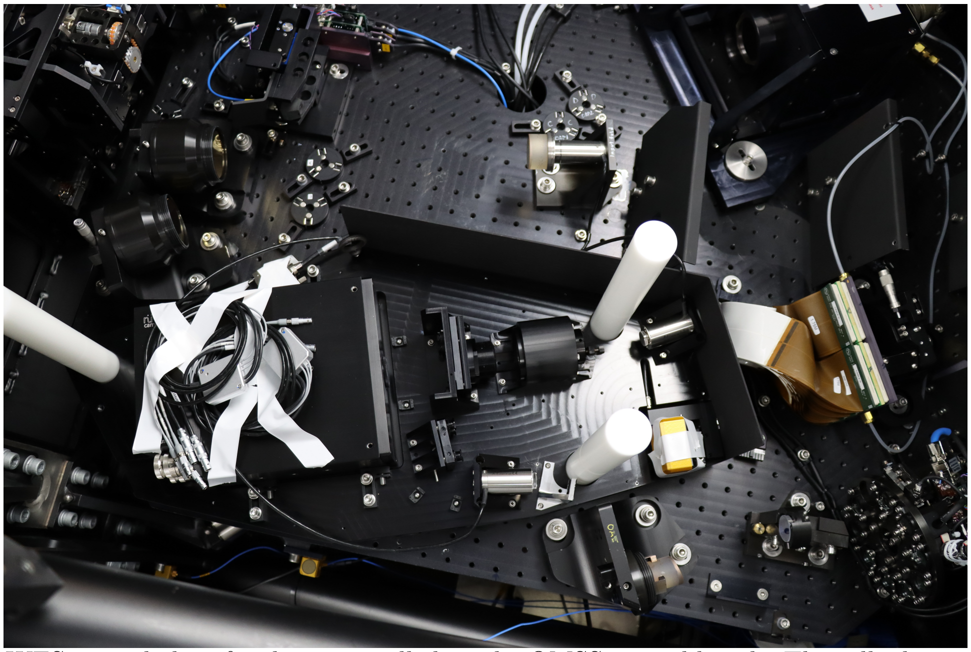

Figure 5: The WFS immedialty after being installed on the OMSS optical bench. The tall white poles were used for alignment

GPI 2.0 will update the open loop models used for internal alignment based on temperature and telescope angle. Finally, GPI's high-level control library, originally implemented in Interactive Data Language (IDL), will be ported to the more modern Python language to improve the reliability of future instrument operations.

5. GPI UPGRADE STATUS

In 2020, GPI 1.0 was expected to be packed and shipped from Gemini South Telescope to the University of Notre Dame. However, due to COVID-19 and civil unrest in Chile, this was delayed by ~2 years. In the Summer of 2022, GPI was finally shipped, and a series of pre- and post-shipping tests were performed to evaluate the instrument's condition.[36] Unfortunately, due to a stuck shutter inside of the CAL, not all tests were able to be completed. These tests were part of the original construction of GPI 1.0 allowing the GPI consortium to maintain a long-term baseline and record of its performance. The approximate two-year delay has resulted in a delay in the upgrade schedule.

5.1 AO WFS Upgrade

GPI's new WFS is located on a sub-bench which is attached to the original optics bench inside of GPI. The individual optics for the WFS are attached to the sub-bench and aligned to each other. The NUVU camera for the WFS has been characterized with is performance described in Do-o et al., 2024.[20] The AO WFS bench passed its install review in the spring of 2024 and in May of 2024. It is currently undergoing final alignment into GPI. The HEART RTC has been being tested in a software only configuration for a year and in June 2024 began communicating with the GPI hardware and DMs. The full status of the AOWSF is described in Perera et al.[37]

5.2 CAL Upgrade

The components described in the hardware upgrade to the CAL's LOWFS has been tested, characterized, and installed.[29] Additionally, in the GPI Focal Plane Mask wheel a Zernike wavefront sensor for non-common path aberrations measurement has been aligned and installed.[38] Finally, GPI's CAL was originally fitted with four uniblitz shutters controlling the entrance light, the exit light, and the light to the HOWFS. Unfortunately, these shutters have slowly failed or become more difficult to operate as they have aged. As part of servicing the CAL, three of the shutters were permanently deactivated or removed. Only the exit shutter, feeding light to the IFS was replaced with an updated shutter using Teflon Coated S.S. Blades to reduce the chances of the shutter becoming stuck in the future.

5.3 IFS Upgrade

The IFS is the last component to be installed into GPI. Once the IFS is installed the AO system and the apodizers can no longer be accessed. Because of this, the IFS is the last subsystem to be upgraded in the schedule. Both he new IFS low-resolution prism and high-resolution prism have been acquired and the cryogenic mechanism to switch between the two spectral prisms and the wollaston prism is currently being tested. All of the new filters for the IFS have been acquired.

As part of the new APLC, new Lyot stops were installed into the IFS. While GPI 1.0 had a design alignment tolerance in rotation of 0.5 degrees per Lyot mask, the operations at Gemini South showed that GPI was able to maintain this rotational alignment to below the the teams ability to measure. The IFS's new Lyot stops have since been installed to less then 0.03 degrees aligemnt to each other, below the 0.1 degree design goal. The final alignment of the Lyot stops to the MEMS will be preformed once the IFS is installed into GPI.

GPI's H2RG was originally procured in 2008 was discovered to have significantly degraded. Original specifications of the H2RG detector measured by Teledyne at 2.0 micron had an operability of 99.71%. A pixel was considered operable if QE$>$ 35%, dark current was $< 1e^{-}$/s, and CDS read noise was $< 50e^{-}$/s. This was the condition of the detector when it was installed to GPI 1.0 IFS in 2009. For GPI's operational life at Gemini South, the detector preformed nearly identically with less then 1% of the pixels being hot. Unfortunately, after the delivery of GPI to Notre Dame, during the instruments testing before being disassembled, the detector was noticed to have a significant increase in hot pixels, with approximately 24% of the pixels having a dark current higher then $1e^{-}$/sec. The team suspects this failure is similar to the JWST near-infrared detector degradation.[39]

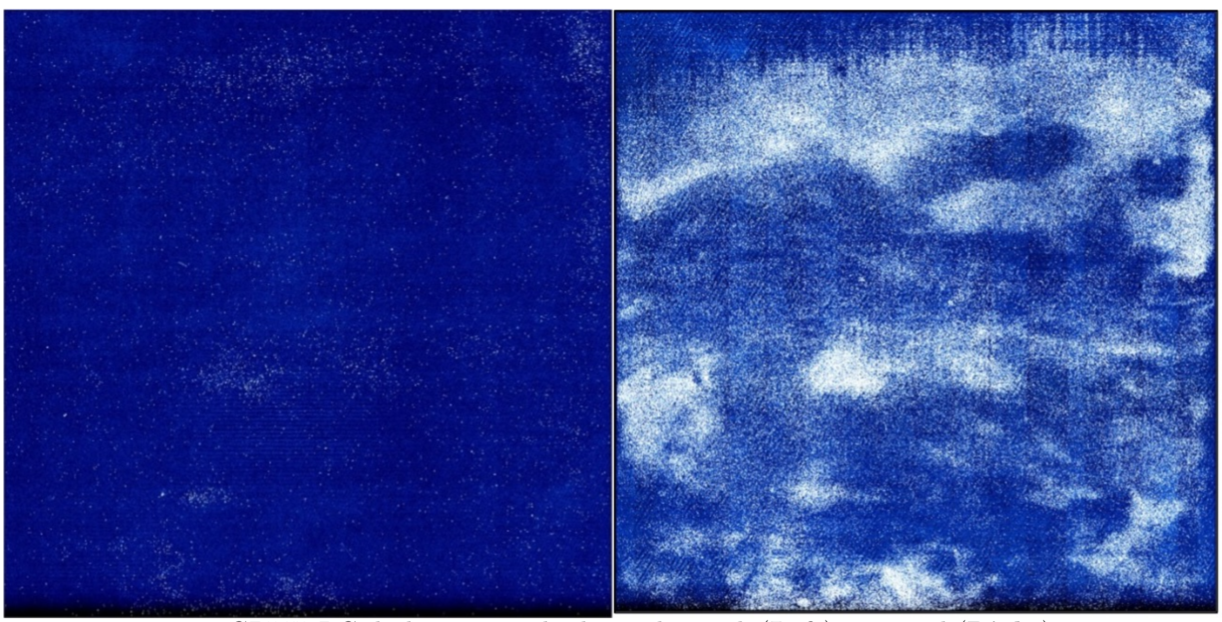

Figure 6: GPI H2RG dark image with identical stretch.(**Left**) 2014 and (**Right**) 2022

5.4 GPI Maintenance

As was noted by the GPI relocation study, GPI was in need of undergoing a major inspection and overhaul. This included an inspection of the overall structure of GPI, the seals on GPI, the optical services, the electronics and electronics enclosures, and the optical services. Multiple items were found to need servicing and the GPI team is currently in the process of servicing those.

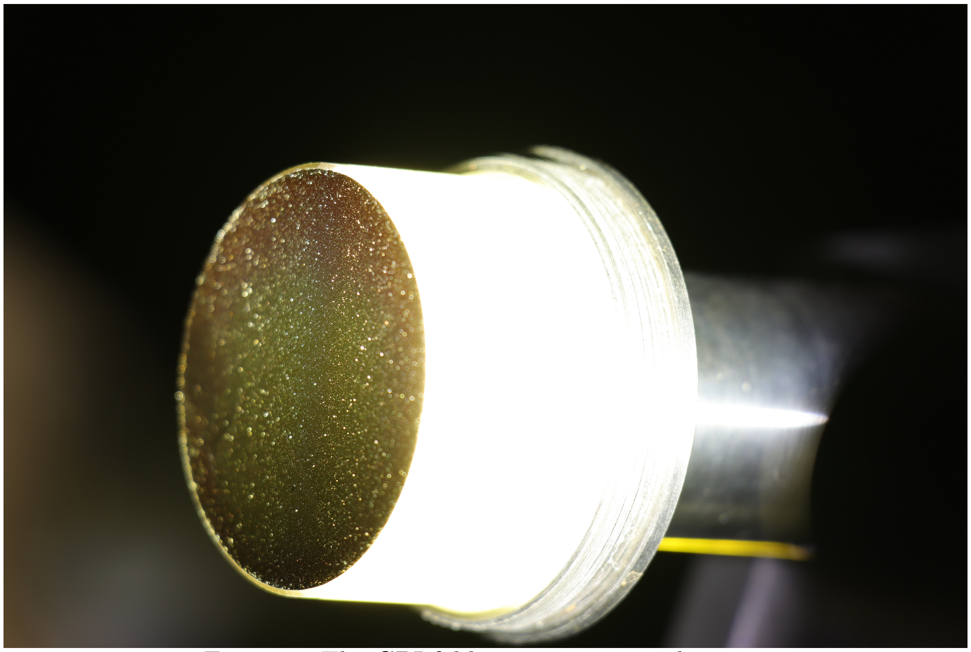
Figure 7: The GPI fold mirror prior to cleaning.

While GPI is designed to keep dust out and a positive pressure environment, it was found that dust had been able to enter the optics enclosure and accumulate on the optics benches and optics despite the covers of GPI not having been opened after 2015. The GPI team is re-cleaned all of the benches and is in the process of upgrading the seals on GPI, the air filters, and cleaning the optical services.

The GPI electronics enclosures (EEs) and electronics themselves were found to have a small sand like material inside of them. While the EEs are closed, they are not designed to maintain the same level of cleanliness as the optics enclosure. The team was uncertain if the source of the sand was from components in the EEs or if the material came from outside of the EEs. After an extensive search could not find a source inside of the EEs, the material was analyzed via high resolution x-ray diffraction and X ray fluorescence as well as under microscope. The material was determined to be weathered silica/sand which has a makeup which looks similar to the materials especially Zr appears to be from Zircon inheritance from long-lived sources of Late Triassic post-orogenic plutons,found near the High Andes, Central Chile region.[40]

6. CONCLUSION

While GPI was installed at Gemini South in 2013, many critical design decisions were made using the best available information in 2004. The technology and field of ExAO systems has greatly advanced in the intervening years. GPI is designed to be a robust and stable instrument enabling long term statistical studies. Since its construction, keeping in mind its science as a stable survey platform, GPI has not undergone any major hardware changes to the instrument. Using the results of the previous decade from multiple large scale surveys, and in-order to stay competitive with cutting edge instruments today, GPI is undertaking a significant upgrade to pursue a science driven upgrade of its hardware. This will accompany a move from Gemini South to Gemini North. These hardware changes and upgrade GPI to enable cutting edge science using GPI from Gemini North for many years.

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REFERENCES

[1] Macintosh, B., Graham, J. R., Ingraham, P., Konopacky, Q., Marois, C., Perrin, M., Poyneer, L., Bauman, B., Barman, T., Burrows, A. S., Cardwell, A., Chilcote, J., De Rosa, R. J., Dillon, D., Doyon, R., Dunn, J., Erikson, D., Fitzgerald, M. P., Gavel, D., Goodsell, S., Hartung, M., Hibon, P., Kalas, P., Larkin, J., Maire, J., Marchis, F., Marley, M. S., McBride, J., Millar-Blanchaer, M., Morzinski, K., Norton, A., Oppenheimer, B. R., Palmer, D., Patience, J., Pueyo, L., Rantakyro, F., Sadakuni, N., Saddlemyer, L., Savransky, D., Serio, A., Soummer, R., Sivaramakrishnan, A., Song, I., Thomas, S., Wallace, J. K., Wiktorowicz, S., and Wolff, S., "First light of the Gemini Planet Imager," *Proceedings of the National Academy of Science* **111**, 12661–12666 (Sept. 2014).

[2] Poyneer, L. A., De Rosa, R. J., Macintosh, B., Palmer, D. W., Perrin, M. D., Sadakuni, N., Savransky, D., Bauman, B., Cardwell, A., Chilcote, J. K., Dillon, D., Gavel, D., Goodsell, S. J., Hartung, M., Hibon, P., Rantakyrö, F. T., Thomas, S., and Veran, J.-P., "On-sky performance during verification and commissioning of the Gemini Planet Imager's adaptive optics system," in [*Adaptive Optics Systems IV*], *Proc. SPIE* **9148**, 91480K (July 2014).

[3] Soummer, R., Sivaramakrishnan, A., Pueyo, L., Macintosh, B., and Oppenheimer, B. R., "Apodized Pupil Lyot Coronagraphs for Arbitrary Apertures. III. Quasi-achromatic Solutions," *Astrophysical Journal* **729**, 144 (Mar. 2011).

[4] Larkin, J. E., Chilcote, J. K., Aliado, T., Bauman, B. J., Brims, G., Canfield, J. M., Cardwell, A., Dillon, D., Doyon, R., Dunn, J., Fitzgerald, M. P., Graham, J. R., Goodsell, S., Hartung, M., Hibon, P., Ingraham, P., Johnson, C. A., Kress, E., Konopacky, Q. M., Macintosh, B. A., Magnone, K. G., Maire, J., McLean, I. S., Palmer, D., Perrin, M. D., Quiroz, C., Rantakyrö, F., Sadakuni, N., Saddlemyer, L., Serio, A., Thibault, S., Thomas, S. J., Vallee, P., and Weiss, J. L., "The integral field spectrograph for the Gemini planet imager," in [*Ground-based and Airborne Instrumentation for Astronomy V*], *Proc. SPIE* **9147**, 91471K (July 2014).

[5] Chilcote, J. K., Larkin, J. E., Maire, J., Perrin, M. D., Fitzgerald, M. P., Doyon, R., Thibault, S., Bauman, B., Macintosh, B. A., Graham, J. R., and Saddlemyer, L., "Performance of the integral field spectrograph for the Gemini Planet Imager," in [*Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series*], *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series* **8446** (Sept. 2012).

[6] Macintosh, B., Graham, J. R., Barman, T., De Rosa, R. J., Konopacky, Q., Marley, M. S., Marois, C., Nielsen, E. L., Pueyo, L., Rajan, A., Rameau, J., Saumon, D., Wang, J. J., Ammons, M., Arriaga, P., Artigau, E., Beckwith, S., Brewster, J., Bruzzone, S., Bulger, J., Burningham, B., Burrows, A. S., Chen, C., Duchene, G., Esposito, T. M., Fabrycky, D., Fitzgerald, M. P., Follette, K. B., Fortney, J. J., Gerard, B., Goodsell, S., Greenbaum, A. Z., Hibon, P., Hinkley, S., Hufford, T., Hung, L.-W., Ingraham, P., Johnson-Groh, M., Kalas, P., Lafreniere, D., Larkin, J. E., Lee, J., Line, M., Long, D., Maire, J., Marchis, F., Matthews, B. C., Max, C. E., Metchev, S., Millar-Blanchaer, M. A., Mittal, T., Morley, C. V., Morzinski, K. M., Murray-Clay, R., Oppenheimer, R., Palmer, D. W., Patel, R., Patience, J., Perrin, M. D., Poyneer, L. A., Rafikov, R. R., Rantakyro, F. T., Rice, E., Rojo, P., Rudy, A. R., Ruffio, J.-B., Ruiz, M. T., Sadakuni, N., Saddlemyer, L., Salama, M., Savransky, D., Schneider, A. C., Sivaramakrishnan, A., Song, I., Soummer, R., Thomas, S., Vasisht, G., Wallace, J. K., Ward-Duong, K., Wiktorowicz, S. J., Wolff, S. G., and Zuckerman, B., "Discovery and spectroscopy of the young jovian planet 51 Eri b with the Gemini Planet Imager.," *Science* **350**, 64–67 (2015).

[7] De Rosa, R. J., Nielsen, E. L., Blunt, S. C., Graham, J. R., Konopacky, Q. M., Marois, C., Pueyo, L., Rameau, J., Ryan, D. M., Wang, J. J., Bailey, V., Chontos, A., Fabrycky, D. C., Follette, K. B., Macintosh, B., Marchis, F., Ammons, S. M., Arriaga, P., Chilcote, J. K., Cotten, T. H., Doyon, R., Duchêne, G.,

Esposito, T. M., Fitzgerald, M. P., Gerard, B., Goodsell, S. J., Greenbaum, A. Z., Hibon, P., Ingraham, P., Johnson-Groh, M., Kalas, P. G., Lafrenière, D., Maire, J., Metchev, S., Millar-Blanchaer, M. A., Morzinski, K. M., Oppenheimer, R., Patel, R. I., Patience, J. L., Perrin, M. D., Rajan, A., Rantakyrö, F. T., Ruffio, J.-B., Schneider, A. C., Sivaramakrishnan, A., Song, I., Tran, D., Vasisht, G., Ward-Duong, K., and Wolff, S. G., "Astrometric Confirmation and Preliminary Orbital Parameters of the Young Exoplanet 51 Eridani b with the Gemini Planet Imager," *Astrophysical Journal Letters* **814**, L3 (Nov. 2015).

[8] Rajan, A., Rameau, J., De Rosa, R. J., Marley, M. S., Graham, J. R., Macintosh, B., Marois, C., Morley, C., Patience, J., Pueyo, L., Saumon, D., Ward-Duong, K., Ammons, S. M., Arriaga, P., Bailey, V. P., Barman, T., Bulger, J., Burrows, A. S., Chilcote, J., Cotten, T., Czekala, I., Doyon, R., Duchêne, G., Esposito, T. M., Fitzgerald, M. P., Follette, K. B., Fortney, J. J., Goodsell, S. J., Greenbaum, A. Z., Hibon, P., Hung, L.-W., Ingraham, P., Johnson-Groh, M., Kalas, P., Konopacky, Q., Lafrenière, D., Larkin, J. E., Maire, J., Marchis, F., Metchev, S., Millar-Blanchaer, M. A., Morzinski, K. M., Nielsen, E. L., Oppenheimer, R., Palmer, D., Patel, R. I., Perrin, M., Poyneer, L., Rantakyrö, F. T., Ruffio, J.-B., Savransky, D., Schneider, A. C., Sivaramakrishnan, A., Song, I., Soummer, R., Thomas, S., Vasisht, G., Wallace, J. K., Wang, J. J., Wiktorowicz, S., and Wolff, S., "Characterizing 51 Eri b from 1 to 5 μm: A Partly Cloudy Exoplanet," *Astronomical Journal* **154**, 10 (July 2017).

[9] Ingraham, P., Marley, M. S., Saumon, D., Marois, C., Macintosh, B., Barman, T., Bauman, B., Burrows, A., Chilcote, J. K., De Rosa, R. J., Dillon, D., Doyon, R., Dunn, J., Erikson, D., Fitzgerald, M. P., Gavel, D., Goodsell, S. J., Graham, J. R., Hartung, M., Hibon, P., Kalas, P. G., Konopacky, Q., Larkin, J. A., Maire, J., Marchis, F., McBride, J., Millar-Blanchaer, M., Morzinski, K. M., Norton, A., Oppenheimer, R., Palmer, D. W., Patience, J., Perrin, M. D., Poyneer, L. A., Pueyo, L., Rantakyrö, F., Sadakuni, N., Saddlemyer, L., Savransky, D., Soummer, R., Sivaramakrishnan, A., Song, I., Thomas, S., Wallace, J. K., Wiktorowicz, S. J., and Wolff, S. G., "Gemini Planet Imager Spectroscopy of the HR 8799 Planets c and d," *Astrophysical Journal Letters* **794**, L15 (Oct. 2014).

[10] Galicher, R., Rameau, J., Bonnefoy, M., Baudino, J.-L., Currie, T., Boccaletti, A., Chauvin, G., Lagrange, A.-M., and Marois, C., "Near-infrared detection and characterization of the exoplanet HD 95086 b with the Gemini Planet Imager," *Astronomy & Astrophysics* **565**, L4 (May 2014).

[11] De Rosa, R. J., Rameau, J., Patience, J., Graham, J. R., Doyon, R., Lafrenière, D., Macintosh, B., Pueyo, L., Rajan, A., Wang, J. J., Ward-Duong, K., Hung, L.-W., Maire, J., Nielsen, E. L., Ammons, S. M., Bulger, J., Cardwell, A., Chilcote, J. K., Galvez, R. L., Gerard, B. L., Goodsell, S., Hartung, M., Hibon, P., Ingraham, P., Johnson-Groh, M., Kalas, P., Konopacky, Q. M., Marchis, F., Marois, C., Metchev, S., Morzinski, K. M., Oppenheimer, R., Perrin, M. D., Rantakyrö, F. T., Savransky, D., and Thomas, S., "Spectroscopic Characterization of HD 95086 b with the Gemini Planet Imager," *Astrophysical Journal* **824**, 121 (June 2016).

[12] Chilcote, J., Pueyo, L., De Rosa, R. J., Vargas, J., Macintosh, B., Bailey, V. P., Barman, T., Bauman, B., Bruzzone, S., Bulger, J., Burrows, A. S., Cardwell, A., Chen, C. H., Cotten, T., Dillon, D., Doyon, R., Draper, Z. H., Duchêne, G., Dunn, J., Erikson, D., Fitzgerald, M. P., Follette, K. B., Gavel, D., Goodsell, S. J., Graham, J. R., Greenbaum, A. Z., Hartung, M., Hibon, P., Hung, L.-W., Ingraham, P., Kalas, P., Konopacky, Q., Larkin, J. E., Maire, J., Marchis, F., Marley, M. S., Marois, C., Metchev, S., Millar-Blanchaer, M. A., Morzinski, K. M., Nielsen, E. L., Norton, A., Oppenheimer, R., Palmer, D., Patience, J., Perrin, M., Poyneer, L., Rajan, A., Rameau, J., Rantakyrö, F. T., Sadakuni, N., Saddlemyer, L., Savransky, D., Schneider, A. C., Serio, A., Sivaramakrishnan, A., Song, I., Soummer, R., Thomas, S., Wallace, J. K., Wang, J. J., Ward-Duong, K., Wiktorowicz, S., and Wolff, S., "1-2.4 μm Near-IR Spectrum of the Giant Planet β Pictoris b Obtained with the Gemini Planet Imager," *Astronomical Journal* **153**, 182 (Apr. 2017).

[13] Johnson-Groh, M., Marois, C., De Rosa, R. J., Nielsen, E. L., Rameau, J., Blunt, S., Vargas, J., Ammons, S. M., Bailey, V. P., Barman, T. S., Bulger, J., Chilcote, J. K., Cotten, T., Doyon, R., Duchêne, G., Fitzgerald, M. P., Follette, K. B., Goodsell, S., Graham, J. R., Greenbaum, A. Z., Hibon, P., Hung, L.-W., Ingraham, P., Kalas, P., Konopacky, Q. M., Larkin, J. E., Macintosh, B., Maire, J., Marchis, F., Marley, M. S., Metchev, S., Millar-Blanchaer, M. A., Oppenheimer, R., Palmer, D. W., Patience, J., Perrin, M., Poyneer, L. A., Pueyo, L., Rajan, A., Rantakyrö, F. T., Savransky, D., Schneider, A. C., Sivaramakrishnan, A., Song, I., Soummer, R., Thomas, S., Vega, D., Wallace, J. K., Wang, J. J., Ward-Duong, K., Wiktorowicz,

S. J., and Wolff, S. G., "Integral Field Spectroscopy of the Low-mass Companion HD 984 B with the Gemini Planet Imager," *Astronomical Journal* **153**, 190 (Apr. 2017).

[14] Greenbaum, A. Z., Pueyo, L., Ruffio, J.-B., Wang, J. J., De Rosa, R. J., Aguilar, J., Rameau, J., Barman, T., Marois, C., Marley, M. S., Konopacky, Q., Rajan, A., Macintosh, B., Ansdell, M., Arriaga, P., Bailey, V. P., Bulger, J., Burrows, A. S., Chilcote, J., Cotten, T., Doyon, R., Duchêne, G., Fitzgerald, M. P., Follette, K. B., Gerard, B., Goodsell, S. J., Graham, J. R., Hibon, P., Hung, L.-W., Ingraham, P., Kalas, P., Larkin, J. E., Maire, J., Marchis, F., Metchev, S., Millar-Blanchaer, M. A., Nielsen, E. L., Norton, A., Oppenheimer, R., Palmer, D., Patience, J., Perrin, M. D., Poyneer, L., Rantakyrö, F. T., Savransky, D., Schneider, A. C., Sivaramakrishnan, A., Song, I., Soummer, R., Thomas, S., Wallace, J. K., Ward-Duong, K., Wiktorowicz, S., and Wolff, S., "GPI Spectra of HR 8799 c, d, and e from 1.5 to 2.4 μm with KLIP Forward Modeling," *Astronomical Journal* **155**, 226 (June 2018).

[15] Crepp, J. R., Principe, D. A., Wolff, S., Giorla Godfrey, P. A., Rice, E. L., Cieza, L., Pueyo, L., Bechter, E. B., and Gonzales, E. J., "GPI Spectroscopy of the Mass, Age, and Metallicity Benchmark Brown Dwarf HD 4747 B," *Astrophysical Journal* **853**, 192 (Feb. 2018).

[16] Nielsen, E. L., De Rosa, R. J., Macintosh, B., Wang, J. J., Ruffio, J.-B., Chiang, E., Marley, M. S., Saumon, D., Savransky, D., Ammons, S. M., Bailey, V. P., Barman, T., Blain, C., Bulger, J., Burrows, A., Chilcote, J., Cotten, T., Czekala, I., Doyon, R., Duchêne, G., Esposito, T. M., Fabrycky, D., Fitzgerald, M. P., Follette, K. B., Fortney, J. J., Gerard, B. L., Goodsell, S. J., Graham, J. R., Greenbaum, A. Z., Hibon, P., Hinkley, S., Hirsch, L. A., Hom, J., Hung, L.-W., Dawson, R. I., Ingraham, P., Kalas, P., Konopacky, Q., Larkin, J. E., Lee, E. J., Lin, J. W., Maire, J., Marchis, F., Marois, C., Metchev, S., Millar-Blanchaer, M. A., Morzinski, K. M., Oppenheimer, R., Palmer, D., Patience, J., Perrin, M., Poyneer, L., Pueyo, L., Rafikov, R. R., Rajan, A., Rameau, J., Rantakyrö, F. T., Ren, B., Schneider, A. C., Sivaramakrishnan, A., Song, I., Soummer, R., Tallis, M., Thomas, S., Ward-Duong, K., and Wolff, S., "The Gemini Planet Imager Exoplanet Survey: Giant Planet and Brown Dwarf Demographics from 10 to 100 au," *Astronomical Journal* **158**, 13 (July 2019).

[17] Fernandes, R. B., Mulders, G. D., Pascucci, I., Mordasini, C., and Emsenhuber, A., "Hints for a Turnover at the Snow Line in the Giant Planet Occurrence Rate," *Astrophysical Journal* **874**, 81 (Mar. 2019).

[18] Marley, M. S., Fortney, J. J., Hubickyj, O., Bodenheimer, P., and Lissauer, J. J., "On the Luminosity of Young Jupiters," *Astrophysical Journal* **655**, 541–549 (Jan. 2007).

[19] Do Ó, C. R., Perera, S., Maire, J., Nguyen, J. S., Levinstein, D. M., Konopacky, Q. M., Chilcote, J., Fitzsimmons, J., Hamper, R., Kerley, D., Macintosh, B., Marois, C., Rantakyrö, F., Savransky, D., Véran, J.-P., Agapito, G., Ammons, S. M., Bonaglia, M., Boucher, M.-A., Dunn, J., Esposito, S., Filion, G., Landry, J.-T., Lardière, O., Li, D., Madurowicz, A., Peng, D., Poyneer, L., and Spalding, E., "GPI 2.0: performance evaluation of the wavefront sensor's EMCCD," in [*Astronomical Telescopes + Instrumentation*], *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series* (Dec. 2022).

[20] Do Ó, C. R., Perera, S., Maire, J., Nguyen, J., Chambouleyron, V., Konopacky, Q., Chilcote, J., Fitzsimmons, J., Hamper, R., Kerley, D., Macintosh, B., Marois, C., Rantakyrö, F., Savransky, D., Veran, J. P., Agapito, G., Ammons, S., Boucher, M., Dunn, J., Esposito, S., Filion, G., Landry, J., Lardiere, O., Duan, L., A., M., Peng, D., Poyneer, L., and E., S., "GPI 2.0: exploring the impact of different readout modes on the wavefront sensor's EMCCD," in [*Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series*], *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series* **13097** (2024).

[21] Agapito, G., Puglisi, A., and Esposito, S., "PASSATA: object oriented numerical simulation software for adaptive optics," in [*Adaptive Optics Systems V*], Marchetti, E., Close, L. M., and Véran, J.-P., eds., *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series* **9909**, 99097E (July 2016).

[22] Fitzsimmons, J., Dunn, J., Kerley, D., Lardiere, O., Marois, C., Veran, J.-P., Macintosh, B., Poyneer, L., Madurowicz, A., Chilcote, J., Konopacky, Q., Savransky, D., Maire, J., Esposito, S., Agapito, G., and Bonaglia, M., "GPI 2.0: Design of the pyramid wave front sensor upgrade for GPI," in [*Astronomical Telescopes + Instrumentation*], *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series* (Dec. 2020).

[23] Nguyen, J. S., Maire, J., Perera, S., Levinstein, D., Do Ó, C. R., Konopacky, Q., Chilcote, J., Fitzsimmons, J., Hamper, R., Kerley, D., Macintosh, B., Marois, C., Rantakyrö, F., Savransky, D., Véran, J.-P., Agapito, G., Ammons, S. M., Bonaglia, M., Boucher, M.-A., Dunn, J., Esposito, S., Filion, G., Landry, J.-T., Lardière,

O., Li, D., Madurowicz, A., Nguyen, M., Nickson, B., Peng, D., Por, E., and Poyneer, L., "GPI 2.0: End-to-end simulations of the AO-coronagraph system," in [*Astronomical Telescopes + Instrumentation*], *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series* (Dec. 2022).

[24] Nguyen, J., Maire, J., Perera, S., Do Ó, C. R., Konopacky, Q., Levinstein, D., Chilcote, J., Fitzsimmons, J., Hamper, R., Kerley, D., Macintosh, B., Marois, C., Rantakyrö, F., Savransky, D., Veran, J. P., Agapito, G., Ammons, S., Boucher, M., Dunn, J., Esposito, S., Filion, G., Landry, J., Lardiere, O., Duan, L., A., M., Nguyen, M., B., N., Peng, D., Por, E., Poyneer, L., Soummer, R., Chambouleyron, V., Galvan, O., Singh, G., Mocnik, T., Quiroz, C., Sands, B., Engstrom, M., and Burke, J., "GPI 2.0: end-to-end simulations of the AO-coronagraph system," in [*Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series*], *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series* **13097** (2024).

[25] Kerley, D., Dunn, J., Véran, J.-P., Muller, L., Chapin, E., Smith, M., Stocks, J., Gamroth, D., Macintosh, B., Marois, C., Lardière, O., Savransky, D., Fitzsimmons, J., Konopacky, Q., and Chilcote, J., "HEART: Gemini Planet Imager upgrade (GPI2.0) Real-Time Controller (RTC) using the Herzberg Extensible Adaptive Real-time Toolkit (HEART)," in [*Adaptive Optics Systems VIII*], Schreiber, L., Schmidt, D., and Vernet, E., eds., *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series* **12185**, 121856H (Aug. 2022).

[26] Soummer, R., "Apodized Pupil Lyot Coronagraphs for Arbitrary Telescope Apertures," *Astrophysical Journal Letters* **618**, L161–L164 (Jan. 2005).

[27] Soummer, R., Pueyo, L., Ferrari, A., Aime, C., Sivaramakrishnan, A., and Yaitskova, N., "Apodized Pupil Lyot Coronagraphs for Arbitrary Apertures. II. Theoretical Properties and Application to Extremely Large Telescopes," *Astrophysical Journal* **695**, 695–706 (Apr. 2009).

[28] Nguyen, M. M., Nickson, B., Por, E. H., Soummer, R., Pueyo, L. A., Perrin, M. D., Macintosh, B. A., Chilcote, J. K., Konopacky, Q. M., and Maire, J., "GPI 2.0: optical designs for the upgrade of the Gemini Planet Imager coronagraphic system," in [*Astronomical Telescopes + Instrumentation*], *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series* (Dec. 2022).

[29] Peng, D. H., Chilcote, J., Konopacky, Q. M., Fitzsimmons, J., Macintosh, B., Marois, C., Rantakyrö, F. T., Aleman, A., Rosa, R. J., Limbach, M. A., Maire, J., Savransky, D., Curliss, M., Hamper, R., Sands, B., Do Ó, C. R., Perera, S., and Spalding, E., "GPI 2.0: Performance of upgrades to the Gemini Planet Imager CAL and IFS," in [*Astronomical Telescopes + Instrumentation*], *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series* (Dec. 2022).

[30] Marois, C., Gerard, B., Lardière, O., Thompson, W., and Véran, J.-P., "Upgrading the Gemini Planet Imager calibration unit with a photon counting focal plane wavefront sensor," in [*Astronomical Telescopes + Instrumentation*], *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series* (Dec. 2020).

[31] Singh, G., Thompson, W., Lardière, O., Marois, C., N'Diaye, M., Johnson, A. B., Véran, J.-P., Herriot, G., Gerard, B., Fu, Q., and Heidrich, W., "Pupil-plane LLOWFS simulation and laboratory results from NEW-EARTH's high-contrast imaging testbed," in [*Astronomical Telescopes + Instrumentation*], *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series* (Dec. 2022).

[32] Johnson, A. B., Marois, C., Gamroth, D., Lardière, O., Thompson, W., Singh, G., Fitzsimmons, J., and Bradley, C., "Blinking the fringes, initial development and results of the Ultra-Low Speed Optical Chopper for the Self-Coherent Camera," in [*Astronomical Telescopes + Instrumentation*], *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series* (Dec. 2022).

[33] Thompson, W. R., Singh, G., Marois, C., Lardière, O., Fu, Q., Heidrich, W., and Gerard, B., "Performance of the FAST Self Coherent Camera at the NEW-EARTH Lab and a Simplified SCC Measurement Algorithm," in [*Astronomical Telescopes + Instrumentation*], *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series* (Dec. 2022).

[34] Marois, C., Lardière, O., Fitzsimmons, J., Boucher, M.-A., Bradley, C., Brousseau, D., Caputa, K., Demers, M., Dunn, J., Dutt, S., Fu, Q., Galvan, O., Gamroth, D., Gerard, B., Hardy, T., Heidrich, W., Herriot, G., Jensen-Clem, R., Johnson, A., Landry, J.-T., Li, D., Mann, C., Nkwari, P., Rawat, S., Savransky, D., Singh, G., Sivanandam, S., Thibault, S., Thompson, W., Kooten, M., and Véran, J.-P., "CAL2: Project update of the NRC Canada facility-class focal plane wavefront sensor for the Gemini Planet Imager 2 upgrade," in

[*Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series*], *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series* **13097** (2024).

[35] Limbach, M. A., Chilcote, J., Konopacky, Q., De Rosa, R., Hamper, R., Macintosh, B., Marois, C., Perrin, M., Savransky, D., Veran, J.-P., Wang, J., and Aleman, A., "GPI 2.0: Upgrades to the IFS including new spectral modes," in [*Astronomical Telescopes + Instrumentation*], *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series* (Dec. 2020).

[36] Spalding, E. A., Do Ó, C. R., Peng, D., Perera, S., Chilcote, J., Hamper, R., Konopacky, Q., Rantakyrö, F., Macintosh, B., and Savransky, D., "GPI 2.0: Baseline testing of the Gemini Planet Imager before the upgrade," in [*Astronomical Telescopes + Instrumentation*], *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series* (Dec. 2022).

[37] Perera, S., Maire, J., Do Ó, C. R., Nguyen, J., Chambouleyron, V., Levinstein, D., Konopacky, Q., Chilcote, J., Sands, B., Engstrom, M., Hamper, R., Fitzsimmons, J., Kerley, D., Macintosh, B., Marois, C., Rantakyrö, F., Savransky, D., Veran, J. P., Agapito, G., Ammons, S., Boucher, M., Boucher, M., Burke, J., Dillon, D., Dunn, J., Esposito, S., Filion, G., Galvan, O., Landry, J., Lardiere, O., Duan, L., A., M., Mocnik, T., Peng, D., Poyneer, L., Quiroz, C., Singh, G., and Eckart, S., "GPI 2.0: integration of the pyramid wavefront sensor," in [*Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series*], *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series* **13097** (2024).

[38] Chambouleyron, V., Salama, M., Guthery, C. E., Perera, S., Konopacky, Q., Veran, J. P., Savransky, D., Chilcote, J., Wallace, J. K., Dillon, D., Jensen-Clem, R., and Macintosh, B., "Gemini planet imager 2.0: implementing a Zernike wavefront sensor for non-common path aberrations measurement," in [*Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series*], *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series* **12680**, 1268002 (Oct. 2023).

[39] Rauscher, B. J., Stahle, C., Hill, R. J., Greenhouse, M., Beletic, J., Babu, S., Blake, P., Cleveland, K., Cofie, E., Eegholm, B., Engelbracht, C. W., Hall, D. N. B., Hoffman, A., Jeffers, B., Jhabvala, C., Kimble, R. A., Kohn, S., Kopp, R., Lee, D., Leidecker, H., Lindler, D., McMurray, R. E., Misselt, K., Mott, D. B., Ohl, R., Pipher, J. L., Piquette, E., Polis, D., Pontius, J., Rieke, M., Smith, R., Tennant, W. E., Wang, L., Wen, Y., Willmer, C. N. A., and Zandian, M., "Commentary: JWST near-infrared detector degradation—finding the problem, fixing the problem, and moving forward," *AIP Advances* **2**, 021901 (June 2012).

[40] Molina, P. G., Parada, M. A., and Ma, C., "Zircon inheritance from long-lived sources of Late Triassic post-orogenic plutons, High Andes, Central Chile (30°S): Magmatic feedbacks and petrogenetic implications," *Lithos* **370**, 105662 (Oct. 2020).