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A New Slow Focus Sensor for GeMS

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ABSTRACT

The Gemini South 8-meter telescope's Multi Conjugate Adaptive Optics System GeMS is about to enter a new era of science with an entire new upgrade for its Natural Guide Star wave front sensor (NGS2). With NGS2 the limiting magnitude of the natural guide stars used for tip/tilt sensing is expected to increase from its current limit of 15.4 to 17+ in R-band. This will provide a much greater sky coverage over the current system. NGS2 is a complete replacement of the current Natural Guide Star wave front sensor (NGS). This presents an interesting challenge as the current NGS includes a Slow Focus Sensor (SFS) used to compensate for the sodium layer mean altitude variations. With the new NGS2 setup, this SFS will be removed and a suitable replacement must be found. Within the Gemini environment there exist two facility wave front sensors, Peripheral Wave Front Sensors one and two (PWFS1 and PWFS2), that could act as an SFS. Only one of these (PWFS1) is located optically in front of the GeMS Adaptive Optics (AO) bench (Canopus). We are currently preparing this wave front sensor as the new SFS for GeMS under the NGS2 setup. The results of several nighttime and daytime tests show that PWFS1 will be an adequate SFS for GeMS in the NGS2 setup providing excellent sky coverage without compromising the GeMS Field of View (FoV).

Keywords: AO, LGS, MCAO

1. INTRODUCTION

1.1 Laser Guide Stars

Adaptive Optics (AO) observations require a bright source to measure wave front distortions. The amount of bright natural guide stars is limited reducing the area of the sky that can be observed with AO. The creation of an artificial guide star with a laser (Foy & Labeyrie 1985)[1] provides a solution to this problem. An artificial guide star can be created from the resonate backscattering of mesospheric sodium atoms. The Gemini observatory uses a constellation of five laser guide stars to feed its Multi-Conjugate Adaptive Optics (MCAO) system GeMS.

1.2 Sodium layer variations

Sodium (Na) atoms in the mesosphere form a layer at an average altitude of 90-95km above sea level, this altitude can very from 85km to 105km. The mean altitude of the sodium layer can vary throughout an AO observation. An AO system must therefore be able to distingue atmosphere-induced focus from the slow focus drift caused by variation in the guide star altitude (Neichel et al. 2013) [2]. GeMS currently has a Slow Focus Sensor (SFS) to monitor the change in the sodium altitude. This SFS is being replaced along with the entire Natural Guide Star WFS (NGSWFS) assembly in an upcoming upgrade to GeMS known as NGS2.

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2. CURRENT SYSTEM

2.1 GeMS Overview

GeMS, is the Gemini Multiconjugate adaptive optics system. It uses a 1' diameter constellation of 5 laser guide stars, produced from a single 50W laser, and 3 natural guide stars for tip-tilt correction. Typical strehls are 20% in K band in a 85”x85” FoV. For a full review of GeMS design and commissioning see Rigaut et al. (2014)[3] and Neichel et al. (2014)[4]. For details about the Gemini South Adaptive Optics Images (GSAOI) see McGregor et al. (2004)[5] and Carrasco et al. (2012)[6].

2.2 The current SFS

The Current SFS in the GeMS system works as an integrated part of the NGSWFS system. The optical light that enters into the GeMS bench is sent to the WFS systems, while the 589nm laser lights is sent to the LGSWFS the remaining optical light is sent to the NGSWFS system. Integrated into one of the 3 NGS guide probes is a beam splitter that sends 30% of the light to the SFS, which is a 2x2 Shack-Hartman wave front sensor. The SFS then will introduce a selectable amount of defocus in the LGS WFS path to compensate for changed in the mean sodium altitude.

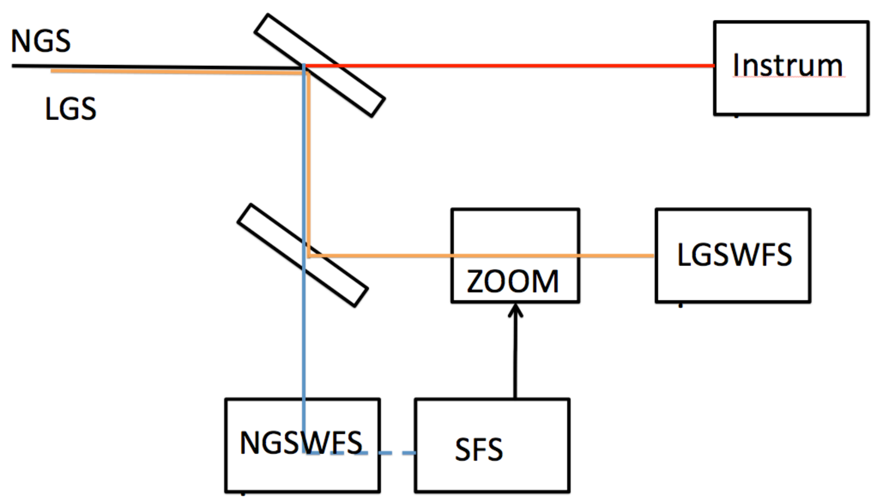

Figure 1. Diagram of the current SFS

3. FUTURE SYSTEM

3.1 NGS2

GeMS is currently scheduled for an upgrade to its NGSWFS, this update will completely remove the current system and replace it with a new system that is fundamentally different. The current system is based on 3 guide probes feeding 3 4x4 APD wave front sensors. This system has been shown to have a far lower throughput than initially planed, and is also very difficult to acquire. This leads to two issues, one is that the sky coverage of GeMS is limited due to the need of finding at least one natural guide star of R= 15.4 Mag and the second issue is that there are large overheads associated with the lengthy NGS acquisition procedure. The new system known as the Next Generation natural guide star wave front sensor for GeMS (NGS2) will be based on a single fast readout EMCCD camera, providing a full view of the 2’x2’ field of view. Being able to see the entire field of view will simplify the acquisition procedure and greatly reduce the overheads. Using a simpler optical chain associated with a fast readout camera will increase the sensitivity of the NGSWFS to ~ R > 17 Mag thus increasing the sky coverage of GeMS significantly. Since NGS2 is a complete replacement of the current NGSWFS the current SFS will be removed and a new SFS has to be found.

4. PWFS1 AS AN SFS

4.1 PWFS1 Overviews

Peripheral Wave Front Sensor 1 (PWFS1) is a facility wave front sensor located in the fourth module of the Gemini Acquisition and Guiding (A&G) unit. This places it optically in front of the adaptive optics fold mirror and thus makes it independent of the GeMS optical path. The wave front sensor is a 6x6 Shack Hartman capable of Tip/Tilt guiding at up to 100 Hz. It can also do focus corrections as slow as 0.03 Hz (30 second exposure time). As this wave front sensor is independent of the GeMS optical path it is available to us in the new NGS2 layout and is our first option as the new SFS. In order to determine if PWFS1 will be an adequate SFS a series of daytime and nighttime test have been done, each test and its results are discussed in the flowing sections.

4.2 Vignetting

PWFS1 is located in the A&G optically in front of the AO fold, therefore it can vignette the GeMS and GSAOI FoV. A sufficient usable annulus for which PWFS1 can be used without compromising the 85"x85" FoV of GSAOI and the 2'x2' FoV of NGS2 is needed for sustainable observations. The Observing Tool (OT) representation in figure 2 shows that there is a usable annulus of 1' from 6'-7' away from the center of the field where GSAOI will not be vignetted by PWFS1. Tests were done to confirm if the OT representation was valid for GSAOI. We began by moving the PWFS1 probe away from the center of the FoV outwards until its shadow was no longer visible on the GSAOI detector. The results from the tests confirmed that the OT representation was correct. However what has yet to be tested is the usable annulus for the 2'x2' FoV of NGS2.

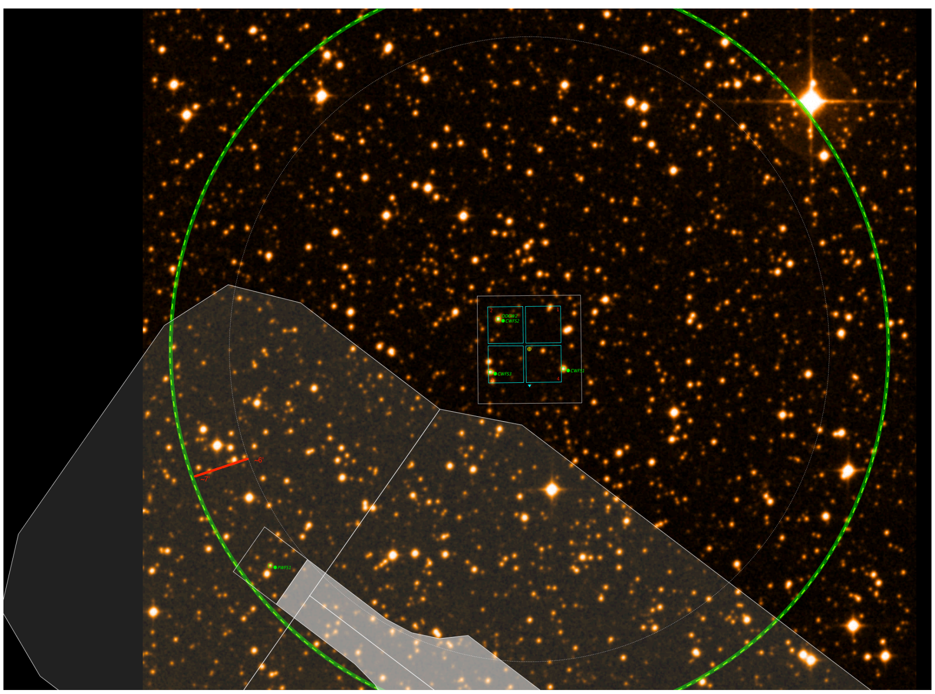

Figure 2 OT representation of PWFS1 usable annulus

4.3 Drift

As PWFS1 is optically in front of the AO fold it acts independently of the GeMS tip/tilt control, therefore, the goal was to verify that a star centered on PWFS1 would remain centered on PWFS1 while the telescope tip/tilt is being controlled by GeMS.

Tests confirmed that while GeMS is controlling the telescope tip/tilt including secondary mirror and mount offloads the drift seen in PWFS1 is sufficiently low that it will not be have a major impact on NGS2. In a 15-minute test the drift in PWFS1 was 0.04" in RA and 0.15" in Dec. Fifteen minutes is longer than the maximum suggested GSAOI exposure, so there is no major concern that the star will drift out of PWFS1 during a GSAOI exposure

4.4 Guide Rate

PWFS1 is currently used at guide rates of 20Hz – 100 Hz, these rates are needed for tip/tilt corrections, but are not needed for slow focus calculations. If PWFS1 is used as an SFS for NGS2 setup it will be used with guide rates < 1 Hz.

We tested the minimum guide rates supported by PWFS1 for only probe guiding and focus calculation. The current high level software only allows for a minimum guide rate of 1 Hz, which is too fast for the faintest stars. In 2015 probe guiding was tested using the PWFS1 engineering interface with a guide rate as low as 0.03 Hz (30 Second exposure) and was found to work without any issues.

4.5 Saturation

Sodium guide star lasers produce visible light at 589nm that can be seen by optical WFS's and interfere with them. To avoid this light a special sodium-blocking filter can be installed into the WFS. After discussion this with engineers at Gemini South, it became clear that installing a sodium notch filter into PWFS1 is non-trivial, thus we began to look for alternatives.

As PWFS1 does not currently have a sodium notch filter, we decided to test if the filters currently present in the PWFS1 filter wheel would block out sufficient sodium light.

Tests were done to check this in 2013 and 2015. The test done in 2013 was preliminary and found that all filters in the current PWFS1 filter wheel except the Blue (B) filter suffered from saturation in exposure times in excess of 5 seconds. The attenuation at 589nm for the blue filter is theoretically 3000 to 4000 (4>ND>3).

In 2015 tests done exclusively with the B filter were done to determine if the increased background would be contaminating focus calculation on the faintest targets. PWFS1 was placed 6' away from the center of the field and a series of images were taken with the laser propagating and not propagating. Table 1 gives the average of 4 images when the LGS is on vs. off at 3 different exposure times likely to be used with PWFS1 acting as an SFS.

Exposure Time (S)	LGS ON/OFF	Mean	Stddev	Max
5	Off	17.5	15.4	43.9
5	On	37.4	14.9	64.4
15	Off	68.9	17.4	100.4
15	On	130.6	22.0	168.4
30	Off	140.9	10.7	178.4
30	On	279.7	33.5	332.7

Table 1: LGS Reyleigh contamination statistics

4.6 Limiting Magnitude

While the test outlined in 4.5 shows that the background level with the B filter can be increased by a factor of 2 with the LGS turned on, the raw count level is still low and thus could be potentially filtered using a higher threshold in the PWFS1 centroids calculation. In order for the B filter to be used with PWFS1 as an SFS for NGS2 it has to have a sufficient throughput to allow the use of faint stars in its usable annulus to allow for a sky coverage at least equal to what is offered by NGS2 if not better. Figure 3 shows the simulated sky coverage of NGS2, the current NGS, and PWFS1, at their limiting magnitudes. The final coverage of NGS2 will be a convolution of the final PWFS1 with the NGS2 curve.

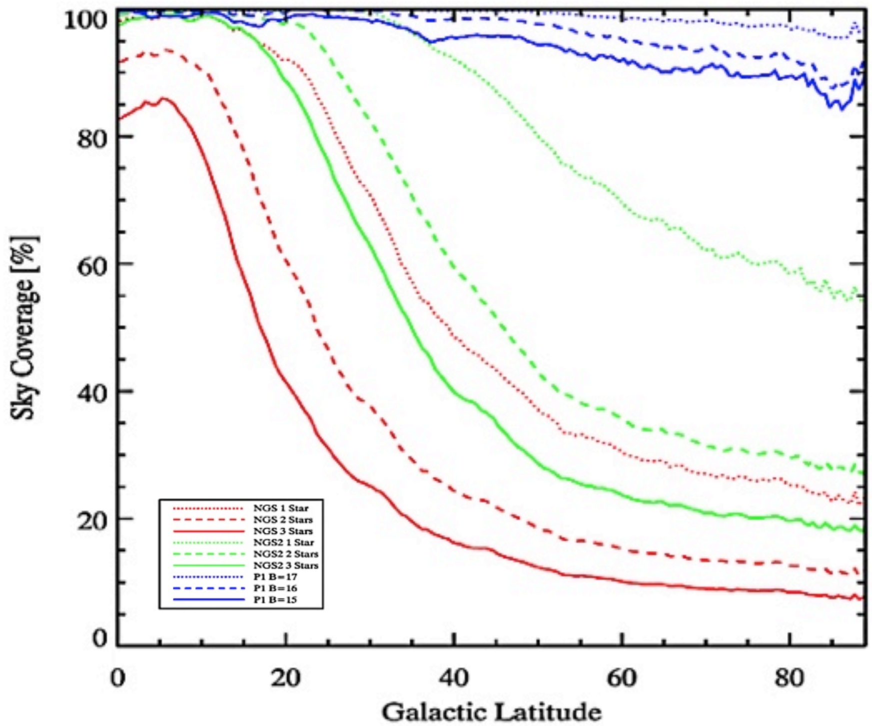

Figure 3: Simulated sky coverage for NGS2

Tests were done in 2015 to check if faint stars will provide enough signal in PWFS1 to be usable. One set of data were taken in dark time with the laser not propagating and only with the GeMS tip/tilt loop closed. These data were taken under good seeing conditions and clear skies. The star had a catalogue B magnitude of 16.9. At an exposure time of 1 second probe guide was possible without issue and the star did not saturate PWFS1 with a 30 second exposure.

As dark time is not typical of GeMS observations and the LGS was not contaminating the field more extensive tests were done. Here a 16.4 B mag star was selected and exposures with both the LGS on and then LGS off were taken at 5, 15, and 30 seconds. These images were taken under cirrus and with a poor performance from the telescopes active Optics system, so they represent a worst-case scenario. Table 2 shows the difference in max signal between the LGS being ON and the LGS being OFF, as the guide loop was not closed there is no comparison of the mean and standard deviations as the images were not similarly illuminated by the guide star.

Exposure Time (S)	LGS ON/OFF	Max Counts	Singnal vs Background
5	Off	1076	14.0
5	On	886	6.6
15	Off	3093	18.2
15	On	2732	9.1
30	Off	5530	25.1
30	On	6268	15.5

Table 2: Difference in max counts between LGS on vs LGS off.

While the max counts are roughly the same with the LGS on compared with the LGS off, the ratio with of the star signal to sky signal is significantly lower with the LGS turned on.

5. CONCLUSIONS

The tests above have shown that the PWFS1 in its current form can function as an SFS in the future NGS2 setup. There should not be an issue with vignetting of the GSAOI FoV, vignetting for NGS2 and future instrumentation has not been checked. Nor should there be issues with the guide rates provided a small change is made to the high level software, and there is no worry of drift on the detector during a typical GSAOI observation.

The most pressing issues of LGS background contamination and limiting magnitudes in the B filter are acceptable for commissioning. While the background level increases by about a factor of two when the LGS is turned on it remains at a relatively low level. The major concern has always been if even at this low level we would introduce sufficient noise as to make it impossible to compute a focus from faint sources at long integration times. The test done with a B=16.4 mag star show that even with the LGS turned on we still have over 6 times more signal from the star than from the background at a 5 second exposure and more than 15 times more signal vs. background with a 30 second exposure. While there is a significant reduction in the ratio of signal to background between the LGS being turned on vs. it being turned off, the ratio is sufficiently high with the LGS on to allow for a proper focus calculation. The sky coverage simulation also show that with a B=16 mag star we have > 90% sky coverage.

6. FUTURE TEST

There are remaining concerns that were not tested. As the background caused by the LGS is not evenly illuminating the detector this may introduce an error in the focus calculation, as some spots will have slightly more background contamination than others. This issue may be corrected by applying a background subtraction, increasing the PWFS1 threshold, or preferably, by in-stalling a sodium notch filter in PWFS1 and using that instead of the blue filter as the transmission should be very near to 0% at 589nm. The options of background subtraction and or threshold modifications would still have to be tested to ensure they will work, but in theory they require minimal effort to implement. Background subtraction is already implemented for PWFS1 and used in normal operations. Having to take an extra background frame while in LGS operations will add some overhead to the acquisition, but it will be minimal. Modifying the threshold for PWFS1+LGS operations will require some software modifications to make the change happen automatically, otherwise the threshold can be modified manually by a trained telescope operator during each slew, as with background subtraction this will add overhead. While installing the sodium notch filter is the most effort intensive of the options, operationally it is by far the simplest to implement and will add no overhead.

The focus calculated by PWFS1 should be compared to the focus calculated by the current SFS located in GeMS. Preliminary work on this has all ready been done and looks promising.

Finally test with a faint guide star and all GeMS loops and offloads enabled should be done as a final sanity check.

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