# Gemini Planet Imager

# Functional and Performance Requirements Document

GPI_FPRD.doc

2010-04-01

Version:7.3

Issued By:

Approved By: Date:

| | | |
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# Revision History

| Date | Rev. No. | Revised By | Description | Approval |
|---|---|---|---|---|
| Sept. 23, 2004 | 0.1 | Leslie Saddlemyer | Initial draft | |
| Oct 26, 2004 | 0.7 | Leslie Saddlemyer | Incorporate major requirements from Mid-Term Review | |
| Oct 29, 2004 | 0.8 | Leslie Saddlemyer | Incorporate review comments from team members. | |
| Nov 01, 2004 | 0.9 | Leslie Saddlemyer | Latest input from team members. | |
| Nov 02, 2004 | 0.10 | Bruce Macintosh | Detailed edits including provisional values for most quantities | Bruce Macintosh |
| Nov 02, 2004 | 0.11 | Bruce Macintosh | Some minor changes by Les. Bruce added discussion of error spatial frequencies and LLNL logo. Reformatted TOC to fix Word error under Office for OS/X. | Bruce Macintosh |
| Dec 07, 2004 | 0.12 | Leslie Saddlemyer | Added traceabilities, updated specifications etc. | |
| Jan 08, 2005 | 0.14 | Bruce Macintosh | Tried to identify areas to be filled in (marked with #) and areas possibly to be removed from FPRD (marked with **) | |
| Jan 14, 2005 | 0.15 | Bruce Macintosh | Modifications based on comments from the midterm review; some # removed but not all | |
| Jan. 19, 2005 | 0.16 | Leslie Saddlemyer | Further update of T.B.D.'s, move some sections to internal ICDs. | |
| Jan 21, 2005 | 0.17 | Leslie Saddlemyer | More details on detectors etc. | |
| Jan 24, 2005 | 0.18 | Leslie Saddlemyer | More details | |
| Jan 24, 2005 | 0.19 | Bruce Macintosh | Minor changes | |
| Jan. 31, 2005 | 1.0 | Leslie Saddlemyer | Changes based on constructive comments from Doug Simons and Joe Jensen | Bruce Macintosh |
| Feb 18, 2005 | 1.01 | Bruce Macintosh | Minor formatting changes for final version | |
| 2007-04-11 | 2.0 | Leslie Saddlemyer | Major re-write and formatting for GPI and Knowledge Tree ingestion. Some sub-system specifics inserted. | Leslie Saddlemyer |
| 2007-04-18 | 2. 1 | Leslie Saddlemyer | Details corrected/added in sub-system sections | Leslie Saddlemyer |
| 2007-04-18 | 2.2 | Leslie Saddlemyer | Changes to IWD and ASU source requirements | Leslie Saddlemyer |
| 2007-04-20 | 2.3, 2.4 | Leslie Saddlemyer | Error in updating protocol | Leslie Saddlemyer |
| 2007-04-24 | 2.5 | Leslie Saddlemyer | More updating of OMSS requirements and assigning of new REQ numbers | Leslie Saddlemyer |

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|---|---|---|---|---|
| 2007-04-24 | 2.6 | Leslie Saddlemyer | Fixed duplicated req. numbers and some improved wording for temp. control | Leslie Saddlemyer |
| 2007-4-27 | 2.7 | Bruce Macintosh | Updated requirements in several subsystems | |
| 2007-5-08 | 2.8 | Bruce Macintosh | Updated OCDD; final definition of mid-frequency; final contrast and coronagraph requirements; final □oronagraph masks (incorporates some 2.7b stuff) | |
| 2007-07-13 | 3.0 | Leslie Saddlemyer | Moving of some sub-system requirements to the SSDDs. Some minor typos fixed | Leslie Saddlemyer |
| 2007-08-11 | 3.1 | Leslie Saddlemyer | Updates based on discussions with Bruce, UCLA and JPL. More TBDs filled in | Leslie Saddlemyer |
| 2007-10-22 | 4.2 | Leslie Saddlemyer | More refined updates | Leslie Saddlemyer |
| 2007-12-10 | 4.3 | Leslie Saddlemyer | Further updates based on mid-CDR face-face meeting | Leslie Saddlemyer |
| 2008-02-26 | 4.4 | Leslie Saddlemyer | Revisions w/Bruce, including changes to FPM responsibility | Leslie Saddlemyer |
| 2008-03-10 | 4.5 | Leslie Saddlemyer | Updates with Dave Palmer, Bruce Macintosh | |
| 2008-04-13 | 4.6 - 4.8 | Bruce Macintosh & Leslie Saddlemyer | Almost final CDR updates | |
| 2008-04-16 | 4.9 | Leslie Saddlemyer | Included AOI of FPM, including elliptical potential for FPMs | Leslie Saddlemyer |
| 2008-05-01 | 5.0 | Leslie Saddlemyer | Final updates for CDR, including OCDD table. | Leslie Saddlemyer |
| 2008-05-07 | 5.1 – 5.3 | Leslie Saddlemyer | Late breaking Lyot mask and FPM wavefront quality values, updated for GS (smaller input pupil) | Leslie Saddlemyer |
| 2008-05-08 | 5.4 | Leslie Saddlemyer | Lyot mask table includes a Blank for IFS darks | Leslie Saddlemyer |
| 2008-10-30 | 5.5 | Leslie Saddlemyer | Ready for revision control review by CCB | Leslie Saddlemyer |
| 2008-11-23 | 6.0 | Leslie Saddlemyer | V6.0 incorporates final changes agreed upon by CCG, ready for CCB review for V7.0 release | Leslie Saddlemyer |
| 2008-11-26 | 6.1 | Leslie Saddlemyer | REQ-FPR-0520 changed to 1x10$^{-7}$ averaged from 6-7 $\lambda$/D from 6x10$^{-7}$ to be testable | Leslie Saddlemyer |
| 2008-12-12 | 7.0 | Leslie Saddlemyer | GPI CCB approvals received, ready for Gemini submission | Leslie Saddlemyer |
| 2009-04-27 | 7.1 | Leslie Saddlemyer | Further TBD resolutions, Joe Jensen and Bruce Macintosh assistance. | Leslie Saddlemyer |
| 2009-07-15 | 7.2 | Leslie Saddlemyer | Add signature to title page, sign-offs started for 8.0 | Leslie Saddlemyer |
| 2010-01-05 | 7.3 | Leslie Saddlemyer<br>Bruce Macintosh<br>Stephen Goodsell | Revisions and clarifications. | Leslie Saddlemyer |

# Table of Contents

# 1 Purpose

The science requirements of the GPI instrument are defined in the Operational Concept Definition Document (OCDD), along with appropriate operational scenarios. Being a facility instrument, there are a variety of interface, environmental and operational constraints and requirements that must be met.

This document, the GPI Functional and Performance Requirements Document (FPRD), has multiple purposes. First, it translates the science requirements, as outlined in the OCDD, into technical requirements. Secondly, it identifies the technical requirements to properly exist as a facility instrument at either Gemini telescope. Thirdly, in association with the OCDD requirements and the Software Requirements Document (SRD), forms the basis for what will become the Acceptance and Test Plan (ATP). In all cases, the requirements are directly traceable to requirements in the OCDD, other sections in the FPRD, Gemini ICDs or Gemini relevant documents.

The FPRD provides the Gemini scientific community with an understanding of the performance capabilities of the GPI and as a guide to the requirements on which to base the GPI designs. In short, the design of the GPI instrument shall be based on this document. All features described here must be satisfied.

The requirements of the GPI will change over time; particularly at the time of each main review (the CoDR, the PDR and the CDR).

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"Volume 2b, Detailed Systems Engineering", http://dms.hia.nrc.ca/view.php?fDocumentId=3344
GPI System Fundamental Values, http://dms.hia.nrc.ca/view.php?fDocumentId=2164
"COR Sub-System Design Document", http://dms.hia.nrc.ca/view.php?fDocumentId=1920

# 3 Acronyms and Abbreviations

All GPI acronyms and abbreviations are listed in the official GPI acronym list 0.

# 4 Introduction

This document describes the current technical capabilities and performance of the Gemini Planet Imager (formerly known as the Extreme Adaptive Optics Coronagraph) instrument.

The GPI is primarily a planet finding and characterising instrument. Although operating over a larger wavelength range, the primary wavelength for discussion and requirements is *H* band (1.65 μm). Coupling a high-strehl AO system with a high performance coronagraph and calibration systems, a science instrument will receive a high quality, high contrast field of view of about 3 arcsec. For more details relating to the science, see 0, the GPI OCDD.

This document makes the distinction between the "functional" requirements and the "performance" requirements. The functional requirement specifies **what** must happen (e.g. the instrument must bolt onto the ISS standard ports and weigh 2000 kg), in contrast with performance requirements that specify **how well** something has to happen (e.g. the AO system shall achieve a Strehl of 92% in *K* in medium seeing at a zenith distance of 60 degrees). However, there is sometimes an almost arbitrary distinction between these two.

## *4.1 Definitions of contrast and performance*

The term contrast is used widely in this document. When used without modifiers, "contrast" refers to the "detectable companion contrast". A contrast of $x$ means that a point source as faint as $x$ times the central star's total intensity at the specified wavelength and image location will have an integrated signal in a photometric aperture (normally of radius $\lambda$/D) equal to 5 times the RMS scatter in the PSF halo signal at that location (typically measured by comparing the PSF intensity in multiple apertures in the same region.) This specification refers to a detection in fully reduced data (including post-processing software speckle suppression). We also refer to "raw contrast", indicating the contrast in the final image before speckle suppression post-processing, and "intensity contrast", defined as the ratio of the halo intensity per unit area to the peak intensity per unit area of the unocculted coronagraphic PSF.

It is important to stress that the system design should be science driven rather than technology driven; what matters is not some formal measure of residual PSF noise in the brightest-star case, but the expected fraction of extrasolar planets that are successfully detected in a given observing campaign. Contrast will be a function of target star brightness, planet spectral properties, atmospheric conditions, and many other factors. For example, post-processing to remove speckle noise will also suppress part of the signal from a planet with a smooth spectrum at small radii but will have less effect on a planet with broad molecular features in its spectrum. Section 5.2.2.1 is formulated to capture this dynamic.

Unless otherwise noted, all specifications are set at the primary science wavelength of *H* band (1.5-1.8 μm). In general, contrast due to residual wavefront errors at a given angle on the sky, is a complicated but weak function of wavelength, while other factors – such as inner and outer working distance – scale linearly with wavelength.

## 4.2 Wavefront error spatial frequency bands

A key concept in ExAO system design is the recognition that a given spatial frequency of wavefront error $f$ (measured in cycles per aperture) corresponds (to first and second order) to a given location in the PSF $\theta = f\lambda/D$. Hence, optimal performance within the range of angles between the inner edge of the coronagrah (~2.5) $\lambda/D$ and outer working distance ~22 $\lambda/D$ requires minimizing not the total wavefront error, but the wavefront errors with between 3 and 22 cycles across the primary mirror. A $N$x$N$ subaperture wavefront sensor can control spatial frequencies up to $N/2$. Hence, for our nominal architecture with 44 subapertures across the primary mirror, we can control errors up to 22 cycles/aperture and achieve an OWD of ~22 $\lambda/D$.

As a result, the error budget (see reference 0) specifies not just total WFE but WFE within three spatial frequency bands. The first, *low frequency errors*, corresponds to $0 < f < 3$ cycles per aperture. These spatial frequencies primarily scatter light within the IWD, an area most likely blocked by the coronagraph focal plane spot. These errors degrade the final Strehl ratio, but static errors in this range do not severely impact contrast. Classical optical errors, such as astigmatism or coma, are in this category. *High-frequency errors* are errors outside the controllable spatial frequency range, corresponding to $f > N/2$ cycles/aperture (22 for the GPI design on a 7.9 m primary). These errors scatter light to large radii and similarly do not directly impact contrast within the dark hole. Small surface roughness errors are primarily in this category. The most important wavefront errors are the *mid-frequency errors* ranging from $3 < f < N/2$, which scatter light directly into the region where GPI will be searching for planets. An example of this class of error are polishing errors on optics, for example, such as those that would be created by a 1 mm tool on a 2 cm mirror. These categories also map into the wavefront sensing capabilities of the CAL system; the CAL LOWFS measures up to 2.5 cycles/aperture, the HOWFS from 3-22, and higher frequencies are not measured.

One additional historic note: the original GPI was designed for N = 44 apertures on a D = 7.9 m Gemini primary mirror. Since the Gemini South primary is stopped down to a smaller size, and since the selected wavefront sensor detector only has 128 pixels, a decision was taken to set N = 43 apertures on the WFS and CAL detector, for a f > 21.5 cycles/aperture cutoff. However, the specs on optics, etc., were left at the N = 44 cutoff. In practice this makes very little difference to the specification of an individual optic.

In each case where a wavefront error spec is given, therefore, it is broken down into low/mid/high frequency components. The mid-frequency component is derived directly from the error budget 0 and directly determine contrast. The low-frequency component is based on an analysis of plausible optical designs and the error budget. High-frequency errors are extrapolated from the mid-frequency errors assuming a typical power law for optical surface quality, but could be adjusted based on discussions with the manufacturers.

These spatial frequency components are defined in Table 1.

| Spatial Frequency Designation | Frequency |
|---|---|
| Low | $0 < f < 3$ |
| Medium | $3 < f < 22$ |
| High | $f > 22$ |

**Table 1 GPI Spatial Frequency Designations**

## 4.3 Wavelength and Coronagraph Operation Definitions

### 4.3.1 Wavelength Definitions

For the purposes of GPI, we define the wavelength bands as:

| Name | ½ power bandpass [microns] | Geometric Central Wavelength [microns] | ½ power bandpass [%] |
|---|---|---|---|
| Y | 0.95 – 1.14 | 1.040 | 18 |
| J | 1.12 – 1.35 | 1.230 | 19 |
| H | 1.50 – 1.80 | 1.643 | 18 |
| K1 | 1.9 – 2.19 | 2.040 | 14 |
| K2 | 2.13 – 2.4 | 2.260 | 12 |

**Table 2 GPI Wavelength definitions**

Where “1/2 power bandpass” is defined as the ratio of the spectral width of the filter divided by the central wavelength. Filter cut-on and cut-off are where the transmission reaches 50%. For example, for the H filter in the table above, that reaches 50% transmission at 1.50 microns, and falls to 50% at 1.80 microns would have a ½ power bandpass of (1.80 – 1.50) / 1.643 * 100 = 18%.

# 5 System Requirements

## 5.1 Requirements Summary

The official requirements for GPI are the set of OCDD, FPRD and SR (Software Requirements). OCDD requirements and SR are specified in the appropriate documents, and the OCDD requirements are repeated here for convenience sake only. It would be redundant, and prone to inconsistencies, to repeat fully these requirements in this document.

This section presents the requirements from all three sources, and forms the basis for the acceptance and test plan (ATP) developed during the PDR and CDR phases.

The requirements are partitioned into logical sections: the initial top-level requirements for the instrument as a whole, then by sub-system as appropriate. As the FPRD forms the basis of the ATP, this will also form the separate sub-system ATPs. Keeping these in one, all-inclusive document is to reduce redundantly kept requirements and to ease readability; both risk reducing goals.

### 5.1.1 OCDD Requirements

This section presents a summary of the OCDD science requirements for the instrument. In case of discrepancy, the official OCDD requirements are as listed in 0.

| | **Final requirement** |
|---|---|
| **Contrast vs. angular separation** | **REQ-SCI-0010:** Planet recovery $\geq 7\%$ at $H$ for $I \leq 8$ mag. field-star survey.<br>**REQ-OCD-0011:** $H$-band point source contrast of $C \leq 3 \times 10^{-7}$ at 0.17 arc sec, $\leq 2 \times 10^{-8}$ at 0.5 arc sec (1 hr 1-$\sigma$) for $I \leq 8$ mag. to edge of dark hole.<br>**REQ-SCI-0012:** Detect $\tau \leq 3 \times 10^{-5}$ debris disks for $I \leq 8$ mag.<br>**REQ-OCD-0013:** Surface brightness contrast $Q \leq 5 \times 10^{-8}$ for $I \leq 8$ mag.<br>**REQ-OCD-0014:** Inner working distance $\leq 0.14$ arc sec. |
| **WFS mag. limit & λ** | **REQ-OCD-0020:** WFS limiting magnitude $I \geq 8$ mag.<br>**REQ-OCD-0021:** WFS bright magnitude $I \leq 0$ mag.<br>**REQ-OCD-0022:** Graceful WFS degradation for $I$ = 8–9 mag. |
| **Speckle suppression** | **REQ-OCD-0030:** Speckle noise suppression $\geq \times 5$ using ADI/SDI.<br>**REQ-OCD-0031:** Suppression of unpolarized speckles $\geq \times 100$. |
| **Science wavelength range** | **REQ-OCD-0040:** Science operating wavelength: 1.1–2.35 µm. |
| **Spectral resolution** | **REQ-OCD-0050:** Spectral resolution $\geq 45$ in $H$ band.<br>**REQ-OCD-0051:** Instantaneous wavelength coverage $\geq 20\%$. |
| **Polarimetry** | **REQ-OCD-0060:** Dual channel polarimetry mode<br>**REQ-OCD-0061:** Precision of linear polarization $\leq 0.3\%$ |

| | |
|---|---|
| **Sensitivity** | **REQ-OCD-0070:** $H$ = 23 mag., ≥ 5-σ, 1 hour. |
| **Detector** | **REQ-OCD-0080:** Detector noise is ≤ 20% of residual photon shot noise and residual speckle noise at $R \approx 50$. |
| **Operability, reliability** | **REQ-OCD-0090:** Survey 2000 stars in 200 nights to **REQ-OCD-0011** level.<br>**REQ-OCD-0091:** Statistical false alarm rate ≤ 5% |
| **Zenith distance limit** | **REQ-OCD-0100:** Zenith distance range ≤ 50$^{o}$ |
| **Accessible Dec. range** | **REQ-SCI-0110:** Working declination range is -70$^{o}$ – +15$^{o}$ |
| **Astrometric accuracy** | **REQ-OCD-0120:** Astrometric accuracy ≤ 1.8 mas, 1σ, (1-axis).<br>**REQ-OCD-0121:** location of target star is known to << 1.8 mas, 1σ, (1-axis).<br>**REQ-OCD-0122:** 10-yr instrument lifetime & astrometric stability |
| **Flat fielding accuracy** | **REQ-OCDD-0130:** Flat field accuracy ≤ $1.5 \times 10^{-4}$ RMS per beam on spatial frequencies ~ $\lambda/D$. |
| **Photometric accuracy** | **REQ-OCD-0140:** Absolute photometric calibration ≤ 10%<br>**REQ-OCD-0141:** Relative photometric accuracy ≤ 5%. |
| **Pixel sampling** | **REQ-OCD-0150:** 14±0.5 mas pixel sampling. |
| **Field of view** | **REQ-OCD-0160:** Field of view in direct imaging is ≥ 2.8 × 2.8 arc sec$^2$<br>**REQ-OCD-0161:** Polarimetry field of view is square ≥ 2.8 × 2.8 arc sec$^2$ |
| **PSF stability** | **REQ-OCD-170:** PSF stability at 4% precision over ≥ 3 hours |

### 5.1.2 Software Requirements

The software requirements are presented in the GPI Software Requirements Document 0.

## 5.2 Top Level

These requirements relate the very top-most requirements for the GPI instrument as a whole. Requirements that pertain quite specifically to a specific sub-system or discipline are covered separately.

### 5.2.1 Top Level Functional Requirements

#### 5.2.1.1 Gemini Telescope Optical Compatibility

REQ-FPR-0110: GPI will accept the raw Gemini telescope beam as defined in the as-built optical prescriptions provided by Gemini to the project, with the pupil at the secondary mirror, either directly on the bottom ISS port or either science instrument side-looking port fed by the Science Fold Mirror. The only ISS orientations that are required to be supported are with GPI at 0 and 180 degrees with respect to the elevation axis (with 45 / 225 as a goal.)

Derived from ICD 1.5.3/1.9 and SOW 0 Section 3.1(e)(3).

#### 5.2.1.2 Gemini Facility Instrument / Mechanical capability

REQ-FPR-0111: GPI will be adhere to standard Gemini mechanical interfaces as defined in ICD 1.5.3/1.9 and be capable of mounting to either the up-looking or side-looking ISS ports.

Derived from ICD 1.5.3/1.9 and SOW 0 Section 3.1(a)(10).

#### 5.2.1.3 Automatic Operation

REQ-FPR-0130: GPI shall be capable of, when presented with a suitable object on-axis to within 2.0 arcsec, locking on and starting an exposure without manual intervention.

Derived from OCDD.

NOTES:

1. This does not require that a single command from the OCS is all that is necessary to start an observation, only that a sequence of commands may be used to configure and start an observation without an observer explicitly checking the status of sub-systems as the observation proceeds. It is nominally the AO system capture range, as this is the first sub-system that will start up.

#### 5.2.1.4 Observing Efficiency

REQ-FPR-0140: The observing time (as defined as science instrument acquiring science target photons) shall be greater than 90%, exclusive of weather, down-time attributed to other systems, or telescope acquisition (i.e. slew and settle on-target) time, with exposure times of 60 minutes. This is interpreted as GPI requiring less than 6 minutes to acquire, lock, calibrate and then start exposure, including overhead between individual subexpsosures (exclusive of delays between subexposures caused by the Gemini DHS.)

Derived from REQ-OCD-0090 (Leslie Saddlemyer).

#### 5.2.1.5 Non-common Path Flexure

REQ-FPR-0150: Flexure, after compensation, will be limited to the following over the specified zenith angle range.

| Location 1 | Location 2 | Max flexure rate with elevation changes | Max total flex |
|---|---|---|---|
| Tweeter | WFS lenslets | ---- | 0.2%. [pupil] (35 microns at Tweeter) |
| Tweeter | PPM | ---- | 0.3% [pupil] (35 microns at PPM) |
| PPM | Lyot stop | | 1% (goal 0.5%) [pupil] (98 microns at Lyot) |
| FPM | IFS lenslets | <=0.5 mas/0.25 degrees (~3.5 microns/0.25 degrees at IFS lenslets) | 1 IFS lenslet |

(Note that some flexures are specified in mm while others are specified as a percentage of the beam size.)
Derived from error budget 0 and astrometric requirement OCDD-121
NOTES:

1. Note that since the normal mode of operation is with the rotator off and GPI at either the 0 or 180 degree position wrt the telescope, the instrument will rotate about an axis parallel to the elevation bearing but not about its own optical axis.
2. Additional specifications (not FPRD-level) are maintained in an alignment document.

#### 5.2.1.6 Downtime

REQ-FPR-0160: The downtime of the instrument shall be less than 2 %, with a goal of less than 1%. This is measured as lost night-time scheduled observing.

Derived from SOW 0 Section 3.1(e)(2).

NOTES:

1. Nominal daytime maintenance that does not require new night-time re-calibrations or alignment of the instrument is not considered downtime. This includes, but is not limited to pumping, cooling/warming and mounting or dismounting GPI on the telescope
2. Any repairs or maintenance that require night-time calibrations or alignments, and hence lost night observing time, count as downtime.

#### 5.2.1.7 Lifetime

REQ-FPR-0170: The GPI instrument shall be designed to operate for 10 years at a duty cycle of 10 hours/night 100 nights per year before requiring more than one re-coating of optical surfaces.

Derived from REQ-OCD-0090 and REQ-OCD-0122

NOTES:

1. A simplified reliability table has been created. In general, components with MTBFs of less than about 20 years are specifically called out, and rate high for spares and/or routine replacement.

#### *5.2.1.8 Wavelength Bands*

REQ-FPR-0175: The GPI instrument shall cover in a single exposure any one of *J, H, K1* or *K2.* (*Y* band is a goal). These are as defined in Table 2.

Derived from REQ-OCD-0040

### 5.2.2 Top Level Performance Requirements

#### 5.2.2.1 Internal Static Contrast Ratio

REQ-FPR-0180: GPI, will attain 1.59 μm internal contrast ratio, including multiwavelength processing (see Section 4.1) given by the following operating on its internal calibration source with no external aberrations.

| Contrast (1-sigma) | Radius [λ/d] |
|---|---|
| $1 \times 10^{-7}$ | 5.5-6.5 |
| $2 \times 10^{-8}$ | 10-12 |
| $1.5 \times 10^{-8}$ | 15-17 |

Derived from REQ-OCD-011 and error budget 0.

NOTES:
1. Since atmospheric aberrations ultimately average out, the raw contrast obtained in a long-exposure image will be limited by internal aberrations, calibration errors, etc., and can be no better than the contrast obtained with only these errors.
2. It is a goal to meet these requirements before multiwavelength processing
3. Will be measured by using the internal artificial star source or external telescope simulator

#### 5.2.2.2 Seeing condition Limits

REQ-FPR-0190: GPI will meet all requirements, in the required zenith distance limits, in median seeing or better conditions. GPI will be capable of operating in seeing conditions representing the 70%ile seeing conditions, but with no guaranteed performance.

Derived from REQ-OCD-0090 and error budget 0.

NOTES:
1. This is necessary to ensure that survey programs may be completed in a reasonable time period. Required to operate in the 70%ile since that's the Gemini band definition. Goal to operate in the 85%ile conditions.
2. Median seeing is r0=14cm. 70%ile seeing is r0=11cm. Based on GLAO feasibility study 0, Figure 3.
3. This requirement sets the conditions under which testing of AO requirements (FPRD and SSDD) occur; it is met by passing the relevant tests.

#### 5.2.2.3 Zenith Distance Limits

REQ-FPR-0200: GPI will meet all requirements, in required seeing conditions, from a zenith distance of 5 to 30 degrees, with a goal of from 1 to 50 degrees under 25% seeing conditions.

Derived from REQ-OCD-0100 and error budget 0.

NOTES:

1. The science requirement is to achieve a zenith distance of 50 degrees. Performance in general will scale with r0 which in turn scales with airmass, so obtaining full contrast at higher airmass may require better than average seeing conditions.
2. This requirement sets the conditions under which e.g. flexure testing to meet requirements (FPRD and SSDD) occur; it is met by passing the relevant tests.

#### 5.2.2.4 Optical Throughput

REQ-FPR-0210: There shall be a total throughput of the system (from input of instrument to detected photons at the science instrument) of 13% in *H* band, including the attenuation caused by the coronagraph.

Derived from REQ-OCD-0070, error budget 0.

#### 5.2.2.5 Science Image Position Stability

1. REQ-FPR-0350: Deprecated, redundant with REQ-FPR-0150.

#### 5.2.2.6 Plate Scale Stability

REQ-FPR-0390: The GPI system will maintain a maximum change in the plate scale of 0.2% over a 4 hour period, 30 degree orientation change and 3.2°C temperature change, and 0.4% over a 12 hour period, full range of orientations and 9.6°C temperature change.

Derived from REQ-FPR-0220, REQ-OCD-0120 and REQ-OCD-0121.

#### 5.2.2.7 Field of View

REQ-FPR-0392: The GPI FOV will be >= 2.8 x 2.8 arcsec at the IFS. As a goal, the 2.8x2.8 arcsec IFS field will be steerable over a (total) 5x5 arcsec range.

Derived from trade studies of FOV vs spectral resolution.

#### 5.2.2.8 Instrumental polarization and Stability

REQ-FPR-0340: The complete optical path upstream of the polarization modulator, excluding telescope optics, will have a total linear polarization of less than 10%, with a stability over >1 week timescales of better than 0.8% RMS, or better. Total instrument circular polarization will be 10% or less.

## 5.3 AO Requirements

This section specifies the requirements that pertain directly to the AO system.

### 5.3.1 AO Functional Requirements

#### 5.3.1.1 ICD requirements

REQ-FPR-0310: The AO system shall meet all the interface requirements as specified in the ICD “1.9.x.1/1.9.x.5 AO to OMSS/SCC ICD” 0 and “1.9.x.n Supplemental GPI Sub-system ICD’s” 0.

#### 5.3.1.2 Limiting Magnitudes

REQ-FPR-0320: The AO system shall be capable of locking onto and maintaining lock on objects from 0 to 9$^{th}$ I magnitude at a zenith distance of up to 50 degrees in 50$^{th}$ percentile seeing conditions. It is a goal to be able to maintain lock down to 10$^{th}$ I magnitude.

Derived from REQ-OCD-0020, REQ-OCD-0021, REQ-OCD-0022, REQ-OCD-0010, REQ-FPR-0190.

NOTES:

1. Contrast performance at $I$=9 is not specified – the OCD requires only full performance to $I$=8 and not to the full 50 degree zenith distance.
2. The goal will accommodate more ancillary science (Les Saddlemyer)

#### 5.3.1.3 Residual Fast Tip/Tilt

REQ-FPR-0360: In 50% best seeing conditions with no additional windshake, or external vibration, the AO module will exhibit a residual Tip/Tilt measured at the WFS of <2 mas RMS (on a bright star / excluding measurement noise contributions).

Derived from error budget 0.

NOTES:

1. With expected Gemini input vibration, total residual tip/tilt measured at the WFS will be <4 mas RMS.
2. To ensure on-axis Strehl ratio is not degraded by more than 5%. Values from the tip/tilt error budget
3. Note that we have no accurate estimates of telescope windshake so this has been removed.
4. Telescope vibration conditions as per 0

### 5.3.2 AO Performance Requirements

#### *5.3.2.1 WFS Optical Throughput*

REQ-FPR-0400: The optical throughput of the WFS path of all optical components (including the GPI input window and WFS beamsplitter) shall be > 60% over the wavelength range of 0.7 to 0.9 μm (goal > 70%). This **excludes** the WFS detector array QE.

Derived from REQ-FPR-0210 and error budget 0.

NOTES:

1. This is a compromise between the science throughput, ghosting and AOWFS throughput, and was lowered from the initial 70% (Les Saddlemyer and Bruce Macintosh).

#### *5.3.2.2 RMS wavefront error (common path)*

1. REQ-FPR-0410: Replaced with the OMSS requirement REQ-OMSS-0010 in the OMSS SSDD 0.

#### *5.3.2.3 RMS wavefront error (non-common path)*

1. REQ-FPR-0420: Replaced with the OMSS requirement REQ-OMSS-0020 in the OMSS SSDD 0.

#### *5.3.2.4 WFS Read noise*

1. REQ-FPR-0421: Replaced with the AO requirement REQ-AO-0010 in the AO SSDD 0.

#### *5.3.2.5 WFS Dark Current*

1. REQ-FPR-0422: Replaced with the AO requirement REQ-AO-0020 in the AO SSDD 0.

#### *5.3.2.6 AO system temporal performance*

1. REQ-FPR-0423: Replaced with the AO requirement REQ-AO-0030 in the AO SSDD 0..

#### *5.3.2.7 WFS QE*

1. REQ-FPR-0424: Replaced with the AO requirement REQ-AO-0030 in the AO SSDD

## 5.4 Coronagraph Requirements

This section specifies the requirements that pertain directly to the COR system.

### 5.4.1 Coronagraph Functional Requirements

#### 5.4.1.1 ICD requirements

REQ-FPR-0465: The Coronagraph system shall meet all the interface requirements as specified in the ICD “1.9.x.2/1.9.x.5 COR to OMSS/SCC ICD”0 and “1.9.x.n Supplemental GPI Sub-system ICD’s” 0.

#### 5.4.1.2 Inner Working Distance

REQ-FPR-0470: The coronagraph module shall achieve the throughput specifications at an inner working distance of $4\lambda/D$ (goal 3.5 $\lambda/D$), where D is the telescope entrance diameter of 7.7701 m.

Derived from REQ-OCD-0014

NOTES:

1. This equates to 175 (goal 153) mas at a wavelength of 1.65 μm
2. This is the smallest angle at which anything would be visible, NOT the highest contrast region. See 5.4.2.1.

#### 5.4.1.3 Operating wavelength

REQ-FPR-0500: The coronagraph will include masks for operating in *J, H* and *K’* bands with a goal of *Y*.

Derived from REQ-OCD-0040.

#### 5.4.1.4 Optical Transmission

REQ-FPR-0505: The coronagraph will have an optical transmission, averaged from the IWD to the edge of the field, of > 35%, for the pupil mask, the focal plane mask and the Lyot stop (explicitly excluding any relay optics and folds).

Derived from error budget 0.

NOTES:

1. Reduced from original 50% due to increased contrast performance.

#### 5.4.1.5 Pupil Plane Masks

REQ-FPR-0510: The coronagraph will supply PPMs that cover the following 7 cases. These will be supplied suitable for the Gemini South telescope, the properties of which are recorded in 0

| PPM designation | Bandpass See Table 1 | Description |
|---|---|---|
| CLEAR | N.A. | Open, larger than GPI pupil |
| CLEARGP | N.A. | GPI pupil (with M2 obstruction but no spiders) |
| APOD_Y | Y | Apodizer |
| APOD_J | J | Apodizer |
| APOD_H | H | Apodizer |
| APOD_K1 | K1 | Apodizer for K1 with 5.6 lambda/D FPM |
| APOD_K2 | K2 | Apodizer for K2 with 5.05 lambda/D FPM |

NOTES:
1. Additonal masks are being provided as goals: H_L, which is a large-IWA H-band mask with slightly improved contrast, and a starshape H mask, and a 15-aperture non-redundant mask.
2. The GS masks will work for GN, but don't take advantage of the slightly larger entrance pupil on GN.

#### 5.4.1.6 Focal Plane Masks

REQ-FPR-0512: The coronagraph will supply the following 5 focal plane masks (FPM).

| FPM designation | Diameter (microns) | Target Wavelength [microns] ([bandpass]) | Description |
|---|---|---|---|
| BLANK | | N.A. | No hole |
| FPM_Y | 383 | Y | Hole |
| FPM_J | 453 | J | Hole |
| FPM_H | 605 | H | Hole |
| FPM_K1 | 751 | K1 and K2 | Hole |

NOTES:
1. A pinhole mask, for test and alignment purposes, not used for operations is provided by JPL.
2. Diameter tolerance is +-1%
3. The design AOI (angle of incidence) on the FPM is 5.77° (total included angle of 11.54°).

#### 5.4.1.7 Lyot Masks

REQ-FPR-0514: The coronagraph will supply 10 Lyot masks, to be designed and used to optimize the APLC performance.

| **Position** | **Lyot Name** | **OD/ID** | **Spider Width** | **Nominal Orientation** | **Notes** |
|---|---|---|---|---|---|
| 1 | Open | 10 [mm] | | | Full GN pupil. |
| 2 | Blank | Solid | | | |
| 3 | Lyot_2_0 | 9.571/2.775 | 2% | 0 | |
| 4 | Lyot_3_0 | 9.571/2.775 | 3% | 0 | |

| | | | | | |
|---|---|---|---|---|---|
| 5 | Lyot_3_45 | 9.571/2.775 | 3% | 45 | |
| 6 | Lyot_4_0 | 9.571/2.775 | 4% | 0 | |
| 7 | Lyot_4_45 | 9.571/2.775 | 4% | 45 | |
| 8 | Lyot_7_0 | 9.571/2.775 | 7% | 0 | |
| 9 | Lyot_10_0 | 8.754/3.543 | 10% | 0 | |
| 10 | Lyot_small | 7.708/2.237 | 3.5% | | |

Tolerance on spider and outer diameter is +-0.5% of the pupil diameter. Pupil diameter is 10 mm so 2% spiders = 200 microns, etc.

Derived from alignment budget.

NOTES:
1. These sizes are specified for the GS telescope, the baseline. Due to the smaller input pupil on GS, this will also work for GN.
2. Due to the 2-way symmetry of the M2 spiders, a single Lyot mask will permit two fixed Cassegrain rotator angle observing positions. Multiple identical masks (rotated 60 or 90 degrees from each other) are be provided to permit multiple field angles to be observed. (all observing is with fixed Cassegrain rotator angles).
3. The spider rotations are nominal; the final alignment wrt the telescope will be a calibration effort once installed.
4. ALT APLC masks will likely be further undersized to potentially mask bad pupil regions

### 5.4.2 Coronagraph Performance Requirements

#### *5.4.2.1 Residual Diffraction Contrast*

REQ-FPR-0520: The coronagraph shall achieve a residual intensity contrast of $1\times10^{-7}$ averaged from 6-7 $\lambda$/D and $>2\times10^{-8}$ at 10-12 $\lambda$/D in the absence of wavefront and tilt errors at its optimal wavelength and excluding the spider-induced diffraction spike region over $\pm1$ $\lambda$/D.

Derived from error budget 0.

NOTES:
1. This is meant to describe the intensity contrast that the coronagraph achieves with an injected flat wavefront.
2. Current modeling indicates that we can take advantage of the excellent APLC performance at the optimal wavelength use require comparison of data to modeling, hunting for PSF asymmetries, rather than a direct image.
3. The contrasts explicitly exclude the spider effects.
4. It is a goal to achieve comparable performance over a 10% bandpass.

#### 5.4.2.2 FPM wavefront error

REQ-FPR-0522: The focal plane masks shall exhibit a surface quality < 20 nm RMS wavefront excluding focus (goal < 10 nm RMS), and < 50 nm RMS wavefront focus measured over a 20mm clear aperture.

Derived from simulations of coronagraph performance and optical performance feed to the IFS and CAL.

#### 5.4.2.3 PPM wavefront error

REQ-FPR-0524: The pupil plane masks shall exhibit a surface quality of better than:

- < 50 (goal 20) nm RMS at low spatial frequencies
- < 5 nm RMS at mid-frequencies
- < 5 (goal 2) nm RMS at high frequencies

Derived from simulations of coronagraph performance and NCP error tolerances..

#### 5.4.2.4 Chromatic wavefront error

REQ-FPR-0540: The average change in wavefront error across each standard filter band from the coronagraph masks shall be < 5 nm (spatial RMS) at low frequencies and <0.5 nm (spatial RMS) at mid frequencies.

NOTES:

1. Present in the AMNH contract
2. This specification is required to insure good PSF quality across the entire band, since the AO/CAL system can only provide a achromatic correction. If inherent chromaticity of the APLC diffraction suppression leads to normal operations using only a subset of the band, this requirement could be relaxed to cover only 10% bandwidths.
3. This can be verified by interpolating wavefront maps between visible and IR wavelengths, or comparison of PSF structure.

## 5.5 Science Instrument Requirements

This section specifies the requirements that pertain directly to the IFS system.

### 5.5.1 Science Instrument Functional Requirements

#### 5.5.1.1 ICD requirements

REQ-FPR-0615: The IFS shall meet all the interface requirements as specified in the ICDs “1.9.x.3/1.9.x.5 IFS to OMSS/SCC ICD” 0 and “1.9.x.n Supplemental GPI Sub-system ICD’s” 0.

#### 5.5.1.2 Spectral Resolution

REQ-FPR-0620: The science instrument(s) shall achieve an average single fixed spectral resolution ($\lambda/\Delta\lambda$ per 2 pixels) ≥ 40 in H and ≥ 30 in all other bands.

Derived from REQ-OCD-0050.

#### 5.5.1.3 Wavelength Coverage

REQ-FPR-0630: The science instrument shall cover at least one complete band of *Y, J*, *H* simultaneously. It is a goal to cover *1.9 to 2.4 microns in at most 2 filters*. These are as defined in Section 4.3.1.

Derived from REQ-OCD-0051 and SOW0 3.1(c)(5).

#### 5.5.1.4 Filter positions

REQ-FPR-0633: The IFS shall have at least 5 filter positions (goal of 6). This will be populated with Y, J, H, K1 and K2 filters as defined in Section 4.3.1.

Derived from science requirements.

#### 5.5.1.5 Lyot Stop

REQ-FPR-0638: The IFS shall provide a cold Lyot stop mechanism with 10, non-rotating, positions (goal of 12) defined as to hold the Lyot masks defined in 5.4.1.7.

Derived from contract and science requirements.

NOTES:
1. The individual masks are not rotatable.
2. This fully restricts observing to the baseline of a fixed Cassegrain angle during an exposure.

#### 5.5.1.6 IFS Optical Throughput

REQ-FPR-0640: Replaced with the IFS requirement REQ-IFS-0010 in the IFS SSDD 0.

#### 5.5.1.7 Internal Opto-Mechanical Flexure Stability

REQ-FPR-0650: Replaced with the IFS requirement REQ-IFS-0020 in the IFS SSDD 0.

#### 5.5.1.8 Image Scale

REQ-FPR-0670: The science instrument will have a pixel scale of $14 \pm 0.5$ mas.

Derived from REQ-OCD-0150.

#### 5.5.1.9 FOV

REQ-FPR-0675: The science instrument will have a FOV of $\geq 2.8$ arcsec x 2.8 arcsec.

Derived from a trade study of FOV vs spectral resolution and spectral cross-talk constraints with a limited detector size.

#### 5.5.1.10 Pupil Viewing Mode

REQ-FPR-0680: The science instrument will provide a pupil imaging mode, in H, with at least 200 pixels (goal: 500 pixels) across the Gemini pupil. This shall achieve a SNR of 10:1 per pixel in 1 second on a $5^{th}$ H magnitude star with the coronagraph elements (PPM, FPM and Lyot) in the brightest parts of the pupil.

Derived from requirement to test, debug and calibrate the integrated instrument.

NOTES:

1. The pupil viewing mode is required for calibration (e.g. flexure), diagnostics and setup of the instrument. Not expected to be required for regular operations.

#### 5.5.1.11 Polarimetry

REQ-FPR-0690: The science instrument will incorporate a dual-channel polarization analyzer. This will permit simultaneous observation of linear orthogonal polarizations, and together with an external modulator mechanism, the ability to observe all Stokes parameters.

NOTE: The waveplate modulator mechanism will be provided by the OMSS.

Derived from contract, REQ-OCD-0060 and REQ-OCD-0061.

#### 5.5.1.12 Cryogenic Cooling System

##### 5.5.1.12.1 Cool Down Time

REQ-FPR-0720: The science instrument will have a cryogenic cooling system capable of cooling the instrument from 20º C to operating conditions within 6 days.

Derived from operational maintenance efficiency and experience with OSIRIS and other cryogenic instruments (James Larkin and Leslie Saddlemyer).

NOTES:

1. This is a balance between the operational desire to have a short warm-cool cycle time to speed I&T, ease operations at the telescope, safety of optics and detectors in the dewar and simplicity of cooling systems (e.g. avoiding complexity of pre-cooling strategies) and the desire to use low vibration CCRs, which tend to have lower cooling capacities.
2. Concerns at UCLA to large thermal gradients in some of the more sensitive optical elements (e.g. CaFl), and hence limits the maximum rate of cool-down and warm-up.
3. Anecdotal evidence that HAWAII-II RG detectors might experience pixel loss when temperatures changed too quickly. Recommended maximum rate is 0.25K/min. This is about 20 hours, and implies a maximum cool-down or warm-up rate.
4. Consider pre-cooling mechanisms to improve the cool-down rate.

##### *5.5.1.12.2 Partial Warmup Tolerance*

REQ-FPR-0722: The IFS shall reach thermal stability, and be ready for observing, within 24 hours after the cryocoolers have been re-started after having been powered down for up to 2 hours.

Derived from operational and maintenance efficiency concerns (Bruce Macintosh, James Larkin and Leslie Saddlemyer).

NOTES:
1. The intention is to accommodate the Gemini process of disconnecting GPI from the services while being installed on the telescope, and still permit operations by the evening of the following day.

##### *5.5.1.12.3 Warm Up Time*

REQ-FPR-0730: The science instrument will not require more than 4 days (96 hours) to warm up the entire instrument from operating conditions to 20º C. It is a strong goal to reduce this to 2 days (48 hours).

Derived from experience with OSIRIS and other cryogenic instruments (James Larkin).

NOTES:
1. See 5.5.1.12.1.
2. Not to utilize additional heaters.

#### *5.5.1.13 Cold Blank-Off*

REQ-FPR-0725: The science instrument will have a cryogenic cold blank-off to facilitate dark current measurements.

Derived from REQ-OCD-0070 and REQ-OCD-0130 (Leslie Saddlemyer/GSAOI example)

NOTES:

1. The location of this blank-off isn't important provided it provides a proper dark (e.g. could be the filter wheel, Lyot wheel.

#### *5.5.1.14 Lenslet position calibration*

REQ-FPR-0740: Removed as redundant with REQ-IFS-0020 in the SSDD 0.

### 5.5.2 Science Instrument Performance Requirements

#### *5.5.2.1 Pixel Intensity Crosstalk*

REQ-FPR-0770: Replaced with the IFS requirement REQ-IFS-0040 in the IFS SSDD 0.

#### *5.5.2.2 Flat Fielding Accuracy and Stability*

1. REQ-FPR-0790: Replaced with the IFS requirement REQ-IFS-0050 in the IFS SSDD 0

#### *5.5.2.3 Science Instrument Detector*

##### *5.5.2.3.1 Detector noise and background*

REQ-FPR-0800: Replaced with the IFS requirements REQ-IFS-0050 in the IFS SSDD 0.

##### *5.5.2.3.2 Quantum Efficiency (QE)*

REQ-FPR-0822: Replaced with the IFS requirement REQ-IFS-0050 in the IFS SSDD 0.

##### *5.5.2.3.3 Readout Speed*

REQ-FPR-0840: Replaced with the IFS requirement REQ-IFS-0050 in the IFS SSDD 0.

##### *5.5.2.3.4 Object Saturation*

REQ-FPR-0845: The science detector will be capable of not saturating on a 2nd *H* magnitude star with no coronagraph occultation (e.g. fully reflective mirror at FPM). It is acceptable for this to be accomplished with a higher readout noise than for the normal mode and very short exposure times and/or sub-arrays with a minimum size of at least 0.2 x 0.2 arcsec.

Derived from requirement to observe bright targets (Bruce Macintosh and Leslie Saddlemyer)

Notes:

1. Softened from 0 magnitude, since on that bright a star other techniques can be used to normalize the PSF.

##### *5.5.2.3.5 Integration Times*

REQ-FPR-0852: The science detector will support integration times of between 1 and 1,200 seconds for a full frame image.

Derived from REQ-OCD-0011.

NOTES: These are NOT co-added values, but single exposures without reset.

## 5.6 Calibration System Requirements

### 5.6.1 Calibration System Functional Requirements

#### 5.6.1.1 ICD requirements

REQ-FPR-0900: The CAL shall meet all the interface requirements as specified in the ICD "1.9.x.4/1.9.x.5 CAL to OMSS/SCC ICD" 0 and "1.9.x.n Supplemental GPI Sub-system ICD's" 0.

#### 5.6.1.2 Initial calibration measurements

REQ-FPR-0940: The daytime procedures needed to calibrate the calibration system relative to the science path will require no more than 10 minutes per coronagraph observing configuration.

Derived from operational requirement to not occupy too much time during daytime maintenance. (Leslie Saddlemyer).

NOTES:

1. The frequency of this (and other daytime) calibrations are assumed to be performed daily. It is understood that during the I&T and commissioning phases that these might be relaxed as knowledge of the stability is gained.

#### 5.6.1.3 Night-time calibration measurements

REQ-FPR-0942: Night-time calibrations, if necessary at the beginning of a science observing sequence, shall require less than 60 seconds, with a strong goal of less than 30 seconds. A 5 second every 10 minute closed-loop calibration (e.g. with DM poke pattern) is permitted during the 1 hour exposure

Derived from operational requirement to maintain the 90% acquire science photons requirement REQ-FPR-0140 and initial allocation towards REQ-FPR-0140 (< 6 min to acquire, lock, calibrate and start exposure).

NOTES:

1. The beginning of observation calibration sequence shall be the added time to the observation. We assume than any mechanism deployments are made during telescope slew time. Hence the time limit is for any measurements and iterations required (e.g. HOWFS, LOWFS, dithering etc) and motion of mechanisms to a position suitable for observations.

#### 5.6.1.4 Bright Star Operation

REQ-FPR-0910: The CAL system will be capable of operating with full performance on a star as bright as $0^{th}$ magnitude in *H* band.

NOTES:

1. Permits operation on the brightest star. Note that this is a limited target list.

#### 5.6.1.5 Filters

REQ-FPR-0920 The CAL shall have a fixed H-band internal filter for all spatial frequencies (eg both LOWFS and HOWFS). This will be utilized for all the bands (i.e. FPMs) as presented in Table 2.

#### 5.6.1.6 Tilt Calibration

REQ-FPR-0925: Now included with the CAL requirement REQ-FPR-0940..

#### 5.6.1.7 Cool-down time

REQ-FPR-0930: The CAL system shall cool from ambient (20C) to operating temperature in less than 12 hours.

Derived from need to ease operations and I&T (Leslie Saddlemyer).

#### 5.6.1.8 FPM Mechanism

REQ-FPR-0945: FPM Mechanism

The CAL system will provide a FPM assembly that will accept 9 FPMs including those shown in, REQ-FPR-0512.

NOTES:

1. For the spare slots, one is nominally allocated for the CAL subsystem calibration source.
2. This will provide some spare slots.

### 5.6.2 Calibration System Performance Requirements

#### 5.6.2.1 Absolute Accuracy

REQ-FPR-0950: The calibration module will achieve an absolute accuracy (while operating in closed-loop mode) of 5/1 nm of low/mid-frequency error in its measurement, on an arbitrarily bright star with no noise, of the science wavefront at the coronagraph occulting spot on a internal reference source, and sustain this accuracy over the course of a 1-hour integration with no additional calibrations (except possibly rephasing as discussed above). Spatial frequencies as defined in Table 1.

Derived from error budget 0

NOTES:

1. Need to define how this is measured – probably through calibration measurements of a quasi-monochromatic source or internal PSF reconstruction. In presence of typical GPI intensity errors.
2. This requirement is specifically to define the limits on systematic errors.

#### 5.6.2.2 Update Rates and Noise

REQ-FPR-0960: The calibration module will provide time-averaged wavefront measurements to the AO system at the following rates and noise in the mid-frequency band (see Table 1).

| I Magnitude | Update Rate [$min^{-1}$] | Noise per Update [nm mid-frequency] |
|---|---|---|
| 5 | > 1 | < 1.0 |
| 8 | > 1 | < 12.0 |

Derived from error budget 0

NOTES:
1. These measurements are to be new measurements once/minute with no additional lag.
2. The 8$^{th}$ magnitude noise has been relaxed from the original 5nm (as per the CAL design) as simulations indicate that this value can be relaxed, although significantly reducing margin.
3. Noise is defined as the RMS deviation of measurements, I.e. from a series of continuous measurements of the same wavefront.

#### 5.6.2.3 Tilt Update Rates and Precision

REQ-FPR-0970: The CAL system will update tilt information at ≥ 1 Hz, with a precision of 1 mas/update on an 8$^{th}$ magnitude star.

NOTES:
1. This is driven by flexure.

#### 5.6.2.4 Tilt Accuracy

REQ-FPR-0972: The CAL system will achieve an absolute accuracy in tilt at the FPM of 1 mas during a 1 hour exposure with no additional calibrations.

Derived from error budget 0 and coronagraph requirement (PDR appendix 2.25)

NOTES:
1. This is defined as verifying that the star, during CAL closed-loop operations (with no chromatic atmospheric dispersion) changes by no more than 1 mas in a1-hour change in gravity vector and temperature.
2. It is expected that the most likely causes of errors are the gravity vector change due to telescope tracking and the maximum 0.8°C environmental change in 1 hour.
3. It is considered acceptable for the gravity change due to tracking to be taken as 10 degrees per hour.

#### 5.6.2.5 RMS wavefront error

REQ-FPR-0530: Replaced with REQ-CAL-0060 in the CAL SSDD 0

## 5.7 OMSS Requirements

### 5.7.1 OMSS Functional Requirements

#### 5.7.1.1 ICD requirements

REQ-FPR-0975: The OMSS shall meet all the interface requirements as specified in the GPI sub-system ICDs. This includes:

- "1.9.x.1/1.9.x.5 AO to OMSS/SCC ICD", Karla Hagans, LLNL0
- "1.9.x.2/1.9.x.5 COR to OMSS/SCC ICD", Karla Hagans, LLNL 0
- "1.9.x.3/1.9.x.5 IFS to OMSS/SCC ICD", Karla Hagans, LLNL0
- "1.9.x.4/1.9.x.5 CAL to OMSS/SCC ICD", Karla Hagans, LLNL0
- "1.9.x.n Supplemental GPI Sub-system ICDs", Karla Hagans, LLNL0

#### 5.7.1.2 Telescope Input Pointing and Centering

REQ-FPR-0977: The OMSS shall provide a method to allow GPI to be pointed and aligned to the telescope beam to accommodate flexure and installation non-repeatability's. This needs to be accomplished to < 1% of the pupil diameter for the pupil alignment (centering), with a resolution of 0.1%. The pupil alignment mechanism shall be capable of performing its full stroke in < 2 seconds.

Derived from the pupil registration budget and astrometric requirements. Mechanism speed to be able to accept AOWFS pupil alignment feedback.

NOTES:

1. Nominally this requires GPI to have an input P&C pair. This is expected to be an input fold mirror (centering) and M2 (pointing).

#### 5.7.1.3 IFS Optical Feed

REQ-FPR-0979: The OMSS will provide the following resolutions of motion of the CAL-IFS P&C mechanisms.

- ≤ 0.1 mas pointing
- ≤ 0.05% pupil steering

Derived from pupil alignment budget and astrometric requirements.

NOTES:

1. There is a goal to be able to move the FOV off-axis by 2 arcsec to accommodate special observing cases where the desired FOV is to one side of the guide star.

#### 5.7.1.4 Input Calibration Source

REQ-FPR-0981: The OMSS will provide an input focus calibration mechanism. This mechanism shall be deployable, and shall, when inserted, define the input focal point for

GPI. This source is not required to reproduce the telescope pupil, but be a flood source, with an output f/ratio faster than f/12. The sources shall include:

- A broad-band light source capable of:
  - 5 – $10^{th}$ magnitude intensity in I band.
  - Output in the 0.7 – 2.3 micron band.
- A bright IR laser source at 1.58 microns +/- 0.03 microns (goal +/- 0.01 microns).
- A bright VIS laser source, (0.6 microns < $\lambda$ < 0.75 microns)

The internal broad-band source will be the normal operating source. It is permissible for the sources to each have their own, dedicated output at the GPI input focus.

The deployment mechanism will have:

- Absolute precision of positioning in the focal plane to < 50 mas (goal < 10 mas) which is < 30 microns (goal < 6 ) w.r.t. the optical bench coordinate system (i.e. the AO relay optical train).
- Capable of small motions of source < 1 mas (< 0.6 microns) for closed loop feedback adjustments.
- Goal of precision ≤ 1 mas absolute offsets (< 0.6 microns).
- Patrol a total field of ≥ 4.0 x 4.0 arcsec, centered on the optical axis.
- A goal to reduce the default deploy time of < 30s to 10s.

Derived from obvious requirement for an internal absolute calibration source.

#### 5.7.1.5 AOWFS Pointing and Centering

REQ-FPR-0983: The OMSS will provide an AOWFS P&C capability. This shall have pointing resolution of < 1 mas and centering resolution of < 0.1% of the pupil diameter. There shall be sufficient range of motions for both corrections, simultaneously, for the compensation of mechanical flexure of the structure.

Derived from obvious requirement for keeping AOWFS aligned. As well, this permits the AO system to be simplified by permitting it to operate to a T/T NULL.

#### 5.7.1.6 AOWFS Focus

REQ-FPR-0985: The OMSS will provide an AOWFS focus stage. This shall have a total range of 2 mm, with a precision of <= 100 microns and a motion resolution of <= 50 microns.

Derived from requirement to mechanically focus the AOWFS to the CAL feedback, which simplifies the AO system by being able to operate to a focus NULL.

Notes:

1. 0.1mm (100 microns) of stage motion corresponds to 5nm PV focus at the FPM.

#### 5.7.1.7 Mechanisms

REQ-FPR-0987: The OMSS will provide the following explicit mechanisms. Note that further OMSS mechanism requirements are contained within the appropriate ICDs.

Derived from contract and obvious need.

NOTES: There is a basic, generic requirement for a maximum configuration time of 30s for any device. We assume this here, and list only goals.

##### 5.7.1.7.1 Input Shutter

The input shutter shall be nominally light-tight, and be upstream of the input window as protection during GPI handling. There is a goal for a configuration time of 5s.

##### 5.7.1.7.2 AOWFS Spatial Filter

The spatial filter mechanism will provide a continuously variable square opening of <= 0.7 arcsec (1.75mm) on a side to >= 2.0 arcsec (5.0mm) on a side

##### 5.7.1.7.3 AOWFS Filters

The OMSS will provide an AOWFS filter selector. This mechanism will have at least 6 positions and be populated with:the following nominal lower cutoff filters. Any long wavelength cutoff must be longer than 1.0 microns.:

1. 0.60 microns
2. 0.70 microns
3. 0.80 microns
4. 0.9 microns
5. 0.90 – 0.91 Narrowband
6. Open

NOTES:

1. The SFWFS performs best over restricted bands and at high WFS strehl ratios. Normal observing will use a bandpass from 0.7 microns to the dichroic cutoff. The main purpose of the additional filters is to attenuate the flux for bright stars. As well, operating at red wavelengths closer to the science band will reduce chromatic differences between the AO system and the science path monitored by the CAL and further enhance SFWFS performance. Hence we attenuate by shortening up on the short wavelength cut-off.
2. As the AOWFS beam-splitter and detector QE will define the long cut-off, we can be very tolerant to any long-wavelength cutoff, it any at all.

##### 5.7.1.7.4 PPM Mechanism

The OMSS will provide a pupil plane mask (FPM) mechanism that will accept the 6 PPMs shown in 5.4.1.5 and 4 spare slots. This is NOT a wheel-in-wheel assembly. There is no requirement to be able to rotate the mask, either at setup/alignment time or anytime after. This will meet the requirements as defined in “1.9.x.2/1.9.x.5 COR to OMSS/SCC ICD”, 0.

NOTES:

##### *5.7.1.7.5 ADC*

The OMSS will provide a "front end" ADC mechanism that feeds the entire instrument with the following:

1. The ability to deploy. It is permissible to require re-focus of the telescope when the ADC is deployed/removed.
2. Arbitrary zenith orientation. This is to accommodate arbitrary Cassegrain rotator angles.
3. Compensate for the entire range of zenith distances in 5.2.2.3, with the assumed goal of from 1 to 50 degrees.

##### *5.7.1.7.6 FPM Mechanism*

- Deprecated, moved to the CAL system responsibility (see Section 5.6.1.8)

##### *5.7.1.7.7 Polarisation Modulator*

The OMSS will provide a polarization modulator mechanism that is deployable. It is a strong goal to reduce the arbitrary angle setting time to less than 15 seconds.

### 5.7.2 OMSS Performance Requirements

#### *5.7.2.1 AO Pupil flexure and thermal requirements*

REQ-FPR-0989: The OMSS will ensure that the relative pupil registrations between tweeter and the coronagraphic PPM don't move out of alignment by more than 0.4% of the pupil diameter.

Derived from pupil alignment budget. In turn, to retain telescope flux rate and resolution.

NOTES:

1. Expected that this will be accomplished by design of the structure, and not use any active elements (i.e. fold mirrors).
2. Woofer – tweeter is 10% of the woofer pitch, large enough to ignore.
3. The frequency with which it will be necessary to re-calibrate the alignment (accomplished by updating the X-Y zero points of the PPM mechanism) will have to be determined during operations. The design of GPI is such that this will only have to be performed after any component replacement, but structural drift (ie aging) might require a periodic recalibration on time periods of many months.

#### *5.7.2.2 AOWFS to Tweeter flexure and thermal registration*

REQ-FPR-0991: The OMSS will ensure that the AOWFS lenslets will remain registered with the tweeter DM to within 10% of a lenslet pitch RMS.

Derived from AO lenslet registration budget (See PDR appendix 3.10.), produces a 2% increase in WF variance.

NOTES:

1. The registration of the lenslets is expected to by accomplished by a P&C mirror pair in the AOWFS leg. It is a CDR level task to determine if this can be accomplished with a lookup table, or requires feedback from the AO control system.
2. The frequency with which it will be necessary to re-calibrate the alignment (accomplished by updating the X-Y zero points of the P&C stages) will have to be determined during operations. The design of GPI is such that this will only have to be performed after any component replacement, but structural drift (ie aging) might require a periodic recalibration on time periods of many months.

### 5.7.2.3 PPM to Lyot flexure and thermal registration

REQ-FPR-0993: The OMSS will ensure that the PPM pupil will remain registered with the Lyot pupil to within 1% of the pupil diameter under any normal operating gravitational vector and range of temperatures.

Derived from pupil alignment budget.

NOTES:

1. This is expected to require active control, likely through a P&C pair.
2. This is measured w.r.t. the mechanical fiducial on the IFS dewar.
3. The frequency with which it will be necessary to re-calibrate the alignment (accomplished by updating the X-Y zero points of the P&C mechanism) will have to be determined during operations. The design of GPI is such that this will only have to be performed after any component replacement, but structural drift (ie aging) might require a periodic recalibration on time periods of many months.

### 5.7.2.4 FPM to IFS lenslets flexure and thermal registration

REQ-FPR-0995: The OMSS will ensure that the FPM (occultor) will remain registered with the IFS lenslets to within 4 µm under any normal operating conditions for a 10 degree change in elevation.

Derived from pupil alignment budget and REQ-FPR-0150.

NOTES:

1. This is expected to require active control, likely through a P&C pair.
2. The frequency with which it will be necessary to re-calibrate the alignment (accomplished by updating the X-Y zero points of the P&C mechanism) will have to be determined during operations. The design of GPI is such that this will only have to be performed after any component replacement, but structural drift (ie aging) might require a periodic recalibration on time periods of many months.

## 5.8 Optical Requirements

### 5.8.1 Optical Functional Requirements

#### 5.8.1.1 Temperature Range of Warm Optics

REQ-FPR-1000: The optics, other than those within the science instrument dewar, will meet specifications at all temperatures within the range of –5 °C to 20 °C, at a maximum temperature change of 0.8 °C/hour.

Derived from ICD-G0013 0.

NOTES:

1. Derived for CP site.
2. It is expected that this is verified by design (e.g. through use of low CTE materials in critical optics.) See below for performance issues.

#### 5.8.1.2 Optical Coatings Lifespan

REQ-FPR-1010: All optical coatings and environment control will be designed to meet reflectivity requirements for a period of 5 years, under normal use and with no regular daytime maintenance.

Derived from REQ-FPR-0170.

NOTES:

1. Meant to meet the nominal lifespan of the instrument assuming a single re-coating of optics.
2. It is a goal for the semi-sealed opto-mechanical bench environment to increase the lifespan of the optical coatings to the 10-year life of the instrument.

### 5.8.2 Optical Performance Requirements

#### 5.8.2.1 Thermal Cycling

REQ-FPR-1020: The overall performance of all optical components and coatings will not be degraded by repeated thermal cycling at a maximum rate of temperature change of 0.8 K/hour at the operating temperature range.

Derived from ICD-G0013 and ICD-G0015.Mechanical

# 6 Overall system operability and environmental requirements

## 6.1 System Functional Requirements

### 6.1.1 Operation and performance over temperature ranges

REQ-FPR-1005: The instrument will be fully operational at temperatures within the range of –5 °C to 20 °C,

Derived from ICD-G0013 0.

NOTES:

1. Derived for CP site.
2. The following requirements also explicitly call out a temperature range and must also be verified: REQ-FPR-0390 (plate scale stability);
3. The following subsystem-level requirements will also be tested, though need not be signed off on for FPRD compliance: WFS dark current; IFS flexure stability; IFS dark current; CAL absolute wavefront measurement.
4. The instrument can be started from "off" condition and brought to operation
5. All computers, detectors and mechanisms operate
6. Internal static contrast ratio (REQ-FPR-0180)
7. Operation of all OMSS mechanisms (REQ-FPR-0987)
8. Input calibration source (REQ-FPR-0981)
9. Operation of CAL system FPM (REQ-FPR-0945)
10. Maximum total flexures (REQ-FPR-0150)

### 6.1.2 Thermal Gradients and Transients

REQ-FPR-1030: GPI will meet performance requirements over one-hour observation sequence operation  during which the temperature changes by no more than the standard Gemini environmental rate (0.8ºC/hour for CP), with per-target calibrations at the beginning of the 1-hour period,

Derived from ICD-G0013 and ICD-G0015.

NOTES:

1. ICD-G0013 stipulates 0.8ºC/hour for CP.
2. In particular, this includes the following:
    1. Internal static contrast ratio (REQ-FPR-1080)
    2. CAL system absolute wavefront accuracy (REQ-FPR-0950) defined for this test as a change in reported wavefront (with no other conditions changing) of less than 5/1 nm low/mid frequency over the 1-hour temperature change. (Since the CAL system is recalibrated at the start of science operations the 12-hour change number is less critical.)
    3. CAL system tilt accuracy (REQ-FPR-0972) defined for this test as the change in position of the CAL tilt control point relative to the center of the FPM being less than 1 mas

4. OMSS flexure requirements explicitly call out temperature changes and musst be verified over both temperature changes: REQ-FPR-0989 (AO pupil flexure), REQ-FPR-0991 (AOWFS to tweeter), REQ-FPR-0995 (FPM to IFS)

### 6.1.3 Thermal Cycling

REQ-FPR-1040: The overall performance of all mechanical components will not be degraded by repeated thermal cycling at a maximum rate of temperature change of 0.8 K/hour of the operating temperature range.

NOTES:

1. This refers to long-term changes/damage due to thermal cycling and is verified by design.

Derived from ICD-G0013 and ICD-G0015.

### 6.1.4 Space Requirement

#### *6.1.4.1 Space Envelope*

REQ-FPR-1050: GPI will be designed to conform to the space envelope requirements as per ICDs 1.1.1/1.9 and 1.5.3/1.9. This space envelope will include any/all thermal enclosures to be mounted on the ISS.

Derived from ICDs 1.1.1/1.9 and 1.5.3/1.9.

#### *6.1.4.2 Access to Thermal Enclosures*

REQ-FPR-1060: For servicing, the thermal enclosures will be accessible, both front and rear panels and any bulkhead connectors, without removing GPI from the ISS or unplugging any services.

Derived from ICD 1.9/3.7.

#### *6.1.4.3 Access to Services Ports*

REQ-FPR-1070: All service ports (coolant, helium, dry compressed air, LAN, GIS, power and any special connections such as fibres) will be accessible for connection/disconnection without removing GPI from the ISS, removing more than one GPI access panel or partially disassembling GPI.

Derived from requirement to simplify and ease instrument maintenance (Leslie Saddlemyer).

#### *6.1.4.4 Mounting Access*

REQ-FPR-1080: GPI will be able to be mounted/dismounted from the ISS without disturbing instruments/facilities on other ISS ports. GPI will be mounted/dismounted as a single unit.

Derived from simplify and ease instrument maintenance (Leslie Saddlemyer).

### 6.1.5 Mass Requirements

#### *6.1.5.1 Total Mass on ISS*

REQ-FPR-1090: GPI, including support frame, thermal enclosures, electronics, cabling, services connections and coolant (i.e. all mass mounted on the ISS) will have a total mass of 2000 kg .

Derived from ICD 1.5.3/1.9.

NOTES:
1. ICD 1.5.3/1.9 does not indicate a tolerance value.
2. Gemini has (technically) accepted a mass waiver to permit a GPI mass of up to an additional 200 kg.

#### *6.1.5.2 Centre of Gravity*

REQ-FPR-1100: GPI will exhibit, for the total ISS mass, a centre of gravity (CofG) located 1000mm out from the ISS mechanical interface (i.e. into GPI) on a line perpendicular to the centre of the science port. The tolerance on the CofG is such that the out-of-balance will not exceed 400 Nm w.r.t. the telescope elevation axis. This must include static imbalance, change in mass moment due to moving elements, and change in mass due to changes in coolant volumes.

Derived from ICD 1.5.3/1.9.

NOTES:
1. Gemini has (technically) accepted a mass waiver. This waiver requires that the moment on the ISS face NOT be changed.

### 6.1.6 Cooling Requirements

#### *6.1.6.1 Cooling System*

REQ-FPR-1120: GPI will use no liquid cryogens.

Derived from requirement to simplify operations. (Leslie Saddlemyer)

#### *6.1.6.2 Cooler Vibration*

REQ-FPR-1130: The cryogenic closed-cycle coolers on the IFS will not introduce vibrations greater than the following into the overall GPI mechanical structure.

| Frequency | Limit [$g^2$/Hz] |
|---|---|
| < 50 | <= 2 x $10^{-9}$ |
| 50 to 100 | <= 3 x $10^{-7}$ |
| 100 to 200 | <= 2 x $10^{-9}$ |
| 200 to 350 | <= 2 x $10^{-8}$ |
| > 350 | <= 2 x $10^{-9}$ |

Derived from error budget 0.

NOTES:
1. Nominally 20% of the Gemini ISS vibration limits agreed upon in the GPI vibration operational levels waiver. 20% is considered to be an insignificant contribution to the existing environment.

### 6.1.7 Vacuum Requirements

#### *6.1.7.1 Vacuum Facilities Compatibility*

REQ-FPR-1140: GPI will require only existing vacuum pumping system facilities at the Gemini Telescopes holding and staging areas. This requires that GPI utilize a KF-40 on the vacuum pumping port.

Derived from requirement for operational simplicity. (Leslie Saddlemyer)

NOTES:
1. GPI has self-contained, redundant pressure gauges so will not require any external readouts.
2. These are intended to be the same as used by NIRI and GSAOI to simplify equipment requirements at the Gemini Facilities.
3. The intention here is to also allow the same standard operating procedures for vacuum pumping and maintenance as for NIRI and GSAOI.
4. QF and KF series are the same fittings.

#### *6.1.7.2 Vacuum Facilities Access on Telescope*

REQ-FPR-1141: Vacuum ports and any service connections (e.g. external vacuum readouts) will be accessible while GPI is mounted on the ISS, and without disturbing any compliant instruments mounted on any of the other ISS ports.

Derived from requirement for operational simplicity (Leslie Saddlemyer).

### 6.1.8 Mechanism Safety

REQ-FPR-1150: No mechanism will cause harm to personnel, equipment or mechanisms in the event of loss of electrical power.

Derived from OBVIOUS.

NOTES:

1. Some devices may move in the event of power loss (e.g. power-off brakes). The intention is that nothing will move in a manner that could cause human harm or damage equipment.

### 6.1.9 Over-Pressure Safety

REQ-FPR-1155: All vacuum dewars, and any containers that may be subject to a potential over-pressurisation risk will have automatic pressure release safety valves.

Derived from obvious safety requirement.

NOTES:

1. Primarily meant for vacuum dewars (which are not designed for pressurized conditions, which can occur due to CCRs, getters and accidental handling).

### 6.1.10 Environmental Cover

REQ-FPR-1160: GPI will be fitted with an environmental cover that can be operated either by the control system or manually in case of power failure. Manual operation must not require more than one access panel to be removed or GPI being removed from the ISS. The cover shall be dust and light tight.

Derived from requirement to have a safety cover for GPI and light-tight enclosure for calibration purposes (Leslie Saddlemyer).

### 6.1.11 Environment Control

#### *6.1.11.1 Dry Air and Dust Reduction System*

REQ-FPR-1170: GPI will be fitted with a dry air and dust reduction system to keep the relative humidity within the optomechanical enclosure to less than 40% relative humidity under any Gemini telescope and instrument operating conditions (See ICD-G0013 0).

With all covers on and dust reduction system in operation, the opto-mechancial enclosure will maintain a Class 100 environment.

Derived from REQ-FPR-1010 and “GPI Dust Budget” 0

NOTES:

1. The MEMs DM humidity and high voltage damage potential will be eliminated by the use of a hermetically sealed DM, removing this as a driver for the humidity reduction.
2. Informal discussions with coating vendors indicate that dry environments increase the lifespan of metallic coatings. It is a goal for the environmental control to increase the life of all optical coatings to the 10-year life of the instrument.

3. Static, due to very dry conditions, can contribute to dust build-up on optics (discussions with LLNL dust/cleanliness experts). However, this alleviated inside the closed Optics Enclosure..

#### *6.1.11.2 Relative Humidity Sensor*

REQ-FPR-1172: GPI will be fitted with a relative humidity sensor(s).

Derived from requirement to monitor RH of optics enclosure and general monitoring of environment.

### 6.1.12 Instrument Handling

REQ-FPR-1180: The GPI structure shall have feet permitting free-standing storage (both in side looking and upward looking configurations) and attachment points for the Gemini instrument handling facilities as per ICD-G0015. This is to include all attachment points/fixtures to permit rotating the instrument from side looking to upward looking positions (and vice-a-versa).

Derived from ICD-G0015

NOTES:

1. Appropriate labels including safe lifting fixtures to be provided on structure.

### 6.1.13 Metric Dimensioning

REQ-FPR1190-: Metric dimensioning will be used in GPI. All dimensions will be in millimetres with appropriate tolerances called out.

Derived from SOW, Leslie Saddlemyer

### 6.1.14 Metric Fasteners

REQ-FPR-1200: All screws, bolts, nuts, tapped holes and fasteners will be of standard metric sizes, and called out as such on the as-built drawings. The only exception will be internal components of commercially purchased mechanisms, or fixtures to attach these (e.g. pre-tapped holes).

Derived from SOW, Leslie Saddlemyer

## *6.2 System Performance Requirements*

### 6.2.1 Mechanisms Operation

#### *6.2.1.1 Mechanism Set Time*

REQ-FPR-1210: Individual GPI mechanisms will have a maximum set time of 30s.
Derived from REQ-FPR-0140.

NOTES:

1. The intention is to keep observing efficiency as high as possible. Here we limit the maximum time that may be taken for individual mechanisms (software and hardware).

#### 6.2.1.2 Mechanism Configuration Time

REQ-FPR-1220: A complete reconfiguration of GPI (i.e. all mechanisms) will be performed in less than 60s.

Derived from REQ-FPR-0140 and REQ-FPR-1210.

NOTES:
1. The intention is to keep observing efficiency as high as possible. Here we limit the overall maximum time (software and hardware).

#### 6.2.1.3 Repeatability of Configuration

REQ-FPR-1230: The total error at the IFS lenslet plane resulting from a total reconfiguration will be less than 0.5 lenslets.

Derived from REQ-FPR-0140.

NOTES:
1. This ensures that no time be lost to calibration after an overall re-init of GPI or moving back to a previous configuration. It is aimed mainly at the repeatability (or precision) of re-indexing assemblies.

# 7 Electrical and Electronic Requirements

## 7.1 Grounding and Shielding

REQ-FPR-1300: Separate ground returns will be provided for low-level signals, electrically noisy components such as relays and motors and hardware components such as enclosures, chassis and racks.
Derived from 0 and SPE-ASA-G0008 0,

## 7.2 Electrostatic Discharge

REQ-FPR-1310: All sensitive components will be protected from electrostatic discharge and labelled.

Derived from 0 and SPE-ASA-G0008 0,

## 7.3 Power Dissipation

### 7.3.1 Unconditioned Heat Release

#### 7.3.1.1 Heat Released Into Ambient Air

REQ-FPR-1320: GPI will not release more than 50W heat into the ambient air.

Derived from ICD 1.5.3/1.9 0.

NOTES:
1. This includes heat dissipated through the thermal enclosures and any electronics outside the thermal enclosures.

#### 7.3.1.2 Heat Conducted into the ISS

REQ-FPR-1330: GPI will not conduct more that 50W of heat into the ISS structure.

Derived from ICD 1.5.3/1.9 0.

#### 7.3.1.3 Individual Mechanism Temperatures

REQ-FPR-1340: The GPI surface will not contain any significant external area (>100 $cm^2$) with a temperature more than ±2 C from ambient.

Derived from ICD 1.5.3/1.9 0.

NOTES:
1. Consistent with tests on LAO high-contrast test-bed. Probably overly stringent. Leslie Saddlemyer

### 7.3.2 Conditioned Heat Load

REQ-FPR-1350: GPI will have a maximum heat load into the cooling glycol of 4 KW.

Derived from ICD 1.5.3/1.9 0, ICD 1.9

NOTES:

1. Email from Doug Simons clarifies that the specification is a total instrument limit into the ISS coolant of 4 kW 0 (e.g. 2 kW/enclosure assuming two enclosures).

# 8 Software Requirements

## 8.1 Software Function Requirements

### 8.1.1 Conforming Instrument

REQ-FPR-1400: GPI will be a conforming instrument, adhering to the "Guidelines for Designing Gemini Aspen Instrument Software" guidelines.

Derived from REQ-FPR-0111 and SOW Key Requirements

NOTES:

1. This means GPI will either have an EPICS control system or the newer Aspen Gemini API control system

### 8.1.2 Meet GPI Software Requirements Specifications

REQ-FPR-1405: GPI will meet all the software specifications indicated in the GPI SRD.

Derived from REQ-FPR-1400.

NOTES:

1. As the SRD lists explicitly all required commands and interactions, it is redundant to repeat them here. See 0.

### 8.1.3 Engineering Interface

REQ-FPR-1410: GPI will provide engineering interfaces that will run on standard Gemini workstations (Linux only), to allow the exercising, testing and verification of all GPI mechanisms and functionality. This includes controlling all mechanisms, reading of sensors and reading all status. This code is a deliverable, but not required to meet any Gemini standard; Gemini will provide engineering GUIs.

Derived from "Guidelines for Designing Aspen Instruments" 0 and REQ-FPR-0111

### 8.1.4 Assembly Control

REQ-FPR-1420: All GPI mechanisms will be controlled through the GPI control system. This includes all low level and coordinated and virtual mechanisms (such as representing a pair of filter wheels as a single virtual filter wheel).

Derived from REQ-FPR-0111

### 8.1.5 Temperature Control

REQ-FPR-1430: The GPI control system will configure the temperature controller(s) controlling any thermally stabilised systems. This includes detectors, cooled/heated mechanisms and monitoring of ambient temperature(s).

Derived from REQ-FPR-0111

NOTES:

1. This requirement fundamentally ensures that operating temperatures are configurable in software.

#### 8.1.5.1 Cold Working Surface Temperatures

REQ-FPR-1440: The control system will configure the temperature control of the Cold Working Surfaces (CWS) in the IFS. This includes cool-down, warm-up and operational.

Derived from REQ-FPR-1430

#### 8.1.5.2 Science Detector Temperature Control

##### 8.1.5.2.1 Temperature Rate of Change

REQ-FPR-1450: The control system will monitor that the maximum rate of change of the detector is 0.25 K/min. The control system will raise a software alarm if this rate is exceeded.

Derived from GSAOI recommendations for HAWAII-2RG, Leslie Saddlemyer. See REQ-FPR-0720.

NOTES:

1. This requirement is only valid when the control system is running, and in no way implies that the cooling system can't be activated with the control system turned off.

##### 8.1.5.2.2 Temperature Stability

REQ-FPR-1452: The control system will configure the temperature setpoint of the science instrument detectors, and raise a software alarm if the monitored temperature deviates by more than 20 mK when in observing mode.

NOTES:

1. The characteristics of the IR detector may/are sensitive to temperature. GSAOI REQ-FPR-0315 in ATP indicates 1 mK to meet bias specification of < 50e/hour.

#### 8.1.5.3 AOFWFS Detector Temperatures

REQ-FPR-1460: The control system will configure the temperature setpoint of the AO fast wavefront sensor detector, and raise a software alarm if the monitored temperature deviates by more than 2 degrees C when in observing mode.

Derived from REQ-FPR-0421.

NOTES:

1. As well, some classes of CCD may have temperature-sensitive gains.

2. Value of 2 degrees selected mainly as an indication that something might be going wrong.

#### 8.1.5.4 CAL Detectors Temperatures

REQ-FPR-1465: The control system must be able to configure the temperature setpoints of the wavefront sensor detectors if they can be set in software, and raise a software alarm if the monitored temperature from the setpoint when in observing mode.

.

Derived from REQ-FPR-0111

NOTES:

1. In particular the HOWFS may have significant temperature dependencies.

#### 8.1.5.5 Environmental Monitoring

REQ-FPR-1470: The control system will monitor and permit turning on and off the logging of the following environmental conditions within GPI. This will allow logging at an adjustable rate of once every 10 to 60 seconds. This includes, but is not limited to:

- Science detector
- Calibration detectors
- AOWFS detector
- CWS temperatures (near cold straps and at furthest mechanical point)
- ambient temperature(s)
- coolant temperatures (inlet and outlet)
- base of all major sub-components (DMs, T/T mirror, AOWFS).
- Relative Humidity.

Derived from REQ-FPR-1430 and general requirement to be able to log GPI state

NOTES:

1. RH primarily to protect the optical coatings.

#### 8.1.5.6 Detector Temperature During Cool-Down/Warm-Up

REQ-FPR-1480: The control system will allow that the following two conditions are able to be kept:

1. Cool-Down: the detector(s) are maintained at a temperature between 5º and 20º C higher than the CWS during cool-down until the CWS is at operating temperature.
2. Warm-Up: the detector(s) are maintained at a temperature between 5º and 20º C higher than the CWS during warm-up until the detector(s) are at ambient temperature.

Derived from GSAOI example (Leslie Saddlemyer).

NOTES:

1. This requirement is to minimize the risk of condensation on the detector.
2. This may be a manual mode of operation. For example, for the operator to select an operating temperature of the detector of 20º C when the cryocooler is turned off in order to warm up GPI, which would keep the detector a little warmer than the CWS.

## 8.2 Software Performance Requirements

### 8.2.1 Configuration Time

REQ-FPR-1490: The software control system overhead for mechanism control will not increase the configuration time by more than the larger of: 5% of the mechanical operation time or 1 second. The software will be able to move multiple assemblies simultaneously.

Derived from REQ-FPR-1210.

NOTES:
1. This is to ensure that the configuration times are maintained.

### 8.2.2 Temperature Control

REQ-FPR-1500: The accuracy of the GPI temperature control will not be limited by the performance of the software system.

Derived from requirement to not have the normal software system, which might be re-booted etc, potentially adversely affect critical temperatures (Les Saddlemyer).

NOTE:
1. This implies that electronic temperature control system(s) is required, and that the software configures, but does not control the temperatures.

### 8.2.3 Science Instrument Detector

REQ-FPR-1510: The software system will not add to the overhead for readout in any way that increases the readout rate, in order to ensure that the detector readout rates as specified in REQ-FPR-0840 can be met.

Derived from REQ-IFS-0050 in the IFS SSDD 0.

NOTES:
1. DHS throughputs likely to be an issue.

# 9 External Interfaces

## 9.1 ISS Interface

### 9.1.1 ISS Ports

REQ-FPR-1600: GPI will be capable of being mounted on and used on any side-looking port and the upward-looking port of the ISS.

Derived from ICD 1.9.

### 9.1.2 ISS Mounting Material

REQ-FPR-1610: GPI will take into account the material of which the ISS is made and will hold differential temperature effects to a level that permits GPI to meet all optical alignment and safety requirements over the entire operating temperature range.

Derived from ICD1.5.3/1.9 0.

### 9.1.3 ISS Mounting Fasteners

REQ-FPR-1620: GPI will utilise fasteners sized for a safe working load including static and dynamic factors of safety to accommodate predicted loads on the Gemini telescope.

Derived from ICD1.5.3/1.9 0.

### 9.1.4 Optical Feed

REQ-FPR-1630: GPI will accept and use the optical feed of the telescope, off of the science fold mirror if mounted on a side-looking port.

Derived from ICD1.5.3/1.9 0.

### 9.1.5 Services

REQ-FPR-1640: GPI will make use of only the following services at the Cassegrain Rotator Utility Box. The umbilical cord(s) will be of sufficient length to reach from the GPI connector(s) location to the Cassegrain Rotator Utility Box. Connectors and specifications will be as specified in ICD 1.9/3.6. All line(s) will be flexible enough to permit easy routing in the ISS environment.

- One high and one low pressure connection to the helium service.
- One pair of “clean” UPS power, 120 VAC (NEMA 5-15).
- One pair of “dirty” power, 120 VAC (NEMA 5-15).
- One coolant water supply and return.
- One dry air supply.
- Control LAN
- Time LAN
- Data LAN
- Synchro Bus

- Gemini Interlock System

### 9.1.6 Gemini Interlock System

REQ-FPR-1650: GPI will interface to the GIS as described in ICD 12 and ICD 1.1.13/1.9.

Derived from ICD 12, ICD 1.1.13/1.9 and SOW.

NOTES:

1. The response to a GIS request from the GIS will be at least a shutdown of all high voltage supplies (> 48V) and the cessation of any motions.
2. GPI should trigger an interlock event for at lease the opening of any access panel, including the doors on the electronics enclosures, and the pressing of any emergency buttons that exist on the GPI instrument.

# 10 Environmental Requirements

These environmental requirements are all derived from ICD-G0013. As for other Gemini Instruments (e.g. GSAOI ATP), no formal analyses are to be performed to test these. However, they form the basis for design and selection of the components of GPI and are listed here for completeness sake.

## 10.1 Storage

REQ-FPR-1700: GPI will meet all the environmental specifications for storage as specified in ICD-G0013.

Derived from ICD-G0013.

## 10.2 Shipping

REQ-FPR-1710: GPI will meet all the environmental specifications for shipping as specified in ICD-G0013.

Derived from ICD-G0013.

## 10.3 Operation

REQ-FPR-1720: GPI will meet all the environmental specifications for operation as specified in ICD-G0013.

Derived from ICD-F0013

# 11 Other Requirements

## 11.1 Training of Gemini Personnel

REQ-FPR-1810: The GPI development team will provide training material and course(s) for Gemini personnel on the operation, maintenance and repair of GPI.

NOTES:

1. This will officially occur during the commissioning phase of GPI. However, training will commence earlier as Gemini personnel attend components of the acceptance tests and integration phases.

## 11.2 Single Point Failures

REQ-FPR-1820: Single point failure modes that will result in significant down-time will be identified, and critical spares list presented.

Derived from necessity to minimise impacts of critical components of GPI. (Leslie Saddlemyer).

## 11.3 Handles

REQ-FPR-1830: Modules meant to be handled directly by personnel weighing more that 20 kg will have suitable handles and be labelled with the nominal mass.

Derived from requirement to protect personnel (Leslie Saddlemyer).

## 11.4 Toxic Components

REQ-FPR-1840: No toxic products will be used for the development, construction or maintenance of GPI without explicit approval of Gemini Observatory and appropriate inclusion in GPI safety document.

Derived from GSAOI example and obvious safety and environmental issues (Leslie Saddlemyer).