Goals and Requirements for Software and Controls

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1 INTRODUCTION

1.1 PURPOSE

This document details the impacts of the Gemini science requirements on the design and implementation of software and controls for the Gemini project. The goal is to provide a guide for the development of systems that are capable of meeting these requirements.

1.2 APPLICABLE DOCUMENTS

This document is based on information found in the following document:

Reference Number	Title	Date
SPE-PS-G001	Gemini Science Requirements, Version 1.1	November 11, 1992

1.3 GLOSSARY, ABBREVIATIONS, AND ACRONYMS

A&G Acquisition and Guidance

ADC Atmospheric Dispersion Compensator

AO Adaptive Optics

Fast guiding The ability of the secondary mirror to move independently of the primary to keep a target appropriately positioned.

FOV Field Of View

FWHM Full-Width, Half-Max

HROS High-resolution Optical Spectrograph

Observing modes The Gemini system supports four observing modes: *Classical*, where the astronomer is interacting closely with the system, on-site, during the observation; *Queue-based*, where observing programs are submitted into a job queue for later execution; *Remote*, where the astronomer interacts with the system from a remote site (there will be a Gemini observer on-site); and *Service*, where the Gemini system performs the observation for the astronomer.

QE Quantum Efficiency

Strehl ratio The ratio of the central intensity of the delivered image to that of a perfect, diffraction limited image.

SIS Sub Arcsecond Imaging Spectrograph
TBD To Be Determined
WiFOS Wide Field Faint Object Spectrograph

2 TOP LEVEL CONSTRAINTS

2.1 PROPERTIES OF TELESCOPE CONFIGURATIONS

To satisfy the science requirements, there are two basic telescope configurations: *High Angular Resolution and Wide Field*. The main telescope properties for each of these three configurations are summarized in Table 2 - 1.

TABLE 2 - 1 **Telescope Configurations (8.0m, f/1.8 primary)**

Parameter	*High Angular Resolution*	*Wide Field*
Focal ratio	16	6
Primary FOV (arcmin)	3.5	45
Usable FOV (arcmin)	>10	45
Primary spectral range(µm)	0.4-30	0.3-1.0
Usable spectral range(µm)	0.36-1000	0.3-2.2
Image quality (FWHM, arcsec)	<0.1 or diffraction limited (λ>2.2µm)	0.25
Location of focalsurface (meters behind primary mirror vortex)	4	`3.5

2.2 GENERAL REQUIREMENTS

There are some general goals and requirements that need to be considered during system development. While lacking the objectivity of more detailed requirements, they nevertheless play critical roles in image quality and system integrity and utility.

2.2.1 Life-span issues

The long-life span anticipated for the Gemini telescopes imposes special constraints on design. It is entirely possible that current component *experts* will not be available throughout the life span of the system, nor can commercial vendors be counted on to continue during this span.

2.2.2 Reduced operation and maintenance cost

The remote placement of the systems and desire to reduce operational and maintenance costs while increasing observing efficiency also impacts all design issues.

2.2.3 Allowance for technology change

Further, the rapid changes in technology demand the capability to assimilate technological improvements with minimal cost.

2.2.4 Provision for upgrades and modifications

All systems need to be designed for ease of upgrade and replacement using, as much as feasible, 'stock' components that are not vendor or personnel specific.

2.2.5 Sole-sourcing

Sole sourcing of components is actively discouraged, for the reasons outlined above.

2.2.6 Ease of operation

The Gemini system is intended to function as a single, integrated environment. Achieving this goal necessitates standard interfaces, autonomous operation, and superior software design in a system-wide framework.

2.2.7 Reduced down-time

The *goal* of <1% downtime and *requirement* for <2% downtime must be considered in development. This impacts selection of components as well as system monitoring, diagnosis, correction, and repair capabilities.

2.2.8 Automation

The different observing modes (*classical, queue-based, remote and service*) impose a high degree of automation with the instrumentation.

2.2.9 Foreign instrumentation

Ultimately, the system may need to support astronomers providing outside instruments for observation. Interface requirements must be clearly stated, allowing developers to construct specialized instrumentation for connection to the Gemini system.

2.2.10 Operational conditions

There must be means of measuring environment conditions and for informing the system of problems in this area. Also, the stability of instruments under varying conditions should be known and the instruments should be ruggedly constructed to survive adverse conditions, handling, etc. There should be a way to safely and rapidly shut down individual system components as well as the entire system under extreme conditions.

2.2.11 Acquisition, guiding, and wavefront sensing

The telescope's ability to perform automatic acquisition, guiding, and wavefront sensing must be considered. In particular, the interface between A&G and other instruments must be determined in advance to ensure the proper role of instruments in these processes. Field rotation must be correctable.

2.2.12 Viewing station optimization

The Gemini telescopes support two standard viewing configurations. Each is optimized for particular needs. This may be important for certain instruments, e.g.:

- High-angular resolution Cassegrain - optimized for IR performance.
- Wide field - optimized for optical and ultraviolet performance.

2.3 MEASURABLE REQUIREMENTS

This section provides the quantizable constraints imposed by the science requirements that apply across all systems.

2.3.1 Low Emissivity

Emissivity is limited to 4% with a goal of 2% immediately after mirror coating or recoating. It should not degrade more than 0.5% during operation at any single wavelength beyond 2.2µm.

2.3.2 Diffraction effects

The diffraction-limited angular resolution of the Gemini telescopes is to be 0.07 arcsec at 2.2 µm.

2.3.3 Changing beam path at Cassegrain focus

Except for changing out secondaries, which is a day-time operation, it should be easy to retarget the beam. For instruments mounted at the Cassegrain focus, the change must be done in 20 minutes or less, with five minutes as the goal. Note that this time is from viewing with one instrument to viewing with another.

2.3.4 Direct beam feeding of spectrographs

There must be support for a FOV of 6-10 arcmin with seeing-limited images over the field. Articulated optics are required to preserve image quality.

2.3.5 Wide field requirement

The wide field arrangement must allow for use of optical fibers for multiple object spectroscopy and sky cancellation. The design supports a 45 arcmin FOV. For direct beam feeding of spectrograph, a FOV of 6-12 arcmin is required.

Top Level Constraints

3 INSTRUMENTATION

3.1 GENERAL REQUIREMENTS

The following general requirements are common to all instruments.

3.1.1 Full exploitation of 8m aperture

Instruments should take full advantage of the capabilities of the Gemini systems, including both the 8m aperture and the excellent image quality available.

3.1.2 Quality of instrumentation

Instruments are expected to be 'facility class' with excellent user interfacing, reliability, and maintainability. Expected reliability should exceed set goals of system.

3.1.3 Stability

All instruments must be stable through at least a one-hour integration, with contributions of no more than 0.1 pixel shift throughout the integration for zenith angles up to 60 degrees.

3.2 SPECIFIC PERFORMANCE REQUIREMENTS FOR INSTRUMENTS

The performance requirements for specific Gemini instruments are given in Table 3 - 1.

TABLE 3 - 1 **Instrument Descriptions**

Instrument	Wave-length (microns)	Spectro-scopic Res-olution	Pixel Scale Slit Width Array Size	Throughput (includes detector)	FOV	Other Properties
f/16 Optical Imager	0.4 - 1		0.1 arsec/pixel 4096x4096 with 15 micron pixels	> 50%	7 arcmin	Incorporates focal reducer Broad and narrow band filters 3.5' unvignetted FOV AO mode 0.024"/pixel and 100 arcsec field
f/16 Infra-red Imager	1 - 5		0.03 arcsec-ond/pixel at 2.2 microns 1024x1024 with 25 micron pixels	> 45% at 2 microns	20 arcsec at 2.2 microns	Standard broad band filters Complement of about 20 narrow band (1%) filters Provision for grisms Provision for polarimetry capability (1% linear)
f/16 Infra-red Spec-trometer	1 - 5	few hun-dred to 20,000	0.1-0.5 arc-second slit width 1024x1024 with 25 micron pixels	> 30%	Up to 2 arcmin slit length	Provision for grisms Privision for polarimetry capability (1% linear)
f/19.6 HROS	0.3 - 1.0	Moderate to 125,000	0.25 - 1 arc-second slit width 4096x4096 with 15 micron pixels	Requires > 10% at max of grating blaze and detector QE	Requires 0.5 arc-min. Goal of 1.0 arc-min	2000 spectral resolution elements/ order sampled with >2 pixels/resolu-tion element and 0.1 arcsec pixels in the spatial direction Complete free spectral range coverage in cross-dispersed mode Minimum 5" inter-order spacing Highest spectral or spatial resolution may be achieved with 0.25" slit Retain capability for dispersion by cross-disperser only

TABLE 3 - 1 Instrument Descriptions

f/6 Optical Imager	0.4 - 1		0.064 arcseconds/pixel 4096x4096 with 15 micron pixels	> 50%	4.4 arcmin	Direct imaging Broad and narrow band filters
f/16 SIS	Req: 0.4 - 1.0 Goal: 1-2 1-2 microns	200-5,000 [i.e., Maximum permitted with grisms]	0.1 arcseconds/pixel 0.2-1 arcsecond slit width 4096x4096 with 15 micron pixels 0.05 arcsec/pixel 0.1 arcsec slit width	> 25% at R =1,000 for 4000-7000 A, without slit losses 1/2 of maximum value at 4000-7000 A, when using low dispersion for the two adjacent ranges of 3600-4000 and 7000-9000 A at comparable resolutions, and for R=5000 in the range 4000-7000 A	Req: 6 arcmin Goal: 10 arcmin	0.1"/pixel, assuming 0.21 delivered to focus by tip/tilt Simultaneous coverage 3600-9000 A at R=2000 Throughput is highest priority Tradeoff study to evaluate dual-beam or cross-dispersed configuration to meet simultaneous wavelength goal vs. simpler layout with cost and exposure time efficiency Capacity to produce multi-aperture masks for the intrument with a slit location accuracy of at least 0.05" Possible imaging mode Capability for second near-IR arm to utilize AO mode
f/6 WiFOS	Req: 0.4-1.0 Goal: 0.4-2	200-5,000	0.5-1 arcsecond slit width 4096x4096 with 15 micron pixels	>25% for 4000-8000 A Peak throughput 45% for 6000-7000 A	Req: 12 arcmin Goal: 15 arcmin	Capability for imaging mode
f/16 8-30 Micron Imager	8-30		0.1 arcsec/pixel at 8 mirons 0.4 arcsec/pixel at 30 microns 256x256 with 25 micron pixels	Req: >20% at 8 microns Goal: >40% at 8 microns	25" at 8 microns 100" at 30 microns	Diffraction limited performance Broad band filters About 10 narrow band filters (NeII, SIV, SiC, Silicate) Provision for spectroscopic mode

TABLE 3 - 1 Instrument Descriptions

f/16 8-30 Micron Spectrometer	8-30	Req: 10,000-60,000 Goal: 1000-60,000	0.15 arcsec/ pixel at 10 microns 0.3 arcsec slit at 10 microns 256x256 with 25 micron pixels	Req: >10% at 10 microns Goal: >20% at 10 microns	Req: 0.5 arcmin	Provision for polarimetry
f/6 Multiple Object Spectrograph (Fiber fed MOS)	Req: 0.4-1.0 Goal: 0.3-1.5	Req: 500-30,000 Goal: up to 1,200,000 with some throughput loss	2000 resolution elements/ exposure with 2 pixels/resolution element for each fiber 12 pixel inter-fiber spacing 3 pixels/fiber spatial profile	>10% at low spectral resolution at maximum detector QE	Req: 40 arcmin Goal: 45 arcmin	Fiber positioning accuracy no worse than 0.1" for zenith angles <60^{o} Minimum of 400 fibers in each mode Range of fiber diameters Reset time <30 minutes to position 400 fibers Requirement for viewing capability at the focal surface Spectrograph mounted in gravity-stable configuration Optimized channesl for red and blue wavelengths

4 Image Quality Specifications

Overall, the Gemini telescopes are intended to degrade the median seeing profile by not more than 10%.

4.1 High-Angular Resolution Configuration

For high-angular resolution configuration the requirements for system performance with a 1 arcmin field at 2.2 µm are:

TABLE 4 - 1 **High-Angular Resolution Performance Requirements**

Encircled energy (%)	Diameter (arcsec)
50	0.10
85	0.25

4.2 Wide Field Configuration

For wide field configuration image quality is to be 0.25 arcsec (FWHM) over a 45 arcmin field within 20^{o} of the zenith. As the telescope moves away from the zenith, the telescope may follow the effects of atmospheric seeing. Image quality should be maintained for up to one hour exposures. The image profile required at 0.55 µm is:

TABLE 4 - 2 **Wide Field Configuratin Performance Requirements**

Encircled energy (%)	Diameter (arcsec)
36	0.25
50	0.33
90	0.75
98	1.35

4.3 NARROW FIELD CONFIGURATION

For narrow field configuration correctors and prisms should improve image quality to 0.21 arcsecs over the (6-10) arcmin field, with the same profile as above.

5 THROUGHPUT

In the infrared, throughput is affected by mirror cover, obscuration by secondary supports etc. Given these assumptions, throughput of the telescope in infrared is to be 91%, with a goal of 93%.

5 THROUGHPUT

6 IR Performance Requirements

6.1 Throughput

The effective collecting area in the IR configuration is 7.9 m diameter with a 1.3 m central hole. The primary and secondary mirror throughput is constrained to 91%, with 93% as a goal.

6.2 Baffles

The IR configuration incorporates deployable baffles around the secondary that must be remotely deployable during an observing session in less than 5 minutes.

6.3 Fast guiding

The fast guiding control is designed so that 90% of high galactic latitude lines of sight will have adequate guide star within 100" of the center of the science field and so that more than 99% of high galactic latitude lines of sight have adequate guide stars within range of the guider.

6.4 Acquisition

It must be possible to identify the science target and place it on the spectrograph slit with a precision no worse than 0.05".

6.5 OFFSETTING

Using a guide star, it must be possible to offset with an error no more than 0.05". Offsets of 60" or less should take no more than 5 seconds, total time. An offset of up to 5 arcsec must be possible in no more than 1 second.

6.6 BLIND OFFSETTING

Blind offsetting should work with at least 10 arcmin and an accuracy of at least 0.1 arcsec rms under median wind conditions.

6.7 IMAGE QUALITY IN IR

The system will produce images at 2.2μm with 50% of point source energy with 0.1 arc diameter and 85% within 0.25 arcsec diameter over a 1.0 arcmin diameter FOV and time intervals of up to one hour with fast guiding enabled and while pointing near the zenith. This requirement will be met at 70% wind speed and image diameters will increase with zenith angle no more than proportional to $sec(z)^{0.6}$.

6.8 IR SECONDARY CHOPPING SYSTEM

This should support amplitudes up to ± 7.5 arcsec at 10Hz and 80% duty cycle, and up to ± 15 arcsec at 5 Hz and 80% duty cycle. However, if a substantial savings in cost/complexity is obtainable, then there is an option of lowering this from 5 Hz to 3 Hz and from 10 Hz to 6 Hz. The image quality during chopping is 50% encircled energy within 0.4 arcsec at 10 μm.

6.9 IR SECONDARY TILTING

The secondary mirror will be capable of two axis tilting, reducing tilt power in the incoming wavefront by at least 90%. This may require motions in the focal plane of ±1 arcsec with a 3 dB bandwidth of 8 Hz.

6.10 SIMULTANEOUS SECONDARY ARTICULATION

The IR secondary system is to be capable of simultaneous chopping and image motion compensation so that image distortion is consistent with the 10μm image quality requirements.

7 FOV

The IR secondary mirror is sized so that the unvignetted FOV of the IR configuration is 3 arcmin in diameter. This FOV is to be unchanged at the extremes of the chopping cycle, resulting in 3.5 arcmin overall diameter.

All points in the 7 arcmin FOV should have an unvignetted view of the secondary mirror.

7 FOV

8 Adaptive Optics

8.1 Low-order adaptive optics

The adaptive optics system must be capable of delivering Strehl ratios >0.5 at 1.6 µm in median seeing conditions and >0.2 at 1.7 µm for the best 10% of conditions using natural guide stars. Throughput should exceed 50%.

8.2 Tilt performance

The goal is to reduce tilt error to a negligible level for 5th order correction estimated response bandwidth =25 Hz.

8.3 Optical quality

Mirror contribution to the wavefront error on all spatial scales must be less than the wavefront error introduced by the atmosphere when viewing is in the best 10%. This means that any 1.0-1.5m diameter area of pupil must be of the optical quality required to produce near diffraction limited performance at 0.7µm for an 8m aperture, w_{diff}=0.02 arcsec.

8.4 ROOM FOR ADAPTIVE OPTICS

There must be room under the primary for the adaptive optics. The recommended allowance is 0.4-0.6 meters. The adaptive optics will work over the range 0.5-3.0 µm and is optimized for 1.0-2.2 µm.

8.5 WAVEFRONT SENSOR

The wavefront sensor must be able to work with stars within the isoplanatic patch with a magnitude limit of at least 16 in the red.

8.6 LASER LAUNCH TELESCOPE

Although not part of the initial commissioning, the Gemini system must allow room in the facility for this (1 meter) telescope and for a light path from the laser to this telescope. This light path is not to be fiber.

9 Wide Field Configuration

9.1 Rapid instrument change

There must be an ability for rapid switching between spectrograph and optical imager. Both optical imagers and spectrographs must be mounted simultaneously and addressable by insertable or rotatable tertiaries.

9.2 Optical imager

The optical imager needs a 6 arcmin FOV and image quality of 0.25 arcseconds FWHM.

9.3 Error signals

Error signals for guiding and rotation are to be generated by the science instrument. There is no requirement for guiding beyond the science field.

9.4 Image de-rotation

The corrector elements are to rotate with the fiber positioner. The ADC is to be independently rotatable.

9.5 FAST GUIDING

There needs to be fast guiding capability in this mode.

9.6 NARROW BAND FILTERS

There should be options to insert narrow band filters, such as a Lyot system.

9.7 WIDE FIELD CORRECTOR CHANGE-OUT

There is no requirement for night-time change-out of wide field corrector.

9.8 NO TERTIARY MIRROR

It is not acceptable to direct the beam to a narrow field spectrograph with a tertiary.

10 TELESCOPE AND ENCLOSURE REQUIREMENTS

10.1 POINTING ACCURACY

The pointing accuracy for zenith distances $\leq 60^{o}$ is 3 arcsec rms while in service (implies 2 arcsec in test) with a goal of 1 arcsec (0.6 in test).

10.2 TRACKING REQUIREMENTS

10.2.1 Open loop

During tracking via open loop, tracking performance needs to be consistent with pointing performance.

10.2.2 Closed loop

Tracking during closed loop requires performance of 0.1 arcsec rms in 10 minutes, 0.25 arcsec rms in 1 hour with goals of 0.02 arcsec rms in 10 minutes and 0.05 arcsec rms in 1 hour.

10.2.3 Fast guiding

With image motion compensation, the requirement is 0.01 arcsec rms for 1 hour.

10.3 TIME TO MOVE BETWEEN TARGETS

With offsets up to 1 arcmin or less, the total time (viewing to viewing) should be done in 5 seconds. When traversing less than 10 degrees and with azimuth motions less than 10 degrees, viewing to viewing should be done in 30 seconds, Moving between any two positions in the sky should take 5 minutes or less.

10.4 OFFSETTING ACCURACY

With open loop, offsetting accuracy should be 0.1 arcsec rms over a 10 arcmin field and 0.2 arcsec rms over a 1 degree field, with goals of 0.05 arcsec rms for 10 arcmin field and 0.15 arcsec rms over a 1 degree field.

10.5 INSTRUMENT CHANGE TIME

Changing between instruments should take 20 minutes or less if both are mounted (includes time to disable first instrument and enable second). (At least two instruments must be mountable at the same time.)

10.6 FOCUS STABILITY

Telescope stability should be to image requirements. Instruments should be mounted with sufficient stiffness and precision that focus adjustments should not compromise imaging requirements.

10.7 COLLIMATION AND TILT OF SECONDARY

These should be consistent with image requirements.

10.8 FOV AND LIMITING MAGNITUDE FOR ACQUISITION

The range motion should be >10 arcmin for narrow field Cassegrain configuration, 45 arcmin at Cassegrain. FOV is 1-5 arcmin, limiting magnitude $\geq$ 23.

10.9 FIELD ROTATION

Field rotation must be correctable at all stations.

10.10 MIRROR FIGURE SENSING

The mirror figure sensor should provide measures of focus, collimation, and mirror figure.

10.11 FREQUENCY BANDWIDTH FOR GUIDING

The frequency bandwidth for guiding should be consistent with removing wind and vibration effects. For f/16 focus the guide signal bandwidth must able to move the IR secondary to reduce tilt power of incoming wavefront by 90%.

10.12 LIMITING MAGNITUDE FOR GUIDING

The guiding system should be sufficient to detect and generate signals from a star within 100" of the sky for lines of sight within the guide field at high galactic latitudes to meet imaging requirements. For the wide-field configuration the guider should be able to detect and correct for wind, telescope and enclosure induced motions over 99% of the available sky.

10.13 ACQUISITION FREQUENCY IN IR

When in IR configuration, acquisition viewing should be in an IR band close to the one used for observation.

11 Communications Requirements

11.1 Remote sites

There should be wide-area networking to Argentina, Brazil, Canada, Chile, the UK and the US.

11.2 WAN Performance

TBD, but at least T1.

12 Data Archiving

12.1 Full Journalling

There should be the ability to recreate observations from the journal information recorded with the data.

12.2 Permanent Record

There should be provisions to make records of observations and ancillary data available in perpetuity.

12.3 Compatibility

Data should be recorded in a from compatible with an existing archive. There is no requirement to establish such an archive.

13 Support Facilities

There should be provision for base, mid-level, and telescope facilities to meet reliability and maintenance needs. Note that this impacts instrumentation; systems should be designed to take advantage of these facilities.

A1 Salient Points in the Science Requirements

This appendix indexes the critical aspects of the Science Requirements - those that impact our software/hardware development. They appear here in the same order they are found in the Science Requirements document (Version 1.1, dated November 11, 1992).

Top Level Science Requirements

Page 3-6

- *Low emissivity* (page 3) - instrument design and configuration must be consistent with this goal.

Gemini Project and Configuration Requirements

Page 7-17

- *Image quality of better than 0.1 arcsec* (page 7) - the costs to image quality of all instrumentation measurable, and considered during design.
- *rapid change between selected instruments* (page 8) - must know time constraints on moving instruments between passive and active modes. Also, the time constraints on installing/removing an instrument must be considered, with standardization of procedures used to simplify and minimize these times.

- *provision for upgrades or modifications* (page 8) - instruments must be designed with maintenance and flexibility as goals.
- *long lifetime* (page 9) - reliance on sole-sourcing must be carefully considered.
- *ease of operation* (page 9) - standard interfaces, autonomous operation, superior software development, etc. are all factors.
- *provision for acquisition, guiding, and wavefront sensing* (page 9) - interfaces between A&G an other instruments must be determined in advance to ensure proper role of instruments in these processes. Field rotation must be correctable.
- *operational conditions* (page 11) - must provide means of measuring environmental conditions and informing the system of problems in this area. Also, the stability of instruments under varying conditions should be known and the instruments should be ruggedly constructed to survive handling, etc. There should be a way to safely and rapidly shut down both individual system components as well as the entire system under extreme conditions.
- *down-time* (page 11) - the restrictions on down time impose constraints on monitoring, diagnosis, correction, and repair.
- *foreign instrumentation* (page 11) - ultimately, the system may need to support astronomers providing outside instruments. Interface requirements must be clearly stated to enable developers to specialized instrumentation to interface to the Gemini system.
- *observing modes* (page 11) - the different observing modes (particularly queue-based) impose a high degree of automation with the instrumentation.
- *changing beam path* (page 12) - must be able to change the beam path rapidly (except for changing secondary), between instruments (quite fast).
- *diffraction effects* (page 13) - must be minimal.
- *direct beam feeding of spectrograph* (page 13) - must support a FOV of 6-10 arcminutes with seeing-limited images over the field. requires articulated optics to preserve image quality.
- *·vertical, rotating high-resolution spectrograph* (page 14) - preserves constant gravity vector while eliminating need for additional optical de-rotator.
- *wide-field requirement* (pages 14-15) - requires use of optical fibers for multiple object spectroscopy and sky cancellation. Design supports 45 arcminute FOV. For direct beam feeding of spectrograph, a FOV of 6-12 arcminutes is required.
- *Mechanisms to insert/remove auxiliary optics and baffles* (page 15)
- *high-angular resolution Cassegrain is optimized for IR performance* (page 15)
- *wind-field configuration optimized for ultraviolet and optical wavelengths* (page 16)

INSTRUMENTS

Page 18-22

The following are common requirements for all Gemini instruments: (page 18)

- *full exploitation of 8m aperture and excellent image quality of Gemini telescopes*
- *facility class instruments with excellent user interfacing*
- *instruments must be stable through at least a one-hour integration, with contributions of no more than 0.1 pixel shift throughout integration for zenith angles up to 60 degrees*
- *instruments should be reliable and easy to maintain with expected reliability exceeding set goals of system*
- *specific performance requirements for instruments (page 20)* - see attached.

IMAGE QUALITY SPECIFICATIONS

Page 23-26

- *For high-angular resolution configuration* (page 24) - the requirements for system performance with a 1 arcmin field at 2.2 mm are:

TABLE 1 - 1 **High-Angular Performance Requirement**

Encircled energy %	Diameter (arcsec)
50	0.1
85	0.25

- *For wide-field configuration* (page 24-25) - image quality is to be 0.25 arcsec over a 45 arcmin field within 20 of the zenith. Image quality should be maintained for up to one hour exposures. The image profile required it 0.55 µm is:

TABLE 1 - 2 Wide-field Configuration Performance

Encircled energy %	Diameter (arcsec)
36	0.25
50	0.33
90	0.75
98	1.35

- *For narrow field configuration* (page 25) - correctors and prisms should improve image quality to 0.21 arcsecs over the (6-10) arcmin field, with the same profile as above.

THROUGHPUT

Page 27-28

There is nothing in this section that impacts instrumentation. It deals with mirror surfaces and obstructions.

IR PERFORMANCE REQUIREMENTS

Page 29-31

- *The IR configuration incorporates deployable baffles around the secondary* (page 27) - must be remotely deployable during an observing session in less than 5 minutes.
- *fast guiding* (page 29)
- *acquisition* (page 29) - must be able to identify science target and place on spectrograph slit with precision of no more than 0.05".
- *Offsetting* (page 29) - must be able to offset, using a guide star, with an error no more than 0.05". Offsets of 60" or less should take no more than 5 seconds, total time.

- *blind offsetting* (page 29) - this should work with at least 10 arcmin with an accuracy of at least 0.1 arcsec rms under median wind conditions.
- IR secondary system chopping (page 30) - amplitude up to $\pm$-7.5 arcsec at 10Hz and 80% duty cycle, and up to $\pm$-15 arcsec at 5 Hz with 80% duty cycle. Image quality during chopping is 50% encircled energy within 0.4 arcsec at 10 μm.

ADAPTIVE OPTICS

Page 32-36

- *λow order adaptive optics* (page 35) - must be capable of delivering Strehl ratios >0.5 at 1.6 m in median seeing conditions and >0.2 at 1.7 m for the best 10% of conditions using natural guide stars. Throughput should exceed 50%.
- *tilt performance* (page 35) - goal is to reduce tilt error to a negligible level for 5th order correction estimated response bandwidth =25 Hz.
- *room for adaptive optics* (page 35) - must allow room under primary for adaptive optics.
- *wavefront sensor* (page 35) - must be able to work with stars within the isoplanatic patch with a magnitude limit of at least 16 in the red.
- *laser launch telescope* (page 36) - must allow room in facility for this (1 meter) and for a light path from laser to this telescope.

WIDE-FIELD CONFIGURATION

Page 37-38

- *rapid instrument change* (page 37) - must have rapid access to optical imager from spectrograph.
- *corrector elements rotate with fiber positioner* (page 37) - ADC rotated independently.
- *error signals for guiding and rotation are to be generated by the science instrument* (page 37) - no requirement for guiding field beyond the science field.
- *·must have rapid access to optical imager with 6 arcmin FOV, image quality of 0.25 arcsec FWHM and profile from above* (page 37) - fast guiding capability and options to include narrow-band filters (such as Lyot system).
- *No requirement for night-time change-out of wide-field corrector* (page 38)
- *Not acceptable to direct beam to narrow-field spectrograph with a tertiary.*

TELESCOPE AND ENCLOSURE REQUIREMENTS

Page 40-43

- *pointing accuracy* (page 40) - for zenith distances <= 60, this is 3 arcsec rms in service (2 arcsec in test) with goal of 1 arcsec in service (0.6 in test).
- *Tracking requirement, open loop* (page 40) - consistent with pointing performance.
- *Tracking requirement, closed loop* (page 40) - 0.1 arcsec rms in 10 minutes, 0.25 arcsec rms in 1 hour with goal of 0.02 arcsec rms in 10 minutes and 0.05 arcsec rms in 1 hour. (With image motion compensation, the requirement is 0.01 arcsec rms for 1 hour.)
- *Time to move between targets (total time to be ready for viewing)* (page 40) - offsets up to 1 arcmin or less in 5 seconds, traverse less than 10 degrees and azimuth motions less than 10 egrees in 30 seconds, and between any two positions in less than 5 minutes.
- *Offsetting accuracy, open loop* (page 40) - requirements of 0.1 arcsec rms over a 10 arcmin field and 0.2 arcsec rms over a 1 degree field, with goals of 0.05 arcsec rms for 10 arcmin field and 0.15 arcsec rms over a 1 degree field
- *Instrument change time* (page 40) - 20 minutes or less if both are mounted (includes time to disable first instrument and enable second).
- *Simultaneous mounting of instruments* (page 40) - at least two instruments mounted at the same time.
- *·Focus stability* (page 41) - to image requirements. Instruments should be mounted with sufficient stiffness and precision that focus adjustments should not compromise imaging requirements.
- *collimation and tilt of secondary* (page 41) - to image requirements
- *FOV and limiting magnitude for acquisition* (page 41) - range motion >10 arcmin for narrow field Cassegrain configuration, 45 arcmin at Cassegrain. FOV is 1-5 arcmin, limiting magnitude $\geq$ 23.
- *field rotation* (page 41) - correctable at all stations
- *mirror figure sensor* (page 41) - provide measures of focus, collimation and mirror figure.
- *·Frequency bandwidth for guiding* (page 41) - consistent with removing wind and vibration effects. For f/16 focus the guide signal bandwidth must able to move the IR secondary to reduce tilt power of incoming wavefront by 90%.

- ·*Limiting magnitude for guiding* (page 41) - sufficient to detect and generate signals from a star within 100" of the sky for lines of sight within the guide field at high galactic latitudes to meet imaging requirements For wide-field configuration the guider should be able to detect and correct for wind, telescope and enclosure induced motions over 99% of the available sky.
- *Frequency* (page 42) - when in IR configuration, acquisition viewing should be in an IR band close to the one used for observation.

COMMUNICATIONS REQUIREMENTS

Page 42

- *Wide area network to Canada, UK, US, and Chile (more now?)* (page 42)
- *Bandwidths on WAN at or greater than T1* (page 42) - or even higher

DATA ARCHIVING

Page 42

- *full journalling* (page 42) - should be able to recreate observations from the journal information recorded with the data.
- *permanent record* (page 42) - records and observations and ancillary data available in perpetuity.
- *compatibility* (page 42) - data should be recorded in a form compatible with an existing archive. No requirement to establish such an archive.

SUPPORT FACILITIES

Page 42-43

- *Provision of base, mid-level, and telescope facilities to meet reliability and maintenance needs* (page 43) - note impact on critical instrumentation.