GEMINI CALUNIT OPERATION CONCEPTS DEFINITION DOCUMENT V2.7

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1. INTRODUCTION

This document sets out the way in which the Gemini calunits will be used to enable to scientific goals of the telescope to be met. It is intended to describe the interaction of the calunit with the other systems, which constitute the Gemini telescopes, primarily the acquisition and guidance system and the telescope control systems. Since the GCAL performance is intimately linked to the instrumentation, the use of the calunits as part of a programme of observations is illustrated using key science proposals from the Phase I instruments: GMOS (MK, CP), HROS (CP), NIRS (MK), NIRI(MK).

2. SCIENTIFIC PERSPECTIVE

The contribution of GCAL to the scientific output from the Gemini telescopes and instruments comes from the increased efficiency and accuracy of observing calibration frames. The requirements on the GCAL arise from the Gemini science drivers, as follows.

Moderate field imaging and spectroscopy at high spatial resolution

The 7’ science field delivered by Gemini will be exploited by the GMOS instruments. Imaging over the central 3’ field will be provided with NIRI. With advent of larger CCDs or mosaics of CCDs, this field can be observed at high spatial resolution. The need for wavelength calibration and flat-field observations over fields from the largest science field (7’ diameter) but also with high spatial resolution requires efficient diffusion and transmission of the beams from the continuum sources.

Flatfielding fulfills a dual purpose with different detailed requirements. The flat must correct the individual pixel gains, and also correct the flux from a star in one part of the field for the effects of vignetting to ensure accurate relative photometry, for example of any source and a standard star measured elsewhere in the field.

The pixel gain measurement simply requires good signal/noise. Correction of sky emission in the NIR, where the sky lines are ~100 times brighter than the object, requires s/n of at least 10^3 on the flat field. The requirements arising from this are on stability of the lamp intensity, and efficiency of the system. Variations of lamp intensity on timescales shorter than the exposure times reduce the signal/noise achieved if they are greater than 5%.

The determination of the vignetting imposes a constraint on the overall flatness of the field. Ideally, the output from the calunit would mimic exactly the output from the telescope, to the photometric limit required (e.g. 1%). It is not practical to achieve this with a calibration unit, therefore we provide a stable output that may be calibrated to match the telescope. Details of the method for this are given below (Section 5.1.2). Of course, not all widefield observations require good relative photometry (e.g. red-shift determinations for a cluster of galaxies).

High spectral resolution observations

One of the strengths of an 8m telescope is the ability to produce high-resolution spectra of faint objects. Gemini provides this facility across a wavelength range from the UV to the infrared. Specific provision is made in the Phase I programme with HROS (R~50000) and GNIRS (R~18000). The calunit will be capable of providing wavelength calibrations that do not significantly reduce the observing efficiency. This requires high throughput, since the faintest arc lines may be the only ones available in the observed spectrum. In taking this advantage to its limit, frequent wavelength calibration will be required to monitor the effects of flexure. The importance of frequent wavelength calibration is stressed in the GMOS scenario ‘Dark Matter in Dwarf Spheroidal Galaxies’. HROS will also require frequent wavelength calibration, interleaved with observations on the astronomical source, to ensure that it attains the highest spectral resolution. (See for example the scenario on measuring QSO absorption lines).

Origin of the GCAL requirements

The requirements on GCAL are largely derived from the requirements of the Phase I instrumentation; the origins of the requirements listed may be found in the instrument

OCDD and FPRDs and also in the reports of the various instrumentation working groups[1]. Section 2.1 is summarised from the GCAL FPRD.

2.1 Summary of the GCAL science requirements

1. The calibration units will provide calibration frames (flat-field and wavelength calibration) for Gemini instruments covering a range of field sizes and wavelengths from the UV to the NIR. MIRI does not rely on the calibration units for flat fields. Each of the calunits will provide sources for all of GMOS, HROS, GNIRS and NIRI.
2. The intrinsic assumption when flat-fielding a detector is that the flux falling in each pixel is the same. The calibration beam at the output of the GCAL must be smoothly varying and the 2D spatial profile well understood. This may be achieved by a combination of intrinsic 'flatness' of the beam at the output of the GCAL (output uniformity) and subsequent calibration of the 2D beam profile with reference to some flat external source such as the sky (output stability). Limits provided by the instrument groups are that the GCAL beam should be flat to 1% over the 7' science field, to 0.1% over scales of 20", and to better than 0.2% over 100". When practical design constraints are considered, this reduces to the following functional requirement on output uniformity, plus a requirement on stability (FR3): The output beam covers 7 arcmin in diameter and should be flat with a monotonic roll-off in intensity of <10% to the edge of the field. Variations over the central 3' field should be 1%.
3. The two dimensional shape of the calibration beam should be stable during the course of a night. It should be stable to 0.3% over 12 hours. This limit is set in order that the final processed flat-field can be rendered uniform to ~1% over the full field as required by GMOS.
4. The flux from the calibration unit should be sufficient to provide calibration frames with the specified signal/noise ratio within the following timescale

    4.1. HROS: Wavelength calibration frames should have one line every 0.3nm that can be measured with a signal/noise of 10 in 5s. Flat fields with signal/noise = 300 in 5s and less than 60s at 310nm.

    4.2. GMOS: The same exposure times are adopted as for HROS. With the array read-out time for calibration frames at 10s, a 5s exposure on the wavelength calibration or flat-field will not affect the observing efficiency.

    4.3. GNIRS: There is no significant overhead in reading the IR arrays, therefore the guideline here is that that calibration frame should not take much longer than the time to move the science fold mirror into the beam (15s goal). A limit of 10s for an arc spectrum with signal/noise = 10 per pixel and 10 s for a flat-field with signal/noise=10^3 is adopted

    4.4. NIRI: As above. A flat-field with a signal/noise of 10^3 per pixel should be obtained in 10s.

5. For instrument/GCAL configurations where the flux output from the calibration unit would saturate the detector, provision for attenuating the flux should be made. For optical instruments, this can either be achieved using neutral density filters in the calibration unit or by some method of aperture control at the source. The exact method is TBD. For the NIR imager, the background thermal emission from a room temperature surfaces in the beam will saturate the detector longwards of ~3um. Cold ND filters must be supplied within the instrument if the instrument is to look at the calibration unit rather than the sky at thermal wavelengths.
6. The calibration unit should contain colour balance filters to flatten the output of lamps

[1] A list of relevant documentation is included in Appendix 1.

with steep spectra so that similar signal/noise at the blue and red ends of the spectra are obtained. The requirement from GMOS is that the continuum strength should not vary by more than a factor of 4 over 100nm between 400nm and 1000nm.

7. Deployment timescales. The calibration unit must be configurable to suit the observing mode within the time taken to change the mode. This limit on changing instruments is set by the science requirements to 30 seconds.

8. Control of lamps. There will be remote on/off control of each lamp.The lamp sources, will be turned on when requested and will be deployed within 5s. The FPRD calls for the continuum sources to remain on all night, in order to meet the intensity stability requirement. However, this is not required for the continuum sources chosen.

9. The pupil must be centred to within 1% of its diameter. The change in this position with telescope attitude should be limited to 1%.

10. The intensity of the continuum sources should be stable to 5% (with a goal of 1%) during any 12hour period.

3. BRIEF DESCRIPTION OF THE CALIBRATION UNIT(S)

The first functional requirement on the GCAL (stated above) highlights the fact that it is to be a telescope facility, designed with the flexibility to provide calibration frames for as yet unspecified instrumentation and throughout the life of the telescopes. The calunit described here provides just such a comprehensive facility covering the wavelength range from 0.3um to 5um, spectral resolution from broadband imaging to R~50,000 spectroscopy and pixel scales as small as 0.02arcsec. The beam from the calibration unit
illuminates the entire 7' diameter Gemini science field.

There are two facility calibration units - one for each of the Gemini telescopes. The design of both calunits is identical.

A list of the light sources is shown in Table 1.

calibration source	**MK GCAL**	**CP GCAL**
quartz halogen lamp	✔	✔
infrared source, temp 1100K	✔	✔
gas lamps: Ar, Kr	✔	✔
hollow cathode lamps, CuAr, ThAr	✔	✔

Table 1: The distribution of calibration sources amongst the GCALs

The optical layout of the Calunit is shown in Figure 1. The optical design can be thought of as consisting of two separate modules: the pupil imaging system and the illumination system (shown in more detail in Figure 2). The pupil imaging system is common to all the instruments; two off-axis aspheric mirrors reproduce the exit pupil of the telescope and simulate the 7' telescope field. The illumination system contains the integrating hemisphere, the continuum and spectral line sources and fills the aperture of the pupil imaging system with a uniform beam of light. The illumination system can be configured so as to provide light for a NIR or optical instrument.

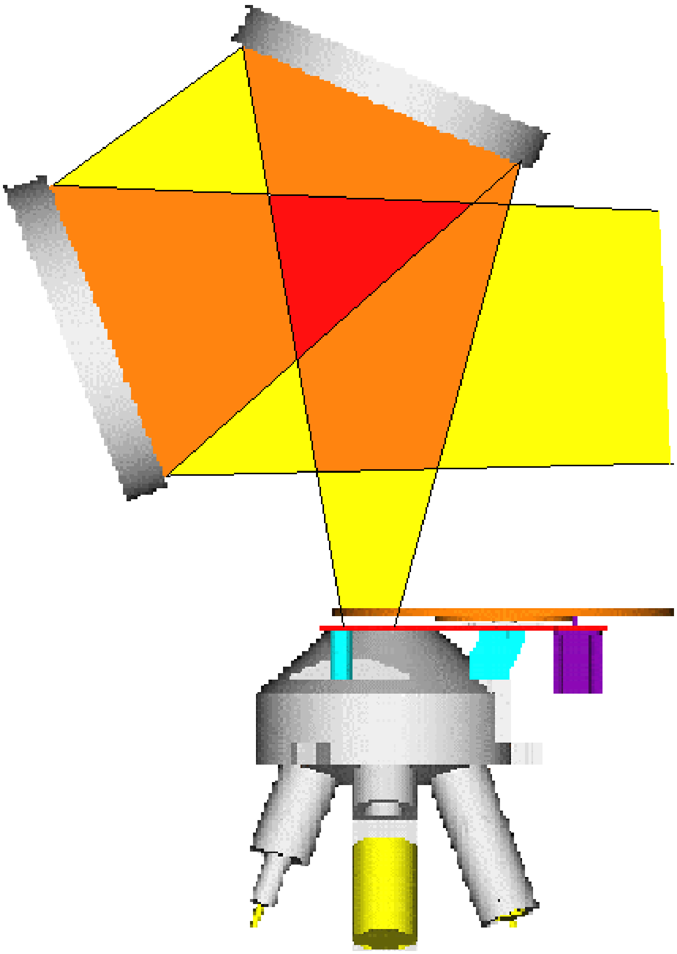

Figure 1: The optical layout of the GCAL.

A means of diffusing the output of the lamps to fill the comparatively large fields of the instrument and to provide a uniform illumination of the field is needed. It is required to do so with minimum loss of light. Table 1 shows the étendue of the lamps compared with the étendue of typical fields. The étendue of the lamps is uncertain to within a factor of a few.

Lamp	Étendue	AΩ 1' field/ AΩ lamp	AΩ 3' field/ AΩ lamp	AΩ 7' field/ AΩ lamp
100W QH Lamp	3.3	1.0	9.0	49.6
Infrared source	1	0.44	3.9	21.6
LPG lamps (Ar,. Kr)	94	0.04	0.3	1.70
Hollow cathode lamps (CuAr, ThAr)	2	0.61	15.0	81.80

Table 2: A comparison of the etendu of the calibration sources with that of typical field sizes of the Gemini Phase I instruments.

To illuminate the 7' field, the majority of the lamps need to be diffused by a large factor. The ratio of the étendue is the unavoidable loss of flux due to the diffusion process. Illuminating, for example, a 7’ field where only a 1’ field is required incurs an additional loss of flux. However, in most cases the predicted time to observe the calibration frame is still with the limits set by the functional requirements.

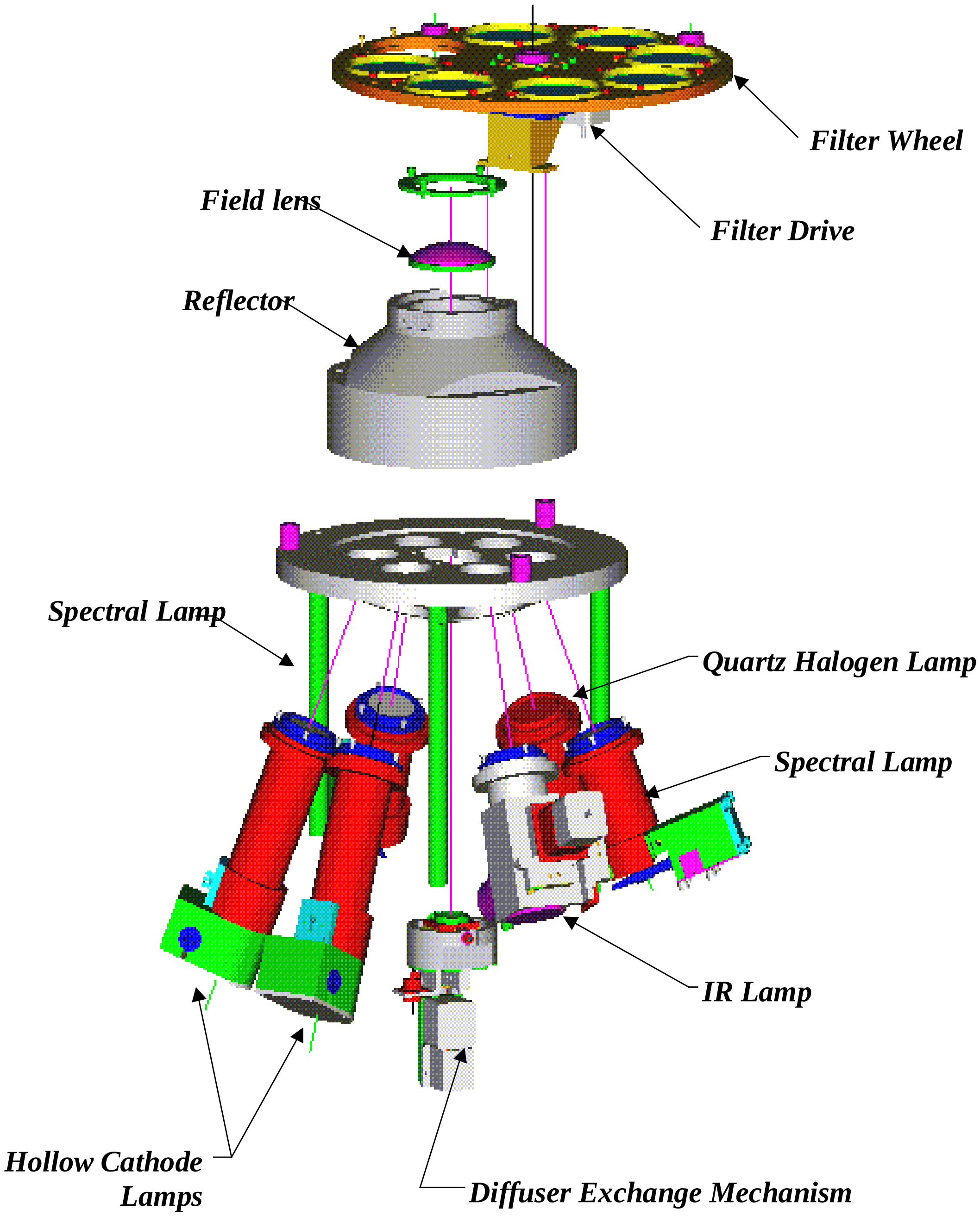

Figure 2: The layout of the illumination system.

The reflecting hemisphere (Figure 3) takes the place of the integrating sphere in a more conventional calibration unit. The driver behind this novel system is throughput, which is ~20 times larger than it would be for an integrating sphere used for this purpose. The throughput is most critical for wavelength calibration; flat-fielding sources generally provide adequate flux.

The illumination system proposed has two basic configurations:

diffuse illumination of a 7' field for NIR calibrations;

diffuse illumination of a 7' field for optical/UV calibrations.

3.1 The illumination system

The mechanical layout of the illumination system is shown in Figure 2. The function of the reflecting hemisphere is shown schematically in Figure 3. Light from any lamp is focussed by a lens in the lamp barrel onto an individual mirror mounted on the curved surface of the integrating hemisphere. It is reflected onto a diffuser from which it is scattered into a hemisphere. Some of the scattered light passes through the aperture stop; the remainder is returned to the diffuser by the hemispherical reflector. A BaF lens at the aperture stop expands the beam. The diffusing source is one of either an infrared or visible optimized diffusing surface. The diffusers are located on a two position wheel controlled by a stepper motor.The need to exchange the diffusers is to obtain both the reflectance of the material and the diffusing properties matched to the wavelength of the observations.

Selection of the lamp is by switching it on (arc lamps, QH lamp) or by opening a shutter (IR source). No movement of the lamp or mirror is required.

3.2 The continuum sources

3.2.1 Flux from the lamps

There are two continuum sources: a Quartz halogen lamp and an infrared source which is a grey-body with a temperature of 1100K and an emissivity of between 0.45 and 0.6 over the 1-5μm wavelength range.

The QH lamp is sufficient to meet the requirements for flat-fielding GMOS and HROS even for the shortest wavelength (300nm). The infrared source is required for the NIR instruments, but these may also use the QH lamp at the shortest wavelengths. The predicted exposure times for various configurations are compared with the requirements in Table 3.

3.2.2 Intensity stability

The intensity stability of the infrared source reflects the stability of the power supply. We expect this to be ±1%. The infrared source does require a warm-up period of 2 minutes and is requires to be left on during the night to maintain efficiency of taking flats. The infrared source is blocked with a shutter when not in use.

The intensity stability of the QH lamp (from the manufacturers' specification) is ± 0.4% rms.

3.3 The arc lamps

For HROS, hollow cathode lamps are required because of the density of spectral lines available. The median line spacing is 0.2nm (ThAr); an argon gas lamp has a mean line separation of 0.2nm. The HROS requirement is for a line every 0.3nm with a signal/noise of ~ 10. GMOS will use the hollow cathode lamps, though the highest resolution mode for GMOS will be 8000, reducing the need to rely in the faintest lines for wavelength calibration compared with HROS. Further, wavelength calibration will not be carried out so frequently during the night. GMOS has lower spectral resolution modes which cannot use the ThAr lamp as the lines are blended. These modes are provided for by including a CuAr hollow cathode lamp.

Calibration	**Requirement**	**Prediction**
HROS: Flat fields	Signal/noise = 300 in 5s at 600nm	S/N > 300 in 5s for λ >~ 400nm
	Signal/noise = 300 in < 60s at 310nm.	S/N = 300 in 60s at 310nm (S/N = 300 in ~20s at 350nm)
GMOS: Flat fields	Signal/noise = 300 in 5s at 600nm	S/N > 300 in 5s for λ > 350nm
NIRS: Flat fields	10s for a flat-field with signal/noise=10^3 is adopted	Short camera, R=6000 , met for λ>2μm Long camera, R=5400, s/n=500 in 10s at λ=2 μm. Requirement can be met at short wavelengths with the QH lamp for all configurations
NIRI imaging: flat fields Assuming 1% filter.	S/N = 10^3 per pixel in 10s.	OK for λ>J with infrared source. S/N ~ 100 obtained for λ<J. QH lamp for S/N = 10^3 and λ<J.
NIRI spectroscopy: flat fields	S/N = 10^3 per pixel in 10s.	Requirement met with the QH lamp.

Table 3: Predicted exposure times for a flat-field with s/n=10^3 . The instrument configurations assumed are shown in a table in Appendix 4.

The GNIRS and NIRI will use low-pressure gas lamps (argon and krypton) for wavelength calibration.

Instrument/calibration	**Requirement**	**Prediction**
HROS: wavelength calibration frames	One line every 0.3nm	ThAr mean separation is 0.2nm (290nm to 1110nm)
	To be measured with a signal/noise of 10 in 5s	At 600nm, lines with flux~1% of the average bright line have S/N=10 in <~10s. (S/N = 8 in 5s)
GMOS: Wavelength Calibration frames	Signal/noise of 10 in 5s	At 600nm, lines with flux~1% of the average bright line have S/N=10 in ~15s. (S/N=6 in 5s)
NIRI spectroscopy: Wavelength calibration	A limit of 10s for an arc spectrum	At 2μm, lines with flux~1% of the average bright line have S/N=10 in ~10s.

Table 4: predicted exposure times for arc frames.

The wavelength calibration sources will be switched on when selected and off when the observation is complete. The illumination system allows more than one arc lamp to be used at once. The predicted exposure times for the arc frames are shown in Table 4.

3.4 The filter wheel

A single filter wheel will contain colour balance and neutral density filters required for the various lamp plus instrument configurations.

A single lamp, for example the QH continuum source must to calibrate GMOS in a configuration where the delivered flux is ~100 times greater than it may be for HROS. Neutral density filters are required to prevent saturation.

A range of neutral density filters is provided with optical densities (D) of 1.0, 1.6, 2.0, 2.6 and 3.0 corresponding to transmission (= 10^{-D}) from 0.1 to 10^{-3}.

For observations at the shortest wavelengths, the gradient of flux from the QH lamp is such that the flux at the extreme wavelengths of an HROS spectrum from 350nm to 700nm will differ by a factor of ~30. This results in a mismatch in signal/noise or the red end of the spectrum saturating. Colour balance filters (CBF) can be used to correct this. The filter size is non-standard, being ~100mm. Two combinations of colour filters are required to satisfy the needs of both GMOS and HROS.

1) The Schott BG34, colour temperature conversion filter, suits GMOS and the 350nm-1000nm configuration of HROS.

It is not suitable for the 300nm - 500nm configuration of HROS, due to the low transmission at short wavelengths.

2) BG24a plus UG5 provides good UV transmission and suits the HROS 300nm-500nm requirements. However, the strong gradients towards the red and the low transmission from 600nm - 700nm make it unsuitable for general purpose work.

The lamp flux from the QH lamp with each of the filter combinations is shown in the two figures below.

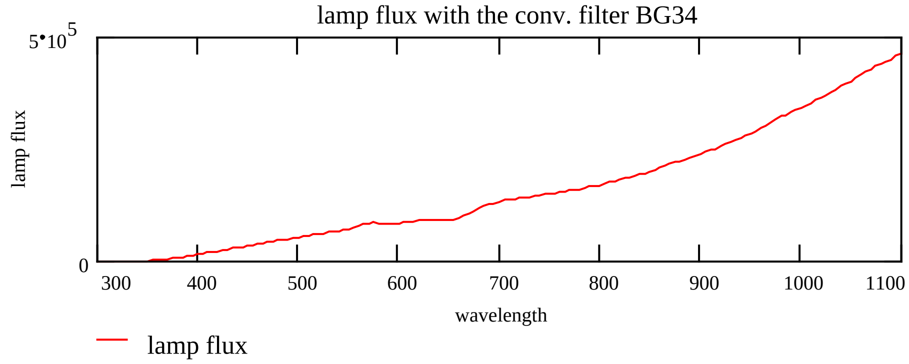

Figure 3: the CBF required for GMOS and long wavelength configurations of HROS.

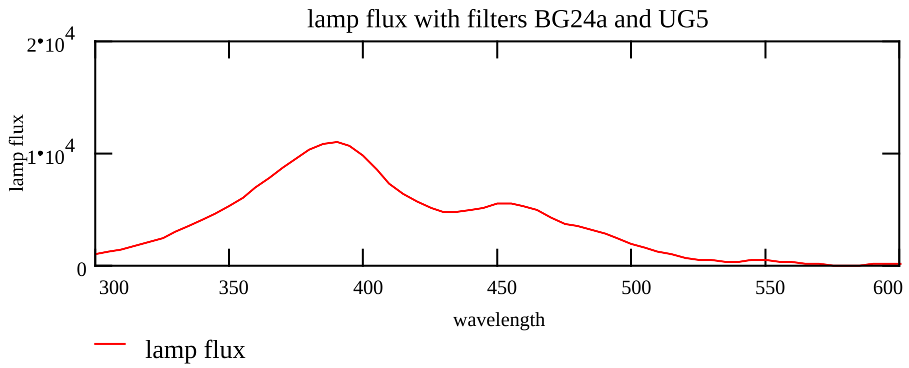

Figure 4: the CBF required for short wavelength configurations of HROS.

The arrangement of filters in the wheel is as given in Table 5. Note that the wheel is balanced for this filter arrangment. Any change to this ordering will require the wheel to be re-balanced.

Filter position on wheel	Filter	Glass name (from Schott)
1	Open	
2	D=1.0	NG4
3	D=1.6	NG9
4	D=2.0	NG9
5	D=2.6	NG9
6	D=3.0	NG9
7	CBF_GMOS	BG34
8	CBF_HROS	BG24A+UG5

Table 5: Location of filters in the wheel.

Table 6 contains a guide to the use of the filters with various instrument configurations. It is far from 'complete' in terms of the range of configurations available with the Phase I instruments. These are the 'worst case' configurations which were examined when drawing up the filter list for the calunit. This table must be updated as the GFCU is commissioned with each instrument.

	mode	**lamp**	**filters**
HROS	300nm-500nm	QH lamp	HROS CBF
	350nm-1000nm	QH lamp	GMOS CBF, D=1.0
GMOS	R=250, 6.25 pixel slit. 0.08" per pixel.	QH lamp	D=3.0 for λ > 700nm
			D=2.6, 530nm < λ < 700nm
			D=2.0, 440nm < λ <530nm
			D=1.6, 370nm<λ < 440nm
			λ = 400nm-800nm simultaneously: GMOS CBF, D=2.6
GMOS:	imaging at U'BVRI with R~9,4.5,6.2,3.2,3.8		Attenuation ~10^4 required **Flat-field on sky**
GNIRS	0.05" pixels, JHK x-disp R=2000	IR source.	D=1.0
	0.05" pixels, JHK x-disp R=2000	QH lamp	D=2.0
	0.05" pixels, R=2000	IR source	D=1.0
	0.15" pixels, R=667	IR source	D=2.0
	0.15" pixels, JHK cross-dispersed	QH lamp,	D=3.0
NIRI	1% filters, 0.12" per pixel	IR source	D=3.0
	1% filters, 0.06" per pixel r	IR source	D=3.0
	1% filters, 0.02" per pixel	IR source	D=3.0

Table 6: Use of the GFCU filters

3.5 The pupil imaging mirrors

There are two mirrors which produce the image of the telescope pupil. These are mounted to the support structure in fixed positions. The mirrors are aluminium, nickel plated, then coated with aluminuum. The surfaces may be stripped and re-coated as required. An all-reflective design was chosen because of the wide wavelength range to be covered and the size of the optics. Two powered mirrors are required to give illumination of the pupil that meets the requirement (FR9).

4. INTERFACES TO THE GEMINI SYSTEMS

The Calunit will be located solely on the side-looking face of the ISS, opposite Altair (on MK). The interface from the GCAL to the ISS is described in ICD 1.5.3/1.7. The GCAL port is shared with the electronics cabinet for the A&G system, which also contains the GCAL electronics. This interface is described in ICD 1.6/1.7.

The GCAL configuration will be downloaded from the Observatory Control System. The Gemini Observing Tool contains information on the calibration unit configuration. The GCAL/OCS ICD describes this interface more fully (ICD 1.7/3.1).

Interaction with the data handling system will be to provide header information about the GCAL configuration, (which arc lamp, which filters).

5. MODES OF OPERATION

5.1 Initial Alignment and Calibration

5.1.1 Alignment to the telescope

The single most important alignment of GCAL to the telescope is to ensure that the pupil is aligned relative to the telescope pupil. Since the High Resolution Wavefront Sensor (HRWFS) is capable of imaging the telescope pupil, it can be used for this task. The size and x/y position of the telescope pupil on the HRWFS detector should be measured and noted and this compared with the simulated pupil from the GCAL. Alignment of the GCAL should be controlled via the mechanical alignment of the GCAL enclosure to the ISS face; the science fold mirror position relative to that face will be fixed previously.

This test is sufficient to measure the static alignment. To extend this to tests of the flexure of the GCAL, then the flexure of the HRWFS must be taken into account.

The procedure would be as follows:

Locate a bright star within the field of the telescope

Deploy the HRWFS into the centre of the field.

(The science fold mirror should be parked.)

Configure the HRWFS for pupil imaging.

Take an image of the pupil with the HRWFS.

Locate the pupil on the detector

Configure the calunit.

Deploy the science fold mirror to direct the calunit beam to the upward looking port.

Take an image of the pupil with the HRWFS.

Verify the size and location of the pupil image relative to the telescope pupil image

Adjust the alignment of the GCAL relative to the port via the mechanical fixings.

5.1.2 Starting the night

The calibration unit contains an infrared source for flat-fielding observations with NIRI and GNIRS. If these instruments are expected to be used, the infrared source must be switched on at the beginning of the night. It has a long warm-up time to stabilise the flux (>2minutes), and cannot be deployed instantaneously. The flux is prevented from entering the reflector by a shutter. This should be closed at the beginning of the night and opened when a flat is to be taken.

5.1.3 Calibration of the output uniformity

The requirement is that the output beam should be flat with a monotonic roll-off in intensity of <10% to the edge of the 7' diameter field. Variations over the 3’ field should be 1%. To achieve a flatter beam than this, requires calibration of the GCAL against the sky with each of the instruments.

This calibration is achieved via a comparison of a ‘sky flat’ and a ‘GCAL flat’. The correction factor required to be made to the GCAL flat in order to make it identical to the sky flat on large scales is:

$$Vcorr(i, j) \equiv \frac{gcal(i, j) \times BB(\lambda)}{tel(i, j)}$$

A derivation of this factor is given in Appendix 2. The frequency with which this vignetting correction will have to be determined depends on the accuracy of photometry desired, the relative flexure of the telescope and the GCAL, and other factors that may alter the telescope vignetting function, such as the build up of dust on the mirrors. This frequency will have to be determined during the commissioning of the instrument and during operations.

5.2 Taking calibration frames with GCAL

5.2.1 Flat-fielding

Flat-field observations can be categorised as those for which the calunit flatness is sufficient and those for which a higher accuracy of relative photometry is required.

5.2.1.1 Observations over a large (>3’ diameter) field

As stated in section 5.1.3, the output uniformity of the GCALs is required to be 10% over the 7’ science field of the telescope. This sets a limit of 10% on the relative photometry of objects at different positions in the field, for example objects in GMOS slits. For observations where this level of accuracy is acceptable (e.g. for red-shift determinations of individual objects in a cluster) the procedure for flat fielding is as follows.

Adopt the calunit configuration

visible diffuser

switch QH lamp on

[Neutral density filter if required - depends on spectral resolution]

[Colour Balance filters if required - depends on wavelength range]

Deploy the science fold mirror to direct the GCAL beam to instrument

Observe the calunit flat

Switch QH lamp off

Redirect the beam from the telescope into the instrument using science fold mirror.

For observations requiring better relative photometry, the correction for the difference between the calunit and telescope vignetting functions must be made. Using GMOS as an example, the procedure then becomes:

During the day: Search archive for a suitable stored vignetting function

Most recent sky flat dates from one month previously and is out of date.

None is found.

During twilight: Observe the sky flat

Adopt the instrument configuration

Insert the clear aperture to allow image of the sky rather than mask observations.

Observe the sky with dithering pattern

Create the flat by median filtering the observations.

Derive the vignetting profile by low-order surface fit to this observation.

Store this as the instrument plus telescope profile.

Some time later.....Observe the calunit flat for use with the observations.

Adopt the calunit configuration

visible diffuser

QH lamp

NDF/CBF depending on configuration

Switch QH lamp on

Insert the science fold mirror

Observe the calunit flat

Reconfigure the science fold mirror again.

Switch QH lamp off

These steps require that the telescope is capable of jittered observations; that it is possible to interrogate the archive and retrieve a suitable flat; that it is possible to apply this flat to the observations in the DHS. All of these are available within the current, planned capabilities of the telescopes and sub-systems.

5.2.1.2 Observations over an intermediate field

The output uniformity of the GCALs is required to be 1% over the 3’ unvignetted field of the telescope. The same comments apply here as above; relative photometry to levels better than 1% will have to be carried out using a combination of sky flats and GCAL flats. The configuration for the GCAL will depend on whether an optical or NIR instrument is being used.

Optical instrument:

visible diffuser

QH lamp: switch on

[Neutral density filter if required - depends on spectral resolution]

[Colour Balance filters if required - depends on wavelength range]

Deploy the science fold mirror to direct the GCAL beam to instrument

Observe the calunit flat

Redirect the beam from the telescope into the instrument using science fold mirror.

Switch QH lamp off

NIR instrument:

nir diffuser

QH lamp or Bbody

[Neutral density filter if required - NB may be located in instrument]

Switch the QH lamp on or open shutter to the infrared source

Deploy the science fold mirror to direct the GCAL beam to instrument

Observe the calunit flat

Redirect the beam from the telescope into the instrument using science fold mirror.

Switch the QH lamp off or close the infrared source shutter

5.2.2 Wavelength calibration

The output flatness of the calunit will be sufficient for all wavelength calibration requirements.

5.2.2.1 Wavelength calibrating HROS

The high-resolution optical spectrograph is calibrated via a ThAr hollow cathode lamp .

Calunit configuration:

HROS configuration: orders covering from 325nm to 1000nm

Adopt calunit configuration

Switch on ThAr lamp

Insert visible light diffuser

Move science fold mirror into place

Observe the arc lamp

Switch off lamp

Replace science fold mirror

Flat fielding the same observation. The HROS field is 1'. The uniformity of the calunit output over this field (better than 1%) should always meet the HROS requirements.

Adopt calunit configuration

Switch QH lamp on

Colour balance filter

Visible diffuser

Insert science fold mirror

Take exposure

Replace science fold mirror

Switch QH lamp off

5.2.2.2 Wavelength calibrating GNIRS

Two lamps are available for wavelength calibrating the infrared spectrometer. One or both of them can be illuminated, depending on the availability of lines in the wavelength region of the observations. This will be particularly useful for high-resolution observations.

GNIRS configuration: hires grating, long camera

Calunit configuration: nir diffuser, Ar and Kr lamps, no filtering

Adopt calunit configuration (may be there already):

Switch on Ar and Kr lamps

Insert NIR diffuser

deploy science fold mirror

Integrate on the arc frame

Switch off lamp(s)

Flat fielding the same observation

CalUnit configuration: infrared source, nir diffuser, no filters

Adopt calunit configuration

Open the shutter to the infrared source

[science fold mirror already in place]

Take exposure

Replace science fold mirror

Close the shutter to the infrared source

5.2.2.3 GMOS multi-slit observations

This is based on the discussion in Section 6.1 (Multi-aperture Spectroscopy) of the GMOS OCDD Version 2.0, much of which is quoted verbatim. The details of setting up to carry out the multi-slit observations are discussed; here, the details of the GCAL configuration are included.

Daytime set-up.

<u>Focus check imaging: GMOS configuration is mask+filter+mirror</u>

The GMOS wavelength coverage is from 370nm to 1um. The visible light diffuser is always applicable. The QH lamp should be used.

GCAL configuration and set-up:

Insert the visible diffuser

Turn on the QH lamp

Insert ND filters as appropriate.

Deploy the science fold mirror

Header information to be passed to the DHS: lamp used, filter used, diffuser used.

The field uniformity with the GCAL is 10% from centre to 7’ diameter. The focus measurement will be independent of this.

Any geometric calibrations (orientation of the slit mask) can be carried out in this configuration.

<u>Focus check spectroscopy: GMOS configuration is focus mask+filter+grating</u>

Insert the visible diffuser

Turn on the QH lamp

Insert ND or colour balance filters as appropriate.

Deploy the science fold mirror

Header information to be passed to the DHS: lamp used, filter used, diffuser used.

To comply with the science requirement that the gradient in the contnuum should be less than a factor of 4 in a 100nm wavelength range, colour balance filters are required for configurations where the wavelength coverage includes the bluest end of the spectrum (370nm-450nm). The colour balance and neutral density filters are combined in one wheel located near a pupil image in the calunit.

<u>Spectroscopic flat-field GMOS configuration: slit mask, spectroscopic filter and grating</u>

GCAL configuration identical to that required for the focus test.

Starting the observing sequence

<u>Flat field calibration</u>

The need for a flat field to replace that taken during the day will depend on the flexure of the grating and the possible need to correct for CCD fringing effects, which will shift with small changes in the grating position. Assuming that a GCAL flat is required once the target has been acquired:

Insert science fold mirror to direct the projected flat into GMOS. GCAL configuration:

visible diffuser, QH lamp, [ND filter, colour balance filter]

The flat so determined will be uniform to 10% at the outer edges of the field. If the relative calibration in the different slitlets is required to be measured more accurately than this then either the correction for the vignetting function must be retrieved from the archive or a new vignetting function must be measured from sky flats on the night in question. The frequency of determining the flats will depend on the stability of the GMOS, the telescope and the GCAL.

Wavelength calibration

Once the target field has been acquired, the science fold mirror is inserted to direct the light from the arc lamp into GMOS. The GCAL configuration is as follows:

visible diffuser , Hollow cathode lamp

The strength of the arc lamps is unlikely to require use of the neutral density or colour balance filters.

Observe arc exposure

Replace science fold mirror

5.3 Calibrating observations with the Altair

The beam from the calunit is not passed through the adaptive optics system, which means that the effect of the Altair optics on the observation (vignetting, dust on mirrors) is not corrected by the flat-field. The pixel-pixel variations are corrected, but not any differences in response over larger scales. A correction must be applied which is the difference between the GCAL response and the Altair response. This is calibrated on the sky. This should be measured and checked and a model for how often this calibration should be applied should be made.

The procedure is the same as that for calibrating the shape of the GCAL output beam (Section 5.1.2).

Take the example of using NIRI with smallest pixel scale (0.02’’) to take an observation of a field with a number of sources e.g. stellar cluster. Relative photometry of the sources is required. The GCAL field is expected to be flat/uniform to 1%, sufficient for the level of photometry, but the contribution of Altair must be quantified.

The significant difference between this calibration and that described above, wherein a frame may be stored and used later, is that the Altair optics can introduce an additional motion of the pupil. Indeed the pupil may be in a different location than that from the calunit.

The GCAL stability requirement is that the pupil should not move by more than 1%. This is tighter than the Altair requirement for motion of the pupil introduced by the AO system, as detailed in the AO FPRD. The implication of a moving pupil is that objects at different points in the field will have slightly different optical paths and therefore be subject to different vignetting. The motion of the pupil will fundamentally limit the flat-fielding accuracy over large spatial scales. It would not be corrected with the GCAL even if the beam from the GCAL were passed through Altair when taking a flat field.

APPENDIX 1: SOURCES

Calunit Functional Requirements V1.6

HROS operational concepts V6.0

GMOS OCDD version 2.0 and CDR docs for instrument description

GNIRS - OCDD/FPRD

NIRI - instrument description from the PDR docs

Altair OCD Revision B

Altair FPRD Revision D

APPENDIX 2: DERIVATION OF THE CORRECTION FACTOR

The calunit vignetting function, or the correction factor, which may have to be applied to the calunit flat-field for wide-field observations requiring excellent photometry, can be derived as follows.

An observation of a star with flux fluxstar(λ) in pixel (i,j) can be described in terms of the various vignetting functions affecting the observation:

$$star(i, j) \equiv G(i, j) \times tel(i, j) \times inst(i, j) \times fluxstar(\lambda)$$

where G(i, j) is the gain of that pixel, tel(i,j) is a function describing the telescope vignetting at a given pixel and inst(i,j) is the equivalent instrument vignetting function.

The process of flat-fielding the observation is two-fold: to determine and correct the gains from individual pixels and to determine and correct for the vignetting suffered by the signal at pixel (i,j). Both steps are required if a star on pixel (i,j) is to be used to flux calibrate an object located at pixel (m,n).

The flat field measured from the calunit has the following form:

$$gcal\_flat(i, j) \equiv G(i, j) \times gcal(i, j) \times inst(i, j) \times BB(\lambda) .$$

The vignetting functions, GCAL(i,j), inst(i,j), are slowly varying and BB(λ) is either a constant (for an imaging configuration) or slowly varying (for spectroscopic observations). G(i,j) is determined by fitting a low order surface (1D or 2D) to the flat and dividing by it, leaving only the high frequency variations which are the pixel gains.

This fitted surface is a measure of the vignetting of the calunit plus instrument; to properly correct for the vignetting suffered by an observation of an astronomical source, the telescope plus instrument vignetting is required. If the calunit identically matched the telescope to the level of photometry desired, then the factor due to the difference in the flat fields would be negligible. Otherwise, the correction to make to the GCAL flat to make it the same as the sky flat is in the form of a vignetting correction.

A (possibly jittered) image of the sky, or sky-flat, gives a matrix of values for pixel i,j as follows:

$$sky\_flat(i,j) \equiv G(i,j) \times sky(i,j) \times tel(i,j) \times inst(i,j)$$

where G(i,j) has been determined above, sky(i,j) is assumed to be flat and tel(i,j) x inst(i,j) is the vignetting function required.

Therefore, an image of the sky can be used to flatten the low order variations of the field. A comparison between the sky flat and the GCAL flat will yield the correction required to be made to the GCAL flat in order to make it identical to the sky flat on large scales:

$$Vcorr(i,j) \equiv \frac{gcal(i,j) \times BB(\lambda)}{tel(i,j)}$$

The frequency with which this vignetting correction will have to be determined depends on the accuracy of photometry desired, the relative flexure of the telescope and the GCAL, and other factors such as the build up of dust on the mirrors. This frequency will have to be determined during the commissioning of the instrument and during operations.

When dividing the star by a calunit flat, the result is:

$$divstar(i,j) \equiv \frac{sky(i,j) \times tel(i,j))}{gcal(i,j) \times BB(\lambda)} \times fluxstar(\lambda)$$

assuming the sky is flat. For imaging observations, BB(λ) is a constant which depends on the filter bandpass and throughput of the GCAL and instrument

APPENDIX 3: NOTE ON CHANGING BULBS

It is expected that the lamp sources in GCAL will require to be changed on occasion. The exact frequency with which this will have to happen is not certain, and in some cases it will be seldom. The manufacturers' stated lifetime of the infrared source is three years.

The lamp housings have been designed to allow the lamps to be changed straightforwardly. This notes concerns possible changes in the output uniformity arising from changing the contrinuum sources. Purchased lamps are individual items; the filaments may have different locations with respect to the base. We have attempted to ensure that the pins are located repeatably in the base, but cannot guarantee that it follows that the filaments are in the same place.

The operation of the diffuser should remove the effects of these small misalignments. It is beyond modelling capabilities to verify that the flat-field uniformity will remain the same to within the 0.3% spec after changing a bulb.

This note is by way of a caveat: the flat-field uniformity should be re-calibrated after a source is replaced.

APPENDIX 4: INSTRUMENT CONFIGURATIONS

These are the parameters used in calculating the exposure times for the calibration frames.

Instrument	**Pixel scale**	**Pixels/slit**	**Resolving power**	**Throughput**
GMOS	0.08arcsecs	3	10,000	30%
HROS	0.13x0.2arcsecs†	3	50,000	15%
GNIRS	0.05arcsecs	2	18000	25%
NIRI imaging	0.022		100 (1% filters)	35%
NIRI spectroscopy	0.022	2	2500	~25%

Table 7: Characteristics of the Gemini Phase I instruments. Most difficult configurations for calibration, i.e. smallest pixels and highest spectral resolution.

†HROS has pixels of 0.2" in the *spectral* direction, 0.13" in the *spatial* direction.