FACILITY CALIBRATION UNIT FUNCTIONAL REQUIREMENTS (V1.1)

DOUG SIMONS
MARCH 1995

This report is intended to summarize basic functionality requirements for the facility calibration unit. The specifications outlined here are derived from material reviewed at recent IRISWG, OISWG, and GSC meetings, during September and October, 1994, as well as from individual contributions. The main difference between V1.0 and V1.1 of this document is that I have structured V1.1 on an instrument-by-instrument basis as much as possible, to help determine which instruments are driving calibration unit design specifications. The most recent GMOS calibration requirements have also been included. Requirements for the near infrared spectrograph and mid infrared imager are forthcoming, pending information from the groups responsible for these instruments.

The table on the following page summarizes performance specifications. In cases where more than one specification has been recommended, I have selected the most demanding specifications. In subsequent sections I have included commentary from various sources to help explain where the values in the summary table came from.

The establishment of the calibration unit's functionality requirements is still in an iterative state and feedback from the Project Scientists, instrument work package teams, and the calibration unit team is certainly welcome. The specifications listed are certainly going to be a challenge, given the performance predictions for the calibration unit expressed during the A&G PDR in November, 1994. For example, a principal trade in the design appears to be between the flux uniformity across the FOV and the intensity of the light in the calibration beam. Preliminary estimates are that for a uniformity of ~5% across a 7 arcmin FOV, ~20 sec exposures with a CCD will be needed. Ultimately the trade between beam uniformity and exposure time needs to be defined. Clearly GMOS is driving the calibration unit the hardest, in terms of field size and intensity uniformity at various spatial scales. At this stage it appears likely that further consideration of the use of sky flats for GMOS will have to be given.

Finally, it should be noted that GMOS requires that the calibration unit be able to pass flux for flat fielding through the AO unit, so that it can be reflected through the same optical path as AO science observations. A goal remains to pass wavelength calibration flux through the AO unit and there is no requirement that a calibration wavefront be injected into the AO unit from the calibration unit.

Instrument	Relevant Spatial Scale	Intensity Variations (%)	Flux Source	Comments
Near Infrared Imager Flat Fielding	~20”	<1	Blackbody	1-5 µm
	~50”	<1	Blackbody	
	~2’	<1	Blackbody	
GMOS Imaging Mode Flat Fielding	~1”	<0.1		0.4 - 1.1 µm
	~10”	<0.1		
	~5.5’	<1		
GMOS IF Mode Flat Fielding	~2’	<0.1		0.4 - 1.1 µm
GMOS Spectro-Mode Flat Fielding	~10”	<0.1		continuum varies <4X between any 100 nm interval from 0.4-1.1 µm and is featureless (<0.1%) over few tens of spectral res. elements
	~100”	<0.2		
	~5.5’	<2		
GMOS IF Mode λ Calibration	~2’	<2% line centroid shift due to spectral lamp non-uniformities acceptable	Fe, CD, Ne, Ar, He	0.4 - 1.1 µm
GMOS Spectro-Mode λ Calibration	~5.5’	<2% line centroid shift due to spectral lamp non-uniformities acceptable	Fe, CD, Ne, Ar, He	0.4 - 1.1 µm
HROS Flat Fielding	~3”	<0.1		0.4 - 1.1 µm
	~10”	<0.5		
	~1’	<2		
HROS λ Calibration	~1’	<2% line centroid shift due to spectral lamp non-uniformities acceptable	Fe, CD, Ne, Ar, He	0.4 - 1.1 µm
Mid Infrared Imager Flat Fielding	?	?	?	8 - 27 µm
Near Infrared Spectrograph Flat Fielding	?	?	?	1-5 µm
Near Infrared Spectrograph λ Calibration	?	?	?	1-5 µm

1-5 µm Infrared Imaging

(Provided by the Gemini IRISWG)

While many infrared imager science applications can use sky flats derived from dithered images (to achieve <5% photometric accuracy) the infrared imager will require a projection flat field system in order to achieve more precise (~1%) photometry. The basic technique employed will be a remotely switchable (on/off) lamp built into the calibration unit. Flat fields will be acquired as the difference between two frames, one made with the calibration lamp on and one made with the lamp off. This serves to isolate various thermal flux sources in the beam from a true (i.e., uniform) beam across the camera's FOV. Note that for thermal applications (λ > 3 µm) it will be possible to use neutral density filters in the camera in the event that the thermal flux along the calibration path plus the blackbody calibration source are too bright. Flat fielding requirements for near infrared cameras based upon the technique of switching on/off a calibration source are discussed in Hodapp et al., 1992, *P.A.S.P.*, **104**, 441.

Optical Imaging

(Provided by Todd Boroson and Jay Gallagher)

Additional requirements to GMOS imaging include:

- <u>Repeatability of Relative Intensities</u>: The relative intensities of any two points must be repeatable over any 12 hours, with a goal of 2 weeks, to a precision of 0.1%. This requirement is independent of telescope position and must be met in cases where the A&G unit is "unconfigured and reconfigured".

- <u>Repeatability of Absolute Intensities</u>: The absolute intensity of any point must be repeatable to 1%, with a goal of 0.1%, over 1 hour and to 5% always.

- <u>Telescope Pupil</u>: The distribution and direction of rays in the telescopes pupil must be matched by the flat field illumination.

GMOS & HROS Spectroscopy

(Provided by Bob Schommer, Steve Heathcote, with helpful comments from the CTIO scientific staff.)

Flat Field Source

Flat fields for GMOS (and HROS) must serve 3 functions:

1. Remove pixel-to-pixel sensitivity variations.
2. Remove variations in sensitivity/transmission of the system along the length of the slit or slits.
3. Remove variations in sensitivity from slit-to-slit in a multi-slit plate and low spatial frequency sensitivity variations in imaging mode.

These functions impose different requirements on the calibration system:

1. Requires a source of illumination with <0.1% variation over spatial scales of a tens to hundreds of pixels and with only slow variations on larger scales. The spectrum of the source must also be featureless (<0.1% variation) on scales of a few tens of spectral resolution elements (say 50-100 Å for R=1000), and should vary slowly on larger scales. Imaging mode adds the requirement that the source spectrum should have a similar slope across the band width of the (broad band) filter in use as the night sky (in practice incandescent lamps plus color balance filters are an adequate match except in the blue/UV). Some thinned CCD's fringe at some wavelengths (typically in the red). Correction of fringing (if present in the Gemini CCD's) requires that the illumination is flat to <0.1% over scales of several fringe spacings (probably tens to hundreds of pixels). It also requires that the source simulates the illumination of the slits by the sky with high fidelity (see later). Unless, fringe correction flats are to be taken during the night, at the position of each object, then fringe correction imposes the same kinds of constraints on stability and lack of flexure for instrument and calibration source as does radial velocity work.

2. Requires that the source has variations <0.1% (perhaps 0.5% might be a more realistic requirement) over the length of the slit - say 6-10 arcsec (or about 100 pixels) for a typical slitlet, but could be the whole field when a single long slit is used. Things must be controlled this tightly in order to permit adequate sky subtraction. The spectral properties of the source are largely irrelevant here.

3. Requires a source of illumination that is flat on large spatial scales to the limit of photometric accuracy which is desired. This is required so that flux standards observed at one place on the CCD or through one slit can be used to calibrate the whole frame. In practice, for spectroscopy (and a few imaging applications) this means variations of <2% over the entire field; for imaging applications which require accurate photometry or detection of objects much fainter than the sky, the limit might be < 0.1% or better. The spectral properties of the source are largely irrelevant here.

When these needs cannot be met by a single source of illumination it is possible, and indeed common practice, to combine different kinds of flat fields. In particular it is unlikely that an internal calibration source (or dome flat) can meet the strictest requirements for large scale spatial uniformity, although it should be satisfactory for 1) and hopefully 2). Hence, it will almost certainly be necessary to use such "projector flats" in conjunction with "sky flats".

Note that sky flats cannot be used alone for spectroscopy - the daytime, twilight and night sky are FULL of weak features and thus do not satisfy the requirements for (1) especially at high resolution. In addition, for HROS, it is unlikely that sufficient flux can be obtained with twilight or dark sky calibrations. A white spot probably won't have sufficient brightness in this case either. (Note that the resolution range of the MOS, from broad band imaging to R~10000, requires a similar large dynamic range in the flat field intensity control. This should be easy to implement, but needs to be readily and remotely available as part of the calibration system control.)

Summary of specifications:

Variations at high frequencies must be held to <0.1% while <2% variations on low spatial frequencies are probably adequate. The stricter requirement must be met over whichever is the larger of (i) the scale length of CCD sensitivity variations (including fringing if present); and (ii) the slit length for typical multislits. The spectrum of the source must also be smooth (<0.1% variations) on wavelength scales of a few hundred Angstroms.

Flats taken with this internal source will have to be supplemented by sky flats for long slit work and imaging applications which either require photometric accuracy or good sky determination/subtraction.

Spectral Lamps for Wavelength Calibration

Regarding illumination from the spectral lamps, the beam should be uniform enough over the field so that a line centroid will not change by more than 1/50 of a resolution element. Again stability of calibration at this level must be met over scales greater than the typical slitlet length in order to permit accurate sky subtraction. For radial velocity work this requirement must be met over the entire field. However, supplementary zero point calibration using day or night time sky exposures could be used if this cannot be achieved. If correction of fringing of the CCD's is an issue, the flat field illumination system may also need to meet this requirement.

GMOS IMAGING & SPECTROSCOPY

(Provided by Tim Davidge, November 10, 1994)

INTRODUCTION

In a recent document describing functional requirements for the A&G calibration unit (hereafter refered to as the CUFRD), dated October 27 1994, Doug Simons summarized general calibration requirements for optical imaging and spectroscopy. Given the complicated nature of the Gemini Multi-Object Spectrograph (GMOS), and the various roles in which it will be expected to serve (e.g. as a faint object spectrograph, science-grade imager, etc), it is important that independent calibration requirements be derived for this instrument. In what follows, I have summarized what I feel are suitable calibration requirements for each of the main tasks to be carried out by the GMOS (ie. imaging, slit spectroscopy, and integral field spectroscopy). It should be noted that this report deals exclusively with the calibration requirements for scientific observations, and does not discuss calibration requirements for ancillary equipment such as the on-instrument wave front sensor, guide probes, etc.

IMAGING

In the case of imaging, flat-field frames are required to remove (1) pixel-to-pixel sensitivity variations on the detector, (2) interference fringes, and (3) variable illumination across the field. Stringent flat-field requirements must be set for the GMOS since (1) this instrument will initially be the only science-grade optical imager on both telescopes, and (2) regardless of the availability of other science imagers, the images produced by GMOS must be of sufficient quality to permit identification of objects for slit mask construction, a task which requires science-grade (or at least near-science-grade) images. The optical imaging flat-field specifications outlined in the CUFRD call for 0.1% and 0.3% variations over spatial scales of 10 and 100 pixels, respectively. However, the latter specification may not be suitable for studies of faint, extended sources (e.g. galaxies in nearby and intermediate redshift clusters), where high-quality background subtraction is required. In this case it may prove necessary to have stability of ~0.1% over scales of ~10 - 20 arcsec. The low frequency requirements discussed in the CUFRD (i.e. 10% variations across 2000 pixels) also need to be tightened. The main reason for this is photometric accuracy - if the flat-field is not uniform, then the photometric calibration will vary across the field. For this reason, the requirement for the flat-field uniformity over the entire science field (i.e. 5.5 arcmin diameter) should be ~1%. Die-hard photometrists investigating, say, globular cluster color-magnitude diagrams, would argue for much more stringent specifications. However, if required, this sort of accuracy could be achieved using sky flats. Sky flats will likely also prove necessary to remove fringing if and when it occurs. (It may be asked at this point why not do ALL flat-fielding for imaging using sky flats? This may prove impractical for fields containing numerous extended objects or a large number of point sources, where dithering may not be effective in suppressing sky sources. Moreover, the dither amplitude sets the maximum distance over which structural information can be recovered - large scale structure can be recovered using a large dither amplitude, but at the expense of field size. For this reason it is suggested that sky flats should NOT be relied upon to correct for basic flat-field variations.)

SLIT SPECTROSCOPY

The types of calibration required for multi-object slit spectroscopy can be divided into three broad categories:

1. Mask set-up - After a slit mask has been cut and installed in the spectrograph, it is necessary to check (1) the alignment of the mask in the mask holder (e.g. is there any evidence for rotation due to, say, a loosely mounted mask? - problems of this nature could prove fatal for narrow slit observations over large field of views, as objects near the edge of the field may not be properly aligned with their slits), and (2) the location of the slits at the focal plane, so that the offset required to align the field with the slit mask can be computed. The information needed to check the mask set-up can be obtained by imaging the illuminated slit mask. The illumination requirements for this task are uniformity to within ~1% over a few arcsec. It should be noted that mask set-up requires a light source that is much fainter than that used

for flat-fielding, as the light is not dispersed. One way to accomplish this is with a neutral-density filter which, presumably, would be located in the calibration unit.

2. Flat-fielding - The CUFRD contains a lengthy discussion of calibration requirements for optical spectroscopy, and many of these are acceptable for faint-object spectroscopy with the GMOS. In particular, one specification calls for ~0.1% illumination uniformity over the length of a slit (~10 arcsec). Experience with the CFHT MOS/SIS suggests that this should be adequate, as a flat-field stability of ~0.2% appears to be required to achieve adequate sky subtraction for sources near the faint limit of the telescope. The CUFRD also specifies ~2% intensity variations over the entire field of view. While this requirement may ultimately prove adequate (but see the discussion above in the imaging section), it is important to specify uniformity requirements over intermediate spatial scales. This will prove useful when studying, say, moderately extended objects in crowded fields (e.g. the cores of nearby and intermediate redshift galaxy clusters) where, in order to fit as many objects onto each mask, or possibly because of crowding of sources, it may not be possible to design masks which sample the sky for all objects. In this case sky measurements must be taken from slits elsewhere in the field, and this requires ~0.2% uniformity over distances larger than typical crowding dimensions (~100 arcsec, say). A desireable goal would be to extend this requirement over the entire field-of-view, so that proper sky subtraction could be obtained for very long-slit observations (of nearby galaxies, say).

   Given the wide baseline wavelength coverage of the GMOS (400 - 1000 nm), there will likely be a need for multiple flat-field sources, as a lamp which provides reasonable flux in the blue will likely saturate in very short times at red and near-IR wavelengths. Moreover, conditions should also be placed on the shape of the continuum produced by the flat-field lamps. One possible goal is that the continuum strength not vary by more than a factor of 4 (and hence prevent variations in the S/N ratio in excess of 2) over any 100 nm interval between 400 and 1000 nm. One way to meet this requirement might be to use a customized color filter, which balances the spectral-energy distribution of the lamp. However, the use of such a filter runs the risk of introducing additional flat-field features, which would not be included in the science observations.

3. Wavelength calibration - Wavelength calibration must be supplied over the entire field-of-view, so the llumination from the arc lamp must be stable over the 5.5 arcmin FOV. Given the wide baseline wavelength coverage for the GMOS, the calibration unit will need to contain multiple arc sources involving Fe, Cd, Ne, Ar, and He.

INTEGRAL FIELD MODE

A critical component of the GMOS is the integral field module, which is mainly intended for spectroscopic studies of faint, extended sources. Current plans are for fibres to direct light from a lenselet array to the slit environment. As with slit spectroscopy, the faint limit which can be achieved is set by the ability to remove sky background. In the case of the integral field unit this translates into the ability to correct fibre-to-fibre sensitivity differences over the observed wavelength interval. These corrections must apply over at least the entire field-of-view of the integral field unit (~20 arcsec), as the sky background for extended sources will be measured near the edges of the FOV. However, for very extended sources it may be necessary to resort to beam-switiching to measure sky levels. In these cases it will be necessary to have uniformity of ~0.1% over scales in excess of, say, an arcmin. Therefore, the requirement for uniformity of illumination for integral field spectroscopy is ~0.1% over the central 60 arcsec.

GMOS and AO

The Mauna Kea GMOS will be used with the AO module (AOM). For the purposes of calibration, the AOM should be thought of as an extension of the instrument. Indeed, the AOM optics will introduce their own flat-field patterns, due to vignetting, slight non-uniformities in the coatings, and dust build-up on the optics. To correct for these, it is essential that light from the A&G calibration unit be capable of passing through the AOM. This requirement is less critical, but nevertheless desireable, for wavelength calibration arcs.

COMMENTS ON WHEN CALIBRATIONS SHOULD BE RECORDED

Observing time will be at a premium on the Gemini telescopes, and there will be considerable pressure to maximize the number of science observations per night. Hence, science observations should be recorded with calibration in mind. For example, if fringing is known to be a problem, then multiple images should be recorded with the telescope pointing dithered between each observation (the removal of fringes from spectroscopic data is much more difficult). For commonly used filters, it may also be possible to construct fringe frames from data recorded throughout the night, independent of the science program. Furthermore, every effort should be made to obtain calibration information during the day. This places tight requirements on the stability of the calibration unit and of the GMOS; for example, flexure must be small if a wavelength solution obtained when the telescope is parked at zenith also applies when the telescope is pointed at the science field. Moreover, as noted in the CUFRD, the flat field illumination must match the distribution and direction of rays in the telescope pupil. Experience with the CFHT MOS/SIS indicates that reliable calibration information can be obtained during daylight hours.

RECOMMENDATIONS

1) The flat-field source in the A&G calibration unit must be capable of meeting the following illumination uniformity requirements:

- 0.1% variations over scales of 60 arcsec (set by faint object spectroscopy with the integral field unit, and the need to achieve accurate sky subtraction for faint extended objects).

- 0.2% variations over scales of 100 arcsec (needed in multi-slit mode to achieve accurate sky subtraction for large extended objects, or for objects in very crowded fields).

- 1.0% variation over the entire science field (needed to maintain photometric stability)

In regards to the continuum shape produced by the flat-field source, variations in the continuum level in excess of a factor of 4 over any 100nm interval between 400 and 1000 nm should be avoided.

2) The wavelength stability of arc sources outlined in the CUFRD are acceptable for the GMOS.

3) It is critical that the calibration unit be capable of feeding light through the AOM.

ACKNOWLEDGEMENTS

Sincere thanks are extended to David Crampton, Glen Herriot, and Jeremy Allington-Smith for commenting on an earlier version of this document.