MODS Draft Calibration Protocol

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1 Overview

This document describes our draft calibration protocol for MODS, establishing the requirements for the instrument calibration system.

2 Generic Calibrations

There are basic calibration steps required by all MODS operating modes:

- Overscan subtraction of the DC bias level associated with each readout amplifier.
- Trimming the overscan sections from the data sections of the raw image.
- Zero (2-D Bias) subtraction to remove any residual bias after DC bias subtraction using the overscan columns.

These steps define the basic components of the OTZ (Overscan/Trim/Zero) model for basic CCD image calibration. OTZ processing precedes all other calibrations, and needs to be applied to both flat-field and comparison-lamp images preparatory to full image calibration.

2.1 Overscan & Trim Calibration

Each raw CCD image from MODS will include an overscan strip for removing the DC bias from each amplifier of each MODS detector.

Device coordinates of the overscan and data sections for each amplifier of each CCD will be stored in the FITS headers. We will adopt the standard header keywords used by IRAF and other image processing packages. Header keywords for MODS are described in a separate document (*MODS FITS Header Specification*).

Because this calibration step is generic to all CCD frames, a provision for mountain-top preprocessing will be considered, although in general most astronomers will wish to perform OT calibration on individual images using their own data-reduction programs.

2.2 Zero (Bias) Calibration

Subtraction of any residual 2-D detector bias left after OT calibration requires that a set of zero frames acquired for each detector. These are usually created by combining many (usually 8-10) zero or bias images. To provide a check on the detector bias stability, bias stacks should be acquired at the start and end of each night.

The MODS data-acquisition system will provide a standard set of scripts for acquiring beginning and ending zero calibration images. Post-processing software to combine the zero images will also be provided as part of a mountain calibration pipeline system.

3 Direct Imaging Mode

3.1 Flat Field Calibration

The large collecting area of the individual LBT primary mirrors makes twilight sky flats the most practical option for direct imaging. The basic procedure will be to park the telescope and allow the sky to drift while flats are being acquired. Software will use a lookup table created during commissioning and a sky-flat model (e.g., Tyson & Gal 1993, AJ, 105, 1206) built into the MODS data acquisition system to provide reasonable automation of the procedure.

For projects requiring flat fields that are color-matched to the night sky, the observer can use a dithering pattern like with IR imaging to eliminate star and galaxy images and form a "superflat" of the night-sky. Adequate results may be obtained from 4 images with good S/N in the sky dithering by ≥5″ between images. The data-taking system will provide commands for automated acquisition of dithered images, using either built-in dithering patterns with adjustable scale or user-provided dithering tables.

Methods for combining sky flats vary depending upon the science goals of the project and the habits of the investigator. No automated pre-reduction pipeline for flat fielding will be provided except OTZ processing of raw flat fields on the mountain. IRAF parameter files to facility image combination on the mountain (or at home) will also be created as part of the commissioning activities.

3.2 Direct Imaging Calibration & Reduction Protocol

The basic calibration protocol for direct imaging is as follows:

1. Zero frames for 2-D bias correction
2. Twilight Sky flats for each filter.

The reduction procedure is:

1. OT process the zero frames and combine into a master Zero frame.
2. OTZ process the twilight sky flats and combine into a normalized sky flat for each filter. Combination would likely be a median combine to eliminate star tracks on the individual images.
3. OTZF process the object images.

Dark correction is not likely to be required for the MODS science CCDs, but the data-taking system will provide the means to collect dark frames if that is felt to be necessary for some observations.

4 Spectroscopic Mode

4.1 Generic Calibrations

Spectral object and calibration images will require the same OTZ pipeline calibration data described in Section 1.

4.2 Flat-Field Calibration

There are two basic components of flat-field calibration for spectral data:

1. "White Light" spectral flats to remove pixel-to-pixel gain variations as a function of wavelength in the CCDs. The source of light can be the same as for the wavelength calibration lamps, but need not be spatially uniform on large scales.
2. An illumination correction frame composed of a spectrum of the twilight sky. The spectral information is collapsed to extract the illumination along the slit to correct the non-uniform illumination of the brighter white-light spectral flats.

White-light flats will be acquired from an illuminated screen near the instrument. Options for the placement of this screen include the back of the tertiary mirror or a screen inside the Gregorian focus volume, perhaps on the back of an instrument space cover.

The light source will likely be a high-intensity quartz lamp shining on a white screen painted with specular paint (the standard Kitt Peak formula for flat-field screens would be ideal, it has good specularity from near-UV to near-IR wavelengths). The requirements for this lamp are that it should have no spectral line or band features, and be bright to keep integration times short. Since aluminum has a strong band in the near-IR, we might consider two different lamp reflector systems: silver for red and aluminum for blue flats. Blue filters in the instrument filter wheel for the blue channel can be used to help boost the blue light signal for extremely blue flats. This is a standard procedure.

Illumination correction frames are formed from spectra of the twilight sky. The twilight sky uniformly illuminates the slit or slit mask along the spatial axis, unlike white-light flats, but the spectral axis records a reflected solar spectrum filled with absorption lines. By collapsing the twilight flats along the spectral axis and building up signal along the spatial axis, these data are used to correct for the non-uniform illumination of the slit by the white-light flats. This allows us to substantially relax the uniformity requirements for the white-light flat system, obviating the need for integrating spheres, special projection systems, or other heroic efforts. The combination of bright but ultimately non-uniform white-light flats with twilight sky spectral flats is a standard procedure: all facility spectrometers require some degree of illumination correction as part of the calibration.

4.3 Wavelength Calibration (General)

The same screen used for white-light flats can be used for spectral line comparison lamps. There is no requirement that the illumination of the slit be uniform, but there does need to be enough illumination across the focal plane to achieve similar (factor of 2 or so) signal across the field of view for both long-slit and multi-object modes.

Possible Lamps:

1. Ne (λ>600nm)
2. Ar (λ>500nm, but some blue lines)
3. HgCd (λ<500nm)
4. He (λ<600nm)

If the target screen is on the tertiary mirror, it will only be possible to take lamp images in zenith-pointing mode (the swing arms can only be changed when zenith pointing). This is less of a problem than it seems if (a) we have a stable grating tilt system coupled with a flexure compensation system and (b) the object integrations are deep enough to also measure enough night-sky lines for correction of the wavelength zero point. In general, the bright comparison lamp frames are used to measure the linear and high-order terms of the wavelength solution, while flexure introduces a zero-point shift without changing the linear or high-order wavelength coefficients. Use of night-sky lines to flexure-correct a wavelength calibration is a standard technique.

If very precise wavelength calibration associated with an object is required (e.g., a radial velocity program studying bright stars were one cannot expect night-sky emission of sufficient brightness in short exposures to provide a precise wavelength zero-point correction), a solution might be to provide a retractable lamp system, for example on the back of a flip-mirror for the secondary alignment system located in front of the slit.

If the illumination screen is located on an instrument-space cover associated with the straight-through Gregorian focus station, that cover should be deployable at arbitrary telescope pointing positions if it is to be useful for on-the-spot calibration.

4.4 Long-Slit Mode

The basic calibration protocol for long-slit spectra is as follows:

3. Zero frames for 2-D bias correction
4. White-light flats at the spectral setting to be used for science targets
5. Twilight Sky spectral flats to provide the slit illumination correction at the spectral setting to be used with the science targets
6. Calibration lamp spectra as required for the wavelength region of interest.

The reduction procedure is:

4. OT process the zero frames and combine into a master Zero frame.
5. OTZ process the white-light flats and combine into a normalized white-light flat.
6. OTZ process the twilight sky spectral flats and combine in a raw twilight flat.
7. Divide the grand twilight flat by the normalized white-light flat, and then sum over wavelengths to get a 1-D cut giving the slit illumination pattern. This may be done in wavelength segments if there is any wavelength-dependence to the illumination (this is an option, for example, in IRAF, best practices will be determined during MODS commissioning).
8. Apply the slit illumination correction image to the normalized white-light flat. This creates the normalized, corrected flat field to be used with all subsequent object and calibration-star spectra.
9. OTZ process the calibration lamp spectra. Flat fielding and slit correction rarely accomplish gains (the line search/measurement algorithms use logarithmic spectra extracted following standard star spectral tracks).

After this processing, object and standard star spectra are OTZF processed using the normalized, corrected flat field. All subsequent reductions to 1-D or 2-D wavelength and flux-calibrated spectra proceed following standard practices.

4.5 Multi-Object Mode

The basic protocol for what calibrations to take in MOS mode is the same as in long-slit mode. The reductions are the same as long-slit mode, except that you now have N slits scattered about the spectral image instead of one that require separate treatment. A second difference is how the twilight spectral flats are used. The twilight sky spectral flats are used in two ways in MOS reductions:

1. Provides the illumination correction function along each microslit, like in long-slit mode.

2. The twilight sky spectrum is extracted from each microslit and then compared within a common wavelength region to compute a “gray shift” for each microslit that is used to scale observations of standard stars acquired in only one or so of the microslits.

Each MOS mask used on a given night will require separate flat-field, twilight, and wavelength calibrations.

5 Calibration System Requirements

The basic requirements of the MODS calibration system are:

- A screen above the slit that may be illuminated with white-light and spectral-line calibration lamps. This screen may be located on the back of the tertiary mirror or on the inside of an instrument-space cover. Both options have consequences for how afternoon and on-the-spot calibration may (or may not) be done with MODS.
- A calibration lamp system including lamp power and projection optics is needed as part of the MODS package, though it may be an “outboard” unit not specifically tied to the spectrometer possible depending on where the calibration screen is located. This system will be operated using the MODS instrument control software.
- Calibration lamps should be bright enough to permit acquisition of the necessary calibration data in a few minutes per exposure. The illumination, however, does not require a high degree of uniformity on large scales, as that can be calibrated adequately using twilight sky spectra.
- Choice of spectral-line calibration lamps depends on what is available on the market that will provide adequate numbers of lines across the spectral range of MODS (340-1000nm).
- The MODS project will provide calibration acquisition scripts and document calibration procedures. Image headers will provide the necessary data to permit creation of data reduction pipelines.