MODS AGW Stage

Use Cases

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Prepared by:	R.W. Pogge, The Ohio State University

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Contents

1 Introduction

1.1 Scope

This document develops basic use cases for the MODS Acquisition/Guide/Wavefront Camera Stage (henceforth the "AGW Stage"). The AGW Stage is an X,Y motion stage that carries the off-axis Acquisition and Wavefront-Sensor cameras across the MODS focal plane, including optics and a filter wheel for the Acquisition and Guiding camera unit. This stage and its functions need to be controlled by the LBTO Guider Control System (GCS), as well as auxiliary control by the MODS instrument control system.

The purpose of these use cases is to inform the development of software interfaces for MODS and the GCS.

1.2 Reference Documents

1. *Telescope Specifications for the LBT*, UA-98-01, 002s004g, 1998 July 6
2. *MODS: A Multi-Object Double Spectrograph for the LBT*, Preliminary Design Review Document, 2001 June 11.
3. *ICIMACS Messaging Protocol Version 2 (IMPv2),* OSU-MODS-2003-007, 2004 April 21

1.3 List of Abbreviations and Acronyms

AG	Acquisition and Guiding
AGW	Acquisition/Guide/Wavefront unit
API	Application Programming Interface
ASCII	American Standard Code for Information Interchange
FOV	Field of View
GCS	Guider Control System (LBTO subsystem)
ICS	Instrument Control System (MODS subsystem)
IMPv2	ICIMACS Messaging Protocol version 2.0 [OSU data system]
LBT	Large Binocular Telescope
LBTPO	Large Binocular Telescope Project Office
MODS	Multi-Object Double Spectrograph
OSU	The Ohio State University
PA	Position Angle
TBD	To-Be-Determined/Defined
TCS	Telescope Control System (LBTO subsystem)
UDP	User Datagram Protocol (connectionless protocol layered on IP)
UI	User Interface
WFS	Wavefront Sensor [Camera]

2 MODS AGW Stage Functional Overview

2.1 Physical Layout and Mechanical Design

The MODS AGW Stage is located in the focal-plane section of the MODS spectrograph, above the slit plane, as shown in Figure 1 below. It provides a carrier for two LBTO-provided CCD cameras:

- Off-axis Wavefront Sensing (WFS) Camera with integrated microlens (GRIN) array.
- Off-axis Acquisition and Guiding (AG) Camera.

Both cameras are Steward Observatory systems using E2V frame-transfer CCDs and communicating with the LBTO GCS/TCS systems via the Steward-provided AzCam systems via fiber optics connectors in the f/15 Gregorian focal plane of the LBT. The MODS spectrograph itself does not do anything with the video signals from either of the AG or WFS cameras.

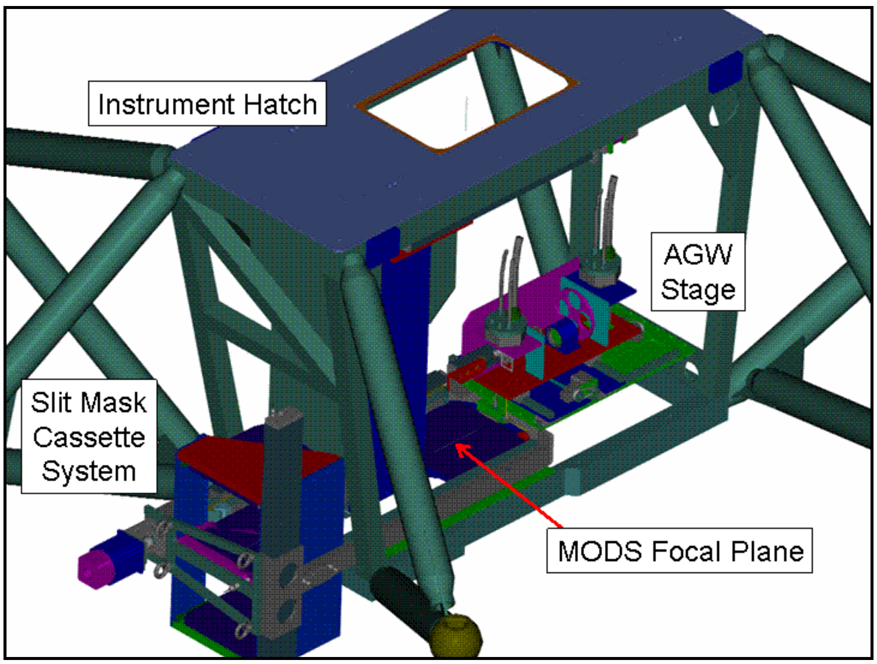

Figure 1: CAD drawing of the MODS AGW stage in the focal plane unit of the MODS spectrograph. Also shown are the instrument top hatch (aka "dark slide"), slit-mask cassette mechanism, and calibration tower that make up the MOD focal-plane mechanism suite. Other elements (cameras and grating turrets) also mounted on the top structural frame have been omitted for clarity.

The AGW stage is comprised of 4 mechanisms:

- X-axis motion with 180mm of travel perpendicular to the spectrograph slit axis.
- Y-axis motion with 200mm of travel parallel to the spectrograph slit
- 25mm focus motion for the camera optics, with a step resolution of 10µm.
- 4-position filter wheel in front of the AG camera. Present planned occupations are clear, red, green, and blue filters, specifications TBD.

A detail of the AGW Stage by itself is shown in Figure 2.

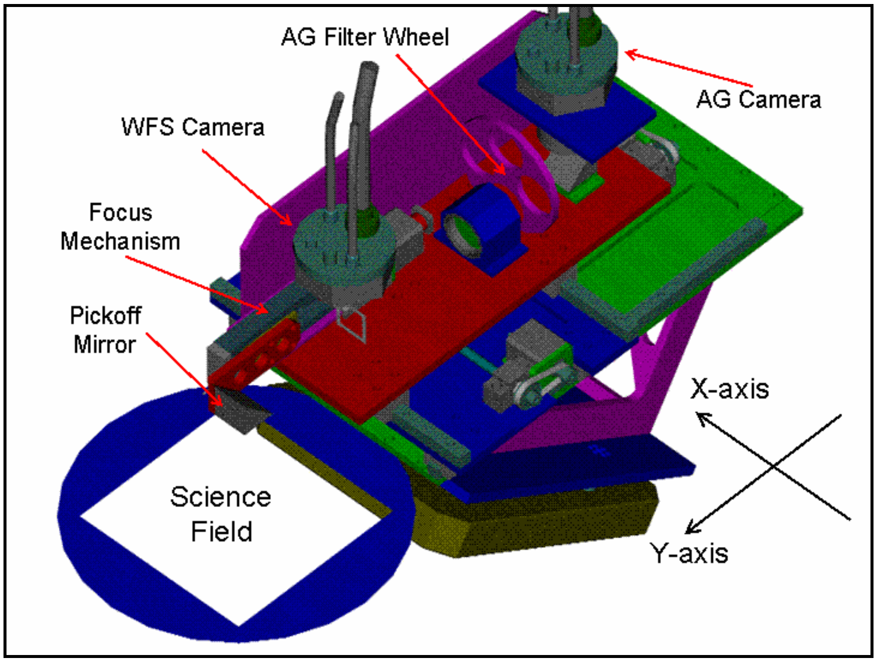

Figure 2: Detail View of the MODS AGW Stage, showing all components (w/o support structures for clarity, we don't intend to levitate the cameras in space...). The structure below the AGW Stage is the red channel folding-flat mirror, which shares the same underlying support structure as the AGW Stage. The X- and Y-axes of the stage are shown with arrows.

Each of the 4 motions (Set X_g, Set Y_g, Set Focus, Filter Select) are controlled by stepper motors and microstep controller modules under software control. The main control "agent" application that operates the AGW Stage is part of the MODS Instrument Control System (ICS). To provide the LBT GCS/TCS with access to AGW Stage functions, a remote interface to the ICS modules responsible for AGW control are provided.

The focus mechanism is a linear lead screw mechanism with 25mm of travel, and a focus resolution of 10μm. The range of motion compensates for the 19.5mm of focal surface "sag" between the center of the science field and the extreme edge of the off-axis patrol field.

The filter wheel has 4 fixed positions populated by an open (unfiltered) position, and 3 filters TBD, likely red, blue, and green broad bandpasses to allow for guiding at the same rough center wavelength as the spectrum being taken to remove problems with differential refraction at different wavelengths.

2.2 MODS AGW Stage Patrol Field

The MODS AGW Stage patrol field is shown in Figure 3. The pickoff mirror patrol field covers 180×200mm region covering half of the science field (3.5×6-arcminutes of the full 6×6-arcminute science field) and a roughly 2.5×6-arcmin offset guider field in which the probe does not encroach upon the science field. The MODS patrol field is restricted on 3 sides by the slit mask cassette mechanism (left side in Figure 3), and the red and blue grating turrets (top and bottom sectors in Figure 3).

The AG camera has a roughly 50x50-arcsec field of view centered on the pickoff mirror. The pickoff mirror is 40×40mm in projected size, and is located 150mm above the f/15 Gregorian focal surface, which is defined by the slit-mask plane of the MODS science field. The off-axis WFS camera is fed by a 5×5mm beamsplitter located at the top of the AG field of view that picks off a roughly 8×8-arcsec field of view (roughly half the light picked off within this square field is directed to the WFS camera, the other half is passed through to the AG camera). The re-imaging optics of the AGW stage are designed make the AG and WFS cameras confocal, requiring only a single focus motion to compensate for the curved f/15 Gregorian focal surface.

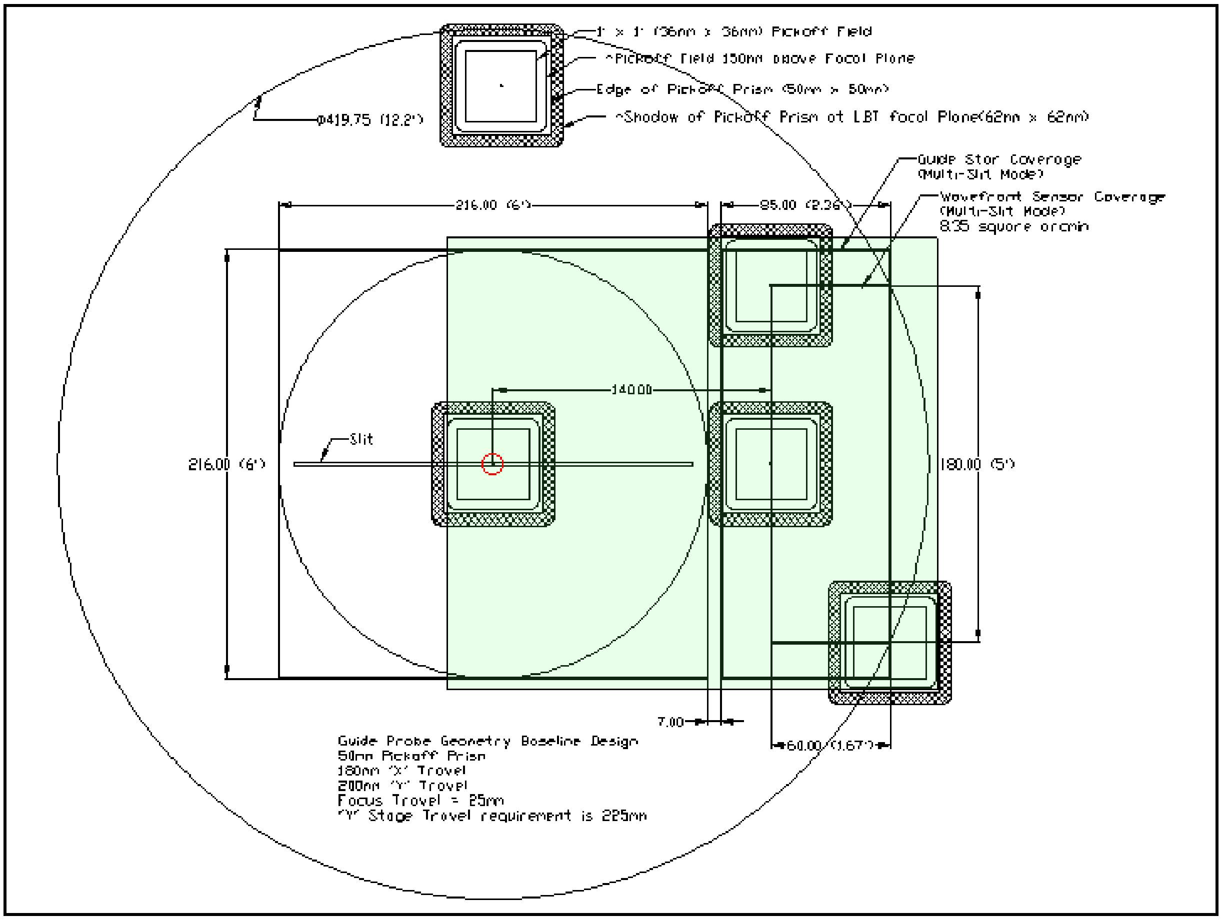

Figure 3: Schematic of the MODS AGW Patrol Field, shown as the green transparent region. Within this region the AG camera has an unvignetted view of the sky. The red circle marks the center of the MODS science field. In this diagram, the AGW stage Y-axis is horizontal, and the X-axis is vertical (instrument rotated 90° CW from its nominal PA=0° orientation). The detail of the pickoff mirror at the top labels its salient features.

Patrol field restrictions depend on the MODS mode being used. Remote applications controlling the MODS AGW Stage should have a MODS "Mode" selection function to allow the operator to select the appropriate mode (e.g., from a pull-down menu of fixed choices). There are three MODS modes of relevance: Imaging, Long-Slit Spectroscopy, and Multi-Object Spectroscopy.

Imaging Mode:

The guide probe must be restricted to the off-axis guiding field (Figure 3, 2.4×5-arcminute field to the right in the diagram) to prevent the pickoff mirror from occulting the science field.

Long-Slit Spectroscopy:

When a long slit is used, a pair of additional patrol regions open up on either side of the long slit (see Figure 3). The probe must avoid positions that occult the slit, but may extend into the nominal science field otherwise for guide or wavefront sensing stars.

Multi-Object Spectroscopy:

In multi-object spectroscopy, in principle the restrictions are identical to those for Imaging Mode, insofar as the pickoff mirror must not occult any of the microslits on the slit mask. However, if a field does not have suitable off-axis guide/wavefront stars, an observer may design a mask that leaves part of the science field accessible to the probe (see Figure 3) that is free of microslits. Calling applications that have a "Multi-Object Mode" should provide for a manual override of the probe position restrictions to allow such cases.

A fourth mode, "ALL" means to ignore any restrictions and access the entire MODS field.

As currently conceived, a full "Phase 2" MODS Instrument Configuration File (.icf file) will often be used to configure the instrument for observations. These files include commands for selecting the AG/WFS pickoff mirror location, using star pre-selected by the observer who prepared the file. In such cases, telescope operator intervention via a GCS console will only be required to operate the GCS functions, but not necessarily to operate the MODS AGW Stage.

2.3 MODS AGW Stage Interface

The MODS AGW Stage software provides the following baseline functions to MODS and LBTO host programs like the GCS:

- Move the pickoff mirror to a given absolute (X_g,Y_g) position in units of millimeters from a hardware zero ("home") position with a precision of 0.01 mm (10μm). In addition, a set of "preset" position commands will be provided to send the pickoff mirror to the science field center ("CENTER"), the hardware zero position ("HOME"), and a safe parked position ("STOW" or "PARK", exact syntax TBD).
- Offset the pickoff mirror by (Δx,Δy) millimeters from the current position. The offsets are given in units of millimeters to a precision of 0.01 mm (10μm).
- Focus the AG/WFS camera re-imaging optics. Focus motions may be requested as either relative or absolute motions in units of microns. An autofocus mode will be available that will use a lookup table to adjust focus to follow the curved focal surface of the f/15 Gregorian focus.
- Select an AG camera filter to put into the AG camera beam. Filters are selected by number (1 thru 4), and calling applications are expected to handle logical bindings between filter position numbers and filter names (e.g., 1=clear, 2=red, etc.).

- Report current AGW Stage status: absolute position, focus, filter selection, and motion status (idle, moving)

The remote command interface for the MODS AGW Stage is based on the IMPv2 messaging protocol used in OSU instruments and using internet sockets for the transport. Specifically, messages are sent in a simple ASCII text protocol via UDP socket calls. The implementation of the socket interface follows POSIX standards, so portability should not be an issue. IMPv2 . An API will be provided to make this interface transparent to external (to MODS) applications like the GCS or TCS. The API will be written in C, and require nothing other than standard Unix system libraries (e.g., sockets, math, etc.). Details of the interface will be described in a separate document.

Remote applications commanding moves of the AGW stage are responsible for converted sky coordinates into (x,y) step coordinates in the AGW stage reference frame, using conversion coefficients to be measured by the MODS Team. The coordinate system of the AGW Stage is rectilinear (x,y) position measured relative to the zero ("home") reference position which is fixed in hardware as (0,0).

2.4 AG and WFS Cameras

No camera operation functions are provided by the MODS AGW Stage Interface, since control of the AG and WFS cameras are fully vested in the relevant LBTO systems. Except for an AzCam system and prototype AG camera provided to the MODS project by Steward Observatory for development and laboratory acceptance testing purposes, we will provide no interfaces to the cameras proper. The use cases below assume that AG and WFS cameras are controlled by LBTO software.

3 MODS AGW Stage Use Cases

3.1 Target Acquisition (all modes)

The most basic use of the MODS AGW is initial target acquisition in imaging or spectroscopic modes. The basic use scenario is as follows:

1. Slew LBT to the nominal target coordinates.
2. Command the MODS AGW Stage to move the pickoff mirror to the CENTER position (known absolute position of the science field center). The AG camera FOV will be centered on the MODS science field FOV.
    a. In the MODS AGW system, the probe will be moved in (x,y) to the fixed CENTER position, and the probe focus auto-adjusted via the relative focus look-up table to the nominal relative focus shift for the CENTER. The interface will report back to the calling application when the probe motion is completed.
3. [Optional] Select a filter for the AG camera.
4. Begin acquisition of AG images for viewing, but *do not initiate guiding*.
5. The observer can now verify the target acquisition on the AG Camera image display, and command small offsets to the TCS to refine the pointing. In the case of a long-slit

observation, a good feature for the AG Camera image display is the ability to overlay a target slit or cross-hair marking the center of the AG camera field, and allow the observer to compute the required TCS pointing offset to center the target in the target slit or cross-hair position.

6. Once target position is verified, command the MODS AGW Stage to retract the pickoff mirror. Options for retracting the pickoff mirror include:
    a. For unguided short observations, stow the probe and disable the AG camera for the time being.
    b. Move to a pre-selected off-axis guide star and setup for autoguiding prior to start of science observations.
    c. Move to a pre-selected off-axis guide star and acquire star images in the AG camera, but do not setup for autoguiding yet as the observer may be taking slit acquisition images with the MODS science camera preparatory to taking long-slit or multi-slit spectra.

Once the target acquisition steps are done, the observer will then proceed with the rest of their observing setup.

3.2 Offset Guide Star Acquisition and Autoguiding

To guide the LBT using an off-axis guide star, the following steps must be taken:

1. Select the MODS Mode (Imaging, Long-Slit, or Multi-Slit) to determine the patrol field restrictions.
2. Select a guide star subject to the patrol field restrictions. This can be done by:
    a. Algorithm to select a candidate star from a catalog subject to magnitude criteria (e.g., "find me a star brighter than 20th magnitude in the field"). The controlling application will need to be able to query the current LBT pointing coordinates and instrument rotator PA, and the patrol field boundaries from the selected mode.
    b. Raster through the patrol field and pick a star at random (the old-fashioned way). The controlling application will only need to know the patrol field boundaries (not TCS info required).
    c. Star pre-selected by the observer during Phase 2 MODS observing preparation. The probe configuration would be done by the MODS data-acquisition system using the contents of an Instrument Configuration File.
3. Center the guide star in the AG Field of view.
4. Setup for autoguiding.
5. Engage the autoguider.

Observer now is ready to commence observing. When the observer is done, disengage the autoguider.

3.3 Off-Axis Wavefront Sensor Star Acquisition

Here we are acquiring a star in the off-axis WFS camera for measuring the wavefront to tweak up the LBT preparatory to observing.

1. Select the MODS Mode (Imaging, Long-Slit, or Multi-Slit) to determine the patrol field restrictions as required. If the MODS mode is irrelevant, selecting ALL will permit use of the entire patrol field.
2. Select a wavefront star subject to the patrol field restrictions. This can be done by catalog search, raster, or pre-selection as for guide star selection in §3.2.
3. Center the guide star in the AG Field of view and verify the target.
4. Instruct the MODS AGW Stage to offset the probe so that the star is placed into the WFS pickoff beam splitter.
5. Verify centering of the WFS star in the WFS camera and on the AG camera field (an overlay cursor box on the display to mark the location of the pickoff prism would be a nice guide).

The operator is now ready to engage the WFS system for measuring the wavefront and related operations.

3.4 Combined guiding and wavefront monitoring during integration.

During long integration sequences, it may be necessary to continuously monitor the wavefront with the off-axis WFS camera using a bright star in the field to keep the LBT image quality adjusted (primarily keeping it in focus), and using a star in the rest of the AG camera field to keep both the science target(s) centered in the slit(s) and the WFS star centered in the off-axis WFS camera.

1. Select the MODS Mode (Imaging, Long-Slit, or Multi-Slit) to determine the patrol field restrictions as required.
2. Select a wavefront star subject to the patrol field restrictions. This can be done by either of the catalog search, raster, or pre-selection as for guide star selection in §3.2.
3. Center the guide star in the AG Field of view and verify the target.
4. Instruct the MODS AGW Stage to offset the probe so that the star is placed into the WFS pickoff beam splitter.
5. Verify centering of the WFS star in the WFS camera and on the AG camera field.
6. From the AG field, select a guide star. It should be possible (in principle) to use the same WFS star, but other suitable stars may be visible on the field.
7. Setup for autoguiding and engage the autoguider once the operator and observer have verified that the science target(s) are centered in the slit(s) and the WFS star is centered in the off-axis WFS camera. This requires close interaction between observer and operator.
8. Start taking science exposures.
9. When done, disengage the autoguider and WFS.

This use case proceeds pretty much as the one described for WFS star acquisition (§3.3), but includes additional steps at the end for guide star acquisition by selecting a suitable star from the AG field shared by the WFS star (the WFS star must, however, be kept centered in the pickoff beam splitter sweet spot, so one cannot hunt around for guide stars by roaming with the probe as we did in §3.2).

3.5 Nod a target along the MODS Slit

In this mode, the observer will take a sequence of spectra with the target offset back and forth between two fixed positions along the slit, a process known generically as "nodding". It is used primarily when observing very faint targets to achieve superior sky subtraction. Target setup and acquisition is as described before, with the following differences in the observation sequence:

1. Setup the autoguider, and engage guiding.
2. Acquire the first integration in the sequence
3. MODS data taking system commands the GCS to disengage the autoguider.
4. MODS data-taking system commands the TCS to offset the telescope by a given "nod offset" in arcseconds along the slit.
5. The MODS data-taking system instructs the AGW stage to offset the pickoff mirror to follow the guide star to its new position.
6. The MODS data-taking system instructs the GCS to resume guiding again.
7. Acquire the second integration in the sequence
8. Reverse steps 3-6 to return to the original position if doing a 2-point nod.

A variation on this theme is Nod-and-Shuffle, where nodding of the telescope is combined with shuffling charge on the CCD. In general, this will require a 3-point nod pattern, but the same basic commands to the GCS (stop/resume guiding) are required. It is transparent to the GCS.

To enable nodding, the GCS will need a facility for the MODS data-taking system to remotely command the GCS to stop and resume guiding. The meanings of these functions are as follows:

> **STOP**: means stop autoguiding measurements and pointing corrections and wait for further instructions.
>
> **RESUME**: means resume guiding on the star using the *same* guide box as before. This may require the GCS to offset the telescope slightly if the star has drifted from the guide box during the idle period since the last STOP command. The goal is to recover the exact same guiding configuration as before.

In either case, the remote commands to the GCS must send an acknowledgment of success or failure back to the requesting remote host (e.g., the MODS data-taking system) after the operation as succeeded or failed. These operations will be requested by an automated observing procedure, not a person, so it must be told it went OK before proceeding to the next step (i.e., a send/expect protocol is used to ensure process synchronization).

3.6 Chopping between Target and Sky

This is a more extreme version of Nodding in which the object is moved completely off the slit and a blank sky spectrum is acquired.

1. Acquire the target and center in the slit.
2. Setup the autoguider, and engage guiding.
3. Acquire the first target integration.
4. MODS data taking system commands the GCS to disengage the autoguider.
5. MODS data-taking system commands the TCS to offset the telescope by a given "chopping offset" in arcminutes away from the target.
6. Acquire the first sky spectrum, *unguided* (GCS remains idle)
7. MODS data-taking system commands the TCS to offset the telescope back to the target.
8. MODS data-taking system commands the GCS to resume guiding. It does this by moving the guide star back into the center of its previous guide box, which will ensure that the target goes back to the same location on the slit.
9. Acquire the second target integration.
10. Repeat steps 4-9 to repeat the sky/target sequence.

The difference with Nodding is that the AGW Stage pickoff mirror remains fixed during the chopping operation. Sky spectra are not guided (no target to keep in the slit).

To summarize:

> **Nodding** is a sequence of *guided* exposures of a target that has been offset by a small amount to different locations along the slit. The guide probe is instructed to follow the guide star.
>
> **Chopping** is alternating between *guided* exposures of a target at a fixed position on the slit and *unguided* sky spectra taken some distance away with the target off the slit. The guide probe is kept fixed at the "on-target" position.

3.7 Calibration Observations

When using the MODS Calibration Lamp system (flat field continuum and spectral lamps), the AGW stage must be stowed out of the field to prevent interference.

1. Query the AGW Stage for its current position.
2. Retract the AGW stage by sending it to a safe "retracted" position out of the calibration system beam.
3. Take calibration data
4. Using the data from step 1, restore the previous AGW stage position if necessary.

The calibration "macros" in the MODS data-taking system will be designed to automatically retract the stage when calibrations are requested, if the stage is in the "forbidden" region.

3.8 Guiding at a non-Sidereal Rate

If a solar system target is being observed with MODS, it will likely be moving across the sky at a non-sidereal rate. The target must be held stationary in the slit, but any guide stars may be moving across the field of view of the off-axis guide camera if the AGW pickoff mirror is held fixed relative to the MODS slit.

The usual practice when faced with a moving guide star because of non-sidereal tracking of a target is to move the guide probe in reflex to compensate for the motion. Sometimes called "reverse-drift guiding", the AGW stage would be instructed to move continuously along some motion vector that follows the guide star across the MODS field, thus keeping it fixed in the guide camera field of view, modulo the tracking drifts that the autoguider must take out.

The MODS AGW Stage control system has the capability to introduce continuous drift rates for the pickoff mirror probe. These would be user supplied; persons who wish to observe moving targets must compute ephemeredes in advance of their run as a matter of course in order to have the non-sidereal rate corrections to provide to the TCS. The reverse tracking rates can be entered either via the MODS data-taking system or via the GCS console as required. The observing procedure might be as follows:

1. Coarse acquire the target using the guide probe fixed at the MODS science field center (no drift rates applied). Enter the non-sidereal rate corrections into the TCS, and then verify that the target is essentially stationary at the field center (i.e., that to first order the non-sidereal rates are able to keep the target centered well enough open-loop to proceed with setting up for slit acquisition and fine-lock).
2. Follow the usual target acquisition procedures as for fixed targets, verify the target is in the slit.
3. Move the AGW stage pickoff probe to acquire a guide star.
4. Enter the reverse tracking rates for the AGW stage and engage drift mode.
5. Center up the guide star as required, and setup the autoguider.
6. Verify the target centering one last time in the slit, lock in fine-guiding.
7. Begin observations.
8. After target is done, release fine guiding lock, and disable the AGW stage reverse tracking.
9. Return the TCS to sidereal tracking rates.

Remembering to remove both reverse-tracking and TCS non-sidereal rates immediately after finishing the integration is required to ensure that such rates are not accidentally left in for the next target. It might be a good idea to have the GCS (and TCS) pop-up a reminder if a new target acquisition is begun while non-zero drift rates are still enabled.