KOSMOS System Design Note 5

Title: **KOSMOS Flexure Performance and Requirements**
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Introduction

This document serves three purposes:

- Documents flexure of the existing RC spectrograph on the Mayall telescope, including both internal flexure (slit to detector) and guider-to-slit flexure.
- Documents slit to detector flexure achieved with OSMOS
- Establishes requirements or goals for flexure for KOSMOS and compares these with expected performance

RC Spectrograph Performance

The RC spectrograph mounts directly on the Mayall telescope rotator guider. KOSMOS will mount by means of an adapter that is approximately 3 inches thick. Since this adapter can be made very rigid, flexure between the front of the instrument, where the slit is located, and the guider should be similar for RCSp and KOSMOS. The mounting arrangements for the Blanco telescope at CTIO would be nearly identical (possibly some difference in the adapter thickness) so COSMOS and KOSMOS performance should be the same.

Glaspey and Elias did a visual inspection of the guider and mounting arrangements in February 2010. In addition, an attempt was made to measure flexure of the guide probes relative to the guider housing with mechanical indicators. These measurements showed that the indicators themselves had enough flexure to complicate interpretation, though the results indicated that guider flexure was probably quite small.

Measurements were made using RCSp on the night of March 2/3, 2010. The measurements were made using a square aperture formed by the smallest decker[1] and a wide slit; the dimensions were approximately 15 x 15 arcsec (see Fig. 1). The grating was set to zero order, the telescope was positioned approximately 3h E at 25 degrees dec, and an appropriate SAO star was centered in the aperture. The guider was used to acquire a reasonable guide star.

[1] Dekker for the British.

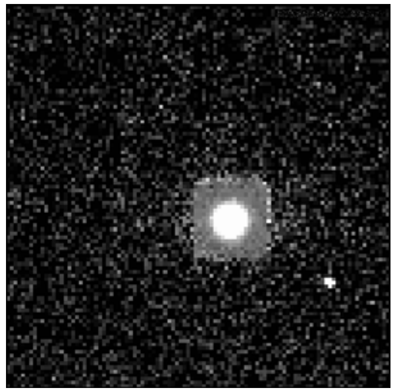

Figure 1 – Image of star in RCSp aperture. Stretch shows background observed through aperture. The vertical axis is right ascension, the horizontal axis is declination. The pixel scale is 0.69 arcsec/pixel.

The telescope was then allowed to track while guiding and observations of the star on the spectrograph detector were made every 10-20 minutes for several hours, until the telescope was over 3h west. Both the spectrograph and the guider used a red cut-on filter to minimize the effects of differential refraction.

The results are summarized below (only a subset of the images were fully reduced). The top pair of plots shows the motion of the star on the detector, the middle pair shows the motion of the aperture on the detector, and the bottom pair is the difference, which represents the motion of the star relative to the aperture. The motions in Y (right ascension) are larger than in X (declination), which is not surprising given the telescope motion.

Guiding Accuracy

The motion of the star relative to the aperture is about 0.1 pixel/hour, equal to 0.07 arcsec/hour. This suggests that with a 1 arcsec slit observations with KOSMOS could go for up to 2 hours without a need to re-center, especially if the slit was oriented E-W.

Spectrograph Flexure

The spectrograph internal flexure (middle plots), that is, motion of the slit on the detector, is about 0.2 pixel/hour, again mostly in the E-W direction, which in this case is perpendicular to the dispersion. Flexure in the dispersion direction for this configuration was very small.

This measurement is for relatively coarse pixels. If the pixel scale were similar to that of KOSMOS (physically smaller pixels and a slightly slower camera), the same motion would be ~0.5 pixel/hour along the slit.

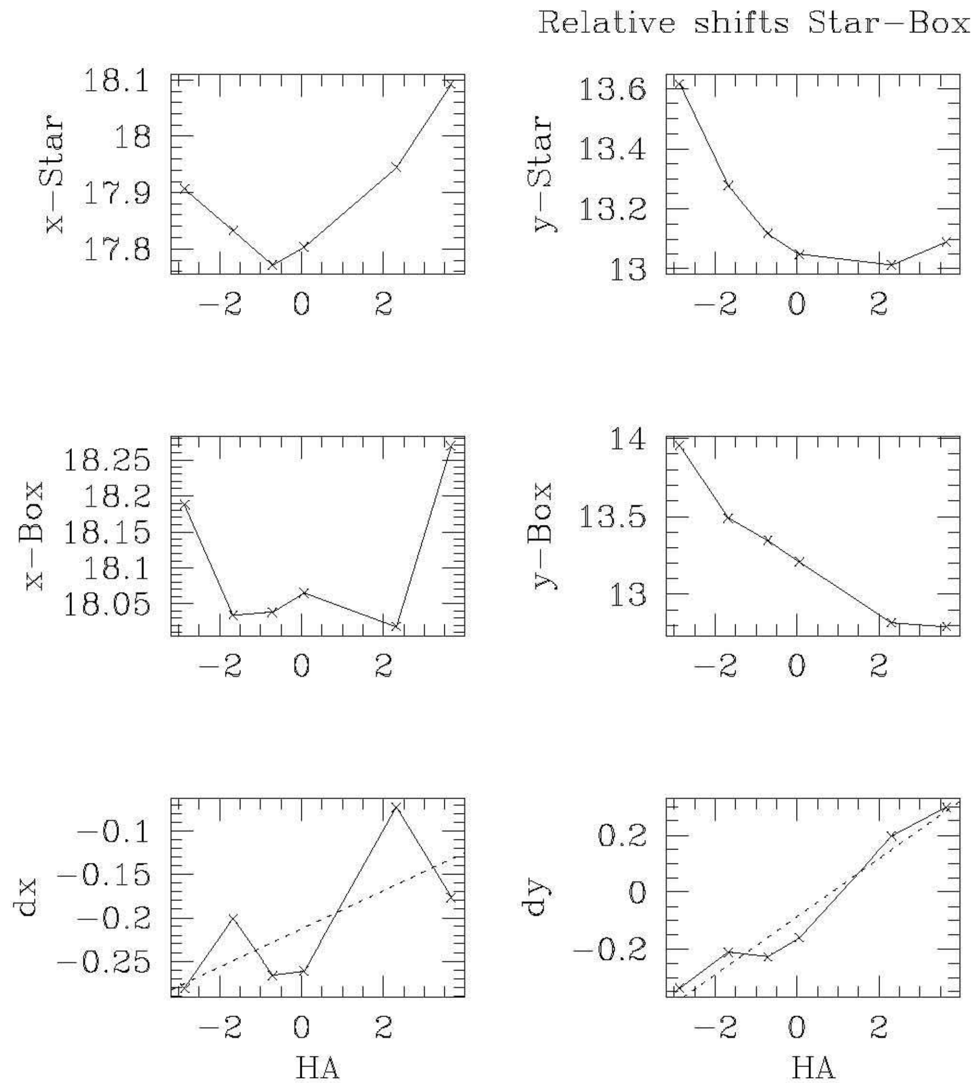

Figure 2 – RC Spectrograph flexure. Motion of star on detector (top); slit on detector (middle) and star on slit (difference, bottom). The pixel scale is 0.69 arcsec/pixel.

OSMOS Performance

Measurements of OSMOS performance were made during its commissioning run in April 2010 on the MDM Hiltner 2.4-m telescope.

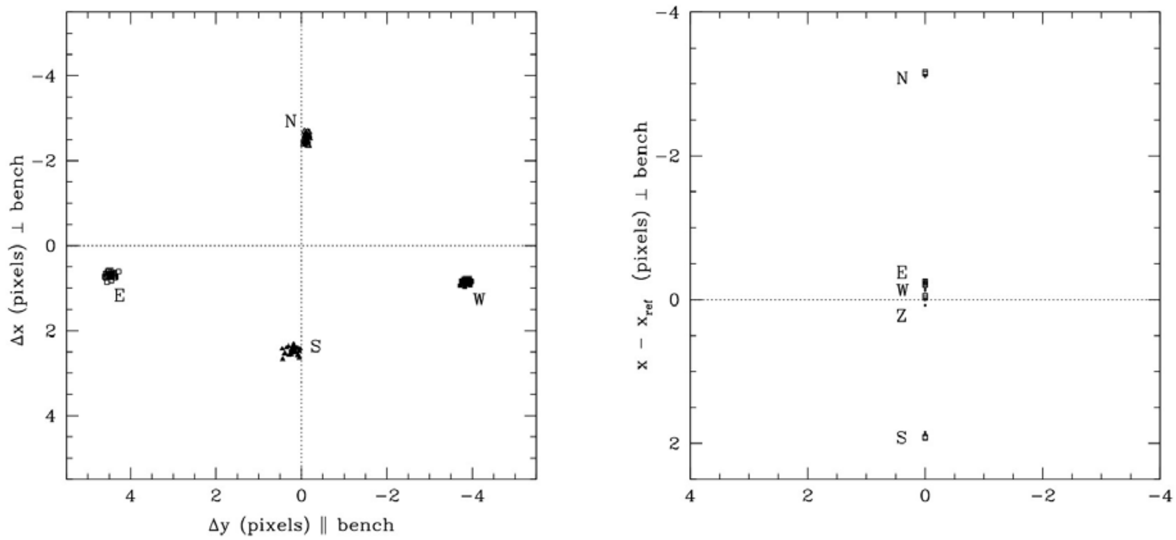

Figure 3 – OSMOS flexure measurements. The left-hand panel shows flexure in imaging mode 60 degrees N and S of zenith and 5h E and W of zenith. The right-hand panel shows motions in the dispersion direction (Y) for the same positions in spectroscopic mode (except 4h E and W). The OSMOS pixel scale is 0.3 arcsec/pixel and the slit is oriented parallel to the bench (E-W in this case).

If the flexure is assumed to be linear with hour angle, then the flexure is approximately 0.8 pixel/hour along the slit while tracking and substantially less (~0.1 pixel/hour) in the dispersion direction. Note that for OSMOS (or KOSMOS) the slit orientation relative to the bench is *fixed*, while the instrument as a whole can be rotated. The preferred slit orientation is presumably as commissioned, with the slit parallel to the bench, since flexure perpendicular to the slit is thereby minimized. For example, if the instrument was configured this way but rotated so the slit ran N-S, flexure in the dispersion direction would be ~0.5 pixel/hour.

KOSMOS will have a somewhat faster camera (~f2/.4 vs. f/4), but should otherwise be very similar. The possibility of using pre-loaded focus stages has been discussed, which might reduce flexure. If the dominant source of flexure is the two focus stages, the observed flexure might be slightly greater, because the faster camera will de-magnify the collimator flexure more. This is not a large effect, however (30%?).

Flexure Requirements

Is it possible to derive reasonable internal flexure requirements (slit to detector) from basic considerations? One should consider the possible impacts:

- Degraded resolution. If the motion of the slit image on the detector is significant for long exposures, resolution in the spectral direction or along the slit is degraded. If the degradation occurs within a single exposure, there is no means of recovery; if it occurs during a series of exposures these can in principle be shifted before they are co-added. Such a shift procedure is an added data reduction step, but not particularly difficult or complex unless objects are very faint. Maximum single exposure lengths are an hour or less, and the KOSMOS spectrograph resolution will be ~3 pixels. A shift of <1 pixel would "soften" line profiles but probably degrade resolution by <10%. The impact along the slit would be similar (assumes typical image profiles of somewhat under 1 arcsec). Thus it is reasonable to set a requirement of 1 pixel/hour and a goal of roughly half this figure.

- Misalignment of multi-slit spectra with calibrations. Ideally, one would take flat fields and lamp spectra during the day at a single telescope orientation. These are typically used to identify and cut the individual spectra in MOS mode. If the calibrations are badly misaligned with the night-time spectra, the ends of slitlets will be lost – either because they weren't cut or because they don't flat-field correctly. If a typical slitlet is ~10 arcsec (30+ pixels) one would like to keep the misalignments under 10% or 3 pixels. Figure 3 indicates this is a potential problem for OSMOS for observations at extreme hour angles, though of course flat fields can be obtained for such fields right after or before the observation, largely eliminating this effect. If taking flat fields during the night is acceptable, then the requirement is relatively loose – certainly 1 pixel/hour would be acceptable. If the goal is to use calibrations taken during the day most of the time, then the requirement ("goal" in this case) would be <3 pixels/6 hours or 0.5 pixel/hour.
- Flat-field accuracy. The flat field response of typical CCDs shows fringing in the red. The fringe pattern is a function of wavelength, and therefore changes as the wavelengths shift on the array. Like the preceding effect, this can in principle be dealt with by taking calibrations during the night when pointed at the science field. Fringing data for the E2V devices that are the KOSMOS baseline are not available right now[2], but if one assumes a periodicity of ~10 pixels and an amplitude of ~10%, a 1-pixel shift will introduce a flat-fielding error of ~1%. This level of flat field is acceptable for most observations[3]. Anything in excess of this is problematic. This suggests that for lengthy observations a flat field every ~2 hours would produce acceptable results for a flexure of 1 pixel/hour. (If the fringing effects are less than the nominal values given above, the requirements are less stringent.) In order to avoid night-time flat fields, the flexure would need to be under 0.3 pixel/hour. Flexure around 0.3 pixel/hour would reduce but not eliminate night-time flat-fielding.

Conclusions

The observed level of flexure in OSMOS clearly allows useful science to be done if it is matched in KOSMOS. For programs where the slit cannot be oriented E-W, it will likely

[2] KOSMOS will also have a available an LBNL red-sensitive device. These CCDs are very thick and the device should have negligible fringing. However, there is increased sensitivity to cosmic rays, so the E2V CCD is likely to be preferred except in the far-red.

[3] The situation in the vicinity of very bright night sky lines is probably the most difficult, since sky subtraction will be imperfect if the flat-fielding is variable along the slit.

be necessary to obtain flat fields during the night – either at the start or end of the observation, and in some cases both.

This need for night-time calibrations would be significantly reduced if the flexure is reduced below 0.5 pixel/hour, and could be largely eliminated if it is reduced still further. Since the single largest contribution to flexure is known to be the focus stages, it is worth investigating whether stiffer mechanisms can be purchased, with the expectation that the first goal could be met. It would likely require a far more extensive design effort to demonstrate that flexure at the 0.2-0.3 pixel/hour level is feasible, and this is probably not worth undertaking.

It should be noted that the ability to perform flat fields at arbitrary positions on the sky will require an upgrade of the calibration lamps and integrating sphere on the guider, since they don't current illuminate the full field of view of KOSMOS.

Versions

Version	**Date**	**Changes**
0	May 26, 2010	First draft