Southern African Large Telescope

Prime Focus Imaging Spectrograph

Science Calibration Analysis: Effect of Variable Pupil on Image Centroids

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1 Summary

The SALT telescope presents an unusual challenge to scientific calibration because the illumination of the telescope pupil changes during an observation as the portion of the primary that illuminates the tracker moves off the center line of the mirror. To calibrate optical effects due to this pupil effect, it is planned to allow the simulation of a scientific observation during daytime calibration observations using the moving baffle at the SAC exit pupil (the PFIS entrance pupil), run at higher than real-time rates. A question which must be answered is where the calibration screen must be located to adequately provide for this simulation. If it is located at the SAC exit pupil, the effects of SAC vignetting will not be simulated; if it is located earlier in the beam, it is not at a pupil, and it is inconveniently located. This document describes an analysis of one aspect of calibration, that of image motion (mainly wavelength calibration) for PFIS. The analysis computes the motion of the image centroid at the detector for a slitless observation, as a function of field angle and tracker position, for the actual telescope/ SAC, and compares this with a uniformly illuminated SAC entrance pupil with a moving baffle at the appropriate positions. We find image motion of up to 15 μ for the actual SAC, which is a strong function of wavelength and a weak function of field angle. A calibration screen with a 40% linear central obscuration reproduces this apparent motion to within about 3 microns. We believe this is adequate, since this 3 μ residual calibration error may be modeled as a function of field angle and track position, certainly allowing a final correction to better than 1 μ, which is comparable to unavoidable errors from slit guiding. 1 μ at the largest PFIS diffraction angle corresponds to 0.4 km/s.

2 Analysis

2.1 Centroid motion for actual SAC

The SALT telescope, with 11m circular aperture primary mirror and the RFQ SAC prescription (F/4.2, 11m pupil) was used to feed the PDR PFIS optical design. A circular aperture in the model was inserted just after the primary mirror, to simulate the offset of the tracker from the centerline of the mirror during a track. At the maximum track angle (6 degrees), the aperture offset is 1/4 of the mirror aperture. This feeds the PFIS instrument in three configurations, imaging (camera unarticulated), and blue and red low dispersion spectroscopy (780 line grating). We modeled these configurations because these are the most stringent imaging configurations for PFIS, due to the large wavelength coverage. These are the configurations which were used to optimize the spectrograph optics. No slit is placed at the spectrograph entrance. Figures 1a, b, and c show the image centroid as a function of tracker position for four wavelengths (left boxes) and as a function of wavelength for the maximum track offset (right boxes). These are shown for four field angles, 0, 2, 3, and 4 arcmin; for the top boxes the field angles are parallel to the track angle, and for the bottom boxes they are perpendicular to the track angle. All centroids are referenced to the image position for track angle zero. Figure 1a shows the results for the imaging configuration (camera unarticulated), and 1b and 1c show the spectroscopic configurations. For the spectroscopic configurations, the track direction is in the direction of dispersion, which results in the error of greatest concern, an error in wavelength. The centroid error rises monotonically with track angle to about 15μ (imaging) and 10μ (spectroscopic). The largest errors are at the extreme wavelengths. Most of the error appears to be due to residual longitudinal chromatic aberration (defocus), which is completely corrected at three wavelengths. The field angle does not have much effect, except for the largest field angle perpendicular to the track direction.

2.2 Centroid motion for calibration screen at SAC exit pupil

The above analysis was repeated for a model consisting of a perfect telescope and SAC, illuminating a pupil at the same position as the actual exit pupil of the SAC. This achieves an even illumination of a calibration screen at the pupil as seen by PFIS. The moving baffle was simulated by a circular aperture just after the pupil, for offsets up to 1/4 the pupil diameter, corresponding to the maximum track angle of 6°. Figures 2a, b, and c present the *difference* between the centroid error for the calibration screen and the actual SAC at the same equivalent track position, field angles and wavelengths. This, then, is the calibration error for the proposed calibration system. Two calibration screens were modeled, an evenly illuminated screen and one with a fixed 40% linear central obscuration (16% areal obscuration), simulating the central obscuration of the SAC. The latter is shown. It has a maximum calibration error of about 5 μ for imaging mode, and 3 μ for spectroscopic mode. The maximum calibration error is for the maximum field angle perpendicular to the track angle. At other positions, the maximum calibration error is about 3 μ (imaging) and 2 μ (spectroscopic). The unobscured calibration screen gives a substantially worse error (about 2×) except at the maximum error position, for which it is the same.

3 Comparison to other calibration errors

Based on the above results, the effects of the variable pupil may be removed with daytime calibration frames taken through a moving baffle at the SAC exit pupil to better than about 3 μ. *This would require that both the moving baffle and the rotation stage simulate a track for a daytime calibration*. If necessary, a model of residual error using the results of this study, calibrated by observations of velocity standards as a function of pupil position, might be expected to reduce the residual error to better than 1 μ. How does this compare with other calibration errors?

- Spectrograph flexure. The specification is < 0.1 arcsec/ hr, or 12μ/hr. This could be accurately calibrated by a daytime wavelength calibration. (Measuring sky line positions in the science exposures would also work, but in the red only, where sky lines are dense enough). *A daytime calibration would require that the moving baffle, the rotation stage, and the hexapod components of the tracker simulate the observation*. An accuracy of 1 μ for this calibration would be very good.

- Guiding. The guider specification is 0.1 arcsec, which is 12 μ at the detector. The centroid error at the detector will be equal to this if the observation is slitless, and somewhat less than this if slit-limited. Because of the dependence on the slit, even given perfect guide information from the telescope, an after-the-fact guide motion compensation will not fully compensate the error at the detector. Also, the actual guide error includes a systematic error due to the additional vignetting of the off-axis guide stars. This will need to be calibrated as a function of field position and track position. Finally, the best result would require an image though the slitmask taken at the beginning and end of the observation to measure the position of the object in the slit. A residual position error of 3 μ after all these corrections would be excellent.

• Telescope de-focus: The focus specification is 10 μ, which gives a defocussed spot of 2.4 microns at the telescope and 1.3μ at the detector. The combination of guide errors with such a defocus would be expected to give an additional centroid error (on top of guiding errors themselves) of this magnitude, 1μ.

We expect that the calibration screen at the SAC exit pupil will result in calibration errors comparable to or smaller than other calibration errors, so it is adequate. The expected errors would be on the order of a few microns. For reference, 1 micron is 1/15 of a detector pixel, 1/70 of the image size for the smallest slit (0.5 arcsec), and 0.4 km/sec for the linear dispersion attained at the maximum camera articulation.

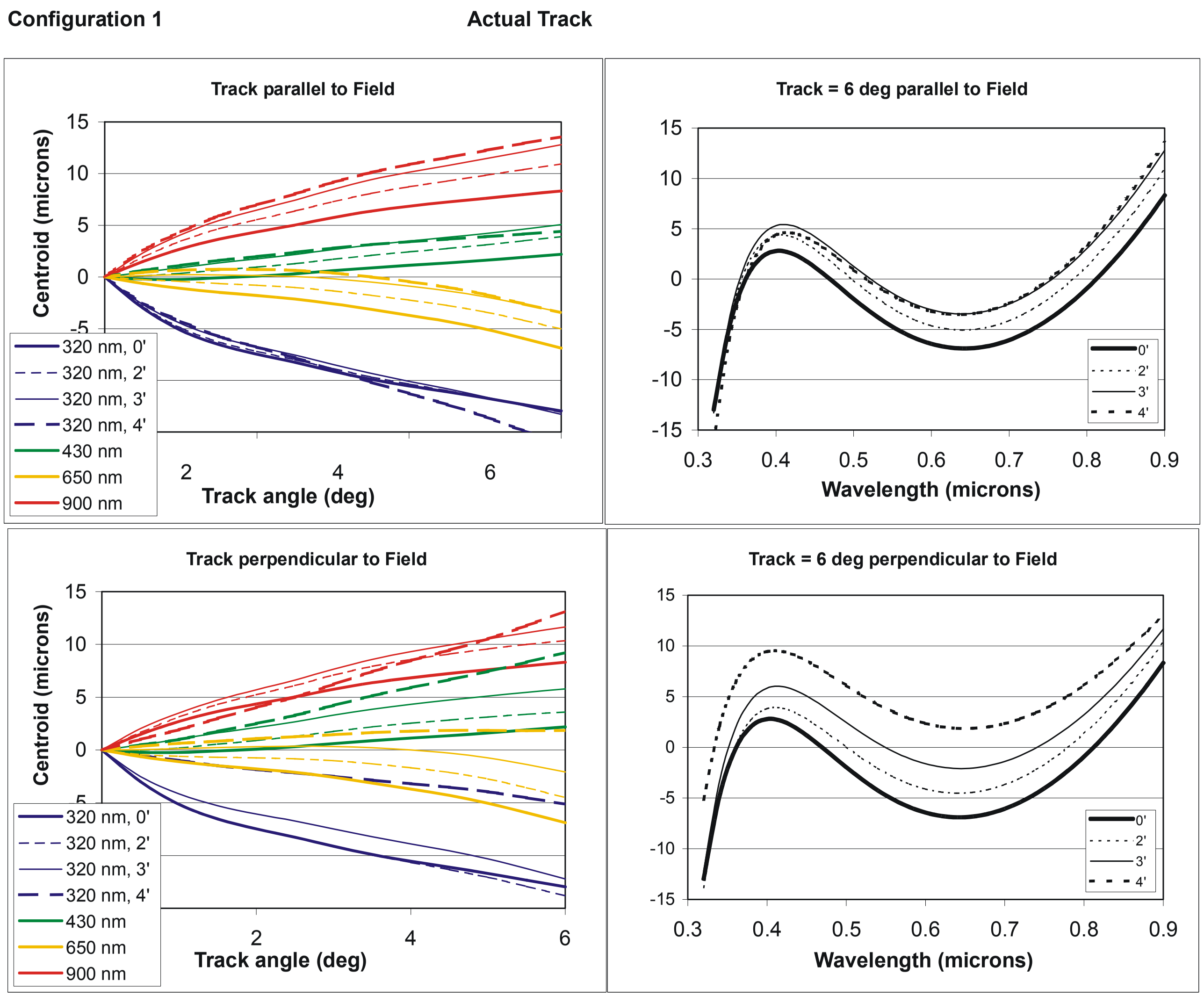


Figure 1a. Centroid motion for actual track, Imaging

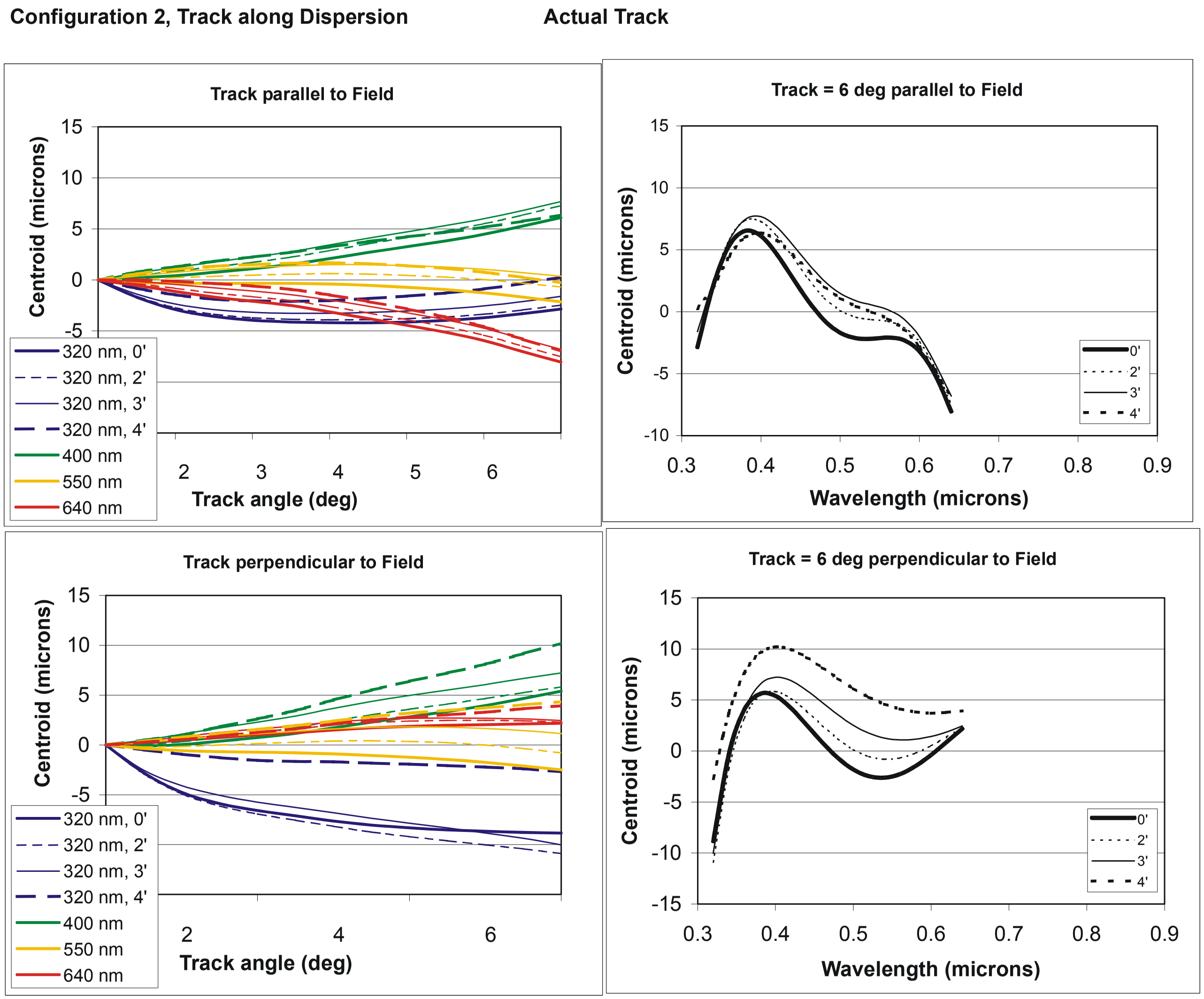


Figure 1b. Centroid motion for actual track, Blue spectroscopy

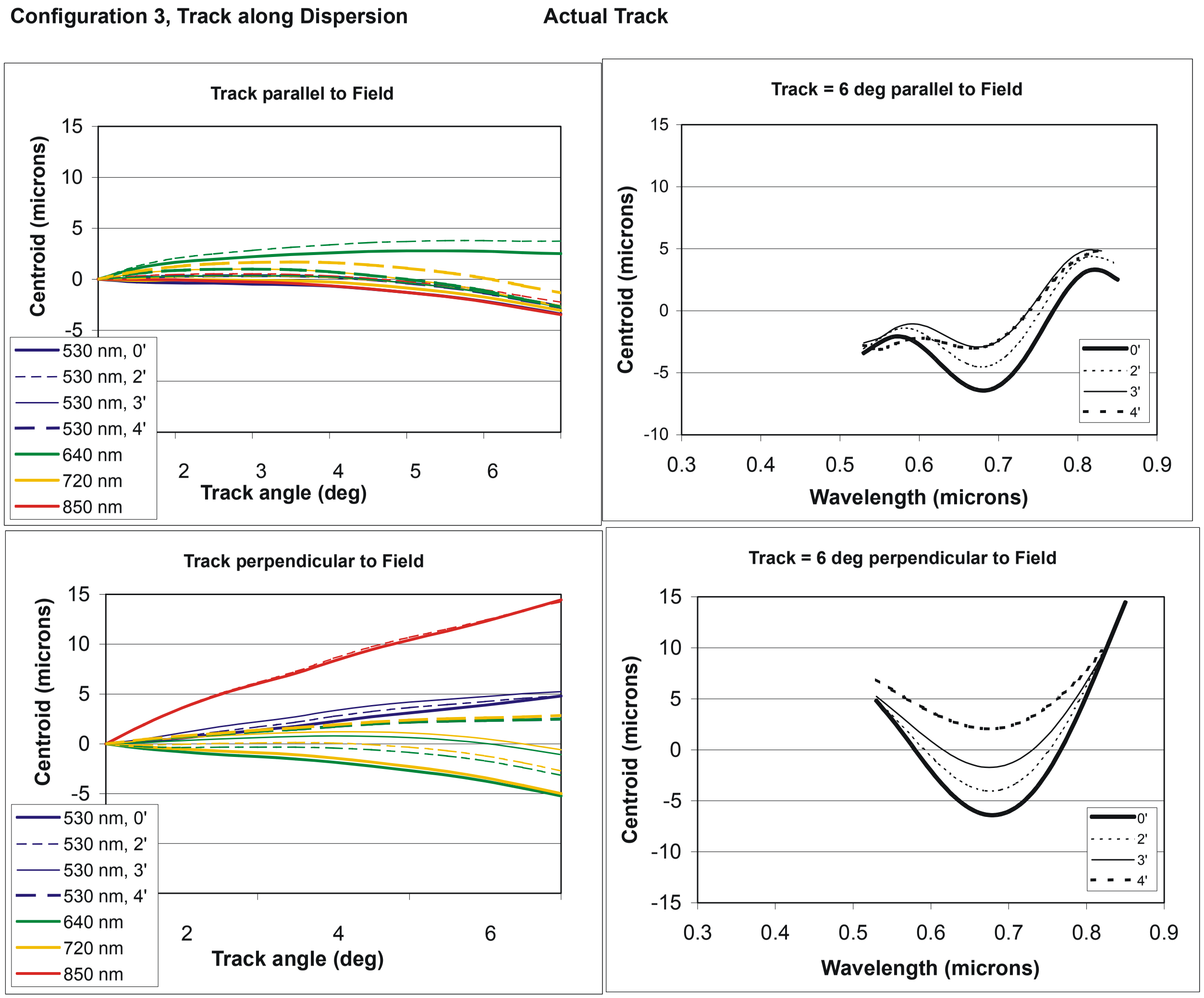


Figure 1c. Centroid motion for actual track, Red spectroscopy

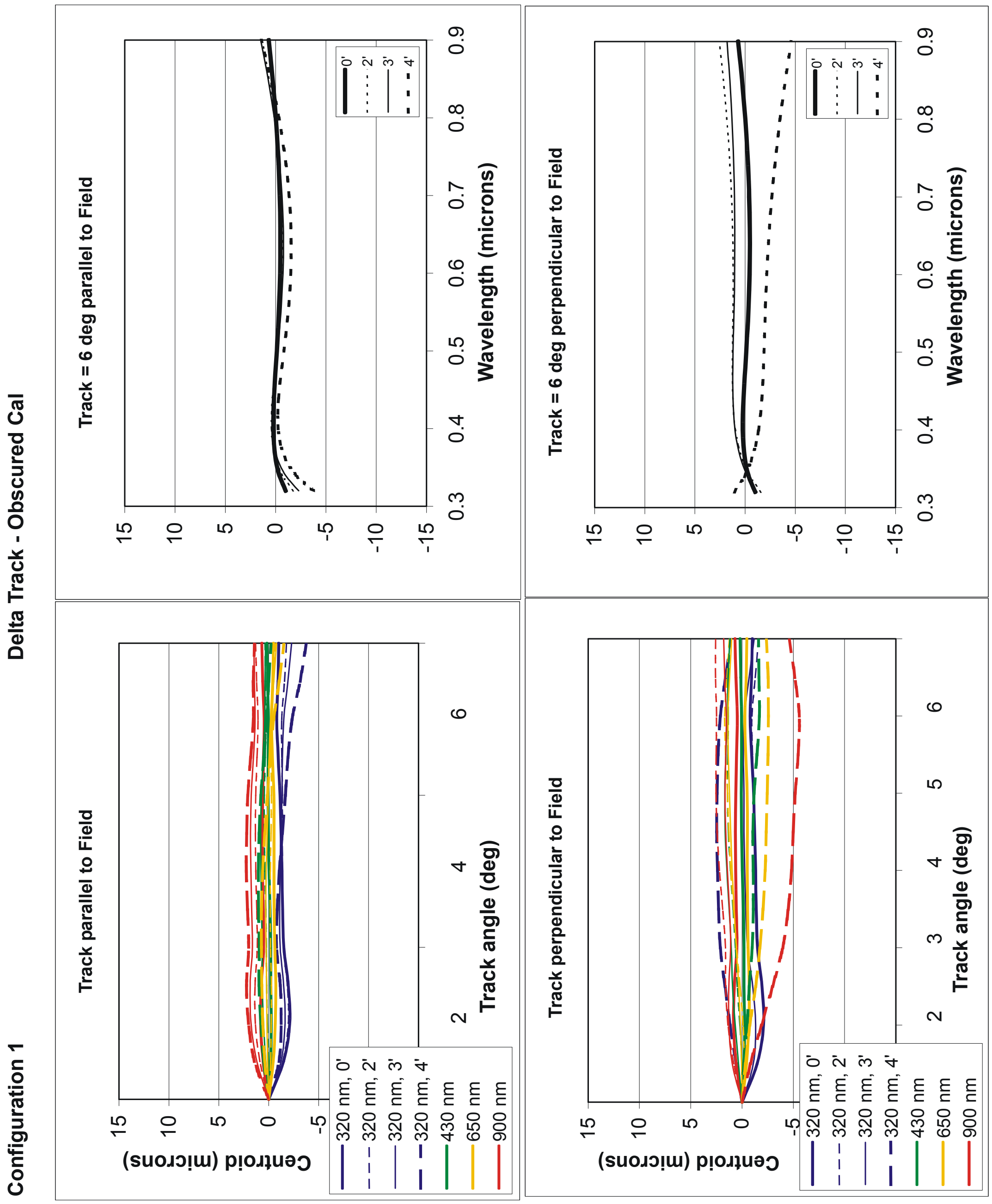
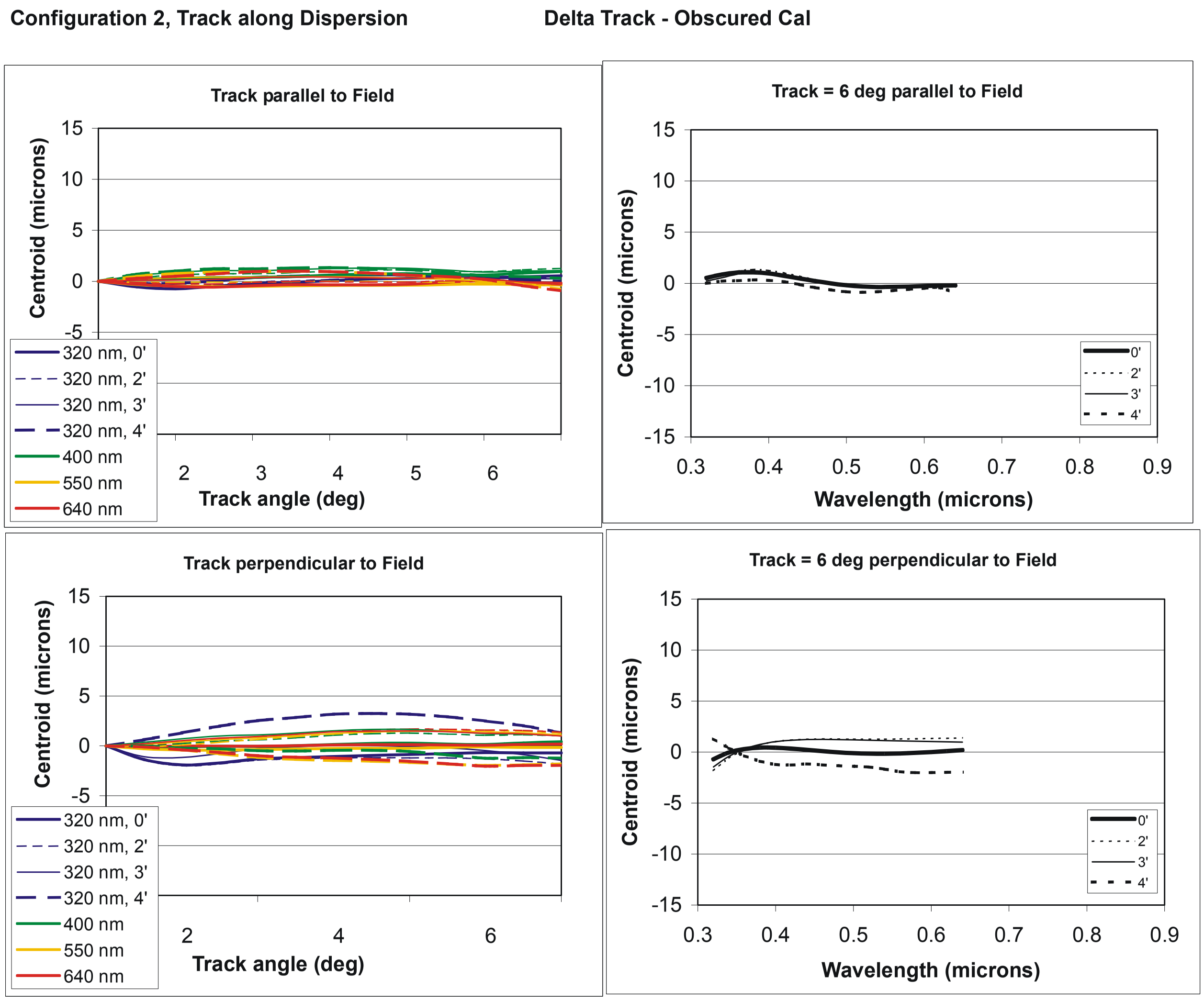


Figure 2a. Delta centroid motion Track - Cal, Imaging


Configuration 2, Track along Dispersion

Delta Track - Obscured Cal

Figure 2b. Delta centroid motion Track - Cal, Blue spectroscopy

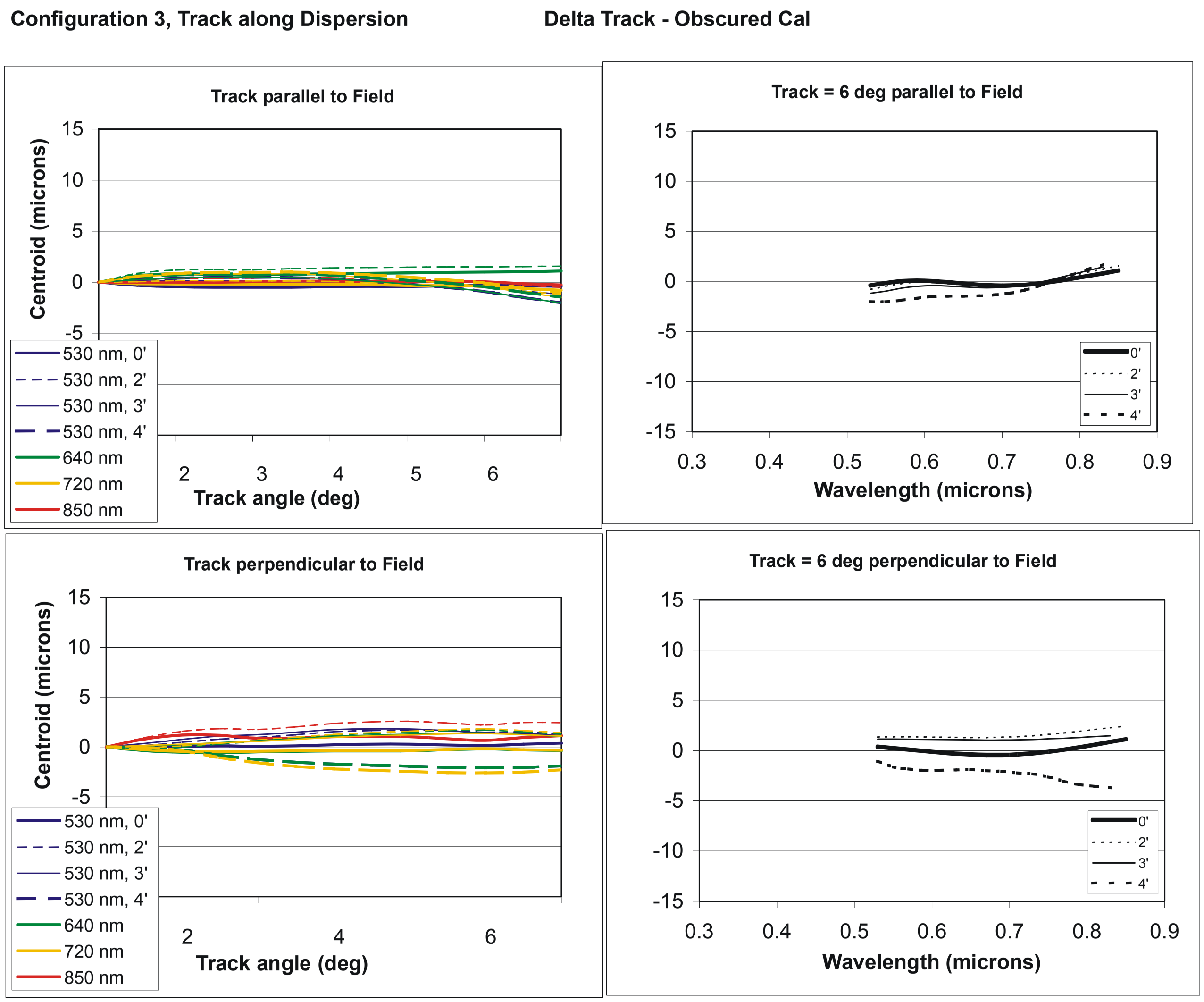


Figure 2c. Delta centroid motion Track - Cal, Red Spectroscopy