



“Centroid Gain” for On-Slit Guiding

2008 December 23

R. W. Goodrich

Introduction

Much of the science done with W. M. Keck Observatory is spectroscopy. In these types of observations, it is common (although not universal) that guiding is done from an image reflected off the spectrograph’s slit. This “on-slit guiding” presents challenges to the guiding algorithm. One aspect is discussed in this technical note: the effective “gain” of a simple centroid calculation done from the image of the star on the slit, which of course is missing the central portion of the image.

“Centroid gain”

When the central part of the stellar image is missing (as the light goes down the slit into the instrument), the resulting centroid calculation is not the same as it would be in the unmodified stellar image. In other words, if the image shifts by one pixel in the focal plane, the change in centroid measured by the guider will not be one pixel. We call the resulting ratio, of actual shift divided by the measured shift, the “centroid gain.”

Qualitatively this effect can be visualized by considering the formula for the centroid.

The centroid, c , is given by:

$$c = \frac{\sum yF}{\sum F}$$

where y is the row value and F is the intensity. The denominator can be thought of as a normalization for the numerator. As the function, F , shifts, this normalization does not change. Now when the image moves by one pixel in the focal plane, the parts of the image that are seen by the guider will also shift by one pixel, so the numerator, $\sum yF$, will change slightly. However, the total flux of the image as seen by the guider is much smaller than the total flux in the actual image, due to the missing central piece, and hence any shift as measured by the numerator will get magnified by a much smaller denominator in the centroid formula. The result is that a one pixel shift in the actual image will be measured as a shift greater (by up to a factor of four or more) by the guider. The above qualitative description is not the whole story, of course, since the numerator changes as well.

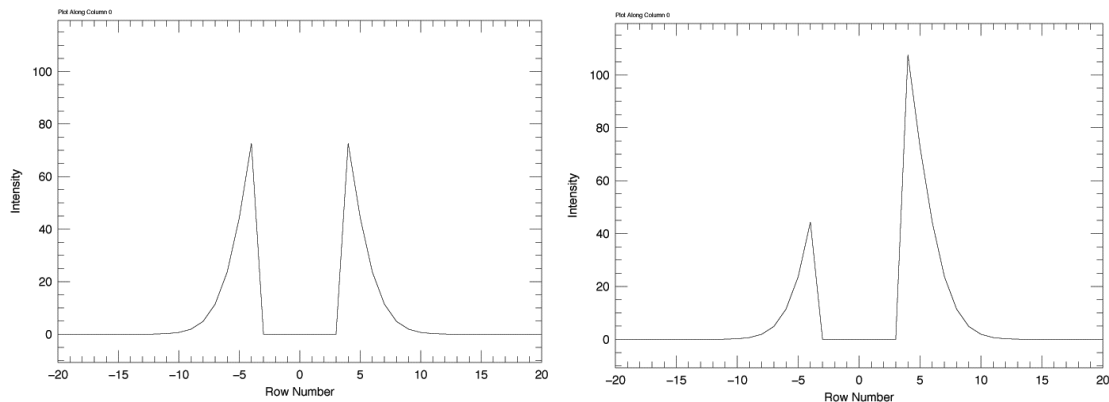


Figure 1. On the left is a simulated guider image of a Gaussian PSF seen reflected off a slit with width equal to the FWHM of the Gaussian. On the right is the same simulation with the Gaussian shifted by one pixel relative to the slit. The centroid of the slit image on the right is measured to be nearly 3 pixels, rather than the one pixel of actual image shift.

The “centroid gain” will hence always be less than one. It can be parameterized by the ratio of the slit width to the width of the actual image. For a very narrow slit, the centroid gain will be near unity, since not much of the PSF is missing in the guider image. For a very wide slit, with the image contained almost completely within the slit, an image shift will not be seen at all, and the centroid gain will tend towards zero. In practice, for conditions normally used in WMKO guiders, the centroid gain never gets below 0.2.

Modeling

Calculations were performed using the image processing package *VISTA*. A 141 x 141 pixel image was created, and a Gaussian profile of given full-width at half maximum (FWHM) placed on the image at (0,1) (i.e. shifted by one pixel in y). A centered slit of seven rows was simulated by zeroing out the flux in the central seven rows of the image (centered on row 0; Fig. 1). The centroid of the resulting image was calculated, and compared to the actual shift of one pixel.

The centroid gain was then calculated as the reciprocal of the measured y -shift, and the result plotted vs. the ratio of slit width to PSF FWHM, as shown in Figure 2.

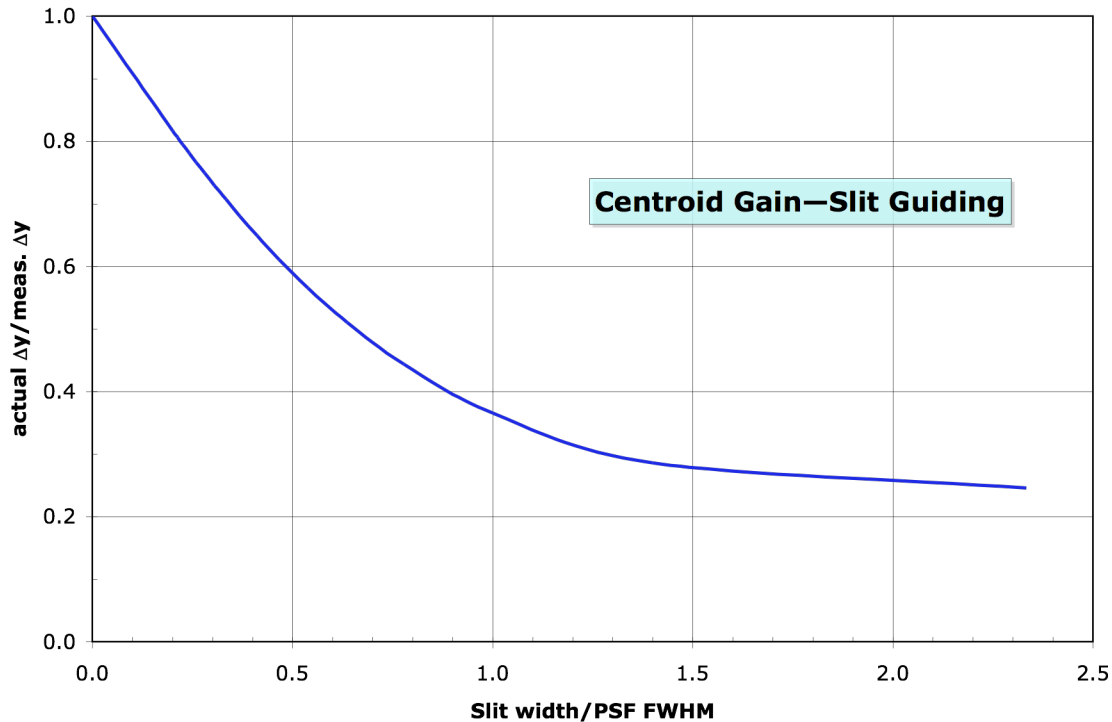


Figure 2. Centroid gain as a function of the ratio of slit width to image PSF. Note that at small slit widths the centroid gain is near unity, as expected, dropping as the slit hides a larger and larger fraction of the PSF. Note that typically the slit width is roughly equal to or slightly greater than the PSF FWHM, implying values of the abscissa above of one or above.

Consequences to guiding

If the guiding algorithm does not account for this effect, it will tend to see larger centroid shifts than are really occurring. This in turn can cause the algorithm to “overguide,” telling the telescope to move larger amounts than are appropriate.

The entire guiding system includes the latency in guide star measurements and calculations (including the exposure time) and the behavior of the telescope servo system, so actual system response is beyond the scope of this limited investigation. However, in principle the above curve could be combined with knowledge of the star’s PSF and the slit width to calculate a guider gain matched to the observing conditions. A smaller gain would be used for PSFs that are narrower compared to the slit.

<i>Author</i>	<i>Date</i>	<i>Comment</i>
Bob Goodrich	12/23/2008	Original