ADC Figure of Merit

Introduction:

The improved performance LRIS in spectroscopic mode with the ADC (over the no-ADC case) has many factors. Concentrating solely on spectral throughput, those factors that degrade performance without the ADC include:

1. Elevation (and its corresponding dispersion);
2. Wavelength range of interest;
3. Seeing;
4. Slitwidth; and
5. Orientation of slit with respect to the parallactic angle.

The ADC provides a correction for the dispersion, but it has some cost as well:

1. Lower transmission;
2. Slight image degradation; and
3. Residual dispersion.

Thus, the parameter space for determining a figure of merit is enormous. Here, we attempt to provide some algorithms for characterizing the effects, and provide a few representative examples.

Throughput:

The dispersion needs to be broken into two components, cross-slit (dx) and along-slit (dy) in order to estimate throughput effects. Obviously, for a given dispersion, $d(Z, \lambda)$:

$dx = d(Z,\lambda) \sin \theta$, and
$dy = d(Z,\lambda) \cos \theta$,

where θ is the angle of the slitlet with respect to the parallactic angle. The total dispersion, $d(Z,\lambda)$ is measured relative to a reference wavelength, $\lambda0$, which also (for convenience) will be assumed to be the effective guider wavelength, and which will be assumed to fall precisely in the center of the slit. We break the relative throughput problem into a cross-slit factor, $f1(dx)$, and an along-slit factor, $f2(dy)$, both with and without the ADC.

We have used the IRAF **artdata** package to construct representative PSFs, and in turn to calculate the amount of light passing through a slit as a function of displacement of source relative to the slit center, at various slit widths and seeing. We assume a Moffat profile PSF. Some representative throughput values are shown (Fig. 1), normalized to the maximum throughput without the ADC.

The ADC introduces some additional image size due to aberrations. We estimate the additional image size due to the ADC using the formula from the Preliminary Design Optics Report that $\mathrm{FWHM}('') = 0.0023\, R\mathit{rms}(\mu m)$; the maximum additional component due to the ADC aberrations is 0.16″. This value is added in quadrature to the original seeing size. Results for the degraded-image case are also plotted in Fig. 1, where we see that the maximum image degradation leads to a reduction of the peak value by a few percent at most, and affects only the results in the center of the slit.

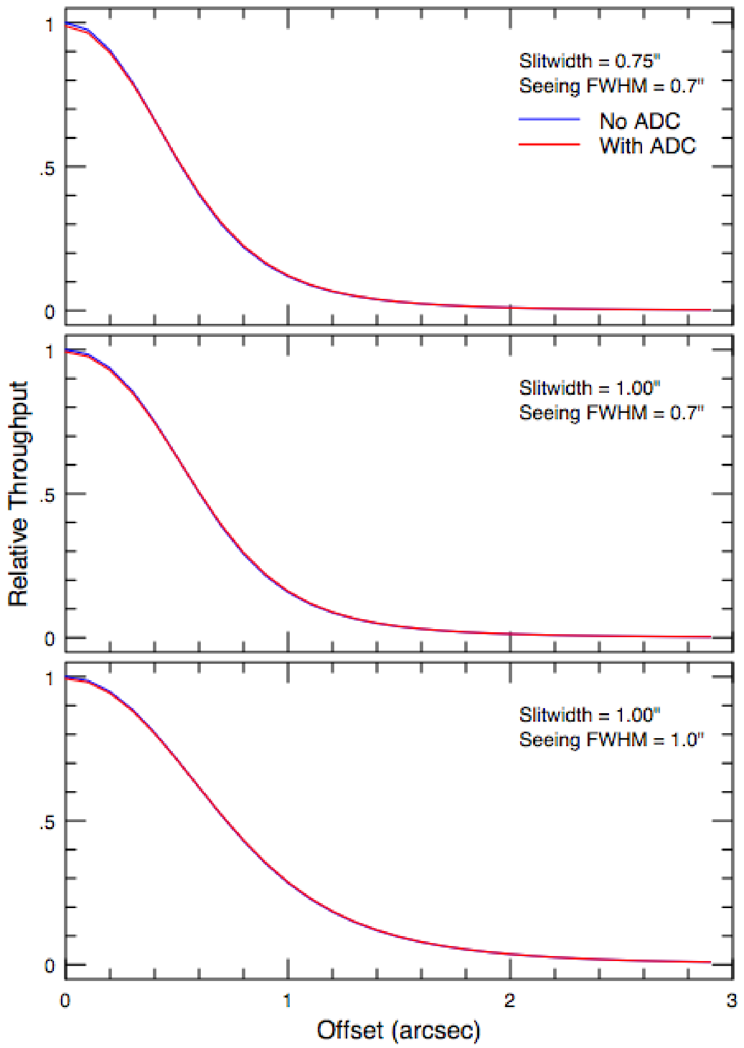

Figure 1: Throughput (relative to no-ADC case) as a function of distance from the slit center. The ADC case shown differs only in slightly lower central throughput, due to slightly larger images.

We can now estimate the throughputs with and without the ADC for the cross-slit direction by using these curves and calculating the displacement from the relative dispersion at the desired elevation, and applying the geometrical factor, sin θ. Thus,

$$f1(\lambda) = E(\mathrm{dx}),$$

where E represents the throughput from the figures. In the case of the ADC, the residual dispersion is used in place of the native dispersion.

Even with perfect alignment between slitlet and parallactic angle, dispersion can still reduce efficiency because a longer slitlet is needed to capture the light. This is purely a geometrical effect, and loss of efficiency can be crudely approximated by a factor

$f2 = \langle\text{slitlen}\rangle / (\langle\text{slitlen}\rangle + |\Delta\text{dy}|)$,

where Δdy represents the total range in the dispersion or residual dispersion. Effectively, slits must be longer and so fewer objects can be observed (note: this tends to be relevant only where target density on the sky is relatively high).

In addition to the two factors above, the ADC includes additional transmission; we describe this as an additional factor, $f3(\lambda)$, which is everywhere > 0.96.

In summary, the spectral throughput without the ADC relative to that with it is given by

$$R = f1(\lambda) \times f2 \,/\, (f1^{ADC}(\lambda) \times f2^{ADC} \times f3^{ADC}(\lambda)),$$

where R depends on seeing, slitwidth, Z, λ, $\lambda0$ and θ. We use these functions in the calculations below. Note that the ADC residual dispersion is never greater than 0.2 arcsec, so that $f2^{ADC} \approx 1$ and $f1^{ADC}(\lambda) \approx (1 - \text{few\%})$ due to slightly larger image size with the ADC.

Examples:

We consider some representative cases:

1. Zenith distances of 20, 40 and 60 degrees;
2. Seeing FHWM 0.7 and 1.0 arcseconds;
3. Slitwidths 0.75 and 1.0 arcseconds;
4. Mismatches of 20 and 70 degrees between slit and parallactic angle. A 20 degree mismatch is probably as good as an observer can expect under normal circumstances, as masks are never used at precisely the design time, particularly given typically long exposure times (1—1.5 hours total); and
5. A slit-length of 15″, chosen as a relatively conservative length in calculating f2.

The results are shown graphically in Fig. 2. The drop in relative throughput at the reference wavelength ($\lambda0 = 0.42$ μm) is due to $f2$, i.e., the need for increased slit lengths. It is interesting to note that even at high elevation (Z=20°), there is effectively no disadvantage to using the ADC, and at even modest zenith distances (Z=40°), the ADC correction in the *well-oriented case* provides improvements of 10—20% in throughput. In all cases, the larger images for the fully-extended ADC are used; in practice, the ADC performance at Z=20° and 40° is better than shown by 1—3%.

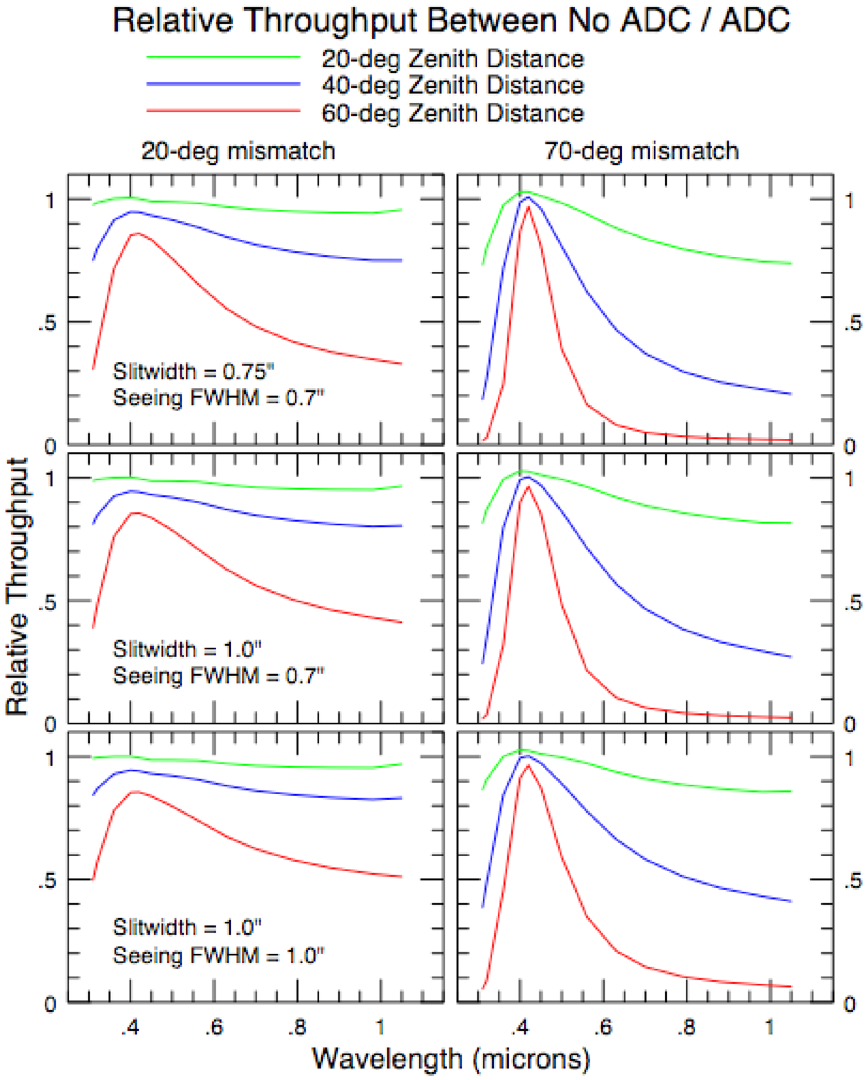

Figure 2: Relative Throughputs, comparing the non-ADC case against the ADC case. Left column shows slits well-oriented with the parallactic angle, right column poorly-aligned. Three elevations are shown in each plot. The decline in throughput at 0.42-µm is due to the need for longer slitlets in the non-ADC case; a slit length of 15″ is assumed.

Other Considerations Not Related to Throughput:

These effects may have serious consequence to the science without effecting throughput:

1. An exposure of significant duration may cover a range of dispersions as elevation changes. At the effective wavelength of the guider, this will have no effect on the spectrum. At other wavelengths, a blurring due to the changing dispersion will occur. For example, assume perfect alignment between slit and the parallactic

angle, and that the guider has an effective wavelength of 7000A. Suppose the relative dispersion between 3500A and 7000A changes by 0.3 arcsecond during the exposure. This means that the spectrum at 3500A will drift 0.3 arcsecond in the spatial direction over the course of the exposure, lowering the contrast and changing the spatial profile. Such a situation can occur in less than a 4-degree change in elevation near Z=60-deg.

2. The distribution of the source light within the slit can have serious ramifications for precision radial velocity work. Dispersion can cause the light distribution within the slit to change at different wavelengths, producing systematically different velocity measurements at different wavelengths. Similarly, for extended objects such as galaxies, different portions of the object will be sampled at different wavelengths if there is any dispersion in the cross-slit direction.