# ADC Options For SALT

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## 1. Introduction

At the SALT Board meeting in 2014 Nov in Pune, the problem of the SALT ADC was re-discussed, especially in the context of the NIR beam of RSS being "on the way". The existing ADC, which was designed by the author for use in the wavelength range 320 to 900 nm (appropriate for RSS-VIS), degrades performance in the NIR. A new design covering 320 to 1700 nm is available but it has its own problems. The question is then what to do: discard the existing ADC and not replace it; build a replacement ADC using the new design; continue with the existing ADC and swap it in and out as required; or some other possibility (as yet undefined).

This study is intended to help arrive at a decision on which way to proceed. .

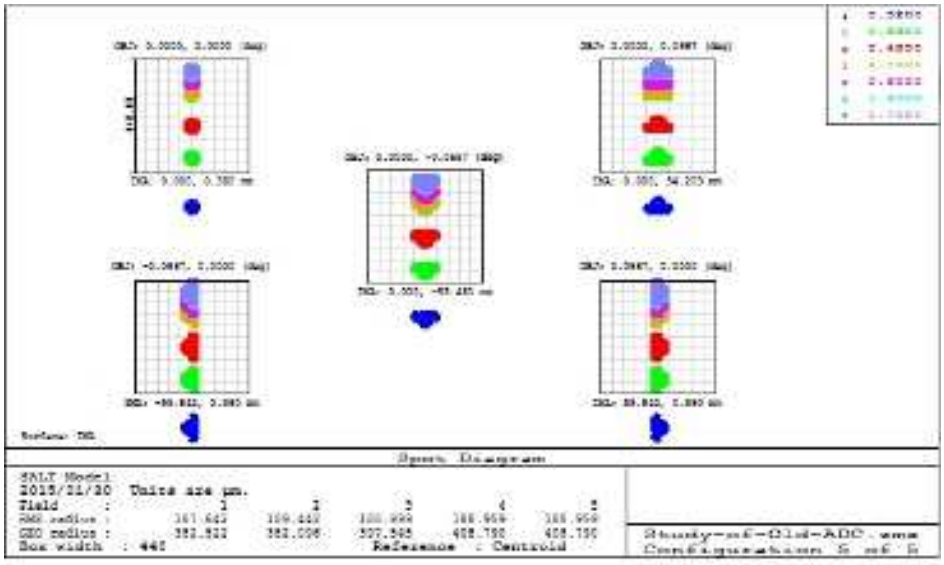


**Fig. 1: Uncorrected atmospheric dispersion in the nominal SALT Optical Model. The boxes are 2 arcsec in size and span the science field of view. The different wavelengths are colour-coded according to: Royal blue: 320 nm; Green: 390 nm; Red: 480 nm; Gold: 700 nm; Magenta: 900 nm; Sky blue: 1400 nm; Purple: 1700 nm.**

## 2. Why Is An ADC Necessary?

The Earth's atmosphere disperses light from celestial sources observed at zenith distances other than zero. The size of the effect for a zenith distance of 37$^{o}$ is shown in Fig, 1. This is a spot diagram showing the optical model of the nominal SALT telescope with 2 arcsec boxes. Atmospheric dispersion produces a spectrum which, in a spot diagram such as in Fig. 1, manifests as a lateral translation of spots of different wavelength. In Fig. 1, the different boxes correspond to different parts of the science field of view with the centre of the field of view at upper left, and

the remaining boxes at 4 arcmin from the centre in each of the cardinal directions. Wavelengths from bottom to top in each box are:

| | |
|---|---|
| Royal blue: | 320 nm |
| Green: | 390 nm |
| Red: | 480 nm |
| Gold: | 700 nm |
| Magenta: | 900 nm |
| Sky blue: | 1400 nm |
| Purple: | 1700 nm |

Fig. 1 shows the expected translation of the spots correlated monotonically with wavelength. The size of the effect is about 2.5 arcsec from shortest to longest wavelengths. It is also obvious that the dependency on wavelength is nonlinear, with most of the effect in the blue, and scarcely any translation from 700 to 1700 nm.

Thus, an ADC is needed to counter the effects of atmospheric dispersion at the slits of spectrographs (in imaging, the bandpass is likely to be much smaller due to the use of filters).

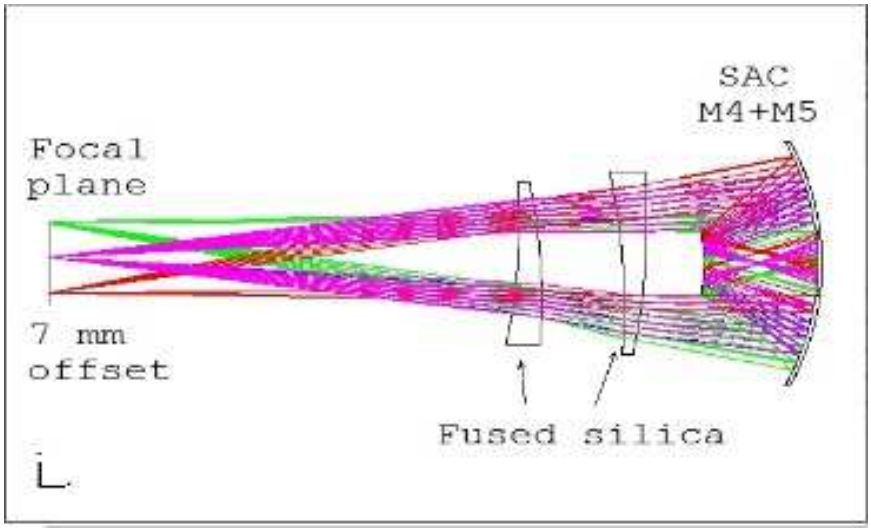



**Fig. 2: Layout of the existing ADC.**

# 3. The Existing ADC

The existing ADC is illustrated in Fig. 2. It comprises two prisms with curved surfaces made of fused silica. The prisms are relatively large for refractive optics: the one closest to the SAC is 280 mm in diameter. They are coated with a broad band anti-reflection coating optimized for the wavelength range 320 to 900 nm.

The correction required of an ADC is variable for SALT as atmospheric dispersions depends on zenith distance and the zenith distance of SALT targets lies in the interval 31 to 43 deg. The existing ADC achieves this by varying the separation of the prisms as a function of zenith distance.

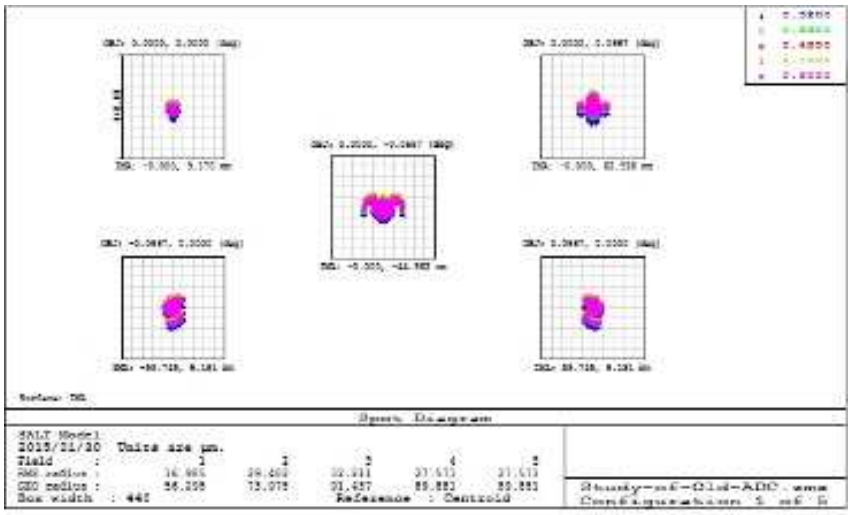


**Fig. 3: Optical performance of the existing ADC over the science field of view and the wavelength range 320 to 900 nm. Boxes are 2 arcsec on a side.**

The performance of the existing ADC is illustrated in Fig. 3(a) and is quite satisfactory for the 320 to 900 nm bandpass. At the time of the construction of SALT, the restriction to this wavelength range was agreed as no design for 320 to 1700 nm was available at the time.

An important point to note is that the existing ADC translates the beam 7 mm laterally with respect to the optical axis of the spherical aberration corrector. The existing configuration of SALT therefore has the rho ring offset from the SAC by 7 mm. It may not be easy to change this.

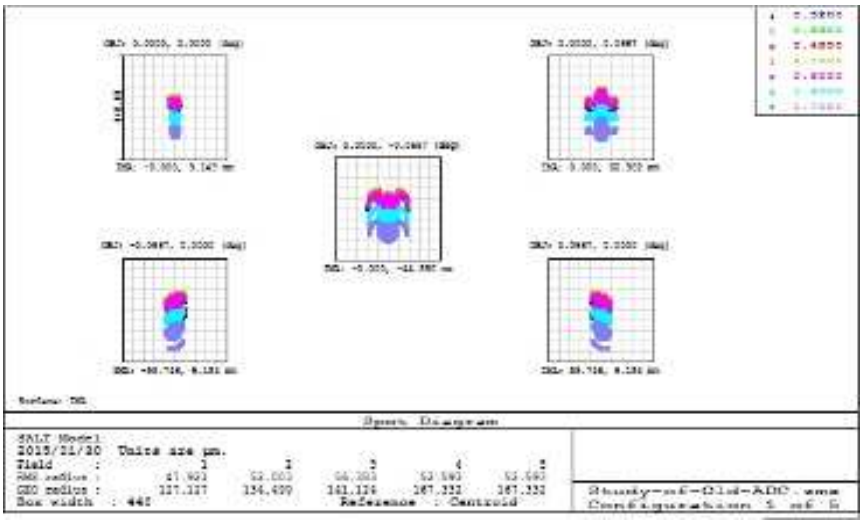


**Fig. 4: As for Fig. 3 except that spots at 1400 and 1700 nm have been included.**

In the NIR, the existing ADC degrades image quality. How bad is the degradation? This can be seen in Fig. 4 which is identical to Fig. 3 except that spots at 1400 and 1700 nm are shown in sky blue and purple respectively. The 1700 nm spot is translated by about 0.6 arcsec w.r.t. the UV-visual wavelengths. This violates the SALT image quality specification which calls for an EE(50) of 0.6 arcsec in the absence of seeing.

Another issue with the existing ADC is that it has anti-reflection coatings optimized for the 320-900 nm bandwidth and which will perform very poorly in the NIR.

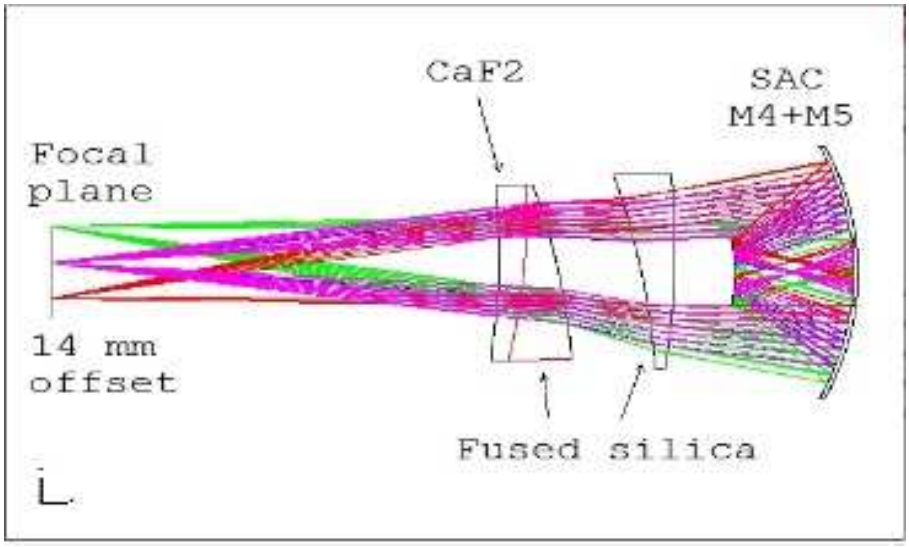



**Fig. 5: Layout of a design for a New ADC.**

## 4. Design For A New ADC

With the prospect of the RSS-NIR being installed on SALT, and the out-of-specification performance of the existing ADC over the whole wavelength range, about 3 years ago the author designed a new ADC (referred to as the "New ADC Design". The layout in this design is shown in Fig. 5. It is conceptually similar to the existing system except that: (i) the apex angles of the prisms are larger; (ii) most importantly, there is a CaF2 element added. It was found impossible to achieve satisfactory performance by adding a third fused silica prism. Including CaF2 seemed unavoidable.

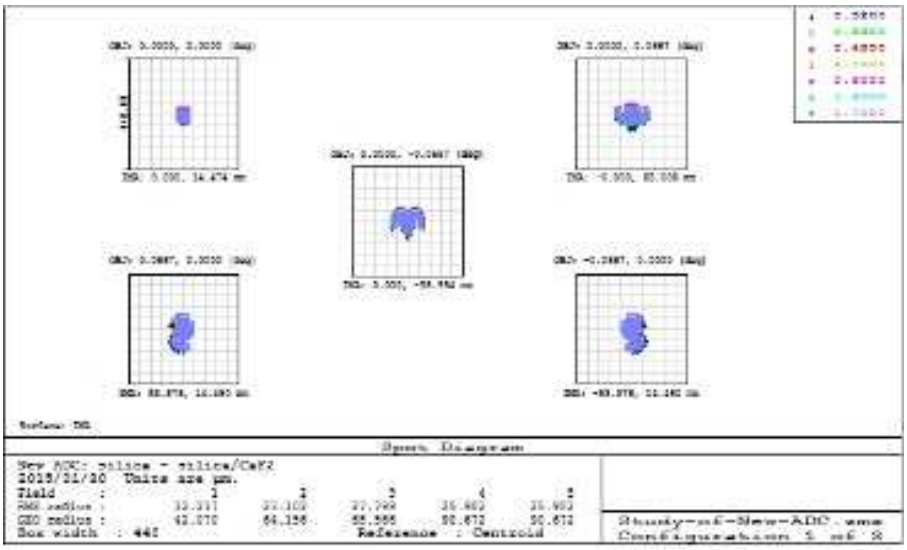


**Fig. 6: Optical performance of the New ADC Design over the science field of view and the wavelength range 320 to 1700 nm. Spots are colour-coded as in Fig. 1. Boxes are 2 arcsec on a side.**

Optical performance of the New ADC Design design (Fig. 6) is excellent over the range 320 to 1700 nm, even better than the existing system for UV+visual wavelengths.

This design has been in existence since 2011. However, the New ADC Design has issues:

- A large CaF2/fused silica doublet will have to be optically coupled in a similar manner to the RSS multiplets with all the complexities experienced with those optics. However, it is very easy to separate the CaF2 and fused silica elements and end up with an ADC comprising 3 air-spaced elements. This route has the drawback that an extra 2 air-glass surfaces have to be anti-reflection coated, with a concomitant throughput loss.
- Ken Nordsieck pointed out that any significant stress-birefringence of the CaF2 element will induce instrumental polarization in RSS in polarimetry mode.
- Based on experience from the RSS Collimator work, the cost of the CaF2 element will be large.
- The New ADC Design requires an offset of SAC to rho stage of 14 mm, double that of the existing ADC. This is so large it will probably require re-engineering of the payload architecture: rho stage or Non-Rotating Structure.

# 5. The Latest ADC Design

At the time of writing, the author decided to revisit the problem and try and find an option more straightforward than the New ADC Design discussed in the previous section. It occurred to him that revamping the spacings in the existing ADC, but starting from optimization for the NIR, and extending back to the UV, might lead to performance which may compromise some performance in the UV, but lead to acceptable performance in the NIR. Fortunately, this was successful and led to performance which is certainly worth considering along with the other options under discussion. This design will be called the “Latest ADC Design”.

It looks very much like the existing ADC and uses the same prisms. However, in the existing ADC (Fig. 2), the prism closest to the SAC is fixed and the other one translates as a function of zenith distance. In the Latest ADC Design, the arrangement is reversed so that the left hand prism is fixed and the other one translates. In addition, the positions of the prisms are different.

Image quality is a little worse in the UV and visible, but much better in the NIR, both on its own and in combination with the UV and visible. Quantitative comparison will be given in the next section.

Re-using the same prisms as in the existing system is very advantageous, of course, but they will have to be removed for recoating and this may entail a small amount of re-polishing. This remains to be seen.

The Latest ADC Design would, in addition, require a new optomechanical mounting and actuator system.

# 6. Comparison of Performance, Cost and Schedule For The Options

We now turn to a comparison of the options discussed above.

## 6.1 Image Quality

Image quality is measured using the diameter, in arcsec, encircling 50 per cent and 80 per cent of the energy over the bandpass. The SALT System Specification calls for EE(50) and EE(80), due to all sources of error but in the absence of atmospheric seeing, to be better than 0.6 and 0.9 arcsec respectively.

**No ADC**: It is clear from Fig. 1 that the NIR arm requires no ADC if used on its own (though acquisition using its detector rather than SALTICAM will be needed): EE50 = 0.3 arcsec and EE80 = 0.5 arcsec.

It is also clear that, without an ADC, image quality in the UV and visual will suffer: EE(50) = 1.4 arcsec and EE(80) = 2.1 arcsec.

A partially mitigating strategy is to operate RSS with its slit at the parallactic angle so that atmospheric dispersion spreads along the slit. This mode of operation is severely restrictive for long slit spectroscopy of those single objects which require a given slit position angle, as well as of extended objects or multi-object spectroscopy which almost certainly do require a specific position angle.

It was originally envisaged during the construction era that the ADC for the UV+visual would be swapped in and out for when the NIR instruments were required. However, this is operationally disadvantageous as it requires a day time operation and therefore limits the range of programs depending on whether the ADC is in or out. In addition, it is not practicable as it requires the removal of the HRS Fiber Instrument Feed and its autoguider to enable the ADC to be removed/replaced. There is a general risk of repeatedly cycling the ADC in and out: it is heavy and manhandling is not easy. Even more concerning is that the operation exposes the HRS fibers to the risk of breakage.

**Continue with the existing ADC as is**: It is clear from Fig. 3 that the UV+visible are, as at present, satisfactorily served by the existing ADC: EE(50) = 0.2 arcsec, EE(80) = 0.3 arcsec.

Performance of the NIR is compromised: even over the NIR wavelength range of 800 to 1700 nm, EE(50) = 0.5 arcsec and EE(80) = 0.75 arcsec, which consumes almost all the IQ error budget.

**Build the New ADC Design:** As mentioned, image quality is very good: EE(50) = 0.15 arcsec, EE(80) = 0.2 arcsec.

**Implement the "Latest ADC Design":** In the UV+visible, EE(50) = 0.22 arcsec and EE(80) = 0.33 arcsec. In the NIR alone (i.e. 800 – 1700 nm): EE(50) = 0.25 and EE(80) = 0.4 arcsec. Across the complete wavelength range (320 – 1700 nm), EE(50) = 0.3 arcsec and EE(80) = 0.5 arcsec.

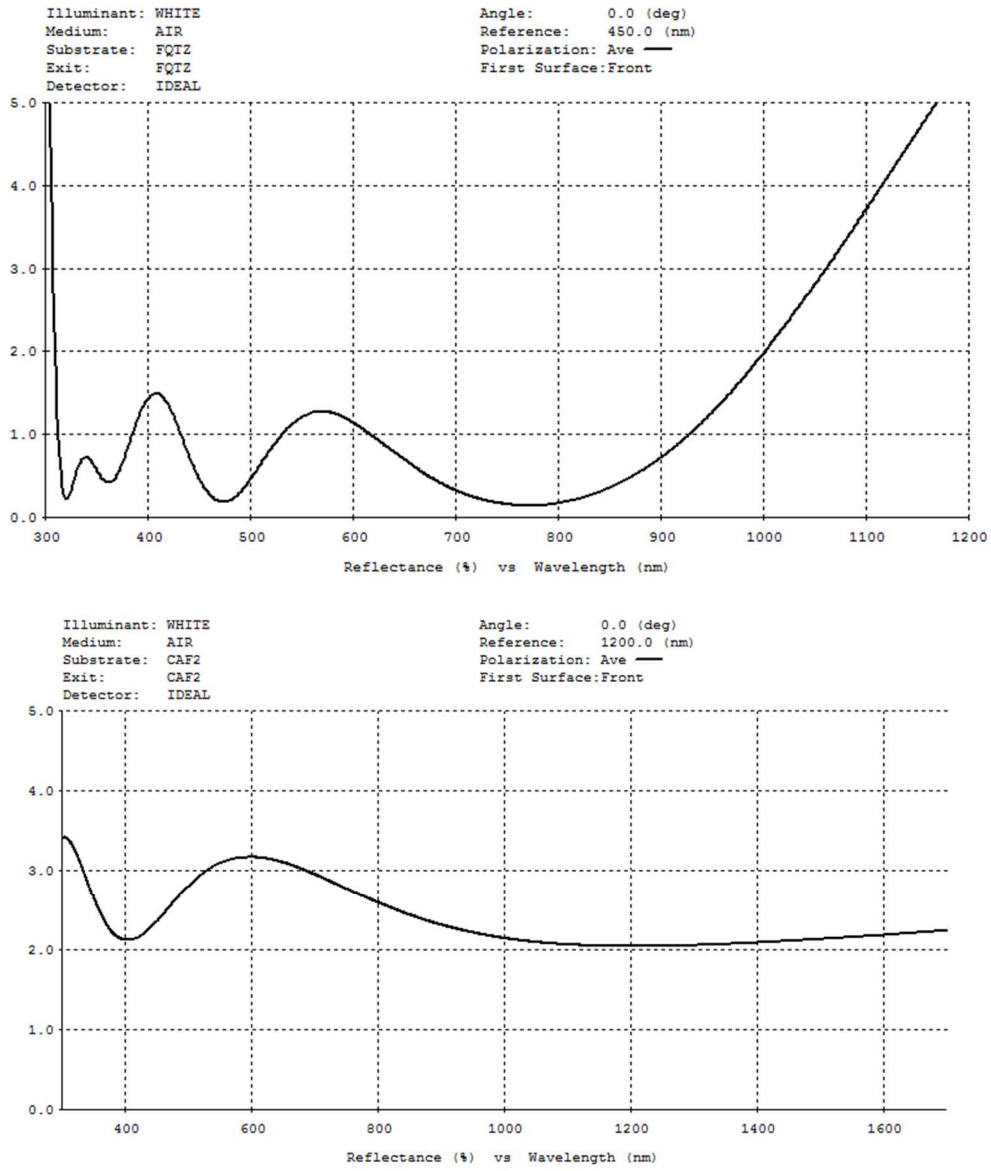



**Fig. 7: Anti-reflection coating performances: (top) coating of the kind that has just been applied to the new RSS Collimator doublet (which is only in the visible beam). (bottom) MgF2 coating applied to the new RSS Collimator Triplet.**

## 6.2 Throughput

All options under consideration use fused silica or CaF2 lens material which is "perfectly transmitting" over the 320 – 1700 nm wavelength range. The throughput issue revolves around anti-reflection coatings. At present, no robust, high performance anti-reflection coating for the full UV+visible+NIR wavelength range is available. The top plot in Fig. 7 shows a multi-layer coating applied a few weeks ago to the new RSS Collimator doublet. This is deployed only in the UV+visible beam so high performance is possible. The lower plot in Fig. 7 shows a MgF2 coating which is the best available option for the entire UV+visible+NIR bandpass.

We now consider the implications for the ADC options:

**No ADC**: It is obvious that performance will improve if the existing ADC is removed. It is coated similarly to the upper plot of Fig. 7. Assuming performance as shown there, removal will increase throughput by about 3 per cent.

**Continue with the existing ADC as is**: This would seem to be an unworkable strategy as the current AR coating is as per the top plot of Fig. 7. Performance rapidly deteriorates in the NIR.

**Build the New ADC Design:** The three elements of this would require the MgF2 coating (bottom plot in Fig. 7) with a loss of 12 to 18 per cent (depending on wavelength) from its 6 air-glass surfaces.

**Implement the "Latest ADC Design":** The existing AR coatings would have to be stripped and replaced with MgF2 coatings as per the bottom plot of Fig. 7. The 4 air-glass surfaces will result in a loss of 8-12 per cent.

An additional consideration is that stripping the existing coatings might require a small amount of re-polishing.

## 6.3 Technical Complexity

**No ADC**: It is, of course, easy to remove but the current 7 mm offset between rho stage (and therefore instruments) and the SAC optical axis, which is currently required by the existing ADC but would no longer be if it were removed, may be difficult to adjust.

**Continue with the existing ADC as is**: No adjustment required but poor performance in the NIR band, as well as poor throughput, as discussed above.

**Build the New ADC Design:** This option is by far the most technically complex:

- A completely new set of 3 prisms would have to procured, anti-reflection coated, optomechanically mounted.
- The CaF2 prism is a delicate glass (though much easier to handle as a singlet). The stress birefringence of the blank would have to be specified and measured to be very small.
- The 7 mm offset mentioned above would become 14 mm and compensating for that may be difficult.

**Implement the "Latest ADC Design":** Modest technical complexity:

- The existing AR coatings would have to be stripped and replaced with MgF2 coatings which might require re-polishing.
- A new optomechanical mount would have to be designed and built.

## 6.4 Cost

**No ADC**: An unknown, but perhaps small cost in fixing the 7 mm offset.

**Continue with the existing ADC as is**: None.

**Build the New ADC Design:** This option is by far the most expensive and would include:

- The cost of a completely new set of 3 prisms which would have to procured, anti-reflection coated, and optomechanically mounted.
- The CaF2 blank is likely to be very expensive.

**Implement the "Latest ADC Design":** Modest cost:

- The cost of stripping the existing AR coatings and replacing with MgF2 coatings, possibly involving a small amount of re-polishing.
- The personnel cost of designing and building a new optomechanical mount and actuator.

### 6.5 Schedule

**No ADC**: An unknown, but perhaps small amount of time requied to fix the 7 mm offset.

**Continue with the existing ADC as is**: None.

**Build the New ADC Design:** This is by far the longest option. A thumbsuck (probably aggressive) would be 12 months from the kickoff of the project.

**Implement the "Latest ADC Design":** Moderate schedule: perhaps 6 months from the kickoff of the project.

## 7. Summary

The table below summarizes the assessment of the options discussed in the previous section.

| Option: | No ADC | Existing ADC | New ADC | Latest ADC |
|---|---|---|---|---|
| **Image Quality** | Very poor | Poor | Excellent | Good |
| **Throughput** | Excellent | Poor in NIR | Average | Good |
| **Technical complexity** | Small | None | Very | Modest |
| **Cost** | Small | None | High | Modest |
| **Schedule** | Small | None | Long | Modest |

The author believes that the "No ADC" option is unacceptable, that the "Existing ADC as is" is a bad choice, and that the "Latest ADC design" is the best option.