The Optical Design of the WIYN One Degree Imager (ODI)

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ABSTRACT

The optical design for the WIYN One Degree Imager (ODI) is based on well-known princples for the design of secondary focus correctors of Ritchey-Chrétien telescopes. It started as the classical two element plus/minus pair of lenses required to correct moderate and wide fields of view whilst working with wide spectral regions. However, since this corrector is required to cover a one degree square and plane field of view, accommodate filters and an atmospheric dispersion compensator, it evolved into three elements. In order to avoid the addition of more glass than was absolutely necessary the third element was designed to serve the dual function of field flattener and dewar window. The final form presented here is plus/minus/minus in power distribution with well-separated elements. The ADC is situated between the first and second elements with filter between the second and third elements in an accessible position. Theoretically the worst-case image given is 90% of the ensquared energy into 2 by 2 pixels in the corner of the one degree square field.

Keywords: wide-field, optical corrector

1. INTRODUCTION

The WIYN Observatory, a consortium of 4 institutions (University of **W**isconsin – Madison, **I**ndiana University, **Y**ale University, and the **N**ational Optical Astronomy Observatory), is developing a large imager for its 3.5-m telescope on Kitt Peak. The telescope was designed and built to provide excellent image quality over a one-degree field of view. The One Degree Imager (ODI) project[1] will provide an optical camera with excellent pixel sampling and tip/tilt correction over the full 1-degree square. An optical corrector is required that delivers excellent images over this full field, at zenith distances <60º, and across a wide spectral region. A summary of the demands on the corrector is given in Table 1.

Table 1. Summary of ODI Corrector Requirements

Field of View	1.4 degrees circular (543 mm diameter)
Spectral bandpasses	UBVRIZ, plus various narrow-band
Spectral range	3200 Å –10,000 Å
Image quality	<10% degradation of delivered images (~0.2")
Pixel scale	0.11" (12μm)
Atmospheric dispersion	ADC required for λ > 4000 Å
Size and weight	Constrained by WIYN altitude bearing
Transmission properties	Minimal light loss
Optical miscellany	Telecentric, low distortion

2. DESIGN CONSIDERATIONS

The design for this 3-element corrector derives from the 2-element Harmer-Wynne corrector[2] developed for the Jacobus Kapteyn Telescope (JKT), a 1-m telescope with a 1.5° field of view located on La Palma. A third element was added to the WIYN 3.5-m design to serve as a field flattener. To reduce the number of glass elements in the beam, this last element also serves as the dewar window. In this role, it must be of the appropriate shape to withstand the atmospheric pressure force, and it must be located sufficiently far from the focal plane to allow for mounting on to the dewar. A direct consequence of this arrangement is that the science filters must be located *within* the corrector beam rather than behind it, as is usually the case. Figure 1 illustrates the basic corrector configuration.

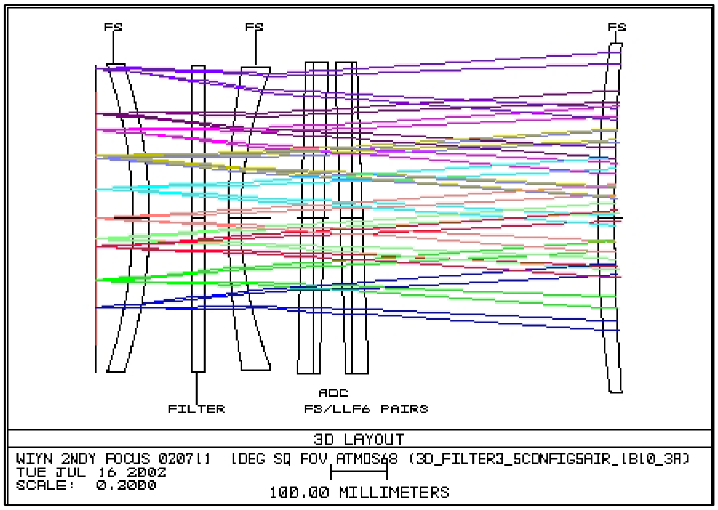


Figure 1. The 1.4 degree FOV corrector for the WIYN 3.5-m telescope with its One Degree Imager. The focal plane is to the left.

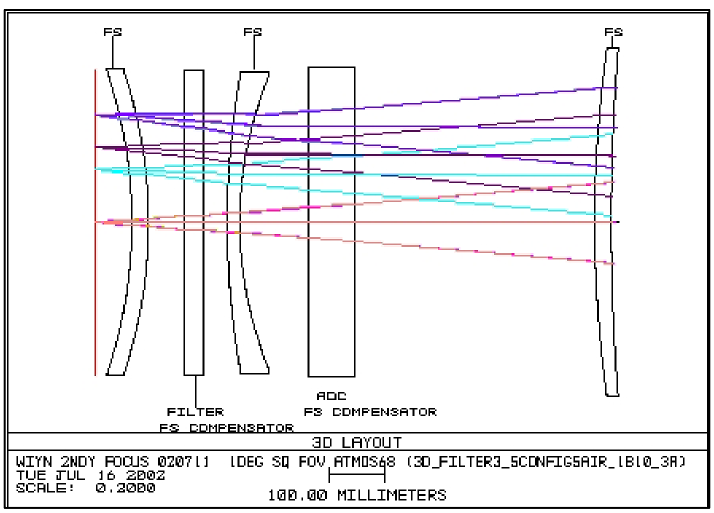


Figure 2. The corrector as above, but now with the ADC replaced by a "dummy" fused silica block to improve the UV transmission.

An overriding goal for ODI is excellent image quality. The WIYN telescope delivers superb images, and ODI's design includes low order adaptive corrections for image motion across the full one-degree field. Median image FWHMs are expected to be about 0.52", 0.45", and 0.35" in the RIZ bands, respectively. In order to maintain the delivered image quality, the corrector must not degrade the images and it must provide for atmospheric dispersion compensation (ADC) to allow operation away from the zenith. In addition, several of the science demands for ODI require good performance well into the blue spectral region. Because there are no 2-glass combinations that work well as an ADC below ~4000 Å without introducing considerable losses, we have devised a "removable" ADC system. The 4 glass elements of the ADC can be physically disengaged from the corrector and replaced by a pure plane fused silica element. Figure 2 shows the non-ADC layout. While, this optional configuration of the corrector no longer provides ADC functionality, it improves the overall glass transmission properties, as shown in Figure 3. No spacing changes are necessary when swapping the ADC with the "dummy" fused silica element.

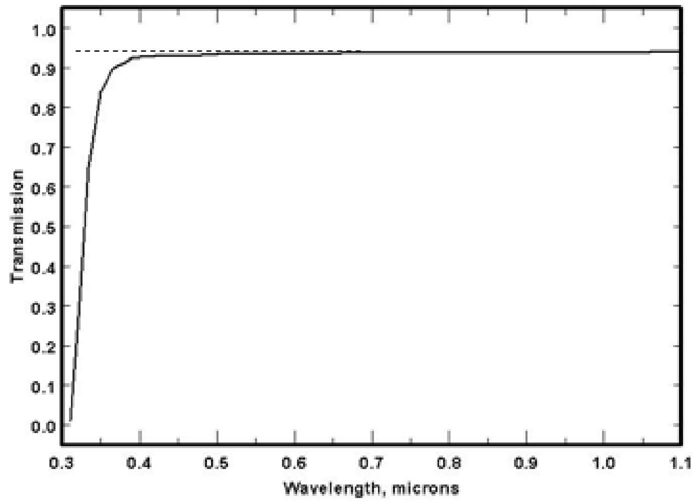


Figure 3. Transmission properties of the entire glass ensemble in the corrector, including losses incurred in the ADC. When the ADC is removed, the transmission is essentially perfectly flat across the spectral range, as shown by the dashed line.

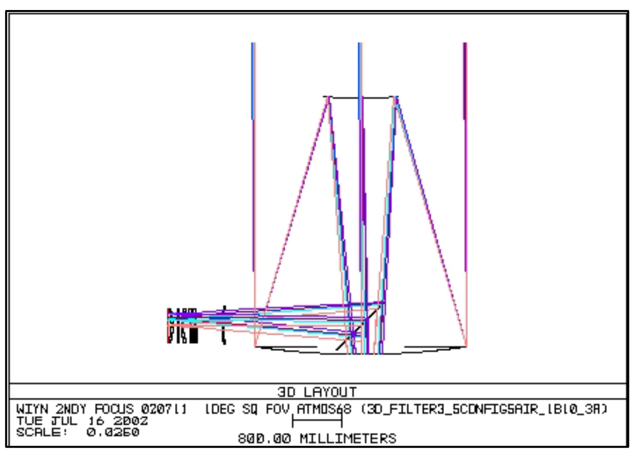


Figure 4. Overall WIYN telescope layout with the one degree corrector shown on the left Nasmyth port.

3. OPTICAL PERFORMANCE

Figure 4 illustrates the overall optical system. It is a Ritchey Chrétien design with an f/1.75 primary and a final delivered f/6.3 at the Nasmyth focus. The uncorrected scale of the system is 9.384"/mm on axis with slight pincushion distortion off-axis. The prescriptions for the telescope and corrector are given in Table 2 for the ADC case. When the ADC is swapped out for use in the UV, "surfaces" 13—23 are replaced by the items shown in Table 3.

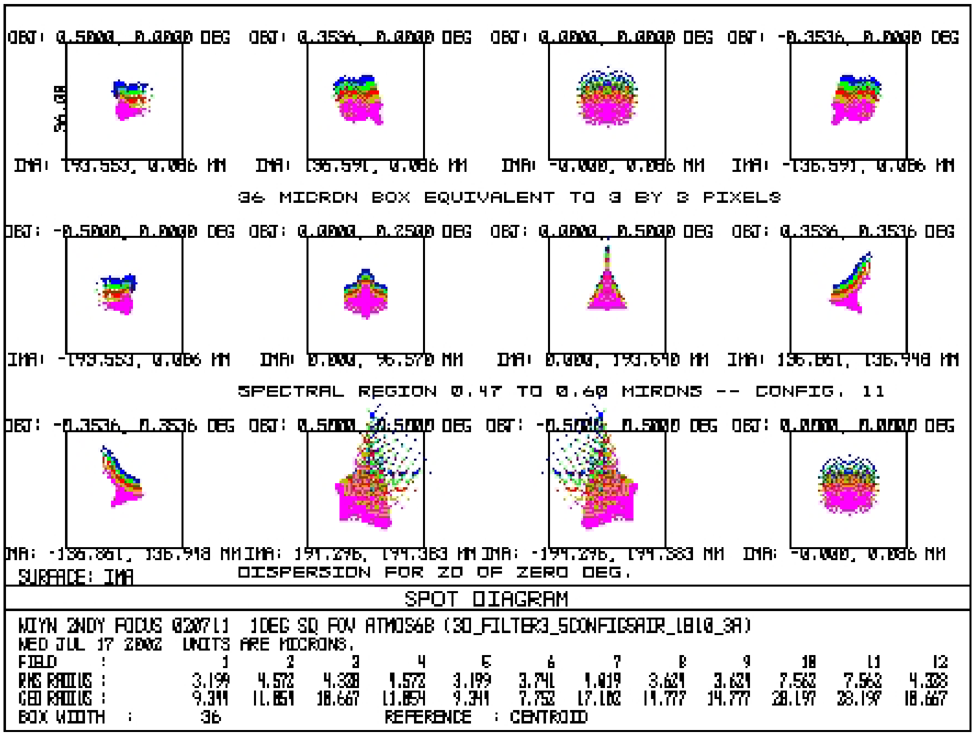
Table 2. Prescription for the WIYN One Degree Corrector

Surface	Type	Radius	Thickness	Glass	Diameter	Conic
OBJ	STANDARD	Infinity	Infinity		0	0
1	ATMOSPHR	Infinity	0		0	0
2	STANDARD	Infinity	5000		0	0
STO	STANDARD	Infinity	124.9238		3500.064	0
4	STANDARD	-12253.5	-4204.134	MIRROR	3500.064	-1.0708
5	STANDARD	-5332.5	4204.134	MIRROR	1212.846	-3.74
6	STANDARD	-12253.5	-475.4		801.4025	-1.0708
7	COORDBRK	-	0		-	-
8	STANDARD	Infinity	0	MIRROR	1154.016	0
9	COORDBRK	-	0		-	-
10	COORDBRK	-	0		-	-
11	STANDARD	Infinity	-2247.56		846.9875	0
12	STANDARD	4005.216	-29.99977	SILICA	629.6678	0
13	STANDARD	2250.28	-424.9986		629.3345	0
14	TILTSURF	-	-20	SILICA	560	-
15	STANDARD	Infinity	-20	LLF6	560	0
16	TILTSURF	-	-30		560	-
17	TILTSURF	-	-20	SILICA	560	-
18	STANDARD	Infinity	-20	LLF6	560	0
19	TILTSURF	-	-109.3662		560	-
20	EVENASPH	665.5526	-22.49983	SILICA	538.8021	0
21	STANDARD	1522.944	-42.44147		546.0576	0
22	STANDARD	Infinity	-25	OG570	548.7329	0
23	STANDARD	Infinity	-75.46893		549.3855	0
24	STANDARD	-861.1733	-29.99989	SILICA	554.3204	0
25	STANDARD	-850	-65.52161		548.881	0
26	STANDARD	Infinity	0		549.8404	0
27	COORDBRK	-	0		-	-
28	STANDARD	Infinity	0		549.8404	0
IMA	STANDARD	Infinity			549.8404	0

Table 3. Changes to Surfaces 13—23 When Replacing the ADC by Fused Silica

13	STANDARD	2250.28	-435.654		629.3345	0
14	TILTSURF	-	-85.12074	SILICA	560	-
15	STANDARD	Infinity	0		560	0
16	TILTSURF	-	0		560	-
17	TILTSURF	-	0		560	-
18	STANDARD	Infinity	0		560	0
19	TILTSURF	-	-123.5902		560	-
20	EVENASPH	665.5526	-22.49983	SILICA	538.8021	0
21	STANDARD	1522.944	-42.44147		546.0576	0
22	STANDARD	Infinity	-34.95722	SILICA	548.7329	0
23	STANDARD	Infinity	-65.51168		549.3855	0

With these designs, the images delivered are excellent across each of the bandpasses. Figures 5 and 6 illustrate the quality of the images with V- and "I"-band spot diagrams at representative zenith distances of 0º and 60º. The box sizes represent a 3x3 pixel grid, or 0.33" on a side. Note that the "I"-band is an ultra-wide selection, from 0.76 – 1.1 µm. By using this very wide bandpass, optimization of the optical design is stressed beyond normal observing conditions.



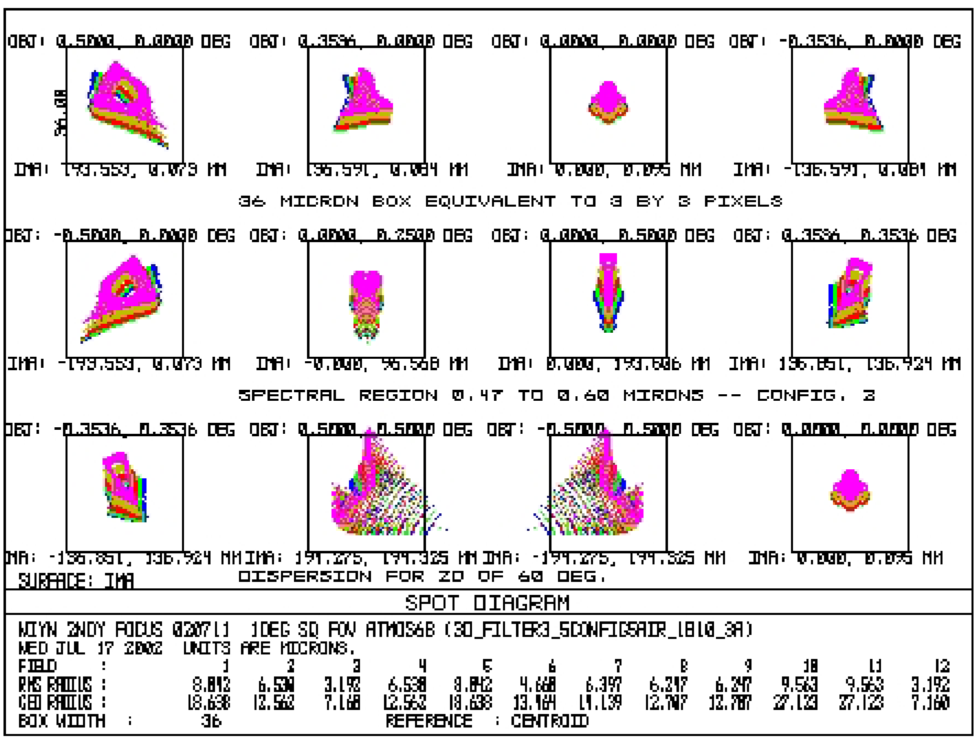
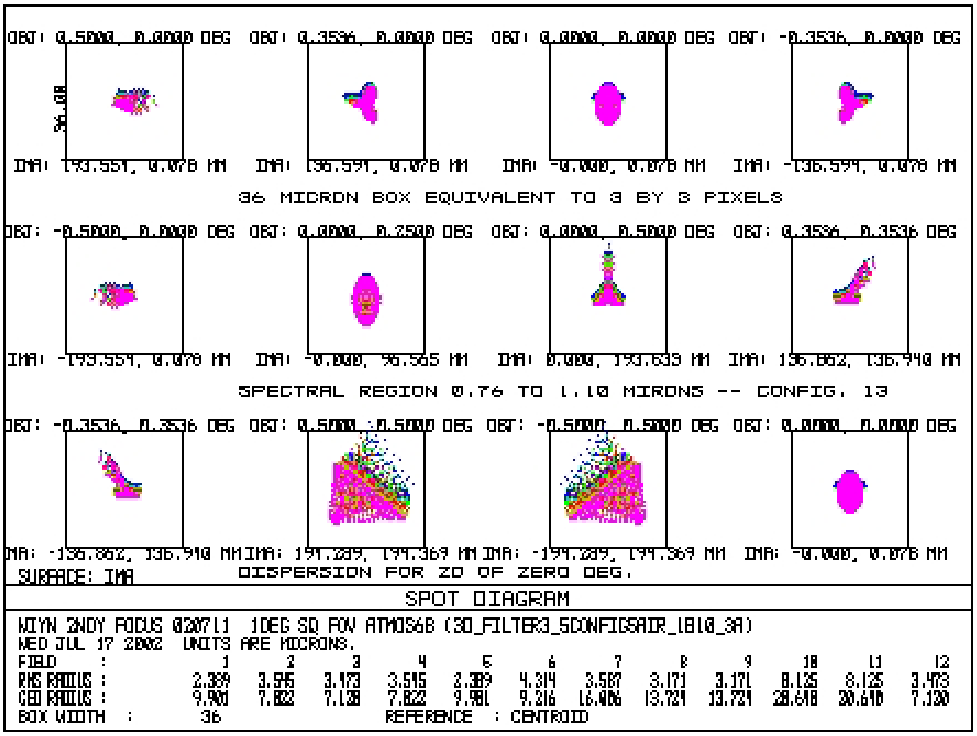


Figure 5. Spot diagrams for the V-band images across the full 1x1 degree field, at zenith distances of 0 (top) and 60 (bottom) degrees. The box sizes for this and the following figures are 3-pixel squares (0.33"x0.33").



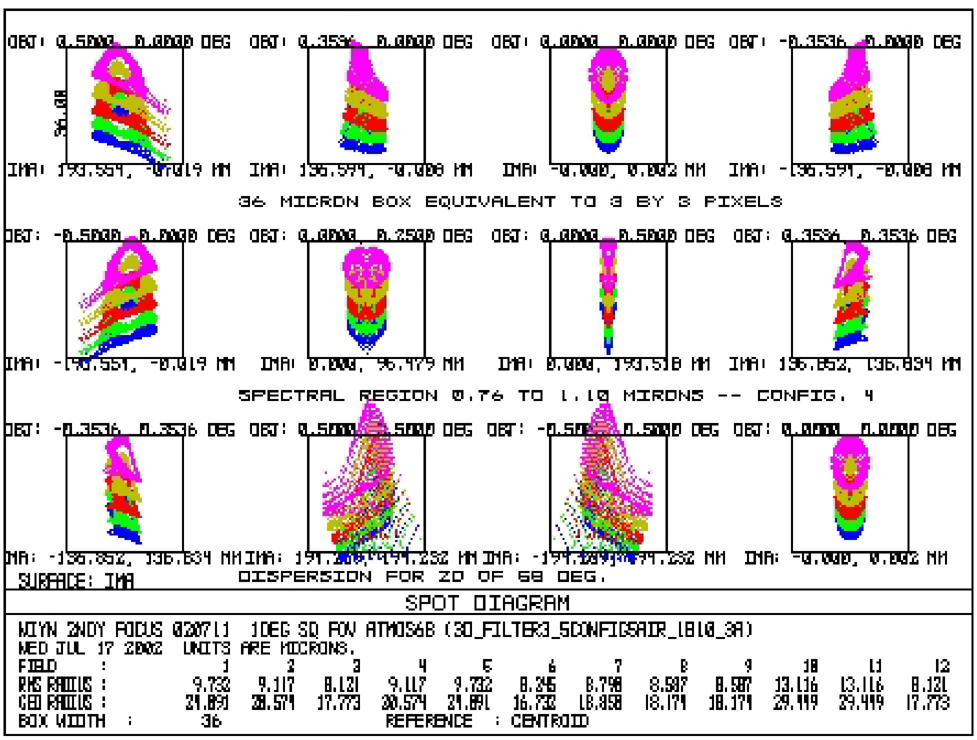


Figure 6. Spot diagrams for the "I"-band images across the field, at zenith distances of 0 (top) and 60 (bottom) degrees.

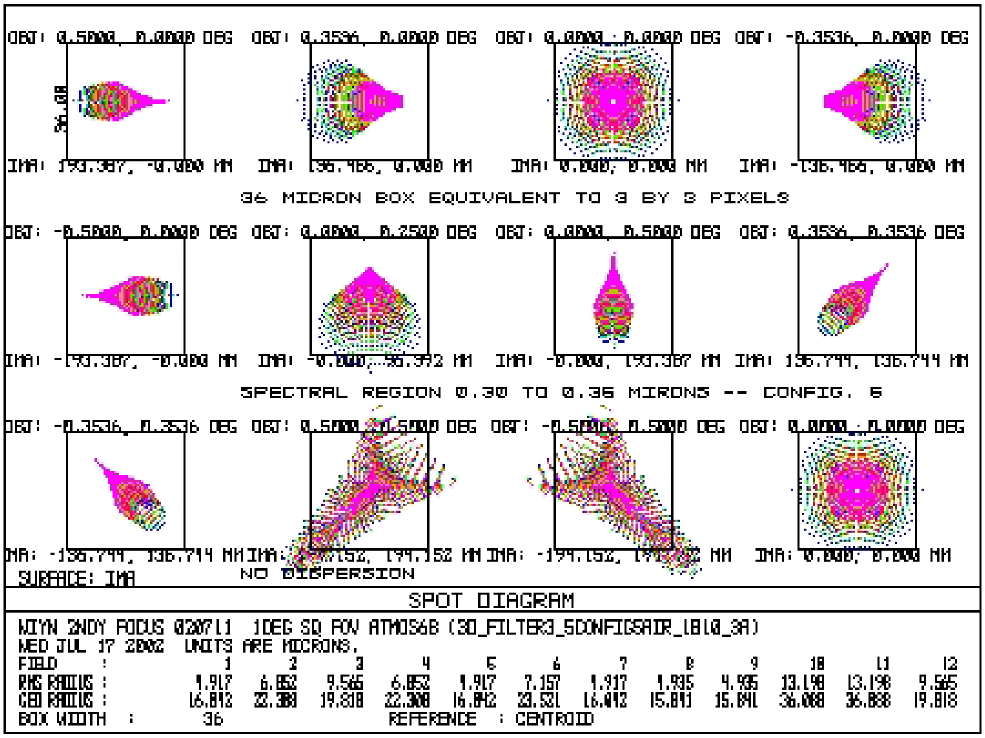


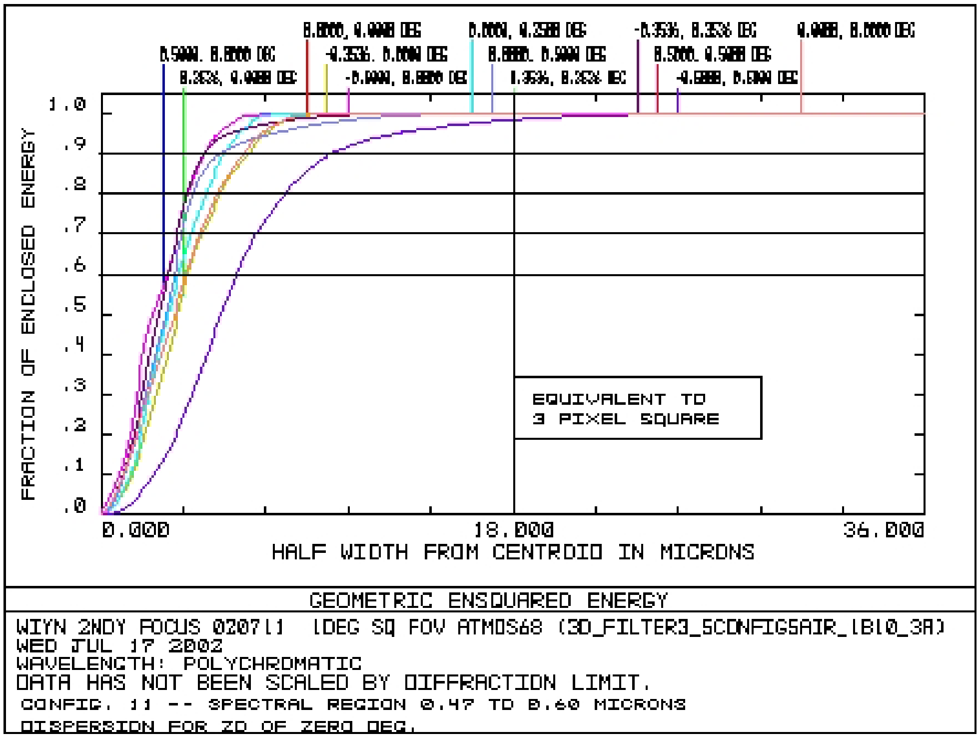
Figure 7. The UV case (at zenith) showing the spot diagrams for the non-ADC/fused silica configuration of the corrector. The bandpass shown is very blue (3000 Å – 3500 Å), as required for certain science cases.

In the UV case, when the ADC is removed and fused silica inserted in its place, there is no compensation for the atmospheric dispersion. This case is shown in Figure 7.The encircled energy diagrams for the cases represented by Figures 5, 6, and 7 are shown in Figures 8, 9, and 10. Encircled energy diagrams provide a more quantitative description of the image quality.

Overall, the images through the telescope plus corrector in the ADC-corrected case are excellent, having 80% encircled energy diameters of 0.13" –0.19". Images in the field corners, though, degrade somewhat, having FWHM values as large as 0.24". Similarly, for the UV case, the worst images are 0.2" or better, except in the corners. For the UV, though, the omission of an ADC will lead to serious atmospheric dispersion aberrations when observing away from the zenith.

Distortion at the WIYN telescope has always been minor. With this new corrector, the distortion, at ~0.8%, remains under control. A sample diagram of the distortion map is shown in Figure 11, magnified by a factor of 5.

The final f/ratio at the corrected focal plane is f/6.31 and the final scale is 9.339"/mm.



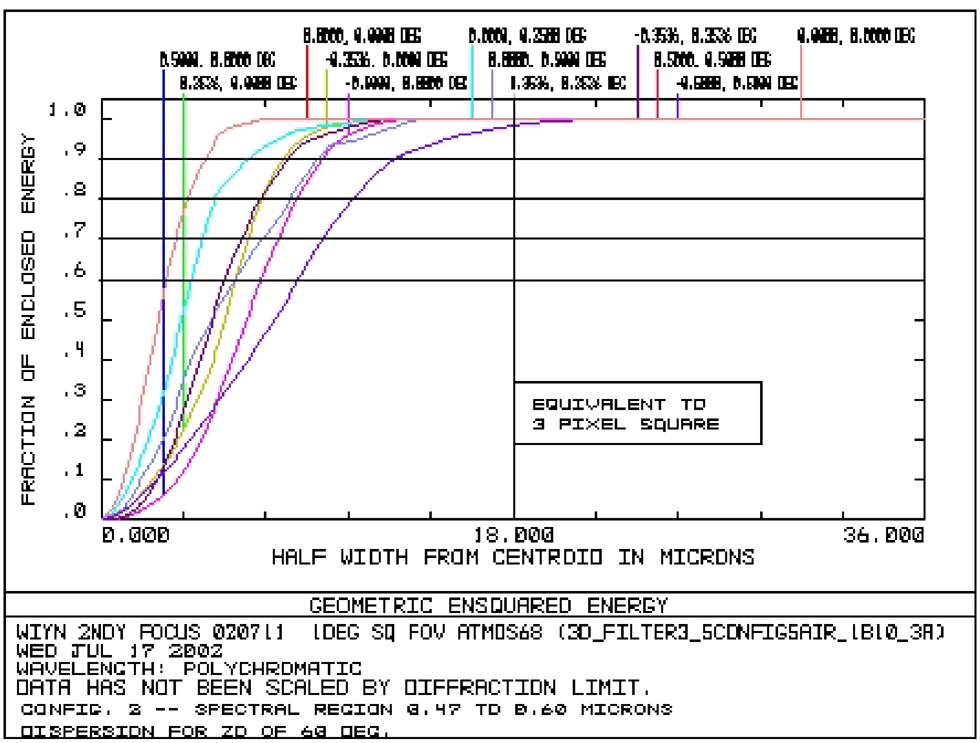
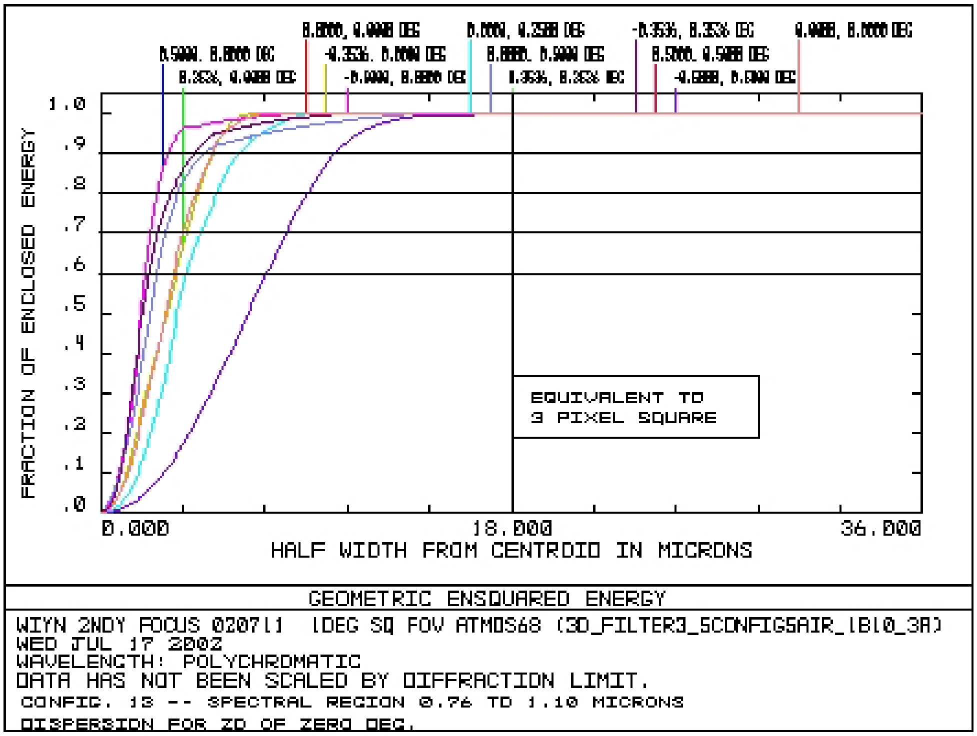


Figure 8. Encircled energy diagrams for the V-Band spots shown in Figure 5.



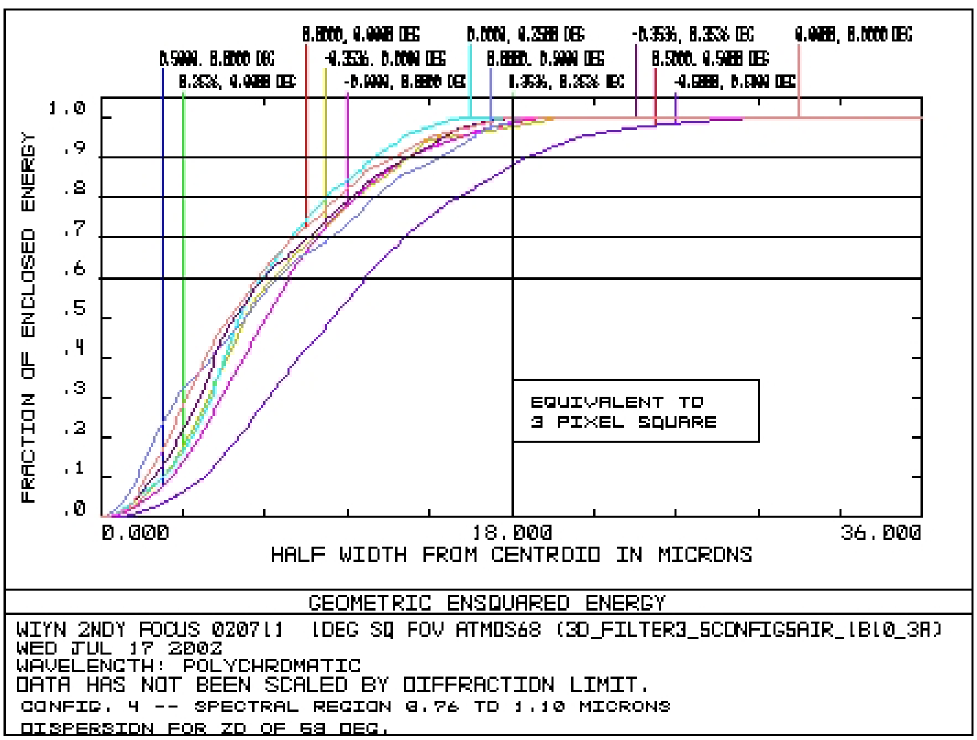


Figure 9. Encircled energy diagrams for the "I"-Band, equivalent to the spots of Figure 6.

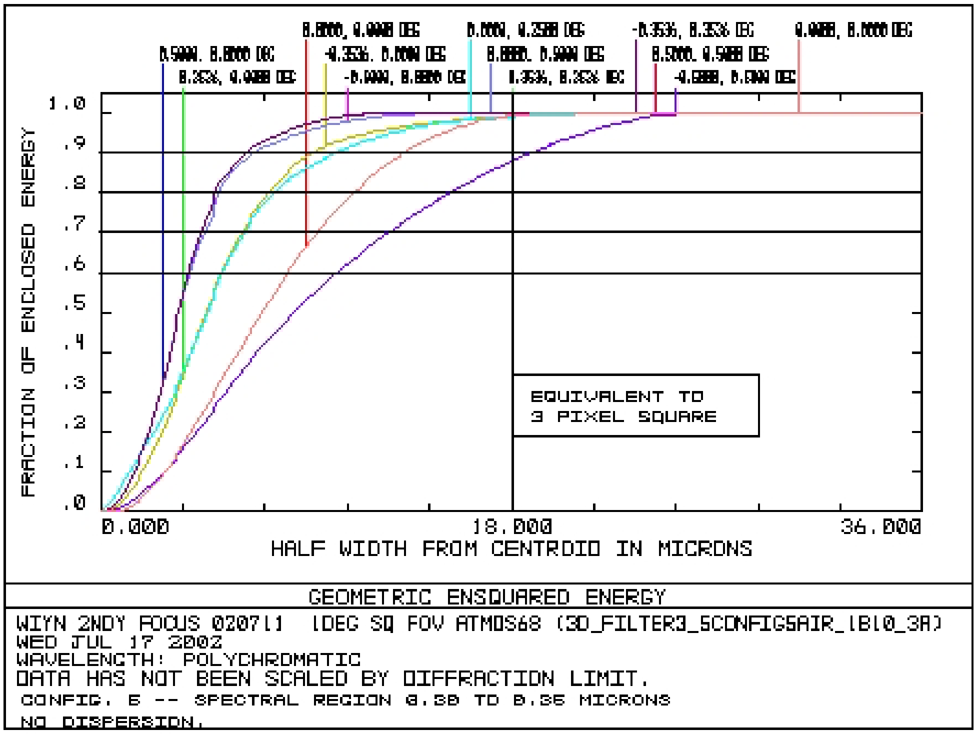


Figure 10. The encircled energy diagram for the very blue case, when the ADC is removed.

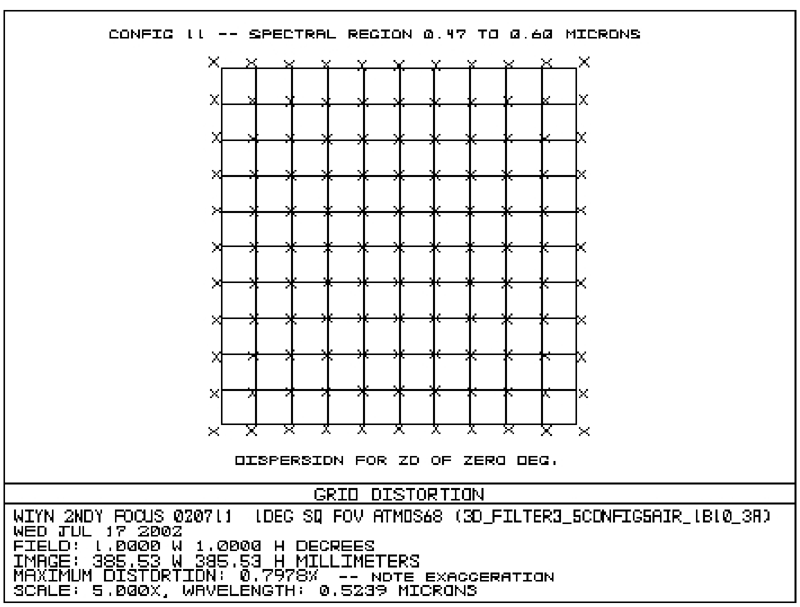


Figure 11. V-Band distortion map magnified by 5X. The pincushion distortion is ~ 0.8%.

4. PHYSICAL CONSTRAINTS

The corrector is constrained somewhat by the physical design of the telescope. While we wish to achieve correction over a full 1 degree square, thereby correcting a circular field of 1.4 degrees in diameter, the telescope was only designed to provide a 1 degree circular field. The Nasmyth bearing opening and its position relative to the telescope optics limits the ultimate field size that can be delivered. Several of the physical dimensions are not accurately known at this time, and WIYN is determining those variables right now. Our best estimate for the available field is slightly larger than 1 degree, but far short of the 1.4 degrees required. The consequent vignetting approaches 40% in the corners of the fields, as shown in Figure 12. Vignetting losses remain under 10%, though, for a field of view having a diameter of 1.1º, or an inscribed square field of 0.78º on a side.

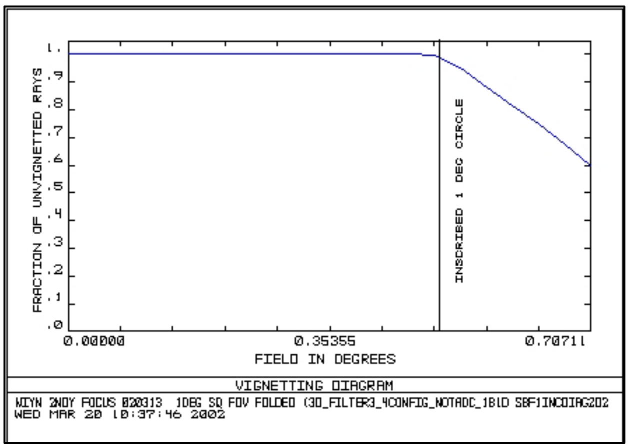


Figure 12. The vignetting function for the one degree corrector as a function of radius. Losses approach 40% in the corners of the field, unless modifications are made to the telescope bearing.

In addition to the field limit set by the bearing aperture, the telescope bearing can support a limited amount of weight and torque. The weight limit that can be supported is 725 kg (1600 lbs). These limits can be partly ameliorated by installing the front elements of the corrector inside the bearing and supporting the instrument+corrector, if necessary, with an additional frame structure that relieves the bearing loads. We do not have a weight estimate for the corrector housing, or the rest of ODI yet, and so, the corrector weight is not an issue at this point.

5. SUMMARY

We have developed a preliminary design for a wide-field corrector for the WIYN 3.5m telescope. The driver for the corrector is a planned One Degree Imager that will image a full 1x1 degree field. Further enhancements to the design will be forthcoming, although the current status is already very close to meeting the specifications. The principal remaining issues to be addressed are improving the image quality in the field corners, and reducing the degree of vignetting through the Nasmyth bearing.

6. REFERENCES

1. G.H. Jacoby, J.L. Tonry, B.E. Burke, C.F. Claver, B. Starr, A. Saha, G.A. Luppino, and C. Harmer, "The WIYN One Degree Imager (ODI)", *SPIE Vol 4836*, this conference
2. C.F.W. Harmer, and C.G. Wynne, "A Simple Wide-Field Cassegrain Telescope", *MNRAS Vol 177*, pp 25p-30p.