The WIYN One Degree Imager Optical Design

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ABSTRACT

The main advantage of the WIYN One Degree Imager (ODI)[1,2] over other wide-field imagers will be its exceptional image quality. The fine pixel scale (0.11”) provides uncompromised sampling of stellar PSFs under most conditions (seeing >0.3”). The telescope routinely delivers the site seeing (median ~ 0.7”) which is often below 0.5” FWHM, and can be as low as 0.25”. The ODI specifications require the optics to maintain native high quality images. A two-element, fused silica, corrector meets the geometric error budget of 0.10” images, but the first element requires a mildly aspheric surface. The other element serves as the dewar window. A pair of cemented prisms (fused silica plus PBL6Y) serve as an ADC, which is essential to meet the image quality requirements for many observing programs. We describe the optical design details and its performance, the tolerances required, and the trade-offs considered for anti-reflection coatings. This paper is an update to a preliminary three-element design[3].

Keywords: wide-field, optical corrector, ADC, anti-reflection coatings, imager

1. INTRODUCTION

1.1 WIYN and the One Degree Imager (ODI)

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[1,2] will provide an optical camera with excellent pixel sampling and tip/tilt correction over the full 1° square. An optical corrector is required to deliver excellent images over the full field, at zenith distances <60°, 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 Design Requirements

Field of View	1.4° circular (543 mm diameter); 1° unvignetted
Spectral bandpasses	U,g’,r’,i’,z’, plus various narrow-band
Spectral range	3400 Å –10,000 Å
Image quality	<10% degradation of delivered images of 0.20"
Pixel scale	0.11" (12μm)
Atmospheric dispersion	ADCs required
Size	Constrained by WIYN altitude bearing (537 mm)
Transmission properties	Minimal light loss via multilayer coatings
Optical miscellany	Telecentric, low distortion

1.2 Costs and Funding

ODI was estimated to cost about $6.5M in 2004, including detector design and development for an entirely new type of CCD array[4]. An agreement through the NSF Telescope System Instrumentation Program (TSIP) is funding $1.6M of the total and the WIYN partners are providing the remainder. Recent cost estimates suggest that the total cost of the project will exceed the original estimate primarily due to detector development, inflation, and the Euro-Dollar exchange rate. The corrector costs increased from the original estimate in two areas: the flint glass needed for the ADC prisms, and the

AR coatings. The TSIP estimate was based on a quote for LLF6HT, which was not available in the sizes needed; Ohara's PBL6Y was used instead. The AR coatings are a complex issue and are discussed in section 6.

2. SCIENCE REQUIREMENTS

The ODI Requirements Document (ODI-AD-01-0008) specifies the optical requirements for the corrector. Table 1 gives an overview of the specifications relevant to the corrector, based on the programs that consortium scientists plan to undertake with ODI.

2.1 Image Quality

There are several wide-field imagers in place or under construction (CFHT Megacam, Dark Energy Camera, PanSTARRS, LSST, Subaru Hyper-Suprime). WIYN's strength among these facilities is image quality. The uncorrected median seeing at WIYN has been 0.7" FWHM over many years; nights of 0.35" seeing are not unusual. When compared to a site monitor, WIYN tracks the site performance very well. Because ODI will implement orthogonal transfer CCDs[4] to correct for tip/tilt image motion due to atmospheric effects, telescope shake, and guider errors, the median images will be improved ~15%. To maintain WIYN's unique place among wide-field imagers, ODI makes no compromises that would significantly impact the delivered image quality (DIQ). Thus, small pixels (0.11") are adopted, and the optics and mechanical supports are designed appropriately. The image quality requirements that affect the corrector design are the following, which must be met over 90% of the unvignetted 1° field of view:

- Image degradation must be less than 10% in seeing of 0.20" in U,g',r',i,'z' for airmasses up to 1.3.
- Images may degrade for airmasses up to 1.5 following an airmass$^{0.6}$ law, thereby requiring an ADC.
- Ellipticity of images must be less than 0.15 and variations in the point spread function (PSF) must be less than 3% on scales smaller than 4 arcmin.
- An atmospheric dispersion compensator (ADC) is required, especially to correct the g' bandpass, up to an airmass of 2. The figure below illustrates the degradation in the g' band at airmass of 1.3 if no ADC is provided – the image quality degrades from 0.4" to ~0.7".

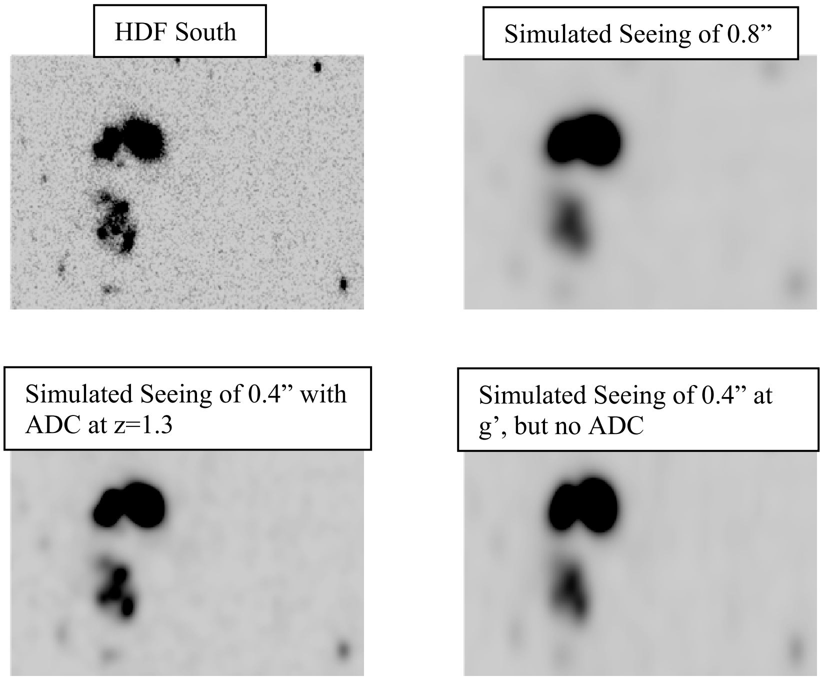


Figure 1. Simulation of the loss in resolution with no ADC to compensate for atmospheric dispersion. The image in the lower left shows that nearly all the galaxies in the HDF image (upper left) are identifiable with the ADC. In the lower right, the image is so smeared that individual galaxies become lost and the effective resolution is almost as bad as 0.7".

2.2 Wavelength Coverage

ODI is required to provide good transmission performance from the Johnson U-band through the SDSS z' band (3400 Å to 10,000 Å). The requirement for an ADC, and our choice to implement dual rotating prism pairs, limits the options for glass selection. The ODI corrector uses fused silica and PBL6Y pairs.

The broad wavelength coverage imposes special demands on the anti-reflection (AR) coatings. With 8 air-glass surfaces, good coatings are necessary to maintain transmission and minimize ghosts (see section 6).

2.3 Narrow-Band Imaging

The slow f/ratio at WIYN (f/6.3) allows the use of narrow-band filters with very little degradation of the filter performance (peak transmission, bandpass expansion, blue shift) that occurs in faster beams. The optical design must accommodate narrow-band filters, implying that the corrector must not reduce the f/ratio significantly, and that there be a location in the light path that is nearly telecentric.

3. OPTICAL AND PHYSICAL CONSTRAINTS

The most significant constraint on the corrector optical design was that it work with the existing telescope. The most difficult aspect of this requirement is that one must know the telescope properties very well. We performed several experiments to verify our understanding of the telescope. For example, we obtained out of focus images at various field positions with no corrector optics. By comparing these images with predictions from the Zemax model at those same field points, we can estimate the accuracy with which we know the telescope as-built mirrors.

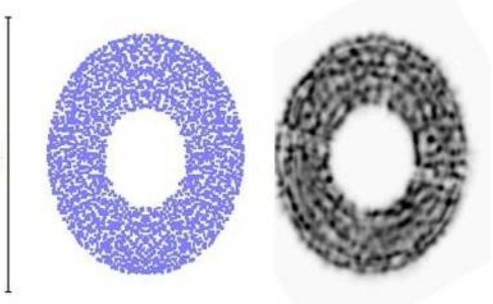


Figure 2. Out of focus images at the edge of the WIYN field of view (0.5°). The vertical bar on the left is 4 mm long in the focal plane. The left "donut" is a prediction from Zemax for this field position, while the image on the right is actual data.

In addition, we verified the scale and distortion terms of the optical system using the Hydra[5] fiber positioner. Hydra is a robotic system that deploys up to 100 optical fibers across a 1° focal plane. By locating stars across the full field and measuring their displacements relative to very accurate astrometry, we mapped out the scale and distortion terms for the as-built telescope. All measurements were correct to within 0.5", which is consistent with the error of the positioner.

The residual uncertainty in the telescope prescription was estimated and added to the total system error budget.

3.1 Field of View

The WIYN telescope is optically and mechanically designed to provide a 1° unvignetted field of view. The dimensions of the tertiary mirror and Nasmyth bearing opening introduce vignetting beyond the design field diameter. Nevertheless, ODI is designed with a 1° *square* detector array, for which the corners will suffer 40-50% vignetting. Image quality and flat-fielding requirements are relaxed beyond the unvignetted field.

3.2 Weight

Five of the 6 glass elements are quite thin – 20-30 mm. The only thick element is the dewar window, which must support the atmospheric pressure. Its thickness varies from 50 mm at the center to 78 mm at the edge. Thus, only this last element has significant weight. It is over-designed, as recommended by panelists at the ODI preliminary design review, to ensure that the valuable focal plane is protected. Weights for each element are given in section 4.5.

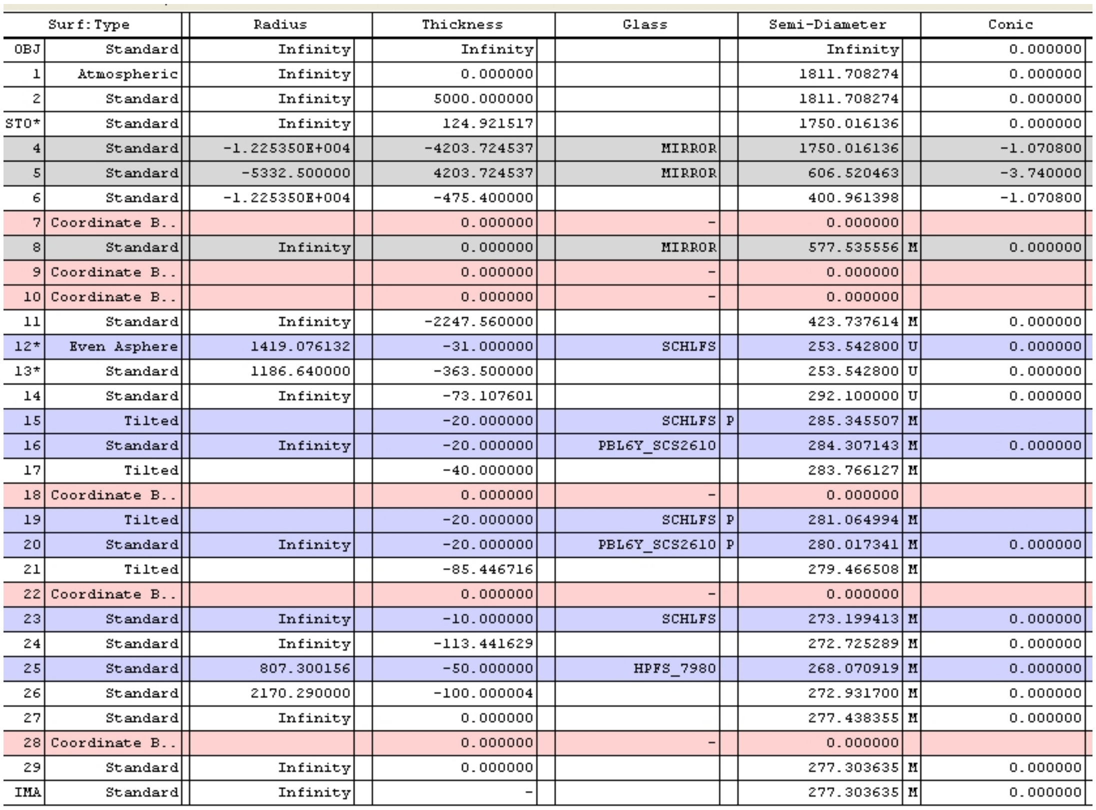
3.3 Glass Availability

In the original plans for the corrector[3], all elements were made from fused silica except for LLF6 ADC prisms. To accommodate the near-UV transmission requirement, we planned to remove the ADC prisms. Operationally, this is not viable because many observing programs change filters into and out of the U-band rapidly and repeatedly. Thus, the ADCs must be usable as far into the UV as possible. One good glass combination that works down to 3400Å is fused silica and PBL6Y (Ohara). High quality blanks of PBL6Y were available in the sizes needed with a 6-8 month lead time.

4. OPTICAL DESIGN

The 2002 design for the ODI corrector[3] was based on 3 elements of fused silica. That design derives from the 2-element Harmer-Wynne corrector[6] developed for the Jacobus Kapteyn Telescope (JKT), a 1-m telescope with a 1.5° field of view located on La Palma. All of those elements had spherical surfaces. By replacing one surface with a mild asphere, we were able to completely remove one element with no significant loss of image quality, thereby reducing weight and the number of parts. From the standpoint of cost, there is some advantage in having the asphere, but the added complexity of polishing and testing the aspheric surface partially compensates for the reduced number of elements. From a system standpoint, there are now two fewer surfaces to coat that might otherwise be adding ghosts, and one less lens cell to design and fabricate. The final prescription of the telescope plus corrector is given below:

Table 2. Zemax description of the telescope and corrector design parameters.



Surf:Type		Radius		Thickness		Glass		Semi-Diameter		Conic
OBJ	Standard	Infinity		Infinity				Infinity		0.000000
1	Atmospheric	Infinity		0.000000				1811.708274		0.000000
2	Standard	Infinity		5000.000000				1811.708274		0.000000
STO*	Standard	Infinity		124.921517				1750.016136		0.000000
4	Standard	-1.225350E+004		-4203.724537		MIRROR		1750.016136		-1.070800
5	Standard	-5332.500000		4203.724537		MIRROR		606.520463		-3.740000
6	Standard	-1.225350E+004		-475.400000				400.961398		-1.070800
7	Coordinate B..			0.000000		-		0.000000		
8	Standard	Infinity		0.000000		MIRROR		577.535556	M	0.000000
9	Coordinate B..			0.000000		-		0.000000		
10	Coordinate B..			0.000000		-		0.000000		
11	Standard	Infinity		-2247.560000				423.737614	M	0.000000
12*	Even Asphere	1419.076132		-31.000000		SCHLFS		253.542800	U	0.000000
13*	Standard	1186.640000		-363.500000				253.542800	U	0.000000
14	Standard	Infinity		-73.107601				292.100000	U	0.000000
15	Tilted			-20.000000		SCHLFS	P	285.345507	M	
16	Standard	Infinity		-20.000000		PBL6Y_SCS2610		284.307143	M	0.000000
17	Tilted			-40.000000				283.766127	M	
18	Coordinate B..			0.000000		-		0.000000		
19	Tilted			-20.000000		SCHLFS	P	281.064994	M	
20	Standard	Infinity		-20.000000		PBL6Y_SCS2610	P	280.017341	M	0.000000
21	Tilted			-85.446716				279.466508	M	
22	Coordinate B..			0.000000		-		0.000000		
23	Standard	Infinity		-10.000000		SCHLFS		273.199413	M	0.000000
24	Standard	Infinity		-113.441629				272.725289	M	0.000000
25	Standard	807.300156		-50.000000		HPFS_7980		268.070919	M	0.000000
26	Standard	2170.290000		-100.000004				272.931700	M	0.000000
27	Standard	Infinity		0.000000				277.438355	M	0.000000
28	Coordinate B..			0.000000		-		0.000000		
29	Standard	Infinity		0.000000				277.303635	M	0.000000
IMA	Standard	Infinity		-				277.303635	M	0.000000

The corrector adds no power to the system, resulting in a final f/ratio of f/6.29 and a plate scale of 9.324”/mm.

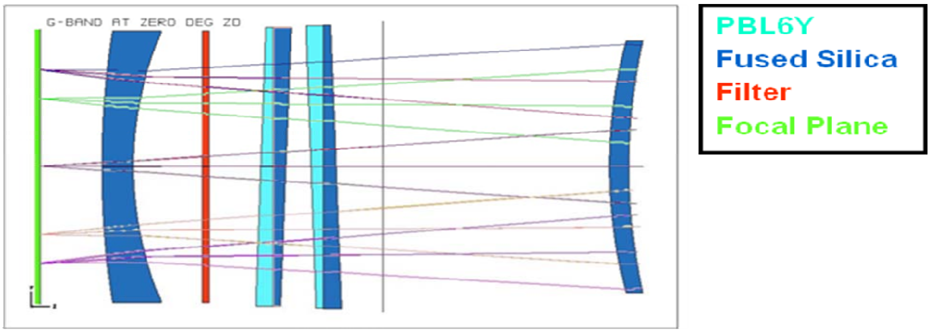


Figure 3. Schematic view of the ODI corrector.

4.1 Aspheric Surface

We experimented with moving the asphere to different surfaces, but the image quality remains fairly constant. If placed on the dewar window (L2), it is so close to the focal plane that the departures from a spherical surface must be large to have an effect – about 500 µm. This is not so large that it cannot be polished, but it was initially a concern. An advantage of the L2 location (the exterior surface of the dewar window) is that the tolerances on the asphere are fairly loose. A disadvantage of this surface is that it may occasionally be fogged because it is a cold surface, and frequent cleaning of the aspheric surface was considered a risk.

Ultimately, the asphere was moved to the first surface of the first element (L1). The arguments for doing so were that its concave shape was somewhat easier to test (like a mirror) during fabrication and that the departure from a spherical surface is quite small – only 72 µm. Because this surface is so far from the focal plane, the tolerance on the surface figure is fairly tight.

The asphere follows the form

$$z = \frac{y^2}{R}\frac{1}{1+\sqrt{1-(1+K)\frac{y^2}{R^2}}} + \alpha_2 y^4 + \alpha_3 y^6 + \alpha_4 y^8 + \alpha_5 y^{10}$$

where:

$R = 1419.08 \pm 1.4$ mm
$K = 0$
$\alpha_2 = 8.2491 \times 10^{-11}$ /mm^3
$\alpha_3 = -2.0896 \times 10^{-16}$ /mm^5
$\alpha_4 = 2.4252 \times 10^{-21}$ /mm^7
$\alpha_5 = -1.4840 \times 10^{-29}$ /mm^9

4.2 Atmospheric Dispersion Compensation (ADC)

The ADC was required to operate in all the standard filters (U, g’, r’, i’, z’), and from the zenith down to 2 airmasses. The fused silica / PBL6Y wedges are able to do so. One can cement the pairs together, which eliminates 4 air-glass surfaces, but introduces some risks, or leave gaps between the wedge pairs, which become a source for significant ghosting.

There are three primary risks in cementing: (1) handling the glass, (2) introducing bubbles in the cemented pair, and (3) creating mechanical stress due to the different thermal expansion coefficients. We plan to proceed with cementing the wedges and managing these risks in the following ways.

1. Handling fixtures were built to allow one element to be safely lowered onto the other after applying cement.

2. The process is being practiced multiple times on test parts (aluminum and lexan) – so far, we have not encountered any problems with bubbles or handling.
3. The cement is selected to be pliable (Dow Sylgard 184) and is cured in an environmental chamber at a median temperature (55 F) so that the worst case temperature deviations seen at the observatory are reduced by 20 F from curing at room temperature.

4.3 Dewar Window

The dewar window is the second element (L2) of the corrector. Under atmospheric pressure, a 23 μm sag will be introduced. For the thickness adopted for ODI, the glass strength is more than adequate to support the pressure. The AR coating on the back of the lens, however, will be stretched and could crack if not designed to be pliable.

4.4 Filter Location

The filters must be placed in a telecentric location, if possible, because they are interference filters. In the 2002 design, which required 3 elements, filters had to be located between L1 and L2 rather than between L2 and L3. Having eliminated one element, filters can be placed anywhere now since they are guaranteed to be between L1 and L2. Thus, we only need to identify a position that meets the mechanical constraints.

4.5 Tolerances

If ODI were simply an imager on a 3.5-m telescope, it would not be competitive with other imagers having a larger field of view (e.g., LSST, Dark Energy Camera, PanSTARRS) or imagers on larger telescopes (e.g., Subaru Suprime and Hyper-Suprime). ODI's raison d'être is image quality and sampling. We have been uncompromising toward the goal of excellent images. Consequently, many of the tolerances on the entire ODI system are tight, including the flatness of the focal plane array, the stiffness of the instrument, the provision to automate telescope focus during exposures, and the optical fabrication. To that end, the optical tolerances were examined in the context of the entire ODI system.

A tolerance budget was prepared, taking into account a reasonable range of airmasses, and considered for the variety of filter bandpasses. For the full system, the image quality specification requires that the FWHM of the images must not degrade more than 20% when the delivered images are 0.25" or more. The error budget was then distributed to the various system components and negotiated with the engineers. Ultimately, the dominant error sources were assigned as optics (20%: manufacture and assembly alignment), gravity deformations (29%: gravity, thermal, vacuum load and vibration), and focal plane/detectors (23%: CCD charge diffusion, flatness, ocus sensor errors). The remaining image error sources are collimation, uncertainty in the telescope as-built prescription, and telescope and rotator tracking. Subsequent negotiations with the optics vendor resulted in small adjustments to tolerances on radii, centration, and tilts to remain within the optics budget while reducing the risks in fabrication. Key parameters are listed below:

Table 3. Tolerances on the radii, thicknesses, and angles of the key corrector elements.

Optical Element	Weight, kg	Parameter (mm or degrees)
L1, surface 1 (asphere)	14.1	Radii and aspheric terms given in Section 4.1; total wavefront error in transmission <60 nm
L1, surface 2 (convex)		R = 1186.6 ± 0.6
L2, surface 1 (concave)	36.3	R = 807.3 ± 0.8
L2, surface 2 (convex)		R = 2170.2 ± 3
ADC 1, 3 (fused silica)	11.9	Thickness = 20.0 ± 0.5; angle = $1.752^{+0.010}_{-0.000}$
ADC 2, 4 (PBL6Y)	15.7	Thickness = 20.0± 0.5; angle = $1.627^{+0.010}_{-0.000}$

Maintaining the alignment of the elements is crucial for performance, and the lens mounts are designed to support the glass within their tolerances. Because some of these elements are thin relative to their diameters, deformation under gravity loading was also considered in the lens mount design[7].

5. PREDICTED PERFORMANCE

Performance of the corrector is measured primarily in terms of image quality. Other key parameters are ghosting, telecentricity, and distortion.

5.1 Spot Diagrams

One graphical metric for image quality is a spot diagram. These are not as quantitative as encircled energy diagrams, but illustrate the image shapes nicely. For this report, we include only the Sloan r’ bandpass at an airmass of 1.3.

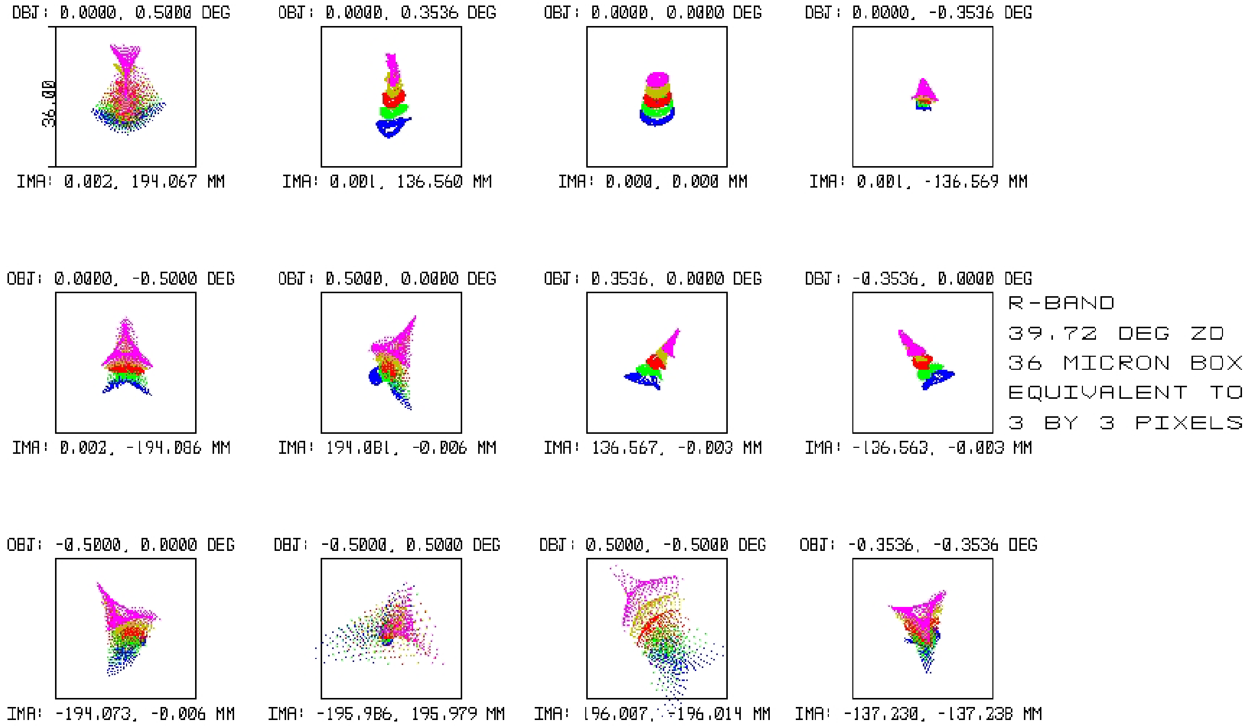


Figure 4. Geometric spot diagram for the r' band at an airmass of 1.3. Each box is 36 µm (3 pixels, or 0.33") on a side. The worst images (central 2 boxes in bottom row) are in the corners of the focal plane, beyond the 1° unvignetted field of view. Typical image sizes (FWHM) are less than 0.10” (~1 pixel).

5.2 60% Encircled Energy vs Bandpass and Field Position

For a pure Gaussian, the FWHM is roughly equivalent to the 60% encircled energy point. The g’ band encircled energy diagram is shown below, and the performance in all bandpasses is summarized in Table 4.

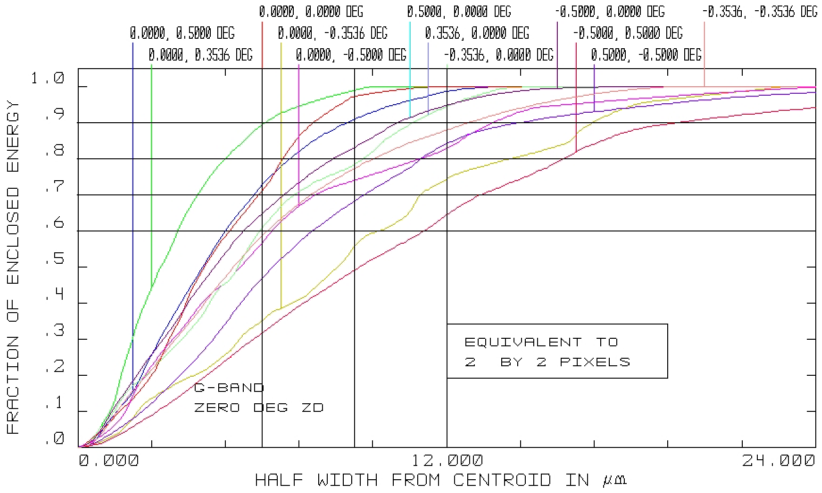


Figure 5. The encircled energy graph for the g' band at zenith. Except for the 2 field points in the corners of the array and one at 0.35 deg off-center, the images have FWHM of about 1 pixel or better.

Table 4. Summary of FWHM as a function of bandpass, ignoring the corner spatial positions.

Bandpass	**Typical FWHM, arcsec**	**Worst FWHM, arcsec**	**Diffraction FWHM, arcsec**
U	0.12	0.14	0.02
g’	0.12	0.18	0.02
r’	0.07	0.09	0.03
i’	0.06	0.08	0.04
z’	0.07	0.09	0.05

5.3 Ghosting

The ghost images of concern in this system are two-bounce reflections. For planar surfaces, these can be thought of as a “delay line” or defocus distance having twice the separation between the offending surfaces. Consequently, the primary source of ghosting in this design is the science filter because, at 10 mm in thickness, it is the thinnest element. This is a very common problem in imagers, and manifests itself as a small donut around bright stars. If we assume the coatings on the filter are 1% or better, then the ghost from the filter has a diameter of 2.5 mm (~23”) and has a surface brightness that is 10^7 below the flux of the star. Because the filters have a relatively narrow bandpass, the AR coatings can be much better than 1% and this factor should increase to 10^8.

The next most critical surface pair is internal to the ADCs. These produce donuts with diameters of 10 mm. Therefore, they have a surface brightness 16 times lower than the filter ghost, but the AR coatings will not be as good as the filter coatings. Other ghosts in the system are much less severe.

Note that filters are sometimes made by cementing thin substrates together (e.g., colored glass). We found that these substrates should not be thinner than 3 mm or internal reflections can become severe, even when the cement is intended to match the indices of the glasses.

5.4 Other Factors: Distortion, Telecentricity, Transmission

Distortion in the corners is about 2.1%, which is within the scientific requirements. Telecentricity degrades linearly from the center, rising to about 1° in the corner. Transmission of the system is degraded below 3800 Å by the PBL6Y wedges. These elements are fairly thin, so their impact is modest, reducing the throughput by 15-20% at 3400 Å.

An additional subtle effect arises from the rotating ADC prisms. The transmission and ghosting vary slightly across the field depending on the rotational positions of the prisms. We have investigated the magnitude of this effect using the Mayall 4-m telescope and its ADC[8] in the r' band. The effect may be much worse in the U-band where the PBL6Y (or LLF6 at the Mayall) begin to lose transmission. The tests suggest that a flat-fielding error of 0.5-1% exists at the Mayall. It is not clear if the magnitude of the problem will be the same with the ODI corrector.

6. ANTI-REFLECTION (AR) COATINGS

Uncoated glass will suffer 3-4% reflection losses per surface. For the 8 air-glass interfaces in the ODI corrector, the light loss will add to roughly 30%. This degree of loss is not considered acceptable for astronomical facilities. More importantly, the introduction of ghost images due to these reflections can severely compromise the scientific value of the images. Most of the serious ghosts in ODI arise from pairs of reflections. Therefore, the magnitude of a ghost image is proportional to the product of the reflections off the 2 surfaces. In general, reflections of 3-4% are unacceptable on this point alone because it becomes very difficult to generate images that can be flat-fielded to meet the 1% photometric performance requirement of the camera. For ODI, these requirements translate to a reflectivity that is <1% from 4000 – 9000 Å, and < 3% from 3400 to 10,000 Å.

6.1 AR Coating Options

We considered 3 principle options for AR coatings: single-layer (e.g., MgF_2), Solgel, and multi-layer coatings. Any of these can improve the reflectivities to less than 1%, and Solgel can reduce the reflection losses to better than 0.2%. However, each option has its own pros and cons, especially when being applied to large diameter surfaces where uniform application is difficult.

- Single-layer coatings are relatively cheap and low risk, and they are available from many vendors, but are only effective over a limited wavelength region. For the broad wavelength needed for ODI, the reflectivities at the end points of the wavelength region approach the uncoated condition.
- Solgel offers superb performance over a wide spectral region, can be applied uniformly, and carries moderate risk. It is a relatively soft coating, so depending on the specific method of application, it may be more or less robust against handling. There is some evidence that the performance can degrade somewhat over time, but this is more folklore than fact, and probably depends strongly on the specific application process. If a problem in the coating arises, it can be removed and re-applied more easily than the single and multi-layer coatings.
- Multi-layer coatings can vary enormously in performance. In general, the best coatings meet the broadband performance required for ODI, but development is needed to generate the masking needed to achieve good spatial uniformity. Although these coatings tend to be costly because of the mask development for uniformity, they can have excellent lifetimes (10 years or more). Some multi-layer coatings can be removed chemically if a problem occurs, without damaging the polished surface.

6.2 Considerations for Each Surface

Because the front surface of L1 is an expensive asphere, its coating should carry a very low risk to minimize the possibility of a bad coating. If the coating needs to be removed, re-polishing the asphere may be required, adding considerable cost and schedule delays to the project. We chose to manage that risk with a single-layer coating. Solgel was another possibility, but this surface is open to the telescope environment and will need frequent cleaning.

The rear surface of L1, and the surfaces of the ADC prisms, are confined to an environment of dry positive pressure. Either Solgel or a multi-layer coating would be an acceptable choice for these surfaces.

The front surface of L2 (the dear window), will be cool relative to ambient. If the dry air flow is interrupted due to a failure, this surface can collect moisture. Thus, the coating must be resistant to water. Solgel may not be a good choice here, so we selected a multi-layer coating.

The rear surface of L2 is in a vacuum and must be able to stretch when the dewar is evacuated. A pliable coating material is preferred here. Some multi-layer options meet this requirement. Also, both surfaces of L2 are close to the focal plane and so, none of the coating materials can be radioactive.

6.3 Predicted AR Coating Performance

WIYN has had fused silica coated by Infinite Optics Inc for other projects. Those coatings have measured performance similar to the curve shown below. This coating was applied to a 150 mm element. The ODI optics have diameters of ~550 mm, and so careful masking is required to obtain spatial uniformity. The vendor selection for the ODI optical coatings is underway.

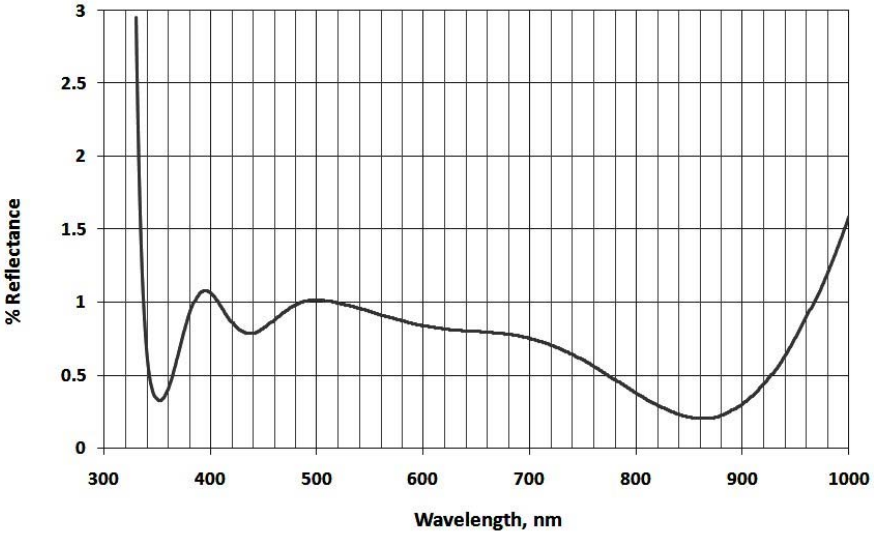


Figure 6. Reflectivity of an AR coating from Infinite Optics applied to fused silica. The averge reflectivity for this coating over the required bandpass (340 – 1000 nm) is well under the 1% requirement.

7. CURRENT STATUS

7.1 Glass Procurement

The PBL6Y was procured directly by WIYN from Ohara far in advance of the polishing contract because of its long lead time. The fused silica was procured by SESO from Schott (Lithosil grade Q2/H2), except for the L2 blank, which was obtained from Corning (HPFS 7980 grade 0F).

7.2 Fabrication

The optical elements are being polished by SESO (Société Européenne de Systèmes Optiques) in Aix-en-Provence, France. As of this writing, the 4 ADC wedges are in the final polishing phase with final testing and acceptance scheduled for the end of June 2008. After receiving the wedges, they will be AR coated and the pairs cemented. The ADC pairs should be fully completed by November.

The L2 dewar window is at the smooth grinding phase, and the L1 lens is next. Both powered elements are expected to be complete by October 2008. After receiving and inspecting these elements, they will be coated and installed into their cells early in 2009. At that time, a full system optical test becomes possible.

The aspheric surface on L1 demands special attention during testing, and several tests have been devised to verify the final shape. The lens will first be tested in reflection via an Offner corrector. It will also be tested in transmission with a different Offner corrector and a 1.3-m spherical reference mirror. This second test also validates the spherical convex surface on the back of the element. All test optics and their mechanical mounts have been fabricated. Because errors in the null lenses can translate into an error in the asphere, two tests were developed to measure the accuracy of the two Offner test setups using two computer generated hologram (CGH) disks in reflection.

7.3 Full System Tests (off and on telescope)

An off-telescope test of the complete optical system would require a major effort and expense to build a telescope simulator. Instead, we will perform an on-axis test of a small field of view. After verification of the on-axis image quality, the opto-mechanical system will be tested on the telescope about 9 months before the detector system and electronics are ready. To verify the corrector performance, an existing small camera and X-Y stage will be attached to the corrector to examine the full-field image quality.

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