

# SPECIFICATION FOR THE MIRRORS

## Spartan IR Camera for the SOAR Telescope

Edwin D. Loh

Department of Physics & Astronomy  
Michigan State University, East Lansing, MI 48824

[Loh@pa.msu.edu](mailto:Loh@pa.msu.edu) 517 353-4869

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This note addresses the requirements for the mirrors of the Spartan IR Camera.

### 1 Physical Requirements

The mirrors are collimator and camera mirrors for the  $f/12$  channel, collimator and camera mirrors for the  $f/21$  channel, and two fold mirrors. See Figure 1.

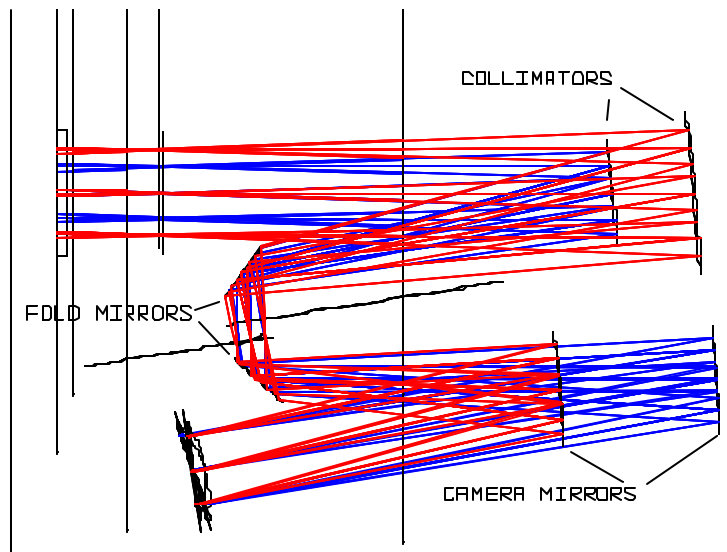


Figure 1 Optical layout.

#### 1.1 Separation between Detector Fields

The detector fields cannot abut without some space between, and two separate designs are possible.

The simplest design is four abutting detectors in a plane, which covers a 96-mm square. A 1-mm wide space separates the detector packages. A 20-mm dead space separates the 38-mm light-sensing regions.

A design that enables a tighter field uses a pyramidal mirror to split the field into four facets. (Figure 2.) The dead space between detectors is 8 mm.

We plan to install the two detectors on hand in the planar arrangement, and to decide on the pyramidal mirror when we install a third detector.

The mirror sizes accommodate the larger, planar field.

## 1.2 Space Envelope

The space envelope of the mirrors is 10 mm beyond the clear aperture for the first fold mirror and 14 mm for the second fold.

The envelope for the aspheric mirrors is not critical. SORL needs 10 mm beyond the clear aperture, and Axsys needs 5 mm.

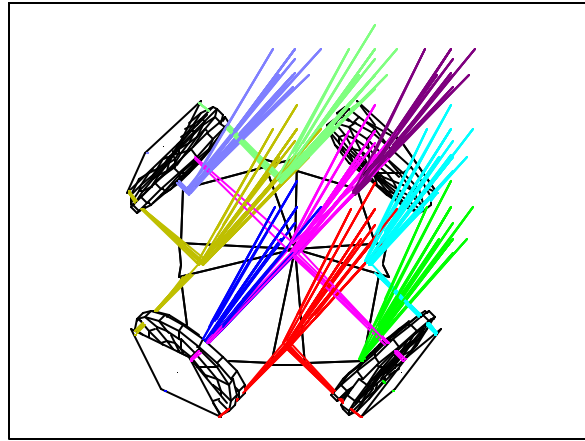


Figure 2 Pyramidal mirror to split focal plane into four facets.

## 2 Alignment

The accuracy of the location of the off-axis, aspheric  $f/12$  collimator mirror is  $(\pm 0.15, \pm 0.55, \pm 1.)$  mm, and the accuracy of the tilt is  $(\pm 0.2, \pm 0.5, \pm 4)$  mrad to achieve a loss in the Strehl at  $1.65\mu$  of 4% for 37 alignment parameters. The accuracies of the other mirrors are comparable.

We plan to position the optics with a DEA Diamond 01.02 coordinate measuring machine (CMM). For short strokes, the  $1-\sigma$  accuracy is  $0.75\mu$  independent of direction. The error is linear with the length of the stroke and doubles at a stroke of 300mm.

Axsys Technologies of Rochester Hills, MI has a superior method for metrology. They pin the aluminum mirror to an aluminum jig, which contains alignment references. With this scheme, the

mirror position and the position of the vertex of the parent are known to a few  $\mu\text{m}$ . We can position the mirror using the same alignment pins.

On the other hand, SORL of Waltham, MA makes a glass mirror without alignment pins. Their metrology is derived from measurements of the Hindel sphere and other parts of their test setup. Because the errors build up, they guarantee that the mirror position and the vertex of the parent are known to a few mm, a thousand times worse than Axsys.

If we use Axsys mirrors, the positional errors of the optics are all well within the accuracy of our CMM, and no optical alignment is necessary. The only optical adjustment is focus.

If we use SORL mirrors, two parameters, the positions transverse to the optical axis, of each aspheric mirror must be found by means of optical alignment. (The tilts can be set by means of the coordinate measuring machine.) The optical alignment involves measuring the Strehl ratio at 600nm to a precision of  $\frac{1}{2}\%$ .

### 3 Error Budget

The error budget (Table 1) has been created by assigning errors that vendors have quoted or we believe achievable. The positional errors are 0.1mm, which are well within the accuracy of the CMM and the positional accuracy of Axsys mirrors. The tilt errors are 0.1mrad, which translates to  $7\mu$  across a 100-mm part. The surface errors are from vendor quotes. We are negotiating a change in the surface errors that will reduce the overall errors and possibly the cost

The effect of the errors on the Strehl ratio cannot be calculated without knowledge of the structure function  $S(x)$ , which is the covariance of the surface error at two points separated by distance  $x$ . However vendors do not normally control the structure function. Instead they control the peak-to-valley error.

We can estimate the reduction in Strehl ratio by Maréchal's formula, which assumes errors are independent of separation. This is clearly not the case, since optics are generally smoother on small scales. Nonetheless, Maréchal's formula shows the Strehl is reduced by 10% for median seeing in the H band.

Alternatively, we have used the shape of the structure function of the telescope<sup>1</sup> to estimate the Strehl ratio. We find the Strehl is reduced by 4% for median seeing in the H band. The difference between these estimates is substantial for the window and field flattening lens, where the beam of a point source is very small. Maréchal's formula assumes there is as much error across the 9-mm beam as the entire 179-mm window.

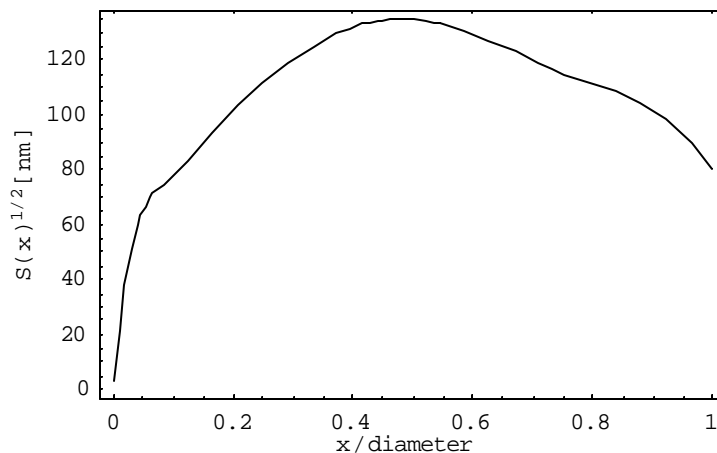


Figure 3 Structure function of the telescope.

Mirrors built by Axsys are likely to be much better than the estimate in the error budget, because the RMS error of their mirrors is much lower than the peak-to-valley error. For one of their mirrors with similar peak-to-valley error, size, and power as ours, the error is very low over most of the mirror (Figure 4), and the ratio of PV to RMS is 8, rather than our assumption of 4.

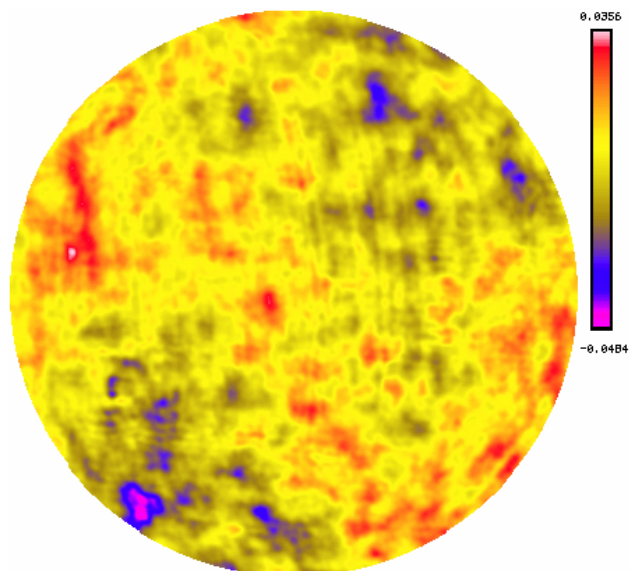


Figure 4 Surface error of an Axsys mirror with peak-to-valley error of  $\lambda/12$ , which is our specification. The range is  $-0.048\lambda$  to  $+0.036\lambda$ , where  $\lambda=632\text{nm}$ . The RMS error is  $0.011\lambda$ .

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<sup>1</sup> Raytheon 2000, SOAR/AOS Critical Design Review

Table 1 Optical error budget, given as the equivalent RMS error for each component and as the reduction in the Strehl ratio for the whole.

Element 1	Surface Spec 2	RMS Error [1000th wave @ 1650nm]									TotalSI 12	Total 13
		SurfSF 3	Surf 4	RC/CC 5	x 6	y 7	z 8	qx 9	qy 10	qx 11		
1 Window	$\lambda$ 2	6.9	21.0								6.9	21.0
2 Focal surface											0.0	0.0
3 f/21 collimator	$\lambda$ 12	9.1	16.0	5.0	0.8	2.3	4.4	2.2	1.3	0.1	11.8	17.6
4 f/11 collimator	$\lambda$ 12	9.1	16.0	5.0	0.9	3.6	0.5	2.1	1.0	0.1	11.3	17.3
5 Fold mirror 1	$\lambda$ 16	7.6	8.5				1.0	3.6	2.6	0.0	8.9	9.6
6 Filter	$\lambda$ 2	18.3	21.0								18.3	21.0
7 Lyot stop											0.0	0.0
8 f/21 camera mirror	$\lambda$ 12	10.3	16.0	5.0	1.0	2.6	2.1	2.6	1.3	0.1	12.3	17.3
9 f/11 camera mirror	$\lambda$ 12	10.3	16.0	5.0	1.4	2.1	0.2	2.2	1.7	0.2	12.1	17.1
10 Fold mirror 2	$\lambda$ 16	7.6	8.5				5.0	2.2	1.4	0.0	9.5	10.2
11 Lens	$\lambda$ 2	4.1	21.0	5.0	1.4	2.2	2.3	0.4	0.1	0.0	7.3	21.9
12 Detector plane								0.8	0.8	0.0	1.1	1.1
<b>Sum (f/21)</b>		26.5	44.5	8.7	1.8	4.1	7.4	5.5	3.5	0.2	30.0	46.6
<b>Reduction in Strehl @1650nm</b>											<b>0.97</b>	<b>0.92</b>
<p>2 Specification for surface error. Peak-to-valley at 632nm.  3 Surface error computed with a structure function. Converted to RMS having equal Strehl by Marechal's formula.  4 Surface error computed as 1/4 of peak-to-valley error  5 Error due to tolerances of conic constants for elements 3,4, 8, and 9 and of radius of curvature for element 11.  6 Error due to positional tolerance of 0.1mm.  9 Error due to rotational tolerance of 0.1mrad.  12 Total error of columns 3, 5-11 summed in quadrature. This accounts for structure function of the surfaces  13 Total error of columns 4-11 summed in quadrature.</p>												