Ghost analysis for the 90" Prime Focus Corrector

Jim Burge
November 30, 2000

An analysis of ghost reflections was performed for the 90" prime focus corrector. The effect of ghosts was determined by simulating all combinations of two reflections between surfaces and looking at the size of the resulting out of focus ghost image on the focal plane. This is compared with the image itself to determine a contrast of the ghosts.

In conclusion, the effects from the smallest lenses near the detector dominate by several orders of magnitude. So, the best way to deal with the ghosts will be put good coatings on L4 and the possibly the filters. Then a single layer of MgF_2 would suffice for the large lenses.

I simulated multiple reflections, and show the results in Table 1. For any given row, the first surface for the reflection is given in the first column. The subsequent columns give the rms diameter of the ghost image. Some values are not included because they were too far out of focus for the simulation to make sense.

Table 1. RMS diameter for out of focus ghost image

		2nd ->	L1 S1	L1 S2	L2 S1	L2 S2	L3 S1	L3 S2	F S1	F S2	L4 S1	L4 S2
1st	Surf #		6	7	8	9	10	11	12	13	14	15
L1 S1	6											
L1 S2	7											
L2 S1	8		246	133								
L2 S2	9			108								
L3 S1	10		193	31	73	127						
L3 S2	11		174	33.1	124	29	50					
F S1	12			17.6	121	136	18.5	46.8				
F S2	13			19.1	122	139	17.8	48.1	1.29			
L4 S1	14			23.5	119	147	14.8	51.6	5.65	4.38		
L4 S2	15			28	121	159	12.8	56.4	9.46	8.16	3.63	
CCD	16			29.2	121	161	12.1	57.5	10.63	9.34	4.79	1.91

To look at the real effect of the ghosts, we need to compare the brightness, or focal plane irradiance E of the ghost reflections with that of the image itself. Making the following definitions:

E = irradiance = power(or photon rate)/unit area
P = total power (or photon rate) from a star
R_1, R_2 reflectivities for the two surfaces that create the ghost
A_{ghost}, A_{image} area of the ghost and of the image in the focal plance
D_{ghost}, A_{image} diameter of the ghost and of the image in the focal plance

It is straightforward to calculate the ratio of the ghost to the image irradiance

$$\frac{E_{ghost}}{E_{image}} = \frac{\left(\dfrac{P * R_1 * R_2}{A_{ghost}}\right)}{\left(\dfrac{P}{A_{image}}\right)} = \frac{R_1 R_2 D_{image}^2}{D_{ghost}^2}$$

To come up with real numbers, I used 1 arcsec images (0.033 mm rms diameter), 2% reflectance for glass-air interfaces and 10% reflectance from the CCD. Table 2 shows the $\log_{10}$ of this ratio.

Table 2. Log_{10} of the ratio of ghost to image irradiance

		2nd ->	L1 S1	L1 S2	L2 S1	L2 S2	L3 S1	L3 S2	F S1	F S2	L4 S1	L4 S2
1st	Surf #		6	7	8	9	10	11	12	13	14	15
L1 S1	6											
L1 S2	7											
L2 S1	8		-11.1	-10.6								
L2 S2	9			-10.4								
L3 S1	10		-10.9	-9.3	-10.1	-10.6						
L3 S2	11		-10.8	-9.4	-10.5	-9.3	-9.8					
F S1	12			-8.9	-10.5	-10.6	-8.9	-9.7				
F S2	13			-8.9	-10.5	-10.6	-8.9	-9.7	-6.6			
L4 S1	14			-9.1	-10.5	-10.7	-8.7	-9.8	-7.9	-7.6		
L4 S2	15			-9.3	-10.5	-10.8	-8.6	-9.9	-8.3	-8.2	-7.5	
CCD	16			-8.6	-9.8	-10.1	-7.8	-9.2	-7.7	-7.6	-7.0	-6.2

So, to interpret this table, look at the reflection from the CCD to lens 4 surface 2 (surface 16 in my simulation). The ghost is 1.91 mm rms diameter. The number of photons from the ghost on any single pixel will be $10^{-6.2}$ or about 6×10^{-7} time smaller than the number of photons per pixel from the image itself.

The two most severe ghosts are from the CCD – dewar window and from the two surfaces of the filter. Since these elements are small, they can be improved by a factor of up to 10 with antireflection coatings.

The results in table 2 can be scaled to accommodate other coatings, or for improved conditions.

I also looked to see if any ghost pupil images are formed on the detector, and I did not find anything significant. These could potentially be a problem if the image of the pupil is near the detector, and is smaller than the field of view.