

HET SAC Mirrors

Reflectivity Measurements

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1. Introduction

In view of the state of the HET primary mirror coating and the fact that all four spherical aberration corrector (SAC) mirrors are also coated with FSS-99, it was decided to measure their reflectivity. A diagram of the location and nomenclature of the SAC mirrors is shown in section 6 for easy reference.

2. Procedure

The TMA μ Scan™ portable scatterometer was used to obtain these measurements. The light source is a 670 nm laser diode. Reflectivity is measured at an incidence angle of 25 degrees. Scattering measurements are taken at 25 degree angle from specular reflection, at two diametrically opposite directions.

Calibration was performed by measuring two reference mirrors: one is an Edmund Scientific Aluminium coated mirror (87.4%), the second one is an FSS-99 silver coated plate glass provided by Denton Vacuum (98.6%). Absolute reflectivity of the references was measured in June 1999 by Optical Data Associates and is traceable to an NIST standard. Both references were measured prior to taking HET SAC mirror reflectivity measurements. This determined the calibration formula, as the μ Scan™ reflectometer seems to exhibit some non-linearity in its response. A simple multiplicative factor was calculated for both references and linearly interpolated in between. The estimated accuracy of the calibration is ~0.5%. Details of the calibration are given at the top of Sheets 1 and 2.

Two sets of measurements were obtained. The first set was taken in-situ (i.e. with PFIP still up in the telescope and all mirrors installed) on June9, 1999. The second set was taken on June 26, 1999 with the SAC mirrors taken out of the PFIP frame and consists of three parts: as is prior to cleaning, after CO₂ snow cleaning, and after strip coat cleaning. Furthermore, scattering measurements were taken at that time.

3. Results

3a. Visual Inspection

Prior to PFIP lift in March 1999, it was noticed that M2's coating showed some pinpoint and bubble-like coating failure features. This led Denton to propose recoating this mirror this summer at no cost to us. M3 is looking simply awful; worse even than any of the primary mirror segment (with the exception of segment 31 which was messed up by strip coating residues). M4 exhibits some slight signs of degradation as does M5. M2 and M4 are facing downward and are expected to gather less dust than M3 and M5. That is indeed the case. As for M3 and M5, they are collecting dust at roughly the same rate of accumulation as the primary mirror array segments are.

3b. In-Situ Measurements

Sheet 1 gives the measured values for each individual SAC mirror. The first column gives raw measurements, while the second column gives the calibrated reflectivities using the adopted scaling formulas given at the top of the spreadsheet. The first conclusion is the very apparent difference between upward and downward looking mirrors. Considering the thick layer of dust coating M3 and M5 that was expected. See the next subsection for reflectivity measurements of these same mirrors after dust removal through CO₂ snow and strip coat cleaning.

Downward looking mirrors are virtually indistinguishable from each others (especially if we do not include the 84.4% low point from M4's statistics) and have lost approximately 4% reflectivity. This also means that extra tarnishing of M2's silver coating, from the pinpoint/bubble-like features, has not really affected reflectivity yet. Upward looking mirrors exhibit a further loss of reflectivity of about 6%, a larger scatter in measured reflectivities; but are otherwise very similar to each others. Not, however, the very low reflectivity (62.7%) measured at one location on SAC M3. The overall reflectivity throughput of the SAC (not including vignetting and obscurations) is estimated at 68%, which is 74% of expected performance for pristine mirror coatings and no significant dust influence on reflectivity.

3c. Post PFIP Removal Measurements

When PFIP was removed from the telescope on June 25 – 27, 1999. Reflectivity measurements of all four SAC mirrors were taken. Three set of measurements were obtained. The first set (Sheet 2) measured the mirrors as they came out of the PFIP assembly, i.e. with no cleaning whatsoever. CO₂ snow cleaning was then performed and the second measurement set taken (Sheet3). Finally, a generous coat of X-59 strip coating was applied to the coated surface of the mirrors and allowed to dry overnight. It was removed the following morning and the third set of measurements was taken then (Sheet4).

Sheets 2 - 4 give the measured values for each individual SAC mirror. The first column gives raw measurements, while the second column gives the calibrated reflectivities using the adopted scaling formulas given at the top of the spreadsheet. The difference between upward and downward looking mirror reflectivity is evident in all three sheets. Considering the thick layer of dust coating M3 and M5 that was expected prior to CO₂ and strip coating the mirrors. That this difference still exist after CO₂ cleaning is an indication of the limitation of CO₂ snow cleaning in removing small dust particles, chemisorbed particles, and molecular contaminant. Cleaning with the X-59 strip coat almost removes this difference between upward and downward looking mirrors and may be taken as an indication of coating degradation rather than dust induced reflectivity reduction. Considering the visual appearance of M3, it is surprising that its reflectivity recovered up to almost 94% after CO₂ and strip cleaning. When taking the whole

spherical aberration corrector 4-mirror optical throughput, the effect of cleaning is quite drastic (10% higher after CO₂ and strip cleaning). The results are summarized in Table 1.

Table 1. Summary of Post-PFIP Removal SAC Reflectivity Measurements

Mirror ID	Orientation	Measured Average Reflectivity (%)		
		Before Cleaning	After CO2 Cleaning ³	After Strip Cleaning ³
SAC M2	Down	93.9	94.4 (+0.5)	94.3 (-0.1)
SAC M3	Up	88.0	92.9 (+4.9)	93.8 (+0.9)
SAC M4	Down	95.3	95.9 (+0.6)	95.5 (-0.4)
SAC M5	Up	89.2	92.3 (+3.1)	94.9 (+2.6)
Up ¹	Up	88.6	92.6 (+4.0)	94.4 (+1.8)
Down ¹	Down	94.6	95.2 (+0.6)	94.9 (-0.3)
Whole ²	Both	70.2	77.6 (+7.4)	80.2 (+2.6)

- 1 Average of the two upward/downward looking mirrors.
- 2 Product of M2, M3, M4, and M5's reflectivities, not an average.
- 3 The number in parentheses are relative improvement from the previous status (i.e. column).

4. Conclusions

The SAC mirrors have been coated at least one year ago. They have been kept in storage until February 1999 when PFIP was lifted at prime focus, except for a short six week stint on the telescope in August 1998. Visual inspection of the SAC mirrors before the February 1999 lift did not reveal significant coating degradation (except for M2's coating failure). It is clear that, despite the covering shroud, dust accumulates on the upward looking SAC mirrors just as fast as it does on the primary mirror segments. This calls for regular CO₂ cleaning of the SAC mirrors and/or the installation of a dry nitrogen purging system in PFIP to prevent such dust accumulation. Whether a dry nitrogen system can deliver the level of cleanliness required is uncertain. Experiments performed by the Subaru telescope scientists has demonstrated that dry nitrogen cleaning of mirrors is far less efficient than CO₂ snow cleaning.

Considering the relatively short "dome exposure time" of the SAC mirrors (i.e. about 4 months) and comparing their reflectivity to those of primary mirror segments that have been installed for 18 – 24 months, the SAC mirror coating degradation is surprisingly fast (approximately 4% over 4 months). On the other hand, the measured reflectivities of uncleaned M3 and M5 fall on the coating degradation curve shown in Fig. 2 of the "HET Reflectivity and Scattering Measurements, Rev. 1" document. The high rate of reflectivity reduction measured on the SAC mirrors might be typical of how the FSS-99 coating degrades: an initial period of high rate of degradation followed by a shallower slope in the reflectivity curve. Whether this scenario is true will be revealed by systematic monitoring of segments 6 and 10 installed five weeks ago in the primary mirror.

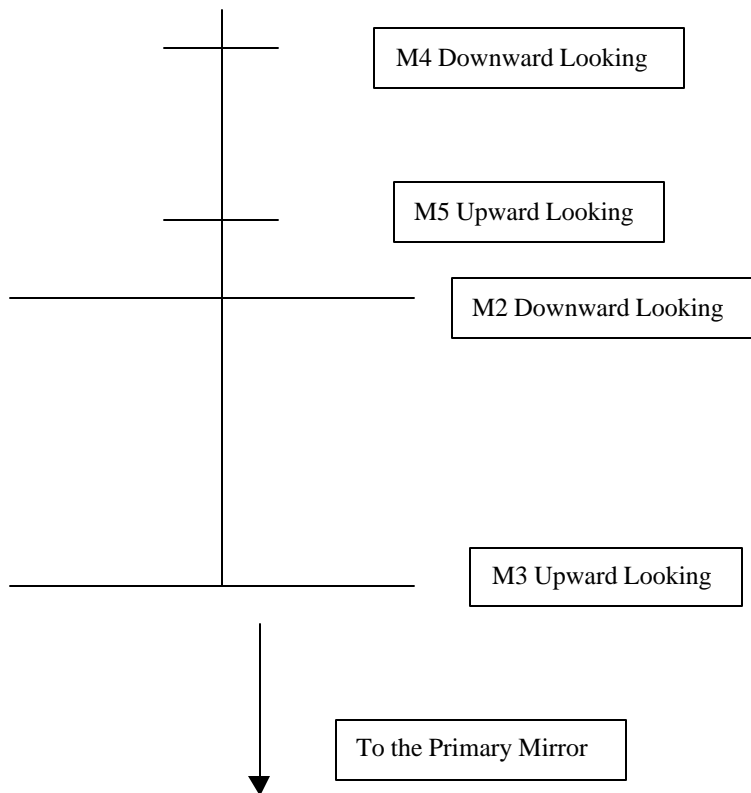
5. Acknowledgment

Thanks to Tom Worthington, Tom Brown for their assistance with taking the in-situ data, and to John Booth for factoring the second set of measurements in the PFIP removal schedule.

5a. Addendum

Denton's inspection of SAC M2 revealed that something was splashed on the mirror surface and stained the substrate.

6. SAC Mirrors Nomenclature



Sheet 1. June 9, 1999 SAC Mirrors Reflectivity Measurement

CALIBRATION

Aluminum coated mirror: 89.8
 90.3
 88.8
 90.1
 90.0

87.4% nominal* average = 89.8 Scale Factor = 0.973
 stdev = 0.6

* The 87.4% comes from the June 99 calibration performed at ODA.

FSS 99 silver coating: 98.7
 99.0
 99.0
 98.8
 99.0

98.6% nominal* average = 98.9 Scale Factor = 0.997
 stdev = 0.1

* The 98.6% comes from the June 99 ODA measurements.

Adopted scale factor = $1.000 + (M - 100.0) * 0.00264$

MEASUREMENTS

SAC M2 Downward looking, fairly clean, known screwed up coating

raw	calibrated	
95.2	94.0	
96.6	95.7	
94.8	93.5	
96.1	95.1	
94.7	93.4	
92.7	90.9	scaled
96.7	95.9	average = 94.0
93.3	91.6	stdev = 1.7
95.6	94.5	min = 90.9
96.1	95.1	max = 95.9

SAC M4 Slight degradation, fairly clean, looking downward

raw	calibrated	
95.3	94.1	
95.1	93.9	
94.7	93.4	
91.7	89.7	
95.2	94.0	
94.8	93.5	scaled
95.3	94.1	average = 93.3
95.8	94.7	stdev = 1.5
94.1	92.6	min = 89.7
87.3	84.4	max = 94.7

SAC M3 Highly degraded, fairly dusty but not as much as M5.

raw	calibrated	
92.3	90.4	
92.3	90.4	
92.3	90.4	
92.4	90.5	
92.1	90.2	
88.6	85.9	scaled
91.0	88.8	average = 88.1
88.7	86.1	stdev = 2.9
85.2	81.9	min = 81.9
89.3	86.8	max = 90.5
68.4	62.7	

SAC M5 No degradation visible, fully coated with dust

raw	calibrated	
91.1	89.0	
90.0	87.6	
92.6	90.8	
90.8	88.6	
92.1	90.2	
93.5	91.9	scaled
91.3	89.2	average = 89.3
91.1	89.0	stdev = 1.4
90.0	87.6	min = 87.6
84.9	81.5	max = 91.9

Not included in statistics.

SAC throughput (not including obscuration and beam vignetting): 67.8%

Sheet 2. SAC Mirror Reflectivity
June 26 - 27, 1999, Before Cleaning

CALIBRATION

Al coated reference mirror	89.8		
	90.1		
	91.0		
	90.6		
	90.6		
87.4% nominal*	average = 90.4	Scale Factor =	0.967
	stdev = 0.5		

* The 87.4% comes from the June 99 calibration performed at ODA.

FSS 99 sample A	100.5		
	99.8		
	99.8		
	101.1		
	100.7		
98.6% nominal*	average = 100.4	Scale Factor =	0.982
	stdev = 0.6		

* The 98.6% comes from the June 99 ODA measurements.

Adopted scale factor = $0.9814 + (M - 100.0) * 0.0015$

MEASUREMENTS

SAC M2	raw	calibrated		SAC M4	raw	calibrated	
Downward	96.9	94.6		Downward	96.8	94.5	
	93.9	91.3			98.5	96.4	
	96.2	93.9			97.8	95.7	
	96.8	94.5			97.0	94.8	
	96.6	94.3			97.7	95.5	
	96.1	93.8			97.2	95.0	
	96.5	94.2	scaled		97.5	95.3	scaled
	96.7	94.4	average = 93.9		97.6	95.4	average = 95.3
	96.1	93.8	stdev = 1.0		96.9	94.6	stdev = 0.6
	91.8	89.0	min = 91.3		97.5	95.3	min = 94.5
			max = 94.6				max = 96.4
SAC M3	raw	calibrated		SAC M5	raw	calibrated	
Upward	88.3	85.1		Upward	92.7	90.0	
	88.5	85.3			91.9	89.1	
	93.2	90.5			92.3	89.5	
	91.6	88.7			86.0	82.6	
	90.8	87.9			91.3	88.4	
	92.9	90.2	scaled		91.5	88.6	scaled
	90.9	88.0	average = 88.0		93.0	90.3	average = 89.2
	91.1	88.2	stdev = 1.8		92.4	89.6	stdev = 3.0
	90.8	87.9	min = 85.1		96.7	94.4	min = 82.6
	91.6	88.7	max = 90.5		82.1	78.4	max = 94.4

Not included in statistics.

Sheet 3. SAC Mirror Reflectivity
June 26 - 27, 1999, After CO₂ Cleaning

CALIBRATION

Al coated reference mirror	91.7		
	91.8		
	91.6		
	91.8		
	91.6		
87.4% nominal*	average = 91.7	Scale Factor = 0.953	
	stdev = 0.1		

* The 87.4% comes from the June 99 calibration performed at ODA.

FSS 99 sample A	100.3		
	100.0		
	100.2		
	100.4		
	100.1		
98.6% nominal*	average = 100.2	Scale Factor = 0.984	
	stdev = 0.2		

* The 98.6% comes from the June 99 ODA measurements.

Adopted scale factor = $0.9833 + (M - 100.0) * 0.00365$

MEASUREMENTS

SAC M2	raw	calibrated		SAC M4	raw	calibrated	
Downward	97.5	95.0		Downward	98.2	95.9	
	97.1	94.5			99.1	97.1	
	95.1	91.8			98.2	95.9	
	97.8	95.4			98.8	96.7	
	97.7	95.2			98.3	96.0	
	96.7	93.9			99.0	97.0	
	97.3	94.7	scaled		98.1	95.8	scaled
	96.7	93.9	average = 94.4		97.4	94.8	average = 95.9
	98.2	95.9	stdev = 1.2		97.5	95.0	stdev = 0.9
	96.2	93.3	min = 91.8		97.3	94.7	min = 94.7
			max = 95.9				max = 97.1
SAC M3	raw	calibrated		SAC M5	raw	calibrated	
Upward	96.8	94.5		Upward	100.3	98.5	
	90.6	87.6			99.5	97.6	
	97.4	95.2			95.9	93.5	
	96.8	94.5			94.1	91.5	
	94.5	92.0			94.5	92.0	
	93.1	90.4			91.4	88.5	
	97.0	94.8	scaled		91.5	88.6	scaled
	94.3	91.7	average = 92.9		92.4	89.6	average = 92.3
	97.4	95.2	stdev = 2.6		96.0	93.6	stdev = 3.5
	81.5	77.7	min = 87.6		92.7	90.0	min = 88.5
			max = 95.2				max = 98.5

Not included in statistics.

Sheet 4. SAC Mirror Reflectivity
June 26 - 27, 1999, After Strip Cleaning

CALIBRATION

Al coated reference mirror	91.0		
	92.3		
	92.2		
	92.7		
	92.5		
87.4% nominal*	average = 92.1	Scale Factor = 0.949	
	stdev = 0.7		

* The 87.4% comes from the June 99 calibration performed at ODA.

FSS 99 sample A	101.0		
	100.8		
	100.3		
	99.9		
	100.8		
98.6% nominal*	average = 100.6	Scale Factor = 0.980	
	stdev = 0.5		

* The 98.6% comes from the June 99 ODA measurements.

Adopted scale factor = $0.9778 + (M - 100.0) * 0.00365$

MEASUREMENTS

SAC M2	raw	calibrated		SAC M4	raw	calibrated	
Downward	96.1	92.6		Downward	97.5	94.4	
	98.2	95.4			97.8	94.8	
	97.4	94.3			96.2	92.7	
	96.6	93.3			98.5	95.8	
	98.1	95.2			98.3	95.5	
	98.7	96.0			99.0	96.4	
	95.8	92.2	average = 94.3		99.5	97.1	average = 95.5
	97.4	94.3	stdev = 1.3		98.5	95.8	stdev = 1.3
	97.9	95.0	min = 92.2		99.3	96.8	min = 92.7
	97.9	95.0	max = 96.0		98.6	95.9	max = 97.1
SAC M3	raw	calibrated		SAC M5	raw	calibrated	
Upward	97.4	94.3		Upward	99.9	97.6	
	97.1	93.9			97.8	94.8	
	95.1	91.3			97.6	94.6	
	96.0	92.5			102.2	100.8	
	98.6	95.9			98.7	96.0	
	96.5	93.1			97.8	94.8	
	98.2	95.4	average = 93.8		94.4	90.4	average = 94.9
	98.8	96.2	stdev = 1.8		97.7	94.7	stdev = 2.9
	95.4	91.7	min = 91.3		97.0	93.8	min = 90.4
	91.5	86.6	max = 96.2		95.4	91.7	max = 100.8

Not included in statistics.