HET Reflectivity

And

Scattering Measurements

Revision 1

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1. Introduction

Visually, the state of the HET mirror FSS-99 silver coating looks pretty awful. There are visible tarnishing clusters in the silver coating. In an attempt to quantify the influence of the coating state to telescope observing efficiency, reflectivity and scattering measurements were taken on a set of mirror. In view of the reflectivity measurements of the aluminum and FSS-99 coated reference mirrors performed by Optical Data Associates, the calibration was re-adjusted to take the reflectometer apparent non-linear response into account. Since the first version of this document was written, a lot more data has become available and, while the new numbers are not presented here, reference to them is made whenever they support the conclusions reached in this document. Mirror numbers (i.e. SN XXX) are blank numbers, while segment numbers (XX) are segment position identifications in the primary array.

2. Procedure

This work was performed March 8th, 1999. A TMA μScan™ 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 was measured in June 1999 by Optical Data Associates and is traceable to an NIST standard. Both references were measured prior to taking HET mirror reflectivity measurements. This determined the calibration formula, as the μScan™ reflectometer seems to exhibit some non-linearity in its response (c.f. Sheet 1). A simple multiplicative factor was calculated for both references and linearly interpolated in between. Only the FSS-99 reference was measured at least once before and after each set of measurements. This was used to reset the zero point of the calibration formula for each mirrors. The estimated accuracy of the calibration is ~0.5%. The measurements for mirrors SN 011, SN 080, and SN 086 were taken successively and are considered one single dataset for calibration purpose.

A total of six mirrors were measured. Mirrors SN 042, SN 056, and SN 058 are currently sitting in the mezzanine awaiting repair. Fifteen measurements were taken at random locations on the coated surface. Mirrors SN 011, SN 080, and SN 086 are currently located on the truss. These last three mirrors were measured to ascertain the possible influence of dust on the data and give some idea of reflectivity degradation rate. Only 5 measurements were taken on them due to the difficulty of reaching the whole mirror front surface from the edge of the truss. Table 1 gives details of selected mirrors.

3. Results

Sheet 2 gives the measured values for each individual mirror. The first column gives the location measured (just the order of data taking as no record of exact location has been kept), 'REF' are the FSS-99 reference measurements. The second and third columns give raw reflectivity measurements and surface roughness determined from bi-directional scattering distribution function measurements. The fourth column gives the calibrated reflectivity values. The calibration formula used for each mirror is given above the table and mirror statistics are given at the lower right. The results are plotted in Fig. 1.

There is a slight reflectivity degradation with time. The larger error bars for mirrors 056 and 058 are mainly due to having 'hit' one or two really bad spots during measurements. The reflectivity of most mirrors is approximately 85%. The most recent mirrors show reflectivity around 90%. Note that even mirror SN 080, which looks real good upon visual inspection, does not give the level of performance exhibited by the FSS-99 reference. Two "pristine" mirrors have been measured from "straight out of the box" and exhibit reflectivity levels of 97.7% and 98.0%. Current monitoring of these two mirrors will allow us to track down how fast the initial drop in reflectivity of brand new mirrors is. We also plan to measure the reflectivity of the four SAC mirrors when the PFIP comes down on June 26 - 27. Recent in-situ measurements of the SAC mirrors reveal a significant drop in reflectivity already.

Surface roughness is more sensitive to coating state than reflectivity is (another good indicator of coating degradation is increase scattering in the reflectivity measurements). Furthermore, notice that mirror SN 011 currently sitting in the dome, with a good layer of dust on it, does not exhibit a larger surface roughness value than the three mirrors (SN 042, SN 056, SN 058) currently situated in the mezzanine with less dust on them. Note also, the lowest surface roughness measured for the newest mirrors (SN 080 and SN 086), which are also covered with a good layer of dust. Therefore, the difference in surface roughness has to be attributed mainly to coating quality. It is clear that most mirrors scatter one to two orders of magnitude (scales roughly as the square of the surface roughness) more light than a brand new FSS-99 coating. More recent scattering measurements on the two "pristine mirrors" confirm this factor of about a hundred. Also, cleaning experiments show that dust removal reduces surface roughness only by about half (from a tenfold increase down to five).

To quantify the coating degradation rate, linear fits to the reflectivity and surface roughness data were obtained. The results are presented in Figs. 2 and 3. The reflectivity decreases at a rate of 2.5% per year. It should be noted that the statistics for mirrors SN 056 and SN 058 were recalculated after removing the worst two measurements (i.e. 3 to 5 σ events) from the sample. That is why their error bars are significantly smaller in Figs. 2 and 3 when compared to Fig. 1.

Looking at the lowest reflectivity values for mirrors SN 056 and SN 058, it can be inferred that, once the entire coating surface is badly tarnished, the reflectivity values will dip

down to around 50%. At the current degradation rate, that should take 10 to 15 years to happen.

4. Conclusions

The degradation of the FSS-99 coating, due to dome environmental conditions, has led to a degradation in mirror reflectivity by 7% to 15% from optimal FSS-99 coating performance. The current value of the mirror array reflectivity is approximately 85%. The rate of reflectivity degradation is 2.5% per year. Measurements of scattering (BDSF) are more sensitive to coating degradation than reflectivity measurements are. Coating degradation has led to an increase in scattered energy by one to two orders of magnitude so far.

With the fraction of mirror area suffering from silver tarnishing increasing with time, it is expected that the mirror reflectivity will reach values of approximately 50% in about 15 years.

5. Acknowledgment

Thanks to Dave Doss for his assistance with the TMA μScan™ scatterometer.

Table 1. Measurement Log

Mirror ID	Location	Time Spent in Dome (Days)
011	Dome #88	750*
042	Mezzanine	628
056	Mezzanine	471
058	Mezzanine	500
080	Dome #10	36
086	Dome #89	132

* The record search has failed to reveal when this mirror was installed, but it was part of the first fifteen mirror batch installed way back when Victor was doing it. So a reasonable guess of 750 days (about December 1996) was made.

Figure Captions

Fig. 1. Average reflectivity (■) and surface roughness (❍) values for six HET mirrors and the FSS-99 plate reference (sample A). The values are plotted against the number of days the mirror (0 for the FSS-99 reference) has spent in the dome.

Fig. 2. Linear fit to the reflectivity data. The FSS-99 reference data point was not included in the fit. There are some indications that the HET mirrors rapidly loose on the order of 5% after exposure to dome environment.

Fig. 3. Linear fit to the surface roughness data. The FSS-99 reference data point was not included in the fit.

Sheet 1. Calibration of Reflectivity

Reference Sample: Aluminium coated Edmund Scientific Mirror : 87.4% reflectivity measured by C
This is the primary calibrator.

Calibrated Sample: FSS-99 plate glass sample: 98.6% reflectivity measured by ODA.
This is the secondary calibrator used throughout the experiment.

Reference Sample Reflectivity: 92.5% and 92.4%
average = 92.45%
scaling factor: 87.4/92.45 = 0.945

Calibrated Sample: 100.6% and 100.7%
average = 100.65%
scaling factor: 98.6/100.65 = 0.980

Scaling factor: $S = 0.9769 + (M - 100.0)*0.00417$
where "S" is the scaling factor appropriate for measurement M.

Sheet 2a. HET 011 Reflectivity and Scattering Measurement

Data taken on 3/8/1999
Data recalibrated 6/15/99

Scaling Factor = 0.9769+(M-100)*0.00417

Position	Reflectivity Raw (%)	Surface Roughness (angstroms)	Reflectivity Calibrated (%)
REF	100.7	16.0	98.7
1	87.8	118.2	81.3
2	91.2	110.5	85.7
3	89.6	103.7	83.6
4	91.9	117.9	86.7
5	91.5	118.1	86.1
REF	100.4	24.0	98.2
REF	100.7	19.3	98.7
Segment Statistics:	Average =	113.7	84.7
	Stdev =	6.5	2.2
	Min =	103.7	81.3
	Max =	118.2	86.7

Sheet 2b. HET 042 Reflectivity and Scattering Measurement

Data taken on 3/8/1999
Data recalibrated 6/15/99

Scaling Factor = 0.9744+(M-100)*0.00417

Position	Reflectivity Raw (%)	Surface Roughness (angstroms)	Reflectivity Calibrated (%)
REF	101.1	16.0	98.9
1	91.2	105.0	85.5
2	89.2	134.0	82.9
3	93.2	91.3	88.1
4	91.0	124.4	85.2
5	87.8	129.2	81.1
6	91.8	101.8	86.3
7	90.9	115.6	85.1
8	92.8	97.9	87.6
9	92.4	99.7	87.1
10	89.5	123.4	83.3
11	92.0	108.5	86.5
12	88.3	129.8	81.7
13	93.5	93.5	88.5
14	89.3	125.6	83.0
15	93.2	92.0	88.1
REF	100.6	22.1	98.2
Segment Statistics:	Average =	111.4	85.3
	Stdev =	15.3	2.4
	Min =	91.3	81.1
	Max =	134.0	88.5

Sheet 2c. HET 056 Reflectivity and Scattering Measurement

Data taken on 3/8/1999
Data recalibrated 6/15/99

Scaling Factor = 0.995+(M-100)*0.00417

Position	Reflectivity Raw (%)	Surface Roughness (angstroms)	Reflectivity Calibrated (%)
REF	98.5	23.2	97.4
1	92.4	105.6	89.0
2	94.2	93.2	91.5
3	92.8	98.4	89.5
4	91.4	100.6	87.7
5	93.3	96.5	90.2
6	93.0	95.8	89.8
7	59.3	321.5	48.9
8	91.9	99.8	88.3
9	92.1	113.2	88.6
10	87.3	152.1	82.2
11	93.1	100.2	90.0
12	90.8	128.5	86.9
13	92.4	100.3	89.0
14	88.7	144.8	84.1
15	77.3	210.0	69.6
REF	99.9	19.9	99.4
Segment Statistics:	Average =	130.7	84.4
	Stdev =	61.4	11.2
	Min =	93.2	48.9
	Max =	321.5	91.5

Sheet 2d. HET 058 Reflectivity and Scattering Measurement

Data taken on 3/8/1999
Data recalibrated 6/15/99

Scaling Factor = 0.9669+(M-100)*0.00417

Position	Reflectivity Raw (%)	Surface Roughness (angstroms)	Reflectivity Calibrated (%)
REF	101.3	7.1	98.5
1	92.0	113.2	85.9
2	92.6	102.8	86.7
3	93.1	102.5	87.3
4	94.2	93.5	88.8
5	97.0	85.1	92.6
6	75.8	211.1	65.6
7	93.1	96.4	87.3
8	91.2	102.3	84.8
9	86.3	155.1	78.5
10	90.1	138.5	83.4
11	66.0	101.7	54.5
12	95.3	84.1	90.3
13	89.2	139.5	82.2
14	94.4	87.1	89.1
15	94.7	83.0	89.5
REF	101.3	7.8	98.5
Segment Statistics:	Average =	113.1	83.1
	Stdev =	34.9	10.2
	Min =	83.0	54.5
	Max =	211.1	92.6

Sheet 2e. HET 080 Reflectivity and Scattering Measurement

Data taken on 3/8/1999
Data recalibrated 6/15/99

Scaling Factor = 0.9769+(M-100)*0.00417

Position	Reflectivity Raw (%)	Surface Roughness (angstroms)	Reflectivity Calibrated (%)
REF	100.7	16.0	98.7
1	92.5	59.0	87.5
2	96.2	40.4	92.5
3	96.2	49.1	92.5
4	94.5	54.3	90.1
5	92.8	100.2	87.9
REF	100.4	24.0	98.2
REF	100.7	19.3	98.7
Segment Statistics: Average =		60.6	90.1
Stdev =		23.2	2.4
Min =		40.4	87.5
Max =		100.2	92.5

Sheet 2f. HET 086 Reflectivity and Scattering Measurement

Data taken on 3/8/1999
Data recalibrated 6/15/99

Scaling Factor = 0.9769+(M-100)*0.00417

Position	Reflectivity Raw (%)	Surface Roughness (angstroms)	Reflectivity Calibrated (%)
REF	100.7	16.0	98.7
1	95.7	58.8	91.8
2	92.5	64.0	87.5
3	91.4	83.4	86.0
4	91.9	67.9	86.7
5	94.9	52.8	90.7
REF	100.4	24.0	98.2
REF	100.7	19.3	98.7
Segment Statistics:	Average =	65.4	88.5
	Stdev =	11.6	2.6
	Min =	52.8	86.0
	Max =	83.4	91.8

Fig. 1. Reflectivity and Scattering Measurement

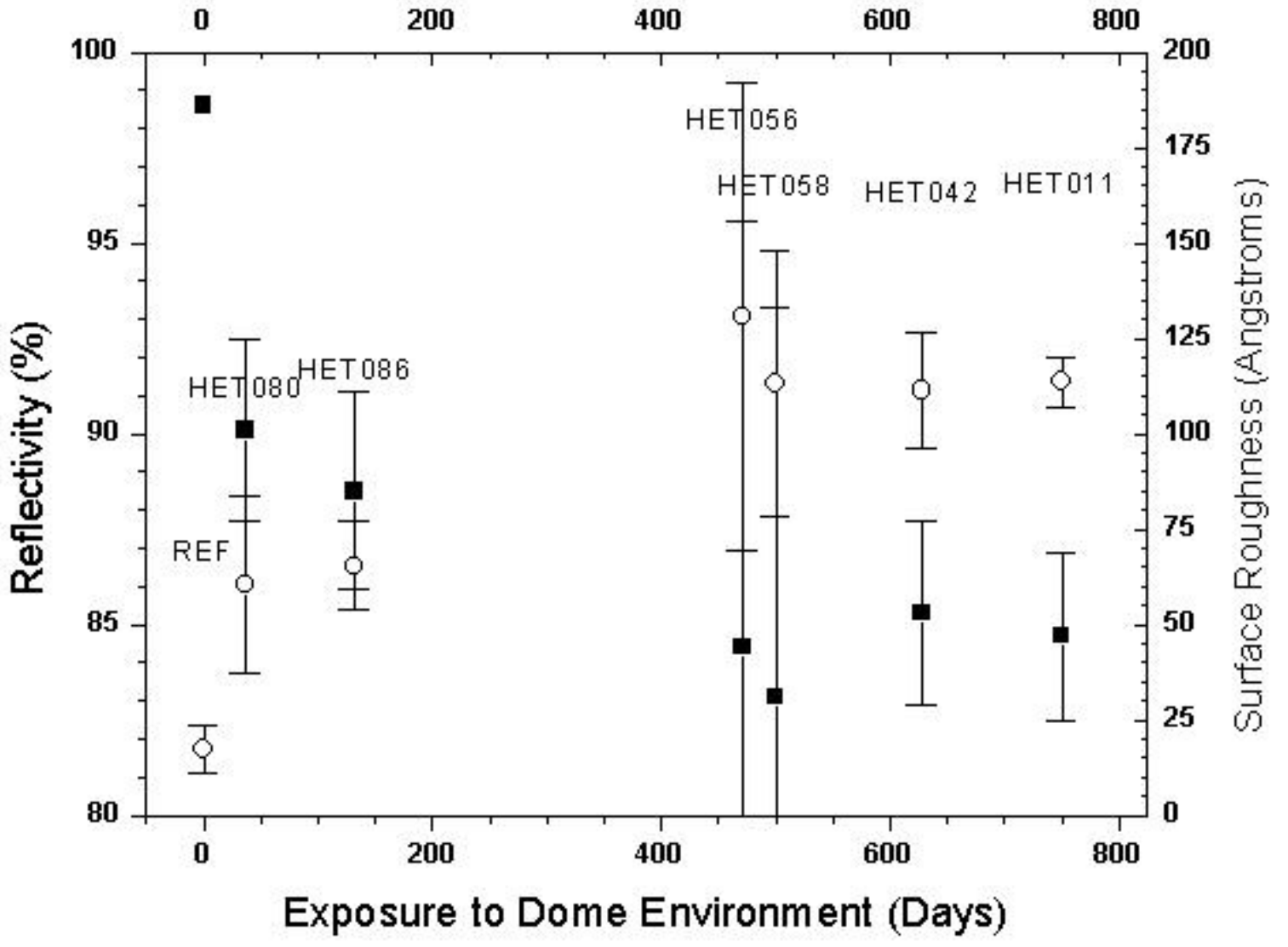

Fig. 2. Reflectivity Time Degradation

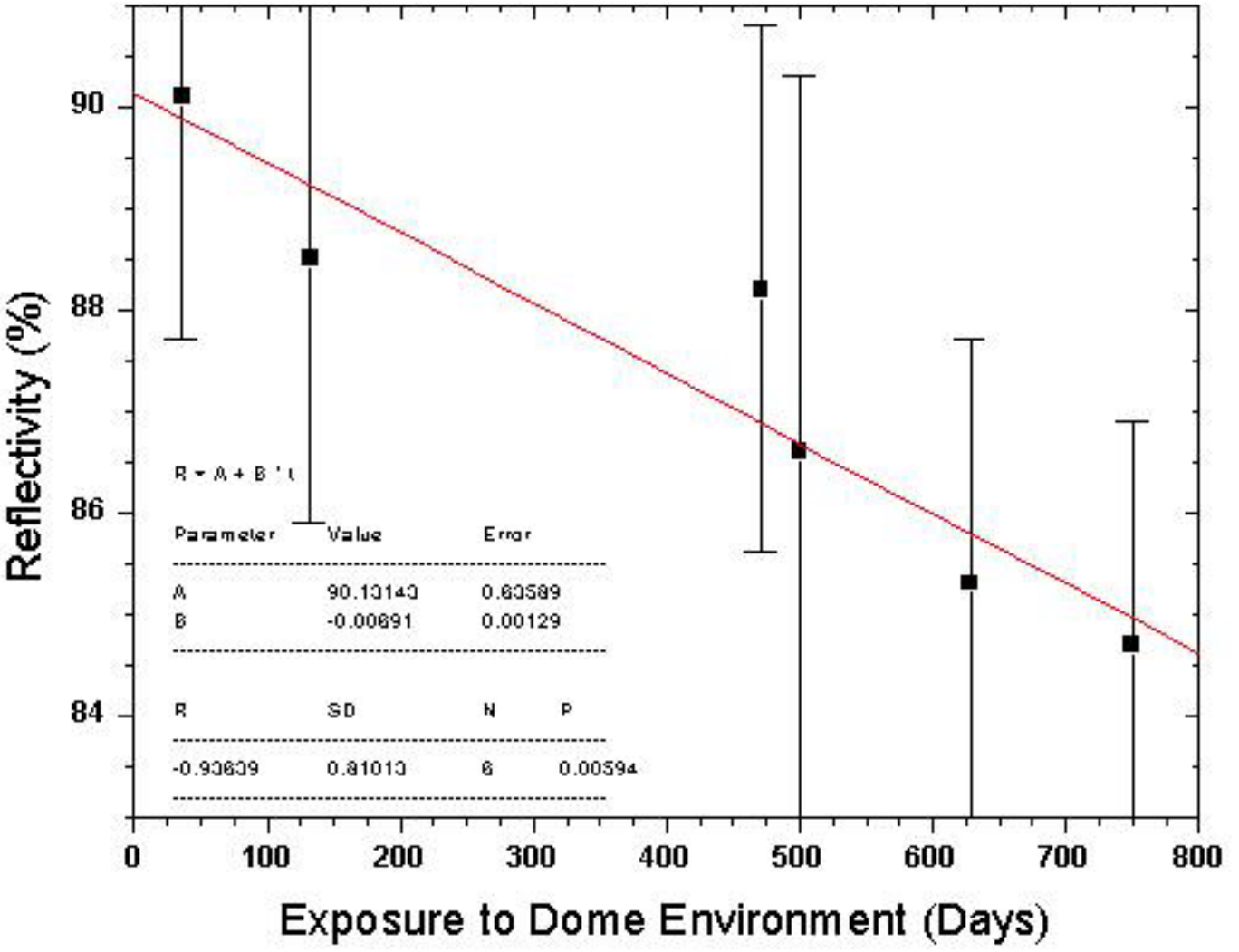

Fig. 3. Scattering Increase With Time