Impact of CO_2 Snow Cleaning on HET Primary Mirror Segment Reflectivity

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1. Introduction

Regular mirror cleaning is an important component of keeping the telescope observing efficiency as high as possible. Any degradation in coating reflectivity, especially with the 4 mirror spherical aberration corrector (SAC) quickly reduces the fraction of photons reaching the detector. Accumulation of dust on optical surfaces leads to degraded reflectivity and increased scattering both of which negatively affect telescope throughput performance. Until recently, the primary mirror was very infrequently cleaned, approximately quarterly. In the past month a regular program of CO_2 snow cleaning has been implemented. To evaluate our cleaning efficiency, we are also measuring reflectivity of a select few mirrors before and after each cleaning is performed. This document presents results available so far, and is intended to be kept updated as monthly cleanings are performed.

2. Procedure

2a. Cleaning the Primary Mirror Array

CO_2 snow cleaning of the primary mirror array is performed monthly (which is made much easier with the smaller JLG basket). This mirror cleaning method is fairly standard at any astronomical observatories. At the HET, this entails the expenditure of 5 to 7 cylinders of liquid CO_2 per cleaning, $126 to $182 for the 99.9% grade used currently. Visual inspection of the mirror array, after CO_2 cleaning, still shows a haze over the mirror surface due to left over small particles. This is also what other observatories report. More involved cleaning methods are needed to remove that remaining haze from the mirror surface. Discussion of various cleaning method merits is beyond the scope of this document.

2b. Reflectivity/Scattering Measurements

The 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 aluminum 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 mirror reflectivity measurements. Data at five different locations on the reference mirrors were taken and averaged together. This determined the calibration formula, as the μScan™ 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 on the various spreadsheets. At least ten measurements were taken at different locations on the mirrors under evaluation. Anomalous low data points are sometimes excluded from the statistical sample to avoid biasing the results.

The reference samples were not available prior to the June 18, 1999 cleaning. Nevertheless an aluminum coated mirror and a large FSS-99 coated plate glass were available. Since the reference samples were available after cleaning was performed, the reflectivity of the aluminum coated mirror and the large FSS-99 plate were checked against the ODA's calibrated references. Details of the first cleaning calibration is given on spreadsheet 3.

3. Results

3a. Pristine Segments

On May 25, 1999 segments 6 and 10 were replaced by mirrors SN 085 and SN 094. These mirrors were part of the last mirror shipment to the HET. They remained in the crate stored in the HET loading bay until installation. Right after the mirrors were positioned on the support frame, reflectivity and scattering measurements were taken. Results are shown on sheets 1 and 2 for reflectivity and scattering respectively. The left side of sheet 1 gives reference measurements and the calibration used, while the right side shows mirror reflectivity. The first column gives raw measurements, while the second column shows calculated reflectivity. Statistics are given at the far right. Both mirrors have high reflectivity giving us a pristine mirror coating baseline against which to evaluate later degradation in reflectivity performance.

For scattering, no calibration is applied. The reference mirrors were measured anyway to provide some baseline against which to evaluate the performance of the brand new "out of the box" mirrors. The reference mirrors have very good coating. The three columns give surface roughness in angstroms, forward and backward scattering in percent respectively. Surface roughness is calculated by the μScan™ portable scatterometer software from the signal sensed by all three detectors assuming a random distribution of surface irregularities. As can be seen, both SN 085 and SN 094 give very good performance with surface roughness a factor of two to three lowers than the reference mirrors. The increased surface roughness of the reference mirrors can be attributed to repeated positioning of the reflectometer detector head onto the reference mirrors.

3b. Cleaning Improvements

Spreadsheet 3 gives calibration details for the June 18 mirror cleaning evaluation. Sheet 4 gives the results of reflectivity measurements performed on six mirrors prior (left column) and after (right column) CO_2 snow cleaning. Statistics and improvement calculations are given in the shaded areas to the right of each tables. The history of the various segments is as follows:

- Segment 1 Installed 27 October 1998. Has been cleaned "weekly" with isopropanol.

- Segment 6 This is SN 094 installed 3 weeks prior to CO_2 snow cleaning.

- Segment 10 This is SN 085 installed 3 weeks prior to CO_2 snow cleaning.

- Segment 14 Installed on 22 September 1997. Seven weeks without cleaning.

- Segment 89 Installed 30 October 1998. Seven weeks since previous cleaning.

- Segment 90 Installed spring 1997. Seven weeks since previous cleaning.

A further note on segment 6: since installation, water has dripped from the dome onto a substantial portion of its surface. Measurements of this segment have been restricted to the cleaned portion of its surface. The selection is such that two newly installed, two "middle aged", and two of the oldest segments are measured. This gives us an adequate sampling to evaluate the effect of CO_2 snow cleaning on the reflectivity of coatings with different level of degradation. All segments selected are situated in the lower portion of the mirror array, such that dust "retention" rate differentials, from variation in elevation angle of the segments, is likely to be minimized.

Results clearly show that dust accumulation has a significant effect on mirror reflectivity performance. SN 085 and SN 094 have lost from 1.8% to 2.6% in only three weeks of exposure. CO_2 cleaning significantly improves mirror reflectivity of all six segments. The three segment "families" show different levels of improvement.

For the new segments (6 and 10), CO_2 snow cleaning restored their reflectivity halfway back to their previous pristine level. More data is needed to determine whether the reflectivity degradation rate is halved over the long run. If dust accumulation is a significant contributing factor in tarnishing the silver coating, we might expect reflectivity degradation rates to decrease by more than a factor of two. "Middle aged" segments show the highest level of improvement from CO_2 snow cleaning. Segment 89 had been accumulating dust for seven weeks and recovered a "whopping" 4.1% in reflectivity. Even segment 1, which had been cleaned with isopropanol only ten days earlier, recovered 1.3% which is as much as most other segments. The old segments show a level of improvement intermediate between the new and "middle aged" segments.

These results can be understood as follows. With degradation, the surface becomes rugged and the FSS-99 coating develops porosity. That the surface becomes rugged is evident when wiping the mirrors with isopropanol. On new segments, the TexWipe glides on the surface; for older segments, friction is sensed. Coating porosity became clear when removing the FSS-99 silver coating from the corner of segments to be repaired. Old segment coating came out easily. The HCl acid had to be left on the surface longer to properly strip the coating of newer segments. For new segments, the surface smoothness probably leads to smaller dust

retention rates and less chemisorbtion (i.e. dust slides more easily across the surface and does not stick to it as readily). As the coating ages, the dust retention rate increases significantly due to increased surface roughness, but the surface is still smooth enough that CO_2 snow crystals are still removing dust efficiently. For older segments, surface roughness becomes such that, not only is dust retention rate higher than for a pristine surface, but CO_2 snow cleaning becomes less efficient as it has a harder time dislodging dust particles from the surface. Data covering a six to nine months period are needed to determined whether the above scenario holds true.

4. Conclusions

There is no doubt that regular monthly CO_2 cleaning of the primary mirror array is highly desirable. Not only does it improve mirror reflectivity by a significant amount, but it might also reduce coating tarnishing rate. The later can only be assessed with a regular and systematic program of monthly CO_2 snow cleaning and reflectivity monitoring lasting at least six to nine months. With only one cleaning performed so far as part of this monitoring program all conclusions reached in this document are necessarily preliminary.

5. Acknowledgment

Thanks to Rex Barrick and Craig Nance for their assistance with mirror cleaning.

Sheet 1. May 25, 1999 Reflectivity Measurement of Mirrors SN 085 and SN 094.

SN 094 Reflectivity

CALIBRATION

Al coated reference mirror		92.9		
		92.6		
		92.1		
		91.7		
		92.6		
87.4% nominal*	average =	92.4	Scale Factor =	0.946
	stdev =	0.5		
FSS 99 sample A		100.4		
		100.9		
		100.7		
		100.9		
		100.7		
98.6% nominal*	average =	100.7	Scale Factor =	0.979
	stdev =	0.2		

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

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

Adopted scale factor = 0.9762 + (M - 100.0)*0.00398

MEASUREMENTS

SN 94 Brand new from out of the box.

raw	calibrated
100.2	97.9
100.2	97.9
100.1	97.8
99.8	97.3
100.2	97.9
99.9	97.5
99.6	97.1
100.7	98.6
99.8	97.3
100.1	97.8

	scaled
average =	97.7
stdev =	0.4
min =	97.1
max =	98.6

SN 085 Reflectivity

CALIBRATION

Al coated reference mirror		92.1		
		92.8		
		92.0		
		92.1		
		92.4		
87.4% nominal*	average =	92.3	Scale Factor =	0.947
	stdev =	0.3		
FSS 99 sample A		100.7		
		100.9		
		101.4		
		100.7		
		100.3		
98.6% nominal*	average =	100.8	Scale Factor =	0.978
	stdev =	0.4		

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

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

Adopted scale factor = 0.9751 + (M - 100.0)*0.00365

MEASUREMENTS

SN 85 Brand new from out of the box.

raw	calibrated
100.3	97.9
100.3	97.9
102.2	100.5
100.2	97.8
100.1	97.6
100.3	97.9
100.2	97.8
100.4	98.0
99.8	97.2
100.0	97.5

	scaled
average =	98.0
stdev =	0.9
min =	97.2
max =	100.5

Sheet 2. May 25, 1999 Scattering Measurement of Mirrors SN 085 and SN 094.

SN 094 Scattering

	σ (RMS) Å	forward (0,0)	backward (-50,180)
Al coated reference mirror	16.2	3.84E-04	6.93E-05
	19.0	7.16E-04	2.87E-04
	19.8	7.79E-04	3.07E-04
	19.9	6.02E-04	1.16E-04
	15.9	4.98E-04	1.86E-04
average =	18.2	5.96E-04	1.93E-04
stdev =	2.0	1.60E-04	1.04E-04

	σ (RMS) Å	forward (0,0)	backward (-50,180)
FSS 99 sample A	11.7	2.83E-04	8.86E-05
	18.8	7.32E-04	2.31E-05
	15.8	5.20E-04	1.71E-05
	21.4	9.38E-04	2.91E-05
	28.1	1.48E-03	3.59E-05
average =	19.2	7.91E-04	3.88E-05
stdev =	6.2	4.56E-04	2.87E-05

SN 094 Brand new from out of the box.

	σ (RMS) Å	forward (0,0)	backward (-50,180)
	8.1	9.78E-05	4.64E-05
	11.4	9.13E-05	8.04E-06
	6.8	5.99E-05	8.35E-06
	7.2	8.79E-05	1.77E-05
	7.4	9.15E-05	1.79E-05
	8.4	5.40E-05	4.95E-06
	13.1	1.20E-04	1.05E-05
	10.4	1.24E-04	1.54E-05
	9.4	6.87E-05	6.41E-06
	8.6	1.23E-04	2.37E-05
average =	9.1	9.18E-05	1.59E-05
stdev =	2.0	2.55E-05	1.23E-05

SN 085 Scattering

	σ (RMS) Å	forward (0,0)	backward (-50,180)
Al coated reference mirror	32.1	2.11E-03	4.23E-04
	20.6	8.39E-04	7.53E-04
	38.2	2.90E-03	3.81E-04
	16.3	5.10E-04	2.58E-04
	47.2	3.79E-03	8.70E-04
average =	30.9	2.03E-03	5.37E-04
stdev =	12.6	1.38E-03	2.61E-04

	σ (RMS) Å	forward (0,0)	backward (-50,180)
FSS 99 sample A	33.0	1.94E-03	4.23E-04
	31.6	2.12E-03	7.53E-04
	23.5	1.15E-03	3.81E-04
	14.3	4.64E-04	2.58E-04
	35.2	2.60E-03	8.70E-04
average =	27.5	1.65E-03	5.37E-04
stdev =	8.6	8.46E-04	2.61E-04

SN 085 Brand new from out of the box.

	σ (RMS) Å	forward (0,0)	backward (-50,180)
	11.8	3.10E-04	1.65E-04
	9.3	1.19E-04	1.79E-05
	12.0	1.28E-04	1.31E-05
	6.2	8.59E-05	4.32E-05
	8.8	9.04E-05	1.16E-05
	7.8	6.64E-05	7.88E-06
	6.3	6.21E-05	1.11E-05
	6.8	7.54E-05	1.40E-05
	11.7	1.24E-04	1.40E-05
	8.1	7.96E-05	1.04E-05
average =	8.9	1.14E-04	3.08E-05
stdev =	2.3	7.28E-05	4.82E-05

Sheet 3. June 18, 1999 CO_2 Snow Cleaning Calibration

Taking the average of before (set #1) and after (set #2) for scaling formula calculation.
Calibration accuracy approximately 0.5%.

Before cleaning: Used CCAS aluminum coated mirror and large FSS-99 plate

		Set #1			Set #2		
CCAS aluminum coated mirror		89.9			89.8		
		91.2			92.0		
		90.3			91.2		
		90.5			91.4		
		90.2			87.8		
87.7% nominal*	average =	90.4	Scale Factor =	0.970	90.4	Scale Factor =	0.970
	stdev =	0.5			1.7		

* The 87.7% comes from comparison with the June 99 calibrated aluminum coated mirror.

		Set #1			Set #2		
Large FSS 99 silver coating		97.1			98.1		
		97.2			98.1		
		97.2			97.4		
		97.2			98.2		
		97.3			97.9		
98.6% nominal*	average =	97.2	Scale Factor =	1.014	97.9	Scale Factor =	1.007
	stdev =	0.1			0.3		

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

Adopted scale factor = 1.0216 + (M - 100.0)*0.00434

After cleaning: Calibrated the CCAS aluminum coated mirror and large FSS-99 plate with ODA's measured references mirror. Used only the ODA's measured reference for determination of the scaling formula.

		Set #1			Set #2		
CCAS aluminum coated mirror		89.6			89.4		
		90.1			90.0		
		89.3			90.7		
		90.7			90.9		
		89.6			88.0		
87.7% nominal*	average =	89.9	Scale Factor =	0.976	89.8	Scale Factor =	0.977
	stdev =	0.6			1.2		

* The 87.7% comes from comparison with the June 99 calibrated aluminum coated mirror.

		Set #1			Set #2		
Large FSS 99 silver coating:		97.8			98.2		
		98.1			98.3		
		97.6			97		
		98.1			97.9		
		97.9			97.5		
98.6% nominal*	average =	97.9	Scale Factor =	1.007	97.8	Scale Factor =	1.008
	stdev =	0.2			0.5		

* Difference from FSS-99 sample A not significant.

		Set #1			Set #2		
Al coated reference mirror		89.4			89.2		
		89.9			89.7		
		89.6			88.8		
		89.9			90.0		
		89.9			89.4		
87.4% nominal*	average =	89.7	Scale Factor =	0.974	89.4	Scale Factor =	0.977
	stdev =	0.2			0.5		

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

		Set #1			Set #2		
FSS 99 sample A		97.7			98.7		
		97.9			98.6		
		98.0			98.2		
		98.2			99.1		
		98.1			98.7		
98.6% nominal*	average =	98.0	Scale Factor =	1.006	98.7	Scale Factor =	0.999
	stdev =	0.2			0.3		

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

Adopted scale factor = 1.0081 + (M - 100.0)*0.00307

Sheet 4. June 18, 1999, Primary Array CO_2 Snow Cleaning

BEFORE CLEANING

AFTER CLEANING

Segment #1 Mostly over the part that is alcool cleaned weekly

raw	calibrated		scaled
94.9	94.8		
91.8	90.5		
95.7	96.0		
95.6	95.8		
95.2	95.3		
92.0	90.8		
94.7	94.6	average =	94.3
96.5	97.1	stdev =	2.2
93.5	92.9	min =	90.5
95.2	95.3	max =	97.1

raw	calibrated		scaled	improvement
95.4	94.8			
95.7	95.2			
95.2	94.6			
96.4	96.1			
98.4	98.7			
95.3	94.7			
95.3	94.7	average =	95.6	1.3
95.7	95.2	stdev =	1.3	-0.9
96.1	95.7	min =	94.6	4.1
96.8	96.6	max =	98.7	1.6
82.1	78.3	not included in statistics		

Segment #89 As new as segment #1, but uncleaned for about 7 weeks.

raw	calibrated		scaled
88.9	86.5		
90.8	89.1		
93.3	92.6		
93.3	92.6		
91.1	89.5		
87.4	84.5		
91.7	90.4	average =	89.7
93.1	92.3	stdev =	2.6
91.8	90.5	min =	84.5
90.8	89.1	max =	92.6

raw	calibrated		scaled	improvement
94.9	94.2			
94.8	94.1			
92.2	90.7			
96.7	96.5			
95.1	94.4			
94.6	93.8			
93.1	91.9	average =	93.8	4.1
94.8	94.1	stdev =	1.5	-1.1
95.0	94.3	min =	90.7	6.2
94.8	94.1	max =	96.5	3.9
87.7	not included in statistics			

Segment #10 (SN 085) Completely new with about one month dust accumulation.

raw	calibrated		scaled
94.4	94.1		
94.1	93.7		
95.4	95.6		
94.9	94.8		
95.1	95.1		
94.9	94.8		
95.7	96.0	average =	95.4
96.6	97.3	stdev =	1.1
96.0	96.4	min =	93.7
95.6	95.8	max =	97.3

raw	calibrated		scaled	improvement
96.1	95.7			
97.4	97.4			
97.3	97.3			
96.8	96.6			
96.8	96.6			
97.2	97.2			
96.0	95.6	average =	96.2	0.8
96.2	95.9	stdev =	1.0	0.0
97.1	97.0	min =	94.2	0.5
95.5	95.0	max =	97.4	0.2
94.9	94.2			

Segment #6 (SN 094) Completely new with about one month dust accumulation.
Measurements done in cleaned areas as water dripped on this mirror quite heavily.

raw	calibrated		scaled
95.3	95.4		
95.3	95.4		
95.7	96.0		
95.6	95.8		
95.7	96.0		
96.1	96.5		
94.8	94.7	average =	95.9
97.0	97.8	stdev =	0.8
95.4	95.6	min =	94.7
95.5	95.7	max =	97.8
92.0	90.8	not included in statistics	

raw	calibrated		scaled	improvement
96.7	96.5			
96.1	95.7			
97.5	97.5			
97.2	97.2			
97.9	98.1			
98.0	98.2			
95.8	95.3	average =	97.0	1.1
97.7	97.8	stdev =	0.9	0.1
97.4	97.4	min =	95.3	0.6
97.4	97.4	max =	98.2	0.4
96.5	96.2			

Segment #14 Older segments installed since fall 1997.

raw	calibrated		scaled
91.8	90.5		
91.1	89.5		
91.9	90.7		
90.8	89.1		
91.3	89.8		
91.3	89.8		
92.9	92.0	average =	89.7
91.1	89.5	stdev =	1.5
91.5	90.1	min =	85.7
91.1	89.5	max =	92.0
88.3	85.7		
85.3	81.7	not included in statistics	
59.3	50.1	not included in statistics	

raw	calibrated		scaled	improvement
91.4	89.7			
92.5	91.1			
95.2	94.6			
96.5	96.2			
92.6	91.2			
93.2	92.0	average =	91.0	1.4
89.4	87.2	stdev =	3.4	1.8
93.1	91.9	min =	85.3	-0.4
87.9	85.3	max =	96.2	4.2
80.2	76.0	not included in statistics		
81.6	77.7	not included in statistics		

Segment #90 X21 segment in place since spring 1997

raw	calibrated		scaled
90.3	88.4		
91.1	89.5		
91.4	90.0		
91.9	90.7		
91.4	90.0		
91.4	90.0	average =	90.3
92.5	91.5	stdev =	1.1
93.0	92.2	min =	88.4
92.1	90.9	max =	92.2
86.8	83.7	not included in statistics	

raw	calibrated		scaled	improvement
93.0	91.8			
93.8	92.8			
92.8	91.5			
92.8	91.5			
92.4	91.0			
90.8	89.0	average =	91.6	1.2
94.3	93.4	stdev =	1.6	0.4
91.4	89.7	min =	89.0	0.5
94.4	93.5	max =	93.5	1.4
82.3	78.5	not included in statistics		

6. Appendix A: Isopropanol Cleaning

Another cleaning experiment has been going on in the background for the past two months. The lower half of segment 1 has been cleaned with isopropanol at a frequency of approximately ten days. This consists in depositing liberal amounts of alcohol onto the mirror surface with a wash bottle and gently wiping the segment surface with a TX606 Technicloth wiper. Reflectivity measurements are taken about every other cleaning. The cleaning and monitoring schedule is shown in Table A1. The aim of this experiment is to assess the efficiency of regular alcohol cleaning and the impact of resulting abrasion damage to the coating.

Results are presented in sheets A1 and A2. Isopropanol cleaning leads to reflectivity improvement on the order of what is achieved with CO_2 snow cleaning. It is somewhat surprising that the improvement level is not better than that as the surface definitely looks better than it does after CO_2 snow cleaning. This might be an indication of abrasion damage to the coating starting to affect reflectivity.

Table A1. Segment 1 Cleaning and Reflectivity Monitoring Log

Date	Cleaning Performed	Measurement Done
May 3, 1999	CO_2 snow	
May 6, 1999	Isopropanol lower half	
May 13, 1999	Isopropanol lower half	
May 19, 1999	Isopropanol lower half	μSCAN Reflectomer
May 27, 1999	Isopropanol lower half	
June 8, 1999	Isopropanol lower half	μSCAN Reflectometer
June 18, 1999	CO_2 snow	μSCAN Reflectometer
July 2, 1999	Isopropanol lower half	

Sheet A1. Reflectivity Measurement of Segment 1.

May 19, 1999

CALIBRATION

Al coated reference mirror		92.2		
		92.2		
		92.0		
		91.8		
		90.6		
87.4% nominal*	average =	91.8	Scale Factor =	0.952
	stdev =	0.7		

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

FSS 99 sample A		100.1		
		99.2		
		100.4		
		100.1		
		100.1		
98.6% nominal*	average =	100.0	Scale Factor =	0.986
	stdev =	0.5		

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

Adopted scale factor = 0.986 + (M - 100.0)*0.00415

MEASUREMENTS

Seg. #1 Lower half has been cleaned with isopropanol weekly. Relatively clean surface.

Before isopropanol cleaning:	raw	calibrated
	95.9	92.9
	97.6	95.3
	97.2	94.7
	92.7	88.6
	96.5	93.7
	93.7	89.9
	98.2	96.1
	97.6	95.3
	98.2	96.1
	96.9	94.3

	scaled
average =	93.7
stdev =	2.5
min =	88.6
max =	96.1

After isopropanol cleaning:	raw	calibrated
	98.0	95.8
	96.5	93.7
	97.4	95.0
	97.9	95.7
	98.6	96.6
	99.1	97.3
	95.3	92.1
	97.9	95.7
	98.1	96.0
	98.7	96.8

	scaled	improvement
average =	95.5	1.8
stdev =	1.5	
min =	92.1	3.5
max =	97.3	1.3

Sheet A2. Reflectivity Measurement of Segment 1.

June 8, 1999

CALIBRATION

Al coated reference mirror		91.8		
		91.4		
		90.9		
		92.0		
		92.0		
87.4% nominal*	average =	91.6	Scale Factor =	0.954
	stdev =	0.5		

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

FSS 99 sample A		100.7		
		100.5		
		100.3		
		100.6		
		100.7		
98.6% nominal*	average =	100.6	Scale Factor =	0.980
	stdev =	0.2		

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

Adopted scale factor = 0.978 + (M - 100.0)*0.004

MEASUREMENTS

Mirror #1 Lower half has been cleaned with isopropanol weekly. Relatively clean surface.

Before isopropanol cleaning:	raw	calibrated
	98.3	95.5
	97.2	94.0
	98.5	95.7
	95.8	92.1
	94.9	90.9
	95.7	91.9
	94.6	90.5
	97.1	93.8
	96.0	92.4
	96.5	93.0

	scaled
average =	93.0
stdev =	1.8
min =	90.5
max =	95.7

After isopropanol cleaning:	raw	calibrated
	98.8	96.2
	98.2	95.3
	98.7	96.0
	97.6	94.5
	94.1	89.8
	98.5	95.7
	96.0	92.4
	97.5	94.4
	97.3	94.1
	97.9	94.9

	scaled	improvement
average =	94.3	1.4
stdev =	1.9	
min =	89.8	-0.7
max =	96.2	0.4