Impact of CO₂ 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 CO₂ 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

CO₂ 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 CO₂ per cleaning, \$126 to \$182 for the 99.9% grade used currently. Visual inspection of the mirror array, after CO₂ 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 $\mu S can^{\scriptscriptstyle{TM}}$ 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 μ ScanTM 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

2 08/17/99

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) CO₂ 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.

3 08/17/99

- Segment 6 This is SN 094 installed 3 weeks prior to CO₂ snow cleaning.
- Segment 10 This is SN 085 installed 3 weeks prior to CO₂ 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 CO₂ 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), CO₂ 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 CO₂ 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

4

08/17/99

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 CO₂ 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 CO₂ 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 CO₂ 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 CO₂ 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.

5

08/17/99

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

SN 094 Reflectivity

CALIBRATION					MEASUR	<u>EMENTS</u>			
Al coated reference mi	rror	92.9			SN 94	Brand new from out of	f the box.		
		92.6				raw	calibrated		
		92.1				100.2	97.9		
		91.7				100.2	97.9		
		92.6				100.1	97.8		
87.4% nominal*	average =	92.4	Scale Factor =	0.946		99.8	97.3		
	stdev =	0.5				100.2	97.9		
* The 87.4% comes from	om the June 9	9 calibratio	n performed at ODA.			99.9	97.5		scaled
						99.6	97.1	average =	97.7
FSS 99 sample A		100.4				100.7	98.6	stdev =	0.4
		100.9				99.8	97.3	min =	97.1
		100.7				100.1	97.8	max =	98.6
		100.9							
		100.7							
98.6% nominal*	average =	100.7	Scale Factor =	0.979					
	stdev =	0.2							

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

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

SN 085 Reflectivity

CALIBRATION					MEASUR	<u>EMENTS</u>			
Al coated reference mi	rror	92.1			SN 85	Brand new from out of	f the box.		
		92.8				raw	calibrated		
		92.0				100.3	97.9		
		92.1				100.3	97.9		
		92.4				102.2	100.5		
87.4% nominal*	average =	92.3	Scale Factor =	0.947		100.2	97.8		
	stdev =	0.3				100.1	97.6		
* The 87.4% comes from	m the June 9	9 calibratio	n performed at ODA.			100.3	97.9		scaled
			·			100.2	97.8	average =	98.0
FSS 99 sample A		100.7				100.4	98.0	stdev =	0.9
•		100.9				99.8	97.2	min =	97.2
		101.4				100.0	97.5	max =	100.5
		100.7							
		100.3							
98.6% nominal*	average =	100.8	Scale Factor =	0.978					
	stdev =	0.4							

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

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

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

SN 094 Scattering

SN 085 Scattering

		σ (RMS)	forward	backward			σ (RMS)	forward	backward
A1		A	(0,0)	(-50,180)		-	A	(0,0)	(-50,180)
Al coated reference m	irror	16.2	3.84E-04	6.93E-05	Al coated reference mi	rror	32.1	2.11E-03	4.23E-04
		19.0	7.16E-04	2.87E-04			20.6	8.39E-04	7.53E-04
		19.8	7.79E-04	3.07E-04			38.2	2.90E-03	3.81E-04
		19.9	6.02E-04	1.16E-04			16.3	5.10E-04	2.58E-04
		15.9	4.98E-04	1.86E-04	ī		47.2		8.70E-04
	average =	18.2		1.93E-04		average =	30.9	2.03E-03	5.37E-04
	stdev =	2.0	1.60E-04	1.04E-04		stdev =	12.6	1.38E-03	2.61E-04
		σ (RMS)	forward	backward			σ (RMS)	forward	backward
		Å	(0,0)	(-50,180)			Å	(0,0)	(-50,180)
FSS 99 sample A	-	11.7	2.83E-04	8.86E-05	FSS 99 sample A	-	33.0	1.94E-03	4.23E-04
1 00 00 campio /		18.8	7.32E-04	2.31E-05	1 CC CC Campio / t		31.6	2.12E-03	7.53E-04
		15.8	5.20E-04	1.71E-05			23.5	1.15E-03	3.81E-04
		21.4	9.38E-04	2.91E-05			14.3	4.64E-04	2.58E-04
		28.1	1.48E-03	3.59E-05			35.2	2.60E-03	8.70E-04
	average =	19.2	7.91E-04	3.88E-05		average =	27.5	1.65E-03	5.37E-04
	stdev =	6.2		2.87E-05		stdev =	8.6	8.46E-04	
SN 094 Brand new	from out of	the hov			SN 085 Brand new	from out of	the hov		
Diana new					Diana new	non out or	ti ic box.		
	nom out or	uio box.							
	nom out or	σ (RMS)	forward	backward			σ (RMS)	forward	backward
	- Hom out or		forward (0,0)	backward (-50,180)			σ (RMS) Å	forward (0,0)	backward (-50,180)
	-	σ (RMS)				-			
	-	σ (RMS) Å	(0,0)	(-50,180)		-	Å	(0,0)	(-50,180)
	-	σ (RMS) Å 8.1	(0,0) 9.78E-05	(-50,180) 4.64E-05		-	Å 11.8	(0,0) 3.10E-04	(-50,180) 1.65E-04
	-	σ (RMS) Å 8.1 11.4	(0,0) 9.78E-05 9.13E-05 5.99E-05 8.79E-05	(-50,180) 4.64E-05 8.04E-06		-	11.8 9.3	(0,0) 3.10E-04 1.19E-04	(-50,180) 1.65E-04 1.79E-05
	-	σ (RMS) Å 8.1 11.4 6.8	(0,0) 9.78E-05 9.13E-05 5.99E-05	(-50,180) 4.64E-05 8.04E-06 8.35E-06		-	Å 11.8 9.3 12.0	(0,0) 3.10E-04 1.19E-04 1.28E-04	(-50,180) 1.65E-04 1.79E-05 1.31E-05
	-	σ (RMS) Å 8.1 11.4 6.8 7.2	(0,0) 9.78E-05 9.13E-05 5.99E-05 8.79E-05	(-50,180) 4.64E-05 8.04E-06 8.35E-06 1.77E-05		-	Å 11.8 9.3 12.0 6.2 8.8 7.8	(0,0) 3.10E-04 1.19E-04 1.28E-04 8.59E-05	(-50,180) 1.65E-04 1.79E-05 1.31E-05 4.32E-05
	-	σ (RMS) Å 8.1 11.4 6.8 7.2 7.4	(0,0) 9.78E-05 9.13E-05 5.99E-05 8.79E-05 9.15E-05	(-50,180) 4.64E-05 8.04E-06 8.35E-06 1.77E-05 1.79E-05		-	Å 11.8 9.3 12.0 6.2 8.8	(0,0) 3.10E-04 1.19E-04 1.28E-04 8.59E-05 9.04E-05	(-50,180) 1.65E-04 1.79E-05 1.31E-05 4.32E-05 1.16E-05
	-	σ (RMS) Å 8.1 11.4 6.8 7.2 7.4 8.4	(0,0) 9.78E-05 9.13E-05 5.99E-05 8.79E-05 9.15E-05 5.40E-05	(-50,180) 4.64E-05 8.04E-06 8.35E-06 1.77E-05 1.79E-05 4.95E-06		-	Å 11.8 9.3 12.0 6.2 8.8 7.8	(0,0) 3.10E-04 1.19E-04 1.28E-04 8.59E-05 9.04E-05 6.64E-05	(-50,180) 1.65E-04 1.79E-05 1.31E-05 4.32E-05 1.16E-05 7.88E-06
	-	σ (RMS) Å 8.1 11.4 6.8 7.2 7.4 8.4 13.1	(0,0) 9.78E-05 9.13E-05 5.99E-05 8.79E-05 9.15E-05 5.40E-05 1.20E-04	(-50,180) 4.64E-05 8.04E-06 8.35E-06 1.77E-05 1.79E-05 4.95E-06 1.05E-05		-	Å 11.8 9.3 12.0 6.2 8.8 7.8 6.3	(0,0) 3.10E-04 1.19E-04 1.28E-04 8.59E-05 9.04E-05 6.64E-05 6.21E-05	(-50,180) 1.65E-04 1.79E-05 1.31E-05 4.32E-05 1.16E-05 7.88E-06 1.11E-05
	-	σ (RMS) Å 8.1 11.4 6.8 7.2 7.4 8.4 13.1 10.4	(0,0) 9.78E-05 9.13E-05 5.99E-05 8.79E-05 9.15E-05 5.40E-05 1.20E-04 1.24E-04	(-50,180) 4.64E-05 8.04E-06 8.35E-06 1.77E-05 1.79E-05 4.95E-06 1.05E-05 1.54E-05	_	-	Å 11.8 9.3 12.0 6.2 8.8 7.8 6.3 6.8	(0,0) 3.10E-04 1.19E-04 1.28E-04 8.59E-05 9.04E-05 6.64E-05 6.21E-05 7.54E-05 1.24E-04	(-50,180) 1.65E-04 1.79E-05 1.31E-05 4.32E-05 1.16E-05 7.88E-06 1.11E-05 1.40E-05
	average =	σ (RMS) Å 8.1 11.4 6.8 7.2 7.4 8.4 13.1 10.4 9.4	(0,0) 9.78E-05 9.13E-05 5.99E-05 8.79E-05 9.15E-05 5.40E-05 1.20E-04 1.24E-04 6.87E-05	(-50,180) 4.64E-05 8.04E-06 8.35E-06 1.77E-05 1.79E-05 4.95E-06 1.05E-05 1.54E-05 6.41E-06 2.37E-05		average =	Å 11.8 9.3 12.0 6.2 8.8 7.8 6.3 6.8 11.7	(0,0) 3.10E-04 1.19E-04 1.28E-04 8.59E-05 9.04E-05 6.64E-05 6.21E-05 7.54E-05 1.24E-04	(-50,180) 1.65E-04 1.79E-05 1.31E-05 4.32E-05 1.16E-05 7.88E-06 1.11E-05 1.40E-05 1.40E-05 3.08E-05

Sheet 3. June 18, 1999 CO₂ 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

CCAS aluminum coat	ed mirror	Set #1 89.9 91.2			Set #2 89.8 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 co	ating	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.

CCAS aluminum coate	d mirror	Set #1 89.6 90.1			Set #2 89.4 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			12		

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

Large FSS 99 silver co	eating:	<u>Set #1</u> 97.8 98.1			<u>Set #2</u> 98.2 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.

Al coated reference mil	rror	<u>Set #1</u> 89.4 89.9 89.6 89.9			Set #2 89.2 89.7 88.8 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
	etdov -	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 C	CO₂ Snow	/ Cleaning	1	
	BEFORE (CLEANING			AFTER C	<u>LEANING</u>		
Segment #1		Mostly over t	he part th	at is alcool cleaned we	eekly			
raw	calibrated			raw	calibrated			
94.9	94.8			95.4	94.8			
91.8	90.5			95.7	95.2			
95.7	96.0			95.2	94.6			
95.6	95.8			96.4	96.1			
95.2	95.3	_		98.4	98.7	_		
92.0	90.8		scaled	95.3	94.7		scaled	improvemer
94.7	94.6	average =	94.3	95.3	94.7	average =	95.6	1.3
96.5	97.1	stdev =	2.2	95.7	95.2	stdev =	1.3	-0.9
93.5	92.9	min =	90.5	96.1	95.7	min =	94.6	4.1
95.2	95.3	max =	97.1	96.8 82.1	96.6 78.3	max = not included	98.7 I in statisti	1.6 cs
Segment #89)	As new as se	egment #1	, but uncleaned for ab	out 7 weeks			
raw	calibrated			raw	calibrated	<u>l</u>		
88.9	86.5			94.9	94.2			
90.8	89.1			94.8	94.1			
93.3	92.6			92.2	90.7			
93.3 91.1	92.6 89.5			96.7 95.1	96.5 94.4			
87.4	84.5		cooled	94.6	93.8		cooled	improvemen
91.7	90.4	overege -	scaled 89.7	93.1	91.9	overege -	scaled 93.8	improvemer 4.1
	92.3	average = stdev =	2.6	94.8	94.1	average = stdev =	1.5	-1.1
93.1 91.8	90.5	min =	84.5	95.0	94.1	min =	90.7	6.2
90.8	89.1	max =	92.6	94.8	94.1	max =	96.5	3.9
30.0	09.1	IIIdA -	32.0	87.7		ed in statistics		3.9
Segment #10	(SN 085)	Completely n	new with a	bout one month dust a	accumulation	ı.		
raw	calibrated			raw	calibrated	L		
94.4	94.1			96.1	95.7			
94.1	93.7			97.4	97.4			
95.4	95.6			97.3	97.3			
94.9	94.8			96.8	96.6			
95.1	95.1		analad	96.8	96.6		اممامما	
94.9	94.8		scaled	97.2	97.2		scaled	improveme
	96.0	average =	95.4	96.0	95.6	average =	96.2	0.8
95.7						stdev =	1.0	0.0
96.6	97.3	stdev =	1.1	96.2	95.9			
96.6 96.0	97.3 96.4	min =	93.7	97.1	97.0	min =	94.2	0.5
96.6	97.3	min = max =	93.7 97.3 new with a	97.1 95.5 94.9 bout one month dust a	97.0 95.0 94.2 accumulation	min = max =	94.2 97.4	0.5 0.2
96.6 96.0 95.6 Segment #6	97.3 96.4 95.8 (SN 094)	min = max =	93.7 97.3 new with a	97.1 95.5 94.9 pout one month dust a cleaned areas as wa	97.0 95.0 94.2 accumulation iter dripped o	min = max =	94.2 97.4	0.5 0.2
96.6 96.0 95.6	97.3 96.4 95.8	min = max =	93.7 97.3 new with a	97.1 95.5 94.9 bout one month dust a	97.0 95.0 94.2 accumulation	min = max =	94.2 97.4	0.5 0.2
96.6 96.0 95.6 Segment #6	97.3 96.4 95.8 (SN 094)	min = max =	93.7 97.3 new with a	97.1 95.5 94.9 pout one month dust a cleaned areas as wa	97.0 95.0 94.2 accumulation tter dripped c	min = max =	94.2 97.4	0.5 0.2
96.6 96.0 95.6 Segment #6	97.3 96.4 95.8 (SN 094) <u>calibrated</u> 95.4	min = max =	93.7 97.3 new with a	97.1 95.5 94.9 bout one month dust a cleaned areas as wa raw 96.7	97.0 95.0 94.2 accumulation ter dripped of calibrated 96.5	min = max =	94.2 97.4	0.5 0.2
96.6 96.0 95.6 Segment #6 <u>raw</u> 95.3 95.3	97.3 96.4 95.8 (SN 094) <u>calibrated</u> 95.4 95.4	min = max =	93.7 97.3 new with a	97.1 95.5 94.9 bout one month dust a cleaned areas as wa raw 96.7 96.1	97.0 95.0 94.2 accumulation ter dripped of calibrated 96.5 95.7	min = max =	94.2 97.4	0.5 0.2
96.6 96.0 95.6 Segment #6 Faw 95.3 95.3 95.7	97.3 96.4 95.8 (SN 094) <u>calibrated</u> 95.4 95.4 96.0	min = max =	93.7 97.3 new with a	97.1 95.5 94.9 cout one month dust a cleaned areas as wa <u>raw</u> 96.7 96.1 97.5	97.0 95.0 94.2 accumulation ater dripped of calibrated 96.5 95.7 97.5	min = max =	94.2 97.4	0.5 0.2
96.6 96.0 95.6 Segment #6 Faw 95.3 95.3 95.7 95.6	97.3 96.4 95.8 (SN 094) <u>calibrated</u> 95.4 96.0 95.8	min = max =	93.7 97.3 new with a	97.1 95.5 94.9 bout one month dust a cleaned areas as wa <u>raw</u> 96.7 96.1 97.5 97.2	97.0 95.0 94.2 accumulation ter dripped of <u>calibrated</u> 96.5 95.7 97.5 97.2	min = max =	94.2 97.4 quite heav	0.5 0.2 /ily.
96.6 96.0 95.6 Segment #6 Faw 95.3 95.3 95.7 95.6 95.7 96.1	97.3 96.4 95.8 (SN 094) <u>calibrated</u> 95.4 95.4 96.0 96.5	min = max = Completely n Measuremen	93.7 97.3 new with a nts done ir	97.1 95.5 94.9 sout one month dust a cleaned areas as wa <u>raw</u> 96.7 96.1 97.5 97.2 97.9 98.0	97.0 95.0 94.2 accumulation iter dripped of calibrated 96.5 95.7 97.5 97.2 98.1 98.2	min = max =	94.2 97.4 quite heav	0.5 0.2 vily.
96.6 96.0 95.6 Segment #6 Faw 95.3 95.3 95.7 95.6 95.7 96.1 94.8	97.3 96.4 95.8 (SN 094) <u>calibrated</u> 95.4 96.0 95.8 96.0 96.5 94.7	min = max = Completely n Measuremen	93.7 97.3 new with ai tts done in	97.1 95.5 94.9 bout one month dust a cleaned areas as wa 96.7 96.1 97.5 97.2 97.9 98.0 95.8	97.0 95.0 94.2 accumulation ster dripped of 26.5 95.7 97.5 97.2 98.1 98.2 95.3	min = max =	94.2 97.4 quite heav	0.5 0.2 rily. improveme 1.1
96.6 96.0 95.6 Segment #6 Faw 95.3 95.3 95.7 95.6 95.7 96.1 94.8 97.0	97.3 96.4 95.8 (SN 094) <u>calibrated</u> 95.4 96.4 96.0 96.5 96.0 96.5 94.7 97.8	min = max = Completely n Measuremen average = stdev =	93.7 97.3 new with a nts done in scaled 95.9 0.8	97.1 95.5 94.9 bout one month dust a cleaned areas as wa 96.7 96.1 97.5 97.2 97.9 98.0 95.8 97.7	97.0 95.0 94.2 accumulation iter dripped of calibrated 96.5 95.7 97.5 97.2 98.1 98.2 95.3 97.8	min = max =	94.2 97.4 quite heav scaled 97.0 0.9	0.5 0.2 //ily.
96.6 96.0 95.6 Segment #6 Faw 95.3 95.3 95.7 95.6 95.7 96.1 94.8 97.0 95.4	97.3 96.4 95.8 (SN 094) calibrated 95.4 96.0 95.8 96.0 96.5 94.7 97.8 95.6	min = max = Completely n Measuremen average = stdev = min =	93.7 97.3 new with a nts done in scaled 95.9 0.8 94.7	97.1 95.5 94.9 sout one month dust a cleaned areas as wa <u>raw</u> 96.7 96.1 97.5 97.2 97.9 98.0 95.8 97.7 97.4	97.0 95.0 94.2 accumulation ter dripped of 2alibrated 96.5 95.7 97.2 98.1 98.2 95.3 97.8 97.8	min = max = on this mirror of average = stdev = min =	94.2 97.4 quite heav scaled 97.0 0.9 95.3	0.5 0.2 vily. improveme 1.1 0.1 0.6
96.6 96.0 95.6 Segment #6 Faw 95.3 95.3 95.7 95.6 95.7 96.1 94.8 97.0	97.3 96.4 95.8 (SN 094) <u>calibrated</u> 95.4 96.4 96.0 96.5 96.0 96.5 94.7 97.8	min = max = Completely n Measuremen average = stdev =	93.7 97.3 new with a nts done in scaled 95.9 0.8 94.7 97.8	97.1 95.5 94.9 bout one month dust a cleaned areas as wa 96.7 96.1 97.5 97.2 97.9 98.0 95.8 97.7 97.4	97.0 95.0 94.2 accumulation iter dripped of calibrated 96.5 95.7 97.5 97.2 98.1 98.2 95.3 97.8	min = max =	94.2 97.4 quite heav scaled 97.0 0.9	0.5 0.2 //ily.
96.6 96.0 95.6 Segment #6 P5.3 95.3 95.3 95.7 95.6 95.7 96.1 94.8 97.0 95.4	97.3 96.4 95.8 (SN 094) calibrated 95.4 96.0 95.8 96.0 96.5 94.7 97.8 95.6 95.6	min = max = Completely n Measuremen average = stdev = min = max = not included	93.7 97.3 new with a atts done in scaled 95.9 0.8 94.7 97.8 in statistic	97.1 95.5 94.9 bout one month dust a cleaned areas as wa 96.7 96.1 97.5 97.2 97.9 98.0 95.8 97.7 97.4	97.0 95.0 94.2 accumulation ter dripped c calibrated 96.5 95.7 97.5 97.2 98.1 98.2 95.3 97.8 97.4	min = max = on this mirror of average = stdev = min =	94.2 97.4 quite heav scaled 97.0 0.9 95.3	0.5 0.2 vily. improveme 1.1 0.1 0.6
96.6 96.0 95.6 Segment #6 Iaw 95.3 95.3 95.7 95.6 95.7 96.1 94.8 97.0 95.4 95.5 92.0	97.3 96.4 95.8 (SN 094) <u>calibrated</u> 95.4 96.0 95.8 96.0 96.5 94.7 97.8 95.6 95.7 90.8	min = max = Completely n Measuremen average = stdev = min = max = not included	93.7 97.3 new with a atts done in scaled 95.9 0.8 94.7 97.8 in statistic	97.1 95.5 94.9 bout one month dust a cicleaned areas as was ready 96.7 96.1 97.5 97.2 97.9 98.0 95.8 97.7 97.4 97.4 96.5 ad since fall 1997.	97.0 95.0 94.2 accumulation ter dripped c 96.5 95.7 97.5 97.2 98.1 98.2 95.3 97.4 96.2	min = max = on this mirror of average = stdev = min = max =	94.2 97.4 quite heav scaled 97.0 0.9 95.3	0.5 0.2 vily. improveme 1.1 0.1 0.6
96.6 96.0 95.6 Segment #6 P5.3 95.3 95.3 95.7 96.1 94.8 97.0 95.5 92.0 Segment #14	97.3 96.4 95.8 (SN 094) calibrated 95.4 95.4 96.0 96.5 94.7 97.8 95.6 95.7 90.8	min = max = Completely n Measuremen average = stdev = min = max = not included	93.7 97.3 new with a atts done in scaled 95.9 0.8 94.7 97.8 in statistic	97.1 95.5 94.9 bout one month dust a cleaned areas as was read to be a cleaned areas read read to be a cleaned areas read to be a cleaned are	97.0 95.0 94.2 accumulation ter dripped of 26.5 96.7 97.2 98.1 98.2 97.8 97.8 97.4 96.2	min = max = on this mirror of average = stdev = min = max =	94.2 97.4 quite heav scaled 97.0 0.9 95.3	0.5 0.2 vily. improveme 1.1 0.1 0.6
96.6 96.0 95.6 Segment #6 Faw 95.3 95.3 95.7 95.6 95.7 96.1 94.8 97.0 95.4 95.5 92.0 95.4 95.5 92.0 95.4	97.3 96.4 95.8 (SN 094) 2016/2016/2016/2016/2016/2016/2016/2016/	min = max = Completely n Measuremen average = stdev = min = max = not included	93.7 97.3 new with a atts done in scaled 95.9 0.8 94.7 97.8 in statistic	97.1 95.5 94.9 bout one month dust a cleaned areas as was read of the second of the se	97.0 95.0 94.2 accumulation ter dripped of calibrated 96.5 95.7 97.5 97.2 98.1 98.2 95.3 97.8 97.4 96.2	min = max = on this mirror of average = stdev = min = max =	94.2 97.4 quite heav scaled 97.0 0.9 95.3	0.5 0.2 vily. improveme 1.1 0.1 0.6
96.6 96.0 95.6 Segment #6 Faw 95.3 95.7 95.6 95.7 96.1 94.8 97.0 95.4 95.5 92.0 Segment #14 91.8 91.8	97.3 96.4 95.8 (SN 094) <u>calibrated</u> 95.4 96.0 96.5 94.7 97.8 95.6 95.7 90.8	min = max = Completely n Measuremen average = stdev = min = max = not included	93.7 97.3 new with a atts done in scaled 95.9 0.8 94.7 97.8 in statistic	97.1 95.5 94.9 bout one month dust a cicleaned areas as was seed as was seed areas as was seed areas as was seed areas as was seed as was seed areas as was seed areas as was seed as was seed a	97.0 95.0 94.2 accumulation ter dripped c 96.5 95.7 97.5 97.2 98.1 98.2 95.3 97.4 96.2 calibrated 89.7 91.1	min = max = on this mirror of average = stdev = min = max =	94.2 97.4 quite heav scaled 97.0 0.9 95.3	0.5 0.2 vily. improveme 1.1 0.1 0.6
96.6 96.0 95.6 Segment #6 P5.3 95.3 95.7 96.1 94.8 97.0 95.5 92.0 Segment #14 P1.9 91.8 91.1 91.9	97.3 96.4 95.8 (SN 094) calibrated 95.4 96.4 96.5 96.5 94.7 97.8 95.6 95.7 90.8 calibrated 90.5 89.5 90.5 89.5 90.5 89.5	min = max = Completely n Measuremen average = stdev = min = max = not included	93.7 97.3 new with a atts done in scaled 95.9 0.8 94.7 97.8 in statistic	97.1 95.5 94.9 bout one month dust a cleaned areas as was read to be seen as a was read to be seen as read to be see	97.0 95.0 95.2 accumulation ter dripped of Calibrated 96.5 95.7 97.5 97.2 98.1 98.2 95.3 97.8 97.4 96.2 calibrated 89.7 91.1 94.6 96.2	min = max = on this mirror of average = stdev = min = max =	94.2 97.4 quite heav scaled 97.0 0.9 95.3 98.2	0.5 0.2 rily. improveme 1.1 0.1 0.6 0.4
96.6 96.0 95.6 95.6 95.3 95.3 95.7 95.6 95.7 96.1 94.8 97.0 95.4 95.5 92.0 91.4 91.1 91.1 91.9 90.8	97.3 96.4 95.8 (SN 094) 26.0 95.4 96.0 96.5 94.7 97.8 95.6 95.7 90.8 26.0 90.5 89.5 90.7 89.5	min = max = Completely n Measuremen average = stdev = min = max = not included	93.7 97.3 new with a new with a new with a new with a 95.9 0.8 94.7 97.8 in statistic	97.1 95.5 94.9 bout one month dust a cleaned areas as we see see see see see see see see see	97.0 95.0 94.2 accumulation ter dripped of 2 calibrated 96.5 95.7 97.5 97.2 98.1 98.2 95.3 97.4 97.4 96.2	min = max = on this mirror of a stdev = min = max =	94.2 97.4 quite heav scaled 97.0 0.9 95.3 98.2	0.5 0.2 vily. improveme 1.1 0.1 0.6 0.4
96.6 96.0 95.6 Segment #6 P5.3 95.3 95.7 95.6 95.7 96.1 94.8 97.0 95.4 95.5 92.0 91.8 91.8 91.9 90.8 91.3	97.3 96.4 95.8 (SN 094) <u>calibrated</u> 95.4 96.0 96.5 94.7 97.8 95.6 95.7 90.8 <u>calibrated</u> 90.5 89.5 89.5 90.7 89.1	min = max = Completely n Measuremer average = stdev = min = max = not included Older segme	93.7 97.3 new with a ants done in scaled 95.9 0.8 94.7 97.8 in statistic ents installed scaled scaled scaled	97.1 95.5 94.9 bout one month dust a cleaned areas as was read to be seen as a was read to be seen as read to be see	97.0 95.0 94.2 accumulation ter dripped c calibrated 96.5 95.7 97.5 97.2 98.1 98.2 95.3 97.4 96.2 calibrated 89.7 91.1 94.6 96.2 91.2	min = max = on this mirror of the min = max = average = stdev = min = max =	94.2 97.4 quite heav scaled 97.0 0.9 95.3 98.2	0.5 0.2 //ily. improveme 1.1 0.1 0.6 0.4
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96.6 96.0 95.6 95.6 95.3 95.3 95.7 95.6 95.7 96.1 94.8 97.0 95.4 95.5 92.0 91.1 91.9 90.8 91.1 91.3 91.3 92.9 91.1	97.3 96.4 95.8 (SN 094) 2010 104 105 105 105 105 105 105 105 105 105 105	min = max = Completely n Measuremer average = stdev = min = max = not included Older segme	93.7 97.3 new with a atts done in scaled 95.9 0.8 94.7 97.8 in statistic ents installed 89.7 1.5	97.1 95.5 94.9 bout one month dust a cleaned areas as well areas as year of the second	97.0 95.0 94.2 accumulation ter dripped of 2 calibrated 96.5 95.7 97.5 97.2 98.1 98.1 98.2 95.3 97.4 97.4 96.2	min = max = average = stdev = min = max =	94.2 97.4 quite heav scaled 97.0 0.9 95.3 98.2	0.5 0.2 //iiy. improveme 1.1 0.6 0.4
96.6 96.0 95.6 Segment #6 1 EaW 95.3 95.7 95.6 95.7 96.1 94.8 97.0 95.4 95.5 92.0 91.8 91.8 91.9 90.8 91.3 92.9 91.1 91.5	97.3 96.4 95.8 (SN 094) calibrated 95.4 96.0 96.5 94.7 97.8 95.6 95.7 90.8 calibrated 90.5 89.5 89.5 89.7 89.1 89.8 92.0 89.5 90.1	min = max = Completely n Measuremer average = stdev = min = not included Older segme average = stdev = min = included	93.7 97.3 new with a ants done in scaled 95.9 0.8 94.7 97.8 in statistic ents installed 89.7 1.5 85.7	97.1 95.5 94.9 bout one month dust a cicleaned areas as was cicleaned areas as was solved areas as was sol	97.0 95.0 94.2 accumulation ter dripped c calibrated 96.5 95.7 97.5 97.2 98.1 98.2 95.3 97.4 96.2 calibrated 89.7 91.1 94.6 96.2 91.9 92.0 87.2 93.3	min = max = average = stdev = max = average = stdev = min = max =	94.2 97.4 quite heav quite heav 97.0 0.9 95.3 98.2 scaled 91.0 3.4 85.3 96.2	improveme 1.1 0.1 0.4 0.4 1.8 -0.4 4.2
96.6 96.0 95.6 95.9 95.6 96.0 95.6 96.1 94.8 97.0 95.4 95.5 92.0 96.4 95.5 92.0 96.4 91.8 91.1 91.9 91.8 91.1 91.9 90.8 91.3 91.3 91.3 91.3 92.9 91.1 91.5 91.1	97.3 96.4 95.8 (SN 094) 2alibrated 95.4 95.4 96.0 96.5 94.7 97.8 95.6 95.7 90.8 2alibrated 90.5 89.5 90.7 89.8 89.8 89.9 90.7 89.8 89.8 90.0 89.5 90.0 89.5 90.7 89.8 89.8	min = max = Completely n Measuremer average = stdev = min = max = not included Older segme	93.7 97.3 new with a atts done in scaled 95.9 0.8 94.7 97.8 in statistic ents installed 89.7 1.5	97.1 95.5 94.9 bout one month dust a cleaned areas as was read areas read are	97.0 95.0 95.2 accumulation ter dripped of calibrated 96.5 95.7 97.5 98.1 98.2 95.3 97.8 97.4 96.2 calibrated 89.7 91.1 94.6 96.2 91.9 96.2 91.9 85.3 76.0	min = max = average = stdev = min = max = average = stdev = min = max = or min = min = min = min = max = not include	94.2 97.4 quite heavenument of the scaled 97.0 0.9 95.3 98.2 scaled 91.0 3.4 85.3 96.2	improveme 1.1 0.1 0.6 0.4 improveme 1.4 1.8 -0.4 4.2 cs
96.6 96.0 95.6 Segment #6 P5.3 95.3 95.7 95.6 95.7 96.1 94.8 97.0 95.4 95.5 92.0 P1.8 91.8 91.9 90.8 91.3 92.9 91.1 91.5 91.1 88.3 85.3	97.3 96.4 95.8 (SN 094) Calibrated 95.4 96.0 96.5 94.7 97.8 96.6 95.7 90.8 Calibrated 90.5 89.5 89.5 89.7 89.1 89.8 99.0 89.8 99.1 89.8 99.1 89.8 99.1 89.8 99.1 89.8 99.7 89.1 89.8 99.7 89.1 89.8 99.7 89.1 89.8 99.7 89.1 89.8 99.7 89.1 89.8 99.7 89.1 89.8 99.7 89.1 89.8 99.7 89.1 89.8 99.7 89.8 99.7 89.1 89.8 99.7 89.8 99.7 89.8 99.7 89.8 99.7 89.8 99.7 89.8 99.7 89.8 99.7 89.8 99.7 89.8 99.7 89.8 99.7 89.8 99.7 89.8 99.7 89.8 99.7 89.8 99.7 89.8 99.7 89.8 99.8 99.7 89.8 99.7 89.8 99.7 89.8 99.7 89.8 99.7 89.8 99.7 89.8 99.7 89.8 99.8 99.8 99.8 99.7 89.8 99.7 89.8 99	min = max = Completely n Measuremer Average = stdev = min = max = not included Older segme average = stdev = min = max = not included	93.7 97.3 new with a ants done in scaled 95.9 0.8 94.7 97.8 in statistic ents installed 89.7 1.5 85.7 92.0	97.1 95.5 94.9 bout one month dust a cicleaned areas as was cicleaned areas as was solved areas as was sol	97.0 95.0 94.2 accumulation ter dripped c calibrated 96.5 95.7 97.5 97.2 98.1 98.2 95.3 97.4 96.2 calibrated 89.7 91.1 94.6 96.2 91.9 92.0 87.2 93.3	min = max = average = stdev = max = average = stdev = min = max =	94.2 97.4 quite heavenument of the scaled 97.0 0.9 95.3 98.2 scaled 91.0 3.4 85.3 96.2	0.5 0.2 hily. improveme 1.1 0.1 0.6 0.4
96.6 96.0 95.6 95.6 Faw 95.3 95.3 95.7 95.6 95.7 96.1 94.8 97.0 95.4 95.5 92.0 91.1 91.9 90.8 91.8 91.3 91.3 91.3 91.3 91.3 91.1 91.5 91.1 91.5	97.3 96.4 95.8 (SN 094) calibrated 95.4 95.4 96.0 96.5 94.7 97.8 95.6 95.7 90.8 calibrated 90.5 89.5 89.5 89.7 89.1 89.8 89.8 89.8 99.0 189.5 89.8 89.8 89.5 90.1 89.5 89.5 89.5 89.7 89.1	min = max = Completely n Measuremer Average = stdev = min = max = not included Older segme average = stdev = min = max = not included not included	93.7 97.3 new with a ants done in scaled 95.9 0.8 94.7 97.8 in statistic installed 89.7 1.5 85.7 92.0 in statistic	97.1 95.5 94.9 bout one month dust a cicleaned areas as was cicleaned areas as was solved areas as was sol	97.0 95.0 95.2 accumulation ter dripped of calibrated 96.5 95.7 97.5 98.1 98.2 95.3 97.8 97.4 96.2 calibrated 89.7 91.1 94.6 96.2 91.9 96.2 91.9 85.3 76.0	min = max = average = stdev = min = max = average = stdev = min = max = or min = min = min = min = max = not include	94.2 97.4 quite heavenument of the scaled 97.0 0.9 95.3 98.2 scaled 91.0 3.4 85.3 96.2	0.5 0.2 hily. improveme 1.1 0.1 0.6 0.4
96.6 96.0 95.6 95.6 Faw 95.3 95.3 95.7 95.6 95.7 96.1 94.8 97.0 95.4 95.5 92.0 91.1 91.9 90.8 91.3 91.3 91.3 91.3 91.3 91.3 92.9 91.1 91.5 91.1 91.5 91.1	97.3 96.4 95.8 (SN 094) calibrated 95.4 95.4 96.0 96.5 94.7 97.8 95.6 95.7 90.8 calibrated 90.5 89.5 89.5 89.7 89.1 89.8 89.8 89.8 99.0 189.5 89.8 89.8 89.5 90.1 89.5 89.5 89.5 89.7 89.1	min = max = Completely n Measuremer Average = stdev = min = max = not included Older segme average = stdev = min = max = not included not included	93.7 97.3 new with a ants done in scaled 95.9 0.8 94.7 97.8 in statistic installed 89.7 1.5 85.7 92.0 in statistic	97.1 95.5 94.9 bout one month dust a cicleaned areas as was cicleaned areas as was read areas read ar	97.0 95.0 95.2 accumulation ter dripped of calibrated 96.5 95.7 97.5 98.1 98.2 95.3 97.8 97.4 96.2 calibrated 89.7 91.1 94.6 96.2 91.9 96.2 91.9 85.3 76.0	min = max = average = stdev = min = max = average = stdev = min = max = not included	94.2 97.4 quite heavenument of the scaled 97.0 0.9 95.3 98.2 scaled 91.0 3.4 85.3 96.2	0.5 0.2 hily. improveme 1.1 0.1 0.6 0.4
96.6 96.0 95.6 95.9 95.6 96.1 94.8 97.0 95.4 95.5 92.0 95.4 91.1 91.9 91.1 91.9 90.8 91.3 91.1 91.9 90.8 91.3 91.3 91.3 92.9 91.1 91.5 92.0 95.6	97.3 96.4 95.8 (SN 094) calibrated 95.4 95.4 96.0 96.5 94.7 97.8 95.6 95.7 90.8 calibrated 90.5 90.7 89.5 90.7 89.8 89.8 99.9 89.5 90.7 89.8 89.8 89.8 99.8	min = max = Completely n Measuremer Average = stdev = min = max = not included Older segme average = stdev = min = max = not included not included	93.7 97.3 new with a ants done in scaled 95.9 0.8 94.7 97.8 in statistic installed 89.7 1.5 85.7 92.0 in statistic	97.1 95.5 94.9 bout one month dust a cleaned areas as was cleaned areas as was read areas read are	97.0 95.0 95.0 94.2 accumulation ter dripped of 26.5 95.7 97.5 98.1 98.2 95.3 97.8 97.4 96.2 calibrated 89.7 91.1 94.6 96.2 92.0 92.0 92.0 97.7 91.7 96.2 97.7 97.7	min = max = average = stdev = min = max = average = stdev = min = max = not included	94.2 97.4 quite heavenument of the scaled 97.0 0.9 95.3 98.2 scaled 91.0 3.4 85.3 96.2	0.5 0.2 hily. improveme 1.1 0.1 0.6 0.4
96.6 96.0 95.6 95.6 Faw 95.3 95.3 95.7 95.6 95.7 96.1 94.8 97.0 95.4 95.5 92.0 91.8 91.8 91.9 91.8 91.3 91.3 91.3 91.3 92.9 91.1 91.5 91.1 91.5 91.1 91.5 91.1	97.3 96.4 95.8 (SN 094) calibrated 95.4 95.4 95.0 96.5 94.7 97.8 95.6 95.7 90.8 calibrated 90.5 89.5 90.7 89.1 89.8 92.0 89.5 90.1 89.5 89.5 90.1 89.5 89.5 90.1	min = max = Completely n Measuremer Average = stdev = min = max = not included Older segme average = stdev = min = max = not included not included	93.7 97.3 new with a ants done in scaled 95.9 0.8 94.7 97.8 in statistic installed 89.7 1.5 85.7 92.0 in statistic	97.1 95.5 94.9 bout one month dust a cicleaned areas as was cicleaned areas as was solved areas as was sol	97.0 95.0 94.2 accumulation ter dripped c calibrated 96.5 95.7 97.5 98.1 98.2 95.3 97.8 97.4 96.2 calibrated 89.7 91.1 94.6 96.2 91.2 92.0 87.2 91.9 85.3 76.0 77.7	min = max = average = stdev = min = max = average = stdev = min = max = not included	94.2 97.4 quite heavenument of the scaled 97.0 0.9 95.3 98.2 scaled 91.0 3.4 85.3 96.2	improveme 1.1 0.1 0.6 0.4 improveme 1.4 1.8 -0.4 4.2 cs
96.6 96.0 95.6 95.9 95.6 95.3 95.3 95.3 95.7 95.6 95.7 95.4 95.5 92.0 95.4 91.1 91.9 90.8 91.1 91.9 90.8 91.3 91.3 91.3 91.3 91.5 91.1 88.3 85.3 59.3 Segment #90	97.3 96.4 95.8 (SN 094) 2016/2016/2016/2016/2016/2016/2016/2016/	min = max = Completely n Measuremer Average = stdev = min = max = not included Older segme average = stdev = min = max = not included not included	93.7 97.3 new with a ants done in scaled 95.9 0.8 94.7 97.8 in statistic installed 89.7 1.5 85.7 92.0 in statistic	97.1 95.5 94.9 bout one month dust a cleaned areas as was a cleaned areas as a cleaned areas as was a cleaned areas as a cleaned areas a	97.0 95.0 95.2 accumulation ter dripped c calibrated 96.5 95.7 97.5 98.1 98.2 95.3 97.4 96.2 Calibrated 89.7 91.1 94.6 96.2 91.2 92.0 87.2 91.2 92.0 87.2 91.7 91.7 Calibrated 91.8	min = max = average = stdev = min = max = average = stdev = min = max = not included	94.2 97.4 quite heavenument of the scaled 97.0 0.9 95.3 98.2 scaled 91.0 3.4 85.3 96.2	improveme 1.1 0.1 0.6 0.4 improveme 1.4 1.8 -0.4 4.2 cs
96.6 96.0 95.6 95.6 Faw 95.3 95.3 95.7 95.6 95.7 96.1 94.8 97.0 95.4 95.5 92.0 91.8 91.8 91.9 91.8 91.3 91.3 91.3 91.3 91.3 92.9 91.1 91.5 91.1 91.5 91.1 91.5 91.1 91.5 91.1	97.3 96.4 95.8 (SN 094) calibrated 95.4 95.4 96.0 96.5 94.7 97.8 95.6 95.7 90.8 calibrated 90.5 89.5 89.5 90.7 89.1 89.8 99.0 89.8 99.0 189.5 90.1 89.5 89.5 90.1 89.5 89.5 90.1 89.5 89.5 90.1 89.5 89.5 90.1 89.5 89.5 90.1 89.5 89.5 90.1 89.5 89.5 90.1 89.5 89.5 90.1 89.5 90.1	min = max = Completely n Measuremer Average = stdev = min = max = not included Older segme average = stdev = min = max = not included not included	93.7 97.3 new with a ants done in scaled 95.9 0.8 94.7 97.8 in statistic installed 89.7 1.5 85.7 92.0 in statistic	97.1 95.5 94.9 bout one month dust a cicleaned areas as was cicleaned areas as was solved areas as was sol	97.0 95.0 94.2 accumulation ter dripped c calibrated 96.5 95.7 97.5 97.2 98.1 98.2 95.3 97.8 97.4 96.2 2 calibrated 89.7 91.1 94.6 96.2 91.9 92.0 87.2 91.9 85.3 76.0 77.7	min = max = average = stdev = min = max = average = stdev = min = max = not included	94.2 97.4 quite heavenument of the scaled 97.0 0.9 95.3 98.2 scaled 91.0 3.4 85.3 96.2	0.5 0.2 hily. improveme 1.1 0.1 0.6 0.4
96.6 96.0 95.6 95.0 95.6 95.8 95.7 95.6 95.7 96.1 94.8 97.0 95.4 95.5 92.0 Segment #14 raw 91.3 91.1 91.9 90.8 91.1 91.1 88.3 85.3 85.3 85.3 85.3 85.3 85.3 85.3	97.3 96.4 95.8 (SN 094) calibrated 95.4 95.4 96.0 96.5 94.7 97.8 96.6 95.7 90.5 89.5 90.7 89.8 89.8 89.9 90.7 89.1 89.5 90.1	min = max = Completely n Measuremer Average = stdev = min = max = not included Older segme average = stdev = min = max = not included not included	93.7 97.3 new with a	97.1 95.5 94.9 bout one month dust a cicleaned areas as was seed as a cicleaned areas as a	97.0 95.0 95.0 94.2 accumulation ter dripped of calibrated 96.5 95.7 97.2 98.1 98.2 95.3 97.8 97.4 96.2 calibrated 89.7 91.1 94.6 96.2 91.2 92.0 97.2 91.2 91.9 85.3 76.0 77.7	min = max = average = stdev = min = max = average = stdev = min = max = not included	94.2 97.4 quite heavenument of the second of	improveme 1.1 0.1 0.6 0.4 improveme 1.4 1.8 -0.4 4.2 cs cs
96.6 96.0 95.6 95.9 95.6 95.3 95.3 95.3 95.7 95.6 95.7 95.4 95.5 92.0 95.4 95.5 92.0 91.1 91.9 90.8 91.3 91.3 91.3 91.3 91.3 91.5 91.1 88.3 85.3 59.3 Segment #90 Eaw 90.3 91.1 91.5 91.1	97.3 96.4 95.8 (SN 094) 2016/2016/2016/2016/2016/2016/2016/2016/	min = max = Completely n Measuremer Measuremer average = stdev = min = max = not included Older segme average = stdev = min = max = not included X21 segmen	93.7 97.3 new with a atts done in scaled 95.9 0.8 94.7 97.8 in statistic ents installed 89.7 15. 85.7 92.0 in statistic in statistic in statistic tringlace is scaled	97.1 95.5 94.9 bout one month dust a cleaned areas as was cleaned areas as was solved	97.0 95.0 94.2 accumulation ter dripped c 2015rated 96.5 95.7 97.5 97.2 98.1 98.2 95.3 97.4 97.4 96.2 2015rated 89.7 91.1 94.6 96.2 219.9 85.3 76.0 77.7	average = stdev = max = average = stdev = min = max = average = not included	94.2 97.4 97.4 97.0 0.9 95.3 98.2 scaled 91.0 3.4 85.3 96.2 li in statisti	improveme 1.1 0.1 0.6 0.4 improveme 1.4 1.8 -0.4 4.2 cs
96.6 96.0 95.6 95.6 Segment #6 Faw 95.3 95.3 95.7 95.6 95.7 96.1 94.8 97.0 95.4 95.5 92.0 95.4 91.8 91.3 91.3 91.3 91.3 92.9 91.8 91.1 91.5 91.1 91.5 91.1 91.5 91.1 91.5 91.1 91.5 91.1 91.5 91.1 91.5 91.1 91.5 91.1 91.5 91.1 91.5 91.1 91.5 91.1 91.5 91.1 91.5 91.1 91.5 91.1 91.4 91.9	97.3 96.4 95.8 (SN 094) calibrated 95.4 95.4 95.8 96.0 96.5 94.7 97.8 95.6 95.7 90.8 calibrated 90.5 89.5 90.7 89.1 89.8 92.0 89.5 90.1 89.5 90.1 89.5 89.5 90.1 89.5 90.1 89.5 90.7 89.1 89.5 90.1 89.5 90.7 90.0	min = max = Completely n Measuremer Average = stdev = min = max = not included Older segme average = stdev = min = max = not included Average = stdev = min = max = not included X21 segmen	93.7 97.3 new with a ants done in scaled 95.9 0.8 94.7 97.8 in statistic ents installed 89.7 1.5 1.5 1.5 1.5 1.5 1.5 1.5 1.5 1.5 1.5	97.1 95.5 94.9 bout one month dust a cicleaned areas as was cicleaned areas as was solved as a cicleaned areas as was solved as a cicleaned areas as was solved as a cicleaned areas as was solved areas as was solved as a cicleaned areas as was solved areas as was solved areas as was solved areas as was solved as a cicleaned areas as was solved as a cicleaned areas	97.0 95.0 94.2 accumulation ter dripped c calibrated 96.5 95.7 97.5 97.2 98.1 98.2 95.3 97.4 96.2 91.9 4.6 96.2 91.2 92.0 87.2 91.9 85.3 76.0 77.7 calibrated 91.8 92.8 91.8 92.8 91.9 91.8 92.0 87.9 91.1 98.0	min = max = average = stdev = min = max = average = stdev included included average = stdev included included	94.2 97.4 quite heave 97.0 0.9 95.3 98.2 scaled 91.0 3.4 85.3 96.2 l in statisti l in statisti	improveme 1.1 0.1 0.6 0.4 1.8 -0.4 4.2 cs cs
96.6 96.0 95.6 95.6 95.9 95.8 95.3 95.3 95.3 95.7 95.6 95.7 95.6 95.7 96.1 94.8 97.0 95.4 95.5 92.0 Segment #14 191.9 90.8 91.3 91.3 91.3 91.3 91.3 91.3 92.9 91.1 91.5 93.8 93.9 91.1 91.5 91.1 91.5 93.9 94.1 91.1 91.1 91.1 91.3 91.3 91.3 91.3 91	97.3 96.4 95.8 (SN 094) calibrated 95.4 95.4 95.4 96.0 96.5 94.7 97.8 95.6 95.7 90.8 89.5 90.7 89.1 89.8 89.8 92.0 89.5 90.7 89.1 89.8 89.8 92.0 89.5 90.7 89.1 89.8 89.8 90.7 89.7 90.7 90.9 90.9	min = max = Completely n Measuremer Average = stdev = min = max = not included Older segme average = stdev = min = max = not included not included X21 segmen average = stdev =	93.7 97.3 new with a ants done in scaled 95.9 0.8 94.7 97.8 in statistic ents installed 89.7 1.5 85.7 92.0 in statistic in statistic in place scaled 90.3 1.1	97.1 95.5 94.9 bout one month dust a cicleaned areas as was seed as a cicleaned areas as a	97.0 95.0 95.0 94.2 accumulation ter dripped of 26.5 95.7 97.5 97.2 98.1 98.2 95.3 97.8 97.4 96.2 2 5.3 2 6.2 2 6.2 2 6.2 2 6.3 6.2 6.2 6.3 6.3 6.0 6.0 77.7 6.0 77.7 6.0 77.7 6.0 77.7 6.0 77.7 6.0 77.7 6.0 91.8 92.8 91.5 91.0 89.0 93.4	min = max = average = stdev = min = max = average = stdev = min = max = not included	94.2 97.4 quite heavenument of the second of	improveme 1.1 0.1 0.6 0.4 1.8 -0.4 4.2 cs cs
96.6 96.0 95.6 95.6 Segment #6 Faw 95.3 95.3 95.7 95.6 95.7 96.1 94.8 97.0 95.4 95.5 92.0 95.4 91.8 91.3 91.3 91.3 91.3 92.9 91.8 91.1 91.5 91.1 91.5 91.1 91.5 91.1 91.5 91.1 91.5 91.1 91.5 91.1 91.5 91.1 91.5 91.1 91.5 91.1 91.5 91.1 91.5 91.1 91.5 91.1 91.5 91.1 91.5 91.1 91.4 91.9	97.3 96.4 95.8 (SN 094) calibrated 95.4 95.4 95.8 96.0 96.5 94.7 97.8 95.6 95.7 90.8 calibrated 90.5 89.5 90.7 89.1 89.8 92.0 89.5 90.1 89.5 90.1 89.5 89.5 90.1 89.5 90.1 89.5 90.7 89.1 89.5 90.1 89.5 90.7 90.0	min = max = Completely n Measuremer Average = stdev = min = max = not included Older segme average = stdev = min = max = not included Average = stdev = min = max = not included X21 segmen	93.7 97.3 new with a ants done in scaled 95.9 0.8 94.7 97.8 in statistic ents installed 89.7 1.5 1.5 1.5 1.5 1.5 1.5 1.5 1.5 1.5 1.5	97.1 95.5 94.9 bout one month dust a cicleaned areas as was cicleaned areas as was solved as a cicleaned areas as was solved as a cicleaned areas as was solved as a cicleaned areas as was solved areas as was solved as a cicleaned areas as was solved areas as was solved areas as was solved areas as was solved as a cicleaned areas as was solved as a cicleaned areas	97.0 95.0 94.2 accumulation ter dripped c calibrated 96.5 95.7 97.5 97.2 98.1 98.2 95.3 97.4 96.2 91.9 4.6 96.2 91.2 92.0 87.2 91.9 85.3 76.0 77.7 calibrated 91.8 92.8 91.8 92.8 91.9 91.8 92.0 87.9 91.1 98.0	min = max = average = stdev = min = max = average = stdev included included average = stdev included included	94.2 97.4 quite heave 97.0 0.9 95.3 98.2 scaled 91.0 3.4 85.3 96.2 l in statisti l in statisti	improvemer 1.1 0.1 0.6 0.4 1.8 -0.4 4.2 cs cs

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	

6

08/17/99

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

stdev = 0.7

Scale Factor = 0.952

^{*} 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		scaled	
	98.2	96.1	average =	93.7	
	97.6	95.3	stdev =	2.5	
	98.2	96.1	min =	88.6	
	96.9	94.3	max =	96.1	
After isopropanol cleaning:	raw	calibrated			
After isopropanol cleaning:	raw 98.0	calibrated 95.8			
After isopropanol cleaning:					
After isopropanol cleaning:	98.0	95.8			
After isopropanol cleaning:	98.0 96.5	95.8 93.7			
After isopropanol cleaning:	98.0 96.5 97.4	95.8 93.7 95.0			
After isopropanol cleaning:	98.0 96.5 97.4 97.9	95.8 93.7 95.0 95.7		scaled	improvement
After isopropanol cleaning:	98.0 96.5 97.4 97.9 98.6	95.8 93.7 95.0 95.7 96.6	average =	scaled 95.5	improvement 1.8
After isopropanol cleaning:	98.0 96.5 97.4 97.9 98.6 99.1	95.8 93.7 95.0 95.7 96.6 97.3	average = stdev =		
After isopropanol cleaning:	98.0 96.5 97.4 97.9 98.6 99.1 95.3	95.8 93.7 95.0 95.7 96.6 97.3 92.1	_	95.5	
After isopropanol cleaning:	98.0 96.5 97.4 97.9 98.6 99.1 95.3 97.9	95.8 93.7 95.0 95.7 96.6 97.3 92.1 95.7	stdev =	95.5 1.5	1.8

Sheet A2. Reflectivity Measurement of Segment 1. <u>June 8, 1999</u>

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		scaled	
	94.6	90.5	average =	93.0	
	97.1	93.8	stdev =	1.8	
	96.0	92.4	min =	90.5	
	96.5	93.0	max =	95.7	
After isopropanol cleaning:	raw	calibrated			
After isopropanol cleaning:	raw 98.8	calibrated 96.2			
After isopropanol cleaning:					
After isopropanol cleaning:	98.8	96.2			
After isopropanol cleaning:	98.8 98.2	96.2 95.3			
After isopropanol cleaning:	98.8 98.2 98.7	96.2 95.3 96.0			
After isopropanol cleaning:	98.8 98.2 98.7 97.6	96.2 95.3 96.0 94.5		scaled	improvement
After isopropanol cleaning:	98.8 98.2 98.7 97.6 94.1	96.2 95.3 96.0 94.5 89.8	average =	scaled 94.3	improvement 1.4
After isopropanol cleaning:	98.8 98.2 98.7 97.6 94.1 98.5	96.2 95.3 96.0 94.5 89.8 95.7	average = stdev =		
After isopropanol cleaning:	98.8 98.2 98.7 97.6 94.1 98.5 96.0	96.2 95.3 96.0 94.5 89.8 95.7 92.4		94.3	
After isopropanol cleaning:	98.8 98.2 98.7 97.6 94.1 98.5 96.0 97.5	96.2 95.3 96.0 94.5 89.8 95.7 92.4 94.4	stdev =	94.3 1.9	1.4