

2016 Aluminization of WHT Primary Mirror (M1) - Reflectivity Data from CT7 reflectometer

Measurement and analysis by Neil O'Mahony. Each measurement at a different location, distributed around the edge of the mirror.

M1 measurements (%R) with CT7 before aluminizing.

	Temp. °C	wavelength of band (nm)							"Dust Indices"								
		365	404	464	522	624	760	970	365	404	464	522	624	760	970		
703	16/05/2016 14:19	3	18.4	87.8	86.5	86.5	86.7	86.2	83.6	89.5	10.5	10.3	10.3	8.1	9.0	8.0	7.7
704	16/05/2016 14:21	3	18.6	88.2	87.2	87.3	87.5	87.0	84.6	90.4	10.3	9.3	9.0	7.3	7.6	6.2	6.3
705	16/05/2016 14:21	3	18.7	88.8	88.0	87.9	88.3	87.6	85.3	91.3	9.3	8.0	7.7	5.4	6.1	4.4	4.0
average				88.3	87.2	87.2	87.5	86.9	84.5	90.4	10.0	9.2	9.0	6.9	7.6	6.2	6.0
range				1.0	1.5	1.4	1.6	1.4	1.7	1.8	1.2	2.3	2.6	2.7	2.9	3.6	3.7

Note: M1 had not been cleaned since 9 March (CO2), losing ~1% R since then.

M1 measurements with CT7 directly after aluminizing. Dust had visibly begun to gather by **the end** of this first set.

706	18/05/2016 10:09	1	18.1	92.9	91.2	90.8	90.8	89.9	87.2	93.3	2.7	2.5	2.4	1.7	1.7	1.3	1.2
707	18/05/2016 10:10	1	18.4	93.1	91.4	91.0	91.0	90.1	87.3	93.4	2.2	1.9	1.9	1.3	1.3	0.9	0.8
708	18/05/2016 10:12	1	18.6	93.2	91.5	91.0	91.0	90.1	87.3	93.3	2.0	1.8	1.7	1.2	1.2	0.9	0.9
709	18/05/2016 10:13	1	18.8	93.1	91.4	91.0	91.0	90.1	87.3	93.3	2.3	2.0	1.9	1.3	1.3	1.0	0.9
710	18/05/2016 10:14	1	18.9	93.0	91.3	90.8	90.9	89.9	87.2	93.2	2.6	2.4	2.2	1.7	1.7	1.2	1.2
711	18/05/2016 10:15	1	19.1	93.1	91.4	90.9	91.0	90.0	87.2	93.2	2.1	1.9	1.9	1.3	1.3	1.0	0.9
712	18/05/2016 10:17	1	19.3	93.0	91.3	90.9	90.9	90.0	87.2	93.2	2.5	2.3	2.2	1.6	1.6	1.2	1.1
713	18/05/2016 10:18	1	19.4	93.2	91.4	91.0	91.0	90.1	87.3	93.2	2.1	2.0	1.9	1.4	1.4	1.0	0.9
average				93.08	91.36	90.93	90.95	90.03	87.25	93.26	2.3	2.1	2.0	1.4	1.4	1.1	1.0
maximum*, n>1				93.2	91.4	91.0	91.0	90.1	87.3	93.3							
range				0.3	0.3	0.2	0.2	0.2	0.1	0.2	0.7	0.7	0.7	0.5	0.5	0.4	0.4
std deviation				0.10	0.09	0.09	0.08	0.09	0.05	0.07	0.3	0.3	0.2	0.2	0.2	0.2	0.2

*maximum value in this set of measurements, if this occurs more than once. Highlighted in green. Note consistency across bands.

This implies that we are detecting locations with different reflectivity immediately after aluminizing.

Note: nominal error on measurement is 0.1, but may be larger in blue bands.

More M1 measurements, half an hour later.

				Tempr. °C	wavelength of band (nm)							"Dust Indices"						
					365	404	464	522	624	760	970	365	404	464	522	624	760	970
714	18/05/2016 10:49	1		17.3	93.0	91.3	90.9	91.0	89.9	87.3	93.3	2.2	2.0	1.8	1.3	1.3	0.9	1.0
715	18/05/2016 10:50	1		17.3	93.1	91.4	90.9	91.0	90.0	87.3	93.4	2.1	1.9	1.8	1.3	1.3	0.9	0.9
716	18/05/2016 10:51	1		17.4	93.0	91.2	90.7	90.7	89.9	87.0	93.1	2.4	2.3	2.3	1.7	1.7	1.4	1.3
717	18/05/2016 10:52	1		17.6	93.1	91.3	90.9	91.0	90.0	87.2	93.3	2.2	2.1	2.1	1.4	1.5	1.1	1.0
718	18/05/2016 10:53	1		17.7	93.1	91.4	90.9	91.0	90.0	87.2	93.2	2.3	2.1	2.0	1.4	1.4	1.0	1.0
average					93.06	91.32	90.86	90.94	89.96	87.20	93.26	2.2	2.1	2.0	1.4	1.4	1.1	1.0
global range					0.3	0.3	0.3	0.3	0.2	0.3	0.3							
difference from earlier average					0.01	0.04	0.07	0.01	0.06	0.05	0.00	much smaller than std.dev.						

Note these differences, though smaller than the standard deviation, are all positive. Maxima are down 0.1% in some bands.

This is within measurement error of the instrument. No significant change has been detected and all data can be grouped together.

global average %R Aluminization	93.07	91.35	90.90	90.95	90.00	87.23	93.26
global std.deviation	0.09	0.09	0.09	0.10	0.08	0.09	0.09

wavebands (nm)	365	404	464	522	624	760	970	Dust Index						
Improvement from Aluminisation	4.8	4.1	3.7	3.5	3.1	2.8	2.9	-7.7	-7.1	-7.0	-5.5	-6.1	-5.1	-5.0

Note that the decrease in Dust Index is larger than the increase in reflectivity. The latter is an independent measurement, using a model.

Calibration/Comparison

CT7 measurements from 2015 aluminisation of Liverpool telescope (finder)

24/06/15 Liverpool Alum	93.4	91.7	91.2	91.2	90.2	87.6	93.6
24/06/15 Liverpool Alum	93.4	91.7	91.2	91.2	90.2	87.5	93.5
Change in readings since 2015	-0.3	-0.4	-0.3	-0.3	-0.2	-0.3	-0.2

New readings slightly lower, however compare reference gauge (G) readings (taken 1 month after aluminisation in 2016):

waveband (nm)	% Reflectivity							"Dust Indices"							
	365	404	464	522	624	760	970	365	404	464	522	624	760	970	
729 24/06/2016 14:49 0 G	23.7	84.7	83.8	88.5	90.7	89.7	83.5	87.0	2.4	3.0	2.6	1.5	1.1	0.8	1.1
25/06/2015 G		84.6	83.5	88.4	90.6	89.6	83.3	86.5							
475 19/05/2015 11:53 0 G	20.2	84.7	83.7	88.5	90.7	89.6	83.2	86.4	2.3	2.9	2.5	1.5	1	0.8	1
change since 2015		0.1	0.3	0.1	0.1	0.1	0.2	0.5	i.e. now measuring higher						

Above figures would suggest CT7 is reading high in recent aluminisation compared with the previous

Difference between aluminisations (2016-2015) when this overestimation is corrected for:

-0.5 -0.6 -0.4 -0.3 -0.4 -0.5 -0.7 (rounded)

Above changes suggest the current WHT M1 aluminisation gave ~0.5% lower reflectivity than the LT Aluminization in 2015.

The Dust Index readings were much lower (0.4 to 0.7 %) on LT Alum. More scattering may explain slightly lower reflectivity in 2016

Difference in Coating measurements compared to values from literature (Hass 1961)

Hass 1961 %R values for Alum.	92.4	92.6	92.3	91.7	90.7
Hass - CT7(2016)	-0.67	1.254	1.4	0.754	0.7
Hass - CT7(2015)	-1.00	0.90	1.10	0.50	0.50

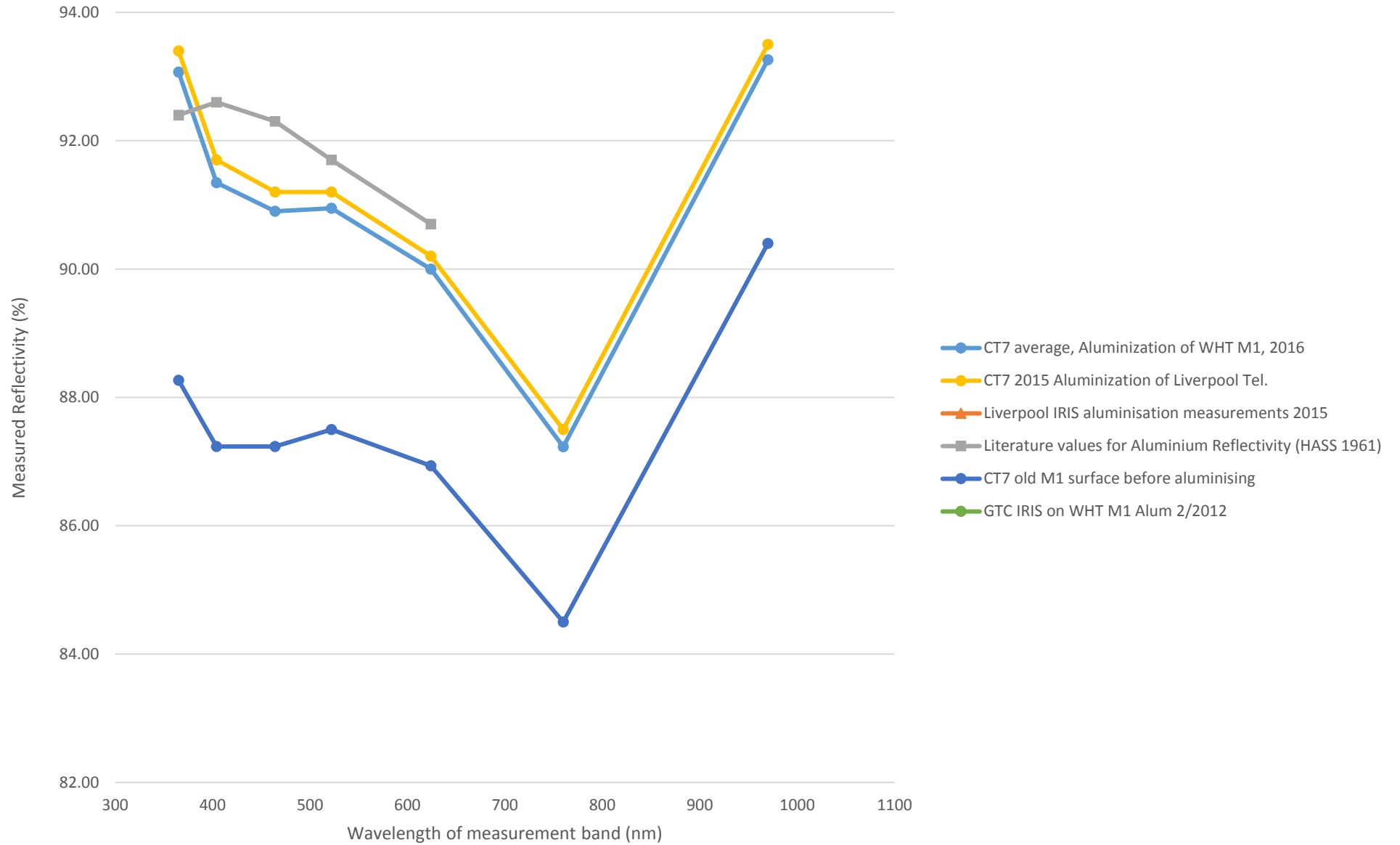
Measurements using IRIS 4-band reflectometer (from GTC, LT) from previous aluminisations

waveband of IRIS (nm)	470	530	650	880
24/06/15 LT-IRIS Liverpool Tel Alum	92.0	91.0	89.7	82.3
24/06/15 CT7 LT Alum (close waveband)	91.7	91.2	91.2	90.2(760nm)
07/02/12 GTC-IRIS WHTM1 Alum	91.1	90.6	89.8	88.1

Conclusion: agreement < 0.5% between CT7 and IRIS in all 3 overlapping bands.

The graph below summarises the most important results. Aluminium absorption band at 820 nm.

Fresh Aluminium Reflectivity by wavelength (interpolated by Excel)



Study of Dust Index and absorption

Following entries show the deviation from 100% of the sum (%Dust Index + %R)

This number represents the "missing light": part is Absorbivity (Dust + Aluminium), part Model deviation (both unknown)

We know aluminium has an absorption band at ~820 nm.

M1 before aluminising

Index	wavelength of band (nm)						
	365	404	464	522	624	760	970
703	1.7	3.2	3.2	5.2	4.8	8.4	2.8
704	1.5	3.5	3.7	5.2	5.4	9.2	3.3
705	1.9	4.0	4.4	6.3	6.3	10.3	4.7

Values for M3 after water washing were similar (2-5%, 11% at 760 nm)

Directly after aluminizing there is no Dust, but Dust had visibly begun to gather by **the end** of this first set.

706	4.4	6.3	6.8	7.5	8.4	11.5	5.5
707	4.7	6.7	7.1	7.7	8.6	11.8	5.8
708	4.8	6.7	7.3	7.8	8.7	11.8	5.8
709	4.6	6.6	7.1	7.7	8.6	11.7	5.8
710	4.4	6.3	7.0	7.4	8.4	11.6	5.6
711	4.8	6.7	7.2	7.7	8.7	11.8	5.9
712	4.5	6.4	6.9	7.5	8.4	11.6	5.7
713	4.7	6.6	7.1	7.6	8.5	11.7	5.9

More M1 measurements, half an hour later.

714	4.8	6.7	7.3	7.7	8.8	11.8	5.7
715	4.8	6.7	7.3	7.7	8.7	11.8	5.7
716	4.6	6.5	7.0	7.6	8.4	11.6	5.6
717	4.7	6.6	7.0	7.6	8.5	11.7	5.7
718	4.6	6.5	7.1	7.6	8.6	11.8	5.8
Range	0.4	0.4	0.5	0.4	0.4	0.3	0.4
average "absorption"	4.6	6.6	7.1	7.6	8.6	11.7	5.7
waveband (nm)	365	404	464	522	624	760	970

With dust present, the "missing light" is lower. This makes sense, since after scattering on the dust, less is available for absorption.

We can also estimate absorptivity from Hass (1961) as $100-R$, but do not know how much these are affected by scattering.

Abs+Scatt from HASS	7.6	7.4	7.7	8.3	9.3
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How much do the missing light values agree?

Abs(Hass)-Abs(CT7)	3.0	0.8	0.6	0.7	0.7
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So, the varying difference between fresh aluminium %R measured by CT7 and by Hass (1961), as seen above graph, seem to be made up by the variations in the DI from CT7, in 4 contiguous wavebands, except for a constant 0.7% offset.

This implies Hass measurements were less affected by scattering (perhaps $< 0.7\%$), but also that DI is a good measure of scattering in that range.

This explains the lower reflectivity measured after this Aluminisation. The calibration in 365 nm is probably deficient.

Summary: This aluminisation gave 91% reflectance, 7% absorption, 2% scattering (and model 0 error) between 404 and 624 nm.

SMS uScan Reflectometer measurements of the WHT Primary mirror after Aluminisation

Lambda	0.67 micron	
Incident Angle	25 deg	<--SMS Summary characteristics
BW Limits	1 0.01	

datum #	Scattering at angles Θ, Φ		Reflectivity	user comment	Roughness RMS(Å)	TIME	DATE
	Θ s->	Φ s->					
		0 50					
		0 180					
20	location 1	9.63E-04 6.46E-05	0.865		51.1	11:10:16	05-18-2016
21		9.64E-04 6.33E-05	0.862		52.4	11:10:20	05-18-2016
22	2	3.86E-03 2.82E-03	0.824		45.5	11:10:28	05-18-2016
23		3.87E-03 2.82E-03	0.829		45.4	11:10:34	05-18-2016
24	3	1.38E-03 4.75E-04	0.831	confirms	28.2	11:10:43	05-18-2016
25	4	1.03E-03 6.10E-05	0.862		60.3	11:11:02	05-18-2016
26		1.02E-03 5.91E-05	0.864		62.4	11:11:06	05-18-2016
27	5	1.30E-03 9.95E-05	0.861	last	52	11:11:27	05-18-2016

Averages: 1.09E-03 7.40E-05 0.862 55.6

Comments: Measurements are as usual obtained in pairs without moving the measurement head in between. The last measurement is apparently not recorded to file but presumably confirmed datum 27 (otherwise another datum would have been taken).

Location 2 shows ~3% lower reflectivity and is confirmed by datum 24 which was obtained by moving the measurement head.

Data for locations 2 and 3 are therefore omitted from averages.

Only the (50,80) degree scattering at location 2 is anomalously high compared with previous aluminisations. Surface roughness at location 3 is unusually low

