Preserving Mirror Coating Performance at WIYN

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Abstract: The WIYN 3.5-meter primary mirror and the Starfire Optical Range (SOR) 3.5-meter primary mirror were both aluminum coated in the Mayall 4-meter chamber at Kitt Peak using similar procedures, yet the WIYN coating has shown rapid degradation in reflectivity and visual appearance while the SOR has not. Comparison of the methods of maintaining the mirror coatings and the operating procedures of the two observatories revealed significant differences in dust control practices and environmental operating procedures. It is concluded that the methods employed at WIYN do not sufficiently prevent dust buildup on the mirror surface and do not adequately guard against the occasional accumulation of moisture on the mirror surface. The reaction of dust and moisture on the aluminum coating is the most likely cause of the rapid corrosion. Plans to take immediate action for improved dust control by increasing the frequency of CO2 snow cleanings, monitoring airborne dust levels and establishing dust shutdown criteria, and more thorough cleaning of the dome and telescope surfaces have been implemented. In addition, environmental shutdown criterion are being modified in that the dewpoint split will be increased and measured relative to the mirror temperature and policies for increased monitoring of humidity and clouds will be implemented. To further evaluate possible causes of coating degradation a series of tests is proposed to investigate the effects of cleaning practices, condensation, and component outgassing.

1. Introduction

The WIYN primary mirror was initially aluminized in April 1994 on Kitt Peak using the Mayall 4-meter aluminizing chamber. Within two years the coating exhibited a 2% drop in reflectivity and a factor of six increase in scattered light as measured with a TMA μSCAN reflectometer @670 nm. The coating had a gray, splotchy visual appearance indicative of corrosion and was thought to be related to a poor coating application in 1994. However, a new coating applied in April 1996 is showing the same deteriorating signs as the first coating and will need to be re-aluminized in early 1998. Alternatively, the SOR 3.5-meter primary mirror was coated on Kitt Peak in March 1993 and is not currently showing signs of deterioration.

In an effort to understand possible causes of the rapid degradation of the WIYN mirror, Sawyer and Reddell visited the Starfire site on June 11, 1997. The operating and maintenance procedures were reviewed and a careful inspection of the SOR 3.5 meter primary mirror was conducted. Reflectivity measurements could not be made on the SOR 3.5 primary, but the slide samples for the SOR 3.5 and Air Force AEOS mirrors were measured (see Appendix A).

Figure 1 shows the measured reflectance at 670 nm wavelength of the WIYN, the KPNO 2.1 and 4 meter, and the SOR 3.5 meter primary mirrors, along with measurements of the Air Force AEOS and SOR slide samples. The Kitt Peak mirrors were measured with a Minolta CM-2002 and the Air Force mirrors were measured using a TMA μSCAN. A direct comparison of the different reflectometers could not be made because the TMA used by the Air Force was not available. However, the AEOS slide samples were measured in March ‘97 with the TMA and then in June ‘97 with the Minolta and the results repeated within 0.1% reflectivity, thus giving an indirect verification of similar instrument calibrations.

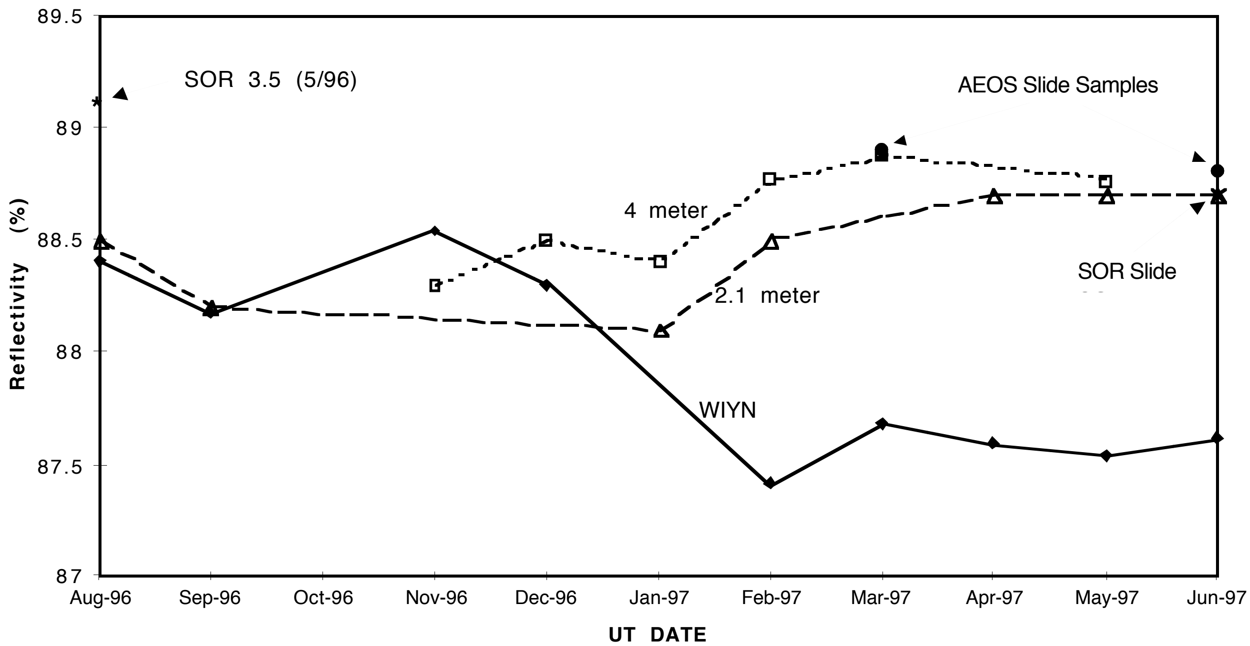

Figure 1: Reflectivity measurements showing the degradation in WIYN reflectivity as compared to the KPNO 2.1 and 4 meter telescopes and the SOR and AEOS Air Force mirrors.

The reflectivity of the SOR 3.5 mirror was last measured in May '96, but was included in the comparison because the age of the coating is greater than the current WIYN coating. All the mirror coatings, with the exception of WIYN, show similar reflectivities. The reflectivity measurements were made near the inside edges of the mirrors where similar radial distances could be compared. The outer edge of the WIYN mirror has a reflectivity approximately 2% lower than that shown and the degradation in reflectivity at blue wavelengths has been more pronounced at WIYN (see plot in Appendix B), but there is no comparative data available for the SOR mirror because of limitations of the TMA μSCAN reflectometer.

2. Mirror Cleaning Techniques

Following a CO2 cleaning demonstration on the SOR primary, Reddell inspected the mirror surface with a flashlight beam at grazing beam angle. The mirror showed a relatively clean surface with light scattered from the surface contaminants even across the mirror surface, as judged by Reddell. Contaminant density was approximately 25 particles/in^2 before and after CO2 cleaning and appeared to be large "adhered" particulate. The SOR mirror was visually free of any of the "gray corrosion" look that WIYN is dominated by. The SOR mirror appeared black when looking at a reflected shadow, whereas WIYN appears slightly gray. The methods used for CO2 cleaning at SOR differ in several ways from the methods used at WIYN as summarized in Table 2.1.

Table 2.1: Comparison of CO2 Cleaning Techniques

Item Compared	SOR	WIYN
CO2 Cleaning Frequency	Weekly with additional cleanings performed on days immediately after high dust events, such as if particles are visible in a flashlight beam at any time during operation. SOR does not use a particle counter (dust monitor).	Typically twice per month with no monitoring of dust events.
CO2 Cleaning Method	A “Va-Tran Snow Gun” is used to apply a large flake, low velocity CO2 snow to the SOR primary. The snow is allowed to roll down the mirror surface producing a thermophoretic cleaning. Cleaning starts halfway up the mirror and works downward toward the bottom. The SOR 3.5 mount has the capability of moving 180 degrees in elevation so that half of the mirror is cleaned in one orientation and the other half with the elevation flipped over	High velocity, small flake CO2 snow which is a kinetic cleaning method used to remove particulate which may be adhering to the surface. Cleaning at WIYN starts at the top of the mirror and works down across the entire surface, as WIYN can only move to one horizon orientation.
CO2 Quality	99.995% pure	99.995% pure
Humidity Limit for Cleaning	Below 40% RH	Below 60% RH

Technicians cleaning the SOR 3.5 mirror are required to wear a clean room jumpsuit with a hood and booties. This is to reduce the level of dust from clothing when near the mirror, but, more importantly, it reminds the technician of the importance of the job and increases the sense of discipline and safety consciousness while working near the mirror.

Washing is never done on the SOR 3.5 mirror. At the time of our visit, there were large particulates stuck to the mirror surface which did not come off with CO2 cleaning, but in general the surface was quite free of dust. The WIYN mirror is washed every six months. The wash procedure incorporates a physical contact with a mechanical -chemical process. *Orvis* soap is mixed with distilled/deionized water (Orvis/water = 75/5000) and is sprayed onto the mirror surface to wash off large particles. Then, using a natural sponge and soapy water sprayed under the sponge, the mirror is washed with small circular strokes and virtually no pressure. It is as though the sponge is not actually touching the surface but floating on a soap film. It should be noted that the water spray is very sudsy. After the entire mirror is sponge washed it is rinsed with distilled/deionized water and blotted dry with Kim-wipes. The Kim-wipes leave dust on the mirror which is then removed with CO2 snow.

3. Dust Reduction Considerations

At SOR, much care is taken to keep the area around the optics clean. A bi-weekly cleaning is done which includes vacuuming the telescope, mirror cavity and dome, as well as wiping down the telescope mount and mirror covers with damp rags. These precautions help to minimize local sources of dust that could be raised by workers or wind.

The mirror covers are closed whenever possible on the SOR 3.5, including idle time during the night, as an extra precaution to keep dust from the mirror surface. The mirror cover is a two piece swinging door type fitted with rubber seals, similar to WIYN. The telescoping dome is raised to minimized side winds if the telescope is being used at high elevation angles. At WIYN, the dome side vents could be closed in modest winds to reduce dust exposure.

During discussions about telescope mount and mirror ventilation schemes, it became apparent that at WIYN the way that air is drawn into the center section above the primary mirror could cause a negative pressure in the mirror cavity if the mirror covers are closed while the active ventilation system is running. This may have the effect of drawing dust into the mirror cavity. Therefore, the telescope mount ventilation system should not be active at anytime the mirror covers are closed.

4. Environmental Conditions

Criteria for telescope closure due to environmental conditions are much more stringent at SOR than on Kitt Peak. Hence, SOR operates significantly fewer nights than WIYN. We did not compare actual observing statistics, but our qualitative estimate is that WIYN operates 30% more of the time. Some of the time that SOR is closed is due to the lack of observing programs so the 30% less observing time is not due entirely to weather, but again, these statistics were not discussed. The following table summarizes the opening and shutdown criterion for both.

Table 4.1: Comparison of Shutdown Criterion

Parameter	SOR	WIYN
Windspeed	Open if < 20 mph	Open if < 45 mph
	Close if > 20 mph	Close if > 45 mph
Dewpoint Spread	Open if > 6°C	Open if > 1°C
	Close if < 5°C	Close if < 1°C
Clouds	Closed if any low level clouds are present anywhere.	Not closed due to clouds unless dark clouds are overhead, the humidity is too high, or light rain or fog are present.
Lightning	Closed if lightning is visible within a 30 mile radius.	Closed if associated clouds are overhead.

A second operator is on-site at SOR during the night and is dedicated to monitoring the clouds and mirror thermal condition. In addition, an on-site meteorologist is usually present at SOR. Although this level of precaution is not feasible at WIYN, there is certainly room for improvement as far as keeping a careful eye on clouds and weighing more on the side of caution.

5. Possible Causes of Corrosion

Our opinion is that the most likely cause of the rapid corrosion of the WIYN primary mirror is the occasional accumulation of moisture on the mirror surface reacting with a dust buildup. As shown in the previous section, the shutdown criterion for SOR in the presence of humidity and/or threatening rain is more restrictive than WIYN. There is a much greater concern about the SOR mirror contacting moisture and, as a result, no water spots were detected on the 3.5 meter mirror during our inspection.

At WIYN, we know that the mirror surface is getting wet on occasion because of the presence of water spots (indeed the WIYN operators have all reported cases where they feel sprinkles outside while still open). Moisture may also be forming on the mirror surface due to humidity. The KPNO shutdown criteria of a 1°C dewpoint split may be too close for mirrors that are thermally cooled. It is also possible that the mirror temperature lags the ambient increase after sunrise enough to produce condensation. The humidity inside the mirror cavity is not currently monitored (except when inspected for cleaning), but there are plans to add a dewpoint sensor inside the mirror cavity for 24-hour monitoring. At the SOR 3.5 they have found that using a handheld hygrometer[1] to measure humidity at several locations inside and outside of the facility during operation gives the best overall sense of the conditions.

Thermal conditioning alone is not believed to cause corrosion because the SOR 3.5-m is thermally cooled and does not exhibit corrosion and also because the WIYN Tertiary mirror is not thermally controlled and is showing signs of corrosion. The WIYN Tertiary mirror is located under the primary mirror covers and is thus contained within the same environment as the primary both day and night. The WIYN secondary mirror does not show signs of corrosion, is exposed during the day, and is the only downward facing mirror.

Additional reasons for surface corrosion were discussed with Jim Mayo and Don Killpatrick (RDA Logicon, Albuquerque). Some of the possible sources identified were, water-dust solutions, water-vapor solutions, material degassing and subsequent effects upon aluminum coatings, coating angles, and aluminum purity. Most interesting was the discussion of different materials and their compatibility with aluminum coatings and possible effects of mass loss and deposition of those materials due to outgassing. A further investigation should be conducted to see if any of the components released from the mirror cell assembly can react with water vapor, water, or directly with the aluminum surface.

6. Conclusions

Many of the operating and maintenance procedures that are different at SOR likely contribute to their excellent mirror coating performance. Their environmental operating constraints cannot be practically implemented at KPNO because of the loss of observing time, but many of their methods of dust and moisture control could be implemented at WIYN without significantly impacting operations. In addition, a test program could be implemented to better assess the effects of cleaning practices and other possible sources of corrosion.

Immediate action should be taken to implement the following dust and moisture control procedures and upgrades. A careful weekly inspection of the optics should be performed and a record of the mirror condition and any maintenance completed should be kept.

<u>Dust Control</u>:

- weekly CO2 snow
- Close mirror covers whenever idle for extended periods
- Turn off telescope ventilation when mirror covers closed
- Install a particle counter to evaluate dust "events" for determination of cleaning needs. Perhaps develop shutdown criterion for high dust events (al la ARC).
- CO2 snow immediately after high dust events
- Bi-weekly wipedown of telescope mount and mirror covers
- Monthly vacuum/cleaning of dome (esp. flat surfaces on the dome structure)

<u>Moisture Control</u>:

- Increase dewpoint split for closing at WIYN to 2°C and measure with respect to the mirror surface temperature.
- Monitor clouds more careful and weigh on the side of caution when closing due to clouds

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[1]Rotronic Hygrometer Model AM3, Probe PN HP101A-LS-K10W1F, Rotronic Instrument Corp., Huntington, NY

- Install dewpoint sensor inside mirror cavity
- Buy handheld hygrometer for humidity monitoring

Implement a Test Program:

Our investigation into the cause of the rapid coating degradation at WIYN raised many questions and concerns that could not be answered without further test efforts. A test program should be implemented to better evaluate the different factors so that cost/benefit can be assessed. The test program should involve producing a set of large (6"x6") test samples coated in the Kitt Peak 4-meter chamber for evaluation over the period of six months to a year. The samples should be used to evaluate the effects of:

- washing
- different CO2 snow Ke's
- condensation
- outgassing of rubber seals and plastic parts

Evaluation of the test samples should include reflectivity and scattered light measurements along with a microscopic inspection.

7. Acknowledgments

We would like to express our thanks to Capt. Jim Brown for making our visit to the SOR site possible and for arranging tours and a cleaning demonstration, allowing us to observe operations, and for devoting a significant amount of his time to answer our questions. Discussions with Ray Ruane, the SOR Senior Engineer, were also very helpful and very much appreciated. We would also like to thank Jim Mayo and Don Killpatrick for meeting with us at RDA Logicon and arranging for the slide sample inspection.

8. Appendices

Appendix A: Inspection of SOR and AEOS Slide Samples

Appendix B: WIYN Reflectivity Plots

Appendix A: Inspection of SOR and AEOS Slide Samples

Test slides from the SOR 3.5 (March 1993) and AEOS 3.67 (February 1996) primary mirror aluminizations on Kitt Peak were examined at RDA Logicon for reflectivity and visible defects. To be consistent with the primary mirror measurements described in this report slides were chosen from the sample set which corresponded to locations near the inner diameter of the primary mirrors.

Reflectivity measurements were made on June 12, 1997 using a Minolta CM-2002. The results showed that degeneration of the reflective surfaces was low, within 0.3% of original new coating measurements.

Microscopic evaluation of the samples showed obvious contamination of the SOR round robin test samples. Contamination of the surface was undoubtedly caused by liquid cleaning of the surface. The contamination caused blisters in the aluminum coating that overwhelmingly resembled a "string of pearls". The blisters were likely left behind from the evaporation of some solvent. Wiping the surface with a lens cloth caused the blisters to flake away leaving "holes" in the aluminum surface. The untested control slide samples showed smooth nearly pit free surfaces. The control samples showed pinhole densities of approximately 1 per $4mm^2$ of slide. The edges of the pinholes showed no sign of corrosion

Appendix B: WIYN Reflectivity Plots

Figure B1: Reflectivity performance of the WIYN primary mirror as a function of wavelength and radial position.