Survey of airborne particle density and the ageing of mirror coatings in the open air at the V L T Observatory

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ABSTRACT

A long term survey of airborne particles was initiated in 1992 at the VLT Observatory of Cerro Paranal to establish the cleanliness of the telescope area before the start of construction work. The results presented in this paper show large variations with time of the density of inhalable particles ($< 10\mu m$), and a very low density of the larger aerosols when compared to clean room industrial standards.

In parallel with the aerosol survey, an analysis of the damage caused to mirror coatings was conducted by periodically exposing sets of mirrors outdoors at 10 m above ground level for periods of two weeks. A follow-up of the evolution with time and meteorological conditions of the reflectivity, diffusion and scattering coefficients gives insights on mirror maintenance requirements in modern telescopes using natural air flushing to fight local seeing.

From the study of damages caused during wind storms, some new constraints on operational limits are discussed, in particular with regards to the protection of an unbaffled secondary mirror.

1 SURVEY OF AIRBORNE PARTICLE CONCENTRATION

1.1 Experimental conditions

A CLIMET (CI-8060) airborne particle counter has been operated for seven months in the Paranal area (Nov. 92 at nearby sub-site, Dec. 92 to May. 93 at Paranal). The device counts particles at six ranges (0.3, 0.5, 0.7, 1.0, 5.0 and 10 μm) simultaneously. A multiport sampler permitting centralized sequential monitoring of several locations was installed in February 93 for the analysis of the effect of height above ground. The device was operated at night only because of restricted electrical power availability. The air inlets are located at the northern end of the flattened Telescope Area, along the metallic structure of a meteorological tower. The area is free from constructions of any kind and the ground is such as it was left by the caterpillars at the end of the levelling work in December 1992 [1].

1.2 Results

As can be seen on Fig. 1, the density of particles of diameter larger than 0.5 μm measured at 10 m above ground over 20 mn averages, shows very large variations with a time base of several days. The theory says that particles of diameter between 0.5 and $1\mu m$, when carried aloft with the wind, fall 1 m in a time varying from days to one hour, which means that the aerosol content measured in the Paranal area is affected by sources located up to several hundred kilometers away. In this range of size one may find human made (mines) as well as natural (pollen, bacteria, sea salt) aerosols. The non random aspect of the temporal variations measured on the site may be due to mining or industrial activity as well as to climatic variations (sea storms or whirlwinds). The results of a correspondence analysis with meteorological conditions are presented in the next section.

1.3 Relation to meteorological variables

Looking for correlations with meteorological variables, we found virtually no relation to the wind direction and only a slight increase of the average density with wind speed, due to a sharp reduction of the number of occurrences of low contamination (< 20000 per cubic foot). On the other hand, the data set presents a well defined correlation with air moisture in the range 5 % to 30 % of relative humidity (the yearly average of the site is 14 %). The origin of hygroscopic particles is multiple: organic aerosols from tropical rain forest (typical diameter TD = 0.15 μm), fine mineral residues from the burning of petroleum derivatives (TD less than 0.1 μm) , or more simply sea salt particles (TD from 3 to less than 0.3 μm) which can be transported at great distances and whose number varies with cresting waves activity. A check with local maritime authorities did not give any indication of correlation of peak

0-8194-1494-8/94/$6.00

Height (m)	Percentile		
	5	50	95
10	1.89197E+03	2.00110E+04	1.39934E+05
8	1.95843E+03	1.97306E+04	1.40844E+05
6	2.14841E+03	2.01242E+04	1.46266E+05
4	2.30775E+03	2.09877E+04	1.46345E+05
2	2.58431E+03	2.10557E+04	1.52442E+05
1	2.54549E+03	2.17447E+04	1.57989E+05

Table 1: Percentiles of airborne particle concentration per cubic foot as a function of height above ground at the VLT telescope area from February to May 1993 for particles larger than 0.5 μm.

concentration with sea storms. The site is also protected from coastal mining activity by a dense and stable layer of clouds at around 800 m above sea level which acts as a filter. Moreover, field measurements [2] have shown that though the ground level pollution is still noticeable at a downwind distance of 15 km from a major mining site, it decreases sharply at distances larger than 20 km for this size of particles. All major mining sites situated upwind from Paranal and above the cloud layer are located at distances larger than 50 km.

It is thus most probable that whirlwinds, a thermal phenomenon particular to the desert areas, are mainly responsible for the noticeable increase of particles density during the warmer (and more humid) months of the year.

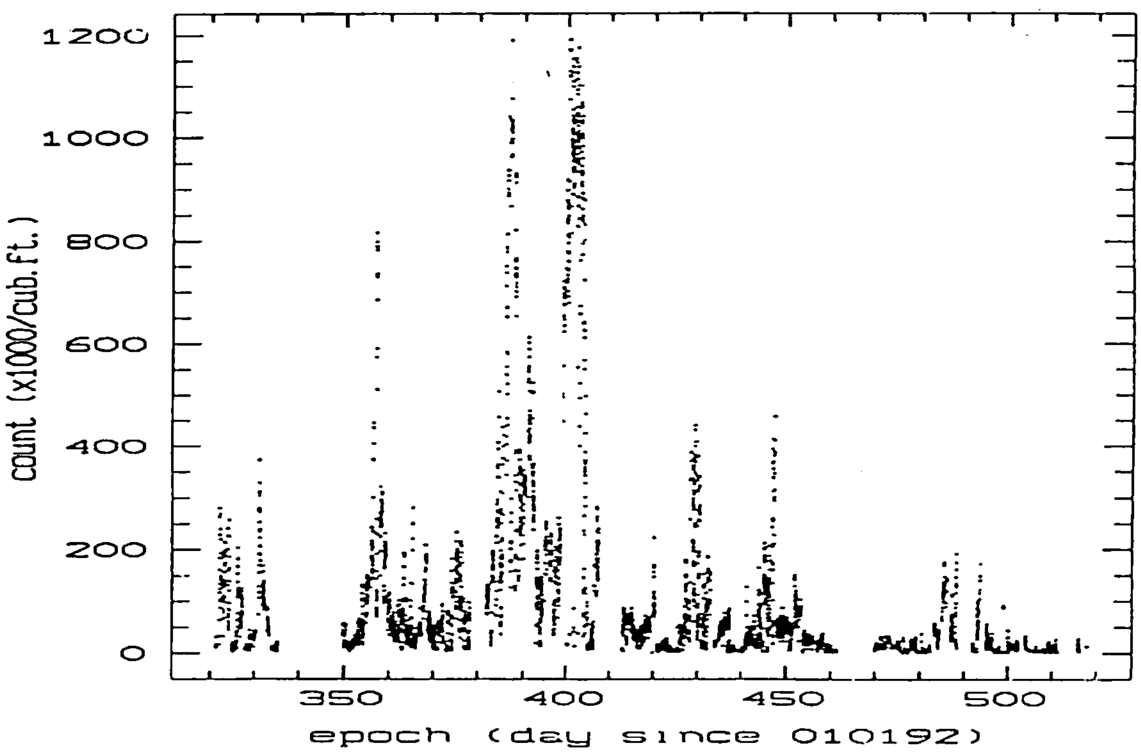

Figure 1: Temporal variation of the aerosol atmospheric content per cubic foot, at Paranal (Dec. 92 to May 93) and subsite (Nov. 92), 10 m above ground for particles of diameter larger than 0.5μm. Summertime in Chile corresponds to days 334 to 425 (December to February) on the horizontal scale.

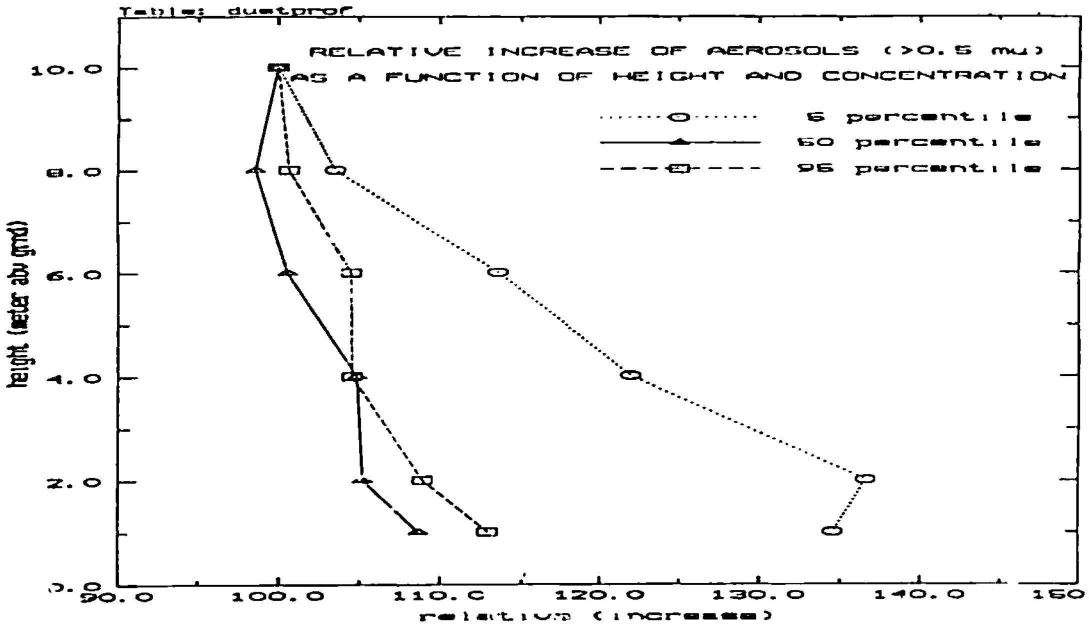

Figure 2: Variation of the aerosol atmospheric content at Paranal for the period Feb.-May 93, as a function of height above ground for particles of diameter larger than $0.5\mu m$, between 1 and 10 m.

1.4 Variation of concentration with height above ground

An analysis of the height distribution over 6 levels from 1 to 10 m above ground is presented on Fig. 2, out of 3000 samples of 10 minutes each, taken at night from February to May 1993. A 40% increase is seen at ground level during events with the lowest aerosol concentration in which cases locally produced contamination is prevailing. With increasing particle concentration, the effect of height becomes marginal showing that the site is then in free air conditions: it can be seen on Fig. 2 that during events with median to high concentration, the increase of aerosol density is negligible from 10 to 5 m and of the order of only 10% from 5 m to 1 m above ground.

1.5 Variation of concentration with particle size

The actual average size distribution at 10 m height is compared to the standard definition of indoor cleanliness in use in industry on Fig. 3. It is seen that the site is better than class 30,000 for particles larger than 1 μm and around class 100,000 for sizes down to 0.3 μm.

2 THE AGEING OF MIRROR COATINGS IN THE OPEN AIR

2.1 Description of the set-up of experiment 1: mirrors 1-2 , mirrors 3-4

A unit composed of two aluminum coated mirrors (diam = 40 mm) was installed at 10 m above ground on the meteorological tower at Cerro Paranal (Fig. 4). One of the mirrors is looking upwards and the second downwards, reproducing the respective positions of primary and secondary mirrors of a telescope.

After an exposure of two weeks in the open air the samples were sent back to ESO Garching for surface analysis (reflectivity, scattering and surface roughness). A second set of mirrors was installed during that time on the mast, giving opportunity for a continuous survey of dust contamination. Shipment back and forth is realized in a dust tight container. The experiment was started at the beginning of January 1993 and is still going on for one more year. A detailed timetable of exposure of the various samples is provided in Table 2. The cumulated exposure time of the mirrors 1-2 and 3-4 are respectively of 115 and 110 days.

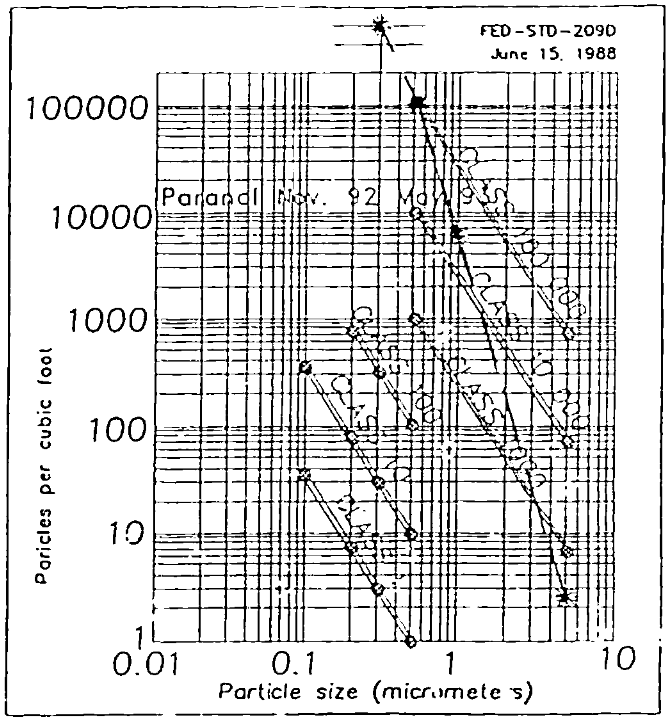

Figure 3: Actual average particle size distribution in the Paranal area (dotted line) at 10 m above ground for the period Nov.92 to May.93, compared to class limits given for industry.

Event	Date	Exposure (Days)	Cumul (Days)
Samples: Mirrors 1 and 2			
Freshly coated mirrors	21/01/1993		0
1st period	on 06/02/1993		16
	off 20/02/1993	14	30
2nd period	on 21/03/1993		59
	off 31/03/1993	10	69
3rd period	on 27/04/1993		96
	off 11/05/1993	14	110
4th period	on 14/06/1993		144
	off 04/07/1993	20	164
5th period	on 28/07/1993		188
	off 11/08/1993	14	202
6th period	on 08/09/1993		230
	off 22/09/1993	14	244
7th period	on 25/10/1993		277
	off 09/11/1993	15	292
8th period	on 12/12/1993		325
	off 26/12/1993	14	339
		total 115	
Samples: Mirrors 3 and 4			
Freshly coated mirrors	21/01/1993		0
1st period	on 20/02/1993		30
	off 06/03/1993	14	44
2nd period	on 31/03/1993		69
	off 15/04/1993	15	84
3rd period	on 11/05/1993		110
	off 07/06/1993	27	137
4th period	on 04/07/1993		164
	off 18/07/1993	14	178
5th period	on 17/08/1993		208
	off 31/08/1993	14	222
6th period	on 12/10/1993		264
	off 24/10/1993	12	276
7th period	on 26/12/1993		339
	off 09/01/1994	15	353
cleaning	25/01/1994	total 110	369

Table 2: Schedule of exposure to dust contamination

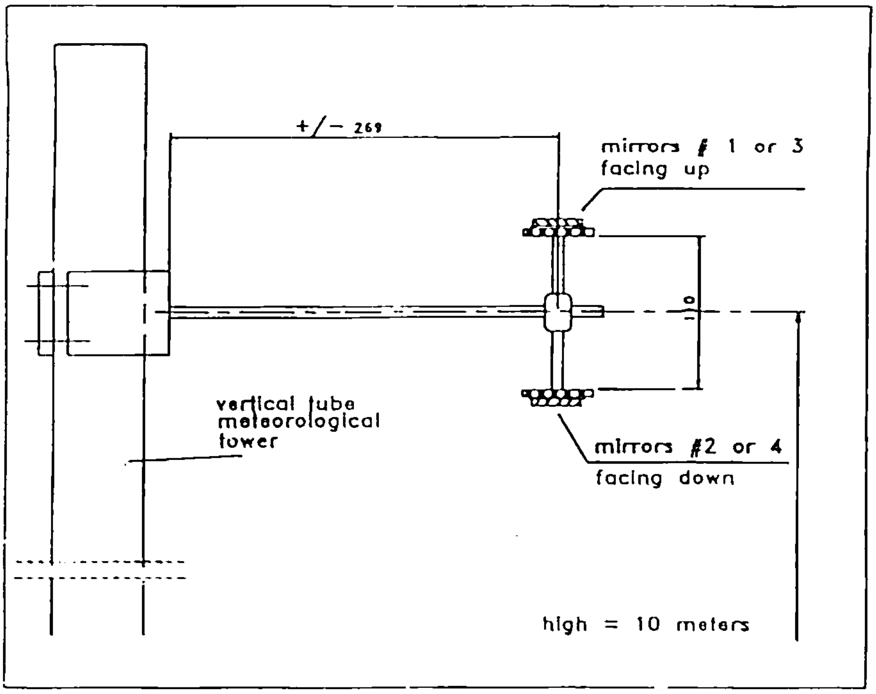

Figure 4: Set-up of Mirrors 1-4 on the Paranal meteorological tower

2.2 Description of the set-up of experiment 2: mirrors 5,6,7 and 8.

A set of 4 mirrors (diam = 40 mm) was installed at the bottom of a metallic box providing them with a lateral protection against wind and thus preventing dust removal. The exposure to dust contamination took place during an uninterrupted period of 6 months including days and nights (May 6 to Nov. 9 1993).

2.3 Evaluation of the samples

The dust contamination of the optical surfaces is evaluated at ESO Garching using the μ Scan scatterometer. It is a portable instrument, from T.M.A technology (USA), designed to measure the quantity of light scattered by surfaces irregularities (Bi-directional Reflectance Distribution Function, BRDF) indifferently due to surface micro defects or dust contamination. Another parameter provided by this instrument is the surface reflectivity at the wavelength of 670 nm. From the scattered light measurements, the rms equivalent micro-roughness of the optical surface quality is computed. The intensive use of the μ Scan, in the laboratory as well as in-situ on the telescopes, confirms the high sensitivity of this equipment and its adequation for the evaluation of dust contamination on optical surfaces. The increase of surface roughness with increasing exposure time is shown on Figs 5 and 6 for mirror sets 1-2 and 3-4 respectively. The corresponding values of reflectivity at 670 nm are shown on Figs 7 and 8 respectively. The differences in the behavior of the two sets of mirrors clearly show the influence of meteorological conditions.

The mirror set 5-8, protected from wind erosion, show an increase of rms roughness from 10 to 110 Å over 180 days (Fig 9). This value is to be compared to the worst case of unprotected mirror 1 where an rms of 100 Å was reached in only 110 days. Discarding the initial period where the roughness increases sharply, the average degradation for exposed mirrors was estimated to 14 Å per month when turned upwards (mirror 1 and 3) and 7 Å per month when turned downwards (mirror 2 and 4). The initial status for this calculation was taken at 50 Å and 20 Å respectively. The same parameters applied to a six month period give a projection of 134 Å upwards and 62 Å downwards. We conclude that though wind baffles on telescope primary mirrors improve the longevity of coatings, we expect primaries in open enclosure to age two times faster than secondaries.

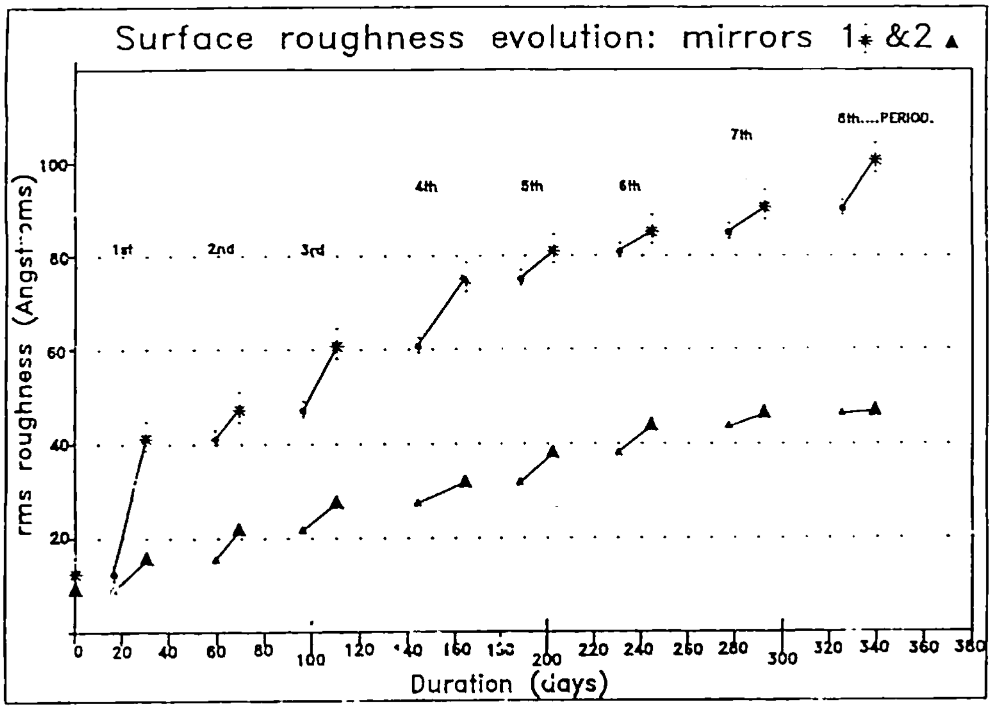

Figure 5: Surface micro-roughness as a function of exposure for mirror set 1-2

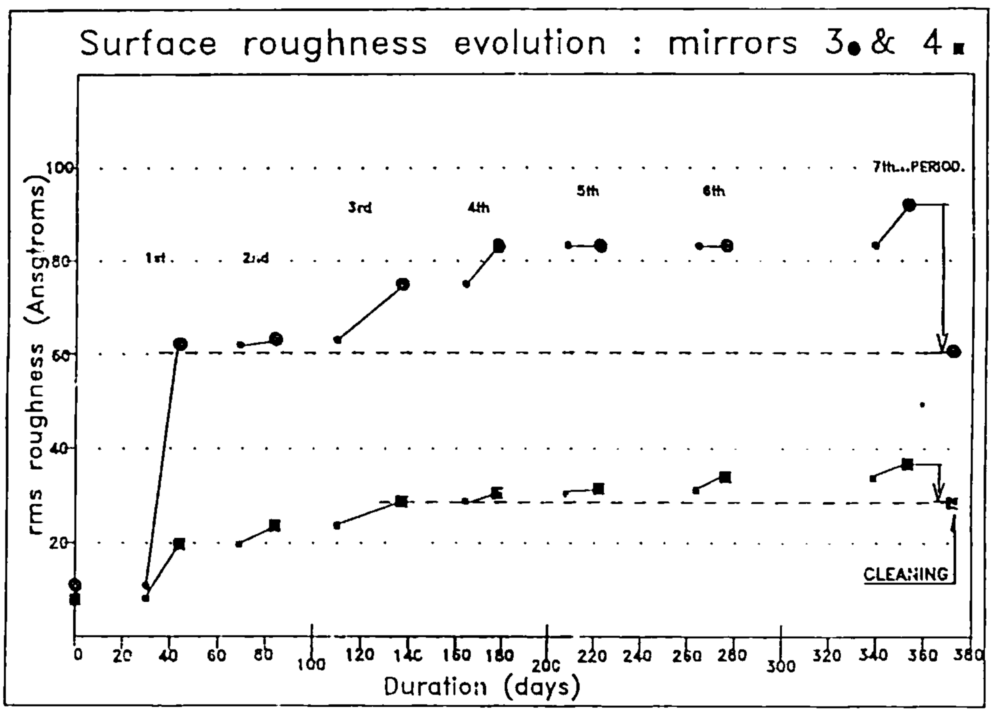

Figure 6: Surface micro-roughness as a function of exposure for mirror set 3-4 and after cleaning with a peel-off product.

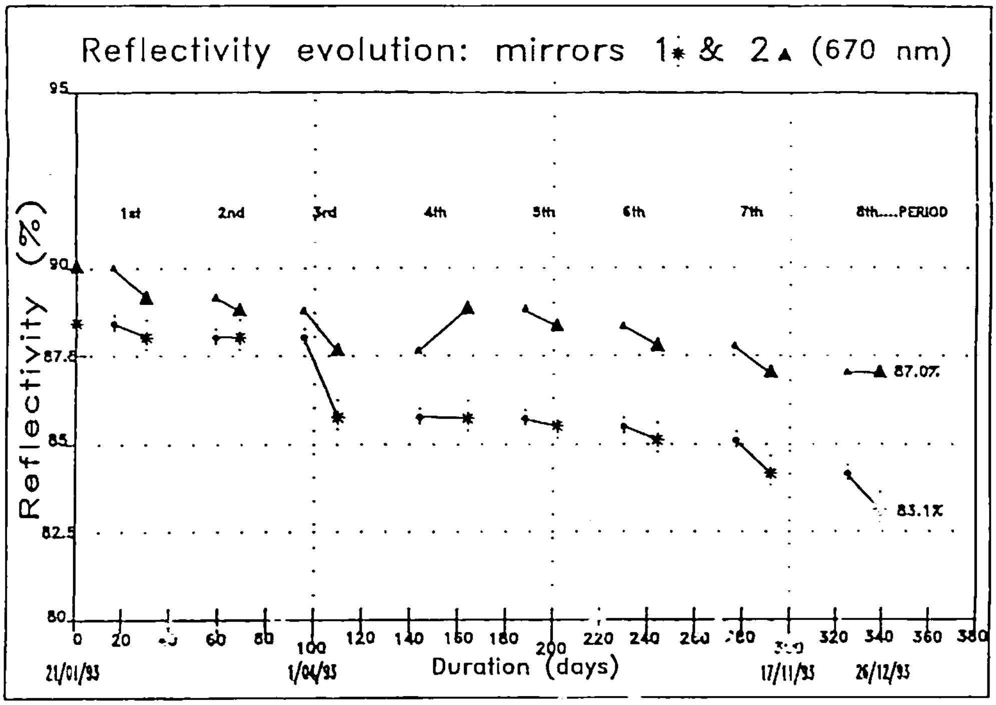

Figure 7: Reflectivity at 670 nm as a function of exposure for mirror set 1-2

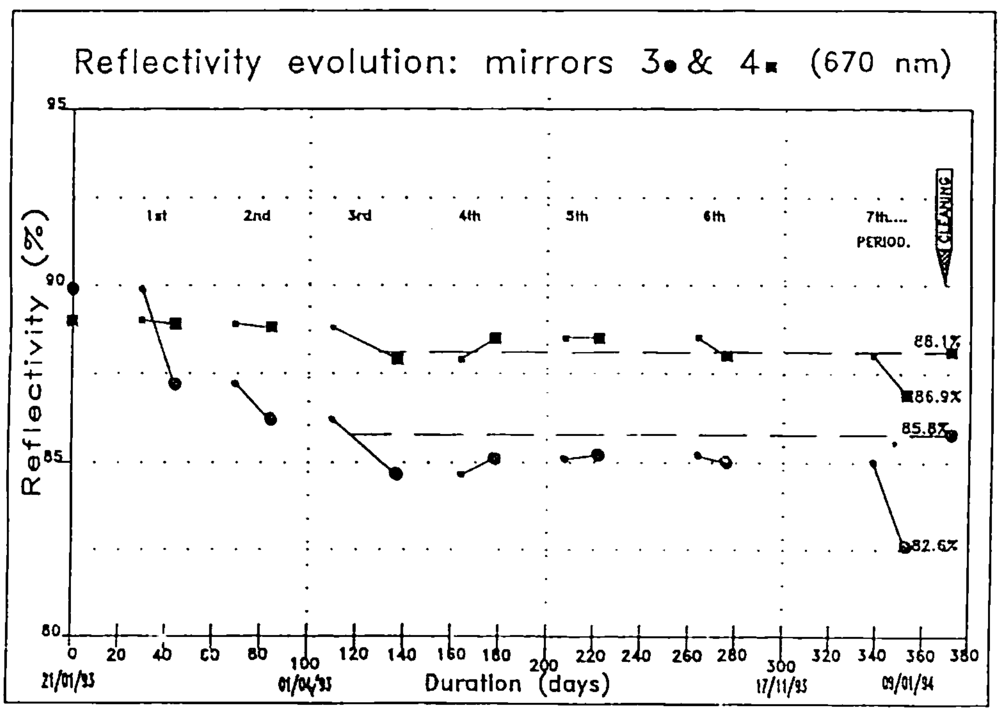

Figure 8: Reflectivity at 670 nm as a function of exposure for mirror set 3-4 and after cleaning with a peel-off product.

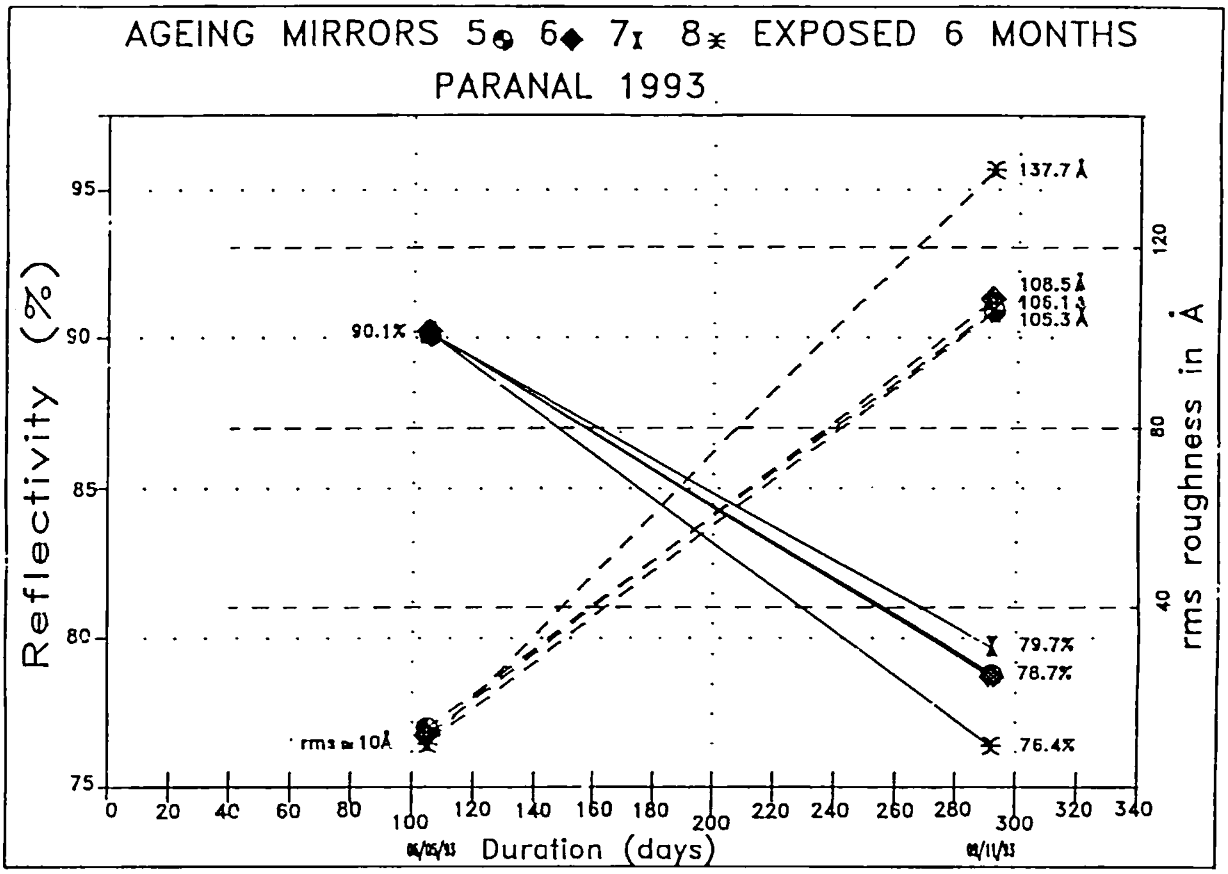

Figure 9: Long term ageing of mirrors in open air, protected from wind buffeting: reflectivity at 670 nm and surface micro-roughness.

2.4 Mirror cleaning

Cleaning the second set after one year noticeably improves surface quality, regaining two third of the ageing in terms of roughness and reflectivity as well. The cleaning method chosen in this case was the peeling technique [4]. Independent measurements have shown that this method, when applied to mirrors exposed for several months in a laboratory environment, allowed to recover nearly 100% of their reflectivity in the band 300 to 1000 nm. We conclude that the non-recoverable roughness after cleaning mirrors 3 and 4 is to be attributed to the numerous impacts produced on their surface by particles in motion during strong wind periods.

The peeling technique is only one out of three solutions considered for the maintenance of the VLT optics:

- CO_2 **snow flake technique** [3]: a pilot system dedicated to the in-situ cleaning of the NTT main mirror was installed in October 1993 at La Silla. Weekly cleanings have been performed since then which satisfactory results.
- **Peeling technique** [4]: a collaboration with Bayer AG (Germany) was fruitful in the selection of a peel-off product adapted to the low cost cleaning of large mirror surfaces. The critical phase of product removal from mirror surface was successfully realized on a 1.6 m glass plate as well as on various aluminum coated mirrors.
- **UV Laser cleaning**: a feasibility study is in progress with Laser Laboratorium Institute in Göttingen (Germany). The first results obtained with an UV Laser at 248 nm are promising, mirror surface behavior and safety issues are being investigated.

3 CONCLUSION

This paper reviewed the various aspects of mirror ageing for astronomical telescopes: characterization of the site, estimate of surface roughness rate of increase and efficiency of periodic cleaning. Even on clean sites like La Silla or Paranal, it is better to protect the primary mirrors from being directly hit by particles at high wind speed so as to reduce the need for aluminizing. On the other hand the reduced flushing increases the amount of dust deposited and justifies to clean the upward looking mirrors on a bi-weekly basis.

4 ACKNOWLEDGMENTS

We are extremely grateful to the Meteorology Team of the VLT Site Services at Cerro Paranal for having performed the field measurements and mirror set-ups. Mirror cleaning tests were conducted with the Optics Group of the La Silla Technical Research Department.

5 REFERENCES

1. B. A. Smith; "New eyes on the universe", National Geographics, January 1994, p 25.

2. M. Santander Nuñoz and L. Vallejo Delgado; "Analisis gravimetrico del material particulado en suspension fino grueso y total, en un perfil lineal en la direccion predominante del viento desde la oficina salitrera Pedro de Valdivia", VLT Technical Report UAN-17400-0418, Universidad de Antofagasta, March 1993.

3. P. Giordano, A. Torrejon; "In-situ cleaning of the NTT main mirror by CO_2 snow-flakes technique", The ESO Messenger 75, March 1994.

4. P. Giordano; "A new approach for the in-situ cleaning of VLT mirrors, the peel-off technique", The ESO Messenger 75, March 1994.