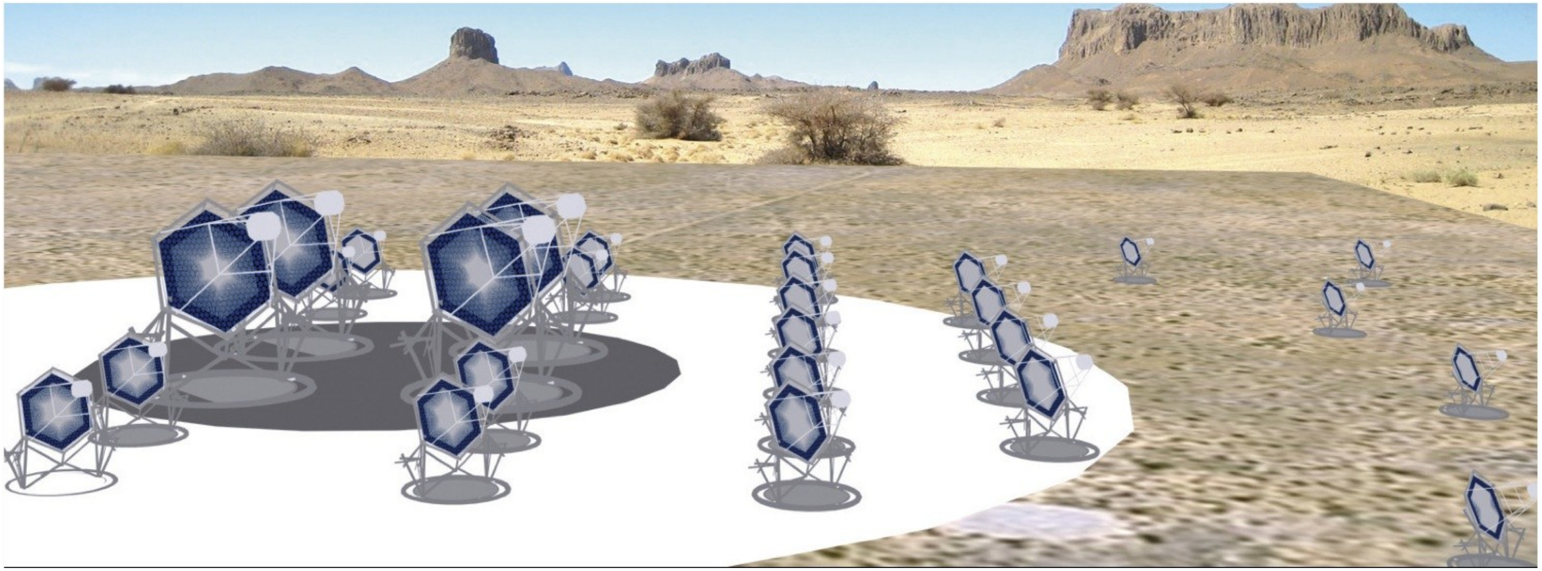
High-reflectance, High-durability Coatings for IACT mirrors



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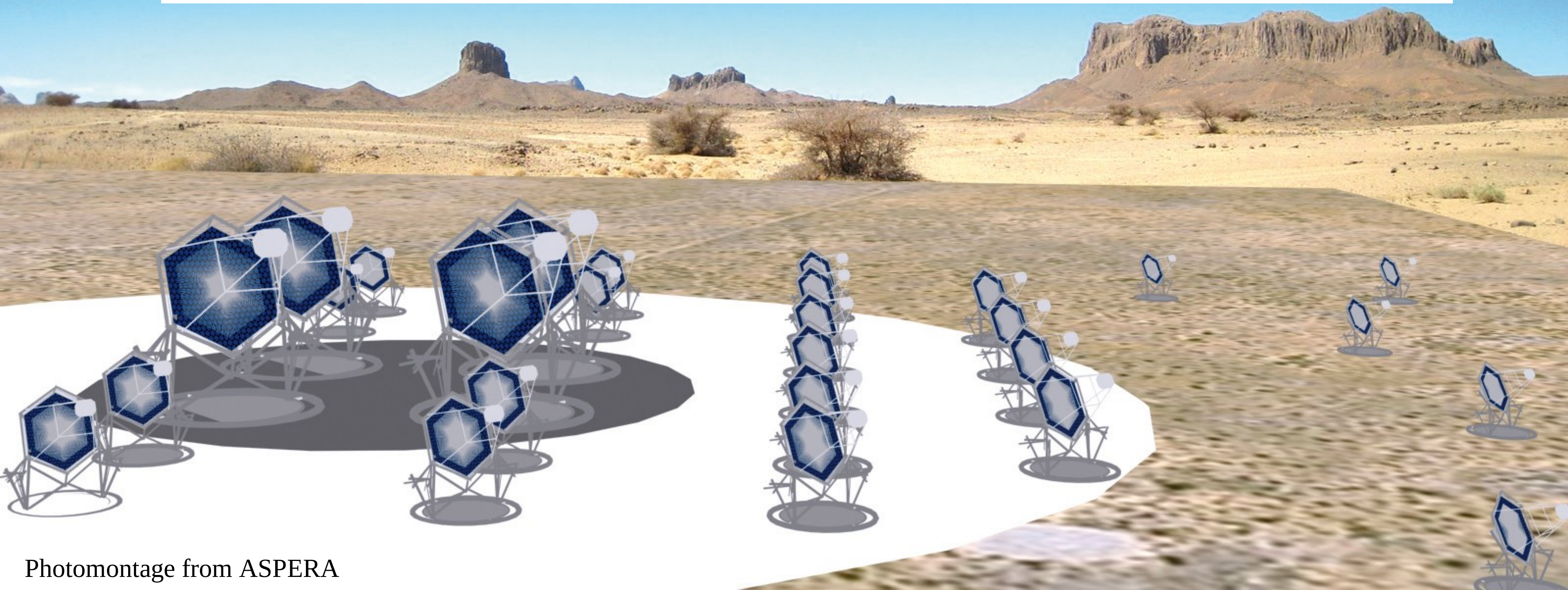
for the CTA Consortium

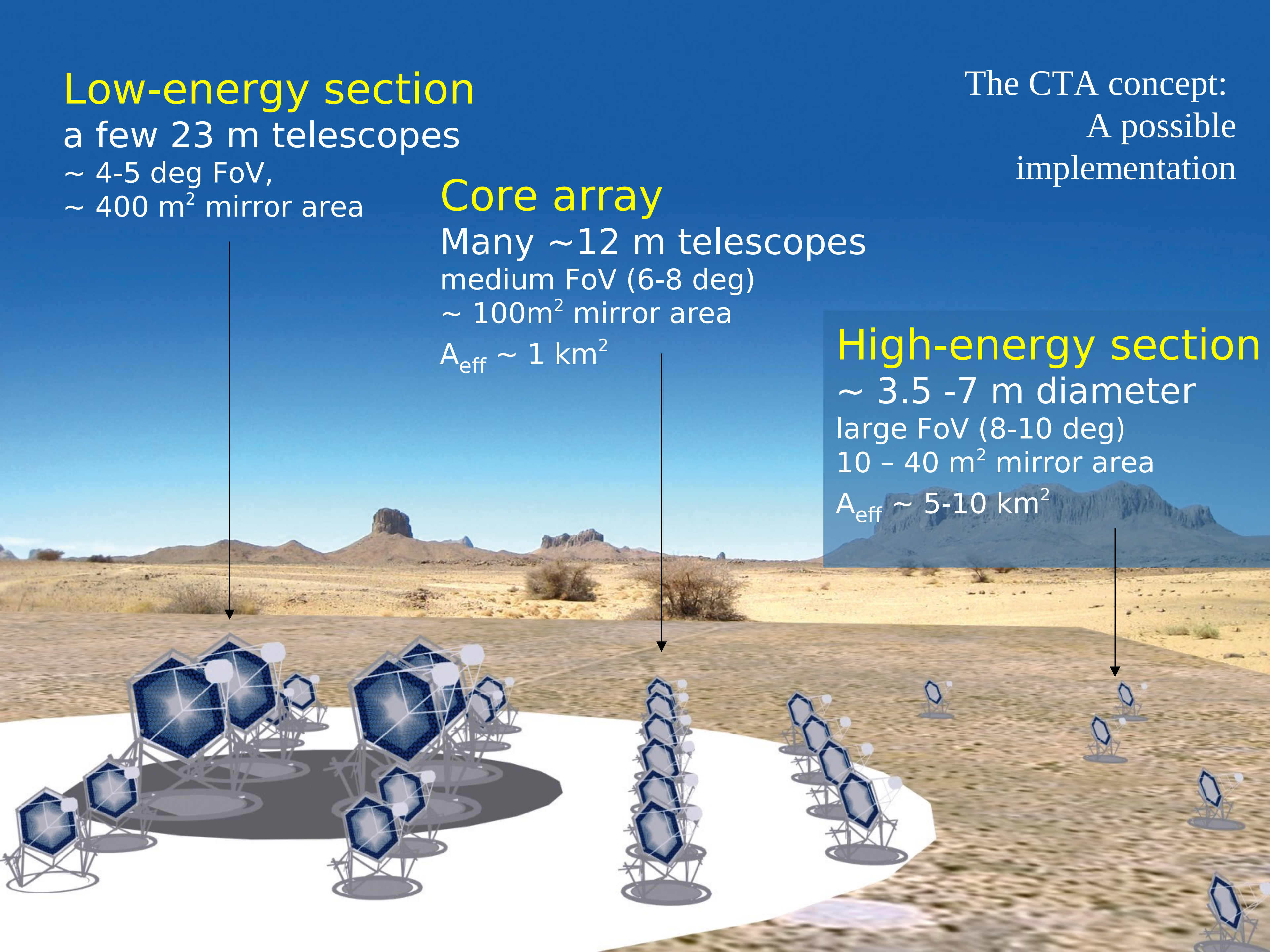
The Cherenkov Telescope Array *CTA*

Goals

- x10 in sensitivity in the core energy range (about 100 GeV to 10 TeV
- Effective area
- Gamma-hadron discrimination
- Angular resolution
- Energy resolution
- Field of view for gamma-rays
- Full sky coverage, through sites on both hemispheres

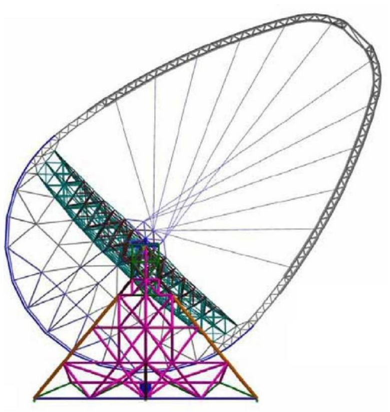


Photomontage from ASPERA

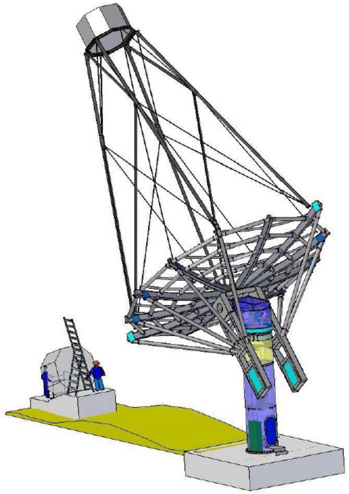

The CTA concept:
A possible
implementation
Low-energy section
a few 23 m telescopes
~ 4-5 deg FoV,
~ 400 m² mirror area
Core array
Many ~12 m telescopes
medium FoV (6-8 deg)
~ 100m² mirror area
A_eff ~ 1 km²
High-energy section
~ 3.5 -7 m diameter
large FoV (8-10 deg)
10 – 40 m² mirror area
A_eff ~ 5-10 km²

The Different Telescopes

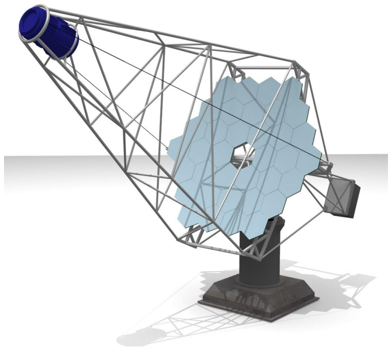
LST:
~400 m^2 area
hexagonal facets
1.5 m flat-to-flat



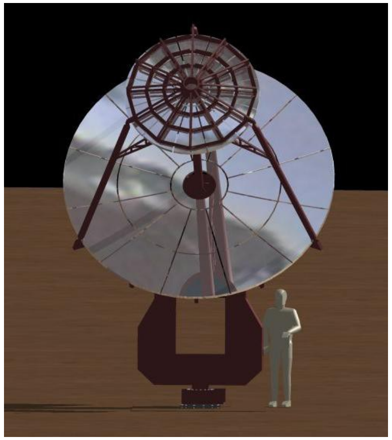
MST:
~100 m^2 area
hexagonal facets
1.2 m flat-to-flat



SST DC:
20-40 m^2 area
hexagonal facets
0.8-1.2 m flat-to-flat



SST SC:
10-20 m^2 area
primary: facets?
secondary: sectors?
monolythic?



Requirements for the Coatimg

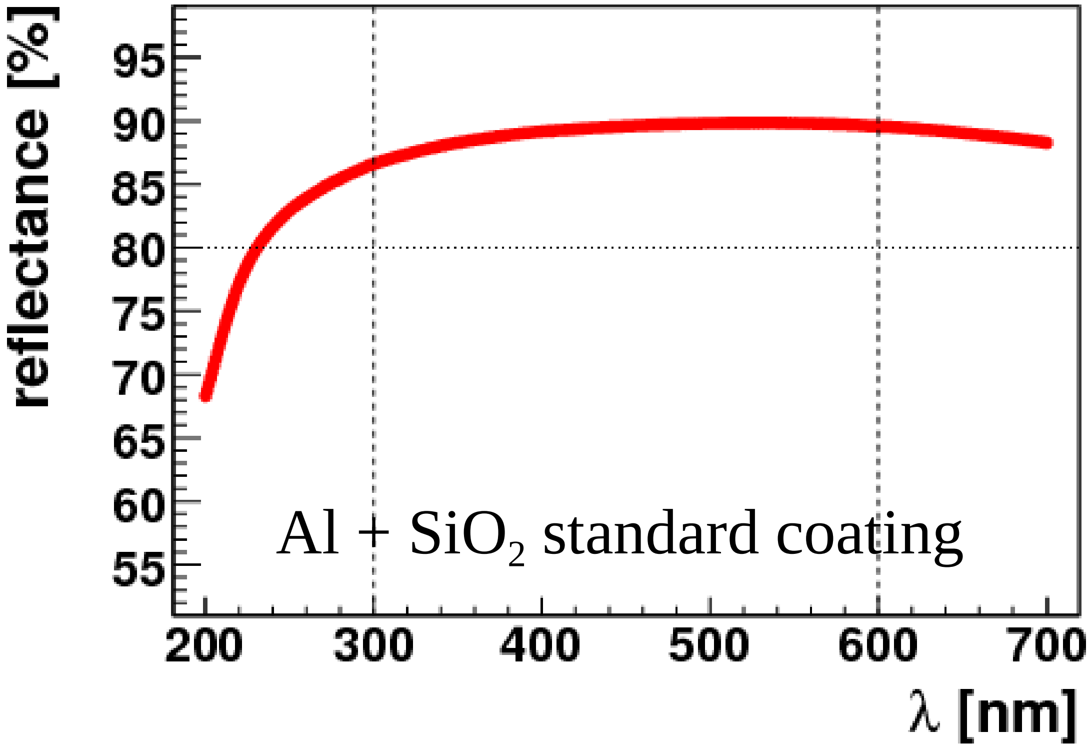
- good reflectance (90% or more) between 300 and 600 nm
  → usually Al for metallic reflective coatings
  → usually front side coated mirrors

- rather low cost (10000 m^2 mirror area in total)

- low substrate temperatures (< 80°) during coating process, since most substrate technologies are glued sandwich structures

- resistance to environmental impact (mirrors outside)
  → protective coating on top of metallic layers

In Principle this is Easy ...



- currently used as protective coatings:
  - SiO_2 (HEGRA,H.E.S.S.)
  - Al_2O_3 (Veritas) [Anodization]
  - SiO_2 with carbon admixtures (MAGIC Al-Mirrors)

… but the Mirrors are Outside!

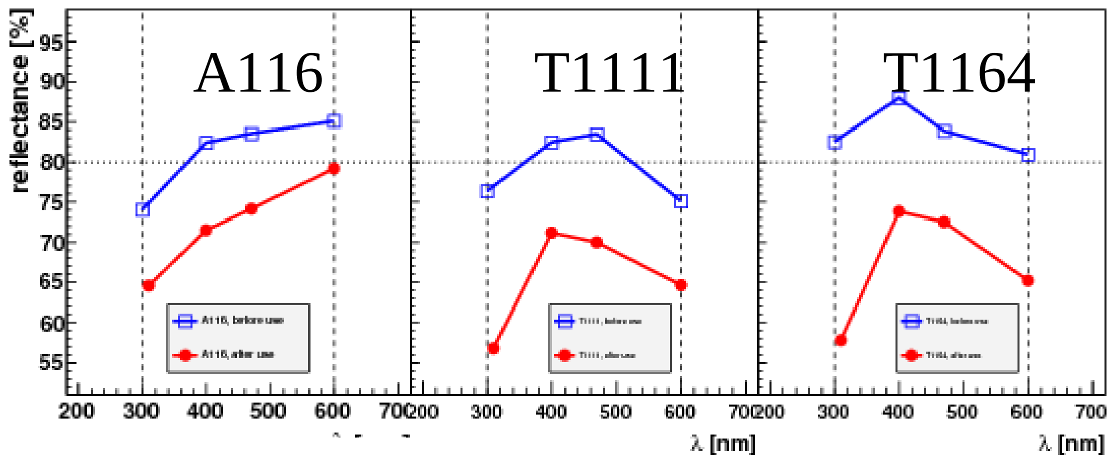
Veritas

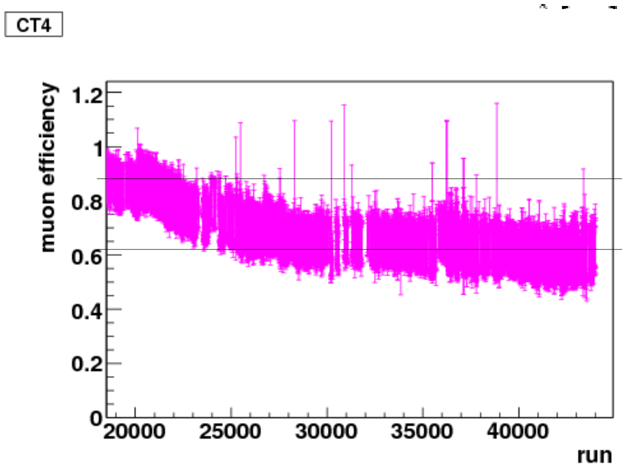
Magic

H.E.S.S.

Outdoor Reflectance Loss

- H.E.S.S. mirrors ($Al+SiO_2$)
- loss of directed reflectance into the spot after 4 years





- loss of the optical efficiency of a telescope after 4 years

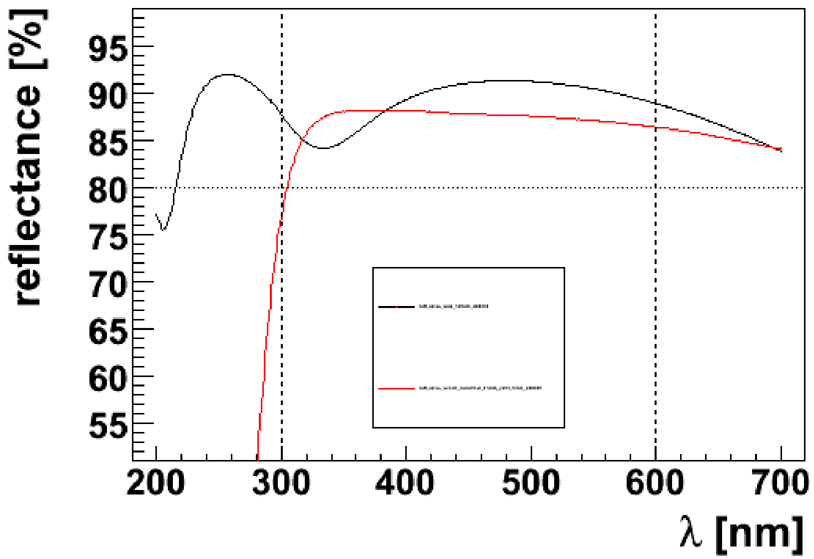
What was / is being investigated for CTA?

- backside coating:	Application of Al coating on backside of thin glass sheets
- standard coatings:	$Al+SiO_2$, $Al+Al_2O_3$
- multilayer prot. coatings:	several alternating layers of low and high index on top of Al might not only enhance lifetime but in addition the reflectance
- purely dielectric coating:	no Al, but many layers of different refractive index

Backside Coating

- idea: Al protected by glass, might be interesting for sandwich mirrors
- but: bad transmission at short wavelengths
  - → either quartz glass needed (expensive, can not be floated)
  - → or very thin sheets

Borofloat 33 thickness: 0.7 mm



- 0.7 mm to thin, would mean additional layer is needed
- for thicker sheets transmission is worse
- tests show faster ice formation on front surface

Approach not followed any longer!

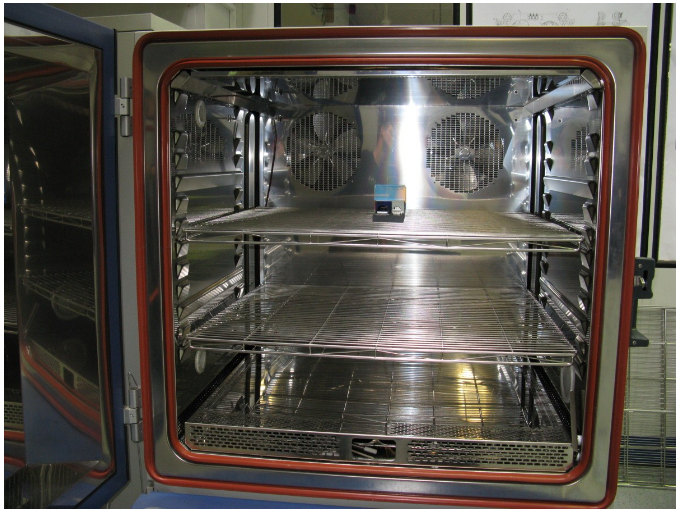
Standard Coatings (Al+SiO_2)

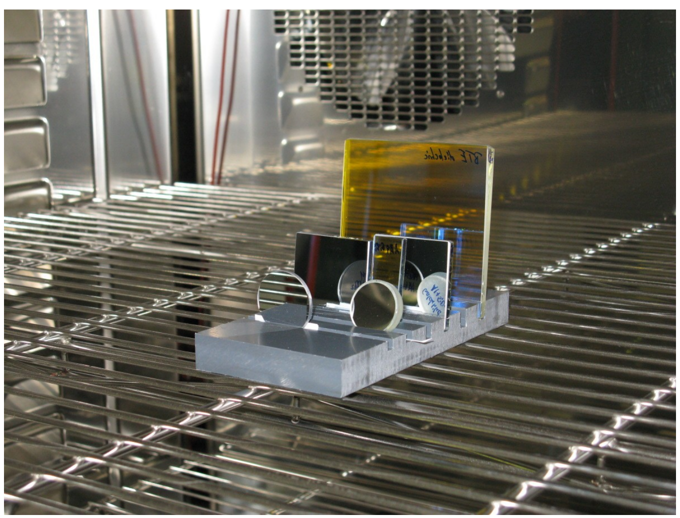
- Al usually between 80 nm (full reflectance) and 200 nm (roughness)
- SiO_2 between 70 nm and 100 nm
- rather easy to apply
- many companies with suitable equipment available
- longterm outdoor experience in H.E.S.S.:
  3-4% loss of reflectance per year

BUT: The durability can be very different from producer to producer.

Comparison of Al+SiO2 coatings from three producers reveiled significant differences (see next slides). More systematic studies needed!

Climate Chamber Test

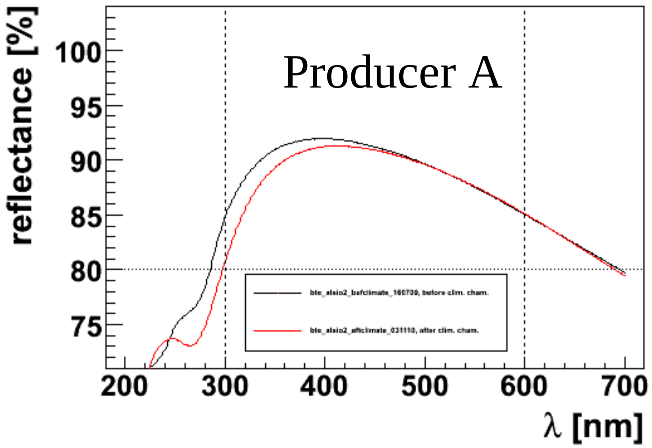


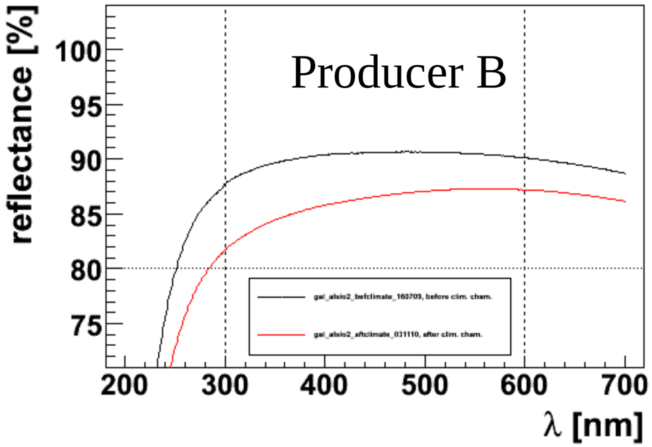


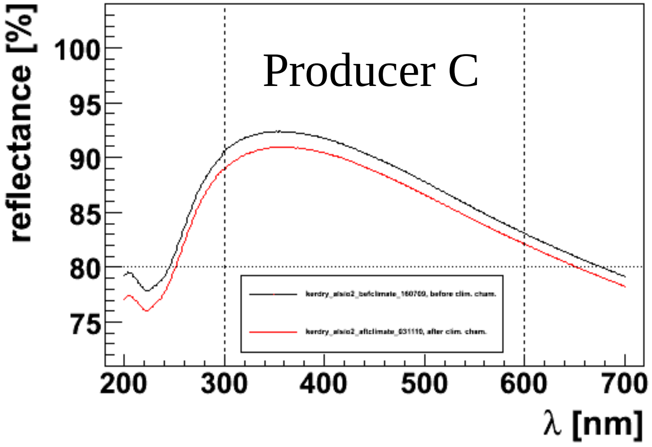
- temperature and humidity cycling of samples going on at the moment
- -10° < T < 60° (cycle length: 5 h)
- 5% < humidity < 95% (cycle length: 8 h)

- 8710 h in total
- 1742 cycles in temperature
- 1088 cycles in humidity

Comparison of SiO_2 Coatings

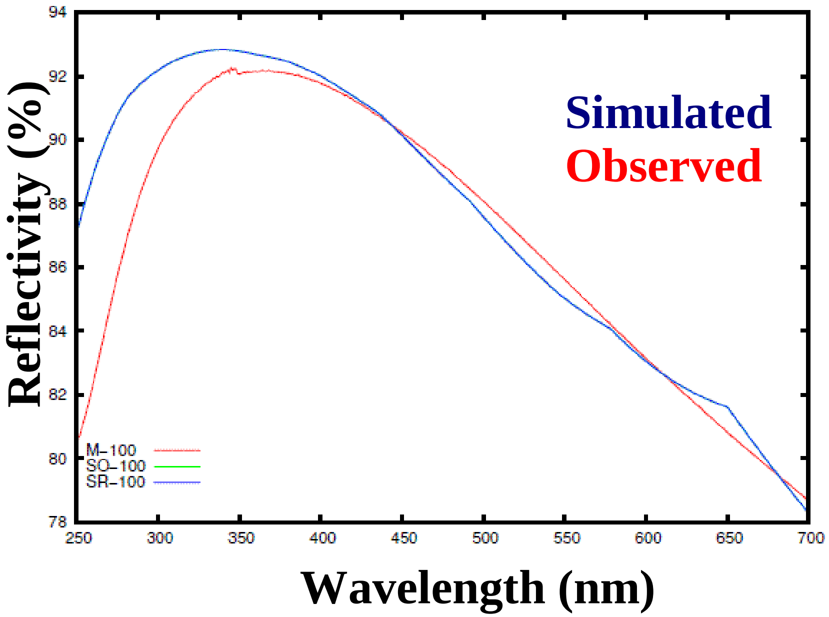






Small In-House Coating Chamber

- old coating chamber re-activated
- fitted with e-beam evaporator
- first samples coated
- in addition: modeling of coating using commercial film design software

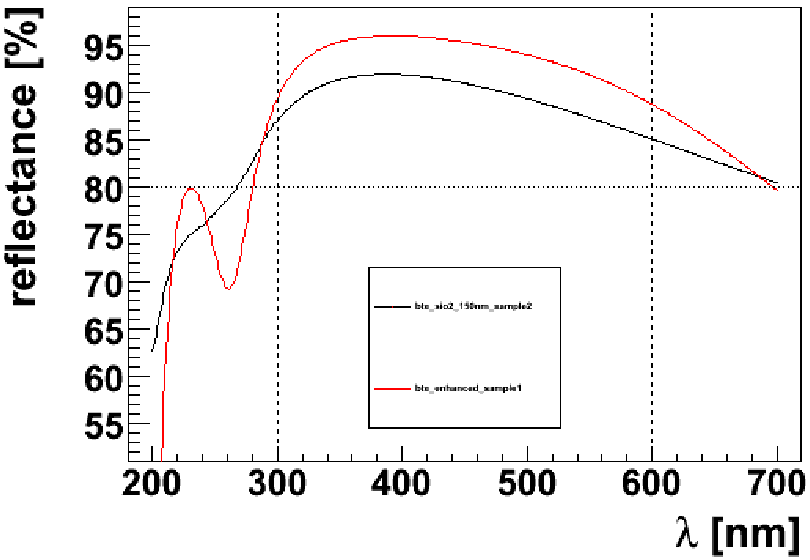


Goals:
- get experience on influence of cleaning procedures
- experimental testbed for new coating ideas to be followed up together with industry later

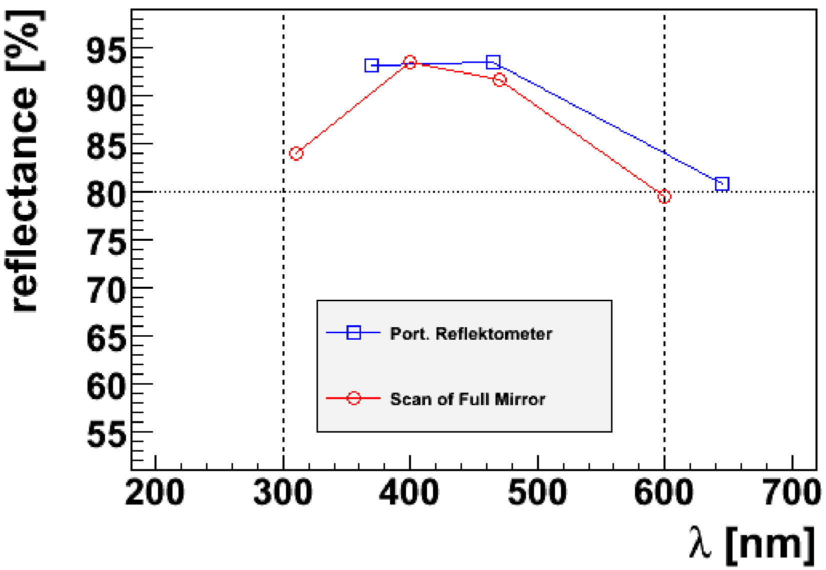
Industrial 3-Layer Protective Coating

- stacks of alternating layers with different refractive indices can enhance the reflectance in a certain wavelength band (e.g. SiO_2 + HfO_2)
- already 3 layers (SiO_2/HfO_2/SiO_2) increase reflectance by ~5%

small sample



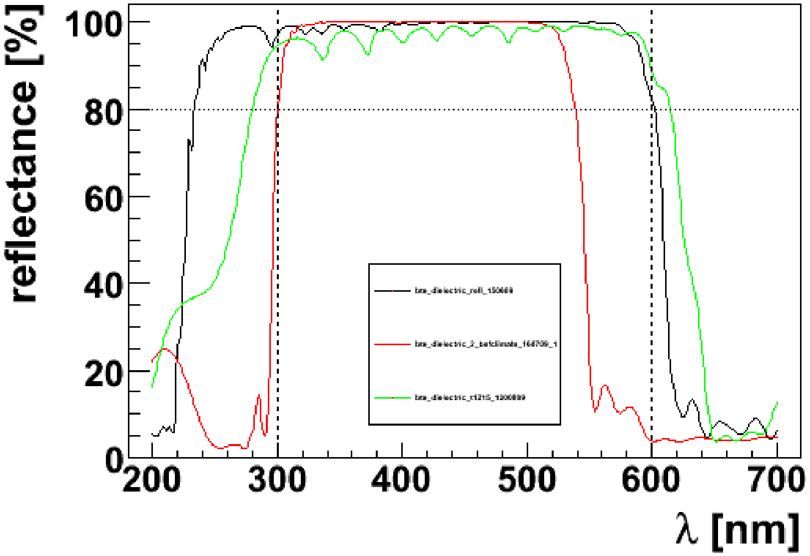
H.E.S.S. I mirror with 3-layer



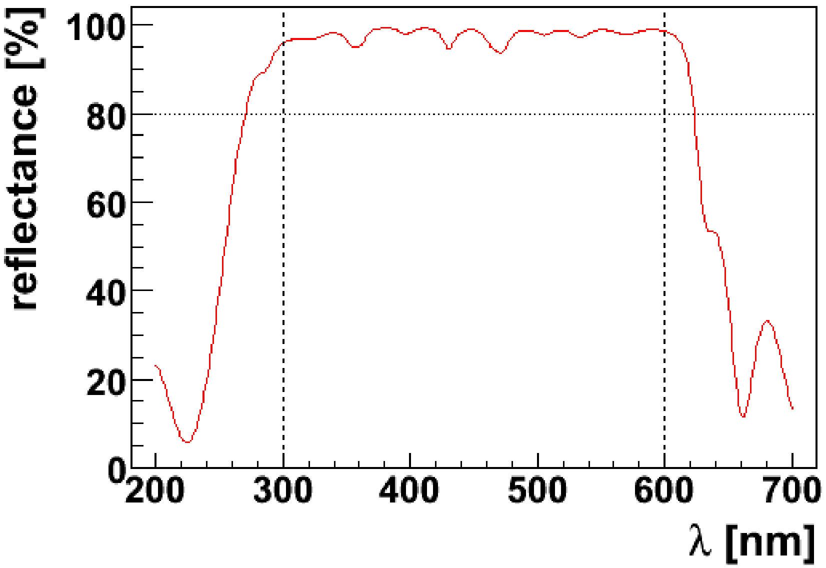
Industrial Dielectric Coating

- no metallic (Al) layer
- maybe possibility to avoid the rather bad adhesion of Al and the fast degradation of the Al?
- only alternating layers of materials with different refractive indices
- left figure: different samples with original process (T=300°C)
- right figure: process at T=150°C

T=300°C



T=150°C



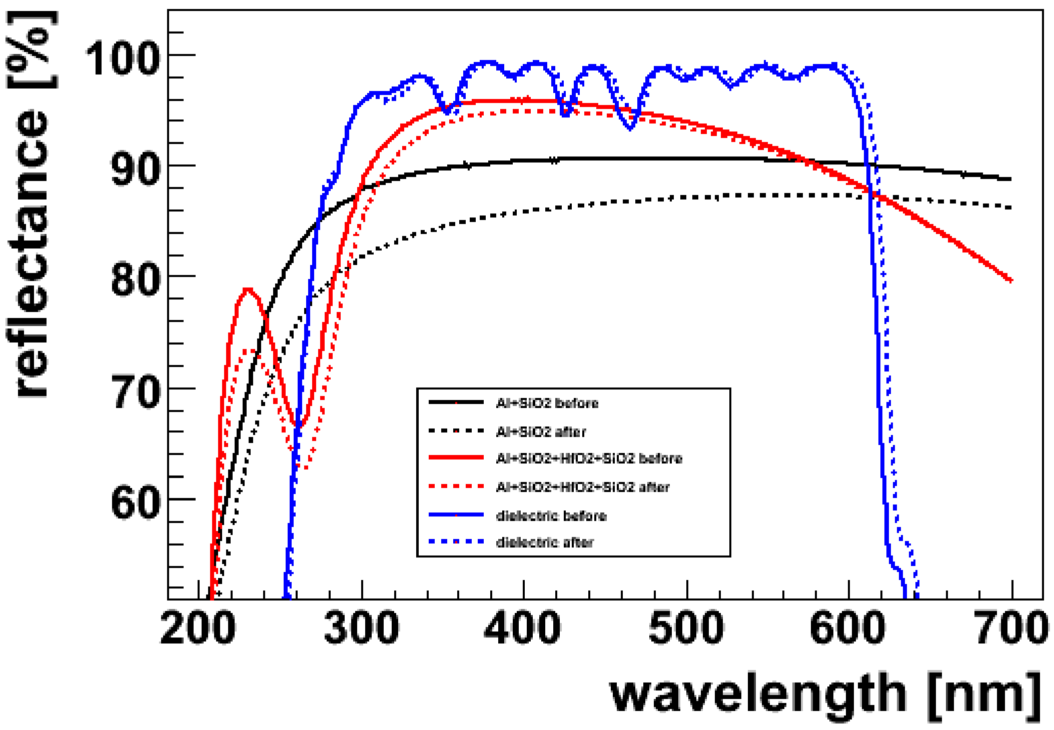
Comparative Testing

Durability tests of $Al+SiO_2+HfO_2+SiO_2$ and the dielectric coating in comparison to $Al+SiO_2$:

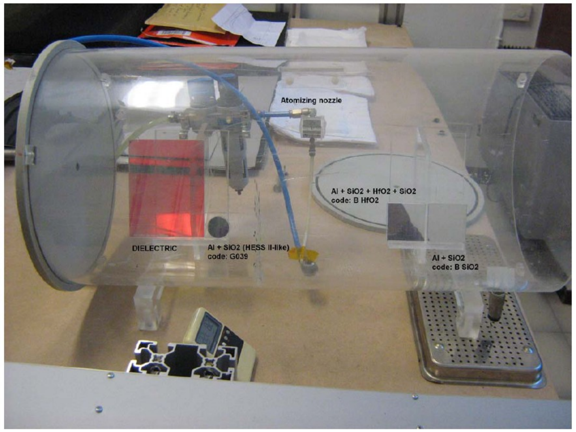
- temperature/humidity cycling
- salt-fog atmosphere
- coating adhesion
- abrasion resistance
- sand blasting
- artificial bird faeces

Temperature and Humidity Cycling

- -10° < T < 60° (cycle length: 5 h)
- 5% < humidity < 95% (cycle length: 8 h)
- 8710 h in total
- 1742 cycles in temperature, 1088 cycles in humidity

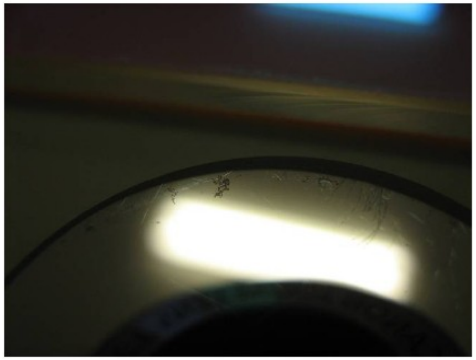


Salt Fog Test



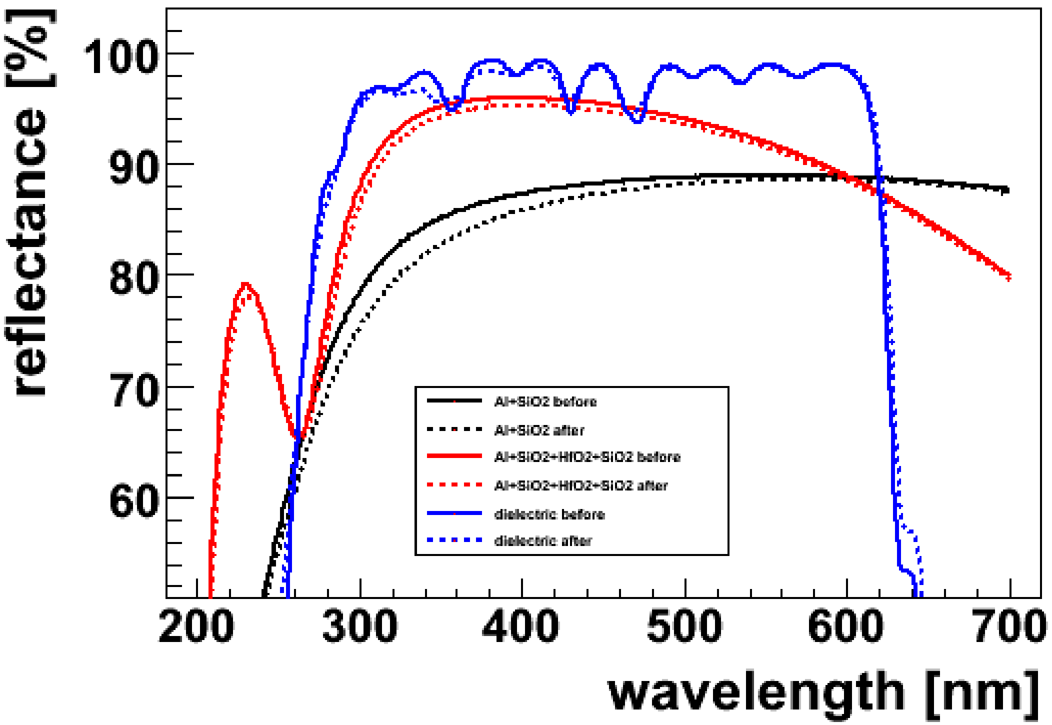
- 5% salt concentration
- T ~ 20°C
- 72h (24h + 48h)
- samples:
  - Al+SiO_2
  - Al+SiO_2+HfO_2+SiO_2
  - dielectric

- both samples with SiO_2 show visible damage, the others not



Salt Fog Test

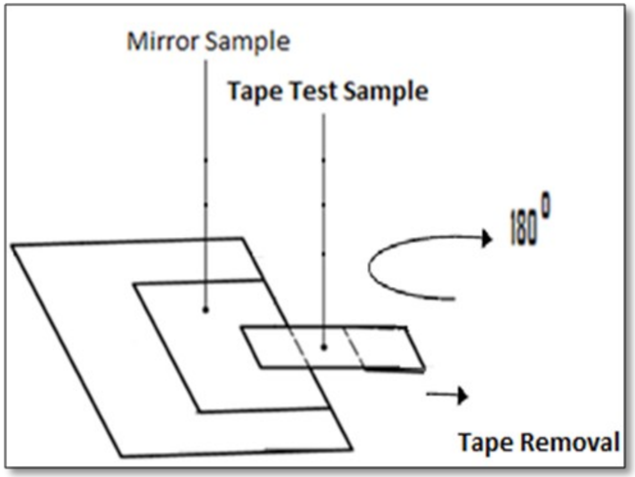
- 5% salt concentration, T ~ 20°C, 72h
- samples with Al+SiO_2 show visible damage at edges



Coating Adhesion

- based on: ISO 9211-4:2006 ; MIL-C-675C; MIL-C-48497A
- tape with peel adhesion 6.3 N/cm
- tape removal under 180° angle with 25 mm/s

Tape	Theoretical Peel Adhesion (N/cm)	Measured Peel Adhesion (N/cm)
Unibond – power duct tape	22	23.2 ± 0.2
Duck – All purpose duct tape	10	10.3 ± 0.2
Sellotape – original (doubled)	6.4	6.3 ± 0.1
Nice day – original parcel	5.2	5.1 ± 0.1



→ all 3 coatings passed

Artificial Bird Faeces

- inspired by BS EN ISO 2812 -4/5:2007
- pancreatin + water 2:1
- 4 weeks at 40°C

→ no damage for all 3 coatings

Abrasion Tests

- according to BS ISO 9211- 4:2006

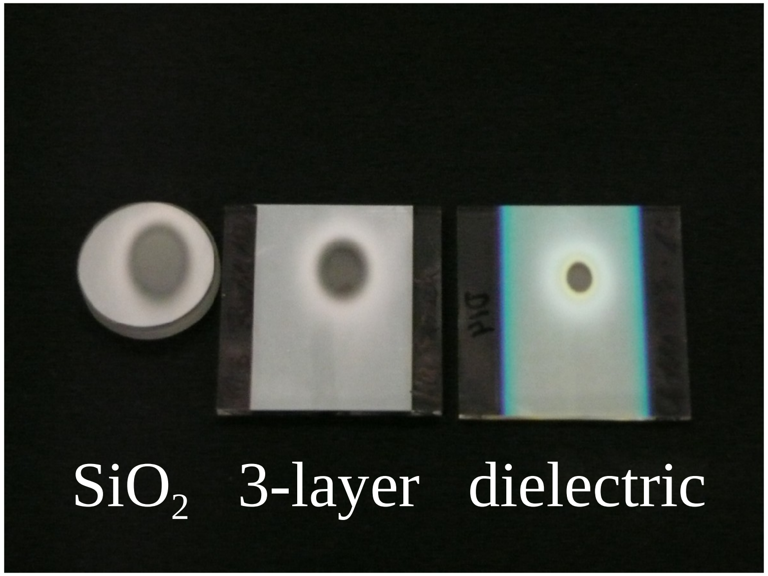
1) Cheesecloth, Force 5N, 50 strokes:
→ no damage to all three coatings

2) Cheesecloth, Force 10N, 50 strokes:
→ scratches in Al + SiO_2 , no scratches in others

3) Eraser, Force 10N, 20 strokes:
→ scratches in all coatings
SiO_2 more than 3-layer more than dielectric

Sand-Blasting

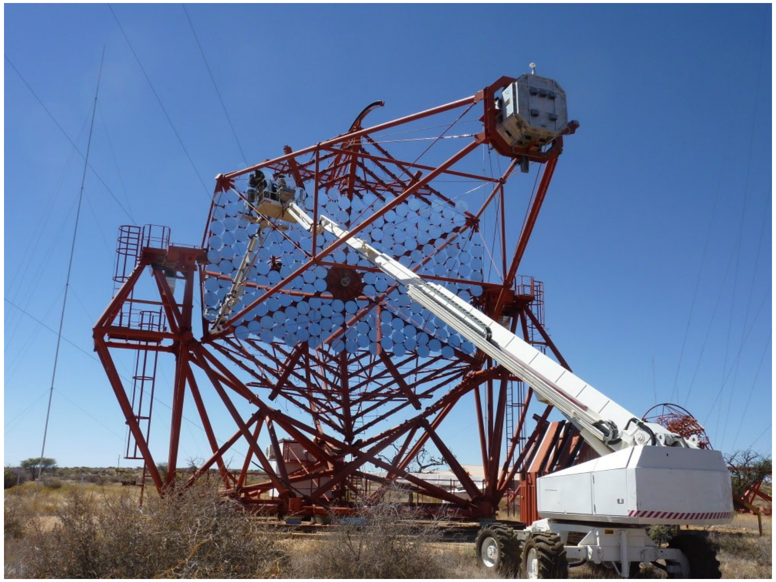
- inspired by BS 12373-10:1999
- SiC (220 µm), flow rate ~20 g/min, 5 min., 45 angle
- area of fully abraded ellipse: measure for resistance



SiO_2: 150mm^2 ; 3-layer: 85mm^2 ; dielectric: 35mm^2

In-situ Testing

- Laboratory tests give a qualitative hint on the durability, but to quantitatively determine the lifetime real exposure is needed
- H.E.S.S. exchanges and re-coats its mirrors at the moment
- spring 2010 380 mirror with Al + SiO_2 on first telescope
- in autumn 2010 mirror with new coating on second telescope
    - 99 mirrors with dielectric coating
    - 278 mirrors with Al + SiO_2 + HfO_2 + SiO_2
- telescopes 3 and 4 with Al + SiO_2 + HfO_2 + SiO_2 in 2011



Summary

What do we need?

- reflectance at least 90% between 300 and 600 nm (more is better!)
- applicable on large surfaces (up to 2 m^2)
- applicable at low substrate temperatures T
- low cost

Where are we currently?

- Al+SiO_2 : available, low T, reasonable cost, but limited lifetime
- Al+SiO_2+HfO_2+SiO_2 : available, slightly increased reflectance, low T, reasonable cost, lifetime? (lab tests slightly better)
- dielectric: sign. better reflectance, T still too high, large surfaces? lifetime? (lab tests sign. better), costs?

Good suggestions are of course welcome!