The telescopes from the technological point of view:

structures and mirrors for IACTs

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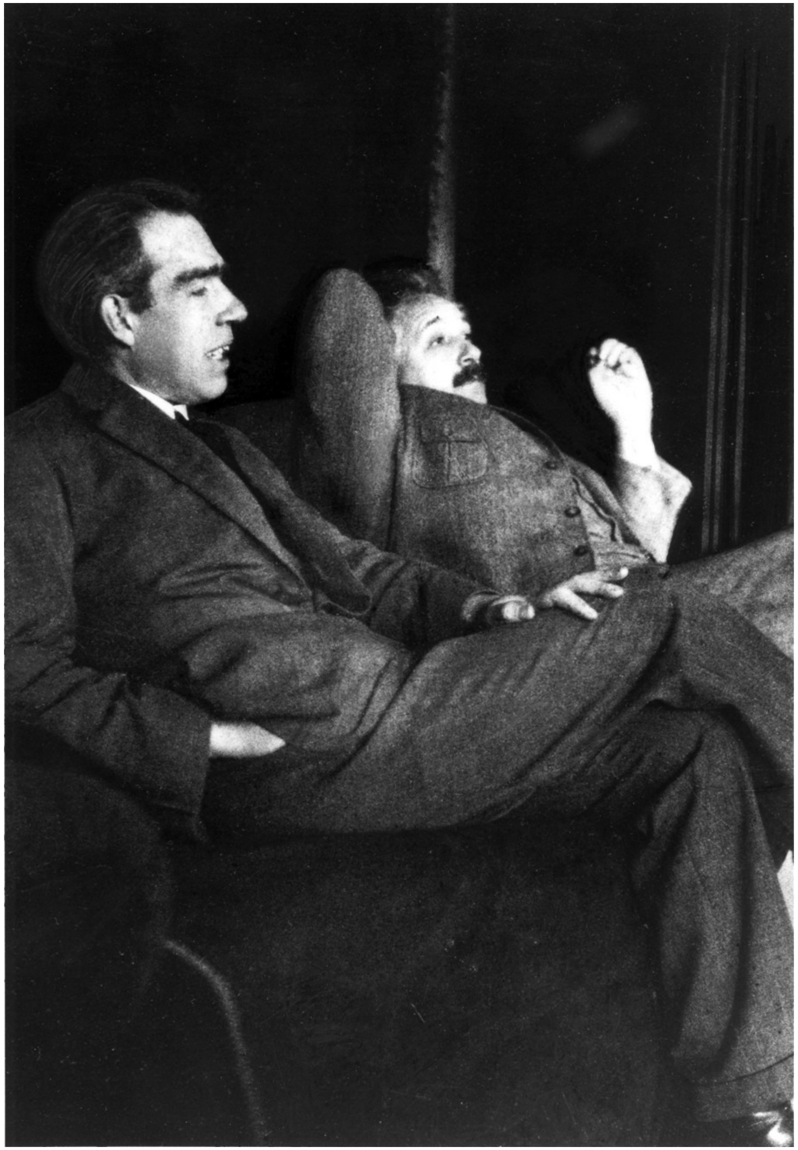
Outline

- Introduction
- The structures
  - Basics
  - Stow position
  - Nomenclature
- Current experiments
- The mirrors
  - The cold glass slumping technology

Introduction



Meanwhile two guys are wasting time talking about the Two Chief World Systems

Albert: *“Dio non gioca a dadi con l'universo.”*

Niels: *“Non dire a Dio come deve giocare.”*

Introduction

Luckily, someone else does the dirty job!

Mariastella: *[…] "alla costruzione del tunnel tra il Cern e i laboratori del Gran Sasso" […]*

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Introduction

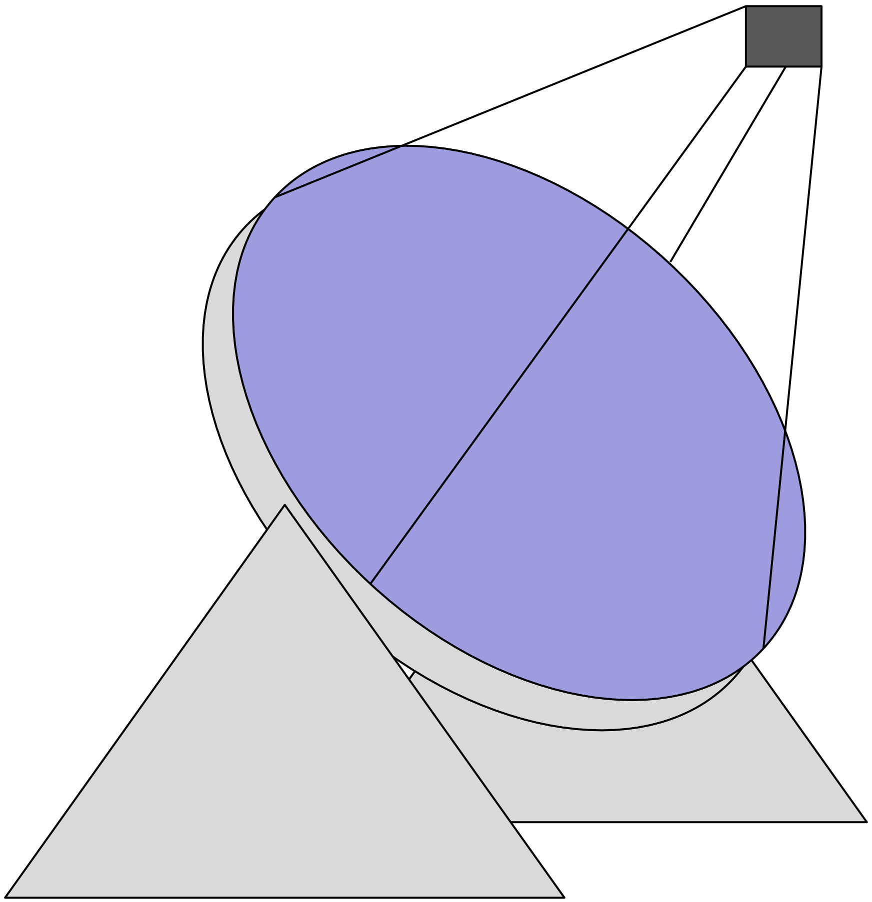
We do both

climb or marbles game with MAGIC

The structures

Mostly of the Cherenkov telescopes look like these

The structures



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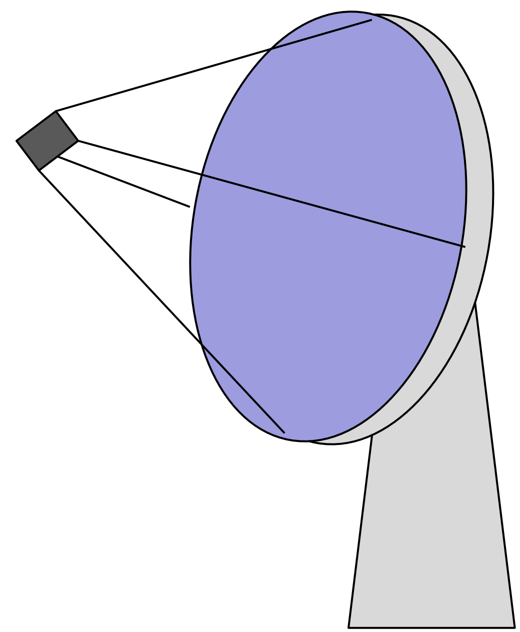
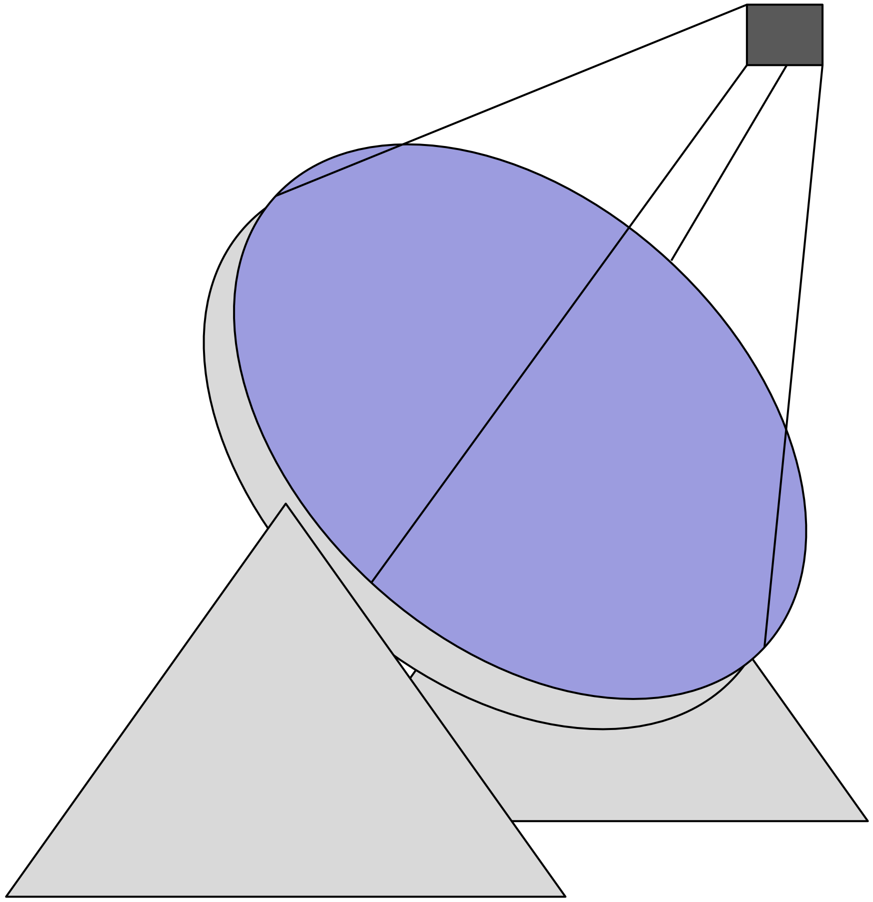
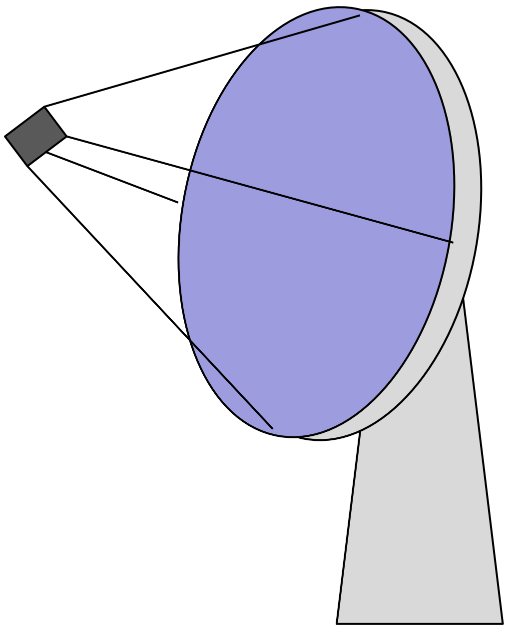


The structures



Mostly of the Cherenkov telescopes look like these

They are very large light collectors



The structures

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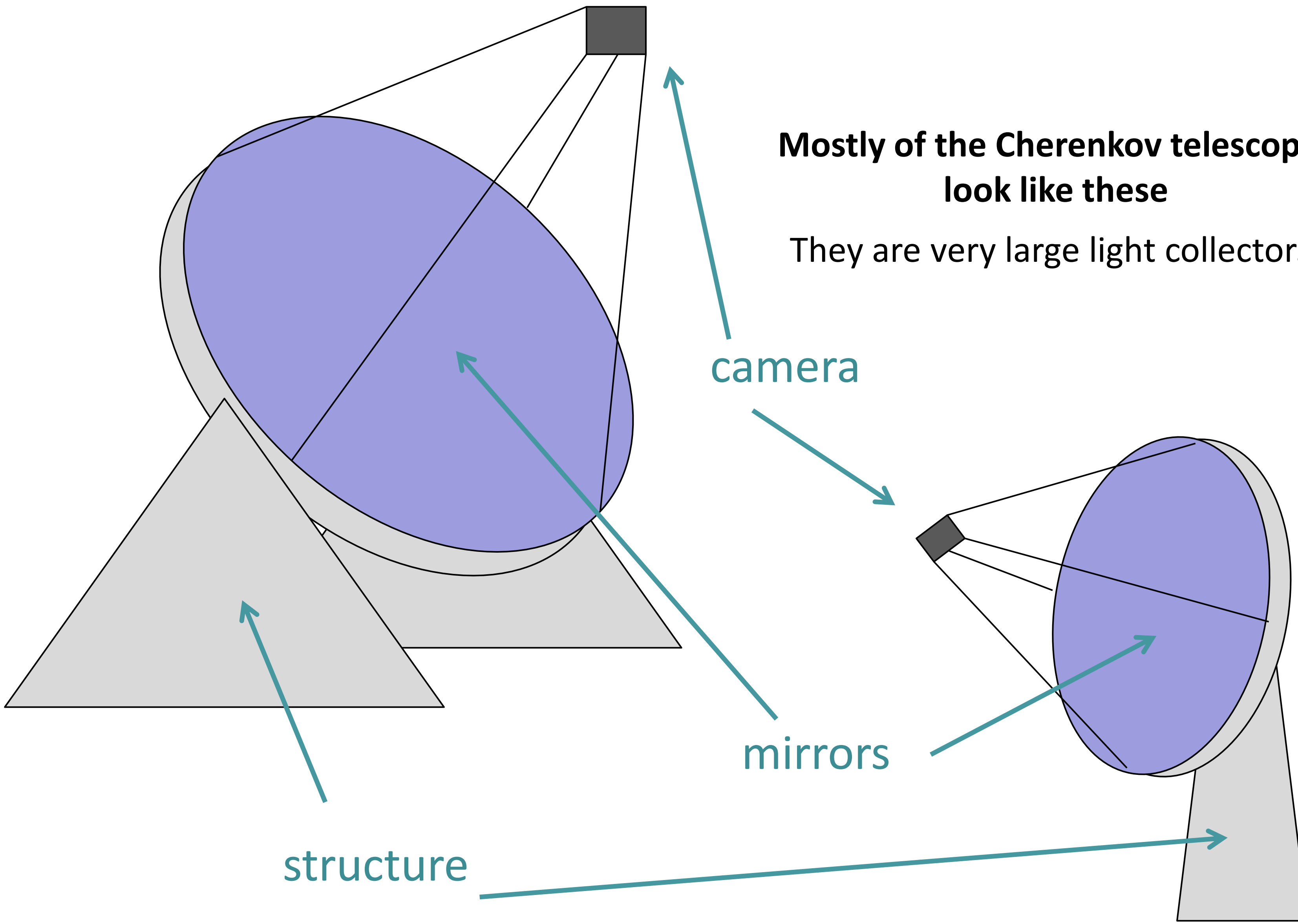
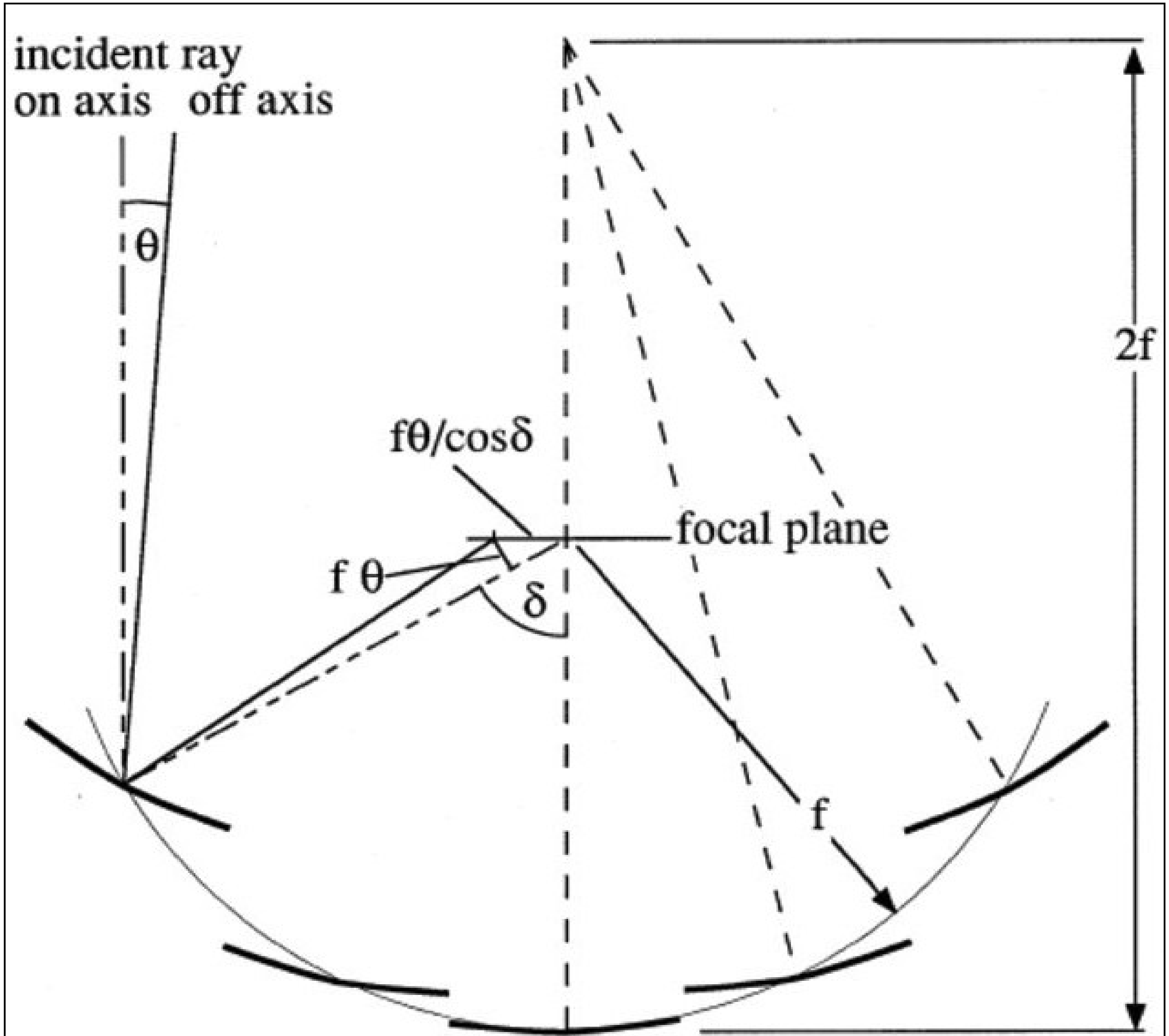
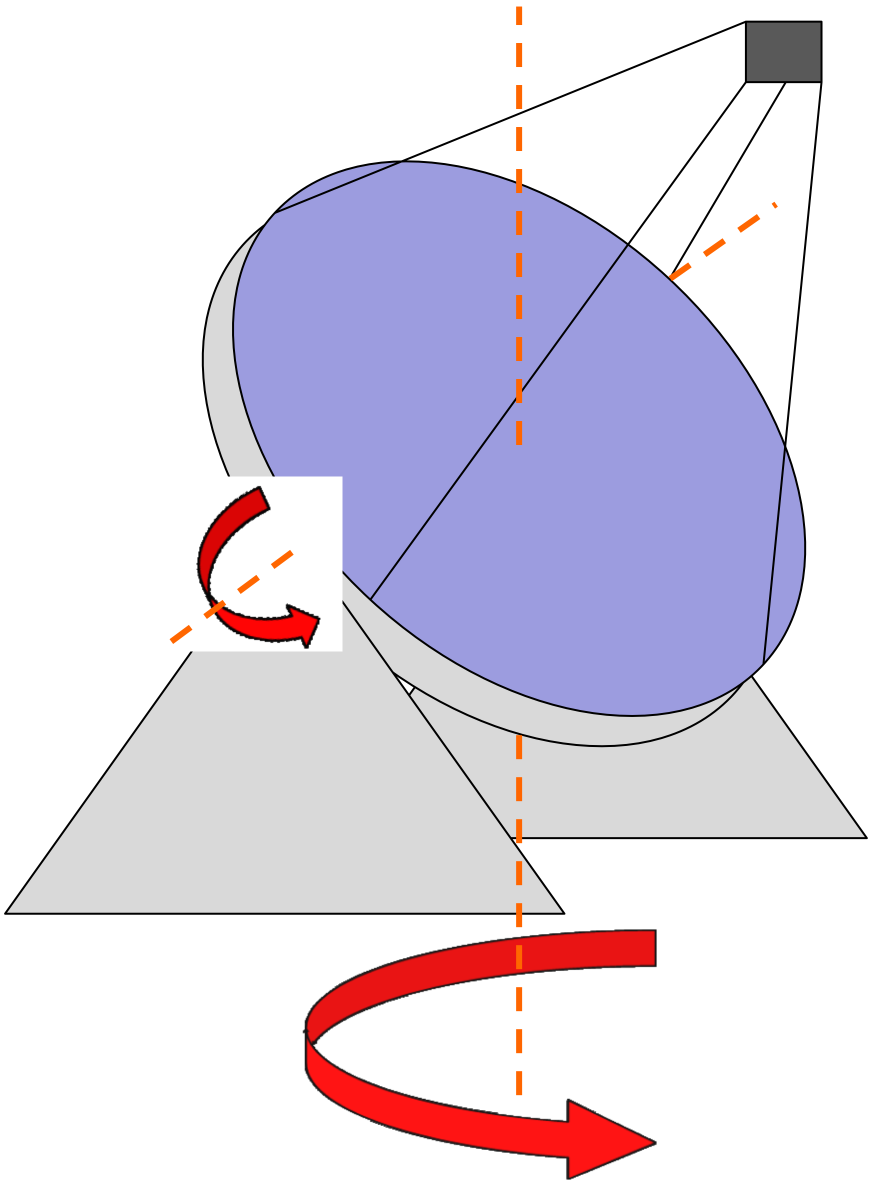


The Davies-Cotton layout



- Originally (1957) proposed for solar concentrators.
- Single reflection.
- Discontinuous optical surface.
- Many identical spherical mirrors accommodated on a spherical structure with the curvature being half of the mirrors one.
- Better performances for off-axis rays when compared to a spherical or parabolic layout.

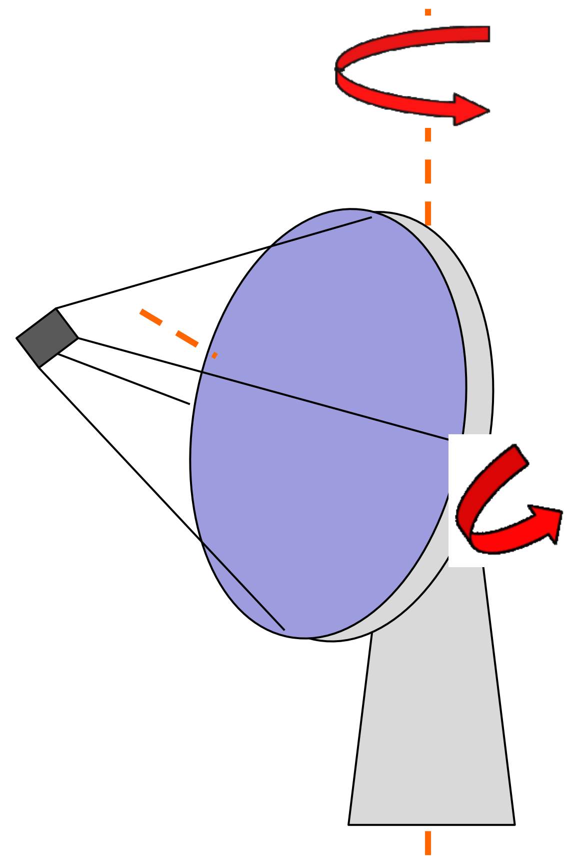
The structures



Alt-Az mount

alt: −20° ÷ 100°

az: ±270°



Stow/safety position

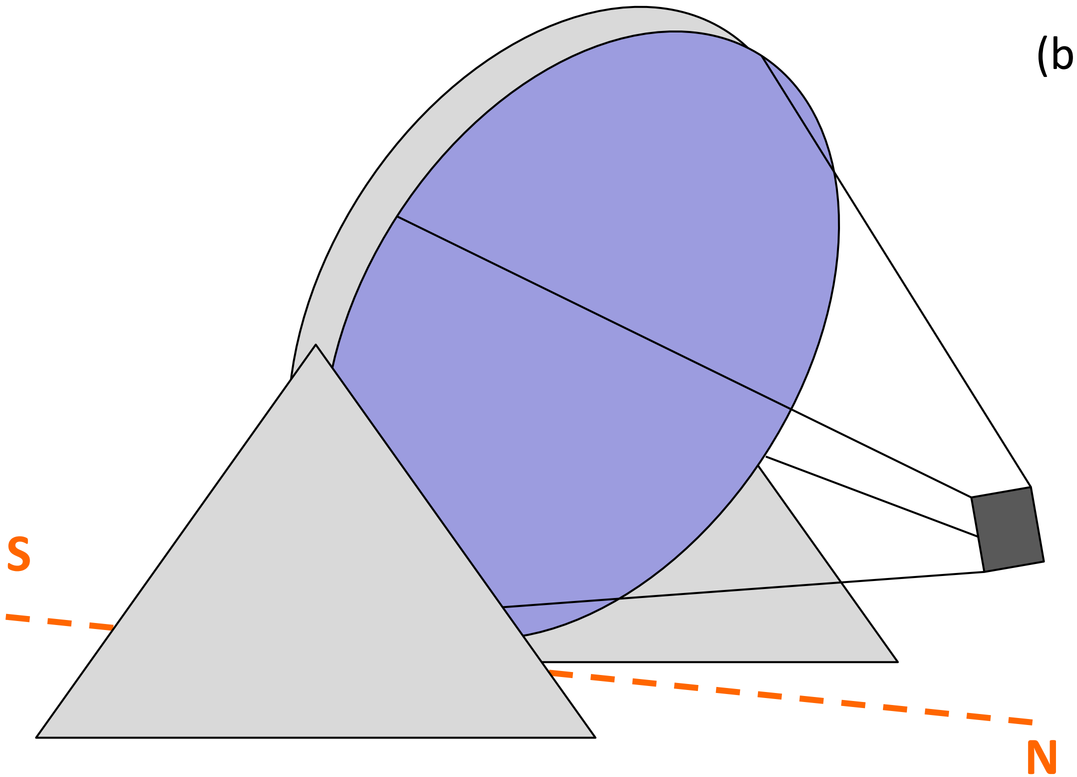
(below) Horizon pointing, toward North

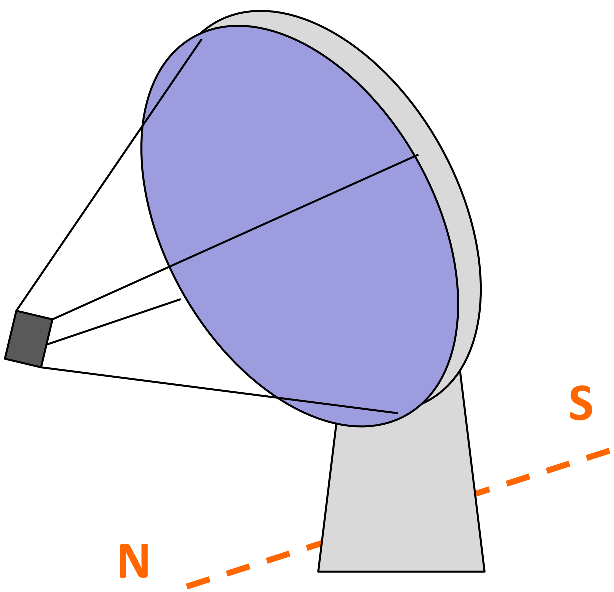
Pros:

- easy access to camera body;
- no Sunlight concentration;
- no accumulation of snow

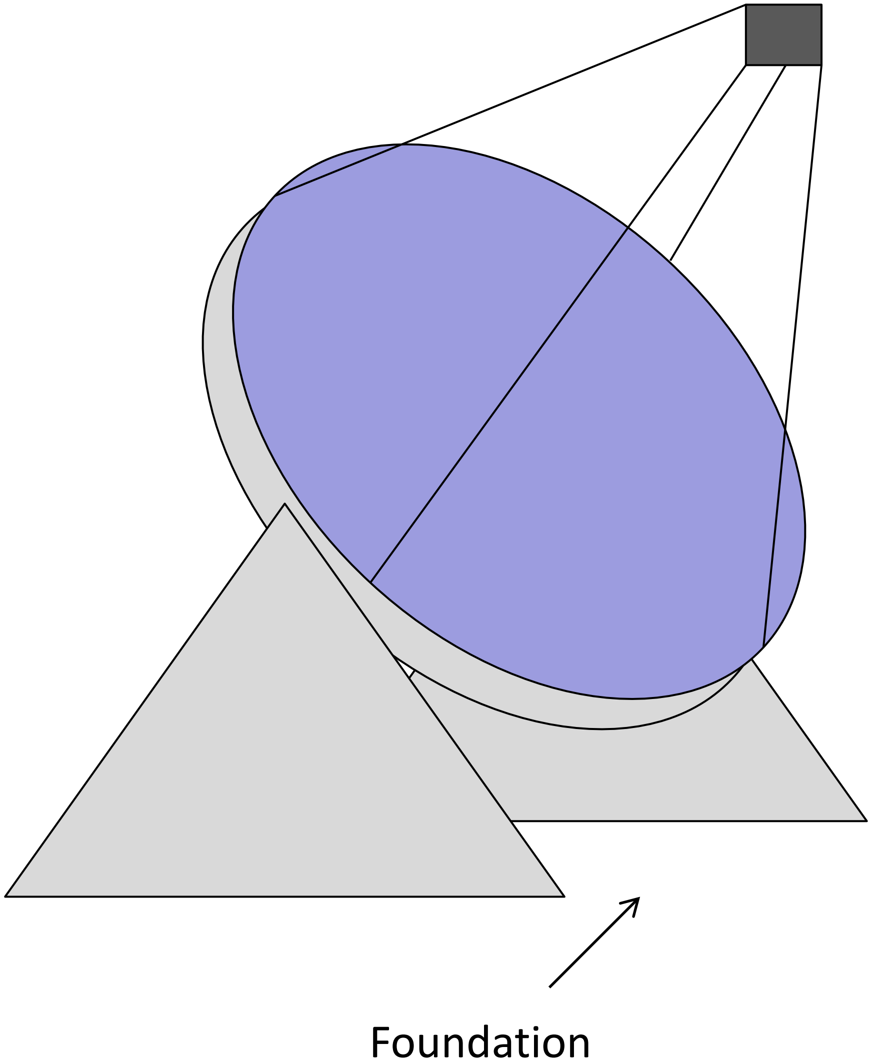
Cons:

- wind effect

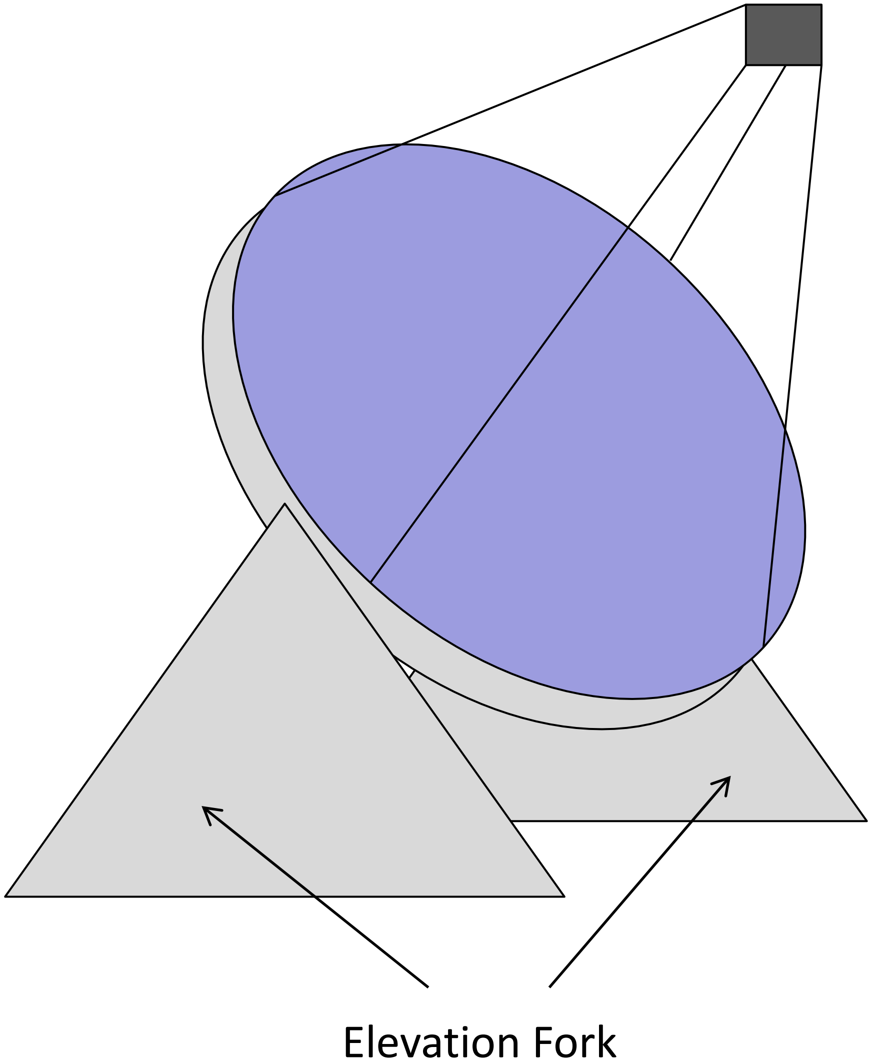




The structures



The structures

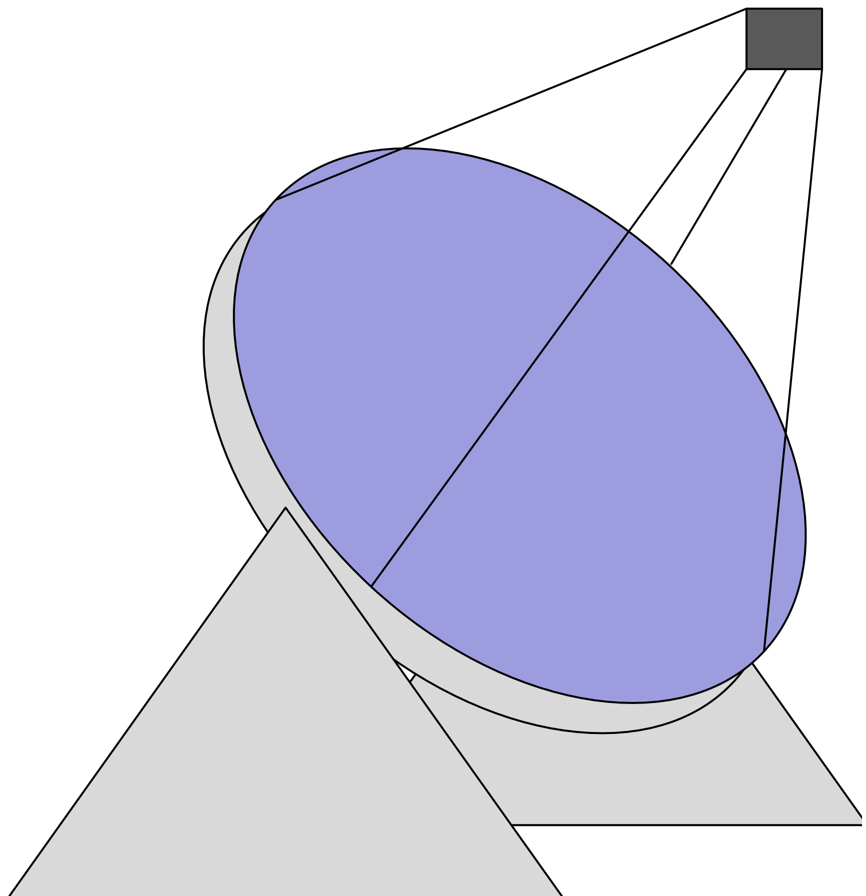


[redacted] tubes

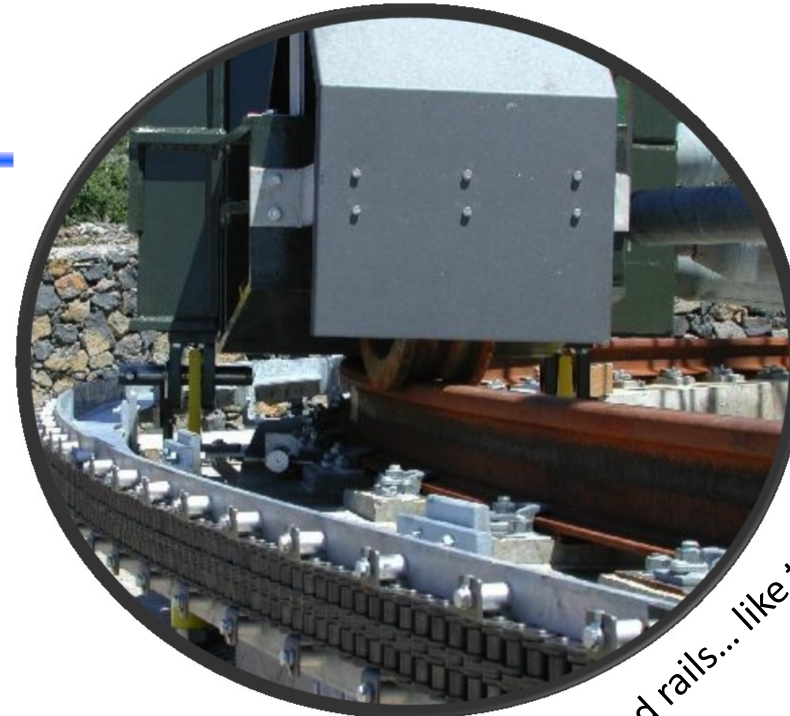
Stainless still tubes

[redacted]

The structures



Azimuth drive system



nd rails... like trains!

Azimuth motor

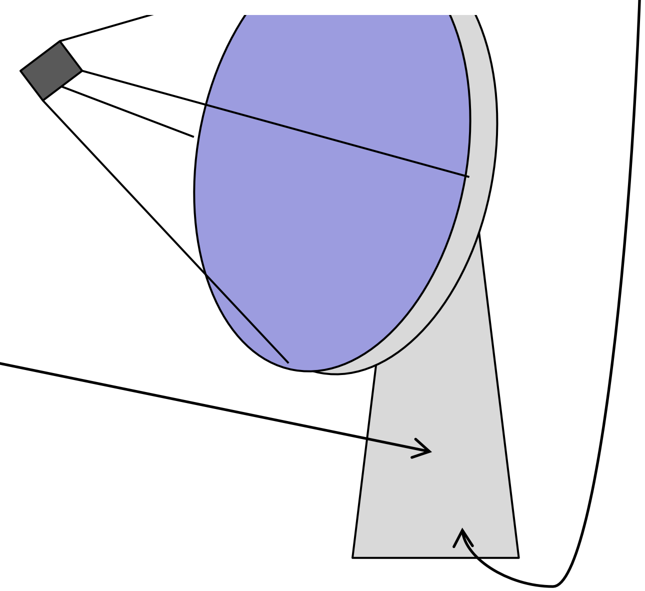
The structures

Elevation drive system

Counterweights

Azimuth drive system

Foundation



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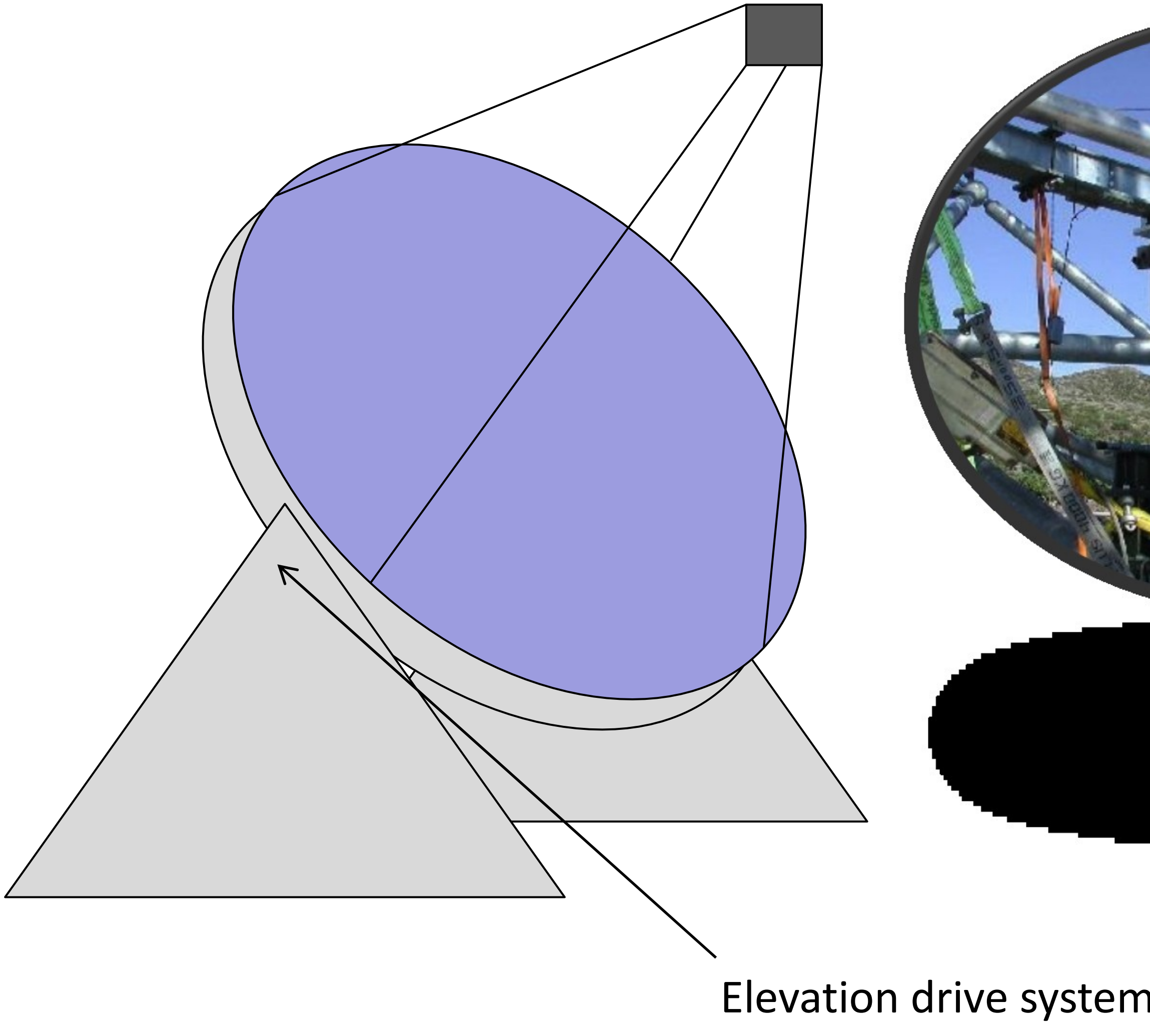
The structures



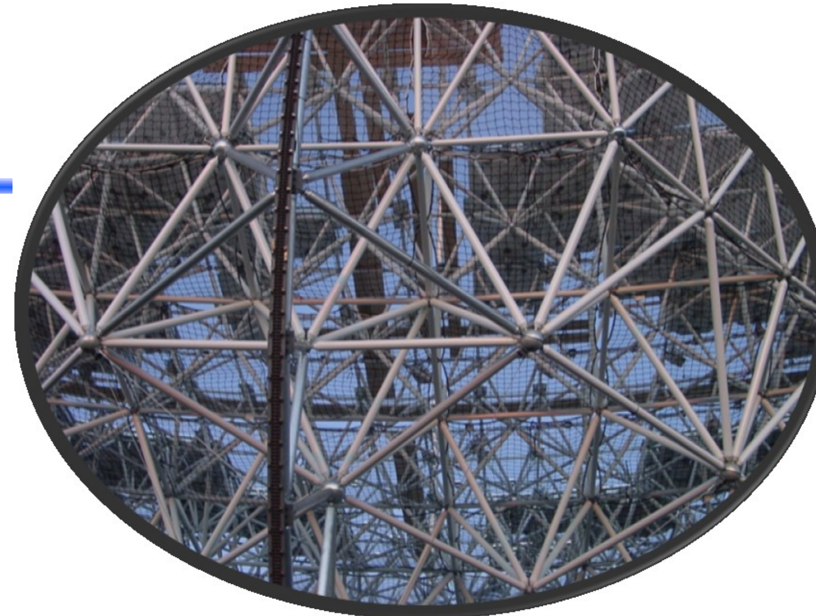
The structures

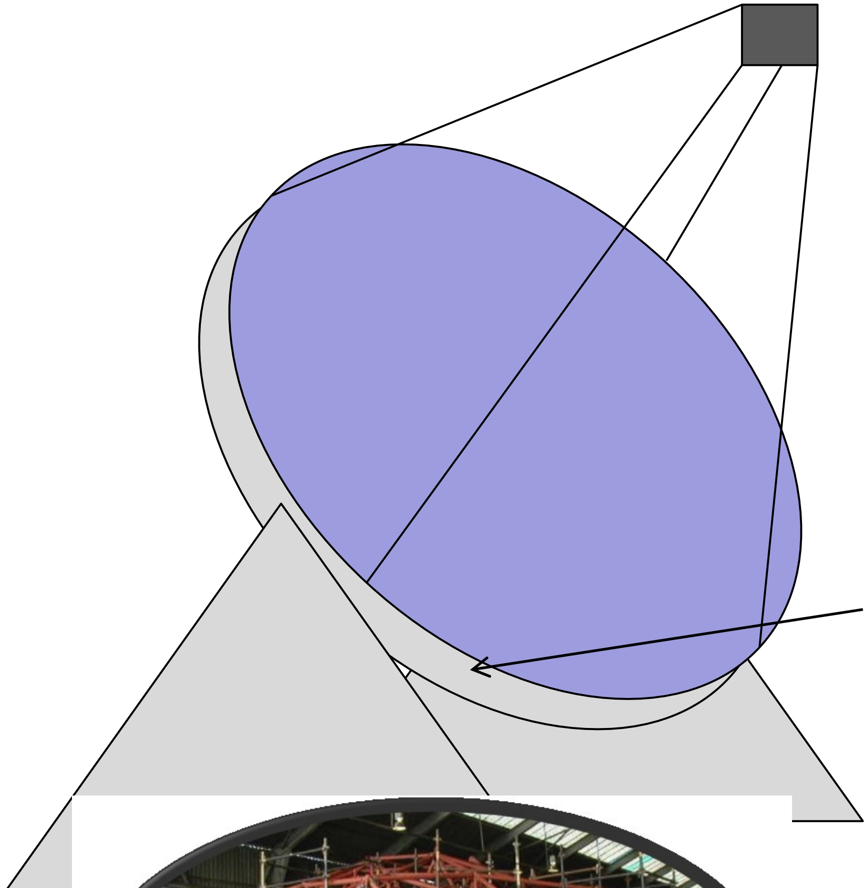
Circular rail system for azimuthal motion, supporting the dish between two elevation towers, as is used by H.E.S.S. and MAGIC. The elevation axis is positioned such that the dish is balanced and little or no counterweight is required. This support scheme will in general permit a large movement range in elevation, allowing the positioning of the camera near ground level for easy access, and the tracking of sources which go through the zenith without repositioning by 180° in azimuth. A disadvantage of a rail system is the considerable on-site effort required: a large ring foundation must be constructed, the azimuth rail needs to be carefully levelled, and drive systems have to be mounted and cabled on-site.

The central positioner as used by VERITAS, in which the dish is supported from near its center in the back. The central positioner construction is often used for radio and radar antennae and mirrors for solar power concentrators. The construction of the foundation is considerably simplified and the on-site installation work reduced which can be of importance at sites with poor access or difficult terrain. In addition, maintenance tends to be simplified since all bearings and drive components are contained and protected within a compact positioner unit, as opposed to rails and wheels which are more exposed. While these advantages make the choice obvious for antennae and solar concentrators, for which focal plane instrumentation is generally of low weight and f/d is normally very short, the trend for Cherenkov telescopes is now towards large f/d ratios, well above 1, to provide improved image quality. More and more components are also being installed in the camera, resulting in increased weight. Large counterweights are then required to balance the elevation axis in the central positioner design, as is visible in the VERITAS case. Without these counterweights, the elevation mechanism has to handle large torques and the desired positioning speeds require much larger drive power than needed for balanced systems. Access to the camera at ground level is also possible in these designs if one locates the elevation axis away from the centre of the tower.

Extract from *"CTA Design Study"*
arXiv/1008.3703

The structures





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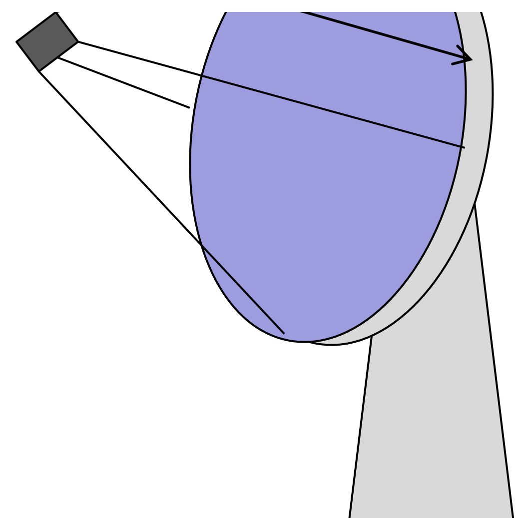
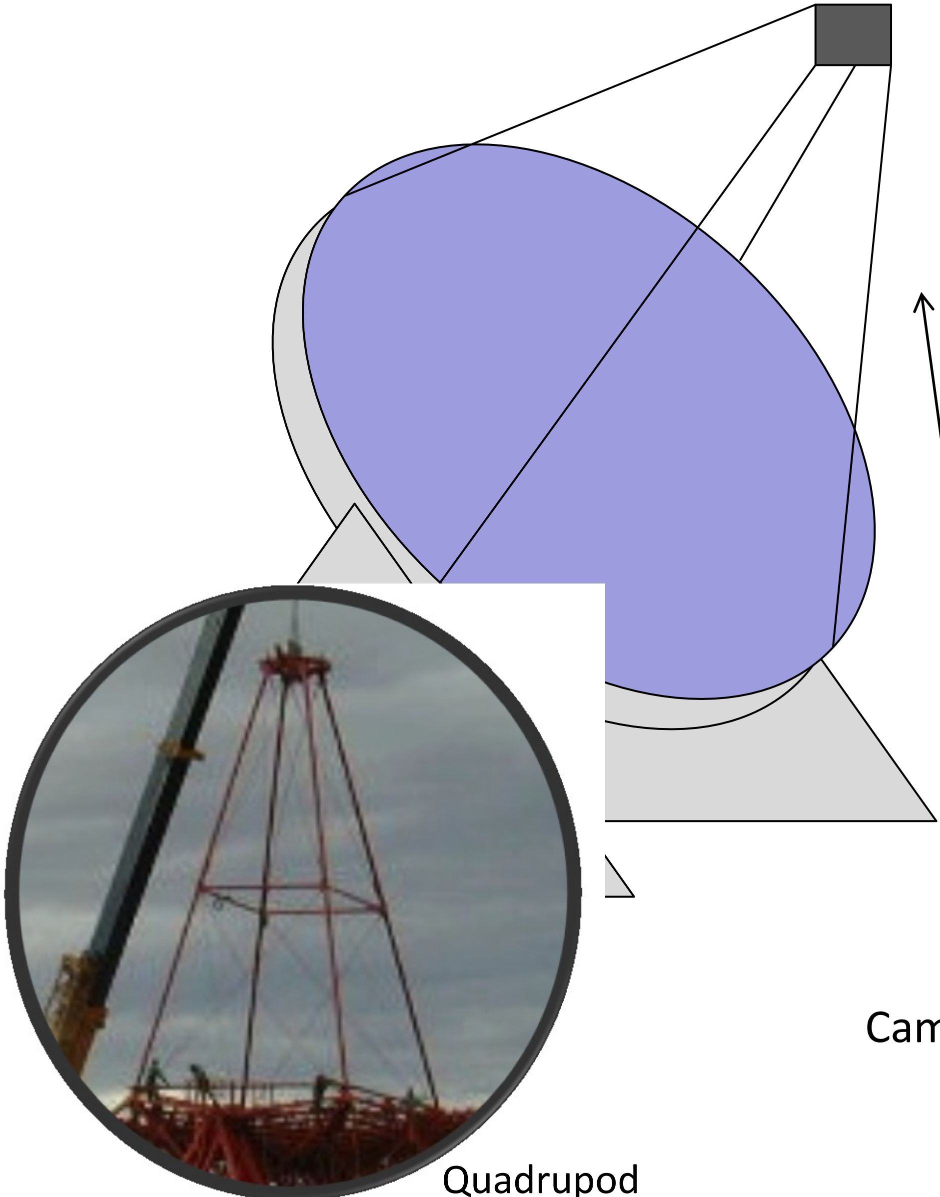
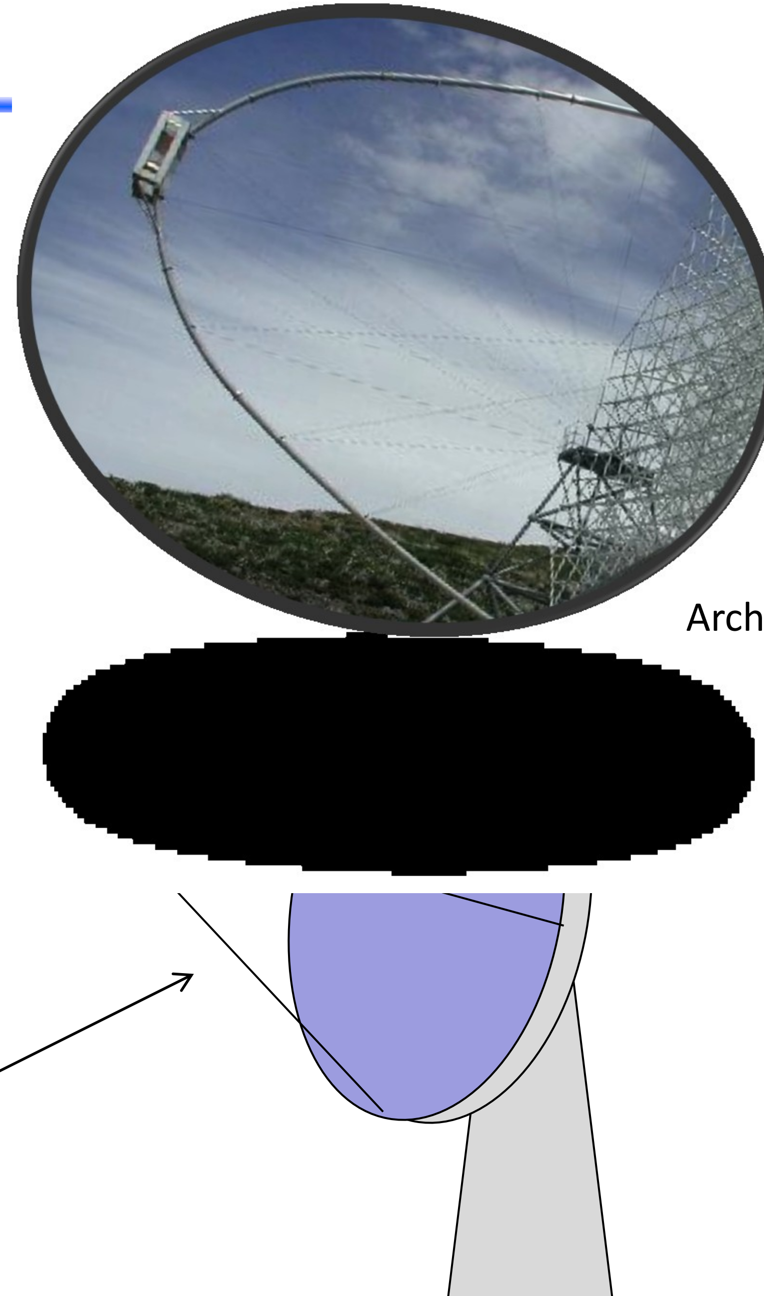


Lattice structure: stainless steel

The structures





Current experiments

Layout: array with 4 telescopes

Mirror area: 4 × 108 m^2

Site: The Khomas Highland of Namibia

Location: 23°16’18” S, 16°30’00” E at 1800 m asl

Operating since: 2002 (array in 2004)

Website: http://www.mpi-hd.mpg.de/hfm/HESS/

Current experiments

Mount and dish

In the design of the H.E.S.S. telescopes, emphasis was placed on the mechanical stability and rigidity of the mount and dish.

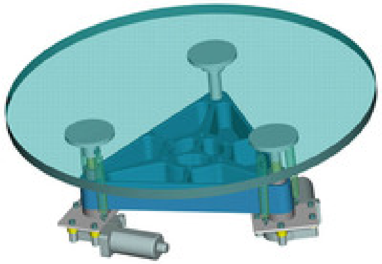
- The telescopes (here before mirror installation, side view, front view) use an alt-azimuth mount, to point the telescope at any point in the sky. A "base frame" rotates around a vertical axis and carries the dish, which rotates around the elevation axis. Both the base frame and the dish are realized as steel space frames. Technical drawings show a telescope from the front and back. Both axes are driven under computer control to track a celestial object across the sky.
- The drive system combines for each axis a servo-controlled AC motor and a backup battery-driven DC motor. In order to reduce the drive forces, the drives act on circular rails of about 7 m radius. The maximum speed of the drive systems is about 100^{o}/min, in order to allow rapid slewing from one object to another. The servo controllers and batteries for the DC drive are located in a small hut on the base frame.
- The pointing is controled by angular position encoders connected to both axes, which provide a resolution of a few arc-seconds (17 bit digitial readout plus an additional analog track). Telescope pointing is in addition monitored by an optical guide telescope (f=800 mm) equipped with a CCD camera, which serves to correct deviations from perfect pointing.
- Weights: complete telescope about 60 t incl. camera, drive systems, mirrors.

Extract from http://www.mpi-hd.mpg.de/hfm/HESS/

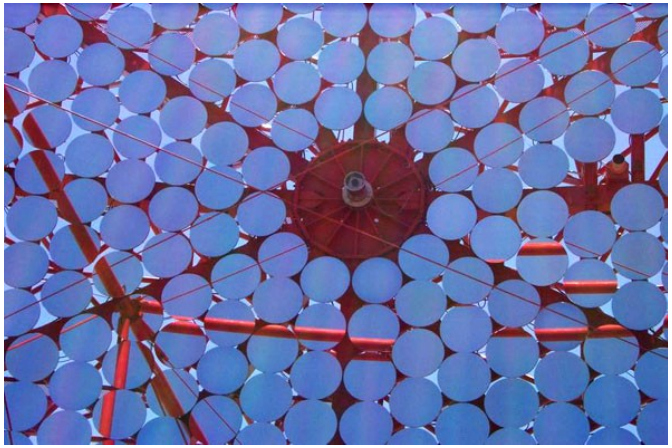
Current experiments

Mirror

The mirror focuses the Cherenkov light of an air shower onto the camera. Relevant for the performance of a telescope are the net mirror area and the quality of the image, i.e. the point spread function (size of the image of a point source).



- For cost reasons, the mirror is segmented into 382 round mirror facets of 60 cm diameter, made of aluminized glass with a quartz coating.
- The mirror has a focal length of 15 m and a d/f ratio of 0.8; the mirror facets are arranged in a Davies-Cotton design (on a sphere of radius f), which provides good imaging also for off-axs rays.
- The total mirror area is 108 m^2 per telescope.
- Mirror reflectivity is >80% (300 to 600 nm). Each mirror tile is individually tested for reflectivity and image quality before it is mounted.
- The orientation of each facet is adjustable by two remote-controlled motors. To align the mirror facets, the image of a star in the focal plane is viewed by a CCD camera in the center of the dish. Before alignment of the facet, each facet generates a light spot. One mirror at a time, the individual mirrors are then moved until all spots converge in the center. The procedure is fully automatic; the initial alignment requires a few nights. The effect of the alignment is visualized by comparing the image of a star before and after alignment. Alignment of mirror will be check regularly; when required, a re-alignment can proceed in a few hours.
- The mirrors of H.E.S.S. telescopes are focused for an object distance of about 10 km, corresponding to the typical distance of an air shower from the telescopes.



Extract from http://www.mpi-hd.mpg.de/hfm/HESS/

Current experiments

Layout: array with 4 telescopes

Mirror area: $4 \times 110\ m^2$

Site: Coronado National Forest, Arizona

Location: +31°40’30” N, -110°57’8” E at 1268 m asl

Operating since: 2003 (array in 2007)

Website: http://veritas.sao.arizona.edu/index.php

Current experiments

Telescope Mechanics and Tracking

The basic mechanical structure of each VERITAS telescope is similar to that of the Whipple 10 m telescope. Each telescope consists of an altitude-over-azimuth commercial positioner (from RPM-PSI, Inc.) and a tubular steel Optical Support Structure (OSS). The camera is supported on a quadrapod, with a mechanical bypass of the upper quadrapod arm transferring the camera load directly to counter-weight supports located at the rear of the OSS. The positioner is a commercially manufactured unit, while the OSS custom-designed.

The maximum slew speed of the telescopes is 1 degree per second with the positioner encoder measurements being logged to an offline database at a rate of 4 Hz. These values are used to monitor any pointing discrepancies with the telescopes. The mechanical pointing accuracy of a VERITAS telescope is typically better than ± 0.01 degrees [1].

Extract from http://veritas.sao.arizona.edu/index.php

Current experiments

Telescope optics

The optics of each VERITAS telescope follows the Davies-Cotton design [2] using 350 identical hexagonal spherical mirrors (of area 0.322 m^2 and radius-of-curvature of approximately 24m) giving a total reflector area of 110 m^2. The use of hexagonal facets allows the full area of the OSS to be exploited.

A VERITAS telescope (here: T4) showing the facet structure of the reflector.

Each mirror facet is made from glass, slumped, polished and then aluminized and anodized. The exposure of the mirror facets to the Arizona desert and the elements will cause the mirror reflectivity of the telescopes to degrade (approximately 3 - 6% of reflectivity at 320nm is lost per telescope per year). To counter the effects of this weathering on the mirror reflectivity, a regular program of re-aluminization and re-anodization of VERITAS facets is carried out at the VERITAS optical coating laboratory (located at the Fred Lawrence Whipple Observatory) and the mirrors are regularly washed. Aluminizing is the process of evaporating aluminum onto a glass surface to create a mirror. The evaporation must be done under vacuum to ensure the purity of the coating which is important for the optical properties and for strong adhesion. Anodizing is the process in which the top layer of the aluminum coating is converted into a harder and more durable layer of aluminum oxide. This is accomplished by submerging a freshly aluminized mirror in an electrolyte solution (ammonium hydroxide, tartaric acid, distilled water and ethylene glycol) which then has an electrical current passed through it. The thickness of the anodized layer determines the wavelength at which peak reflectivity of the mirror is obtained. For VERITAS mirrors, approximately 80nm of the aluminum coating is oxidized which ensures that the reflectance of the mirrors exceeds 90% at 320nm (in the wavelength regime of Cherenkov radiation). Each mirror facet also focuses >90% of light onto a circle of diameter 5.7 ± 1.9 mm [3] which is well within the diameter of a VERITAS PMT (see Cameras section below). Each mirror is mounted on the OSS via a triangular frame with 3 adjustment screws (these adjustment screws are used in alignment of the optics, see discussion below). More details of the work carried out at the VERITAS mirror maintenance lab at the Fred Lawrence Whipple Observatory can be found in [4].

Extract from http://veritas.sao.arizona.edu/index.php

Current experiments

MAGIC

Gamma-ray astronomy at lo

Layout: array with 2 telescopes

Mirror area: 2 × 236 m^2

Site: Roque de los Muchachos, La Palma, Canary Islands

Location: +28°45’42” N, -17°53’25” E at 2200 m asl

Operating since: 2004 (array in 2009)

Website: http://magic.mppmu.mpg.de/

Current experiments

2.2.1 The Mounting and Drive System

The reflector frame satisfies at the same time four main demands: a) it is very large, b) it is light–weight, c) it is very stiff and d) it allows for fast repositioning. The space frame is made from carbon fiber reinforced plastic (CFRP) tubes and has a weight of only 5.5 tons. CFRP is a very strong but light composite reinforced fiber, similar to Fibreglass™. The tubes are joined with aluminum knots as shown in Figure 2.3(c). The CFRP construction is about three times stiffer and has less than a third of the weight of an equivalent steel construction [4]. The structure of an alt-azimuth design is mounted on a circular rail of 19 m □. The telescope can be moved from -80° to 105° in declination and 450° in azimuth. The camera at a distance of around 17 m from the reflector is carried by a single aluminum tubular arc. The weight of the camera is around half a ton, and the small bending, unavoidable during the telescope tracking, is corrected via a re-orientation of the mirror. Two motors control the motion in azimuth and one motor the zenith motion with a maximum power consumption of □ 7 kW per motor, see Figure 2.3(a), 2.3(b). The angular positions are controlled by absolute shaft-encoders of 14-bit precision/360°. In addition, a starguider camera, shown in Figure 2.3(d), mounted at the centre of the reflector, monitors the positioning of the telescope by viewing both the camera of the telescope and the corresponding section of the sky star-field [16]. The lightweight structure allows for very fast repositioning of the telescope to any position in the sky within □ 30 s. This challenging feature was designed to instantly react to Gamma-Ray Burst (GRB) alerts from dedicated satellites detecting GRBs in the KeV/MeV domain.

(a) Azimuth motor

(b) Zenith motor

(c) CFRP tubes

(d) SBIG camera

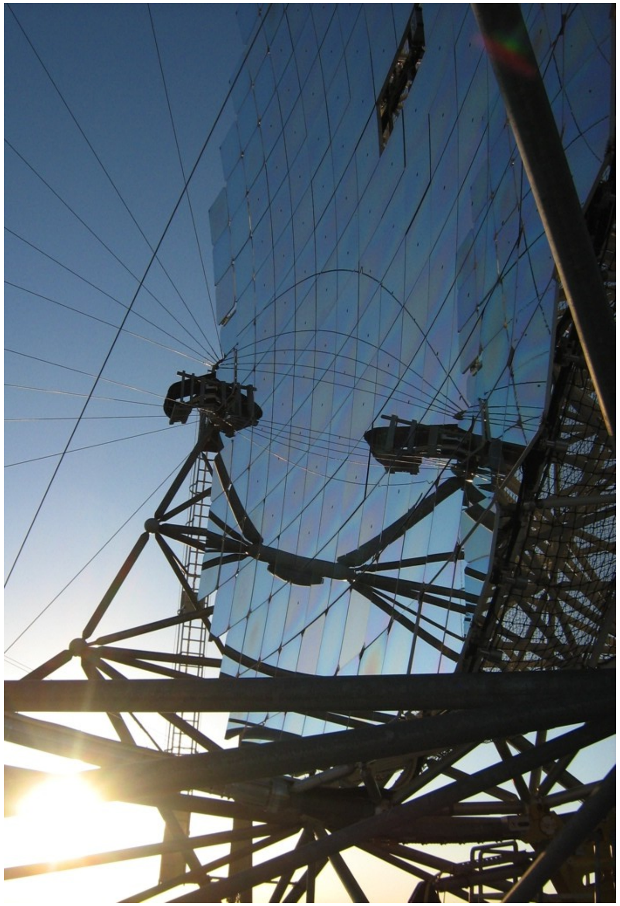
Extract from PhD Thesis, Michele Doro

Current experiments

2.2.2 The Reflector and Details on its Construction

The 17 m diameter reflector (17 m focal distance) follows a parabolic profile which was chosen to maintain the temporal structure of the shower light flashes. The reflector of MAGIC I is tessellated and comprises 956 mirrors with a total area of 234 m^2. Each mirror is a square of 0.495 m side length and has a spherical profile whose radius of curvature is optimized for the position in the telescope to best approximate the paraboloid. MAGIC I mirrors are grouped onto panels of 4 or 3 elements and each panel can be moved by the Active Mirror Control system (AMC) [6]. The AMC was designed to correct small deformations of the mirror support dish during telescope positioning and tracking. The mirrors are an all-aluminum, light weight sandwich construction composed of an Al-skin and an Al-box and filled with a Hexcell honeycomb structure [9]. A heating wire mesh, embedded in the sandwich, can be switched on in cases of dew or ice deposits on the mirrors. The total power consumption for heating the entire reflector is 40 KW. The reflecting aluminum surface of the mirror elements is diamond turned using the so-called fly-cutter technique, which provides an average roughness of 4 nm and a mean reflectivity of 85%. The surface of the mirrors was coated with a thin layer of quartz (with some admixture of carbon) for protection against corrosion and acid rain. Very little degradation (< 3%/ year) of the reflectivity was observed after 4 years exposure to the atmosphere at La Palma. The overall adjusted reflector has, for an infinite point-like source, a point spread function (PSF) of the reflected spot of ~ 10 mm φ at the camera of the telescope.

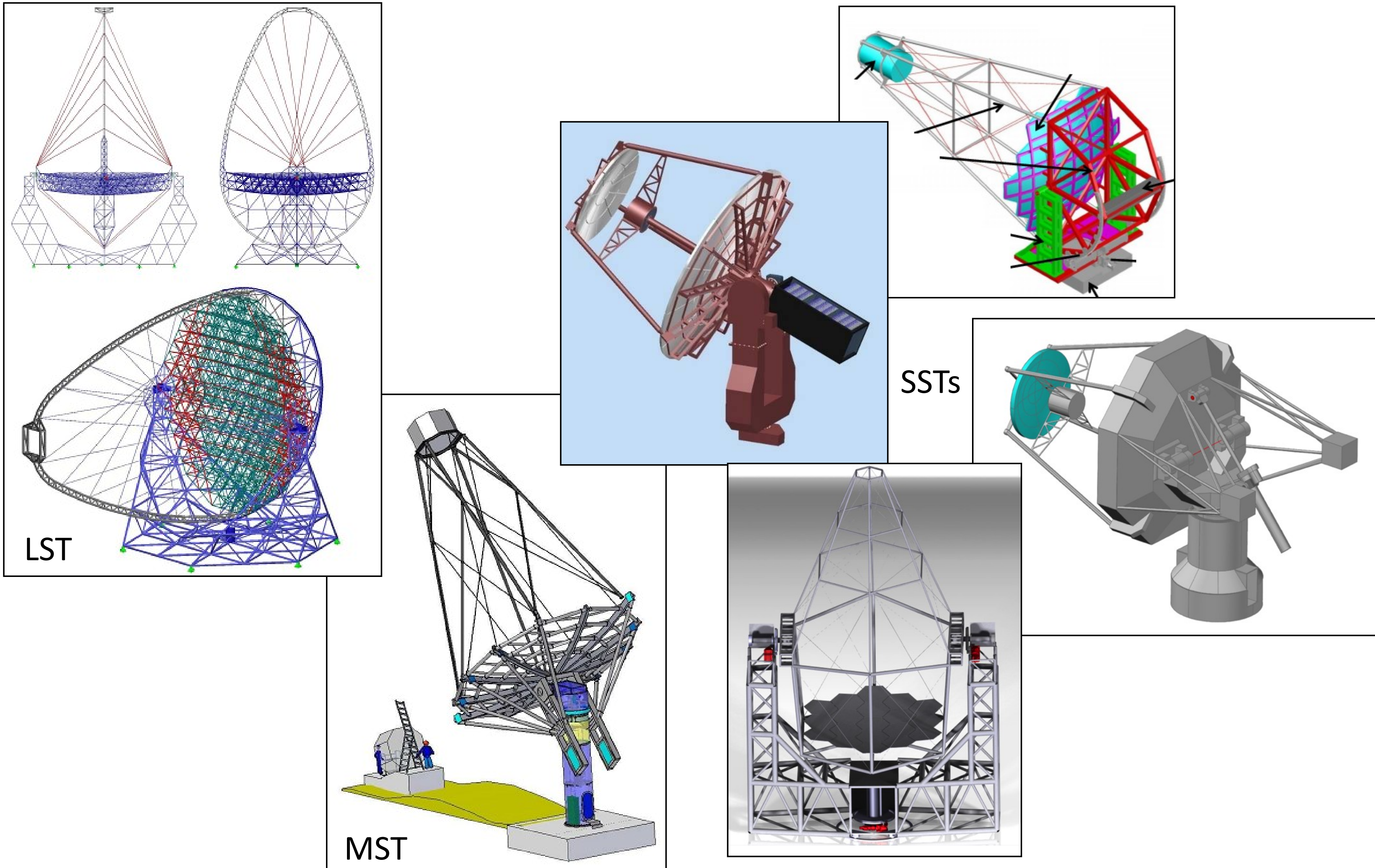
A more complete description of the telescope optics and mirrors, which is a relevant part of my PhD activities, is left to a dedicated section (Chapters 3 and 4).



Mirrors The MAGIC II reflector is composed of two types of mirrors: 143 full–aluminum mirrors similar to MAGIC I mirrors but with a larger area of 1 m^2 and improved design and 104 cold–slumped glass–aluminum sandwich developed at INAF–Milano. The work on MAGIC II reflector and mirrors is the most relevant activity I performed during the PhD. This is therefore, dealt with in greater detail in the following two chapters 3 and 4.

Extract from PhD Thesis, Michele Doro

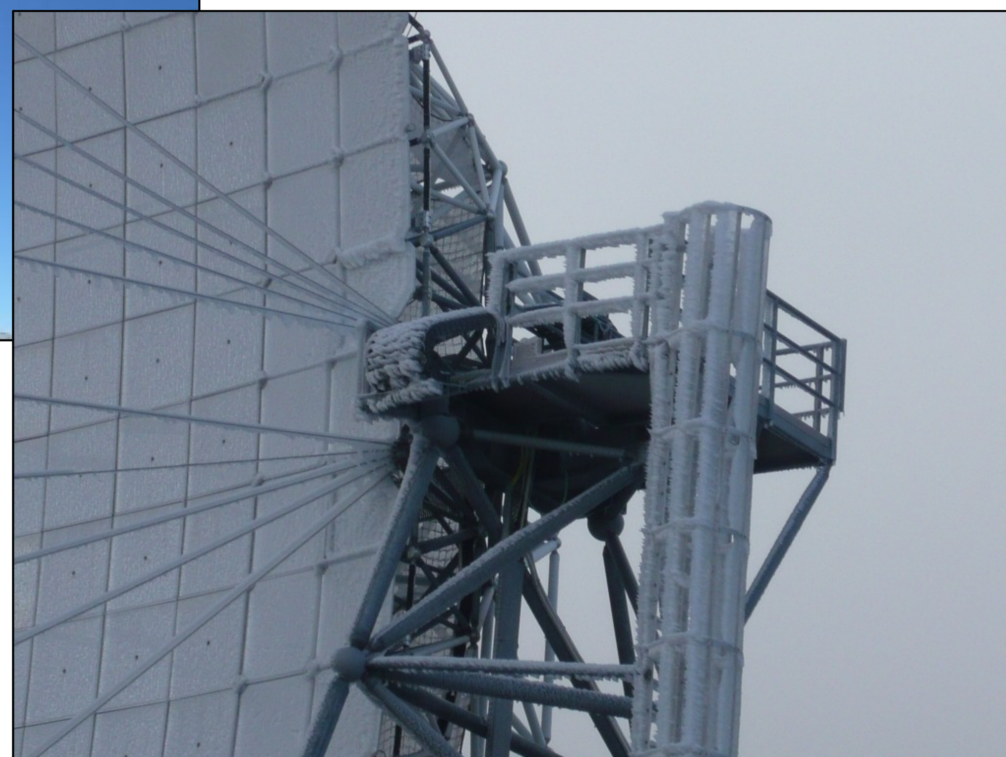
The solutions adopted for CTA



The mirrors

Parameter	Min Value	Max Value
Temperature range	-25°C	+60°C
Winds speed	0 km/h	200 km/h
Humidity	0%	100%
Snow, ice		
Hail		
Sandblasting		
UV radiation		

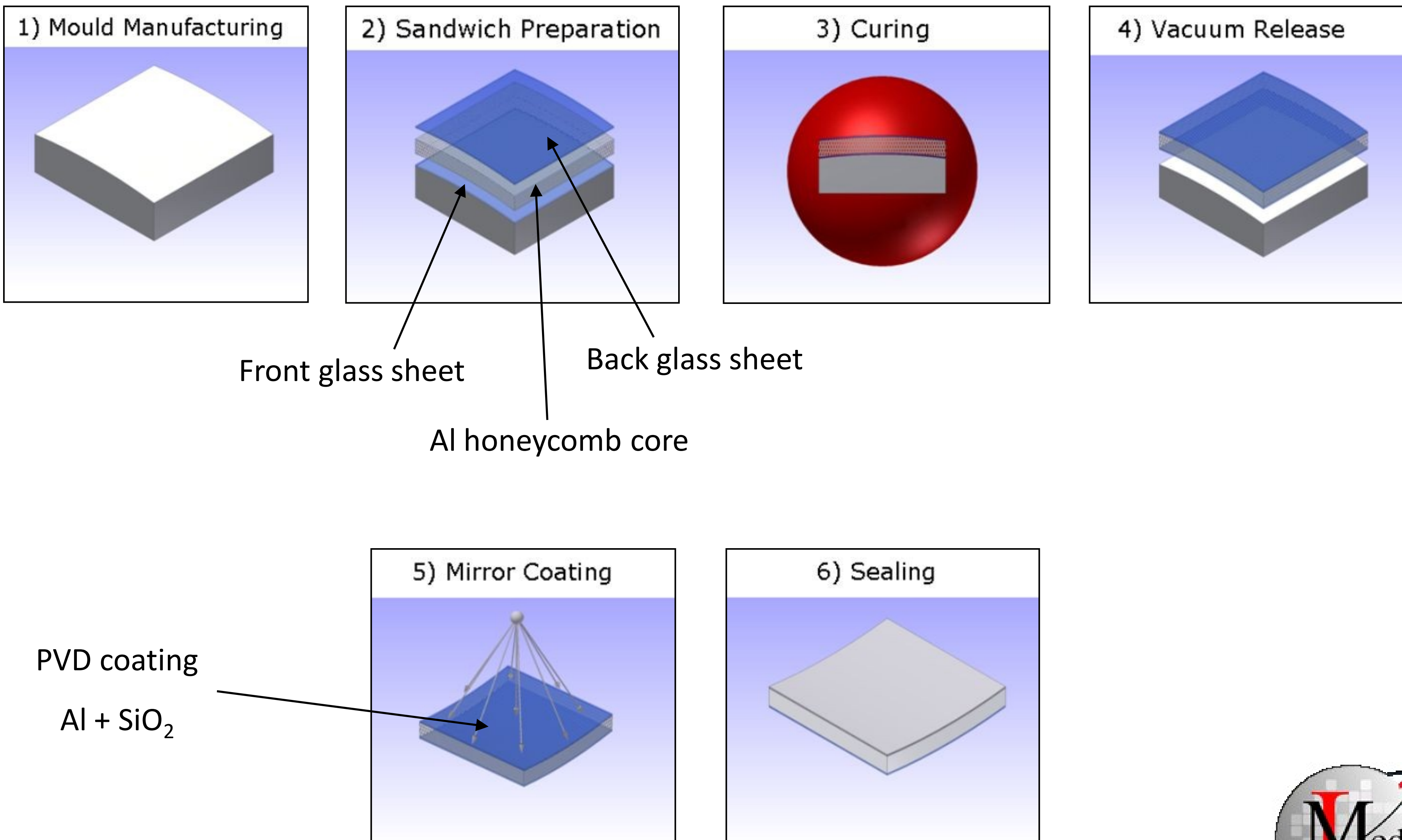
The mirrors



The mirrors

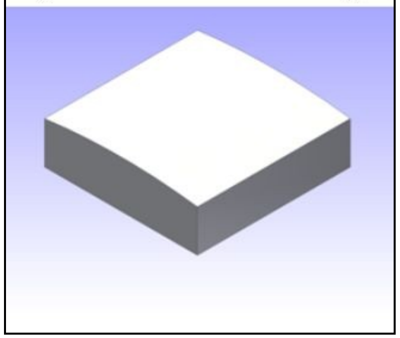
Parameter	Cherenkov	Optical
Optical quality	few arcmin	sub-arcsec
Areal density	20 kg/m^2	70 kg/m^2
Cost	2 k€/m^2	100-300 k€/m^2

The cold glass slumping technique

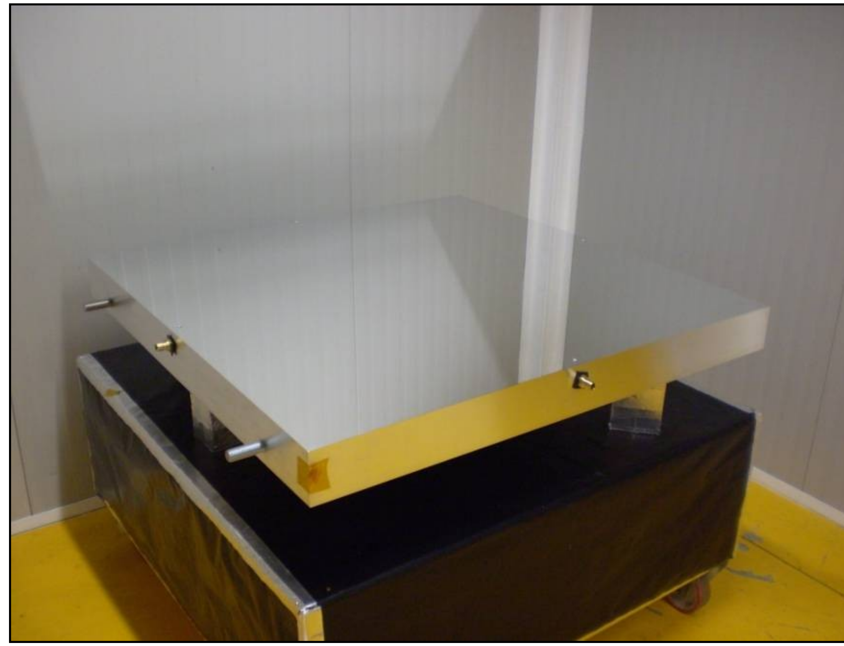


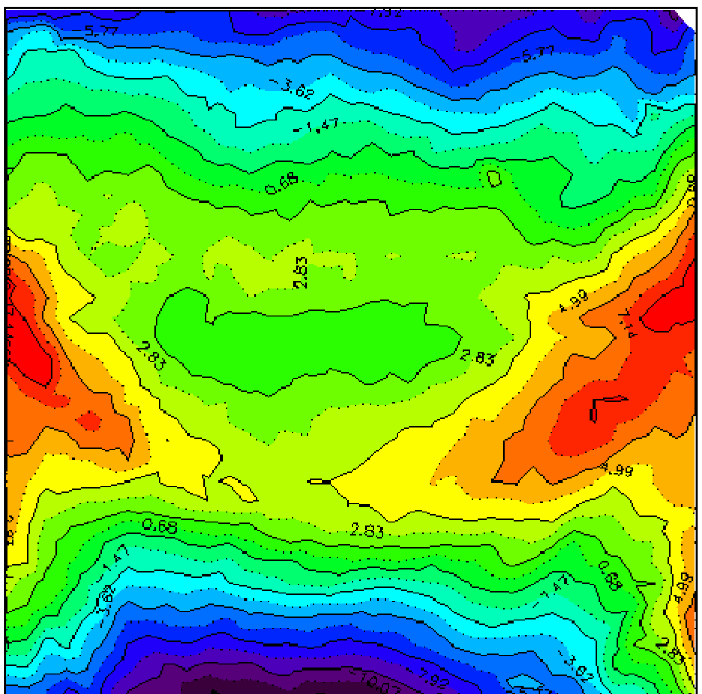
The cold glass slumping technique

1) Mould Manufacturing



Aluminum master 1040 x 1040 mm





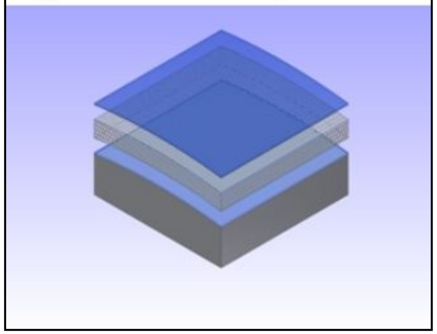
Points: 392

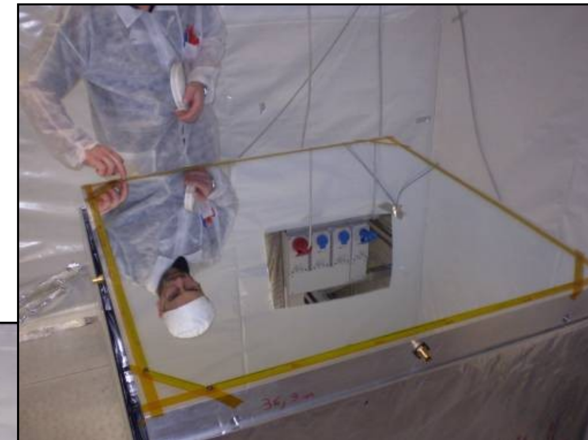
P-V: 21.5 µm

RMS: 4.6 µm

The cold glass slumping technique

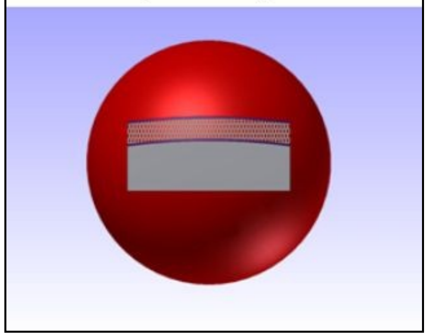
2) Sandwich Preparation



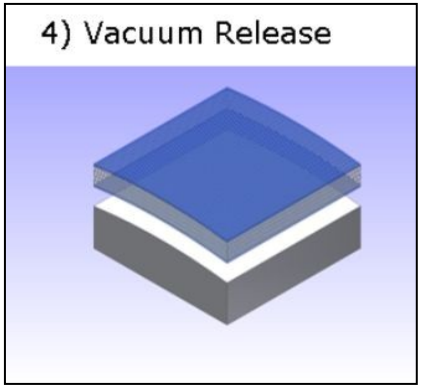


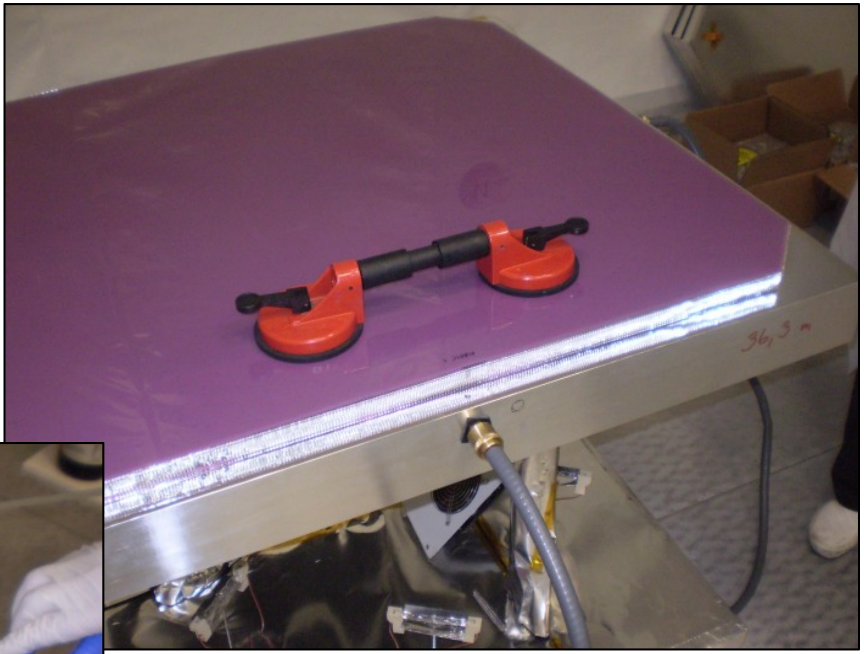
The cold glass slumping technique

3) Curing

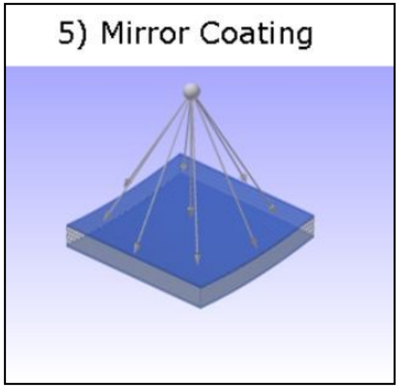


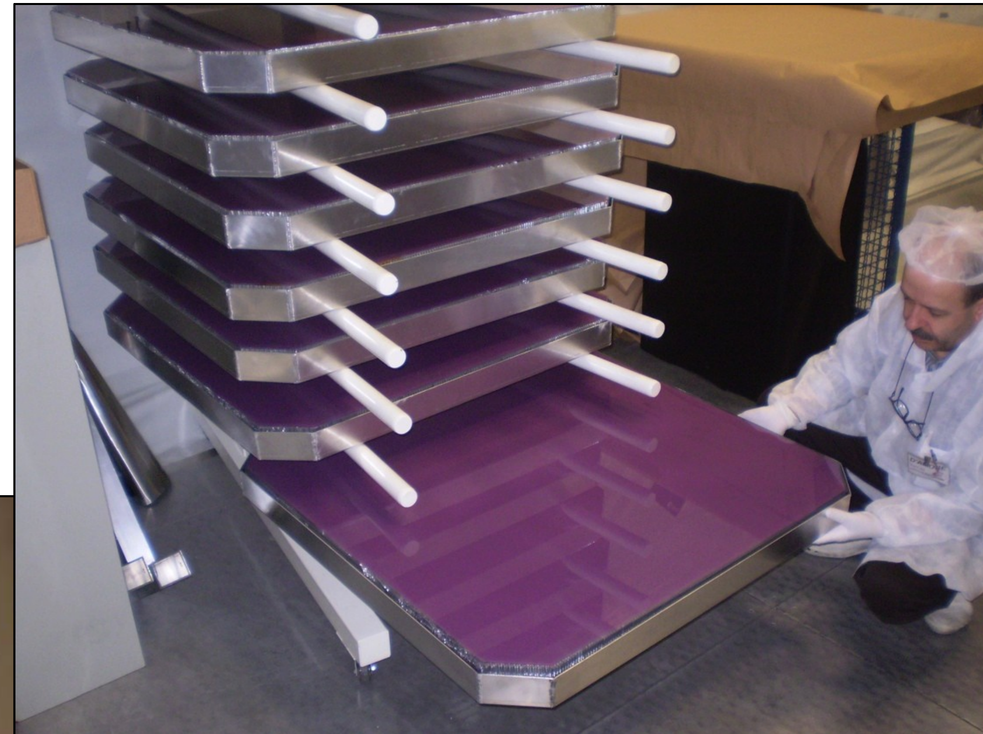
The cold glass slumping technique





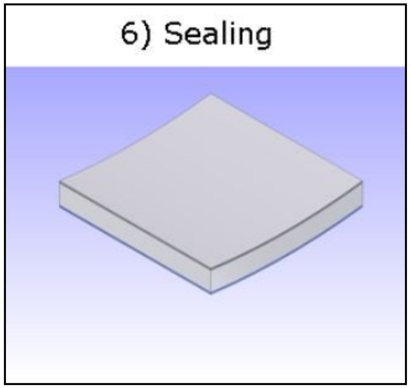
The cold glass slumping technique





PVD coating: Al + SiO_2

The cold glass slumping technique



The cold glass slumping technique

Qualification test	**On each mirror**	**On mirror prototype**	**On sample**
Curvature radius	X	X	X
PSF spot size	X	X	X
PSF spot size after thermal cycling		X	
Glass microroughness			X
Reflectivity		X	X
Reflectivity before and after weathering test			X
Reflectivity before and after Salt and fog test			X
Coating adhesion test		X	X
Sealing test		X