The VTT in a nutshell

Fig. 1: The VTT seen from South-West, with partially opened dome (Foto W. Schmidt, 2007)

Introduction

The Vacuum Tower Telescope (VTT) has been designed at the Kiepenheuer-Institut für Sonnenphysik in the early 1970s. The building was erected at the Observatorio del Teide on Tenerife between 1983 and 1987 (Fig. 1). The VTT has an aperture of 70 cm and a focal ratio of 66. The image scale is 4.6”/mm. The telescope saw *First Light* in 1988. A high-order adaptive optics was installed in 2002.

Item	Size	Material	Shape (& focal length)
Coelostat			
M1	80 cm	Zerodur	Flat
M2	80 cm	Zerodur	Flat
Telescope			
Entrance window	75 cm	BK7	Flat
M1	70 cm	Zerodur	Spherical, f=45 m
M2	45 cm	Zerodur	Flat
Exit window	20 cm	BK7	Flat
Adaptive optics			
Collimator	30 cm	Zerodur	Spherical, f=3 m
Tip-Tilt mirror	5 cm	Zerodur	Flat
Deformable mirror	5 cm		Adaptive,37 subapertures
Camera	30 cm	Zerodur	Spherical, f=3 m
Spectrograph			
Entrance slit	Length 60 mm	Zerodur	Several slits, with fixed widths (40, 80, 100 µm)
Predisp. collimator	18 cm	Zerodur	Spherical, f=4,2 m
Predisp. grating	7 cm x 9 cm	Zerodur	Flat, 150 gr/mm, 2,15° Blaze
Predisp. camera			Spherical, f=4,2 m
Exit slit		Aluminum	One or more slits
Main collimator	35 cm		Spherical, f=15 m
Grating	22cm x 42 cm	Zerodur	Flat, 79 gr/mm, 63,4° Blaze
Camera	60 cm	Zerodur	Spherical, f=7,4 m
Focal plane	125 mm x 500 mm		Flat

Table 1: Characteristic numbers of the VTT

Telescope optics

The telescope's optical path starts with a classical 2-mirror coelostat (Fig. 2) mounted on a platform 33 meters above ground. The diameter of each coelostat mirrors is 80 cm. The first mirror of the coelostat has a parallactic mount and is nominally placed in the North of the telescope entrance; the mirror mount itself is located on circular rails, which are centered on the telescope's optical axis. These rails allow to move that mirror between ± 90 degrees

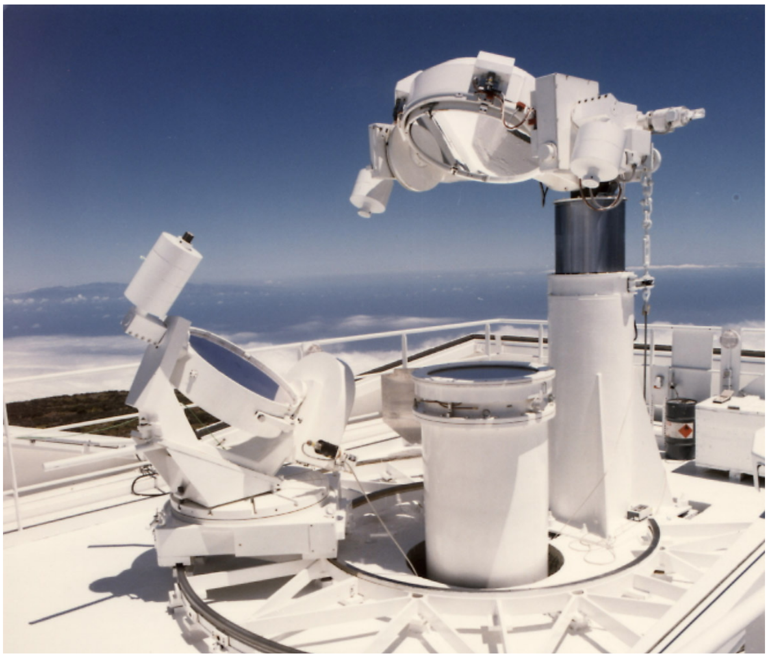


Fig. 2: The coelostat of the VTT. M1 is placed at an azimuth of about 45 degrees. The top part of the vacuum tank with the telescope entrance window is at the center, M2 on its adjustable pillar at the right. (Foto W. Schmidt, 1989)

in azimuth to avoid shadowing by the coelostat's secondary mirror, M2. The height of M2 is adjustable to ensure that the light beam from M1 is always centered on M2 for all declination angles of the Sun. In addition, M2 is tilted such that the light beam is reflected vertically downward through the entrance window onto the telescope's primary. Whenever M1 is not at 0 degrees azimuth, M2 is slightly tilted sideways to fold the beam vertically downward to the telescope primary mirror. From M2, the light bundle passes vertically through the 75cm [1] of the Vacuum telescope. The spherical primary of the telescope is located below the entrance window, at the bottom of the 25 m vacuum tank. From there, the beam is reflected to the folding flat, and the primary image with a plate scale of 4.59 arcsec/mm is formed on

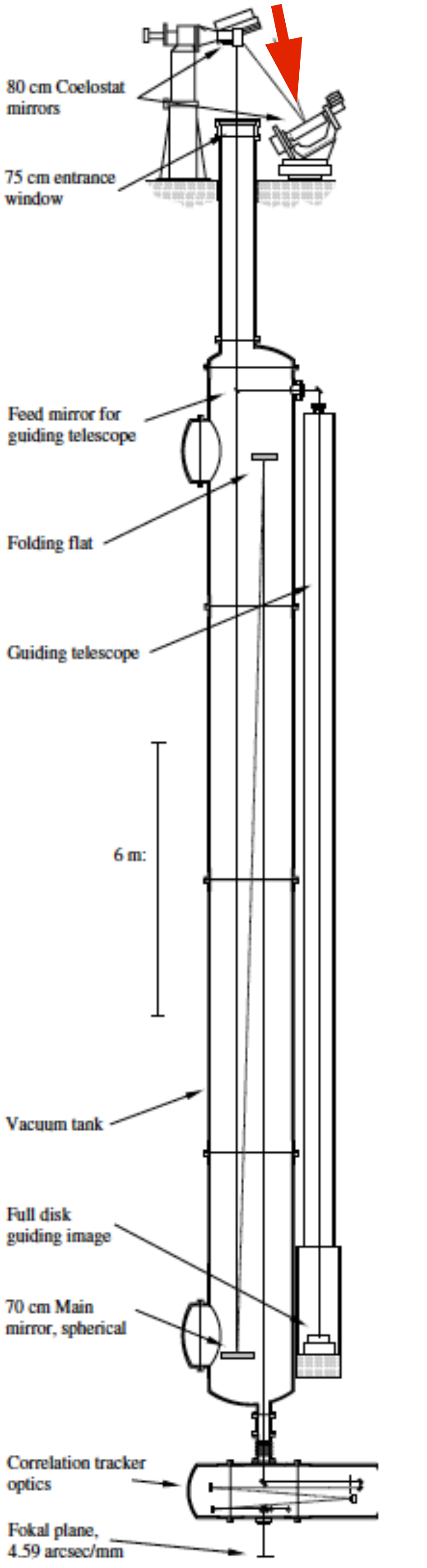
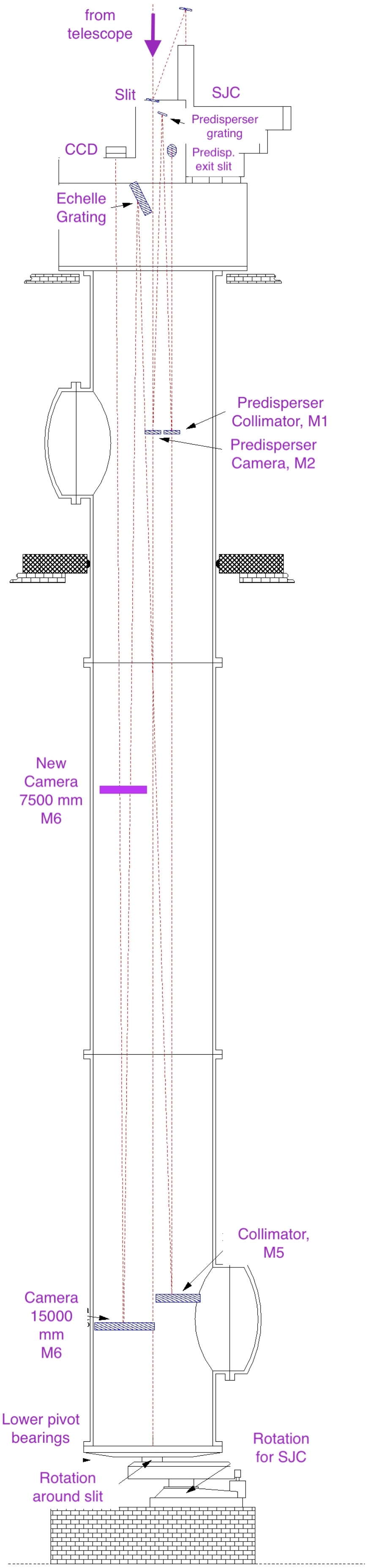


Fig. 3: Optical scheme of the VTT. The sunlight hits the first mirror of the coelostat (red arrow), is then deflected downward to the70 cm main mirror, which forms an image on the optical bench of the correlation tracker. A relay optics produces a pupil image on the 50mm deformable mirror and a secondary image on the spectrograph entrance slit. (From W. Schmidt, Encycl. Astron.& Astrophys., 2001, drawing by T. Kentischer)

[1] The entrance window broke after 30 years. It will be replaced in 2019.



the optical bench of the adaptive optics (called correlation tracker optics in Fig. 3). Thanks to the coelostat, the solar image does not rotate during the day. The reimaging system of the adaptive optics forms a secondary image with the same plate scale as the primary image at the spectrograph entrance slit. The adaptive optics bench contains the the tip-tilt and the deformable mirrors, and a Shack-Hartmann wavefront sensor to measure the wavefront distortion. The 2 telescope mirrors are located in a vacuum tank to avoid local turbulence above the main mirror. An exit window at the bottom of the main vacuum tank seals that part from the adaptive optics bench, which itself is in a vacuum tank. The latter is mostly used at ambient pressure, to facilitate manual alignment of the adaptive optics. At the prime focus, a filter wheel holds several field stops with 20, 40, and 60 mm diameter (corresponding to a field of view of 90, 180, and 270”), a dark field, a pinhole and an AF target. Downstream of the prime focus, 2 fold mirrors on a motorized stage are used to focus the tertiary image to the spectropraph slit or in one of the optical labs. The 60 mm field stop in the filter wheel transmits a circular field of view with a diameter of 270”.

Guiding system

A small 45° mirror (5 cm diameter, see Fig. 3)), placed in the center of the beam near the top of the vacuum tank feeds the guiding system of the VTT. A lens forms an image of the full solar disk with a diameter of 20 cm, which is imaged to a quad cell arrangement. Each quad cell is a circular segment, covering nearly 90° of the solar circumference. The difference signal of facing cells is used for guiding and positioning. The quad cells are connected in closed loop with the coelostat M2, which is tilted in 2 orthogonal axes, until the solar image is

Fig. 4: Scheme of the Echelle spectrograph. From the entrance slit, seen at top left, the light passes through the predisperser to the predisperser exit slit. From there, the beam hits the collimator (M5), which forms an image of the entrance pupil on the Echelle grating. The camera mirror, M6, images the spectrum to the final focal plane (top left, labelled „CCD“. All optical components are mounted in a steel tank, to reduce local turbulence along the optical path. (Slightly modified version of a drawing originally prepared by T. Kentischer)

centered again on the quad cells. The quad cells are mounted on a motorized x-y stage. Motion of this stage allows — through the servo-coupling to M2 — a very precise positioning of the solar image in the focal plane.

Echelle spectrograph

The Echelle spectrograph of the VTT has 2 parts: a predisperser with a focal length of 4 m, with low dispersion for order selection, and a main disperser with a spectral resolution of 750.000 (8mÅ at 600 nm) and a focal length of 7.4 m. (The original focal length was 15 m, but that value was impractical for modern digital detectors with their small pixels.) Figure 4 shows a vertical cut through the spectrograph. The predisperser produces a spectrum with a range of about 2000 Å, the center of which is freely chosen within the visible or near-IR wavelength region. An exit slit mask allows to choose several narrow spectral regions, which are then imaged with high dispersion side by side in the focal plane of the main disperser. The linear dispersion in the focal plane of the main disperser is about 0.2 Å/mm. Since the spectral regions in the final focal plane must not overlap, the number of simultaneously observable spectral lines is typically limited to 4 or 5. The spectrograph tank as a whole rotates around a vertical axis centered on the entrance slit. This allows to position the spectrograph slit at any desired position relative to the solar image.

The tower

The vertical cut through the VTT shows its double-tower configuration. The telescope and the spectrograph are installed in an inner tower (red in Fig. 5), while all laboratories and other rooms are located in an outer tower. The latter was supposed to act as a wind shield, to reduce image motion caused by pendulum motion of the tower. In addition, the double tower should isolate the „busy“ rooms (laboratories, mechanical workshop, living quarters) from the telescope. To inhibit the excitation of oscillations from the outer to the inner tower, the eigenfrequency of the inner tower was chosen lower than that of the outer tower (by about a factor of 2). Unfortunately, a low eigenfrequency is accompanied by reduced

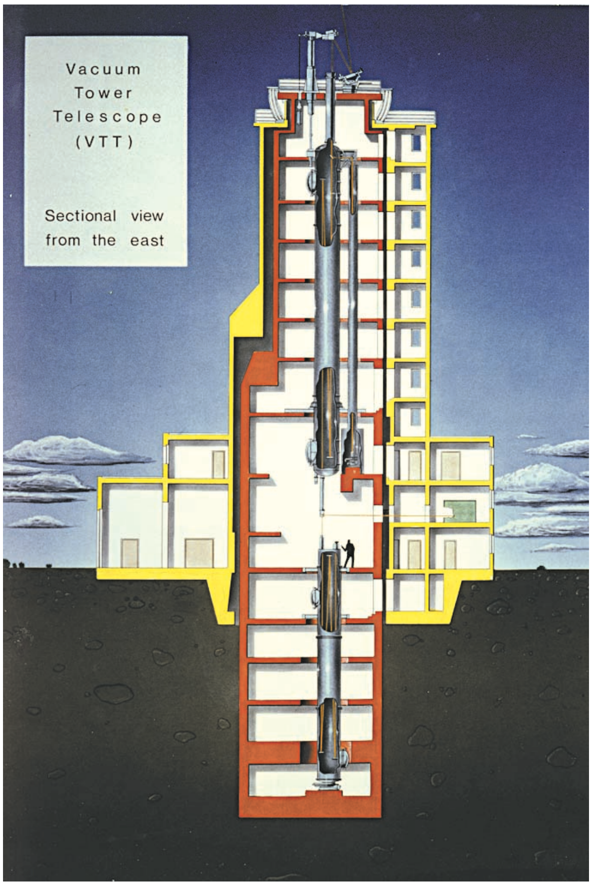


Fig. 5: Vertical cut (seen from East) through the VTT. The Echelle spectrograph is located in the underground floors. The telescope extends over 10 floors. The clamshell dome is open. Red and yellow denote the inner and outer tower. The drawing from 1985 does not include the adaptive optics (cf. Fig. 1)

stiffness. It turned out that the above a certain wind speed, the wind force on the coelostat, which is in the free air, is sufficient to excite oscillations of the inner tower. Therefore, the inner tower was connected with the outer one near the coelostat platform, to benefit from the greater stiffness of the outer tower. The also desired vibration isolation of the lower floors from the telescope area is still functioning. It is worth noting that a perfect separation of inner and outer tower is not possible, since both rest on the same underground which transmits some vibrations from the outer to the inner tower.

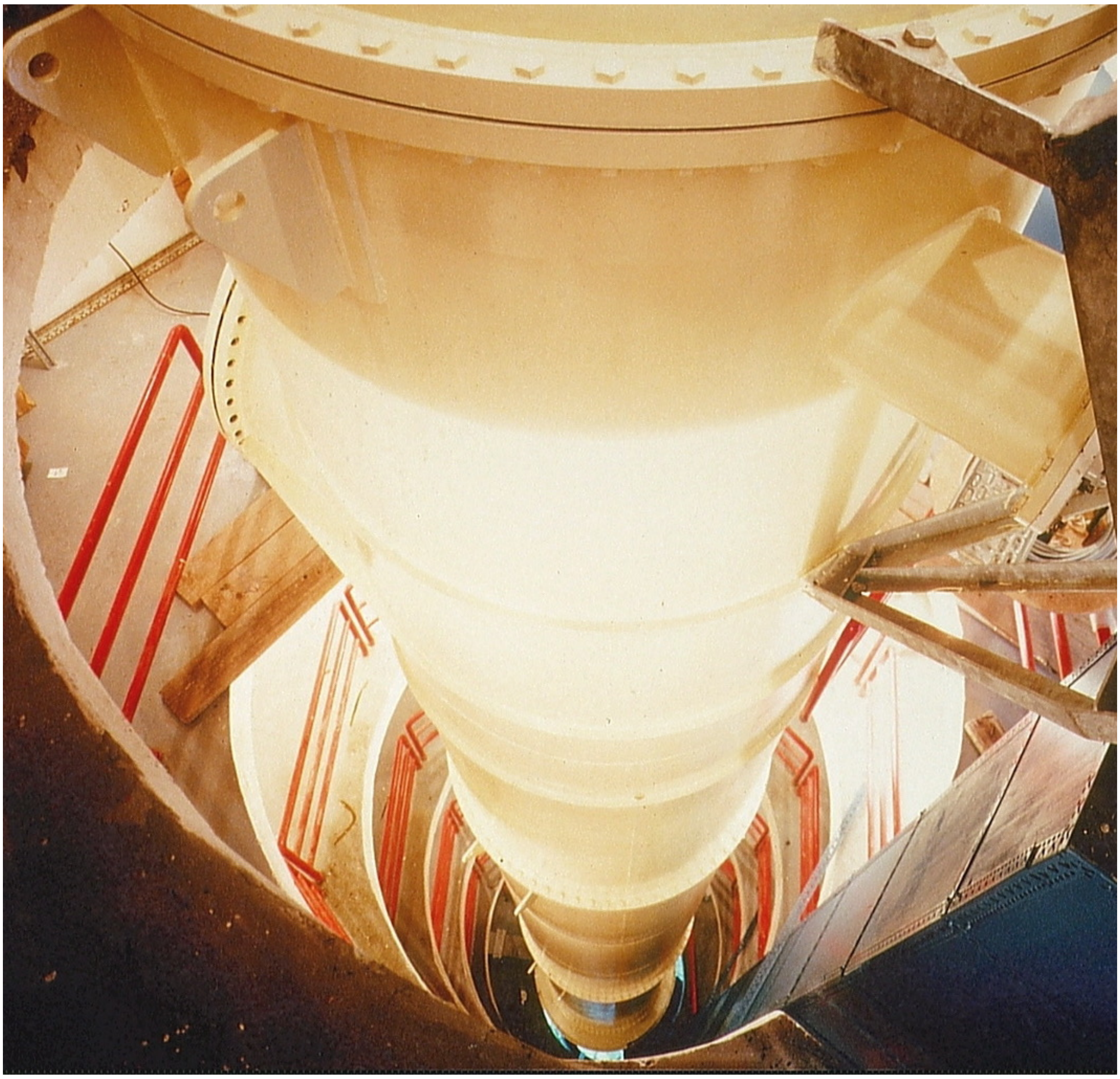


Fig. 6: Vacuum tower of the VTT, seen from the top. Near the top, the exit flange for the guiding beam is visible.

In case of the VTT, a tower is required to accommodate the tall telescope. In fact, the building was designed around the telescope optical design. The total vertical extent of the building is about 55 m, 38 m above ground (with closed dome), and 17 m below ground.
The height of 33 m above ground of the coelostat platform is also important to get away from ground-layer turbulence, caused by solar irradiation. Therefore, modern compact telescopes, like GREGOR, the GST or the DKIST are installed at heights of at least 20 meters above ground.