Astron. Nachr. / AN **x**, No. x, 1 – 10 (2012) / **DOI** ***please set DOI!***

# Open-foldable domes with high-tension textile membranes – The GREGOR dome

**R.H. Hammerschlag**[1,⋆], **J.N. Kommers**[2], **S. Visser**[3], **F.C.M. Bettonvil**[4,5], **A.G.M. van Schie**[6], **S.J. van Leverink**[7], **G. Sliepen**[8], **A.P.L. Jägers**[1], **W. Schmidt**[9], and **R. Volkmer**[9]

[1] Department of Physics & Astronomy, Utrecht University, Postbus 80000, 3508TA Utrecht, the Netherlands
[2] Hankom Engineering, Ruivenstraat 6/D, 3036DE Rotterdam, the Netherlands
[3] Poly-Ned BV, Oostermeentherand 16, 8332JZ Steenwijk, the Netherlands
[4] NOVA Op-IR group at ASTRON, P.O.Box 2, 7990AA Dwingeloo, the Netherlands
[5] Leiden Observatory, P.O. Box 9513, 2300RA Leiden, the Netherlands
[6] DEMO, Delft University of Technology, P.O. Box 5031, 2600GA Delft, the Netherlands
[7] Royal Duyvis Wiener BV, Schipperslaan 15, 1541KD Koog aan de Zaan, the Netherlands
[8] Institute for Solar Physics, Royal Swedish Academy of Sciences, AlbaNova University Center, 10691 Stockholm, Sweden
[9] Kiepenheuer-Institut für Sonnenphysik, Schöneckstr. 6, 79104 Freiburg, Germany

Received 25 Sep 2012, accepted xx Nov 2012

**Key words** methods: observational – Sun: general – techniques: high angular resolution – telescopes

Double layers of high-tensioned textile membranes were applied to the completely open-foldable dome for the GREGOR telescope for the first time. Simultaneous climate measurements inside and outside the dome have proven the thermal-insulating capability of this double-layer construction. The GREGOR dome is the result of the continuation of the ESO research on open-foldable domes with textile structures, followed by the research for the DOT dome with high-tensioned textile membranes. It cleared the way to extreme stability required for astronomical practice on high mountain sites with heavy storms and ice formation. The storm Delta with 245 km/h 1-minute mean maximum at the location of the GREGOR caused no problems, nor did other storms afterwards. Opening and closing experiences up to wind speeds of 90 km/h were without problems. New technical developments were implemented and tested at the GREGOR dome, opening the way for application to much larger domes up to the 30 m diameter-class range.

## 1 Introduction

Seeing conditions are best around an optical astronomical telescope when it is completely open. This means that the large-diameter optical beams are so-to-say part of the surrounding air mass with a minimum of disturbance of the primary beam by the structure elements of the telescope.

The spatial-resolution capabilities of ground-based telescopes improved drastically by modern image-reconstruction and wave-front-correction techniques like Speckle Reconstruction, Phase Diversity, Multi-Object Multi-Frame Blind Deconvolution, Adaptive Optics and Multiple Conjugate Adaptive Optics. However all these reconstruction techniques are limited in the gain of image improvement. Therefore, the quality of the raw images determines the feasible final image resolution.

The raw-image quality is limited by fast refractive-index fluctuations in the light path through the earth's atmosphere, deforming the optical wave fronts. These refractive-index fluctuations are caused by density fluctuations in the air, which in turn can be produced by fluctuations in temperature and pressure. Wave-front-correction and image-reconstruction techniques are more effective for wave-front deformations on a larger scale of cell diameter in the beam. Consequently, it is important that air temperature and pressure are homogeneous on small scales. Calculations show that the temperature fluctuations by far dominate the cause of wave-front deformations. Temperature fluctuations larger than $0.1^\circ$ C over scales of 5 cm and less are harmful, as discussed in section 2 of Hammerschlag et al. (2010). The foregoing concerns the visible wavelength range. The short-wavelength part, i.e. the blue part, is even more sensitive.

It will be extremely difficult to keep all surfaces inside a dome within $0.1^\circ$ C deviations during daytime and the first part of the night, as is known from experience. For this reason solar observers went to vacuum telescopes. However, the maximum practical beam diameter for vacuum is 1 m. For larger beam diameters, the temperature of the air in the primary beam has to be kept sufficiently homogeneous.

Decisive factors for the magnitude of the air-temperature fluctuations within the primary optical beam are the magnitudes of the temperature differences in the incoming air to the object surfaces and the length of time the

---

⋆ Corresponding author: e-mail: R.H.Hammerschlag@astro-uu.nl

**Fig. 1** Vacuum Tower Telescope (VTT) enclosure of open-foldable solid segments. *Left:* closed with 3 segments visible at each side. *Right:* open with all segments under the telescope platform.

air is nearby these surfaces. The disturbing optical wave-front deformations are proportional to the integration of the temperature deviations over the thickness of the deviating layer. It follows that to minimize the wave-front deformations the objects in the airstream to the optical beam should be as small as possible. Especially, these objects should not cause stagnant air, because then the length of time the air remains nearby objects with deviating temperature increases drastically. The tubes and/or profile beams of an open framework construction of a telescope fulfill the requirement of very short contact with air of the passing wind and of no stagnant air. Practice has shown that a wind breeze of 1.5 m/s is enough for objects of up to several meters, when there are no places where the air is caught and stagnant air patches are formed. The way to reach this situation for a high-resolution optical telescope is an open telescope structure and a completely open-foldable enclosure for bad weather protection.

## 2 Developments towards completely open-foldable domes

Domes using solid segments, which can be moved downward, are already known for a longer time. Examples of this type of domes are the Vacuum Tower Telescope (VTT) for solar observations on Tenerife and the US Air Force Telescopes at Kirtland Air Force Base, New Mexico (3.5 m) and at Maui Space Surveillance Complex, Haleakala on the Hawaii Island Maui (3.67 m Advanced Electro-Optical System AEOS) for nighttime observations. The design of the solid segments in these two examples is completely different. The VTT dome is half a cylinder with a horizontal axis at the bottom side. This half cylinder is split into six segments, which rotate downward around the horizontal axis; see Fig. 1. The AEOS dome is a cylinder with a vertical axis. On top is a construction of large-scale slides. After opening the latter, the cylinder can be moved downward with the opened slides. Both constructions are heavy and require a large special designed construction underneath the telescope platform. In the case of a tower, like for a solar telescope, it is necessary that the tower is adequately designed to carry this heavy construction. In the case of a location on the ground, an expensive large cellar construction is required.

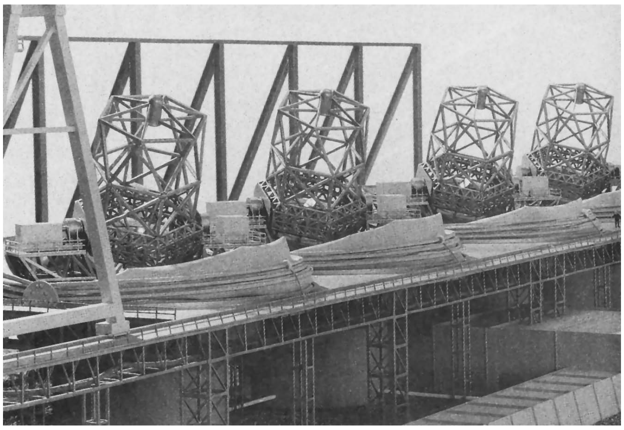

**Fig. 2** The open concept of the four VLT telescopes with open-folded domes of the ESO.

In the eighties, the European Southern Observatory (ESO) recognized the value of open-telescope design to obtain the best possible seeing and planned operation of the four connected telescopes of the Very Large Telescope (VLT) in the open air; see Fig. 2. A project was started to develop a retractable dome based on strong tent cloth, which folds completely together to a ring of small cross-section when opened. It leaves the telescope entirely free in

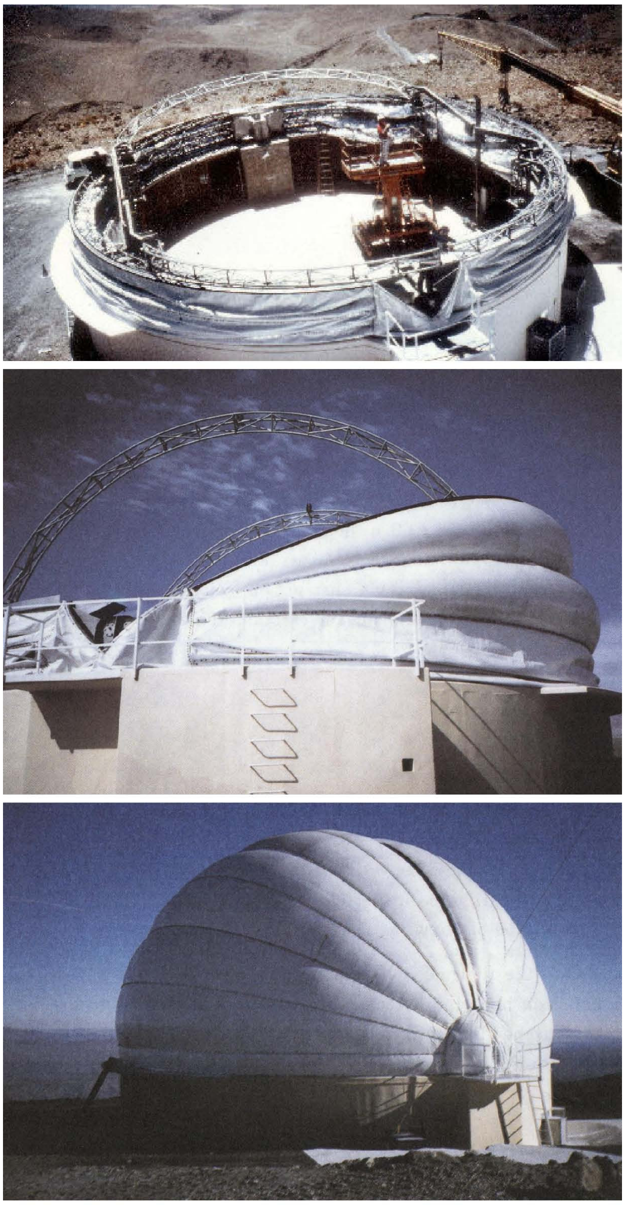

**Fig. 3** The test dome of the ESO. *Top:* test dome in Chile completely open. *Center:* test dome partly closed. *Bottom:* test dome closed.

the open air. In addition, the heat capacity of such an enclosure is very low and adapts fast to changing air temperature. No heavy tower constructions or large expensive cellar installations are required. An inflatable tent construction was chosen for a test dome; see Fig. 3 (Bonneau & Zago 1986, 1988). When closed, the strength of the dome against wind and rain, snow or hail is based on double-clothed ribs, forming a kind of tubes blown up by pressurized air. On the one hand, the dome gets its strength by the blowing up, on the other hand, it can only be opened and closed when ribs are depressurized. Domes of this type are used for tennis courts and other sports facilities. These can only be opened and closed during days of good weather with only low wind velocities. Many of these domes are opened in spring and closed in autumn, hence operate in a yearly cycle, or are installed temporarily for special events. The ESO test dome, erected in Chile, had two additional framework steel bows along which the tubes moved during opening and closing; see Fig. 3. Nevertheless, the experiences showed that opening and closing could only be practiced safely for wind speeds up to 5 m/s. This allowed low value made the construction unsuitable for astronomical observing praxis, where a clear sky and good seeing with sharp images can occur during wind speeds up to 20 m/s. When this weather type changes into bad weather with clouds and rain, the tent construction still has to be closed safely. The ESO abandoned the open principle and classical domes were built around the VLT telescopes.

In the nineties, the Dutch Open Telescope (DOT), a development towards a high-resolution solar telescope without vacuum, was built with financial support of the Technology Foundation STW in the Netherlands. A telescope design as much open as possible was selected, including the design for an open tower. Erection of the DOT was planned on La Palma at the Observatorio del Roque de los Muchachos (ORM) of the Instituto de Astrofísica de Canarias (IAC). Originally, the DOT was thought to operate without any protection over the whole telescope, only lids on the optical components were planned. Warnings about possible severe weather conditions at the observatory, namely heavy storms and specifically gigantic ice growth in a short time, led to the development of a protective construction, which when opened would not harm the open-telescope operation. In continuation of the work on inflatable domes at ESO, the application of tensioned strong textile was kept. However, the tension source was switched from inflation by pressurized air to strong and movable steel bows. In the latter case, the textile parts – membranes – between the bows have to be cut in saddle shape. The textile is curved in one direction in the half-sphere shape of the dome, whereas in the perpendicular direction it is curved in the opposite direction, i.e. to the inside of the dome. Static roofs based on this tensioning principle are known and belong to the manufacturing program of Poly Nederland, the Dutch company that made the cloth parts, first for the ESO dome and later for the DOT dome. The DOT team, in cooperation with the workshop DEMO of the Delft University of Technology, developed the completely new design of movable and sufficiently strong steel bows, which still are very lightweighed compared to the domes made of solid segments. Moreover, the new design leaves only a remarkably compact ring when opened, as shown in Fig. 4. Additional advantage over the inflatable domes is the independence of power when closed, whereas the inflatable domes continually need the standby of a blower to replenish air to keep its strength and hence storm stability. Just during extreme weather conditions the risk for failure of running machines increases. The DOT enclosure is the first tent-cloth construction suitable for closing during strong wind and withstanding heavy storm, snowfall and ice forming; see also Fig. 5. The DOT

**Fig. 4** Dutch Open Telescope (DOT) with open-folded dome of textile membranes between steel bows moved down, leaving the telescope completely free in natural flushing of the wind.

**Fig. 5** DOT enclosure in closed position with strongly tensioned cloth segments. Practically no snow or ice sticks on the membranes due to its smooth coating.

became the pioneering demonstrator of the open-telescope technology for high-resolution solar observations (Rutten et al. 2004).

## 3 Design of the GREGOR dome

As a result of the conclusive proof of storm- and ice resistance of the DOT dome, an open-foldable dome was selected for the German new open GREGOR telescope with a 1.5 m diameter primary mirror as a replacement for the 0.45 m vacuum Gregory Coudé telescope on top of the existing 20 m high building at the Observatorio del Teide (OT) on Tenerife, also operated by the IAC. A dome consisting of solid segments like the VTT dome had been considered, but this would have required a far-reaching structural alteration of the building. A dome based on the principal of the DOT dome was developed and built for the GREGOR, again by cooperation of the DOT team, the workshop DEMO of the Delft University of Technology and Poly Nederland. A similarity between the VTT- and DOT dome is noteworthy: both consist of two halves of which each consists of three segments rotatable around a horizontal axis. The upper segments are driven and lift the other segments upward when closing. The big difference is that the segments of the DOT dome fold completely together when opening. The size of the GREGOR dome was determined by the maximum available space on the roof of the building after removal of the old dome of the Gregory Coudé telescope. The dome diameter became 9 m, larger than the 7 m DOT dome. The 9 m dimension leaves narrow pathways between the roof fence and the dome. The height of the dome is 5 m. A three-dimensional drawing of the structure of the bows is shown in Fig. 6, both in closed and open situation. Fig. 7 presents projection drawings of the dome with an indication of the camber of the membranes.

In the closed situation the membranes have to be brought to a high tension by a clamp mechanism. A single clamp of 25 kN on top of the dome effectuates this for the DOT dome of 7 m diameter. Domes of a larger diame-

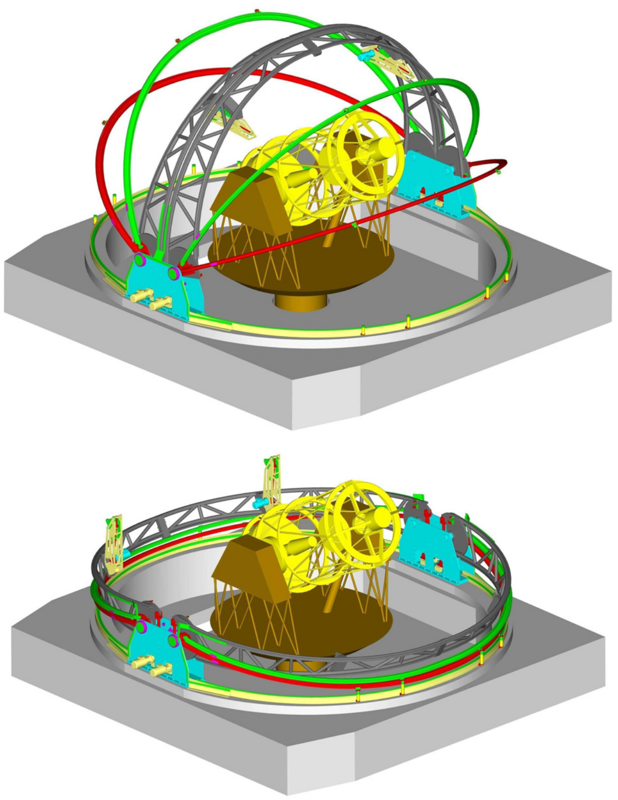

**Fig. 6** Three-dimensional drawing of the structure of the bows for the GREGOR dome. *Top:* closed. *Bottom:* open. The shown telescope structure (at the time of the dome design) deviates somewhat from the final design.

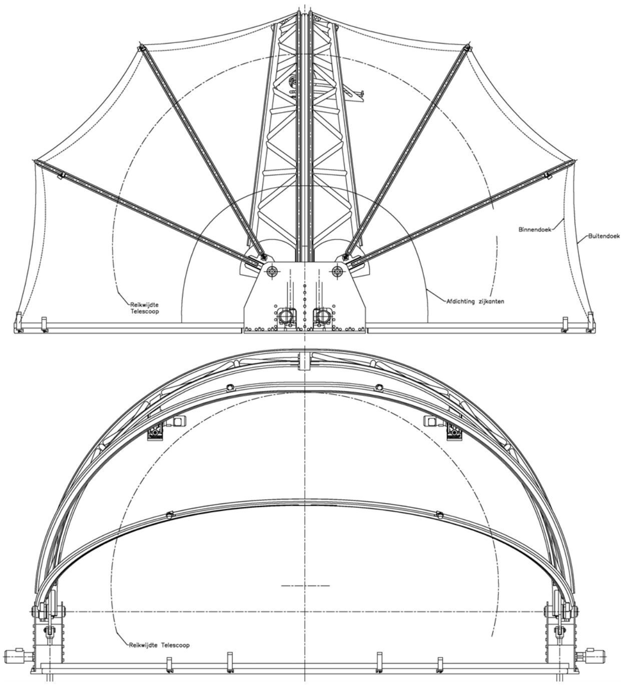

**Fig. 7** Projection drawings of the GREGOR dome. *Top:* Front view. The outer membranes are indicated in full lines, the inner ones in dashed lines. *Bottom:* Side view. The two clamps at the sides are clearly visible. The diameter of the dome is 9 m and its height is 5 m.

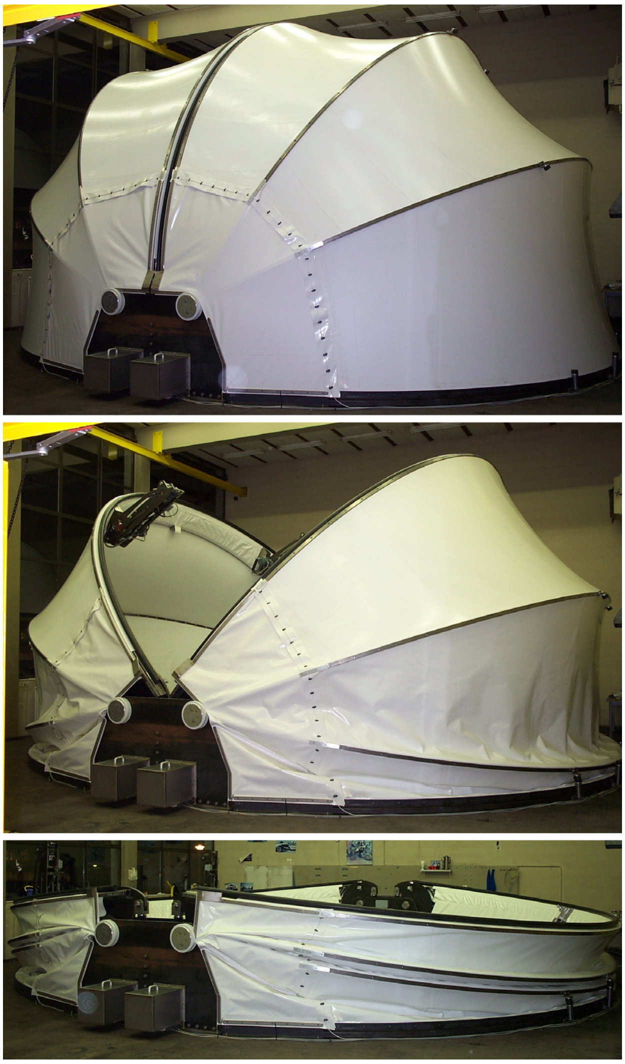

**Fig. 8** The GREGOR dome in the assembling hall of the workshop DEMO at Delft. *Top:* closed. *Center:* half open. One of the clamps is well visible, the second one is for a large part hidden behind the dome segments in front. The clamps divide the main bow in about three equal parts of 60°. *Bottom:* open.

ter with a single clamp would require a much larger clamp and main bows that are able to bring the high tension to the membrane over the whole length of the bows. The latter requirement would lead to a heavy-bow design. It is more attractive to apply several clamps over which the tension force can be spread. However, clamps that are not placed at the top of the dome are more complicate to be attached to the bows due to the more complex geometrical situation. The plane of motion of a connection point on the bow is not perpendicular to the bow direction. The 9 m-diameter GREGOR dome is equipped with two clamps to the sides, such that the whole bow of 180° is divided in about three equal parts; see the drawings in Fig. 6 and 7. The geometrical problems of attaching the clamps to the bows have been solved very satisfactorily. Pictures of the test assembly in the workshop at Delft are shown in Fig. 8 and 9. The two clamps are visible from outside the dome in its half-open

**Fig. 9** The closed GREGOR dome seen from the inside during the tests in the workshop DEMO at Delft. The picture shows at the bottom one of the two drive units for the main center bows and on top one of the two clamps, which bring the textile membranes to high tension when the clamps move the two center bows together into their final position in a completely closed dome. The main center bows are covered at the inside by an additional cloth for thermal insulation.

position in the picture at the center of Fig. 8. In Fig. 9 one of the two clamps is visible in the closed position of the dome. The successful realization of the clamps on the sides of the GREGOR dome opens the way to large-sized open-foldable domes with several clamps, as planned for the European Solar Telescope (EST) (Hammerschlag et al. 2010, 2012).

The GREGOR dome mounted on top of the 20 m-high tower building at OT is shown in Fig. 10. The dome is the top part of a building protecting telescope and complex instrumentation underneath. Consequently, it was obvious that for the GREGOR dome thermal insulation and good sealing to the roof floor of the building were new requirements compared to the DOT dome on an open tower and with an excellent wetness protection of its telescope optics by double lids when not in operation. Two layers of textile membrane are applied, as can be seen in Fig. 7. The outside layer is fixed to the outside of the bows, while the inside layer is fixed to the inside of the bows. This results in a

**Fig. 10** Total view of the closed GREGOR dome on top of the tower located at the Observatorio del Teide (OT) on Tenerife.

**Fig. 11** Comfortable atmosphere inside the GREGOR dome. Topping-out and housewarming party at the same time: with the installation of the open-foldable dome the highest point was reached and the dome was ready for use. At the back row, the person standing most to the right is Piet Hoogendoorn of the Utrecht workshop and at the front row third from left is Jos van Meurs of the Delft workshop. Both were essential for the project during the construction at the workshop and the erection on site.

**Fig. 12** Start of the opening of the GREGOR dome on top of the building. View to one of the two head ends with drives. Additional membrane parts are put around these regions where the main membranes end. A closed connection is realized between main membranes and the head ends. The upper main membrane parts are still tensioned because of the weight of the in-between bows. This fact contributes to a safe opening and closing during strong wind because it prevents flapping of the upper membranes, which are more exposed to the wind.

relatively simple construction with a 5 to 10 cm air layer between the two membranes. For the inside layer a thinner textile has been applied, which does not negatively influence the high tension on the outside layer against storm stability. The double layer serves a comfortable inside atmosphere; see Fig. 11.

Besides the double membranes, other provisions are made for a better thermal insulation. Additional membrane parts are put around the regions of the rotation shafts with main actuators of the bows at the place where the main membranes end. In this way, a closed connection is realized between main membranes and the housing of shafts and actuators: see Fig. 8 and specifically Fig. 12. At the inside, the main bows are covered with additional membranes for thermal insulation around these steel parts; see Fig. 9. The other bows are covered with the inside cloth. The screws to the bows are thermally insulated; see Fig. 13. Climate measurements inside and outside the DOT and GREGOR domes showed the much better insulation of the GREGOR dome (Sliepen et al. 2010). Fig. 14 demonstrates the perfect insulation of the GREGOR dome.

## 4 Wind load experiences and measurements

Storm Delta – originally a Caribbean hurricane – passed over the Canary Islands in the night of 28 to 29 November 2005. Both GREGOR- and DOT domes had no damage at all, whereas some other telescope installations had. A weather station of the meteorological state institute (Agencia Estatal de Meteorología) is situated nearby the GREGOR at OT and measured a 1-minute mean maximum of 245 km/h (Martín Léon et al. 2006); see Fig. 15. The GREGOR was during the maximum of the storm at the wind-upward site WNW of the weather station. Consequently, the GREGOR was exposed to at least the wind speeds measured at this station. In addition, the peak wind velocities must have been higher than the 1-minute mean. As a comparison, dome-design point of departure for gusts was 70 m/s (i.e. 252 km/h) and engineering safety factors of about 1.5 were applied. In the Saffir-Simpson Hurricane Scale, 249 km/h is the boundary between categories 4 and 5, the latter being the highest category, which is qualified to cause complete

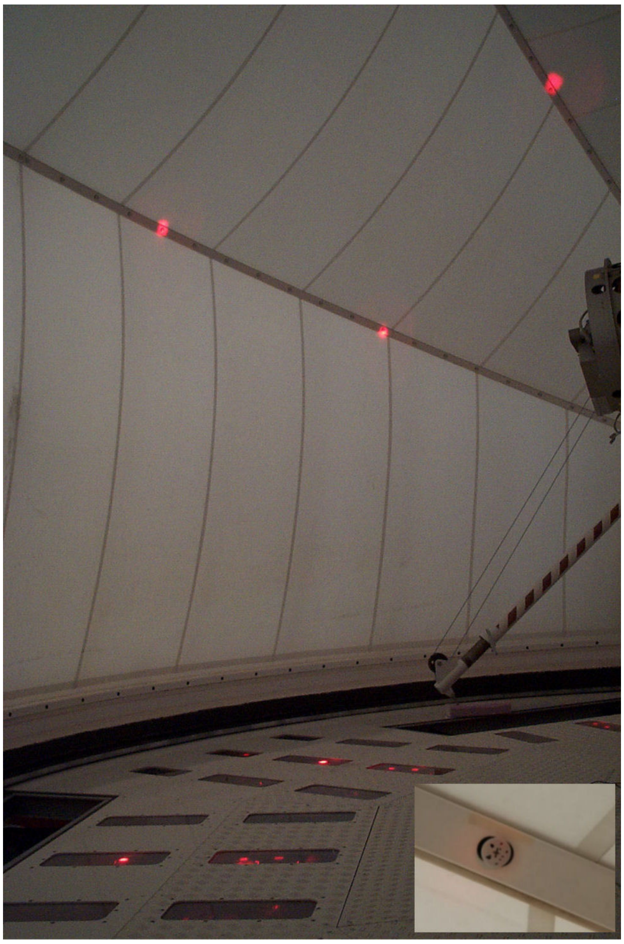

**Fig. 13** Inside the GREGOR dome during twilight. This picture shows clearly that each membrane part consists of many strips welded together to form the saddle shape, which is not possible from a single piece of membrane. Visible here, are the inside membranes which are fixed to the bows by metal tube strips lying over the cloth. The screws to the bows are thermally insulated from the fixing strips by plastic rings. The screw heads are covered by white plastic screw caps. Some of the screw caps are used as measuring points for the dome deformation measurements by optical units located underneath floorboards with path-through windows for the optical beams. Some black dots are placed with a fine fibre-tip pen at random on these screw caps; see inset at bottom right. Illumination by red diode beams serves the possibility to make measurements, also during the night. Three of such measuring points are visible in this picture.

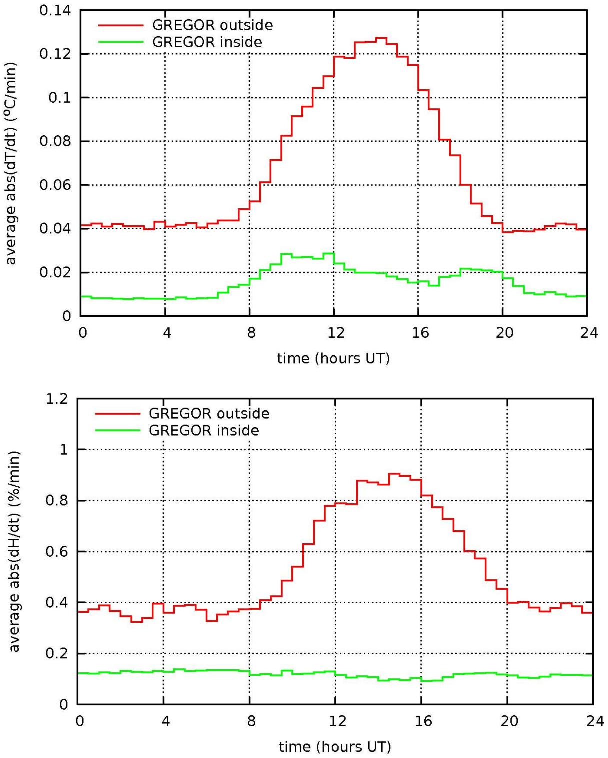

**Fig. 14** Temperature (*top*) and humidity (*bottom*) variations outside (upper curves) and inside (lower curves) the GREGOR dome versus the time of the day. Plotted are mean values over a whole year from August 2008 up to July 2009, obtained during all periods that the dome was closed. During daytime the temperature fluctuations outside are up to three times as large as during nighttime, humidity fluctuations are two and a half time as large. This is one of the reasons that during daytime a conventional dome disturbs high-resolution observations. The GREGOR dome with its two layers of membranes reduces temperature and humidity fluctuations effectively when closed.

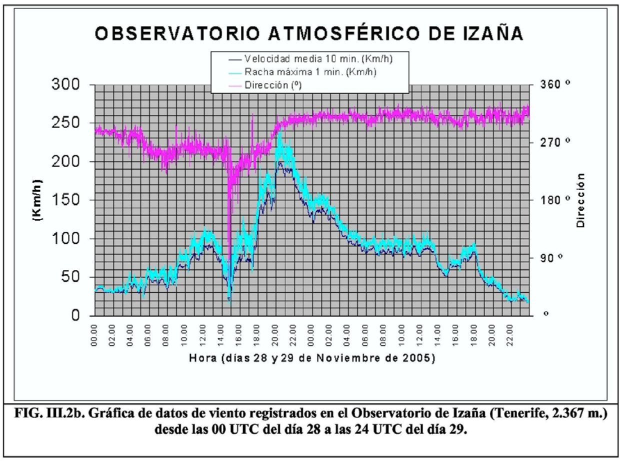

**FIG. III.2b. Gráfica de datos de viento registrados en el Observatorio de Izaña (Tenerife, 2.367 m.) desde las 00 UTC del día 28 a las 24 UTC del día 29.**

**Fig. 15** Wind velocity (blue) and -direction (magenta) at the observatory on Tenerife during storm Delta. The highest 1-minute gust peaks are 245 km/h at 20:30 and 230 km/h at 21:30.

**Fig. 16** Sensors on and around the GREGOR dome. The pressure sensors on the bows were just mounted. The wind cups and vanes were already mounted on the fence around the platform for some time. There are nine sets of which three are visible in the picture.

damage to buildings. Additional information about the DOT dome at the La Palma observatory during the Delta storm can be found in Hammerschlag et al. (2012).

Opening and closing experiences in strong wind exist up to velocities of 90 km/h and never caused problems for both enclosures. To drive the main top bows a very compact system near the hinges with electrically driven actuators has been designed. The other bows between the different membrane parts are not driven; only hinges are placed at the bow ends. Still, the upper membrane segments are sufficiently tensioned during opening and closing due to the weight of these in-between bows; see Fig. 12. The membranes always fold to the inside, even during strong wind because of the saddle shape. Moreover, during the folding phase the membranes do not give flapping problems in the wind due to this saddle shape and the relatively heavy textile quality.

Highest loads on the construction and actuators occur halfway during opening and closing, where a dome-half can catch maximum wind load on the inside surface, while in addition, considerable weight loads are present. Calculations were based on 30 m/s (i.e. 108 km/h) wind gusts.

In view of the design of much larger domes, particularly for the EST, measuring set-ups were installed in the years 2007 to 2009. Sets of wind-velocity and wind-direction sensors were placed around the DOT- and GREGOR domes. On the dome bows air-pressure gauges were put; see Fig. 16. These instruments measure the wind load on the dome and the wind load allows us to calculate the deformations and stresses of the bows. It is of high importance to compare the results of these calculations with measurements, particularly regarding the dynamic behaviour.

The displacements under wind load of many points of the bows and membranes were measured from under the dome floor with newly developed optical units, so-called 3DD3 instruments, shown in Fig. 13. The measuring pre-

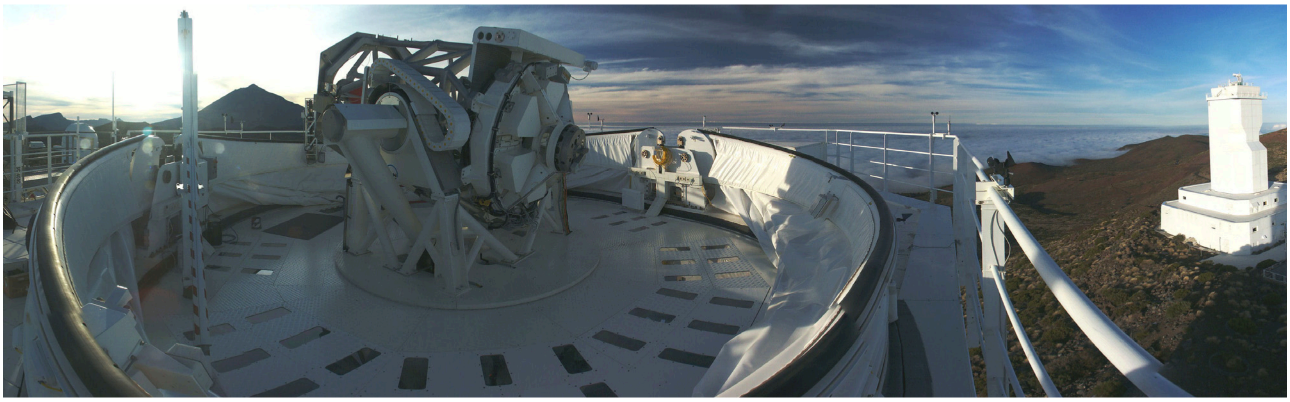

**Fig. 18** Panorama view in open position of the GREGOR dome. The membranes fold up compactly and leave ample space around the telescope. This wide-field picture shows an overview of the pattern of windows in the floor for the optical beams used for dome-deformation measurements, It is an evening view with the telescope pointing to the sun near the western horizon with the Teide at the background.

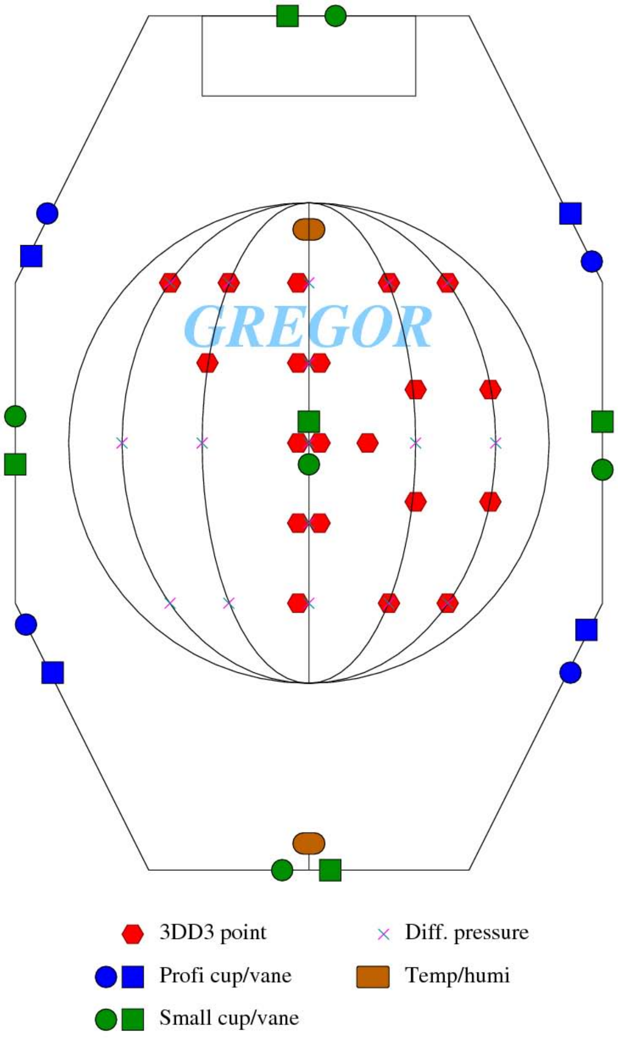

**Fig. 17** Map of the location of all sensors in and around the GREGOR dome.

cision is high: 5 $\mu$m in both directions transversal to the optical beam from the 3DD3 unit to the measuring point and 50 $\mu$m along the optical beam. The dynamic response is high too: 30 measurements per second. However, in most cases only 15 measurements per second were stored. Fig. 17 presents a floor map of the location of all sensors at the GREGOR: dome-displacement points, wind cups and vanes, differential air-pressure gauges and also temperature plus humidity sensors. A description of the measuring devices and the measurement results can be found in Jägers et al. (2008), Sliepen et al. (2008, 2010) and Hammerschlag et al. (2012). Fig. 18 shows a panorama view of the GREGOR platform with the dome in open position. One can clearly see the pattern of windows in the floor for the optical measuring beams. The extensive measurements led to the following most important results: *(i)* the dynamic correlation between wind load and deformation is very clear, while resonance vibrations are completely absent; *(ii)* the measurements prove that the membrane textile introduces sufficient damping to prevent vibrations of the long and slender steel bows.

## 5 Conclusions

The 9 m diameter GREGOR dome has proven to be a very successful completely open-foldable dome construction based on highly tensioned textile membranes. An obvious advantage is the low mass and, consequently, the low heat capacity, which serves fast temperature adaption when open. Closed, the double textile membranes supply good thermal insulation and humidity protection in extremely bad weather situations which occasionally occur at mountain-site observatories. The mechanical stability has proven to be excellent. Extensive measurements of wind load and dome deformations supplied the needed information for reliable designs of much larger domes.

The basic geometry, of which the GREGOR dome has demonstrated its practicability and reliability, can be scaled up to the much larger sizes.

*Acknowledgements.* The Technology Foundation STW in the Netherlands financially supported the dome developments. We thank the ESO for making available the technical information of their experimental open-foldable dome at the observatory in Chile. The DOT and GREGOR dome have been built by instrumentation groups of Utrecht University, the Central Workshop of Delft University (now DEMO-TU-Delft) and several firms with specialized tasks. The DOT is located at Observatorio del Roque de los Muchachos (ORM) on La Palma. The 1.5-meter GREGOR solar telescope was build by a German consortium under the leadership of the Kiepenheuer-Institut für Sonnenphysik in Freiburg with the Leibniz-Institut für Astrophysik Potsdam, the Institut für Astrophysik Göttingen, and the Max-Planck-Institut für Sonnensystemforschung in Katlenburg-Lindau as partners, and with contributions by the Instituto de Astrofísica de Canarias and the Astronomical Institute of the Academy of Sciences of the Czech Republic. It is located at the Observatorio del Teide (OT) on Tenerife. Both observatories are operated by the Instituto de Astrofísica de Canarias (IAC) in Spain.

## References

Bonneau, A., Zago, L.: 1986, in: L. Barr (ed.), *Advanced Technology Optical Telescopes III*, Proc. SPIE 628, p.342

Bonneau, A., Zago, L.: 1988, in: M.-H. Ulrich (ed.), *ESO Conference on Very Large Telescopes and their Instrumentation*, Vol. 2, p.867

Hammerschlag, R.H., Kommers, J.N.M., van Leverink, S.J., Bettonvil, F.C.M., Visser, S., Jägers, A.P.L., Sliepen, G.: 2010, in: L.M. Stepp, R. Gilmozzi, H.J. Hall (eds.), *Ground-based and Airborne Telescopes III*, Proc. SPIE 7733, p.77330J-1

Hammerschlag, R.H., Kommers, J.N.M., Visser, S., Bettonvil, F.C.M., van Schie, A.G.M., van Leverink, S.J., Sliepen, G., Jägers, A.P.L. : 2012, in: R. Navarro, C.R. Cunningham, E. Prieto (eds.), *Modern Technologies in Space- and Ground-based Telescopes and Instrumentation II*, Proc. SPIE 8450, paper 8450-7, in press

Jägers, A.P.L., Sliepen, G., Bettonvil, F.C.M., Hammerschlag, R.H.: 2008, in: E. Atad-Ettedgui, D. Lemke (eds.), *Advanced Optical and Mechanical Technologies in Telescopes and Instrumentation*, Proc. SPIE 7018, p.70181R-1

Martín Léon, F., Alejo Herrera, C.J., de Bustos Seguela, J.J., Calvo Sánchez, F.J., San Ambrosio Beirán, I., Sánchez-Laulhé Ollero, J.M., Santos Muñoz, D.: 2006, ”Estudio de la tormenta tropical ’Delta’,” (Capítulo III, p. 6) at http://www.aemet.es/es/divulgacion/estudios/

Rutten, R.J., Hammerschlag, R.H., Bettonvil, F.C.M., Sütterlin, P., de Wijn, A.G.: 2004, A&A 413, 1183

Sliepen, G., Jägers, A.P.L., Bettonvil, F.C.M., Hammerschlag, R.H.: 2008, in: E. Atad-Ettedgui, D. Lemke (eds.), *Advanced Optical and Mechanical Technologies in Telescopes and Instrumentation*, Proc. SPIE 7018, p.70181C-1

Sliepen, G., Jägers, A.P.L., Hammerschlag, R.H., Bettonvil, F.C.M.: 2010, in: L.M. Stepp, R. Gilmozzi, H.J. Hall (eds.), *Ground-based and Airborne Telescopes III*, Proc. SPIE 7733, p.773332-1