N. Mein and S. Sahal-Bréchot (Eds.), Proceedings THEMIS Forum “Science with THEMIS” Observatoire de Paris at Meudon, 285-291, 1997.

The Dutch Open Telescope

R.J. Rutten, R.H. Hammerschlag, F.C.M. Bettonvil

Sterrekundig Instituut, Postbus 80 000, NL–3508 TA Utrecht, The Netherlands

Summary. The Utrecht Open Tower Telescope, recently renamed into “Dutch Open Telescope”, is now being installed at the Roque de los Muchachos Observatory on La Palma (Fig. 1). Like THEMIS, the DOT is a solar telescope of novel design, is located at a superior site, aims at high spatial resolution, is suited to polarimetry, has been long in the making, and should start its scientific career in 1997. Unlike THEMIS, the DOT has no dome, no vacuum enclosure, no post-focus equipment, and no long-term funding.

1 Introduction

In this contribution the *Dutch Open Telescope* (DOT) is discussed in the light of THEMIS by comparing the histories, the aims, the technical solutions, and the prospects of the two telescopes.

The DOT received its name only recently, in a La Palma ceremony (Fig. 1) that preceded the royalty-attended inauguration of the Italian Galileo telescope by one hour and the royalty-attended inauguration of THEMIS by one day. Its new name expresses the fact that the DOT is the first fully Dutch telescope on La Palma[1].

Like THEMIS, the DOT originated from JOSO activities over two decades ago. Kees Zwaan started the OTT/DOT initially as a relocatable site test telescope, in the context of JOSO’s philosophy that LEST would require site comparison and site verification using medium-aperture high-quality solar telescopes. LEST itself represented the third phase of JOSO’s action list. Phase I was the initial site selection, using proxy techniques such as measuring temperature fluctuations and judging granulation with small telescopes. Phase II consisted of the installation of national telescopes at the “best” site in Europe.

Two decades later, we still don’t know whether Izaña is a better site than the Roque de los Muchachos or the other way around, nor do we know the extent of local quality differences at each mountain ridge. Ongoing Seykora scintillometry (Seykora 1992, Beckers 1993, Coulter et al. 1996) with the all-sky irradiance sensors now installed at THEMIS, at the DOT, and at the LEST site (by J.M. Beckers in a test campaign for the NSO CLEAR project) should soon tell us more about these comparative performances. In any case, the daytime seeing is often good and sometimes superb at both sites.

THEMIS and the DOT now represent the latest of JOSO’s Phase II “national facilities” taking advantage of this good seeing, with THEMIS having become bi-national in the meantime and the DOT in dire need of similar partnership (see below). LEST remains below the horizon, with only its site solidly defined by a hole in the Roque de los Muchachos. The DOT stands close to the latter, similarly downslope from the Swedish Vacuum Solar Telescope (SVST) but to the Northwest rather than to the Northeast.

[1] The three Isaac Newton Group telescopes are only one-fifth Dutch. The DOT does not include the word ”solar” in its name because it will also be useful to nighttime astronomy, in particular for planetary imaging. The name “Hammerschlag Solar Telescope” was earlier contemplated but that would have resulted in a confusing abbreviation. Actually, the abbreviation DOT is also confusing when specifying computer addresses such as `dot3.dot.iac.es` aloud — five dots in total.

Figure 1: Left: the DOT christening ceremony. The Dutch ambassador to Spain, Baron W.O. Bentinck van Schoonheten, hit a button at which the DOT bad-weather canopy slowly opened and a thousand balloons escaped. If this reproduction were in color, they would be seen to represent the Dutch, Spanish and Swedish flags acknowledging that Spain (the IAC) provides the formal umbrella under which the DOT is installed at La Palma and that Sweden (the Royal Academy) provides hospitality at the Research Station for Astrophysics (SVST building). Right: the DOT on its site. The canopy is folded down. The support tower is 15 m high. The telescope points due North in this picture. The Residencia is seen in the far distance, the Carlsberg Transit Telescope building nearby.

The DOT is a much smaller project than THEMIS. Nevertheless, it took about as long because it has been largely a one-man (Hammerschlag) project through the years. Recently, its progress accelerated from a generous grant by the Dutch foundation for technological research (STW) supporting the completion of the telescope. STW also funds the current installation and performance tests.

2 Telescope characteristics

The DOT and THEMIS share similar goals at large design disparity. Both telescopes aim to observe the solar surface at the high spatial resolution that the Canary Island sites permit at good seeing. Both telescopes point directly to the sun, avoiding the large and variable polarization of heliostat mirrors that would complicate high-precision polarimetry. But that is where the similarity ends. The DOT sits not in a dome but out in the open, sits not on top of a building but on an open steel structure, and is open itself rather than evacuated or filled with helium. Its mount is not alt-azimuth but equatorial.

The open principle distinguishes the DOT from all other telescopes, including the current design for CLEAR which has an enveloping shroud. The basic concept is that the strong 5–10 m/s winds that bring good seeing on La Palma should blow right through the telescope. The open structure of the telescope and support tower aims to minimize obstruction to these winds, and relies on them to minimize locally-induced turbulence within the telescope itself. In essence, the telescope consists of a bare parabolic mirror, pointed at the sun with full exposure to the upslope wind. At present, the aperture is 45 cm, but the mechanical structure admits an 80 cm mirror without modification and even larger mirrors with only minor modification. Thus, if the open principle turns out to be a good one, the DOT may grow to THEMIS aperture class.

The DOT goals are similar to the THEMIS ones but more limited. Rather than supplying a general-purpose facility, the DOT aims first of all to test the open principle as a new venue for solar telescopes. That done and proven, the DOT will remain a basic special-purpose telescope for high-resolution imaging, its open nature necessitating robust, easy to operate postfocus instrumentation. Its design symmetry and direct pointing make it suitable to polarimetry.

As is the case for THEMIS, the quality of the prime mirror sets a basic constraint to the angular resolution of the telescope. The DOT mirror has been tested interferometrically. Its rms deviations are better than $\lambda/50$ and its mount, with 9-point purely axial support from the back and 3-point radial support of the central hole, keeps the mirror deformations that result from varying telescope orientation below $\lambda/40$.

The THEMIS and DOT concepts differ utterly in what follows after the prime mirror. The DOT mirror projects its image (at $f/D = 4.44$) onto a field stop which passes only the $2' \times 2'$ on-axis measurement field and reflects the remainder out of the telescope structure. This diaphragm is water cooled to ambient temperature, while air suction will be employed to inhibit thermal eddies in the incoming beam. Post-focus instrumentation with geometrically small cross section may be mounted behind the diaphragm, while larger volume is available to the side of the incoming beam and behind the prime mirror with no more than two reflections (of which one may be servoed actively). Since the mount is parallactic there is no diurnal image rotation in these foci.

In fact, the optical scheme of the DOT resembles the SVST much more than it resembles THEMIS in terms of underlying philosophy. The SVST is a refractor, and it is not a pointed telescope in the sense that it has a Sacramento Peak style alt-azimuth turret, but just as in the DOT its imaging piece of optics represents the very first optical element that is encountered by impinging solar photons. The clever trick of the SVST is that this element (the refractor doublet) doubles as vacuum window. It is followed by a minimum of reflections (three flat mirrors, the third being servoed actively). Therefore, the DOT and the SVST represent the extremes of simplicity in the open reflector concept versus the vacuum refractor concept, both minimizing the degradation that may result from co-focusing, alignment, and multi-reflection problems in more complex layouts. THEMIS sits on the other end of the scale, representing rather the extreme of complexity when one traces its beam along its 10 reflections to prime focus and along the additional 10 or more reflections on the way to the final MSDP focus.

Neither the DOT nor THEMIS possesses a laboratory where one may feed a solar image to a spacious horizontal optical table, as is done so successfully in the SVST and also at the German VTT and the NSO/SP VTT (the "horizontal spectrograph" and the ASP), representing facilities where one may again aim for simplicity in setting up and testing new post-focus instrumentation such as the innovative liquid crystal Stokes magnetographs that are currently being developed at the SVST. The strength of THEMIS sits rather in its comprehensive complexity, in the sense that its elaborate and extensively researched Italian and French post-focus instruments are designed to take full care of current as well as future needs in solar narrow-band imaging, spectrometry, polarimetry and MSDP-ometry[2].

Much of the long DOT development time has gone into its mechanical aspects. The prime mirror sits out and open, at 15 m height well above the layer of ground convections, but its pointing should not suffer from windshake due to the strong trade winds that tend to bring good seeing at La Palma. Thus, the pointing should be stable to below $0.1''$ even while the telescope, platform, and support tower are buffeted by strong wind gusts. This is not a simple requirement! In order

[2] We really need a new term for the use of an MSDP — meinometry?

to meet it, the eight-leg support tower has been designed to permit only lateral displacements of the platform, without tilts, so that wind buffeting does not result in angular pointing excursions. The right ascension and declination gear wheels, the transmission gears and the motors are much oversized. The total dissipation is of order 20 W, three orders of magnitude less than the heat produced by the oil bearings of the William Herschel Telescope. The imbalance moments are purposely large, 5000 kg m for the right ascension drive and 2000 kg m for the declination drive. There are two brushless servo motors per drive in counter-push preload configuration, coupled to the 2300 kg right ascension wheel and the 1200 kg δ declination wheel (only half a circle) through 1:75 000 four-step transmissions. The latter contain free-floating gear wheels which engage with self-seeking full-tooth alignment, in order to inhibit the pivoting motions permitted by point-to-point contacts. The new technology embedded in these drives forms the motivation for STW's interest and its willingness to fund the on-site installation and performance test.

The worst winds at La Palma are the ones that follow on humid low-temperature breezes. The latter may cause terrific ice buildup, characteristically in the form of icicles pointing windward from any structure on wich ice may deposit. If such an icing period is followed by one of the tremendous storms that sometimes hit the Canaries' mountain ridges, any structure that relies on balancing its mass against gravity is in danger. Indeed, various telescope builders have seen their cranes collapse from such a weather sequence. The DOT is designed to withstand such onslaught. The tower structure may harbor massive ice loads, for example the 30 tons of ice that would fill the elevator and staircase structure completely. The tower legs are anchored with chemically bonded bolts to the four 25 m^3 blocks of concrete on which they rest. The telescope itself is protected by a clam-like folding enclosure of tough polyester fabric with heavy steel ribs. It may be closed in winds up to 30 m/s and should withstand 70 m/s (Beaufort 12) storms when closed. The open-mesh platform floor is covered in wintertime; local heating then keeps the telescope ice free.

3 Status

At present, the DOT is erected at its site (Fig. 1). It was hoisted up at the end of July. Since then, the cabling has been completed. A conduit to the SVST contains the power, control and signal lines, a few hundred in total. The control electronics is located in one of the SVST's basement rooms from which the DOT will be operated. We are very fortunate to have been offered hospitality in the SVST building. It also makes it easy to run the two telescopes in tandem, a desirable option for many applications.

The next step consists of mounting the main mirror and the initial prime-focus equipment, which consists of magnification optics, a G–band filter and a simple video CCD camera. With these in place, the open-telescope principle is finally up for actual testing. An exiting prospect is to compare live DOT and SVST images of the same solar region.

Formally, the DOT is tested at La Palma under the umbrella of the IAC. Dutch astronomy is present on La Palma as part of the UK/NL cooperation which runs the Isaac Newton Group of telescopes (with René G.M. Rutten, not to be confused with the first author, the ING Head of Astronomy), but there is no formal agreement yet between Spain and The Netherlands as there exists for the other nations that are astronomically present on the Canary Islands. This is an unfortunate situation which must be remedied. In the meantime, we appreciate the patronage of the IAC which permits us to at least install and test the telescope.

4 Initial science

Obviously, the absence of both an SVST-style laboratory and of THEMIS-style elaborate postfocus equipment limits the initial DOT science options. The intrinsic DOT characteristic of being an open, pointed reflector on top of an open platform makes it a solar facility requiring robust and relatively small postfocus instrumentation. The DOT test configuration consists of parabolic mirror, water-cooled field stop, 20:1 magnification optics, a $\lambda = 430.5$ nm G–band filter and a video camera of which the signals are transported optically to the SVST basement and are there digitized with a PC frame grabber. This is the minimum setup needed for testing the open-telescope principle and for experiments with the telescope heat budget control. Such experiments aim to optimize the internal seeing of the telescope by checking out local heat sources and sinks and by fine-tuning the water cooling and air suction.

In addition, the initial system will serve to develop a numerical model of the telescope and tower pointing characteristics. With such a model, the high pointing stability of the DOT may be utilized to make it an absolute-coordinate pointing system suited to solar astrometry. To do so, the model must contain and correct diurnal effects such as unequal tower leg illumination as well as gearwheel properties that produce reproducible slow pointing modulations.

The test configuration also serves for G–band research of the type started at Pic du Midi by Richard Muller and colleagues (Muller et al. 1989, Auffret & Muller 1991, Muller & Roudier 1992, Muller et al. 1994, Roudier et al. 1994, Muller & Roudier 1994, Dermendjev et al. 1994, Montagne et al. 1996) and taken up also at the SVST, especially by the Lockheed group (Berger et al. 1995, Berger & Title 1996, Title & Berger 1996). At super-quality seeing, the G–band turns out to be a highly valuable diagnostic of the tiny magnetic flux patches that make up the magnetic network as well as plage. For reasons that are not understood, the CH lines which constitute the G–band around $\lambda = 430.5$ nm (the label was given by Fraunhofer, his list ended with H for the Ca II doublet) may brighten considerably, in very dynamical fashion, at the intergranular locations where magnetic fields exist in strong-field concentration. At less than super seeing, the highly promising technique of phase-diverse speckle registration enables sufficiently unique restoration for the atmospheric degradation that these bright points may yet be identified and traced (Paxman et al. 1996). An obvious project in this context is to obtain long sequences of G–band images in concert with SOHO's MDI in high-resolution mode and to study flux emergence and flux migration with the pattern topology derived from MDI's undistorted magnetograms and the small-scale dynamics contributed from La Palma.

5 Future options

Assuming that the DOT's open-telescope principle is validated in the initial performance tests and that funding is found to actually use the telescope for solar physics, there are various venues of interest:

- filter channels. Obviously, a multi-channel filtergraph mode as frequently set up at the SVST is the next item on the DOT agenda. Options include accommodation of large tunable filters behind the prime mirror, such as the versatile Lockheed SOUP instrument and the tunable Hα filter that was previously used at Gaizauskas' Ottawa River Solar Observatory and that we now have on loan from the Canadian Research Council;

- polarimetry per MOF. Cacciani's magneto-optic filter represents proven technoloogy both in low-l helioseismology and in full-disk polarimetry (Cimino et al. 1968, Cimino et al. 1970, Agnelli et al. 1975, Cacciani & Fofi 1978, Rhodes et al. 1988, Cacciani et al. 1988, Cacciani et al. 1990, Rhodes et al. 1990, Cacciani et al. 1991, Cacciani et al. 1993, Tomczyk et al. 1995, Basu et al. 1996). From the DOT point of view, adding a MOF is attractive because of its compact structure, permitting a mount near prime focus. From the MOF point of view, putting one on the DOT is attractive because this extends its usage to high-resolution magnetometry;

- aperture increase. The mechanical structure of the DOT accepts an 80 cm mirror. Even larger apertures can be accommodated without changing the basic telescope structure, only the focus support. Such aperture increase is desirable if the open-telescope principle performs well, pointing the way for much larger solar telescopes;

- fiber spectrometry. The concept of a fiber spectrometer was presented in a separate poster at the THEMIS Forum. The basic idea is to transform a square input field by fiber into a linear slit, enabling 2D spectrometry. For example, to reformat a $5'' \times 5''$ field into a linear slit illuminating a $2\text{K} \times 2\text{K}$ chip with one's choice of spectral lines. The plus points are that such 2D-spectrometry-per-isoplanatic-patch permits phase-diverse speckle restoration per monochromatic wavelength, that it permits 2D Stokes encoding using full profile information, and that it permits physical separation of telescope and spectrometer — perhaps all the way from DOT focus to SVST building. However, the minus point is that current fibers seem too coarse to make this a viable option for small telescopes with resolution elements that are geometrically small. Magnification doesn't help because the fibers then cause too much beam spreading. Thus, this option rides on fiber specifications.

This list of future possibilities demonstrates that the DOT is quite a different project from THEMIS, where future needs are already accommodated by existing instrumentation. An illustration of the latter point is given by phase-diversity methods. As was pointed out by various speakers at the THEMIS Forum the advent of multi-channel speckle restoration, phase-diverse restoration and phase-diverse speckle restoration as developed by Keller & von der Lühe (1992), de Boer & Kneer (1992), von der Lühe (1993, 1994), Löfdahl & Scharmer (1994), Seldin & Paxman (1994) and most convincingly demonstrated by Paxman et al. (1996) promises a breakthough in our business of trying to beat the earth's atmosphere. Such restoration is yet too computer-demanding for practical daily application, but there is no basic reason why it should not become a standard mode of observing that increases the ground-based collection of high-resolution images with a sizable factor — just what JOSO was all about.

This prospect implies that future solar observing must be two-dimensional in order to accommodate phase-diverse registration. Fast scanning of a spectrometer slit is a feasible option (Keller & Johannesson 1995), but simultaneous 2D imaging is a much better venue also in spectrometry. Although narrow-band exposures lack the signal to noise per seeing-freezing time that is needed for direct restoration, they may be deconvolved when taken along with broad-band phase-diverse frames as in the multi-channel speckle technique of Keller & von der Lühe (1992).

The MSDP fulfills the 2D condition admirably. While thinking about the fiber spectrometer listed above, with its small $5'' \times 5''$ field, we came to fully appreciate that the MSDP technique is perhaps intrinsically the most efficient of all simultaneous-2D spectral options. The MSDP splits the incoming solar photons most parsimoniously between two spatial dimensions and an optimized amount of spectral encoding, sacrificing spatial coverage in only one direction to obtain more detailed simultaneous spectral profile information than filtergraphs can provide. The left-over spatial domain represents a linear array of isoplanatic patches. This property combined with the inherent multi-channel simultaneity make monochromatic phase-diverse speckle restoration a definite MSDP option.

6 Prospects

As mentioned above, the current DOT installation and performance tests are funded by STW on the basis of technological interest. It ends at the completion of the telescope. We hope then to be able, with the test images in hand, to convince our Dutch astronomy colleagues that solar physics with this telescope is a worthwhile enterprise. This is not going to be easy. It should perhaps be noted here that Dutch solar physics is much smaller now than it was in the JOSO site test era, no longer a main activity but a minor one even within the Utrecht Institute. In effect, the future of observational solar physics in Holland now rides on the DOT. Of course, similar statements may be made about THEMIS, but with the recent influx of young astrophysicists into French solar physics, the budding of a THEMIS-oriented team at Naples, and its secure funding THEMIS is obviously in much better shape.

We hope that the DOT will provide an impulse to the interest in solar physics in our country. But even then, we will probably need international partnerships to keep the DOT afloat and we certainly welcome colleagues to use the DOT. Clearly, the open-telescope principle requires vindication before you all come trooping in, but we confidently expect that the DOT will be a new facility for high-resolution imaging which merits your attention.

On a larger scale, the fact that THEMIS and DOT are the last of JOSO's Phase II installations while the Phase III LEST does not seem to materialize implies that the current Canary Island installations are what European solar physicists have got in terms of ground-based optical facilities

— now and in the future. We should make the most out of them, in a cooperative spirit. One way to formalize, demonstrate and exploit such cooperation is within the framework of an EU–TMR network.

Acknowledgements. The DOT was built by the Sterrekundig Instituut Utrecht, the Physics Instrumentation Group of Utrecht University and the Central Workshop of Delft Technical University. The DOT completion, installation and verification are funded by the Stichting Technische Wetenschappen (STW) of the Netherlands Organization for Scientific Research (NWO). The current installation at La Palma proceeds under the umbrella of the Instituto de Astrofísica de Canarias. The DOT team enjoys splendid hospitality of the Royal Swedish Academy of Sciences at the Swedish Vacuum Solar Telescope with much support from Paco Armas, Goran Hosinsky, Rolf Kever and Goran Scharmer.

References

Agnelli G., Cacciani A., Fofi M., 1975, Sol. Phys. 44, 509
Auffret H., Muller R., 1991, A&A 246, 264
Basu S., Christensen-Dalsgaard J., Schou J., Thompson M. J., Tomczyk S., 1996, ApJ 460, 1064
Beckers J. M., 1993, Sol. Phys. 145, 399
Berger T. E., Schrijver C. J., Shine R. A., Tarbell T. D., Title A. M., Scharmer G., 1995, ApJ 454, 531
Berger T. E., Title A. M., 1996, ApJ 463, 365
Cacciani A., Fofi M., 1978, Sol. Phys. 59, 179
Cacciani A., Moretti P. F., Papaldo D., Paverani E., 1993, Sol. Phys. 144, 205
Cacciani A., Ricci D., Rosati P., Rhodes, Edward J. J., Smith E., Tomczyk S., Ulrich R. K., 1988, in ESA, Seismology of the Sun and Sun-Like Stars p 185-188 (SEE N89-25819 19-92), p. 185
Cacciani A., Smith E., Zirin H., 1991, in L. J. November (ed.), Solar Polarimetry, Proc. 11th NSO/SP Summer Workshop, National Solar Observatory, Sunspot, p. 133
Cacciani A., Varsik J., Zirin H., 1990, Sol. Phys. 125, 173
Cimino M., Cacciani A., Fofi M., 1970, Sol. Phys. 3, 319
Cimino M., Cacciani A., Sopranzi N., 1968, Sol. Phys. 3, 618
Coulter R., Kuhn J. R., Rimmele T., 1996, Sol. Phys. 163, 7
de Boer C. R., Kneer F., 1992, A&A 264, L24
Dermendjev V. N., Muller R., Madjarska M. S., 1994, Sol. Phys. 155, 45
Keller C. U., Johannesson A., 1995, Astronomy and Astrophysics Supplement Series 110, 565
Keller C. U., von der Lühe O., 1992, A&A 261, 321
Löfdahl G., Scharmer G. B., 1994, Astronomy and Astrophysics Supplement Series 107, 243
Montagne M., Müller R., Vigneau J., 1996, A&A 311, 304
Muller R., Hulot J. C., Roudier T., 1989, Sol. Phys. 119, 229
Muller R., Roudier T., 1992, Sol. Phys. 141, 27
Muller R., Roudier T., 1994, Sol. Phys. 152, 131
Muller R., Roudier T., Vigneau J., Auffret H., 1994, A&A 283, 232
Paxman R. G., Seldin J. H., Löfdahl M. G., Scharmer G. B., Keller C. U., 1996, ApJ 466, 1087
Rhodes E. J., Cacciani A., Garneau G., Misch T., Progovac D., Shieber T., Tomczyk S., Ulrich R. K., 1988, in R. C. Canfield, B. R. Dennis (eds.), MAX'91 Workshop #1, Summary and Reports, p. 33
Rhodes, Edward J. J., Cacciani A., Korzennik S., Tomczyk S., Ulrich R. K., Woodard M. F., 1990, ApJ 351, 687
Roudier T., Espagnet O., Muller R., Vigneau J., 1994, A&A 287, 982
Seldin J. H., Paxman R. G., 1994, in T. J. Schulz, D. L. Snyder (eds.), Image Reconstruction and Restoration, Procs. Soc. Photo-Opt. Instrum. Eng. 2302–19, p. 268
Seykora E. J., 1992, Sol. Phys. 145, 389
Title A. M., Berger T. E., 1996, ApJ 463, 797
Tomczyk S., Streander K., Card G., Elmore D., Hull H., Cacciani A., 1995, Sol. Phys. 159, 1
von der Lühe O., 1993, A&A 268, 374
von der Lühe O., 1994, A&A 281, 889