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The Dutch Open Telescope: History, Status, Prospects

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Abstract. After many years of persistent telescope design and telescope construction, R.H. Hammerschlag has installed his Dutch Open Telescope (DOT) on La Palma. I briefly review its history and design. The future of optical solar physics at Utrecht hinges on a recently-funded three-year DOT science validation period. The initial aim is to obtain high-resolution image sequences in the G band, Ca II K and Hα as proxy-magnetometry in support of SOHO and TRACE.

1. Introduction

Figure 1 shows the cover of the proceedings of the 1980 Sacramento Peak summer workshop. It addressed essentially the same topic as the present one, but with the difference that it was organized by Dick Dunn rather then dedicated to him. He used the emptiness of the telescope platform of R.H. Hammerschlag's open tower to symbolize the need to define future solar telescope concepts and projects. At that time the open tower was ready but yet awaiting its open telescope. Now, eighteen years later, the tower and the telescope are finally joined on La Palma into what is now called the Dutch Open Telescope (DOT; Figure 2). The DOT story is obviously a long one but it is given only briefly below. I also describe what we hope to use the DOT for the coming years and what you may want to do with it.

2. DOT principle

Figure 2 demonstrates the open nature of the DOT. The principle of both the tower and the telescope is to minimize obstruction to the local airflow. The aim is to optimize the seeing conditions near the telescope and to minimize internal seeing within the telescope through wind flushing. There is no building or dome, only a fold-away clamshell canopy.

The airflow through the telescope must be sufficiently strong to achieve sufficient telescope flushing. At the Roque de los Muchachos the best daytime seeing tends to occur when the trade wind blows upslope from Northern directions in considerable strength, at wind speeds of 5–10 m/s. The good seeing may then last all day, making the site intrinsically different from US mountain sites (cf. Beckers & Rutten 1998) and permitting the collection of long time sequences

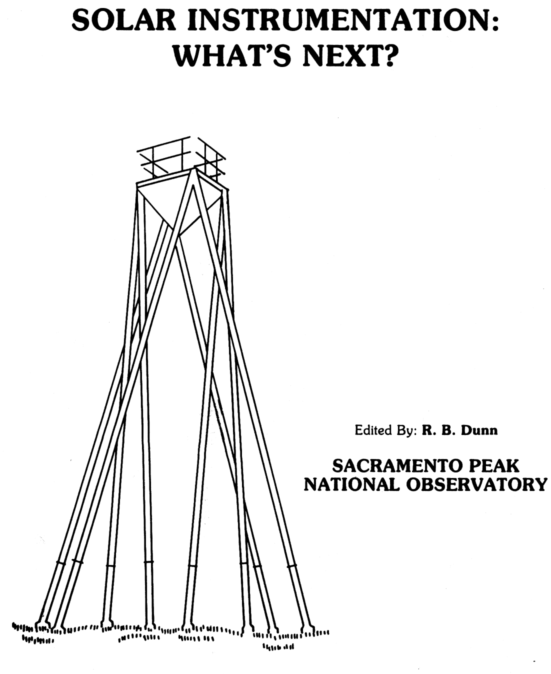

Figure 1. The cover of the 1980 Sac Peak workshop proceedings edited by Dunn (1981), derived from a photograph of Hammerschlag's open tower (then located near the Westerbork radio telescope).

at high resolution. The prime example is the one taken by Simon et al. (1994) at the SVST which has rms granulation contrast around and over 8% during eleven hours (Figure 1 of Hoekzema et al. 1998). The DOT principle aims to exploit these particular La Palma conditions.

The optical scheme is very simple. The parabolic primary mirror (Figure 2) projects a prime-focus image on a water-cooled reflective field stop which transmits only a small part of the solar image and takes away most of the heat. Behind it, beam splitters, magnification optics and narrowband filters may be used to project images on CCD cameras mounted directly on the main axis behind the prime focus, or besides the incoming beam using 90-degree beam folding, or behind the primary mirror by deflecting the secondary beam around the prime focus stop and sending it through the central hole in the mirror. At present, the slender pipe seen in Figure 2 contains only relay optics and a simple video camera.

The optical scheme does not possess axial symmetry because Hammerschlag prefered asymmetrical support of the prime focus structure for mechanical rigidity. However, the telescope polarization is yet favorable because it is time-independent, the DOT having a parallactic mount with hour angle and declination drives. There is no diurnal image rotation either.

Its open structure makes the DOT differ from all other solar telescopes currently in use. Almost all rely on internal evacuation to avoid internal seeing from

Figure 2. The Dutch Open Telescope on La Palma, December 1997. Altitude about 2300 m. North is to the right, the SVST to the back of the photographer, the Carlsberg transit telescope just below the DOT, the Residencia way down past the black fire mark covering part of the HEGRA array. The Atlantic spreads to the far horizon.

solar heating of the telescope structure, in particular around their foci where the solar heat is concentrated[1]. The use of vacuum windows sets a diameter limit at about one meter, also when a lens rather than a plane window is used as in the SVST (Scharmer et al. 1985) and its planned successor (the NSST, see Scharmer et al. 1999). It is therefore clear, also from the concept studies for CLEAR (Beckers 1999), that the DOT principle is of interest to the design of future solar telescopes with multi-meter aperture.

The DOT aperture, defined by its $D = 45\,\mathrm{cm}$, $f = 200\,\mathrm{cm}$ primary and nearly equal to the 48 cm SVST aperture, is yet well below the 1 m limit above which the open principle may be the key strategy, but as can be seen in Figure 2, the DOT mechanical structure accepts a larger primary, up to 100 cm without major modification.

3. DOT history

The DOT tale obviously centers on Rob Hammerschlag. He designed and built the DOT during the past decades with admirable tenacity, keeping the project going amidst storms of criticism that mostly concerned progress speed.

However, the story starts with Kees Zwaan who came up with the original idea of trying out an open telescope. This happened in the early seventies when De Jager, Zwaan and others at Utrecht were part of the extensive JOSO efforts to find the best site in Europe for ground-based solar observing and to put a large European telescope there. The latter task was later split off from JOSO to become the ill-fated LEST, a long story by itself laid down in tall stacks of orange books in many a solar physicist's office. In those years, Zwaan led a sequence of site testing campaigns that concentrated on sea level island sites off the southern coast of Portugal. He even joined a navy expedition to the Islas Selvagem, a few austere rocks in the Portuguese Atlantic. Testing these sites with small Questar-class telescopes led to the desire to have a 40 cm telescope that might be transported from site to site. The JOSO philosophy then, later jettisoned by the LEST Foundation when it simply declared La Palma to be the best site worldwide, was to nail down the number of LEST candidate sites to just a few and then use such medium-size telescopes to select and "verify" the final one through solar imaging with an aperture exceeding the Fried diameter. At the time, Rob Hammerschlag had been hired as an optics engineer at Utrecht to support a totally different project (stellar interferometry using heterodyne down-conversion, part of a non-successful and long-defunct Utrecht enterprise called laboratory astrophysics). Zwaan's enthusiasm inspired him to try his hand at a transportable open test telescope for LEST.

LEST is dead now but the DOT is finally coming alive. Over the years, Hammerschlag tended to promise completion within two years; these two years

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[1] The NSO/Kitt Peak Pierce-McMath telescope is not evacuated, but can not be considered a high resolution optical telescope in terms of angular resolution (though it performs better in the infrared and its FTS provides superior spectral resolution). Also, as Beckers and Scharmer have pointed out during this meeting and elsewhere, some vacuum telescopes including the German VTT on Tenerife are partially open in the sense that their heliostats are outside the vacuum, are outside in the open air, and are wind flushed (and wind shaken).

became two decades eventually, and even now the telescope is not yet ready for science. Clearly, the project did not progress as originally anticipated. In the meantime, Kees Zwaan was retired (forcefully, there is no right to work beyond 65 in Holland) five years ago (cf. Rutten & Schrijver 1994), making me DOT project scientist by default. I might not have chosen to assume that role had I been asked two decades ago but nevertheless, I profess great admiration for Hammerschlag's efforts, tenacity and product. Even if the DOT has been overly slow in coming, certainly much slower than promised, in the end it is yet as novel and innovative a telescope as it was at its conception.

In addition, it is fair to note that other solar telescope projects have taken as long (THEMIS) or have not succeeded at all (LEST; SOT/HRSO/OSL). The most notable exception is of course Scharmer's SVST which came on-line remarkably fast and gained an outstanding track record that makes the successor NSST the most promising solar telescope project on the drawing board. In addition, Scharmer plays a key role in the DOT project by accommodating the DOT team most hospitably in the SVST building from which the DOT is operated, and by furnishing much material and political help as well as highly appreciated advice.

Hammerschlag is not a Scharmer. Göran Scharmer seems to set out on a new tack every few years, pioneering a revolutionary technique with utter simplicity and utter quality at the same time. First it was radiative transfer, then a solar refractor, then image selection and wavefront restoration; this year the NSST. Rob Hammerschlag reminds me much more of Dick Dunn even though Dick speaks faster even than I do. The similarity is that over the years, Dick Dunn has through thick and thin[2] kept going at his great telescope. The DST[3] materialized considerably faster than the DOT (be it at considerably higher cost), but in the thirty years since the initial DST completion Dick Dunn has persevered in improving it further with Hammerschlaggian tenacity. Clearly, the DST is Dick Dunn's life's work just as the DOT is Rob Hammerschlag's.

Why did the DOT take so long? First of all, it has largely been a one-man project. In the seventies, Utrecht Observatory was still rather rich (although we didn't appreciate that at the time) and had mechanical and electronics workshops large enough to start a project such as this. Even so, Hammerschlag cornered the interest and cooperation of the yet larger Central Workshop of Delft Technical University, his alma mater, where both the tower and the telescope were eventually assembled at minimal cost. During the years, steady erosion of the Utrecht astronomy funding took away both our workshops, in addition to almost all other support personnel as well as over half the staff. This demise accelerated when the newly named Sterrekundig Instituut Utrecht moved into the out-of-town physics laboratory while bequeathing Sterrewacht Sonnenborgh to amateur astronomy. It so lost its relative independence from the physics administration — which regarded the DOT project with large misgivings given its history. The manpower and the money allocated to the DOT went down to a subcritical drizzle until Hammerschlag and Zwaan managed to acquire a gener-

[2]What's in a name — thick thin is dik dun in Dutch, tlusty hubený in Czech.

[3]I propose that the unwieldy name "NSO/Sacramento Peak Richard B. Dunn Solar Telescope" be abbreviated in actual practice to Dunn Solar Telescope or DST.

ous external grant from the Dutch Foundation for Technical Sciences STW. It funded the completion of the DOT and its installation on La Palma — not to provide a new toy to solar astrophysicists but out of interest in the innovative mechanical technology implemented in the DOT.

4. DOT structure

The mechanical specifications that Hammerschlag wrote down as design requirements at the start of his project constitute a second reason why the project took so long. An open telescope that relies on flushing by 5–10 m/s winds to perform near its diffraction limit should not shake or vibrate while being buffeted by such strong winds. The requirement of 0.05 arcsec pointing stability made Hammerschlag evolve from an optics engineer into a mechanical engineer; it also took a large amount of development and construction time. Many of Hammerschlag's solutions are new to astronomy; it is fitting that Dick Dunn concluded his solar telescope review in the celebratory 100th volume of *Solar Physics* with the following judgment:

> *The Utrecht telescope, designed by Hammerschlag, will also be useful for Stokes, but its aperture is somewhat small; however, even partial success of its many innovations will open up exciting new design possibilities for high resolution solar telescopes.* Dunn (1985)

These mechanical innovations should be written up and explained by Hammerschlag himself, not by a non-expert outsider like me; let me therefore just mention a few.

The principle of the 15 m high tower that lifts the telescope above the layer of ground-heated turbulence is to use triangles everywhere, as is done in all DOT support structures. The four large triangles made up by the eight steel tubes that constitute the tower legs keep the platform pairwise from tilting. It might pivot around the axis defined by the two triangles in the plane of the wind direction, but then the other two triangles inhibit such rotation and permit motion of the platform parallel to itself alone. The sun being a source at infinity makes this OK.

The massive drive wheels supplying the hour angle and declination rotation (the hour angle one alone weighs 2300 kg) are driven through self-aligning gear trains that achieve 1:75.000 reduction. The gear wheels are not fixed to any axis but have freedom of motion, enabling them to engage each other along the whole length of their teeth. This alignment inhibits the pivoting freedom that results from the single-point contact normally occurring in gear engagement.

The DOT gear trains are driven in preloaded backlash-free push-pull configuration by twin sets of brushless servo motors. They have 3–4 kW capacity but use only a few tens of Watts in normal operation in order to keep the dissipation low, three orders of magnitude below that of the oil bearings in the nearby William Herschel Telescope. The latter needed cooling plants far from the telescope to clean up the dome seeing; the DOT drive dissipation is so low that the problem does not occur.

The hour angle wheel rotates under a dust-tight cover in order to avoid problems with the frequent occurrence of Sahara dust deposition at La Palma.

The declination wheel moves together with a similar cover. The driving of both wheels is done with considerable imbalance, respectively 2300 kg m and 1200 kg m, so that large variable wind loads (or ice loads) are accommodated.

The clam-shell canopy combines large strength with the possibility of being closed (or opened, less likely) in gale conditions. The strength comes from the combination of heavy steel ribs and two-dimensional curvature of the polyester fabric between the ribs, inhibiting flapping. The teflon-like fabric coating resists ice deposition, an important characteristic at the Roque de los Muchachos where below-zero winter fogs often cause heavy ice growth on metal surfaces.

The platform has an open-mesh floor, covered only in winter when the DOT will not be manned (Hammerschlag and I fulfilling considerable teaching loads). It is reached by elevator or ladders in an independent stairwell structure that may carry large ice loads and withstand large wind loads by itself (the combination is the worst and has toppled over large cranes on both the La Palma and Tenerife observatory sites).

5. DOT status

Hammerschlag and his team (in particular P.W. Hoogendoorn and F.C.M. Bettonvil, assisted by numerous young trainees from technical schools around Utrecht) installed the DOT at the International Roque de los Muchachos Observatory at a site close to SVST during 1996 and 1997. The DOT first light ceremony was held on October 31, 1997 (upper part of Figure 3). Soon after, first images of excellent quality were obtained with a simple video camera through a modem link to the SVST. One is shown in the lower part of Figure 3 and others may be inspected at http://www.astro.uu.nl/∼rutten/dot. The simple initial equipment so served to establish the DOT's capability for high-resolution observation.

However, the first light and the first images also marked the end of the funding by the Dutch technology foundation STW as well as the final closure of our mechanical workshop. It has taken nearly a year to obtain funding to resume working on and with the DOT. Various fortunate circumstances have contributed to finally getting green light again last September. The first was the selection of the European Solar Magnetometry Network as a TMR programme by the European Commission. It provides salaries and travel allowances for three-year postdocs at eight European solar physics groups, one going to the DOT. Details are given at http://www.astro.uu.nl/∼rutten/tmr. Second was the selection of a DOT science program for funding by the Dutch Science Foundation NWO from a grant program outside the regular astronomy allocation. The quality of the first DOT images had much to do with the the favorable tone of the referee reports. The third was the selection of Dutch astronomy in general as best of all Dutch science in a new NWO grant program aiming at supporting top quality university research. The four Dutch university institutes combined into what is called the Netherlands Graduate School for Astronomy (NOVA), is led by T. de Zeeuw and E.P.J. van den Heuvel, and has cornered a large allocation of "new" money of which a significant part is specifically intended to support new instrumentation. NOVA has allocated a small but politically instrumental grant to the DOT. Last but not least, the present administrations of the Faculty of Physics and Astronomy and the Sterrekundig Instituut of Utrecht University have decided

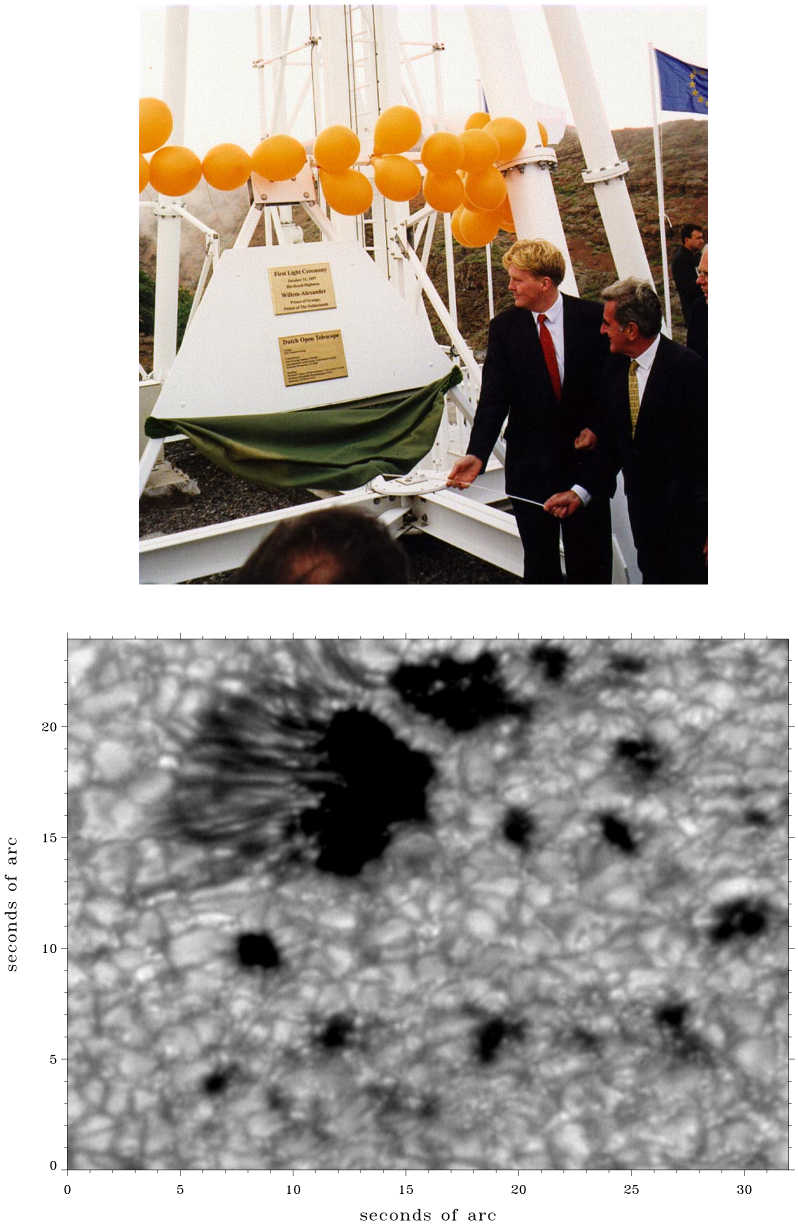

Figure 3. Top: DOT first light ceremony held on October 31, 1998, performed by His Royal Highness Willem-Alexander, Prince of Orange, and His Excellency Manuel Hermoso Rojas, President of the Canary Islands. Since it was clouded with rain coming on they (and many other dignitaries) were shown a canned movie of video images taken a few days earlier. Göran Scharmer, Oskar von der Lühe and Valentin Martínez Pillet represented the solar physics community. Bottom: DOT image taken on December 5, 1997 through a wide-band filter centered on $\lambda = 546$ nm. More photographs and images at http://www.astro.uu.nl/$\sim$rutten/dot.

that the DOT deserves a chance to prove its scientific worth. Together, these five funding agencies support a three-year "DOT science validation" period to do so.

The program for which this three-year funding is allocated consists of simultaneous imaging in three wavelength bands: the molecular CH band around $\lambda = 430.5$ nm (G band), the Ca II K line and Hα. The first two require simple interference filters; for Hα we have the tunable Zeiss filter on loan that was previously used by V. Gaizauskas at ORSO. This three-channel imaging will provide "proxy magnetometry", respectively of the deep photosphere (G band), the low chromosphere (Ca II K) and the high chromosphere (Hα). The techniques will closely follow the examples set by Scharmer and his team at the SVST in collaboration with the Lockheed-Martin group. The observations will concentrate on joint programs supporting SOHO and TRACE campaigns. Obvious research topics are the mapping of solar magnetic structures at various heights, tracing their evolution, and measuring their dynamical behavior. The DOT technical team (Hammerschlag, Bettonvil, Hoogendoorn) returned to La Palma during October 1998 to test appropriate optics designs. We hope to initialize scientific data collection by the summer of 1999.

6. DOT prospects

A dozen Utrecht-educated solar physicists is presently active outside The Netherlands, but at Utrecht itself Hammerschlag and I are the only staff members devoted full-time to the field (apart from our obligatory teaching). Hoyng, Kuijpers and Kuperus maintain only partial interest. Thus, solar physics survives at Utrecht but meagerly compared with the days of Minnaert and De Jager. None of the solar physics chairs had a solar physics successor (De Jager, Houtgast, Fokker, Zwaan) or will have one (Kuperus). There is no solar physics at the other Dutch university astronomy departments (Amsterdam, Groningen and Leiden); the Sun is not mentioned in NOVA's charter[4].

In this context, the three-year DOT science validation program and funding represent an important new impetus to optical solar physics at Utrecht. The program scale is small compared with what is desirable for running a full-fledged facility, but it does give us opportunity to hire some graduate students and postdocs which we otherwise wouldn't have had. It is clear that the future of Utrecht solar physics rides on it.

One thing that we are *not* funded to do is to experiment with the DOT as a step on the way to larger solar telescopes. It is of obvious interest to use the DOT as a testbed facility for trying out new techniques — thermal mirror control, CLEAR-like shrouds, wavefront monitoring, prime mirror adaptivity, etc. The DOT science validation program is explicitly limited to the three-channel imaging for which the funding is allocated. Therefore, if you have interest in open-principle performance experiments, that is where *you* come in. Such co-

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[4] Fortunately, the plasma physics theory group led by Prof. Hans Goedbloed at the Dutch plasma physics laboratory Rijnhuizen (a non-university institute in Nieuwegein nearby Utrecht) has turned from tokamak theory to coronal theory. Perhaps this is a telltale sign that solar physics is too difficult for astronomers and requires takeover by regular physicists?

operation is very welcome.

Acknowledgments. The DOT was designed by R.H. Hammerschlag and built by the Sterrekundig Instituut Utrecht, the Physics Instrumentation Group of Utrecht University, and the Central Workshop of Delft Technical University. The DOT completion and installation at La Palma were funded by the Stichting Technische Wetenschappen (STW) of the Netherlands Organization for Scientific Research (NWO), and proceeded under the hospitable umbrella of the Instituto de Astrofísica de Canarias. The three-year science validation phase is funded by the Netherlands Organization for Scientific Research (NWO), the Netherlands Graduate School for Astronomy (NOVA), Utrecht University, the Sterrekundig Instituut Utrecht, and the European Commission via a TMR grant to the European Solar Magnetometry Network. The DOT team (R.H. Hammerschlag, F.C.M. Bettonvil, P.W. Hoogendoorn and E.B.J. van der Zalm) enjoys splendid hospitality of the Royal Swedish Academy of Sciences at the SVST with much support from Paco Armas, Göran Hosinsky, Rolf Kever and Göran Scharmer.

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