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# DUTCH OPEN TELESCOPE: STATUS, RESULTS, PROSPECTS

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## ABSTRACT

The *Dutch Open Telescope* (DOT) on La Palma is a revolutionary telescope achieving high-resolution imaging of the solar surface. The DOT combines a pioneering open design at an excellent wind-swept site with image restoration through speckle interferometry. Its open principle is now followed in major solar-telescope projects elsewhere.

In the past three years the DOT became the first solar telescope to regularly obtain 0.2″ resolution in extended image sequences, *i.e.,* reaching the diffraction limit of its 45-cm primary mirror.

Our aim for 2003–2005 is to turn the DOT into a 0.2″ tomographic mapper of the solar atmosphere with frequent partnership in international multi-telescope campaigns through student-serviced time allocation.

After 2005 we aim to triple the DOT resolution to 0.07″ by increasing the aperture to 140 cm and to renew the speckle cameras and the speckle pipeline in order to increase the field size and sequence duration appreciably. These upgrades will maintain the DOT's niche as a tomographic high-resolution mapper in the era when GREGOR, Solar-B and SDO set the stage.

## 1. PAST

The DOT history goes back to the early 1970s when JOSO had many European solar physicists searching for the best location for optical solar observations. Utrecht professor Kees Zwaan (1928–1999) was then chairman of JOSO's Working Group on Site Testing. At that time, Zwaan was also instrumental in starting the Solar Physics Section which ever since organises European solar physics conferences in three-year cadence of which the present meeting is the 10th (see Zwaan obituary in Rutten 2000). We offer this report at this JOSO/SPS meeting as a fitting tribute to a great and beloved scientist.

Zwaan's involvement in testing sites with particular emphasis on locations where a strong oceanic breeze suppresses near-ground turbulence caused by solar heating led him to suggest that an open telescope on top of an open tower placed in such a breeze might replace the ubiquitous vacuum telescope solution to internal seeing for high-resolution observing. His insight became the motivation for Hammerschlag to design and build his open telescope. Design detail is given in older JOSO Annual Reports and in Hammerschlag (1981), Hammerschlag & Bettonvil (1998), Bettonvil et al. (2002), and Hammerschlag et al. (2002).

*Figure 1: The Dutch Open Telescope on La Palma.*

Eventually, Hammerschlag's long-term project

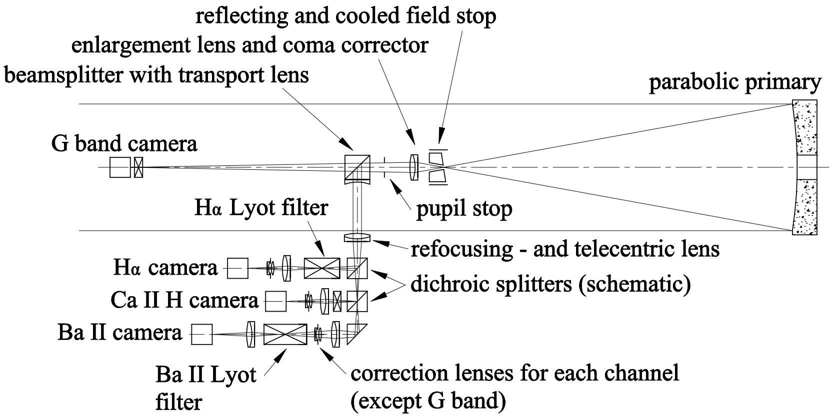


*Figure 2: Schematic diagram of the DOT multi-channel system. There are six different channels, respectively for imaging in Ca II H at 396.8 nm (bandwidth 0.1 nm), the G band at 430.5 nm (1 nm), continuum at 432 nm (1 nm), Ba II 455.4 nm (tunable 0.008 nm), continuum at 651 nm (1 nm) and Hα at 656.3 nm (tunable 0.025 nm). The two continuum channels are not shown. The actual design is more complex. All six cameras operate synchronously in speckle burst mode. The 100-frame bursts are transported by optical fibers to the DOT control room in the Swedish telescope building. Each camera feeds its own frame-acquisition PC with 72 GB storage, archived on an Exabyte Mammoth 2 seven-tape library.*

became the Dutch Open Telescope (DOT) on La Palma. It stands there close to the Swedish telescope (formerly the SVST, now the NSST) from whose building the DOT is operated.

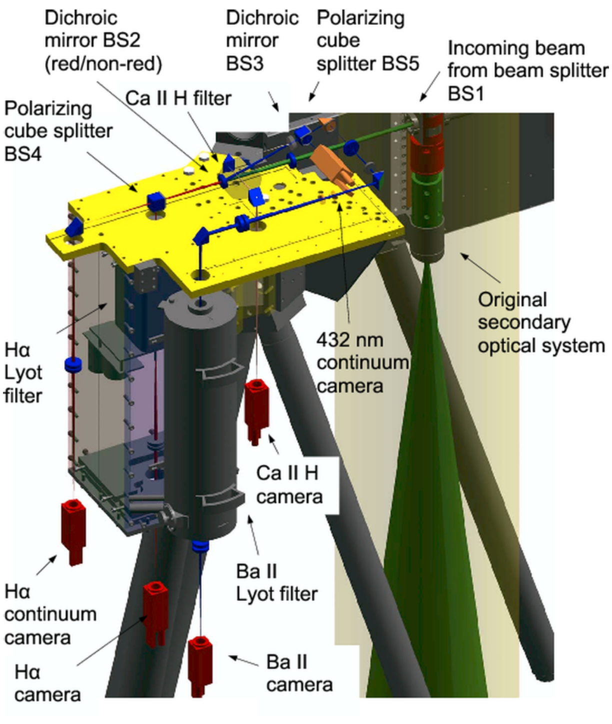


*Figure 3: Actual design of the DOT multi-channel optics.*

## 2. PRESENT

The DOT currently achieves optical solar imaging with 0.2″ angular resolution over relatively long durations (multiple hours) and over relatively wide fields of view (90″×70″) thanks to the combination of its innovative open design, the excellent wind-swept site, superb optical performance, exceptional mechanical stability, and consistent application of speckle reconstruction.

The success of the DOT's open principle became evident soon after first light and inspired large-diameter telescope projects elsewhere (GREGOR, ATST). The open structure and strong up-slope oceanic trade wind often combine to excellent seeing without image spoiling within and near the telescope. The remaining above-the-telescope seeing is corrected through speckle restoration. The DOT speckle code uses the speckle masking method of Weigelt (1977) and Hofmann & Weigelt (1986) as implemented at Göttingen (de Boer & Kneer 1992, de Boer 1993) and ported to the DOT by Sütterlin.

The resulting DOT movies are world famous. They are available at `http://dot.astro.uu.nl` together with DOT publications and reports.

We are presently installing a six-camera multi-channel speckle image acquisition system which will serve for solar atmosphere tomography (Figs. 2–3). The first two channels (blue continuum and G band) are working. The Ca II H and red continuum channel will follow later this autumn. The remaining two channels, planned for next year, use tunable birefringent Lyot filters for sampling the profiles of Ba II 455.4 nm and Hα. The Ba II filter has very narrow bandwidth (0.008 nm) and was built by V. I. Skomorovsky and colleagues at Irkutsk. It was tested at the former SVST and demonstrated superb Dopplergram capability (Sütterlin et al. 2001). The Hα filter is the Zeiss filter formerly used by V. Gaizauskas at the Ottawa River Solar Observatory. We plan to implement speckle processing for these narrowband filters using the two-channel restoration technique of Keller & von der Lühe (1992).

The science capabilities that the DOT will have after the completion of its multi-wavelength system

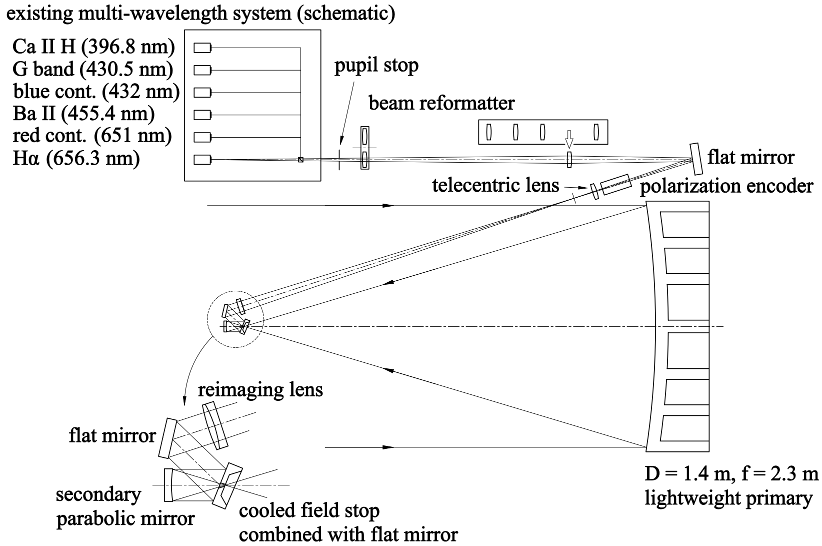


*Figure 4: Optics design for DOT aperture tripling. A new light-weight parabolic primary mirror of 140 cm diameter will feed the existing multi-wavelength recording system via new beam folding and reformatting optics. A super-reflective, water-cooled field stop with air suction around it in prime focus reflects most of the solar image and passes the field of view to the relay mirrors, of which the first one is parabolic and cancels the coma of the parabolic primary, producing a large field of view. A telecentric region can harbour polarisation encoders for Ba II 455.4 nm magnetometry. A choice of beam reformatting lens combinations and a fixed pupil stop permits flexible user-selectable trade-off between resolution and field size, producing a $f/45$ beam into the multi-wavelength system just as in the present 45-cm DOT. The G-band channel will no longer be on-axis so that the central obscuration will be small.*

are summarised in Rutten *et al.* (2001a, 2001b). The underlying science strategy and niche are discussed in Rutten (2001).

## 3. RESULTS

We refer the reader to the DOT website for DOT movies and preprints and reprints with DOT science. Of particular importance is the temporal homogeneity of the DOT image sequences. When the La Palma seeing is good enough for speckle restoration down to the $0.2''$ diffraction limit, which is the case for Fried parameter $r_0 > 7$ cm, an entire multi-hour image sequence possesses diffraction-limited resolution consistently. The solar-physics emphasis on magnetic field evolution and dynamics makes such homogeneity essential. The space-based counterpart demonstration of its importance is given by the constant-quality movies from TRACE. Whereas astronomy is becoming a science of pictures (*viz. "The Astronomy Picture of the Day"* website), solar physics becomes a science of movies!

All DOT data are public. If you are interested in analysing DOT data you may request FITS files from Peter Sütterlin at `P.Suetterlin@astro.uu.nl`.

## 4. FUTURE: 2003 – 2005

Our short-term goal is to exploit the DOT high-resolution tomography capability by frequent sharing in international observing campaigns. This can be done only infrequently at present because our current computer power limits the DOT speckle processing to only a few multi-wavelength image sequences per year. Such small but high-quality harvest does suffice for the research needs of the small solar physics group presently at Utrecht, but severely underuses the DOT's full science capability. We therefore aim to install a large-capacity speckle-processing system and to initiate a student-service program bringing many students to La Palma to assist in the observing. These plans are detailed in Rutten et al. (2002). They are yet unfunded but are our top priority after the completion of the multi-channel system. A parallel version of the speckle code has already been tested on a multi-processor cluster (de Wijn).

Another goal for the coming years is to expand Utrecht solar physics. At present it consists only of the first five authors to this contribution, with only the Roberts on permanent positions — a far cry from the past when over a dozen staff members were devoted to solar physics at Utrecht. Nowadays most Dutch solar physicists live abroad. Fortunately, the DOT success causes a turn of the tide: we have permission to search for a full professor in solar physics, effectively re-instating Kees Zwaan's chair.

## 5. FUTURE: 2006 – 2010

On a longer time scale we also know exactly what we want. Tripling the size of the DOT primary mirror to 140 cm aperture as sketched in Figs. 4–5 is feasible with the present telescope mount. A new telescope top is needed but the multi-wavelength optics system can be maintained through beam folding with relay

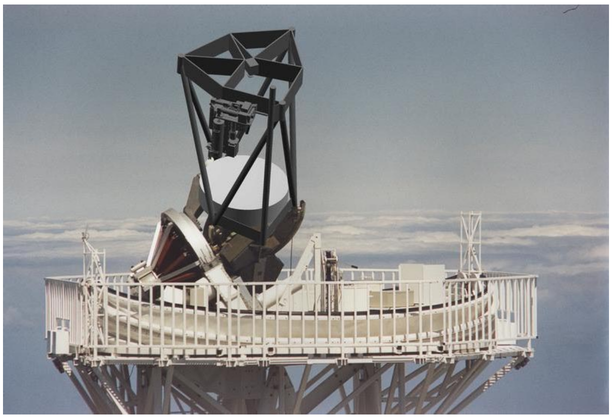

*Figure 5: Design drawing of a 1.4-m aperture DOT superimposed on an actual DOT photograph. The telescope mount will remain the same. A new top structure will support the existing multi-wavelength system. The resulting telescope still fits within the bad-weather canopy.*

optics converting the beam to the present $f/45$. The design includes a variable-pupil beam reformatter enabling trade-off between resolution and field. At superb seeing, when speckle restoration will work down to the 0.07″ diffraction limit of the 140-cm aperture, the aperture tripling will fully regain the DOT's role of tomographic imager even in the Solar-B era — and actually enhance Solar-B through co-observing: the DOT can then image at 0.07″ (50 km on the solar surface, equal to the photon mean free path in the photosphere) what Solar-B diagnoses at 0.2″. When the seeing is less good one opts for lower resolution but a concomitantly larger field of view on the camera chips.

The introduction of a parabolic secondary mirror will cancel coma from the parabolic primary which presently limits the useful DOT field of view to three arcmin. Since much larger CCD chips with the 10 frames/s readout speed needed for speckle burst registration should become affordable with time, we intend later in this decade to revamp the DOT cameras and speckle pipeline with state-of-the-art hardware and so increase the field of view considerably at any resolution. For example, during non-superb seeing 4K×4K chips would register 300″×300″ at 0.2″ resolution and enable studies of the topology and dynamics of whole active regions including complete coronal loop anchoring. When the seeing turns excellent — as flagged by our reliable Seykora-Beckers scintillometer — shift to 0.07″ resolution then reduces the field to 100″×100″, still large enough to contain a complete mature sunspot with its moat. Increasing the disk storage (or accelerating the speckle processing to real-time turnaround) will increase the maximum sequence duration.

We are confident that a multi-wavelength tomographic imager with these capabilities will be of large complementary value to many solar physics programs employing quantitative spectropolarimetry at 0.1″ resolution with NSST and/or GREGOR, and/or employing 0.2″ diagnostics with Solar-B, and/or employing 1″ high-cadence full-disk super-MDI and super-TRACE imaging with SDO. The first step towards realization has been set in the form of a preliminary proposal.

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