DUTCH OPEN TELESCOPE

Report for NOVA ISC meeting nr. 9

R.J. Rutten, Utrecht, March 11 2001

Summary

The three-year DOT "initial science validation" ends in September. The planned exploration of image reconstruction options has been accelerated into full implementation in the form of a large-volume five-camera speckle recording system, now essentially complete and with the first image sequence in hand. The optics design for each of the wavelengths of the planned multi-diagnostic tomography system (G band, Ca II H, Lyot-tuned Hα, with accompanying continua) has been tested by actual speckle runs at the DOT. The resulting image sequences are of outstanding quality, have demonstrated the superior imaging capability of the combined DOT, La Palma seeing and speckle reconstruction worldwide, and are now producing initial DOT science papers. The multi-channel design is now complete, all optics ordered, the mechanical accommodation halfway complete. The first multi-channel observations are planned for early summer. A test of the Dopplergram capability of a tunable Lyot filter from Irkutsk using the Ba II 455.4 nm resonance line was so promising that integration of this filter is now planned as well. By the end of the month, a high-level DOT Evaluation Committee will advise on the DOT capabilities for front-line solar physics research.

Contents

1 Overall status

Three-year program. The DOT project is currently funded by SIU, UU, NWO-GBE, NOVA, and EC-TMR in a three-year "initial science validation" program which ends formally in September[1]. The aim of the program was to expand the DOT from its initial configuration (funded by STW to demonstrate the open-telescope principle and prove that the mechanical stability and optical quality fulfilled the stringent DOT design specifications) into a facility for front-line solar physics research. The proposed program consisted of:

(i) – installation of three-channel proxy-magnetometry filter imaging (G band, Ca II K, rapidly tuned Hα);

(ii) – observations with the above, especially in concert with SOHO, TRACE, and/or other Canary Island telescopes;

(iii) – software development of phase-diverse and/or speckle restoration.

At the time, item (iii) was thought the hardest and to be explorative only, but it actually became a success very quickly after the hiring of ESMN[2] postdoc Pit Sütterlin. He brought German speckle expertise to Utrecht and it turned out that speckle restoration was feasible even with the simple analog video camera and 8-bit digitization of the initial DOT configuration. All DOT movies[3] taken since are speckle reconstructions. This breakthrough success led quickly to the decision to leapfrog the image restoration development into full completion already within this initial period, by combining large-volume speckle registration hardware realization with the planned multi-wavelength camera system. It is detailed below.

Science niche. This combination together with the superb DOT image quality and the frequency of La Palma seeing good enough for speckle restoration ($R_0 > 6$ cm) constitutes a unique and valuable solar physics niche for the DOT, namely diffraction-limited multi-layer tomography of solar magnetic topology and dynamics over long durations[4] and over a wide field[5]. This niche will remain a unique and important one the coming decade while other high-resolution solar telescopes[6] pursue deployment of adaptive optics since AO delivers full restoration to the diffraction limit only for the central isoplanatic patch[7].

[1] Effectively next spring; the temporary DOT employees (postdoc P. Sütterlin, OIO J.M. Krijger, engineer F.C.M. Bettonvil) continue until May/October 2002, respectively.

[2] European Solar Magnetometry Network, http://www.astro.uu.nl/~rutten, EC-TMR network.

[3] All available at the DOT website: http://dot.astro.uu.nl.

[4] Up to multiple hours, much longer than the even at La Palma brief (and very rare) flashes of 0.2 arcsec daytime seeing.

[5] 92×73 arcsec at 0.071 arcsec/px corresponding to the 0.2 arcsec telescope resolution.

[6] NSST = New Swedish Solar Telescope, ongoing retrofit of the Swedish Vacuum Solar Telescope (SVST) on La Palma turning it into a 96 cm refractor, GREGOR = planned retrofit of the German Gregory-Coudé telescope on Tenerife into an open 1.5 m reflector with a DOT foldaway canopy, and ATST = Advanced Technology Solar Telescope, a proposed major new US facility to be built the coming decade at a not yet identified site. In addition, the French-Italian THEMIS telescope on Tenerife may partially solve its critical angular resolution problem through adaptive optics.

[7] Multiconjugate AO was first formulated for solar physics (Beckers), but won't be daily practice soon.

Of course, AO delivers the important capability to feed spectrometer slits for high-resolution Stokes spectropolarimetry which is not possible at the DOT. However, Stokes filter magnetometry seems very well in reach on the DOT which combines absence of diurnal image rotation with absence of time-varying reflections, in particular with the Ba II 455.4 nm filter since this line has the largest linear polarization sensitivity of all lines in the visible. The accommodation design for this filter includes polarization coding. AO spectropolarimetry at other telescopes and tomographic wide-field imaging at the DOT, both with consistent long-duration 0.2 arcsec resolution, will be highly complementary and a desirable combination to many research programs.

Speckle system. The new DOT data-acquisition system collects solar images exclusively in the form of synchronous speckle bursts, using five digital cameras, data transmission via optical fibers to the Swedish telescope building, initial storage on RAID disk arrays, and archiving on high-density Exabyte AME tape cartridges, totalling up to 350 Gbyte per observing run (up to 2.5 hours at 30 s burst cadence).

The data-acquisition system has been designed and realized by IGF (Instrumentele Groep Fysica) at Utrecht with the DOT team. It is now essentially complete. The five cameras are 10-bit Hitachi KP-F100 cameras with 1296×1030 px chips. The optical fiber links were custom-built by IGF. The control computer and the data-acquisition computers (one per camera, each with digital frame grabber and 70 Gb RAID array) are from COMPAQ. The tape storage is an Exabyte Mammoth-2 with 7-tape library. The control software was designed and written by IGF.

The initial use of the new system took place on the DOT in February, using the G-band prime-focus channel and producing an excellent image sequence that is currently being speckle-restored (on the DOT computers on La Palma since these harbour larger processing capacity than the computer power available in Utrecht). It will probably be completed and available for inspection by the ISC9 meeting; a sample is shown in Fig. 1. Earlier trial runs identified various software problems that were remedied in the meantime by IGF. A test run using two cameras synchronously was also successful. Further software development is foreseen but basically, the system works.

Multi-wavelength system. The multi-wavelength secondary optics proved a much harder task than was originally anticipated. The main difficulty is that using lenses to achieve the necessary $10\times$ remagnification (the prime focus image has $0.2'' = 2\ \mu$m diffractive resolution) generates severe tolerance problems when requiring diffraction-limited resolution at wavelengths as diverse as Ca II H (396.8 nm) and Hα (656.3 nm). An elegant solution using secondary parabolic reflection was eventually discarded in favour of realization speed when it turned out that a lens system with affordable optics could be realized that requires less mechanical development (a mirror system would put the foci near the primary mirror; the lens system rides at the top of the telescope besides the incoming beam). This system is now being built, the design being complete and the extensive mechanical work half done. An unanticipated delay has arisen from initial lack of quality on the side of the lens manufacturer; this has been remedied by better testing and final-stage perfection procedures at the company, with input from the DOT team.

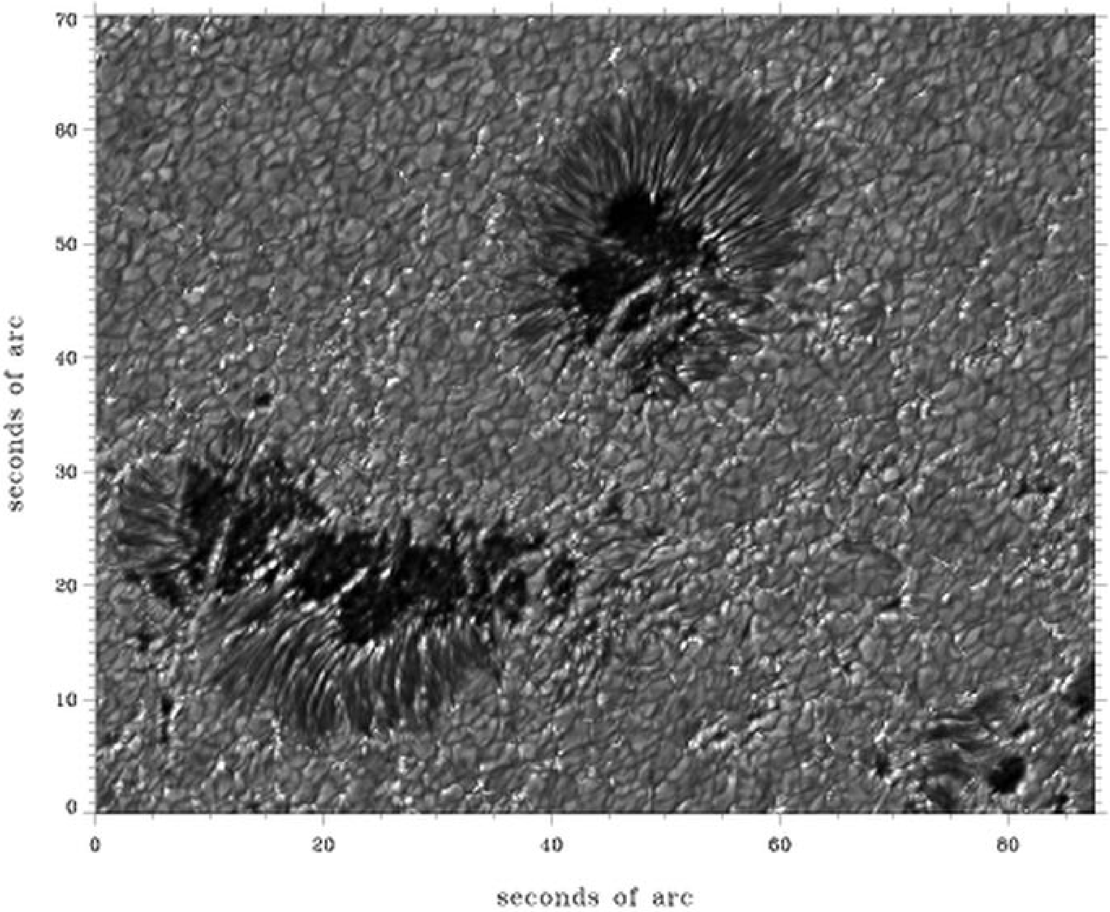

Figure 1: First speckle reconstruction with the new DOT data-acquisition system. G band ($\lambda = 430.5$ nm, FWHM 1 nm), active region AR 9359, February 23 2001, 09:19:49 UT.

Test observations. Observing campaigns were executed at the DOT during the past years primarily for test purposes. The G band, Ca II H and Hα optics designs were all tested and validated by actual observing runs using the initial video camera. Some of these runs were already part of international campaigns including space missions as anticipated in program item (ii). The resulting speckle-restored movies are of superb quality, are all available on the DOT website, have been widely advertised[8], and are presently the basis for work on the first DOT science papers at Utrecht (nature of umbral flashes, G-band bright point formation) and elsewhere (Stockholm, Ondrejov, La Laguna) as well as for PhD student proposals (Utrecht, Nijmegen, Stockholm, Irkutsk).

Additional channels. The multichannel system has five optics channels and five cameras plus speckle data pipelines in order to add wide-band continua to the narrow-band spectral

[8]Including a highly condensed movie on the *Astronomy Picture of the Day*, being the first Dutch APOD entry, and twice already as "conference highlight" during conference summary talks. The conference write-ups and popular accounts are available under "(p)reprints" at http://dot.astro.uu.nl.

diagnostics. These have science value on their own (for example to separate fluxtube bright point dynamics from non-fluxtube bright point dynamics) but are added especially to permit two-channel speckle restoration, a technique formulated by Keller & von der Lühe in which the narrow-band channel with insufficient S/N per speckle freezing time is restored through deconvolution from the synchronously measured wide-band MTF. This is most likely necessary for Hα for which the complex line formation physics requires five or more wavelength spacings across the line within the solar subsonic change time of 20 s per 0.2 arcsec.

An unforeseen but exciting extension to the multi-channel system has originated from a test of a tunable Lyot filter. This filter, built by V. Skomorovsky and G. Domishev at Irkutsk, selects a very narrow passband tuned to and across the Ba II 455.4 nm resonance line. The combination of filter and line turns out to deliver Dopplergrams of unprecendented resolution and sensitivity. The test was performed at the late SVST shortly before its demise because the filter is very large and not easily accommodated in the DOT. The results (available on the DOT website, with a popular account in Dutch) are so promising that the decision was taken to add this filter to the multi-wavelength system, as optional replacement of the blue continuum channel. The mechanical accommodation design is complete. The travel of Skomorovsky and Domishev to la Palma for the test was funded by NOVA, LKBF and SOZOU[9]. Last week INTAS (Brussels) has selected our proposal to support this Irkutsk–DOT collaboration the coming years.

DOT review. At the start of the DOT science validation period it was stipulated that towards its end an expert panel should review the DOT capability for front-line solar physics research. Accordingly, a DOT Evaluation Committee (DEC) has been formed by SIU director A. Achterberg. It consists of:

- Dr. Stephen E. Keil, director US National Solar Observatory (Tucson/Sunspot)
- Prof. Oskar von der Lühe, director Kiepenheuer-Institut für Sonnenphysik (Freiburg)
- Dr. René G.M. Rutten, director Isaac Newton Group (La Palma)

and will gather at Utrecht during March 29–30.

2 Project management, meetings, reviews

While it is no secret that the DOT project itself has no project manager but has and is being run as lifelong endeavour by DOT designer and builder R.H. Hammerschlag in a team too small (Hammerschlag and Bettonvil with stagiaires on the technical side, Sütterlin and me as scientists) to be managed, there is external management at various levels:

- IGF management under J. Verkerk, both with respect to the speckle data acquisition system ("electronische groep", P. van Haren and J. Builtjes), and with respect to the mechanical accommodation of the multi-wavelength optics ("mechanische groep", R. Klöpping);

[9]A fund supporting optical solar physics at Utrecht bequested by the late C. Zwaan, the DOT initiator.

- "DOT Technische begeleidingscommissie" (TBC) chaired by Achterberg, with J.W. Pel and J. Verkerk as non-DOT members, which advises on and reviews the DOT efforts;
- science management including outside reporting (NWO-GBE, EC, NATO, INTAS grants, coordinated and reported by me).

The TBC has been instrumental in settling the choice of optical system for the multi-wavelength system and detailing its design with help from the optical group at Dwingeloo. Its most recent meeting (March 1) addressed preparations for the coming DEC review.

The speckle data acquisition system was defined and developed in numerous IGF–DOT planning meetings. Mechanical planning was part of the regular IGF procedures.

The major science management activity was the ESMN mid-term review on Tenerife (September 2000) in which the network was rated "very excellent" by the EC controller from Brussels.

Presently, an extensive report on the DOT is being written for the DEC review. It will include financial detail. The NOVA-1 allocation to the DOT was in the form of a lump sum (275 kf) for technical support by IGF which requires no further detailing here.

3 Progress since last ISC report

- sucessful tests of the Ca II K and Hα optics at the DOT;
- procurement and completion of the five-pipeline speckle data acquisition hardware;
- completion of the basic speckle data acquisition software;
- completion of the multi-wavelength optics design;
- realization of most of the mechanics for the multi-wavelength optics;
- presentation of DOT movies in many talks, including five conferences abroad;
- first science result (umbral flash power distribution, presently being written up);
- INTAS grant awarded for Irkutsk–Kiev DOT collaboration.

4 Milestones

- March 26: UU Dies cluster project (see below);
- March 29-30: DEC review;
- May: installation of second wavelength channel and start of two-channel observations (G-band and blue continuum);
- September: installation of Ca II H channel and initial three-channel observations;
- late autumn: tests of the Hα Lyot filter;
- next spring: Stokes vector polarimetry tests with the Ba II Lyot filter.

5 Relations with collaborators

Dutch. The DOT has played a prominent role in technical education since its actual assembly on La Palma has relied on cheap labour from dozens of stagiaires (trainees) from technical schools around Utrecht. The emphasis in bringing students to the DOT will shift to astrophyscis when regular observing becomes feasible. The move of J. Kuijpers to Nijmegen widens astronomical DOT interests to outside Utrecht; he has submitted an OIO proposal relying on DOT observations of prominences.

Spaniards. The DOT is permitted on La Palma under a MoU with the IAC, in the absence of a formal Netherlands–Spain agreement regarding the Dutch presence on La Palma (in the ING Holland participates under the UK umbrella). The IAC director has consistently tried to use the DOT as leverage to realize a formal national agreement, or at least to get Spanish salaries paid from Dutch funding according to the "postdoc" clause in other agreements (including the Spain–UK one). Presently, he has consented to the view that the successful ESMN bid for Brussels funding and the resulting three-year ESMN postdoc at the IAC fulfilled this condition.

The IAC solar group participates also in the INTAS grant that was awarded a few days ago. They are prepared to help defend the notion that their share of this grant (20 kEuro for IAC stays by Kiev scientists) should be seen as DOT-related manpower fulfilment the coming two years.

The ESMN ends April 30, 2002. It is likely that I will again act as coordinator in a new solar-physics network bid in the current (and last, deadline May 4) round of the 4th Framework TMR program. If so, the IAC group will again be a partner.

The IAC solar group has world-leader expertise in polarimetry. They have offered to participate in DOT polarimetry tests with the Siberian Ba II filter. These are foreseen for autumn.

Swedes. The DOT is operated from the Swedish solar telescope building on La Palma without rent other than cost sharing. The DOT team has gotten and gets much help from the Swedish team (Research Station for Astrophysics of the Royal Swedish Aacdemy of Sciences), in particular its director G. Scharmer and the local staff on La Palma (four persons). Reversedly, Hammerschlag has extensively assisted in the design and fabrication of the new turret for the NSST.

The close collaboration is seen as highly beneficial to both by both groups. In addition, there is intense scientific collaboration (including a PhD student at Stockholm from Utrecht working on a thesis combining DOT and SVST sunspot observations), also within ESMN context.

Other Europeans. As noted above, a new bid for a TMR network grant will probably be submitted in April.

Americans. The solar physics group at Bozeman (Montana) has suggested to submit a joint proposal to NSF asking funding for collaboration in which Montana students come to the DOT for co-observing. On our side, such collaboration is welcome by the time

DOT observing by outsiders becomes feasible (see below). Depending on the DEC review outcome, we anticipate joint writing of such a proposal this autumn.

Big Bear Solar Observatory (formerly of Caltech, now of NJIT) has the best seeing of US solar observatories and may be seen as the US counterpart to La Palma. It is the only other solar observatory aiming at consistent speckle processing. There is close contact regarding speckle techniques (C. Denker) and future co-observing (P. Goode, director). At 99° (6.6 hours) separation both sequence overlap and continuation are science desirables.

The ATST, for which the National Solar Observatory is the main agent, must necessarily be an open telescope. Its road map specifies the DOT as example to be studied. This role is likely to be taken up with the NSO director during the DEC review.

Ukrainians and Russians. A currently held NATO linkage grant includes collaboration at the DOT by colleagues from Kiev. Two Kiev instrumentalists (S. Osipov and O. Andriyenko) will probably come to La Palma this summer to help with the initial two-channel observations. The INTAS grant also covers future trips by these two to the DOT, in addition to future stays of Skomorovsky and Domishev to work on and with their Ba II filter.

6 Critical areas

DOT future. Obviously, the major threat to the DOT is lack of future funding. The present funding ends formally in September, effectively next spring. A proposal for subsequent support has been submitted to NWO.

It is equally obvious that much depends on the outcome of the DEC review and on the longer-term policy decision that SIU must take in the near future whether solar physics should remain an Utrecht interest or not.

Manpower. The DOT has always been and still is a manpower-limited project. Hammerschlag has managed to build a world-class telescope on a shoestring budget with much smaller manpower investment than any solar telescope elsewhere (the next smallest solar telescope operation is the Swedish one, at double the present DOT budget and including two full-time and two part-time support staff on La Palma).

A major constraint set by manpower limitations is that observing at the DOT competes seriously with DOT development. DOT observing presently requires the presence of Hammerschlag, Bettonvil and Sütterlin at the telescope, or at least two of them if everything works to perfection. On the other hand, the realization of the multi-wavelength hardware at IGF requires the presence of Hammerschlag and Bettonvil at Utrecht, and the development of the speckle processing software (see below) requires the presence of Sütterlin at Utrecht. In the future, DOT observing should become sufficiently foolproof that others (like me, students, colleagues from abroad desiring DOT observations or DOT co-observing) can run the telescope by themselves (which indeed is the way in which the SVST was handled). This needs considerable investment in developing the required safeguarding hard- and software, however, and has lower priority at present than getting the multi-channel system to work.

A consequence of this constraint is that the DOT is not yet formally announced as solar facility available to others; there is no formal DOT time allocation committee yet. Requests for DOT observing reach us regularly[10] and are handled on a best-effort basis: we try to combine DOT observing sessions with international campaigns, and indeed have succeeded to do so with various test runs sofar (prominence Hα coordinated by Göttingen, sunspot oscillations coordinated by Potsdam and by Stockholm). The observations that we do take and process are available to anyone in an open-data policy that is becoming the norm in solar physics[11].

Speckle processing. The obvious disadvantage of post-detection speckle restoration over AO is the stupendous amount of computer processing that it requires. A 2.5 hour run requires about two weeks of processing per camera using the DOT computers on La Palma. A limiting constraint at Utrecht is the availability of (expensive) IDL licenses (the present code is in IDL). The large amount of postprocessing represents another major manpower limitation restricting DOT data gathering to campaigns rather than full-season operation.

Scientifically, limited campaigning is not as bad as it would seem from nighttime practices where 100% telescope utilization is an overriding requirement. Solar physics has been far more limited by the scarcity of really good seeing than nighttime astronomy, making telescope availability a minor factor[12]. This situation is now changing with the advent of speckle restoration and AO, but initially, campaignwise operation is one with which we can live.

Speckle processing must and will get considerably faster. Affordable computer processing doubles every two years in speed, but more importantly, speckle reconstruction lends itself well to parallellization (treating the hundreds of isoplanatic patches covering the full field independently). An effort has started to convert the IDL code into C as a first step, accelerated by strong support from UULUG[13] who aim to achieve parallel DOT speckle restoration as demonstration on a temporary 365–computer cluster they try to set up as celebration of the 365th UU anniversary on March 26.

On a longer time scale, the development of parallell speckle codes and the realization of parallel computing at La Palma are high on the DOT priority list. Overnight processing of the daily harvest is a realistic goal. When that is realized and DOT observation is made foolproof and therefore open to outsiders, the DOT should become the first-choice high-resolution imager for almost any solar physics program.

[10]Solar physics is a relatively small community. The more serious potential users are all well-known to us and vice-versa. In any case, most solar observing is nowadays done in multi-telescope campaigns with worldwide coordination and webbased daily targeting.

[11]Even for space missions. TRACE data are immediately available, YOHKOH has just canceled its one-year restriction.

[12]For example, the many important papers generated by the SVST are all based on just a few good days per full observing season. Characteristically, the Lockheed group took over the SVST for a month at a time, flew their optics, computer, and observing experts in sequentially, then took hundreds of data tapes home, but ended up actually analysing only the best two or three of these.

[13]Utrecht University Linux User Group, the largest in Holland.