DUTCH OPEN TELESCOPE

Status and Prospects

Report for the DOT Evaluation Committee

DOT Team

Utrecht, March 22, 2001

Contents

1 Summary

The three-year "initial science validation" funding period of the Dutch Open Telescope (DOT) ends formally in September. The three-year plan aimed to (i) realize a three-wavelength imaging system, (ii) initiate science observing, and (iii) explore post-detection image reconstruction.

A review by external experts was stipulated to take place towards the end of the three-year period. The present report serves as introduction for this evaluation.

Image reconstruction was 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 and have demonstrated the superior imaging capability of the combination of DOT optics and mechanics, La Palma seeing, and speckle reconstruction. They are also producing initial DOT science. The definitive design combines all test setups in an elaborate extension to the telescope top. All optics are now in production with the component quality confirmed; the mechanical accommodation is halfway complete. The first multi-channel observations should become available this 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, as are polarimetry tests with this filter.

The science niche that the DOT may and should fill the coming years in solar physics is to be the premier high-resolution tomographic imager of the magnetic fine structure, topology, and dynamics of the photosphere, low chromosphere, and high chromosphere. The new data acquisition system, the relatively large field (set by the camera chips, not by the isoplanatic patch) and the frequency of seeing good enough for restoration to the diffraction limit ($0.2''$) at La Palma combine into long-duration large-field multi-wavelength imaging capability that will be desirable for both standalone solar physics programs and in joint multi-telescope campaigns, in particular teaming up with AO-fed Stokes spectropolarimeters that will come on-line elsewhere, and with solar telescopes in space.

Lack of funding is the major dark cloud on the DOT horizon. The present manpower (2 permanent, 4 temporary positions) is a minimum and too small to combine frequent observing with telescope development. Budget estimates are given below with financial detail on the past period. DOT continuation requires minimally 620 kf/year[1] plus science support.

[1] Monetary conventions in The Netherlands (until next year): 1 f = 1 Dutch guilder, 1 kf = 10^3 guilders, 1 Mf = 10^6 guilders. Exchange rates: 1 \$ $\approx$ 2.4 f, 1 Euro = 2.204 f.

2 Preamble

2.1 Dutch Open Telescope

The DOT is an innovative optical solar telescope which achieves high angular resolution (0.2″) through combining openness (avoiding internal seeing not through telescope evacuation but through wind flushing of the primary mirror and the telescope interior) with an open support tower (avoiding the excitation of local turbulence by wind blocking) and an excellent site on La Palma where the trade winds are often sufficiently strong for telescope flushing and to keep the ground-heated boundary layer of turbulent convection all day below the 15 m DOT tower height.

2.2 DOT Evaluation

This report describes the status and prospects of the Dutch Open Telescope (DOT) for the DOT Evaluation Committee (DEC).

The DEC has been called together by Utrecht Sterrekundig Instituut (SIU) Director A. Achterberg to advise on the science viability of the DOT at the end of its three-year "science validation" period which formally ends in September (effectively next spring).

The DEC consists of

- Dr. Stephen E. Keil, director NSO;
- Prof. Oskar von der Lühe, director KIS;
- Dr. René G.M. Rutten, director ING.

The DEC gathers at Utrecht during March 29 and 30.

2.3 This document

This report condenses information that is spread over proposals, progress reports and conference proceedings. The report assumes expertise in solar physics and optical instrumentation.

This report uses many abbreviations, *viz.* of funding agencies, solar institutes, solar telescopes. An abbreviations glossary including weblinks is given in Section 6 on page 19.

2.4 Other documents

2.4.1 Websites

These are websites of immediate relevance to the DEC:

- DEC documents: http://dot.astro.uu.nl/DEC. A collection of documents that may be useful to the DEC, including this report. Specified in the next section.
- DOT home page: http://dot.astro.uu.nl.
  The public DOT homepage, with links to the database and movie pages. The (P)reprints links, the DOT photographs and the images from the Ba II filter test may be most interesting to the DEC.

– DOT database: http://hst33127.phys.uu.nl/∼pit/DOT.
The DOT has an open data policy: all DOT data are made available on request. This web page provides a thumbnail overview.

– DOT movies: http://hst33127.phys.uu.nl/∼ pit/DOT/Showpiece/movies.html.
This page summarizes DOT achievements most succinctly. Playing the movies taken sofar in DOT optics tests (G-band, Ca II K, Hα) is highly recommended as a quick insight in the DOT imaging capabilities.

– ESMN home page: http://www.astro.uu.nl/∼rutten/tmr.
Home page of the EC-TMR network in which our efforts are embedded.

2.4.2 Proposals and reports

Copies of the documents below are made available to the DEC at the specific DEC website (above) and will also be handed out at the start of the visitation.

– this report. File: *decreport.pdf*.

– NWO/GBE proposal dd. Oct 15, 1997. This proposal asked 200 kf/year over five years to equip the DOT with secondary optics and data acquisition, explore image restoration methods, and initialize science observing. The request was to ASTRON (at that time the national astronomy foundation of NWO); the first three-year tranche of the proposal (600 kf) was eventually awarded by NWO-GBE. This grant together with the EC-TMR ESMN grant laid the foundation for the three-year "science validation period". File: *nwoprop1997.pdf*.

– NOVA proposal dd. June 8, 1998. This proposal "Instrumentation for the Dutch Open Telescope" to NOVA resulted in the additional funding by NOVA, FNS and SIU that completed the "three-year science validation" allocation. The planning and financial tables in this proposal formed the basis for the three-year budget. File: *novaprop1998.pdf*.

– ISC9: DOT progress report to the NOVA Instrument Steering Committee, dd. May 11 2001. Some content is duplicated below. File: *isc9dot.pdf*.

– NWO/GBE proposal dd. Feb. 1, 2001 by Rutten and Hammerschlag. This new proposal to NWO asks for 1 Mf for 2002–2006 to use the DOT for studies of the magnetic coupling between photosphere and corona and of the dynamics and evolution of solar active regions. The verdict should be in by autumn. File: *nwoprop2001.pdf*.

– ESMN midterm report dd. Aug 28, 2000. Of less direct importance to the DEC but showing how the DOT efforts are embedded in European networking[2]. File: *esmn-midterm.pdf*.

– INTAS proposal dd. Sep 21, 2000. Of less direct importance to the DEC but showing how the DOT efforts also use East-West funding. This proposal was recently accepted by INTAS[3]. File: *intasprop2000.txt*.

[2] Actually, the ESMN was triggered by the DOT since DOT funding need motivated the proposal and the Utrecht coordinator role. A renewal bid for a TMR network starting in May 2002 will probably be submitted in April.

[3] An earlier NATO Linkage Grant will support travel of the same two Kiev instrumentalists (Osipov and Andriyenko) to the DOT this summer/autumn. Another grant proposal for the Irkutsk collaboration (Skomorovsky and Domishev) has been submitted to a Dutch fund (Pieter Langerhuizen Fonds). The test of the Irkutsk Ba II filter in 2000 was funded by SOZOU, NOVA and LKBF.

2.4.3 Conference presentations

The following publications are a selection of the (p)reprints available on the DOT website:

- Sütterlin et al. (2001): description of the new data acquisition system and presentation of the Ba II filter test;
- Rutten et al. (2001a), Rutten (1999): DOT progress reports for solar physicists;
- Rutten et al. (2001b): review for a wider audience including climatologists.

There are also older reports as well as popular accounts (mostly in Dutch) on the DOT website. A special one is a C. Zwaan memorial published in the 1999 JOSO Annual Report discussing the JOSO origins of the DOT project.

2.4.4 Science papers

DOT science awaits the completion of the multi-wavelength imaging system, but two papers that result from the test campaigns are in preparation:

- Sloover *et al.*: umbral dynamics, based on DOT and SVST Ca II H & K filtergram sequences. It addresses the chromospheric umbral flash phenomenon, which is found to have an intriguing spatial power distribution at 3 min periodicity over the umbra and inner penumbra.
- Sütterlin *et al.*: description of the Ba II filter test. It was performed at the SVST, but by the DOT team and with the DOT image acquisition system because the SVST Megaplus-based system was found to be too slow for speckle registration. The resulting speckle-restored Dopplergrams are superb.

Other papers are currently being completed that address the diagnostics and analysis techniques on which the DOT multi-wavelength science will be based:

- Kiselman *et al.*: formation of G-band bright points. The contrast enhancement that makes tiny magnetic field concentrations ("fluxtubes") stand out as network bright points in the G band is essential to the DOT as photospheric field topology indicator but not fully understood (issues clarified in Rutten et al. 2001c).
- Krijger *et al.*: chromospheric dynamics from TRACE. Krijger has spent his graduate-studentship sofar on developing the Fourier and correlation tracking techniques that will be needed to analyze DOT multi-wavelength image sequences. He used multi-wavelength image sequences from TRACE for this purpose, also developing the space-data analysis software needed for future DOT–TRACE and other joint DOT–space telescope campaigns. This paper is a comprehensive study of chromospheric oscillations and is close to submission. Other papers on correlation tracking and granular pistoning are in preparation (with external coworkers B.W. Lites, R.A. Shine, T.D. Tarbell, Th. Straus, P. Heinzel, W. Curdt, Th. Roudier).

3 Introduction

3.1 Solar physics in The Netherlands

Solar physics started in The Netherlands at the Utrecht Physics Laboratory at the start of the 20th century and moved with Minnaert to Utrecht Observatory. Solar physics was the major field pursued there during 1930–1960 (*e.g.,* Minnaert, Houtgast, de Jager, Fokker, Zwaan, Kuperus, Kuijpers, Rutten plus other staff members, many graduate students, and postdocs including van den Oord and Schrijver).

De Jager also initiated and led a sizable solar physics group at the non-University Space Research Laboratory (now SRON; de Graaff, de Feiter, Brinkman, van Beek, Hoyng, Mewe and others).

At present, solar physics is a minor part of Utrecht astrophysics. At the SIU Kuperus retires this autumn, Kuijpers has left for Nijmegen, van den Oord has left solar physics. The remaining SIU solar physics contingent equals the DOT team specified in Table 1 on page 11, with permanent staff limited to Hammerschlag and Rutten.

SRON solar physics is now limited to P. Hoyng who maintains a parttime interest in dynamo theory.

Outside Utrecht solar physics is now also done at the Institute for Plasma Physics (NWO) in Nieuwegein by Prof. J. Goedbloed with postdocs and students and at the Physics Faculty of Nijmegen University by Prof. J. Kuijpers (who recently accepted a fulltime position there). Both groups are oriented towards theoretical plasma-astrophysics. Kuijpers is presently president of the Solar Physics Section of the EPS/EAS. Goedbloed is part of the EC–TMR PLATON network.

At the SIU, a NOVA-funded "dakpan" (overlap replacement of a member of the permanent staff well before retirement) at professorial level may or may not be devoted to solar physics in the near future.

3.2 Brief DOT history

The DOT project was started by C. Zwaan and Hammerschlag in the early 1970's as a follow-up of their site-testing activities in JOSO context (cf. Rutten 1999, Rutten 2000, Rutten et al. 2001a). The design was described by Hammerschlag (1981) in Dick Dunn's 1980 Sac Peak Summer Workshop proceedings and earlier in JOSO annual reports. The actual realization took long, primarily due to the combination of new technology and small manpower.

The DOT (then called OTT) project accelerated with a grant from STW which funded the temporary hiring of two engineers, the assembly at Delft University, and the installation on La Palma during 1996–1997. The DOT First Light Ceremony was performed on October 31, 1997 by high dignitaries (Dutch Crown Prince Willem-Alexander and the President of the Canary Islands) in the presence of many officials.

The DOT demonstrated soon after its first light with a simple video camera that the open-telescope concept can indeed replace the vacuum solution to internal seeing used sofar in high-resolution solar telescopes. This breakthrough success is now being copied in the major new solar telescope projects abroad (GREGOR, ATST).

The award of an EC-TMR grant (proposal available on the ESMN website) and of an NWO-GBE grant (document *nwoprop1997.pdf* in the DEC directory) laid the foundation to extend the simple STW-funded technology-demonstration configuration with science-viable secondary optics and image registration. Additional funding from NOVA convinced the Faculteit Natuur- en Sterrekunde

(FNS) and the Sterrekundig Instituut (SIU) of Utrecht University to allocate considerable amounts to the project as well (DEC document *novaprop1998.pdf*). The resulting three-year "science implementation period" eventually started in September 1999 with a total budget of 3 Mf

NWO–GBE and FNS stipulated that an expert review be held towards the end of the three-year period to evaluate the progress and advise the Dutch agencies on the resulting science capability of the DOT. Hence the DEC visitation and this report.

3.3 DOT three-year plan

The three-year plan aimed to implement secondary optics and data acquisition systems to bring the DOT science capabilities at the forefront in optical solar physics, and to demonstrate these capabilities. The program goals were:

(i) – installation of multi-channel optics to feed solar images at different wavelengths simultaneously to synchronized CCD cameras in order to realize "tomographic" imaging of the deep photosphere (G band around 4305 Å), the low chromosphere (Ca II K at 3933 Å) and the high chromosphere (Hα at 6563 Å, rapidly tunable);

(ii) – initiation of high-resolution observing of the topology and dynamics of solar magnetism;

(iii) – exploration of image restoration techniques.

Officially this program expires coming September. Effectively, the funding ends next spring/summer (both salaries and exploitation, see Table 1 on page 11 and Section 4.9 on page 12).

The funding was used to develop and build a new DOT imaging system that meets the above goals and is presently being installed after extensive on-telescope component tests which included initial science observations. More below in Section 4.

3.4 DOT management

The DOT effort has no formal manager but has been and is led by Hammerschlag in a team that has varied from very small to quite large at times when many trainees and/or IGF personnel share in assembly. External management exists at various levels:

- IGF management and planning under J. Verkerk, currently with respect to both the speckle data acquisition system and the mechanical accommodation of the multi-wavelength optics. The IGF is briefly described in Section 4.8.
- "DOT Technische Begeleidingscommissie" (DTBC) chaired by Achterberg, with J.W. Pel (University of Groningen) and J. Verkerk (IGF) as non-DOT members. The TBC advises on and reviews the DOT efforts;
- NOVA–ISC scrutiny twice a year, requiring formal reports and presentations;
- science management including outside reporting (NWO–GBE, EC–TMR, NATO, INTAS grants, coordinated and reported[4] by Rutten).

[4]The major science reporting activity has been the ESMN Mid-Term Review last autumn on Tenerife in which the network was rated "very excellent" by the Brussels EC controller (document *esmn-midterm.pdf*).

4 Current status

4.1 Initial speckle tests

The DOT project is currently funded by SIU, UU, NWO-GBE, NOVA, and EC–TMR in the three-year "initial science validation" program described above. At the start, program goal (iii) was thought the hardest and to be explorative only, but it actually became a success very quickly after the hiring of ESMN postdoc P. Sütterlin. He brought German speckle expertise to Utrecht, specifically the speckle masking technique (*e.g.,* Weigelt 1977; von der Lühe 1985, 1993; de Boer 1995) which was found successful even with the simple analog DOT video camera used sofar with digitization at only 8 bits. Test runs with this initial system, mostly part of international multi-telescope observing campaigns, produced outstanding movies (DOT website). 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 in the form of five digital 10-bit large-field cameras that run synchronously in speckle mode and dump speckle bursts on a storage system large enough to permit continuous observing during many hours. This elaborate and sophisticated system is now ready thanks to large design and implementation effort of the Utrecht IGF and is being installed on the telescope. Details are given below and in Sütterlin et al. (2001); first images are shown on the DOT website.

4.2 Speckle imaging system

The new DOT data-acquisition system collects solar images consistently 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: they are bi-directional and include camera-specific control from the distant master computer. The latter 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 (via the web on the DOT computers on La Palma since these harbor larger processing capacity than the computer power available in Utrecht). It will be available for inspection by the DEC; a sample is shown in Fig. 1. A test run running two cameras synchronously was also successful. Further software desires and development are foreseen but basically, the system works — fulfilling the ultimate goal of program item (iii) well in advance.

4.3 Multi-wavelength system

The multi-wavelength secondary optics (program goal (i)) proved a much harder task than originally anticipated. The main difficulty is that to achieve the necessary 10× remagnification (the prime focus image has $0.2''$ = 2 μm diffractive resolution) custom lens combinations are needed

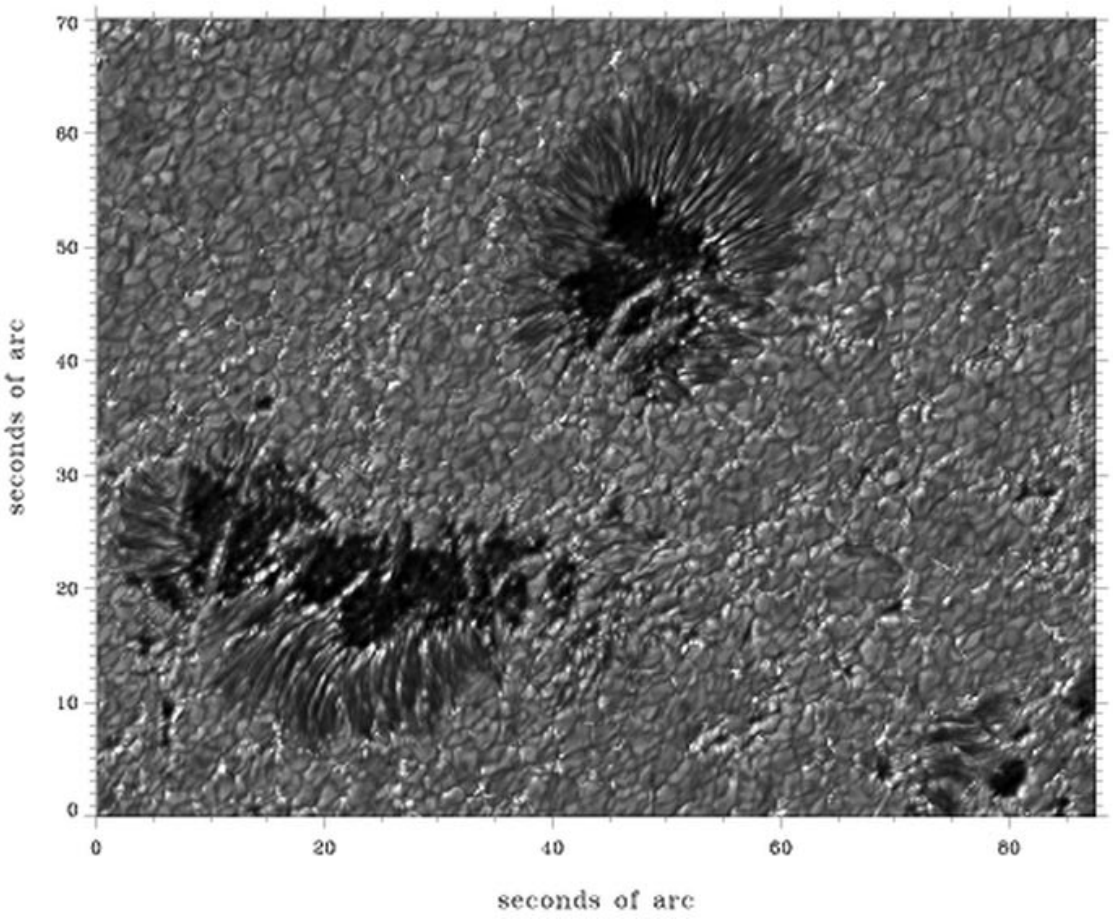

Figure 1: First speckle reconstruction with the new DOT data-acquisition system. G band ($\lambda = 430.5$ nm, FWHM 1 nm), active region AR 9359, February 23 2001, 09:19:49 UT. The full movie is now avaialble on the DOT website.

per beam for diffraction-limited resolution at wavelengths as diverse as Ca II H (396.8 nm) and Hα (656.3 nm). Extensive optics modeling and testing showed eventually that a remagnification system with affordable lenses can be realized. This secondary optics system consists of beamsplitter cubes, dichroic mirrors and lenses, and permits telecentric filter mounting even for the large Lyot filters. It rides at the top of the telescope besides the incoming beam (except for the G-band beam which is axial). The design is complete, most of the optics has now been manufactured (initial quality problems at one production firm were remedied by quality-control input from the DOT team; interferometric tests confirmed recently that the lenses now meet the specifications). The extensive mechanical work is half done (IGF).

The first multi-wavelength observations should be in by summer, before the formal end of the three-year period. By the effective end of the present funding (late next spring) the three-wavelength system (G band, Ca II H and Hα) should be operational.

4.4 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 analog video cameras. Some of these runs were already part of international campaigns including space missions as anticipated in program goal (ii). The resulting speckle-restored movies are of superb quality, are all available on the DOT website, have been widely advertised[5], and are presently the basis for current work on the first DOT science papers here (Section 2.4.4) and elsewhere (Stockholm[6], Ondrejov[7], La Laguna[8]) as well as for PhD student proposals (Utrecht[9], Nijmegen[10], Irkutsk[11]).

4.5 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 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 and demonstrated by Keller and von der Lühe (1992) 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 samplings across the profile within the solar subsonic change time of 20 s per $0.2''$.

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 unprecedented 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 under (P)reprints) 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 SOZOU, NOVA, and LKBF. Recently, INTAS (Brussels) has selected our proposal to support this Irkutsk–DOT collaboration the coming years.

4.6 Personnel

4.7 SIU personnel

The current DOT personnel located at the SIU is specified in Table 1. Rutten and Hammerschlag are permanent; Sütterlin, Bettonvil and Krijger have temporary contracts that end next year. A brief indication of their respective roles, split between instrumentation and science:

[5] Including a highly condensed movie on the *Astronomy Picture of the Day*, being the first Dutch APOD entry, and shown twice already during conference summary talks.

[6] L. Rouppe van der Voort, PhD thesis on sunspot dynamics.

[7] M. Sobotka, on umbral fine structure.

[8] V. Martínez Pillet and J. Sánchez Almeida, testing their MIASMA hypothesis in penumbrae and quiet sun.

[9] AIO vacancy, and 2 OIO's requested in NWO-GBE proposal (*nwoprop2001.pdf*).

[10] OIO requested by Kuijpers from NWO-GBE for research on prominence plasma physics with DOT data.

[11] V. Skomorovsky, completing a Russian "Doktor" thesis including the Ba II filter test.

Table 1: Present DOT personnel at the SIU. All at 100% of their time except teaching obligations (permanent staff 40%, AIO's & OIO's 15%). Graduate student (title "Drs.") supervision is by Rutten.

name	title	speciality	employer	period
R.J. Rutten	Dr.	solar physics	SIU staff	until 2007 (nominal)
R.H. Hammerschlag	Dr. Ir.	optics/mechanics	SIU staff	until 2009 (nominal)
P. Sütterlin (PD)	Dr.	solar physics	EC–TMR	until 30-04-2002
F.C.M. Bettonvil	Ir.	optics/mechanics	GBE (ASTRON)	until 30-09-2002
J.M. Krijger (OIO)	Drs.	astrophysics	GBE	until 30-09-2002
vacancy (AIO)	Drs.	(astro-)physics	SIU	2001 – 2005

- Hammerschlag: DOT project manager, DOT design and realization;
- Bettonvil: opto-mechanics engineer. On the project since 1992 in successive temporary postings, presently on the NWO/GBE grant through ASTRON. His contribution to the DOT effort is and remains essential for the project but his UU contract was terminated last year by FNS without hope of renewal. NWO-GBE then consented to re-allocate the funding for the still open science postdoc in the NWO-GBE grant to cover his salary instead, on the premise that without completion of the multi-wavelength system there can be no science with it. ASTRON was willing to be the effective hiring agency and is prepared to keep him allocated to the DOT and stationed at SIU as long as external funding covers his salary;
- Rutten: DOT project scientist, DOT science utilization;
- Sütterlin: ESMN postdoc, speckle data-acquisition architecture, speckle processing, solar physics applications;
- Krijger: graduate student on the NWO/GBE grant, so far using multi-wavelength TRACE sequences as precursor to DOT multi-wavelength analysis.
- AIO vacancy: left open awaiting multi-channel observing and to be filled soon now that the imaging system nears completion. The thesis effort will consist of multi-wavelength observation and tomographic analysis of magnetic fine structure.

Additional SIU effort has been spent on the DOT project by SIU computer manager E.B.J. van der Zalm.

Mechanic P.W. Hoogendoorn has been part of the DOT team from the OTT start, as member of the SIU until recently when the SIU workshop was dismantled and he transfered to IGF. He has been and is the main actual DOT "builder". IGF is willing to keep him allocated to the DOT while his salary is externally funded.

Over the years, dozens of students from technical schools in and around Utrecht have assisted through traineeships in the assembly of the DOT at Delft, Utrecht and La Palma. In the future, more students will come from astronomy, especially when student observing becomes feasible. Student participation in DOT operation is educationally desirable since Utrecht students have no other access to hands-on telescope experience.

4.8 IGF personnel

IGF is a faculty service department and workshop for the professional development and realization of sophisticated scientific instrumentation, with engineering expertise at the academic level in electronics, software and mechanics.

The electronic and software engineers who worked on the DOT data-acquisition system and the fiber links are J. Builtjes, D. Driessens, P. van Haren, J. Haverkamp, O. Jalving, H. Langedijk, J. Langerak, and Chr. Straman. Together they spent 4771 hours in the project during 2000.

The mechanical engineers who worked on the DOT structure and optical design are A. Jägers, J. de Ruijter, and L. Kok. The manufacture and assembly was carried out by M. van de Berg, J. van Veldhuizen, P. Hoogendoorn, G. van Voorst, G. Hörchner, J. Janssen, G. de Jong, J. Bos and D. Stoker.

4.9 Finances

4.9.1 Three-year budget outline

The three-year DOT needs were defined in Tables 1 – 3 in proposal "Instrumentation for the Dutch Open Telescope" dd. June 8, 1998, (file *novaprop1998.pdf*) with a distribution over funding agencies and grants given in Table 4 of that document. A summary of the non-personnel costs is given here in last column of Table 2. The first column specifies the projected coverage from the different funding agencies as laid down in the three-year balance defined by A. Achterberg in September 1998.

Table 2: Non-personnel budget for the three-year DOT program as defined in 1998. The costs in the righthand part are specified in more detail in novaprop1998.pdf. The coverage from the various funding sources in the lefthand part was specified by A. Achterberg to FNS (September 1998).

Source	Income (kf)	Cost category	Expenditure (kf)
SIU	536	Exploitation	825
FNS	328	DOT removal reservation	36
NOVA	275	Instrumentation	390
GBE	190	Observing trips	149
EC–TMR	71		
Personnel	pm	Personnel	pm
Total	personnel + 1400	Total	personnel + 1400

Comments to Table 2:

- Exploitation costs. Detailed in Table 3 in document *novaprop1998.pdf* , including the CCI contribution, cost sharing with the Swedish group, local manpower (mostly members of the Swedish group on hourly basis), telescope hardware, maintenance, insurance, and travel to La Palma for technical purposes (100 kf/year).
- DOT removal reservation. The DOT is operated under a temporary agreement[12] between NWO and the IAC which stipulates that the DOT shall be removed if the agreement is not continued.

[12] The agreement is up for renewal this autumn. The clause that the DOT presence on La Palma requires Dutch

The DOT budget contains contingency for this unhoped-for event.

- Instrumentation. Table 2 of *novaprop1998.pdf* details the original cost estimate which relied for an additional 160 kf on using older Kodak Megaplus cameras of the SVST. The quick success of speckle processing and subsequent definition of the speckle imaging system superseded the estimate.
- Observing trips. These were put in the budget as distinctive from maintenance and instrumentation travel to the DOT, but in practice these two have been mixed since all DOT observing sofar was also part of installation development, optics tests, etc. The costs of observing trips were and are budgeted at 1 kf for travel and 75 f/day per person[13].
- Personnel. The pm entries in Table 1 were detailed in document *novaprop1998.pdf* and covered salaries for:
  - engineer Bettonvil (2 years)
  - mechanic Hoogendoorn
  - one ESMN postdoc
  - one postdoc from NWO-GBE
  - one graduate student from NWO-GBE (OIO)
  - one graduate student from SIU (AIO)

  in addition to permanent SIU personnel (Hammerschlag, Rutten, van der Zalm).

These tables formed the input to a detailed and complex budget scheduling proposal (in Dutch, so not copied to the DEC directory) to FNS by SIU director Achterberg, in which the estimates above were met from the total mixture of funding from SIU, FNS, NWO-GBE, NOVA, and EC–TMR as specified in the lefthand part of Table 2.

As noted above, Bettonvil's salary was covered only until last year by FNS; he now occupies the GBE postdoc slot originally intended for DOT science. Hoogendoorn was transfered from SIU to IGF in the meantime.

Small additional amounts were awarded later by NATO, SOZOU, and LKBF.

4.9.2 Three-year budget expenditures

The actual expenditures of the three-year program are summarized in Table 3. Direct comparisons to the original budget schedule are nontrivial though various circumstances: the mixing of technical and observing travels to the DOT, the budgetary split between expenditures on La Palma and at Utrecht, the separate treatment of ESMN (EC–TMR) accounting, various commitments, and non-coverage of costs which will be made the coming observing season versus already budgeted costs of salaries until their ending dates next year (Table 1). For this reason the personnel costs are again taken out.

Comments to Table 3:

- Travel to La Palma, a total of 59 trips and 1220 mandays at La Palma sofar. Mostly plane tickets, plus equipment transported as flight bagage, insurances, small allowances (f 25/day) for non-academics.

funding for a partial salary at the IAC has sofar been waived in recognition of the fact that Rutten's ESMN coordinatorship has brought a three-year postdoc to La Laguna. The recently awarded INTAS grant may fill a similar role during 2002–2003.

[13] The DOT team does not stay in the RdlM Residencia but rents cheaper housing on the west side of the mountain, as close as possible to RdlM but still at least 30 min away, driving two ancient cars left over from the 1996 STW-funded DOT assembly.

Table 3: Non-personnel expenditures of the three-year DOT program sofar.

Description	Amount (kf)
Travel to La Palma	87
Exploitation La Palma	202
Computing (general)	43
Instrumentation	457
Personnel	pm
Total	personnel + 789

- Exploitation costs. This item covers the total expenditure at La Palma for which bookkeeping is done in pesetas (132 kf; housing rents, transport costs, RdlM Residencia meals, DOT structural maintenance, Swedish building cost sharing) plus the RdlM Common Services (30 kf sofar, the present IAC bill is late) and 40 kf paid in The Netherlands for tools, pointing control electronics and maintenance materials. The outline specification in Table 3 of document *novaprop1998.pdf* amounted to 275 kf/year, including operations travel (100 kf/year) and computing. The actual expenditure (87 + 202 + 43 = 332 kf) is appreciably lower because the multi-wavelength system is not operational yet, at a yearly cost level of 130 kf plus travel.
- Computing (general). This item covers computers, disks, memory extensions, IDL licenses etc. for the guiding control, data processing at La Palma and analysis at Utrecht. The data acquisition computers (5 COMPAQ PC's) are part of item Instrumentation.
- Instrumentation. The realization of a full speckle system led to higher expenditure than budgeted. The system is essentially complete except for the necessary purchase of tape cassettes for speckle data storage (f 230 per 60 Gbyte tape). The amount is made up by the digital CCD cameras, fiber links, data-acquisition computers, UPS, optical components and mechanical hardware.
- Total. The actual left-over funding available for the completion of the multi-wavelength system amounts to 560 kf and suffices to maintain the DOT efforts until next summer. A commitment of 50 kf to organize the third ESMN school[14] brings the total (789 + 560 + 50 = 1399) to the budgeted 1400 kf in Table 2.

[14]The first was "Radiation Hydrodynamics" at Oslo, the second "Astrophysical spectropolarimetry" on Tenerife. The third will be "Solar magnetism" the coming winter and may take place at Dwingeloo.

5 Outlook

5.1 DOT niche

The superb DOT opto-mechanical image quality, the frequency of La Palma seeing good enough for speckle restoration ($r_0 > 6$ cm), the consistent speckle reconstruction and the multi-wavelength capability of the new imaging system together constitute 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[15] and over a wide field[16]. This niche will remain a unique and important one the coming decade while other high-resolution solar telescopes (in likely starting order NSST, GREGOR, THEMIS, ATST) realize deployment of adaptive optics, since AO delivers full restoration to the diffraction limit only for the central isoplanatic patch[17].

Of course, AO delivers the important capability to feed spectrometer slits for high-resolution Stokes spectropolarimetry which is not possible at the DOT and is a major motivation to develop AO elsewhere. Such AO spectropolarimetry at other telescopes and tomographic wide-field imaging at the DOT, both with consistent long-duration $0.2''$ resolution, will be highly complementary and therefore form a desirable combination to many research programs.

In addition, accurate Stokes filter magnetometry seems 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 space for polarization coding.

5.2 DOT future

Obviously, the major threat to the DOT is lack of future funding. The present funding ends effectively next spring. A proposal for subsequent support has been submitted to NWO (document *nwoprop2001.pdf*).

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

The remainder of this section is written on the assumption that the DOT will survive after next year as a Utrecht project, supported technically at a level at least comparable to the present one. This minimum level is budgeted in Section 5.5.

5.3 Short-term plans

5.3.1 Multi-wavelength science

Document *nwoprop2001.pdf* details the science we aim to concentrate on the coming years. The themes are "The magnetic coupling between photosphere and corona" and "Dynamics and evolution of active regions". The additional DOT proposal by J.M. Kuijpers (Nijmegen) to NWO addresses the magnetic topology and dynamics of prominences.

It is highly likely that when DOT observing can be opened to students and outsiders (*i.e.,* not requiring the full DOT team, see below) and speckle processing becomes quick and easy (see below),

[15] Up to multiple hours, much longer than the even at La Palma brief (and rare) flashes of $0.2''$ daytime seeing.
[16] Currently $92'' \times 73''$ at $0.071''$/px corresponding to the $0.2''$ telescope resolution.
[17] Multiconjugate AO was first formulated for solar physics but won't be daily practice soon.

the DOT should become a prime-choice high-resolution tomographic imager for almost any solar physics program. We anticipate frequent requests for observing time and for co-observing in multi-telescope and ground-plus-spacebased diagnostic-combination campaigns.

5.3.2 Foolproof observing

A major constraint set by current 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 (students and colleagues from abroad desiring DOT observations or DOT co-observing) can run the telescope largely by themselves. This needs considerable investment in developing the required safeguarding hard- and software which has lower priority at present than getting the multi-channel system to work, but must become a high-priority item soon.

5.3.3 Parallel speckle processing

The obvious disadvantage of post-detection speckle restoration over AO is the large amount of computer processing that it requires. A 2.5 hour run requires about two weeks of processing per camera. 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 astronomy 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[18]. This situation is now changing with the advent of speckle restoration and AO, but initially, campaignwise operation of the DOT is a mode which we can live with.

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 parallelization (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 towards parallelization The further development of parallel speckle codes and the realization of a parallel processing cluster at La Palma rides high on the DOT priority list. Overnight reduction of the daily harvest seems a realistic goal.

5.3.4 Ba II polarimetry

Addition of the Ba II 4554 filter from Irkutsk is now planned as part of the multi-wavelength setup, with the accommodation design complete. This decision was based on the superb Dopplergrams obtained in the filter test at the SVST, but it is likely that Stokes polarimetry with this filter may also become a major science asset. Expert IAC colleagues (M. Collados Vera, J. Trujillo Bueno)

[18] 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 months at a time, flew their optics, computer, and observing experts in sequentially, then took hundreds of data tapes home, but ended up actually analyzing only the best two or three of these. The famous SVST image sequence of Simon et al. (1994) alone generated over a dozen different papers.

are interested to participate in initial polarimetry tests with the filter. The DOT team sees such tests as an urgent goal after the completion of the Hα filter installation.

5.4 Long-term desires

There are obvious desires for the DOT on a longer time scale:

- Larger speckle pipeline, say order of 10 Tbyte/day. This requires replacing the COMPAQ computers, grabbers, data links and data storage with higher-capacity hardware as it becomes available in the continuous improvement of computer equipment.
- Larger field, to the $3' \times 3'$ size permitted by the telescope optics. This requires larger CCD chip sizes and/or zoom optics to trade field size against angular resolution. Realization of the latter choice is especially important for Hα where a large field is often desirable to map both footpoints of low-lying loops seen as Hα fibrils.
- Larger aperture, from 45 cm to 1 m diameter. A 75 cm mirror may replace the current one without much modification, for a 1 m mirror the telescope top should be rebuilt. The gain is increase of angular resolution to $0.1''$.

Obviously, data pipeline increase is required to accommodate a larger field and higher resolution without sacrifice vice-versa.

5.5 Budget estimate

The minimum budget needed to run the DOT is specified in Table 4.

Table 4: Minimum yearly funding required for future DOT operation.

Description	Amount (kf/year)
Exploitation	200
Instrumentation & processing	100
Optomechanical engineer	100
Mechanical technician (IGF)	80
Software engineer	100
Part-time on-site observer	40
Scientists	pm
Total	scientists + 620

Comments to Table 4:

- Exploitation: including the CCI contribution, Swedish building cost sharing, expenditures at La Palma, travel. The estimate assumes that the IAC postdoc requirement will again be met from outside funding. Supporting frequent co-observing requires a larger sum.
- Instrumentation & processing: optics, mechanical hardware, computer equipment, but not including parallel cluster hardware and development manpower (these may be met through specific funding proposals).

– Technical personnel: the first three replicate the present team (Hammerschlag being permanent staff and therefore not included). Speckle processing requires a full-time software engineer or scientist at postdoc level. A parttime observer on-site becomes highly desirable when frequent observing is feasible. Much more IGF effort than specified here is probably needed to realize the latter.

– Scientific personnel: Rutten plus 1–2 graduate students represents a subcritical team to exploit the DOT science potential. The latter requires and merits a more substantial professor-led solar physics group at Utrecht.

6 Abbreviations glossary

AIO graduate student funded by a university (4 years).

AO Adaptive Optics. Although the sun is not a point object the solar surface contains enough modulation at relevant angular frequencies that wavefront distortions can be measured and corrected for to a high Zernike number.

ASTRON = NFRA: NWO foundation for groundbased astronomy instrumentation, mostly radio astronomy but with a small optics group. Located at Dwingeloo. Director: Prof. Dr. H. Butcher.
Website: http://www.nfra.nl.

ATST Advanced Technoloy Solar Telescope, US project led by NSO to build a 4-meter class next generation solar telescope.
Website: http://www.sunspot.noao.edu/ATST.

CCI Comité Científico Internacional, international steering committee of the Observatorio del Roque de los Muchachos (RdlM) on La Palma and the Observatorio del Teide at Izaña on Tenerife.

DEC DOT Evaluation Committee, see Section 2.2.

DOT Dutch Open Telescope, 45 cm reflecting telescope on La Palma.
Website: http://dot.astro.uu.nl.

Drs Doctorandus, the official Dutch title bestowed upon graduation from a Dutch university. The level equals a Ms. from a (good) US university.

DST Richard B. Dunn Solar Telescope, of NSO at Sacramento Peak. Principal solar telescope for high-resolution studies the past thirty years.

ESMN European Solar Magnetometry Network. An EC–TMR network comprising 8 solar physics groups. The grant totals 1.3 MEuro and expires April 30,2002. Coordinator: R.J. Rutten.
Website: http://www.astro.uu.nl/∼ rutten/tmr.

FNS Faculteit Natuur- en Sterrekunde = Faculty of Physics & Astronomy of Utrecht University. Dean: Prof. Dr. J. van Himbergen
Website: http://www1.phys.uu.nl/home_eng.htm.

GBE Gebiedsbestuur Exacte Wetenschappen: division of NWO. (New name: EW.)

GREGOR New 1.5 m German reflecting telescope that will replace the German Gregory Coudé Telescope on Tenerife and be equipped with an AO system. The telescope part will be open and weather-protected by a larger version of the DOT clamshell canopy.
Website: http://gregor.kis.uni-freiburg.de.

IAC Instituto de Astrofísica de Canarias at la Laguna. Proprietor of the Roque de los Muchachos Observatory. Director: Prof. Dr. F. Sánchez.
Website: http://www.iac.es.

IGF Instrumentele Groep Fysica, combined mechanics and electronics workshop at Urecht (part of the Faculteit FNS). IGF designed and built the new DOT data-acquisition system hardware and software, and is currently realizing the multi-wavelength mechanical hardware. Chief: J. Verkerk.
Website: http://www.phys.uu.nl/∼wwwigf (Dutch)

ING Isaac Newton Group, UK/NL group of three night-time telescopes on La Palma. Director: Dr. R.G.M. Rutten.
Website: http://www.ing.iac.es.

INTAS independent "International Association formed by the European Community, European Union's Member States and like-minded countries acting to preserve and promote the valuable scientific potential of the INTAS partner countries through East-West Scientific co-operation."
Website: http://www.intas.be/mainfs.htm.

ISC Instrument Steering Committee, NOVA watchdog committee on NOVA instrumentation programs. Chair: Prof. Dr. M. Perryman (ESTEC).

JOSO Joint Organization for Solar Observations, a Europe-wide collaboration which led to the identification of the Canary Islands volcano summits as the best site for solar observing. The site testing was long led by C. Zwaan; it inspired him to propose an open telescope to Hammerschlag.
Website: http://joso.oat.ts.astro.it.

KIS Kiepenheuer Institut für Sonnenphysik, Freiburg. Principal European solar physics institute. Director: Prof. Dr. O. von der Lühe.
Website: http://www.kis.uni-freiburg.de/kiswwwe.html.

KVA Royal Swedish Academy of Sciences, to which the group running the Swedish telescope on La Palma (late SVST, future NSST) belongs. Director: Prof. Dr. G. Scharmer.
Website: http://www.astro.su.se/groups/solar.

LKBF Leids Kerkhoven-Bosscha Fonds, a private fund supporting international travel by Dutch astronomers (to conferences and for work visits but not for instrumentation or observing).

MDI Michelson Doppler Imager onboard SOHO, delivering full-disk and higher resolution ($1''$) images, Dopplergrams and magnetograms at regular and uninterrupted cadences.
Website: http://soi.stanford.edu.

NOVA Netherlands Research School for Astronomy, Dutch astronomy collaboration platform funded via NWO. The first tranche covers 1999–2004, the second tranche should cover 1994–2009. Total budget about 1 Mf/year. Director: Prof. Dr. T. de Zeeuw.
Website: http://www.strw.LeidenUniv.nl/nova.

NSO US National Solar Observatory, located at Tucson (Kitt Peak) and Sunspot (Sacramento Peak). Director: Dr. S.E. Keil.
Website: http://argo.tuc.noao.edu.

NSST New Swedish Solar telescope, major upgrade of the SVST on La Palma from 48 cm to 96 cm apertunre objective lens. The NSST will be equipped with a demonstrated AO system and is likely to become the first solar telescope to use AO habitually. Director: Prof. Dr. G. Scharmer.
Website: http://www.astro.su.se/groups/solar.

NWO Netherlands Organization for Research = Dutch science foundation. Division for exact sciences: EW or GBE. NOVA and ASTRON are funded through NWO. STW is also part of NWO (but as formerly independent when it funded the OTT (=DOT) installation on La Palma.
Website: http://www.nwo.nl/english.

OIO graduate student funded from NWO (4 years).

OTT Open Toren Telescoop, initial name of the DOT project.

RdlM Roque de los Muchachos Observatory, on La Palma. The collection of telescopes on La Palma form different European nations of which the DOT is one. Operated by the IAC.

SIU Sterrekundig Instituut Utrecht, successor (in 1987) to Utrecht Observatory (Sterrewacht Sonnenborgh). Director: Prof. Dr. A. Achterberg.

Website: http://www.fys.ruu.nl/∼wwwstk/extern.html
Travel directions: http://www.astro.uu.nl/∼ rutten.

SO Solar Orbiter, ESA project for a space mission to observe the sun as close as 0.21 AU.
Website: http://solarsystem.estec.esa.nl/projects/solar_orbiter.htm

SOHO ESA's first cornerstone mission, large solar observatory with telescopes, spectrometers and in-situ solar wind samplers, located near L1.
Website: http://sohowww.estec.esa.nl/

Solar-B ISAS/PPARC/NASA solar mission to be launched in 2005, for optical, UV and X-ray imaging, spectrometry and polarimetry of the solar atmosphere.
Website: http://wwwssl.msfc.nasa.gov/ssl/pad/solar/solar-b.htm

SOZOU Foundation for observational solar research by SIU staff members, a fund established and bequested by the late C. Zwaan. Board: Dr. C.J. Schrijver (chair), Dr. P. Hoyng (secretary), Drs. D.P.C. Ochtman, Dr. H.C. Spruit.

SRON Space Research Organization Netherlands, NWO subsidiary ("Foundation") for space research with laboratories in Utrecht and Groningen. The emphasis has been on X-ray and infrared/submm astronomy but now includes earth climate observation. Director: Prof. Dr. J. Bleeker.
Website: http://www.sron.nl.

STW Technology Foundation, funding agency for technologically oriented research. STW funded the assembly of the DOT (then OTT) at Delft University and the installation on La Palma. Now part of NWO.
Website: http://www.stw.nl.

SVST Swedish Vacuum Solar Telescope, 48 cm vacuum refractor on La Palma, dismantled in the autumn of 2000 to make place for the NSST. The DOT is operated from the Swedish telescope building thanks to splendid hospitality of the Swedish group (without rent, only cost sharing). Director: Prof. Dr. G. Scharmer.
Website: http://www.astro.su.se/groups/solar.

TMR Funding program of the EC, supporting the ESMN.
Website: http://www.cordis.lu/tmr/home.html.

TRACE Transition Region and Coronal Explorer, NASA Small Explorer Mission imaging the sun in different ultraviolet and extreme-ultraviolet wavelengths.
Website: http://www.space.lockheed.com/TRACE.

UU Utrecht University. Website: http://www.uu.nl/uupublish/home/english/1757main.html (presently still under construction).

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