



**DOT WWW Pages — Plain Text Copy – November 26, 2019**

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Plain version: no images, photographs or figures

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**Welcome to the DOT web pages**



The Dutch Open Telescope on La Palma is an innovative solar telescope for high-resolution imaging of the Sun.  
*DOT showroom:* solar movies solar images DOT photographs DOT publications DOT outreach  
*DOT data:* search engine chronological index DOT database  
*DOT observing:* wiki external usage webcam

## 1 DOT news

- no DOT news anymore, unfortunately. The DOT is in principle available but remains mothballed until a revival gets funded. That requires manpower (two to four salaries) plus 50-100 kEuro/year for running costs. You are very welcome to get yourself a very nice solar telescope named after you!
- January 2012: Utrecht astronomy is gone. The DOT is mothballed until somebody supplies funding for restarting observations. The DOT website is now at <http://www.staff.science.uu.nl/~rutte101/dot>. The DOT database is now at <ftp://dotdb.strw.leidenuniv.nl> with the chronological data index at <http://dotdb.strw.leidenuniv.nl/DOT>, the search engine at <http://dotdb.strw.leidenuniv.nl/search>, and the observing wiki at <http://dotdb.strw.leidenuniv.nl/wiki>.
- December 2011: Utrecht University terminates its astronomy program (which it started back in 1642, the year Isaac Newton was born). The DOT database server moves to Leiden Observatory, with the group of C.U. Keller including F.C.M. Bettonvil. The future of the DOT is highly uncertain, but in principle the DOT remains available for self-funded external usage.
- Spring 2011: F.C.M. Bettonvil took up a job with NOVA and G. Sliepen moved to the SST.
- December 2010: USA/NSF-funded Helio Research concluded a successful year of gathering many filament and prominence observations with the DOT (over 70 Terabyte in total). Quick-look frame-select movies are available in the DOT database. Selected image sequences are under speckle reconstruction.
- July 2010: addition of a speckle demonstration movie comparing full speckle reconstruction with Keller - von der Lühe restoration and with frame selection. See DOT speckle modes.
- Spring 2010: the start of USA/NSF-funded Helio Research campaigns triggered much improvement of the DOT observers wiki by G. Sliepen.
- October 2009: EC-funded DOT observer V. Olshevsky has speckle-reconstructed the DOT observations from 2008, reducing the large backlog that was built up after P. Sütterlin moved to the SST. These data will appear in the DOT database.
- June 2009: the tunable narrow-band Lyot filter for Ba II 4554, built by V. Skomorovsky and colleagues at Irkutsk, finally came on line after extensive refurbishment and installation funded by INTAS. Due to poor camera characteristics the images are noisy but still suited to make Dopplergrams. You are welcome to supply a better camera!
- Autumn 2008: DOT observers wiki started by EC-funded DOT observer S. Vargas Dominguez.
- February 2008: DOT database search engine constructed by EC-funded Tim van Werkhoven.
- January 1, 2008: our major sponsors during the past years (Utrecht University Department of Physics and Astronomy, NWO, NOVA) have terminated their contributions. In consequence, Dr. P. Sütterlin moved to the SST and Ir. F.C.M. Bettonvil transited to design studies for the EST. Nevertheless, DOT availability is continued partially, on a much reduced budget. Partnerships bringing external funding for on-site observers and telescope upgrades are welcome.
- April 2007: new DOT poster designed by Frans Snik.
- October 2006: invitation to join in a major DOT upgrade, with various design options.
- September 2004: the H $\alpha$  filter was installed in the DOT top, pointed at AR10675, and produced a beautiful H $\alpha$  mosaic of active region AR10675 with a monochrome morph and a false-color morph sequentially showing the photosphere sampled in the G band, the low chromosphere sampled simultaneously in Ca II H, and the high chromosphere sampled simultaneously in H $\alpha$ . A simple version served as Astronomy Picture of the Day and was pictured in the Frankfurter Allgemeine.
- July 2004: start of "Open DOT" time allocation to external observers.

- June 8, 2004: the first Venus transit in 122 years was recorded beautifully by the DOT.
- June 18, 2003: a short near-limb Ca II H movie showing "straws", with a companion four-panel movie showing the same scene also in the blue continuum, G band, and the wing of Ca II H.
- February 23, 2000: this sunspot movie was posted as the first video on Astronomy Picture of the Day.
- October 31, 1997: DOT First Light Ceremony featuring Crown Prince Willem-Alexander, Science Minister Jo Ritzen and many other dignitaries. More photographs here.

## 2 DOT at a glance

Encyclopedic overview: Wikipedia's DOT article.

Photographic overview: DOT photo gallery.

The Dutch Open Telescope (DOT) is an innovative solar telescope located at the Observatorio del Roque de los Muchachos of the Instituto de Astrofísica de Canarias.

The DOT achieves high-resolution imaging of the sun simultaneously in multiple wavelengths which sample the solar atmosphere tomographically at different heights. All DOT data are public. More detail is given under DOT tomography, in our professional DOT publications and outreach descriptions, and in the reports under DOT documents.

The initiator of the DOT was Prof. C. Zwaan (obituary) while he led Europe-wide site testing for solar telescopes. At his suggestion of an open design the DOT was designed and built by R.H. Hammerschlag of the Sterrekundig Instituut Utrecht with a small team of coworkers at IGF Utrecht and DTO Delft.

The novel open design of the DOT is seen well on this photograph. It exploits the often excellent La Palma conditions through minimal obstruction to the strong trade winds that make La Palma an outstanding site for solar as well as night-time astronomy. They go together with a low inversion, often keeping the cloud layer below the volcano rim, and confine local turbulent convection from solar ground heating to a thin layer below the 15 m high open-tower top. They blow right through the telescope, also flushing the 45 cm diameter primary mirror, so that no internal turbulence develops. The DOT's simple optical scheme permits precise optical alignment for optimum performance. The DOT's extraordinary mechanical stability gives high pointing precision even in strong wind buffeting. The fold-away clamshell canopy survives even the severe La Palma winter storms and heavy ice loads.

The first results after the DOT first light confirmed the viability of the open principle. P. Sütterlin's experiments with his version of the Göttingen speckle reconstruction code then gave such spectacular results that a multi-camera speckle acquisition system was realized. The combination of superb imaging and speckle restoration made the DOT the first solar telescope to regularly obtain 0.2 arcsec resolution throughout extended image sequences. Such movies are taken synchronously with identical cameras in blue and red continua, the G band, Ca II H including blue-wing tunability, and profile-sampling narrow-band H $\alpha$  and Ba II 4554. The laboriousness of the speckle processing limited the movie production severely until the installation of the advanced NWO-funded DOT Speckle Processor with 70 water-cooled processors which delivered fast on-site speckle processing and permitted an Open DOT program providing observing time to external colleagues. See Rutten et al., A&A, 413, 1183, 2004 for more detail.

We also ran a popular Students to the DOT education program for on-site tutoring in observational solar physics.

The open principle of the DOT may be upscaled to much larger aperture than is feasible for traditional vacuum telescopes requiring entrance windows. Its success together with the advent of adaptive optics inspired the 1.5 m German GREGOR telescope, the 1.6 m BBSO NST telescope, contributed to the ambitious US project to build a four-meter Advanced Technology Solar Telescope, and is upscaled far beyond that size in the GISOT concept. The mechanical structure of the DOT itself permits relatively cheap upgrades from 45 cm to much larger aperture.

During its first decade the DOT operation was funded primarily by the Department of Physics and Astronomy of Utrecht University, NWO and NOVA. These sponsors terminated their contribution by the end of 2007. During 2008 and 2009 only part-time DOT observing could be performed, on EC funding. During much of 2010 Helio Research (USA) funded and ran full-time DOT operation on a grant from the US National Science Foundation. Such

partnerships, in which external groups supply DOT operation costs, the on-site observers, and manpower for the data processing are the only way to un-mothball the DOT for new data gathering.

Since Utrecht University's support for the DOT, solar physics, and in fact all astronomy has gone (it terminated its whole astronomy department early in 2012), industrial sponsoring is obviously very welcome. The construction and engineering firm PelsierHartman (English website) sets a good example as DOT Ambassador.

### 3 DOT showpieces: specials, movies, images, photographs

*DOT specials:* selection of particularly beautiful movies, images, image mosaics, morph-overs, with explanation.

*DOT movie album:* index to all DOT movies, both in .avi and .mov format.

*DOT image album:* thumbnail index to an album of high-resolution solar images taken with the DOT, some in colour, in both bitmap and postscript format, with explanatory captions.

*DOT photograph album:* thumbnail index to an album of high-resolution photographs and design drawings of the DOT, with explanatory captions.

Clicking on the selected thumbnail downloads the corresponding file. This may take long! In MacOS, for example, Safari may show only the QuickTime logo without progress indication during its lengthy download of a .mov file, and may not download an .avi file but just show a question mark in its logo without further information. Firefox does a better job for both formats. The first movie in the movie album is a small short blinker to test your downloader, player, file saver.

Save a copy by a right-mouse click on the movie/image/photograph, or by clicking on the browser file opener, and then selecting the "save as" option.

You can also download DOT movies, images, photographs directly from the album directories:

<http://www.staff.science.uu.nl/rutte101/dot/albums/movies>

<http://www.staff.science.uu.nl/rutte101/dot/albums/images>

<http://www.staff.science.uu.nl/rutte101/dot/albums/photographs>

The original DOT movies are in .mpg format and available at <http://www.staff.science.uu.nl/rutte101/dot/web/movies>. They are 24 fps, too fast for poor players as QuickTime but can be slowed down with the VLC player or with `mplayer -fs -fps 10 file.mpg -loop 0` (Linux/Unix).

Under Linux/Unix downloading many album files at once can be done through e.g.:

```
lftp http://www.staff.science.uu.nl/rutte101/dot/albums/movies
ls
du -hs
mirror -n .
mget *AR10786*avi
exit
```

connect to desired direc  
show directory content  
show total directory siz  
get all (new) files  
get all AR10786 .avi m  
when done

If you need PostScript files for insertion in LaTeX you may produce them from bitmap files (e.g. .tif) with the Linux/Unix command `convert -geometry XxY file.tif file.ps` where *X* and *Y* are the pixel sizes of the image.

More DOT images and movies are available via the database search engine, the chronological database index. Here is the original DOT movie page.

You are welcome to use any DOT material in publications and presentations of any kind (bijvoorbeeld profielwerkstukken natuurkunde/sterrenkunde over de zon). We appreciate acknowledgement to "Dutch Open Telescope" (short), or "Dutch Open Telescope, operated at the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofísica de Canarias" (long).

### 3.1 DOT specials

NB: during lengthy downloads you may only see the QuickTime logo. Recipes for downloading directly from the repositories are given under DOT showpieces.

General explanation:

The light in spectral lines in the solar spectrum escapes at different heights in the solar atmosphere, higher at wavelengths in which the gas is less transparent. The DOT takes images simultaneously in blue and red continuum windows and in the blue G band (many lines from CH molecules), one of the two resonance lines of Ca II (violet, once-ionized calcium atoms, strongest lines in the visible solar spectrum), and the Balmer H $\alpha$  line (red, excited neutral hydrogen atoms, most enigmatic line in the solar spectrum).

The continua and the G band show the photospheric solar surface covered by convective granules and tiny bright magnetic elements between these. The latter are best visible in the G band. Sunspots show a dark umbra surrounded by a filamentary penumbra. The strong Ca II H line samples the low chromosphere, a few hundred kilometers higher up. At that height the granulation appears reversed, acoustic shocks abound, and the magnetic elements appear considerably brighter. The H $\alpha$  line shows fibrils in the high chromosphere that lie at a few thousand kilometer height and are obviously controlled by magnetic fields.

The fibrils demonstrate that solar magnetic fields have a much more complex structure than the Earth's magnetic field, which is approximately a simple North-South dipole like a bar magnet. The photospheric fields visible as tiny bright points in the G band are mostly vertical but can flip in polarity (upward or inward field direction) over small horizontal distances. The chromospheric fields mapped by H $\alpha$  fibrils connect these photospheric "footpoints" like a dome ("magnetic canopy"). These connections evolve while the footpoints move and emergence of opposite fields causes magnetic reconnection. The latter is one important heating mechanism; waves running along the field lines are another. The complexity of solar magnetic fields governs much of the solar activity, including the Sun's spectacular outbursts which arise when the field topology gets overloaded and shorts in electric currents. The ejecta sometimes hit the Earth.

Tomographic multi-layer slicing with the DOT helps to unravel the field's secrets by connecting the chromospheric structure and dynamics to the photospheric footpoints. The multi-layer DOT movies vividly illustrate the dynamical behaviour of the magnetic features. They show solar fine structure so sharply thanks to the combination of the outstanding wind-swept observing conditions ("seeing") at La Palma, the wind-flushed open structure of the DOT, the excellent DOT optics and mechanical stability, and the consistent application of numerical speckle reconstruction through which each image is corrected for the degradation by the remaining atmospheric seeing above the DOT.

More detail is given in Rutten et al. 2004, and under course material and lesmateriaal at the author's website.

Aug 1, 2010: a demonstration movie comparing the two different modes of speckle reconstruction employed at the DOT: full speckle restoration versus "Keller - von der Lühe" two-channel restoration. The movie is available at 1 fps play rate as 2005-10-19-QS-hac-speckledemo.avi and 2005-10-19-QS-hac-speckledemo.mov, both in the DOT movie album, while the original 24 fps movie is 2005-10-19-QS-hac-speckledemo.mpg in the DOT mpg directory. See DOT speckle modes for explanation.

April 12, 2007: the sun gets awfully quiet towards the close of Cycle 23. This quiet-sun mosaic blinker steps through blue continuum, G band, red continuum, Ca II H wing, Ca II H core, H $\alpha$  wing, and H $\alpha$  Doppler. In such quiet areas the H $\alpha$  chromosphere is not filled with long parallel fibrils but shows smaller-scale and highly dynamical patterning.

September 23, 2006: This mosaic blinker steps through G band, Ca II H core, and H $\alpha$  core for a small active region with a small spot. Even at such modest activity the H $\alpha$  chromosphere is organised in extended fibrillar patterns outlining the magnetic field. The separate mosaics are available in the DOT image album. A smaller subfield is followed with time in this four-panel movie.

Autumn 2006: DOT sunflowers adorned the back cover of the Nederlands Tijdschrift voor Natuurkunde.

July 8, 2005: another beautiful DOT active region morph. Active region AR10786, field 182 x 133 arcsec. It shifts from G band via Ca II H to H $\alpha$ . The Earth inset shows the scale. And here is a synchronous quartet movie showing part of this active region a day earlier simultaneously in the G band, Ca II H wing, H $\alpha$  line center, and H $\alpha$  Dopplershift.

September 29, 2004: the newly-installed H $\alpha$  filter produced a beautiful three-level image-mosaic morph of

active region AR10675:

monochrome morph      false-color morph

It sequentially shows the photosphere sampled in the G band, the low chromosphere sampled simultaneously in Ca II H, and the high chromosphere sampled simultaneously in H $\alpha$ . A simple version served as Astronomy Picture of the Day and was pictured in the Frankfurter Allgemeine. The coloring is false, just to make a nice display - except for the Earth, indeed a magnificent blue-white-redbrown jewel of a planet. As scientists, we prefer the monochrome versions which give a more precise rendering of the solar scene.

June 8, 2004: the DOT recorded the first Venus transit in 122 years in splendid movies including detailed egress ones. See DOT and the 2004 Venus transit.

November 2, 2003: the DOT observed the spectacular active region AR10486 two days before it sent off the largest flare ever recorded. Here is a false-colour morph (9.2 MByte) of simultaneously taken image mosaics at different wavelengths, from red continuum (red) via G band (colored green here) to Ca II H (blue) and back to red. A monochrome version with different panels for the four wavelengths (scales in arcsec) is available here (0.5 MB) and also at full resolution (7862 x 7862 px; 6 MB). A surge sent off by AR10486 two hours before the big flare was also registered with the DOT. It is shown in this extreme-limb Ca II H movie and was analysed in this A&A paper.

August 9, 2003: a beautiful three-hour double sunspot movie combines the chromospheric Ca II H view at left with the synchronous photospheric G-band view at right. It very clearly shows the inward migration of small bright features along the penumbral filaments and the outward migration of bright magnetic features across the moat around the sunspot. Also available as separate movies plus the companion blue continuum movie in the DOT database.

June 18, 2003: a short near-limb Ca II H movie showing "straws", with a companion four-panel movie showing the same scene also in the blue continuum, G band, and the wing of Ca II H. The solar limb is at bottom left. The straws are very long, very slender structures that stick more or less upright out of the chromospheric network and display rapid swaying motions.

June 6, 2003. A remarkable photosphere-chromosphere fade-over which morphs a photospheric (G band) mosaic of active region AR10375 into the overlying low-chromosphere (Ca II H) scene, co-spatially and simultaneously. The field measures 250 x 220 arcsec (1 arcsec is about 725 km on the sun). The smallest axis ticks measure 1 arcsec. A scaled photograph of the Earth is inserted at the upper right to show the geometrical scale. Three-by-three pixel summation was applied to make the field fit your screen; the actual resolution is three times higher. There are substantial changes in magnetic field topology between photosphere and chromosphere. Actually, the DOT took four simultaneous mosaics, also in blue continuum and the continuum near H $\alpha$ ; here is the corresponding four-wavelength morph sequence with the red-continuum contrast steepened to resemble the G-band image. Here is a mosaic with the four images in four panels (scales in arcsec).

May 2, 2003: a quadruple movie of a quiet region near the solar center combines the photospheric view in the G band and blue and red continua with the chromospheric Ca II H view at the lower left. There is some fairly dense network. All four movies are synchronous and have been Fourier-filtered to remove acoustic oscillations (removing all features that move with apparent supersonic speed over the solar surface). The four movies are separately available in the DOT database.

December 8, 2002: a one-hour synchronous double movie the first tomographic one taken with the DOT. It features disk-center G-band and Ca II H simultaneously and co-spatially. The lefthand movie is from the low photosphere and show granulation plus tiny magnetic elements. The righthand movie from the high photosphere shows the magnetic network, inversed granulation, and rapidly-changing wave patterns. The seeing was only fair but the speckle restoration produces quite good quality. Results from an elaborate analysis are given in Rutten, de Wijn & Sütterlin, A&A 416, 333 and compared to a numerical simulation in Leenaarts & Wedemeyer-Böhm, A&A 431, 687.

July 3, 2002: a 143 x 118 arcsec G-band mosaic of active region AR10019

October 17, 2001: a double movie using two cameras to register the G band and nearby continuum simultaneously. Thanks to the strictly synchronous speckle burst registration, these images can be pairwise subtracted to separate the hydrodynamically dominated granules and the magnetically dominated G-band bright points from each other. These data were analysed in Nisenson, van Ballegooijen, de Wijn & Sütterlin, Ap. J. 587, 458, 2003.

April 2, 2001: a mosaic of active region AR9393 shows the largest sunspot group of the past solar activity cycle. Here is a plain image version with a photograph of the Earth inserted as scale indicator (upper right corner), and here is a large 4300 x 2500 pixel poster version to print at large size for wall decoration.

April 1, 2001: sixty-minute sunspot movie of AR9407 which illustrates the large field of the new DOT cameras. Here is a scaled-down jpeg image taken from the movie, and here is an annotated copy of the same image (also as pdf file from Sütterlin, A&A 374, 21, 2001). The corner inset displays intergranular magnetic elements at high spatial resolution.

February 23, 2000: this sunspot movie was posted as Astronomy Picture of the Day. It was taken with the simple video camera that initially served to test the viability of the DOT's open principle - indeed superbly demonstrated by this movie. Here is a snapshot image from the movie.

### 3.1.1 DOT and the 2004 Venus transit

On June 8, 2004 the DOT recorded the first Venus transit in 122 years at high angular resolution in the G band and in the Ca II H line. The DOT observers also used full-disk cameras in white light and Halpha.

- Full-disk movies:    white light    Halpha
- High-resolution movies:    G band (photosphere)    egress in G band with bright Venus atmosphere  
Ca II H (chromosphere)
- Sample images:    G band    Ca II H    G band egress    Ca II H band egress

*Notes:*

- The DOT missed the ingress because the Sun rose over La Palma only after the start of the transit.
- The DOT has a parallactic mount so that the transit path is straight. Celestial North is up.
- The G band (so named by Joseph von Fraunhofer in 1817, consisting of molecular CH lines at wavelength 430.5 nm in the blue part of the solar spectrum) samples the solar photosphere from which most sunlight escapes. This apparent "surface" (made of hot gas, not one to walk on) shows granules and intergranular lanes which are produced by convection in the outer layers of the Sun.
- The Ca II H line at wavelength 396.8 nm (violet, once-ionised calcium atoms) samples the low solar chromosphere, at about 500 km above the white-light (or G-band) surface. The pattern shown in the Ca II H line contains very bright patches made up by magnetic concentrations (much stronger than the Earth's magnetic field) and weaker patches produced by sound waves which permeate the solar atmosphere as well as the solar interior (the Sun rings like a giant church bell but at much lower frequencies: 0.001 - 0.01 Hz).
- The Halpha line at wavelength 656.3 nm (red, highly excited hydrogen atoms) samples the high solar chromosphere at about 1000 km above the white-light surface. Active regions with very strong magnetism appear bright in this spectral line (except for sunspots which remain somewhat dark).
- The Venus atmosphere becomes bright just outside the solar limb in the logarithmically-scaled G band egress movie and sample image. This remarkable brightening, known since Mikhail Lomonosov's observation of the 1761 transit, is due to refraction in the Venus atmosphere which bends the transmitted sunlight toward us. Similar brightening is seen in a companion Ca II H image where one also observes the chromospheric forest of solar spicules extending outward from the solar limb.
- The near-limb "black drop" phenomenon (which hampered the measurement of the ingress and egress times in many historical determinations of the solar parallax) is not seen at egress in our Ca II H movie because the DOT is a high-resolution telescope while the Sun shows only slight limb darkening in this scattering-dominated spectral line. It is momentarily seen, but very weak, in the third frame of the logarithmically-scaled G band egress movie. It becomes much more pronounced at lower resolution.

## 4 DOT observing: tomography, external usage

### 4.1 DOT tomography

During past years the DOT was available to external users in the "Open DOT program" described in Rutten et al., A&A, 413, 1183, 2004. At present, DOT availability depends on DOT partnerships (see DOT external usage).

The table below defines the DOT tomography wavelengths. The DOT standard product consists of co-spatial synchronous image sequences taken in these wavelengths with parallel cameras at 20-30 second speckle burst sampling cadence.

The field of view covers  $91 \times 72$  arcsec with 0.071 arcsec/pixel sampling resolution for the blue wavelengths (Hitachi KPF100 cameras). The newer Halpha and red continuum cameras (Redlake MegaPlus II ES4020 cameras) have  $113 \times 113$  arcsec field of view at 0.110 arcsec/pixel. In the speckle burst processing a few arcsec are lost at the field edges through tip-tilt correction; usually, more are lost when co-registering sequences from multiple cameras.

The guiding may or may not include solar rotation compensation, as desired.

These different diagnostics sample different heights in the solar atmosphere. Precise heights of formation cannot be specified, because they depend on the actual time-dependent conditions. Numerical modeling is needed to evaluate the response of each diagnostic to a particular type of solar structure or dynamical phenomenon. However, generally the blue continuum samples the deep photosphere, the G band and red continua originate some tens of kilometers higher, the Ca II H line spans a few hundred kilometers from the outer wing to its core. Halpha fibrils can be located at any height but generally lie one to a few thousand kilometers above the photosphere. The Ba II 4554 line samples the upper photosphere.

Ba II 4554 is the major Ba II resonance line, similar to Ca II K in ionic structure but at lower opacity due to smaller abundance. It has a boxy core due to hyperfine and isotope splitting. The large atomic weight and the steep line flanks make it an excellent Doppler diagnostic. It is a promising Zeeman and Hanle diagnostic, but polarimetry is not implemented at the DOT.

Both Ca II H and Ba II 4554 tend to have LTE opacities but scattering-dominated source functions. Halpha has large departures from LTE in both its opacity and source function; Halpha fibrils can be optically thick or optically thin. The far Halpha wings, especially the blue one, are excellent LTE diagnostics to locate and track intergranular magnetic elements unless these are shielded by Doppler-shifted fibrils.

#### DOT filters:

<i>designation</i>	<i>abbreviation</i>	<i>wavelength ()</i>	<i>filter FWHM ()</i>	<i>type</i>	<i>tuning</i>
blue continuum	bc	4320	6	interference	fixed
red continuum	rc	6550	2.4	interference	tilt-shift to 6535
red prominence	pr	6563	2.3	interference	tilt-shift to blue
G band (CH lines)	gb	4305	10	interference	fixed
Ca II H	ca	3968	1.35	interference	tilt-shift throughout violet wing
Halpha	ha	6563	0.25	Lyot	tunable to +/- 8
Ba II 4554	ba	4554	0.08	Lyot	tunable to +/- 2
barium continuum	bk	4505	5.4	interference	fixed
Hbeta	hb	4861	1.5	interference	manual tilting

The wavelength setting of the tilt-shiftable and the two tunable Lyot filters can be changed between successive speckle bursts under program control. The red continuum and red prominence (Halpha wide) filters are in a computer-controlled filterwheel, the choice is made from the control room. Similarly, the barium continuum filter and the wide Hbeta filter are also in a filterwheel. The Hbeta filter can only be tilted manually when the DOT is not observing.

The continuum-near-Halalpha and continuum-near-Ba II 4554 passbands serve for two-channel speckle restoration following Keller & von der L uhe (1992). In this technique, the wide-band wavefront estimation is used to restore the narrow-band frames. When sequences of multiple wavelengths are chosen for the two Lyot filters (Halalpha and Ba II 454), these can be taken in smaller subbursts (generally  $100/N$  frames/burst, where  $N$  is the number of wavelengths, down to 20 fpb). This results in faster cadence and excellent rubber-sheet co-registration since the different subbursts are slaved to the single full-burst wide-band speckle reconstruction. If the filters are kept fixed at one wavelength the cadence can be as fast as 2 seconds. The disadvantage is lower image quality then for full



100 fpb burst reconstruction. Because our cameras have low well depth while the exposures must be synchronous per pair, the photon flux for the wide-band cameras is reduced appropriately through the use of neutral density filters. For an example movie see DOT speckle modes.

The prominence filter is a better choice for Keller & von der L u he reconstruction at the limb (since H $\alpha$  shows fibrils crossing the limb, providing radial wave-front encoding). It also serves to register the profile-integrated H $\alpha$  emission from an off-limb prominence.

Tomographic speckle sequences can be taken whenever the DOT is manned and the seeing is at least reasonable, say Fried parameter above 6 cm. At Fried parameter 10 cm (good but not perfect) the resolution already approaches the 0.2 arcsec diffraction limit. This sometimes happens during multiple hours, also in afternoons. Such high-resolution long-duration multi-camera sequences provide excellent science input in themselves, but are also highly valuable as context tomography for spectrometry and spectropolarimetry at other telescopes, and in combination with EUV imaging and spectroscopy from space.

The speckle-restored image sequences from the DOT are stored on and available from the DOT database server.

## 4.2 DOT external usage

Since January 2008 there is no funding to operate the DOT in the service-mode fashion in which the telescope was used before. There is no longer a DOT observer, nor manpower to handle the elaborate speckle processing and alignment processing that contributed much to the high quality of DOT image sequences.

External DOT usage is therefore necessarily in external-user mode, in which a user is responsible for telescope targeting, data acquisition, and data reduction including speckle processing. These tasks are far from trivial and require at least a capable on-site observer. In addition, we no longer have funding for DOT operation costs. We therefore invite potential DOT users to supply funding for DOT operation including sufficient manpower to handle the observing, speckle reconstruction, and alignment processing. The return consists of DOT observing time. Enquiries: email R.J.Rutten at uu.nl and R.H.Hammerschlag at astro-uu.nl.

In 2008 and 2009, respectively, Santiago Vargas Dominguez and Vyacheslav Olshevsky worked as DOT observer on EC funding that then terminated. During 2010 the DOT was entered into a formal partnership with Helio Research (USA), which funded the DOT operation with a grant from the US National Science Foundation. Helio Research provided the operation cost and the manpower for the DOT observing and data processing.

Since then the DOT is mothballed but ready to observe upon renewed funding.

## 4.3 DOT time allocation

*All DOT scheduling remains contingent on funding and on DOT team members being on-site.* From 2010 external usage is limited to *external-user mode* in which the proposer contributes the DOT operation cost and performs the on-site observing and speckle reconstruction. See DOT external usage.

*CCI-ITP and Spanish time.* When the DOT is operational it is contractually obliged to provide access in the context of CCI-ITP (5%) and Spanish observing time (20%). When the DOT is used on external funding it must set aside CCI-ITP and Spanish time if such is requested and independently funded. CCI-ITP proposals are reviewed through the EAST TAC.

*External observing proposals.* The DOT team handles external DOT observing requests other than CCI-ITP DOT proposals. They should be sent as a pdf file per email attachment to F.C.M.Bettonvil at strw.leidenuniv.nl. There are no specific forms. DOT observing proposals should define and argue the science case, list which other telescopes will be used for what purpose, give timing suggestions and constraints, and specify the observers and the funding for external-user operation. Yearly deadline: January 31.

## 4.4 DOT wiki

Technical instructions for DOT observers are supplied at the DOT wiki pages

## 5 DOT data: database, search engine, chronological index, description, software

*Explanation of DOT data formats: see Database description.*

*DOT software: see Software.*

*DOT data are public.* You are welcome to use DOT data for detailed analysis without restriction. We appreciate acknowledgement to "Dutch Open Telescope" (short) or "Dutch Open Telescope at the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofísica de Canarias" (long). We also welcome research collaborations using DOT data, in particular contributions to the "DOT tomography of the solar atmosphere" article series. P. Sütterlin is the principal candidate for DOT co-authorship for all data taken before 2008. During the autumn of 2008 Santiago Vargas Dominguez was the DOT observer, during the summer and autumn of 2009 Vyacheslav Olshevsky.

*DOT database search engine:* a user interface to select specific DOT data, setting the time(s) of observation, type of object, wavelength(s), viewing angle(s), Fried parameter (seeing quality), etc. It returns lists of data sets that fit the criteria, with data sequence information including small thumbnail images and a link to the pertinent data, similarly to the chronological index which it replaces.

*Chronological DOT database index:* an older overview using sample images from each observing session. Move your mouse over the clickable dates for a quick indication of the target (blue continuum image). Clicking on a selected date then opens quick-look information. For each observing session, the panel below the sample images specifies the target, observing mode, time of observation, cadence, solar disk location, average seeing quality (Fried parameter  $r_0$ ), a link to the pertinent Mees active region map, a burst-by-burst plot of the Fried parameter, and a "Get data" link to the corresponding directory in the DOT database. <ftp://dotdb.strw.leidenuniv.nl>. The same information is also returned by the database search engine.

*DOT database:* ftp server containing all DOT data available for downloading.

*How to get DOT data:* Select the data sequence you like with the search engine to the DOT database or the chronological database index, and then get the data through the "get data" clickers provided there.

Under Linux/Unix downloading many files at once may also be done through e.g.:

<code>lftp ftp://dotdb.strw.leidenuniv.nl/2005/2005-10-19</code>	connect to desired database directory (data)
<code>ls</code>	show directory contents
<code>du -hs</code>	show total directory size
<code>mirror -n .</code>	get all (new) files, also in subdirectories
<code>mget -d FITS/*</code>	get all dirs with files below FITS
<code>mget Cubes/*-ha*</code>	get only the Halpha cubes, or use: <code>cd</code>
<code>exit</code>	when done

### 5.1 DOT database description

The basic DOT data product consists of the fits files in the FITS directories of the DOT database. For many runs processed data are supplied as well in Cubes directories. The directories are ordered per observing run (usually the date).

The spatial sampling in the x and y directions is 0.071 arcsec/pixel for the blue cameras and the older red cameras; the newer red cameras have 0.110 arcsec/px. The x direction is East–West, parallel to the geocentric celestial equator and corresponding to the horizontal direction in the Mees active region maps accessible per observing session from the database search engine and the chronological database index. The heliographic coordinate X used by SOHO and TRACE is tilted Eastward from this direction over the solar pole position angle P0.

The diagnostic wavelength abbreviations are defined in the table in section DOT tomography.

The FITS directories are split between DOT cameras as specified by the diagnostic wavelengths. Each fits file usually contains three images as 16-bit integer arrays: the speckle reconstruction, the best frame of the speckle burst, and the temporal average of the whole speckle burst. Each fits file is usually about 7 MByte. A fast way

to display them is to enter them in John Bradley's xv. Linux/Unix command `xv *fits` will show all reconstructions in the directory; step forward and backward in time with space and backspace (pagedown and pageup sample the three images per file).

The fits headers specify the array size, the time of observation (also as Julian Day), the wavelength, the angular scale, and the seeing-quality alpha determined in the speckle reconstruction of each burst (alpha = Strehl percentage; for DOT data alpha times 0.45 = Fried parameter in cm). The FITS directories contain files *alphalist* and *alphalist.sort* enabling you to quickly select the best images (largest value of alpha). Graphs of the burst-by-burst variation of the Fried parameter  $r_0$  are available per observing session in the database search engine and the chronological database index.

Unfortunately, we can not yet supply DOT pointing coordinates more precisely than the specifications given in the database search engine and the chronological database index. A good recipe is to align the scene with space data, for example Ca II H with TRACE 1600 .

For Halpha line-profile sampling (filenames containing "scan") the FITS files contain N+1 frames per file, where N is the number of wavelength samplings (usually 3 or 5). The first is the red continuum image, then follow the N narrow-band Halpha filtergrams. They are reconstructed together with the first through two-channel speckle processing following Keller & von der Luehe (1992). Unfortunately the FITS header does not yet specify the narrow-band wavelengths, but they are inserted in the file names in the Cubes directories. Such profile-sampling cubes are perfectly aligned with each other spatially, but their temporal sampling differs slightly within the specified cadence intervals.

The files in the Cubes directories of the DOT database result from processing of all FITS files per pointing into co-aligned image sequences. From these we also produce our DOT movies. They are three-dimensional 16-bit integer arrays readable with IDL, most easily with Tim van Werkhoven's procedure `readdotcube.pro`, as for example in

```
HalphaRed=readdotcube('QS-ha+0350-20051019-cube-1112x818x71-dt60').
```

The cube file names specify the diagnostic, the x, y, and time dimensions, and the time step in seconds. For example, the cube above is a three-dimensional integer array containing a quiet-sun (QS) image sequence ("data cube") sampling Balmer Halpha (ha) at +350 mÅ from line center (+350), taken on October 19, 2005 (20051019), having array size  $n_x=1112$ ,  $n_y=818$ ,  $n_t=71$  ( $1112 \times 818 \times 71 = 130$  MByte), taken at regular 60s cadence (dt60), and thus having 71 minute duration. Cubes with the same file name except for the diagnostic are exactly synchronous. They are also aligned to be co-spatial. A zero value for the time step means that the cadence is irregular and that the precise times of each exposure should be distilled from the FITS headers. Cubes of which the file name contains *-lo7* have been 3D-cone Fourier-filtered to remove modulations travelling horizontally at speeds larger than the 7 km/s sound speed ("subsonic").

Cubes such as *Limb-ca-0000-20051013-cube-1046x744x86-dt50-even* and *Limb-ca-1000-20051013-cube-1046x744x86-dt50-odd* are alternating sequences where the wavelength of the Ca II H filter was switched sequentially between line center (0000) and the blue wing at -1000 m. The designation *even* implies that these images correspond to the even frame numbers (starting IDL-wise at 0) of the other cubes which have twice the cadence.

Other directories in the DOT database furnish image mosaics, movies, and some of the IDL bookkeeping and programs used in our processing. README files give information in some directories.

For further DOT descriptions and DOT data analyses see DOT publications. The Open DOT program, the telescope specifications, and DOT multi-wavelength tomography are described in Rutten et al., A&A, 413, 1183, 2004.

## 5.2 DOT software

DOT observers wiki

IDL programs for DOT data reduction

IDL programs for DOT image sequence analysis with corresponding manual

Simple IDL manual for beginners

## 6 DOT publications: scientific publications, popular-science descriptions, management documents

You are welcome to use DOT material in publications of any kind. We appreciate acknowledgement to "Dutch Open Telescope" (short), or "Dutch Open Telescope, operated at the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofísica de Canarias" (long).

Most publications in the wider solar physics research area to which the DOT caters are accessible at [http://www.staff.science.uu.nl/rutte101/solar\\_abstracts](http://www.staff.science.uu.nl/rutte101/solar_abstracts).

### 6.1 DOT publications

DOT bibliography (pdf)

DOT bibliography (BibTeX)

- R.H. Hammerschlag et al., 2017  
*Completely open-foldable domes remaining cool in sunshine*  
Procs. SPIE 9912, id. 9912E
- R.J. Rutten, 2017  
*Solar H-alpha features with hot onsets. III. Long fibrils in Lyman-alpha and with ALMA*  
Astron. Astrophys. 598, A89
- M. Bodnárová, D. Utz, J. Rybák, 2016  
*The Effect of Area Averaging on the Approximated Profile of the H  $\alpha$  Spectral Line*  
Astron. Soc. Pacific Conf. Ser., 504, 23
- N. Freij, I. Dorotovič, R.J. Morton, M.S. Ruderman, V. Karlovský, R. Erdélyi, 2016  
*On the Properties of Slow MHD Sausage Waves within Small-scale Photospheric Magnetic Structures*  
Astrophys. J. 817, 44
- E. Sungging Mumpuni, D. Herdiwijaya, M. Djamal, T. Djamaluddin, 2015  
*Multi-wavelength fibril dynamics and oscillations above a sunspot - I. Morphological signature*  
Research Ast. Astrophys. 15, 1843
- A.D. Joshi, T.G. Forbes, S.H. Park, K.S. Cho, 2015  
*A Trio of Confined Flares in AR 11087*  
Astrophys. J. 798, 97
- A. Berlicki, P. Heinzel, 2014  
*Observations and NLTE modeling of Ellerman bombs*  
Astron. Astrophys. 567, 110
- M. Bodnárová, D. Utz, J. Rybák, 2014  
*On Dynamics of G-Band bright points*  
Solar Phys. 289, 1543
- F. Zuccarello, S.L. Guglielmino, P. Romano, 2014  
*Evolution and dynamics of orphan penumbrae in the solar photosphere: analysis from multi-instrument observations*  
Astrophys. J. 787, 57
- J. Koza, J. Rybák, P. Gömöry, A. Kučera, 2014  
*Inferring spectral characteristics of the H $\alpha$  spectral line observed by the DOT Lyot filter*  
Contr. Astron. Obs. Skalnaté Pleso, 44, 43
- J.-L. Schiralli, 2014  
*A comparison of solar prominence data between H $\alpha$  and EUV (He II 304)*  
PhD Thesis Univ. North Dakota

- V. Aparna, 2014  
*The structures, mass motions and footpoints of solar filaments*  
PhD Thesis Univ. South Dakota
- J. Koza, R.H. Hammerschlag, J. Rybák, P. Gömöry, A. Kučera, P. Schwartz, 2014  
*Transmission profile of the Dutch Open Telescope H $\alpha$  Lyot filter*  
Astron. Nachrichten 335, 409
- O. Panasenco, S.-F. Martin, M. Velli, 2014  
*Apparent Solar Tornado-Like Prominences*  
Solar Physics, 289, 603
- S. Feng, L. Deng, Y. Yang, K. Yi, 2013  
*Statistical study of photospheric bright points in an active region and quiet Sun*  
Astrophys. Space Science, 348, 17
- I. Kontogiannis, G. Tsiropoula, K. Tziotziou, 2013  
*Transmission and conversion of magneto-acoustic waves in the quiet solar chromosphere*  
11th Hellenic Astron. Conf. 6
- S.-F. Martin, M. Mkhitarian, 2013  
*Elementary bipoles, the building blocks of active regions*  
AAS/Solar Physics Div. Meeting 44, 109
- V. Aparna, P.-S. Hardersen, S.-F. Martin, 2013  
*Footpoint detection and mass-motion in chromospheric filaments*  
AAS/Solar Physics Div. Meeting 44, 06
- I. Kontogiannis, G. Tsiropoula, K. Tziotziou, 2013  
*Mode conversion and transmission of waves in quiet solar regions*  
EGU Gen. Ass. Conf. abstracts
- J. Koza, P. Sütterlin, P. Gömöry, J. Rybák, A. Kučera, 2013,  
*Search for Alfvén waves in a bright network element observed in H $\alpha$*   
Contr. Astron. Obs. Skalnaté Pleso, 43,5
- A.D. Joshi, N. Srivastava, S.K. Mathew, S.F. Martin, 2013  
*Rapid formation and disappearance of a filament barb*  
Solar Physics, 288, 191
- R.H. Hammerschlag, G. Sliepen, F.C.M. Bettonvil, A.P.L. Jägers, P. Sütterlin, Y. Lin, S.F. Martin, O. Panasenco, E.P. Romashets, 2013  
*Large-field high-resolution mosaic movies*  
SPIE Optical Engineering, August issue 2013
- R.J. Rutten, G.J.M. Vissers, L.H.M. Rouppe van der Voort, P. Sütterlin, N. Vitas, 2013  
*Ellerman bombs: fallacies, fads, usage*  
J. Physics Conference Series, 440, 1, 012007
- R.H.Hammerschlag, F.C.M. Bettonvil, 2013  
*Kees Zwaan, open principle, future of high-resolution solar telescopes*  
ASP Conf. Series, 470, 381
- H. Uitenbroek, 2013  
*Eyes on the Sun: solar instrumentation*  
ASP Conf. Series, 470, 83
- R.J. Rutten, 2013  
*Twists to solar spicules*  
ASP Conf. Series, 470, 49

- G.Tsiropoula, K. Tziotziou, I. Kontogiannis, M.S. Madjarska, J.G. Doyle, Y. Suematsu, 2012  
*Solar Fine-Scale Structures. I. Spicules and Other Small-Scale, Jet-Like Events at the Chromospheric Level: Observations and Physical Parameters*  
Space Sci. Rev. 169, 181, preprint
- R.H. Hammerschlag, J.N. Kommers, S. Visser, F.C.M. Bettonvil, A.G.M. van Schie, S.J. van Leverink, G. Sliepen, A.P.L. Jägers, W. Schmidt, R. Volkmer, 2012  
*Open-foldable domes with high-tension textile membranes: the GREGOR dome*  
AN 333 830, preprint
- A. Joshi, S.-F. Martin, S. Mathew, N. Srivastava, 2012  
*High-resolution observations of a filament showing activated barb*  
39th COSPAR Scientific Assembly
- S. Feng, K.-f. Ji, H. Deng, F. Wang, X.-d. Fu, 2012  
*Automatic detection and extraction algorithm of inter-granular bright points*  
J. Korean Astron. Society, 45. 167
- R.J. Rutten, H. Uitenbroek, 2012  
*Chromospheric backradiation in ultraviolet continua and H $\alpha$*   
A&A 540, A86
- P. Tanga, T. Widemann, B. Sicardy, J.-M. Pasachoff, J. Arnaud, L. Comolli, A. Rondi, S. Rondi, P. Sütterlin, 2012,  
*Sunlight refraction in the mesosphere of Venus during the transit on June 8th, 2004*  
Icarus 218 207, preprint
- C. Kuckein, V. Martínez Pillet, R. Centeno, 2012  
*An active region filament studied simultaneously in the chromosphere and photosphere: I - Magnetic structure*  
A&A 539, A131
- I. Kontogiannis, G. Tsiropoula, K. Tziotziou, 2012  
*Multi-wavelengths observations of oscillatory phenomena in a solar network region and their relation to the magnetic field*  
10th Hellenic Astronomical Conference
- M. Herlender, A. Berlicki, 2011  
*Multi-wavelength analysis of Ellerman Bomb light curves*  
Central European Astrophys. Bull. 35, 181
- P.-A. Bourdin, 2011  
*Denoising observational data*  
Contrib. Astron. Obs. Skalnaté Pleso, 41, 149
- M. Bodnárová, J. Rybák, D. Utz, A. Hanslmeier, 2010  
*Dynamika fotosférických jasných bodov v G-páse odvodená použitím dvoch plne automatických algoritmov*  
Procs. 20th Slovak National Solar Physics Meeting
- I. Kontogiannis, G. Tsiropoula, K. Tziotziou, M.K. Georgoulis, 2010  
*Oscillations in a network region observed in the H $\alpha$  line and their relation to the magnetic field*  
A&A 524, A12
- A. Berlicki, P. Heinzel, E.H. Avrett, 2010  
*Photometric analysis of Ellerman bombs*  
Mem. Soc. Astron. Italiana, 81, 646
- M. Bodnárová, D. Utz, J. Rybák, A. Hanslmeier, 2010  
*Dynamics of G-band bright points derived using two fully automated algorithms*  
Central European Astrophys. Bull. 34, 1, 25

- R.H. Hammerschlag et al., 2010  
*The Irkutsk Barium filter for narrow-band wide-field high-resolution solar images at the Dutch Open Telescope*  
SPIE 7735, 265
- G. Sliepen, A.P. Jägers, F.C.M. Bettonvil, R.H. Hammerschlag, 2010  
*Seeing measurements with autonomous, short-baseline shadow band rangiers*  
SPIE 7733, 144
- F.C.M. Bettonvil et al., 2010  
*The pier and building of the European Solar Telescope (EST)*  
SPIE 7733, 97
- F.C.M. Bettonvil et al., 2010  
*The enclosure for the European Solar Telescope (EST)*  
SPIE 7733, 96
- G. Sliepen, A.P.L. Jägers, R.H. Hammerschlag, F.C.M. Bettonvil, 2010  
*Foldable dome climate measurements and thermal properties*  
SPIE 7733, 95
- R.H. Hammerschlag et al., 2010  
*Mechanical design of a completely open-foldable dome for EST*  
SPIE 7733, 17
- R.J. Rutten, 2010  
*The quiet chromosphere. Old wisdom, new insights, future needs*  
Procs. 25th NSO Workshop, Mem. Soc. Astr. It. 81, 565  
preprint
- R.J. Rutten, 2010  
*Solar Spectroscopy and (Pseudo-)Diagnostics of the Solar Chromosphere*  
Procs. Kodaikanal Conference “Recent Advances in Spectroscopy”, Springer, 163  
Arxiv0905.2623
- I. Kontogiannis, G. Tsiropula, K. Tziotziou, 2010  
*Power halo and magnetic shadow in a solar quiet region observed in the Halpha line*  
A&A 510, A41
- I. Kontogiannis, G. Tsiropoula, K. Tziotziou, 2010  
*Comparative Analysis of Oscillations of a Solar Quiet Region Using Multi-Wavelength Observations*  
ASP Conf. Series, 424, 31
- R.H. Hammerschlag, F.C.M. Bettonvil, A.P.L. Jägers, G. Sliepen, 2009  
*Open Principle for Large High-Resolution Solar Telescopes*  
Earth, Moon, Planet 104, 83
- S. Berkebile-Stoiser, P. Gömöry, A.M. Veronig, J. Rybák, P. Sütterlin, 2009  
*Multi-wavelength fine structure and mass flows in solar microflares*  
A&A 505, 811
- B. Bein, A. Veronig, J. Rybak, P. Gömöry, S. Berkebile-Stoiser, P. Sütterlin, 2009  
*Multi-wavelength Observations of Microflares Near an Active Region*  
Central European Astrophys. Bull., 33, 179
- W. Pötzi, 2009,  
*Granulation Properties in DOT Images from Solar Maximum to Minimum*  
Central European Astrophys. Bull., 33, 59

- M.J.Martínez González, L.R. Bellot Rubio, 2009  
*Emergence of Small-scale Magnetic Loops Through the Quiet Solar Atmosphere*  
ApJ 700, 1391
- G. Tsiropoula, K. Tziotziou, P. Schwartz, P. Heinzel, 2009  
*Oscillatory phenomena in a solar network region*  
IAU Symp. 257, 181
- R.H. Hammerschlag, F.C.M. Bettonvil, A.P.L. Jägers, G. Sliepen, 2009  
*Open Principle for Large High-Resolution Solar Telescopes*  
Earth Moon and Planets, 104, 83
- K. Tziotziou, G. Tsiropoula, K. Tziotziou, P. Schwartz, P. Heinzel, 2008  
*Oscillatory phenomena in a solar network region*  
Procs. 12th European Solar Physics Meeting  
2008ESPM...12.2.41T
- T. Roudier, J.M. Malherbe, M. Švanda, G. Molodij, S. Keil, P. Sütterlin, B. Schmieder, V. Bommier, G. Aulanier, N. Meunier, M. Rieutord, S. Rondi, 2008  
*Photospheric flows around a quiescent filament at large and small scale and their effects on filament destabilization*  
SF2A-2008, 569
- R.J. Rutten, 2008  
*Concluding Remarks*  
Procs. 12th European Solar Physics Meeting  
2008ESPM...12..7.1R
- G. Tsiropoula, K. Tziotziou, P. Schwartz, P. Heinzel, 2008  
*Multiwavelength analysis of a solar quiet region*  
A&A 493, 217
- G. Tsiropoula, K. Tziotziou, P. Schwartz, P. Heinzel, 2008  
*Multi-wavelength analysis of a solar network region*  
Central European Astrophys. Bull. 32, 109
- B. Bovelet, E. Wiehr, 2008  
*The quiet Sun's magnetic flux estimated from Ca II H bright inter-granular G-band structures*  
A&A 488, 1101
- P.N. Brandt, A.V. Getling, 2008  
*Do Long-Lived Features Really Exist in the Solar Photosphere?*  
*II. Contrast of Time-Averaged Granulation Images*  
Solar Physics, 249, 307
- S.S. Hasan, A.A. van Ballegooijen, 2008  
*Dynamics of the solar magnetic network. II. Heating the magnetized chromosphere*  
ApJ 680, 1542
- R.J. Rutten, B. van Veelen, P. Sütterlin, 2008  
*DOT Tomography of the Solar Atmosphere VII. Chromospheric Response to Acoustic Events*  
Solar Physics 251, 533
- R.J. Rutten, 2008  
*Halpa as chromospheric diagnostic*  
Procs. First Hinode Science Meeting (Dublin)  
ASP Conf. Series 397, 54



- Ø. Langangen, M. Carlsson, L. Rouppe van der Voort, V. Hansteen, B. DePontieu, 2008  
*Spectroscopic measurements of dynamic fibrils in the Ca II 8662 line*  
ApJ 673, 1194
- R.H. Hammerschlag, F.C.M. Bettonvil, A.P.L. Jägers, G. Sliepen, 2008  
*Cornelis Zwaan, open principle, and the future of high-resolution solar telescopes*  
SPIE 7012E, 20
- A.P.L. Jägers, G. Sliepen, F.C.M. Bettonvil, R.H. Hammerschlag, 2008  
*Fast foldable tent domes*  
SPIE 7018E, 56
- F.C.M. Bettonvil, R.H. Hammerschlag, A.P.L. Jägers, G. Sliepen, 2008  
*Large fully retractable telescope enclosures still closable in strong wind*  
SPIE 7018E, 52
- G. Sliepen, A.P.L. Jägers, F.C.M. Bettonvil, R.H. Hammerschlag, 2008  
*Contactless sub-millimeter displacement measurements*  
SPIE 7018E, 41
- B. Bovelet, E. Wiehr, 2007  
*Multiple-Scale Pattern Recognition Applied to Faint Intergranular G-band Structures*  
Solar Physics 243, 121
- J. Sánchez Almeida, L. Teriaca, P. Sütterlin, D. Spadaro, W. Schühle, R. J. Rutten, 2007  
*Search for photospheric footpoints of quiet-Sun transition region loops*  
A&A 475, 1101
- C. Beck, L.R. Bellot Rubio, R. Schlichenmaier, P. Sütterlin, 2007  
*Magnetic properties of G-band bright points in a sunspot moat*  
A&A 472, 607
- S. Rondi, T. Roudier, G. Molodji, V. Bommier, S. Keil, P. Sütterlin, J.-M. Malherbe, N. Meunier, B. Schmieder, P. Maloney, 2007  
*Photospheric flows around a quiescent filament*  
A&A 467, 1289
- Y. Katsukawa, 2007  
*Observational analysis of the relation between coronal loop heating and photospheric magnetic fields*  
Procs. Solar-B workshop  
ASP Conf. Series 369, 287
- R.H. Hammerschlag, F.C.M. Bettonvil, A.P.L. Jägers, R.J. Rutten, 2007  
*Aperture increase options for the Dutch Open Telescope*  
Procs. Coimbra conference  
ASP Conf. Series 368, 573
- R.J. Rutten, 2007  
*Observing the solar chromosphere*  
Procs. Coimbra conference  
ASP Conf. Series 368, 27
- G. Tsiropoula, K. Tziotziou, J. Giannikakis, P. Young, U. Schühle, P. Heinzel, 2007  
*Multi-wavelength Analysis of a Solar Quiet Region*  
Procs. Coimbra conference  
ASP Conf. Series 368, 171

- J. Koza, P. Sütterlin, A. Kučera, J. Rybák, 2007  
*Temporal Variations in the Orientation of Fibrils*  
Procs. Coimbra conference  
ASP Conf. Series 368, 115
- Ø. Langanen, M. Carlsson, L. Rouppe van der Voort, V. Hansteen, 2007  
*Chromospheric Spectroscopy at High Spatial Resolution*  
Procs. Coimbra conference  
ASP Conf. Series 368, 45
- C. Beck, K. Mikurda, L.R. Bellot Rubio, R. Schlichenmaier, P. Sütterlin, 2007  
*Magnetic properties of G-band bright points*  
Procs. Göttingen conference
- D. Cabrera Solana, L.R. Bellot Rubio, C. Beck, J.C. del Toro Iniesta, 2006  
*Evershed Clouds as Precursors of Moving Magnetic Features around Sunspots*  
ApJ 649, L41
- J.W. Harvey, 2006  
*Chromospheric Magnetism*  
ASP Conf. Series 358, 419
- W. Pötzi, P.N. Brandt, 2006  
*Divergence and vorticity at solar mesogranular scales*  
Central European Astrophys. Bull. 1, 1
- R.H. Hammerschlag, F.C.M. Bettonvil, A.P.L. Jägers, 2006  
*Towers for telescopes with extreme stability: active or passive?*  
SPIE 6273E, 50
- R.H. Hammerschlag, F.C.M. Bettonvil, A.P.L. Jägers, G.B. Scharmer, 2006  
*Large bearings with incorporated gears, high stiffness, and precision for the Swedish Solar Telescope (SST) on La Palma,*  
SPIE 6273E, 34
- F.C.M. Bettonvil, R.H. Hammerschlag, P. Sütterlin, R.J. Rutten, A.P.L. Jägers, G. Sliepen, 2006  
*Tunable H-alpha Lyot filter with advanced servo system and image processing: instrument design and new scientific results with the Dutch Open Telescope*  
SPIE 6269E, 12
- E. Lanford, M. Swain, C. Meyers, T. Muramatsu, G. Nielson, V. Olson, S. Ronsse, N. Vinding, E. Nyden, R. Hammerschlag, P. Little, 2006  
*Concept study and validation of Antarctic telescope tower*  
SPIE 6268E, 36
- P. Heinzel, U. Anzer, 2006  
*On the fine structure of solar filaments*  
ApJ 643, L65
- C. Beck, W. Schmidt, L.R. Bellot Rubio, R. Schlichenmaier, P. Sütterlin, B.W. Lites, 2006  
*Polarimetric observations of the formation of a G-band bright point*  
Procs. 4th Solar Polarization Workshop  
ASP Conf. Series, 358, 72
- F. Snik, F.C.M. Bettonvil, A.P.L. Jägers, R.H. Hammerschlag, R.J. Rutten, C.U. Keller, 2006  
*The Ba II 4554 / Hbeta imaging polarimeter for the Dutch Open Telescope*  
Procs. 4th Solar Polarization Workshop  
ASP Conf. Series, 358, 205

- J. Leenaarts, R.J. Rutten, P. Sütterlin, M. Carlsson, H. Uitenbroek, 2006  
*DOT tomography of the solar atmosphere VI. Magnetic elements as bright points in the blue wing of H $\alpha$*   
A&A 449, 1209
- R.J. Rutten, 2006  
*On the nature of the solar chromosphere*  
Procs. 23rd NSO Workshop  
ASP Conf. Series, 354, 282
- A.G. de Wijn, R.J. Rutten, E.M.W.P. Haverkamp, P. Sütterlin, 2006  
*Magnetic patches in internetwork areas*  
Procs. 23rd NSO Workshop  
ASP Conf. Series, 354, 20
- H. Zaun, 2006  
*Unter permanenter Observation*  
Persepolis 23
- K. Tziotziou, G. Tsiropoula, P. Sütterlin, 2005  
*DOT tomography of the solar atmosphere V. Analysis of a surge from AR10486*  
A&A 444, 265
- A.G. de Wijn, R.J. Rutten, E.M.W.P. Haverkamp, P. Sütterlin, 2005  
*DOT tomography of the solar atmosphere IV. Magnetic patches in internetwork areas*  
A&A 441, 1183
- L. Bellot Rubio, C. Beck, 2005  
*Magnetic Flux Cancellation in the Moat of Sunspots: Results from Simultaneous Vector Spectropolarimetry in the Visible and the Infrared*  
ApJ 626, L125
- J. Leenaarts, P. Sütterlin, R.J. Rutten, M. Carlsson, H. Uitenbroek, 2005,  
*Small-scale magnetic elements as bright points in the blue H $\alpha$  wing*  
ESA SP-596, 15
- J. Leenaarts, S. Wedemeyer-Böhm, 2005  
*DOT tomography of the solar atmosphere III. Observations and simulations of reversed granulation*  
A&A 431, 687
- S. Shelyag, M. Schüssler, S.K. Solanki, S.V. Berdyugina, A. Vögler, 2004  
*G-band spectral synthesis and diagnostics of simulated solar magneto-convection*  
A&A 427, 335
- W. Pötzi, P.N. Brandt, 2004  
*Is solar plasma sinking down in vortices?*  
Hvar Obs. Bull. 29, 1
- T.E. Berger, A.M. Title, 2004  
*Recent progress in high-resolution observations*  
Procs. Fifth Solar-B Science Meeting  
ASP Conf. Series, 325, 95
- A.G. de Wijn, K. Tziotziou, G. Tsiropoula, P. Sütterlin, 2004  
*DOT studies of chromospheric fine structure in active region AR10486*  
Poster Nederlandse Astronomenconferentie
- R.H. Hammerschlag, O. von der Lühe, F.C.M. Bettonvil, A.P.L. Jägers, F. Snik, 2004  
*GISOT: A giant solar telescope*  
SPIE 5489, 491

- F.C.M. Bettonvil, R.H. Hammerschlag, P. Sütterlin, R.J. Rutten, A.P.L. Jägers, F. Snik, 2004  
*DOT++: The Dutch Open Telescope with 1.4-m aperture*  
SPIE 5489, 362
- R.J. Rutten, F.C.M. Bettonvil, R.H. Hammerschlag, A.P.L. Jägers, J. Leenaarts, F. Snik, P. Sütterlin, K. Tziotziou, A.G. de Wijn, 2004  
*The Dutch Open Telescope on La Palma*  
Procs. IAU Symposium 223, 597
- P. Sütterlin, L.R. Bellot Rubio, R. Schlichenmaier, 2004  
*Asymmetrical appearance of dark-cored filaments in sunspot penumbrae*  
A&A 424, 1049
- R.J. Rutten, A.G. de Wijn, P. Sütterlin, 2004  
*DOT tomography of the solar atmosphere II. Reversed granulation in Ca II H*  
A&A 416, 333
- R.J. Rutten, R.H. Hammerschlag, F.C.M. Bettonvil, P. Sütterlin, A.G. de Wijn, 2004  
*DOT tomography of the solar atmosphere I. Telescope summary and program definition*  
A&A 413, 1183
- B. Bovelet, E. Wiehr, 2003  
*Dynamics of the solar active region fine structure*  
A&A 412, 249
- L.H.M. Rouppe van der Voort, R.J. Rutten, P. Sütterlin, P. J. Sloover, J. M. Krijger, 2003  
*La Palma observations of umbral flashes*  
A&A 403, 277
- L.H.M. Rouppe van der Voort, 2003  
*On the time variability of the Evershed effect*  
A&A 397, 757
- P. Nisenson, A. A. van Ballegooijen, A. G. de Wijn, P. Sütterlin, 2003  
*Motions of isolated G-band bright points in the solar photosphere*  
ApJ 587, 458
- R.J. Rutten, 2003  
*The Dutch Open Telescope*  
in "The future of small telescopes in the new millennium II. The telescopes we use",  
Astrophys. Space Science Lib. 288, Vol. II, Kluwer, 111
- R.J. Rutten, 2003  
*High-Resolution Solar Physics*  
Procs. Udaipur Solar Observatory Silver Jubilee "Probing the Sun with High Resolution"  
Narosa Publ. House, New Delhi, 39
- R.H. Hammerschlag, A. P. L. Jägers, F.C.M. Bettonvil, 2003  
*Large open telescope: size upscaling from DOT to LOT*  
SPIE 4853, 294
- F.C.M. Bettonvil, R.H. Hammerschlag, P. Sütterlin, A. P. L. Jägers, R.J. Rutten, 2003  
*Multi-wavelength imaging system for the Dutch Open Telescope*  
SPIE 4853, 306
- R.J. Rutten, P. Sütterlin, A.G. de Wijn, R.H. Hammerschlag, F.C.M. Bettonvil, P. W. Hoogendoorn, A. P. L. Jägers, 2002  
*Dutch Open Telescope: status, results, prospects*  
Procs. 10th European Solar Meeting (Prague) "Solar Variability: From Core to Outer Frontiers"  
ESA SP-506, 903

- G.I. Kushtal, V.I. Skomorovsky, 2002  
*Advance of the geometrical measurement of the birefringent filter's crystal plates and two-dimensional measurements of Doppler velocity in the solar atmosphere*  
SPIE 4900, 504
- R.J. Rutten, A.G. de Wijn, P. Sütterlin, F.C.M. Bettonvil, R.H. Hammerschlag, 2002  
*Opening the Dutch Open Telescope*  
Procs. Santorini Euroconference and IAU Colloquium 188 "Magnetic Coupling of the Solar Atmosphere"  
ESA SP-505, 565
- C. Briand, M Collados, P. Sütterlin, 2002  
*THEMIS and DOT joint observations on NOAA 9716*  
Procs. Santorini Euroconference and IAU Colloquium 188 "Magnetic Coupling of the Solar Atmosphere"  
ESA SP-505, 361
- H. Balthasar, P. Sütterlin, M. Collados, 2001  
*Penumbra fine structure: need for larger telescopes*  
AN 322, 367
- M. Sobotka, P. Sütterlin, 2001  
*Fine structure in sunspots IV. Penumbra grains in speckle reconstructed images*  
A&A 380, 714
- P. Sütterlin, R.J. Rutten, V.I. Skomorovsky, 2001  
*Ba II 4554 speckle imaging as solar Doppler diagnostic*  
A&A 378, 251
- P. Sütterlin, 2001  
*The size of penumbra fine structure*  
A&A 374, 21
- R.J. Rutten, 2001  
*DOT strategies versus Orbiter strategies*  
Procs. "Solar Encounter: the First Solar Orbiter Workshop"  
ESA SP-493, 357
- P. Sütterlin, R.H. Hammerschlag, F.C.M. Bettonvil, R.J. Rutten, V.I. Skomorovsky, G.N. Domyshv, 2001  
*A Multi-Channel Speckle Imaging System for the DOT*  
Procs. 20th NSO/SP Summer Workshop "Advanced Solar Polarimetry – Theory, Observation, and Instrumentation"  
ASP Conf. Series, 236, 431
- R.J. Rutten, R.H. Hammerschlag, P. Sütterlin, F.C.M. Bettonvil, 2001  
*Proxy magnetometry with the Dutch Open Telescope*  
Procs. 20th NSO/SP Summer Workshop "Advanced Solar Polarimetry – Theory, Observation, and Instrumentation"  
ASP Conf. Series, 236, 25
- R.J. Rutten, R.H. Hammerschlag, P. Sütterlin, F.C.M. Bettonvil, E.B.J. van der Zalm, 2001  
*Solar Magnetometry with the Dutch Open Telescope*  
Procs. 1st SOLSPA Euroconference "The Solar Cycle and Terrestrial Climate"  
ESA SP-463, 611
- R.J. Rutten, 1999  
*Two-Dimensional Phase-Diverse Stokes Spectrometer*  
Procs. NSO/SP Summer Workshop "High Resolution Solar Physics: Theory, Observations, and Techniques",  
ASP Conf. Series 183, 296

- R.J. Rutten, 1999  
*The Dutch Open Telescope: History, Status, Prospects*  
Procs. NSO/SP Summer Workshop "High Resolution Solar Physics: Theory, Observations, and Techniques",  
ASP Conf. Series 183, 147
- R.J. Rutten, R.H. Hammerschlag, F.C.M. Bettonvil, 1999  
*The Dutch Open Telescope*  
Procs. Armagh Workshop "Solar and Stellar Activity: Similarities and Differences",  
ASP Conf. Series 158, 57
- Robert H. Hammerschlag, Felix C.M. Bettonvil, 1998  
*The Dutch Open Telescope at the Roque de los Muchachos Observatory*  
New Astronomy Reviews 42, 485
- R.J. Rutten, R.H. Hammerschlag, F.C.M. Bettonvil, 1997  
*The Dutch Open Telescope*  
Procs. THEMIS Forum "Science with THEMIS"  
Pub. Meudon, 285
- R.J. Rutten, R.H. Hammerschlag, F.C.M. Bettonvil, 1997  
*The Dutch Open Telescope*  
Procs. SCORE96: "Solar Convection and Oscillations and their Relationship"  
Astrophys. Space Science Lib. 225, Kluwer, 289
- R.H. Hammerschlag, 1986  
*Friction and stick-slip in a telescope construction*  
Wear 113, 17
- R.H. Hammerschlag, 1983  
*A telescope drive with emphasis on stability*  
SPIE 444, 128
- R.H. Hammerschlag, 1981  
*Construction outlines of the Utrecht Open Solar Telescope*  
Procs. Sacramento Peak Workshop "Solar Instrumentation: What's Next?"  
Sunspot Workshop, 247
- R.H. Hammerschlag, 1981  
*Aperture screens for solar telescopes*  
Procs. Sacramento Peak Workshop "Solar Instrumentation: What's Next?"  
Sunspot Workshop, 274
- R.H. Hammerschlag, 1981  
*Excursion: tower, parking lot, geostationary orbit,*  
Procs. Sacramento Peak Workshop "Solar Instrumentation: What's Next?"  
Sunspot Workshop, 583
- R.H. Hammerschlag and C. Zwaan, 1973  
*Semitransparent wind shields*  
JOSO Annual Report 1973
- R.H. Hammerschlag and C. Zwaan, 1973  
*An efficient wind shield for the protection of telescopes*  
PASP 85, 468

## 6.2 DOT popular-science descriptions

- Jean-Paul Keulen, 2012  
*Zonnetapijt*  
KIJK, juninummer, 2
- Július Koza, 2010  
*Žiarenie slnečnej chromosféry*  
20th Solar Seminar, Papradno
- Ivan Dorotovič, 2010  
*Moderné slnečné ďalekohľady na Kanárskych ostrovoch a v USA*  
Kozmos, 4, 21
- Július Koza, 2010  
*Moderné prístroje a metódy astronómického výskumu*  
Czechoslovak Journal for Physics 60, 74
- Július Koza, 2009  
*Moderné prístroje a metódy astronómického výskumu*  
Proceedings Slovak astronomical seminar for teachers 2010, 7
- Július Koza, 2009  
*Slnko v roku astronómie*  
Advances of mathematics, physics, and astronomy, 54, 117
- Július Koza, 2007  
*Holandský otvorený teleskop*  
Kozmos, 5, 24
- Július Koza, 2007  
*Jemná štruktúra chromosféry a prechodovej vrstvy*  
Kozmos, 5, 27
- Judith Palacios Hernández, 2007  
*Astronomía con el DOT*  
Revista Huygens 65, 10
- Rob Rutten, 2004  
*DOTtige lijnkernen*  
Vakidoot 2003–2004 nr. 4
- Rob Rutten, 2003  
*De zon en de DOT*  
Universum 37 nr. 3, 6-11
- Felix Bettonvil, Rob Hammerschlag, Pit Sütterlin, 2001,  
*Kijken met de ogen van de DOT*  
Zenit 28, 395
- Rob Rutten, 2001  
*Zwaarwichtige expedities*  
Vakidoot 2000–2001/3
- Rob Rutten, 1999  
*Dutch Open Telescope - Spiegel op de tocht*  
Natuur & Techniek 65, nr. 5, 70-79

- Rob Rutten, 1999  
*Zonsonderzoek met de DOT*  
Vakidoot 1999–2000/1
- Rob Rutten, 1998  
*Eerste licht voor de Dutch Open Telescope*  
Zenit 25, 69
- R.J. Rutten, R.H. Hammerschlag, F.C.M. Bettonvil, 1997  
*De Dutch Open Telescope. Nieuwe zonnetelescoop op La Palma*  
Zenit 24, 481
- Rob Rutten, 1997  
*De Dutch Open Telescope. I. Inleiding*  
Vakidoot 96-97/4
- Rob Rutten, 1966  
*De [eerste] inauguratie van de DOT*  
Fylakra 40, 4/46-50
- Rob Rutten, 1996  
*DOT ziet zon*  
Utrechtscoop nr. 5  
Manuscript
- Rob Rutten, 1992  
*Granulatie van zon en sterren*  
Zenit, nr. 4, 146-156

### 6.3 DOT management documents

Information sheet on foldable domes, January 2011

Annual ENO/CCI report over 2006, autumn 2007.

Report to NOVA ISC, September 2007

Report to NOVA ISC, February 2007

Final Report on ESMN, December 2006

Report to NOVA ISC, September 2006

Report to NOVA ISC, March 2006

Report to NOVA ISC, September 2005

Design for DOT polarimetry, April 2005

Report to NOVA ISC, February 2005

Report on ESMN, September 2004

Report to NOVA ISC, September 2004

DSP description, September 2004

Report to NOVA ISC, March 2004

MOU USO Collaboration in Solar Physics, February 2004

Report on ESMN, December 2003

Report to NOVA ISC, September 2003

Report to NOVA ISC, March 2003



DOT++ proposal to NOVA, March 2003  
DOT Speckle Processor proposal to NWO, January 2003  
Study on parallel speckle processing for the DOT, October 2002  
Report to NOVA ISC, October 2002  
DOT++ preproposal to NOVA, September 2002  
Work plan for the ESMN EC-RTN network, September 2002  
Final Report on the ESMN EC-TMR network, June 2002  
Report to NOVA ISC, March 2002  
White paper on future DOT observing modes, October 2001  
Report to NOVA ISC, September 2001  
Report by DOT Evaluation Committee, June 2001  
Report to DOT Evaluation Committee, March 2001  
Specification of speckle data acquisition, IGF, March 2001  
Report to NOVA ISC, March 2001  
Nota on DOT speckle data acquisition, June 1999  
Speckle proposal to ASTRON, May 1997  
Speckle proposal to ASTRON, July 1992

## **7 DOT detail: technology, speckle modes, facts**

### **7.1 DOT technology**

The DOT is a reflector with a parabolic mirror that sits out in the open at a height of 15 m (photograph). The mirror (presently Cervit, 45 cm diameter, focal length 200 cm) focuses the incoming beam onto a water-cooled 1.6 mm field stop that reflects most of the image out of the telescope and transmits only a 2.5 by 2.5 arcmin subfield to the re-imaging optics and cameras.

The 15 m high support tower, at a weight of 13 ton considerably lighter than the telescope itself, permits only lateral motion of the platform while inhibiting tilts. Even in strong wind buffeting the telescope therefore maintains precise tracking. The tower puts the telescope above much of the turbulent boundary layer caused by solar ground heating, especially when the strong trade wind blows up-slope from Northern directions in the best-seeing weather pattern. The tower consists of open steel-tube triangles and is designed to withstand large ice loads and wind pressure. The ladder and elevator cage may be filled by 30 tons of ice without harm!

The bad-weather canopy (photograph) opens clamshell-like and folds fully away to the sides. It is made of heavy polyester fabric mounted on steel ribs and may be closed in winds up to 30 m/s (or opened, but that is less likely). When closed it withstands the 70 m/s (Bf 12) or stronger winds that can hit Roque de los Muchachos in the harsh La Palma winter storms. The coated fabric also resists ice deposition, a major problem at the Canary Island mountain summits where undercooled fogs often cause heavy upwind icicle growth. The combination of massive ice loads with hurricane-strength storms is a major building risk at the La Palma and Tenerife observatories. A scaled-up copy of this canopy for German GREGOR telescope has been constructed at DTO Delft under supervision of the DOT team and installed on the GREGOR platform by the DOT team.

The tower, platform, telescope, and canopy were mounted on the La Palma site during 1996-1997. The optics were mounted in a full-size interferometer at Utrecht in order to construct a precise major-axis and focus defining laser system that guarantees high-precision alignment. It was used to define the optical axis exactly when the mirror and secondary optics were installed.

The mirror (photograph) is mounted deformation-free with nine-point axial and three-point radial support in a par-

allactic telescope structure that is considerably overdimensioned as well as unbalanced in order to obtain extreme pointing stability at very low dissipation. The latter amounts to only about 20 W (three orders of magnitude less than the heat production of the oil bearings in the nearby William Herschel Telescope). Brushless pairs of servo motors in push-pull preload configuration without backlash drive four-step gear trains (photograph) achieving 1:75,000 reduction with self-aligning gears.

The DOT top is constructed with very stiff supports capable of carrying large weight. The resulting DOT aperture (shadow of the on-axis tube and support beams on the primary) is asymmetric; its unusual shape is accounted for in the speckle processing. Here is an example of the DOT + speckle transfer function (amplitude modulation transfer function averaged over many specklegrams).

The DOT secondary optics consisted initially of on-axis re-imaging lenses, focus mechanism, and analog video camera. All DOT movies from before April 2000 were made with this simple technology-demonstration system. Even at 8-bit digitization (with a PC frame grabber), speckle reconstruction was found to be feasible and worthwhile. Science-grade data followed with the installation of digital cameras.

Multi-channel observation was initiated by the installation of a second camera (the first one mounted besides the incoming beam) which observes continuum near the G-band and enables separation of granular and fluxtube motions through image subtraction, a technique that exploits the strict synchronicity of the DOT speckle imaging system (e.g. Nisenson, van Ballegoijen, de Wijn & Sütterlin, *Ap. J.* 587, 458, 2003).

Subsequently, an elaborate multi-wavelength system was designed using seven digital CCD cameras of which six are located, each with its own optimised re-imaging optics, in the DOT top besides the incoming beam. Here is a schematic of the DOT top. Beam splitters (including dichroic ones) divide the light between the G band (on-axis tube and camera), a continuum band near the G band, Ca II H, Halpha, a continuum band near Halpha, and Ba II 4554 with nearby continuum. Detail is given in 2003hawaii-dot.pdf.

Interference filters are used for the continua, G band and Ca II H. The Halpha beam utilises a Zeiss Lyot filter from the former Ottawa River Solar Observatory which can be tuned rapidly through the line. The similar but even narrower-band tunable Lyot filter from Irkutsk provides Ba II 4554 Dopplergrams. The narrow-band filters are mounted with telecentric re-imaging optics to produce bandpass homogeneity over the full field at the full resolution given by the primary-mirror diffraction limit at each wavelength. The cameras run in synchronous speckle mode, each obtaining many-frame bursts at up to 12 frames/s rate. The digital frames are transported per custom-made optical fiber links to the control room. The telescope and camera operation is also remotely controlled through optical fibers. The incoming speckle bursts are handled by a multi-computer network encompassing a control computer, image-storing computers, each with its own disks and connections to the DOT Speckle Processor. For more detail see Rutten et al., *A&A* 413, 1183, 2004.

The continuum-near-Halalpha and continuum-near-Ba II 4554 speckle registration serves for restoration following Keller & von der Lühe (1992). In this multi-channel technique, the wide-band wavefront estimation is used to restore the narrow-band frames. An important advantage is that when the two Lyot filters for Halalpha and Ba II 4554 are sequentially tuned to multiple wavelengths, smaller sub-bursts per wavelength suffice and so permit faster cadence, and also the different wavelength samples are perfectly co-registered through rubber-sheet slaving to the single wide-band channel speckle reconstruction. However, independent full-burst reconstruction delivers higher quality. A demonstration movie is presented and discussed under DOT speckle modes.

The DOT control room is located in the nearby Swedish telescope building, - where the DOT team enjoys generous hospitality - and adjacent to the Swedish 1-m Solar Telescope (SST) control room and image laboratory. Their proximity obviously facilitates tandem operation of the two telescopes.

The on-site parallel DOT Speckle Processor delivers fast speckle processing. The reduced data are disseminated via the DOT database in Utrecht.

## 7.2 DOT speckle modes

Since 1999 the DOT data collection has employed speckle reconstruction, as originally suggested in a 1992 proposal inspired by the important paper of Keller & von der Lühe (1992). All DOT data sets and the resulting images and movies are either made with full single-channel speckle reconstruction or with "Keller - von der Lühe" (KvdL) two-channel reconstruction. Both techniques were implemented at the DOT by P. Sütterlin, building on earlier

code developments at Freiburg and Göttingen by and under O. von der Lüche and F. Kneer. This section discusses the two methods and compares them in the form of a movie.

**Speckle demonstration movie.** The comparison movie is available with 1 fps play rate as 2005-10-19-QS-hac-speckledemo.avi and as 2005-10-19-QS-hac-speckledemo.mov, both in the DOT movie album. The original 24 fps movie is available as 2005-10-19-QS-hac-speckledemo.mpg in the DOT mpg directory.

The movie was made from an 1.2-hour data sequence obtained on October 19, 2005. The target was a very quiet area near disk center. At the request of P. Gömöry, the DOT was programmed by P. Sütterlin to sequentially switch the Halpha speckle burst collection between the two modes, i.e., taking complete 100-frame bursts at Halpha line center alternated by 5-wavelength Halpha profile scans using 20 frames/burst in KvdL mode. The storage of the full-burst results as FITS files in the DOT database has the standard DOT format, containing not only the reconstruction (first FITS-file image) but also the sharpest frame of the full burst (second image) and the burst average after alignment (third image). This switched data set enabled the construction of a demonstration movie comparing frame selection, full speckle reconstruction, and KvdL reconstruction.

The movie shows only Halpha line-center data. The movie has four submovies, of which each is bytescaled separately for maximum display contrast. They cover only a  $36 \times 27$  arcsec cutout of the full field of view in order to maintain the DOT pixel resolution (the other 4-panel DOT movies in the DOT movie album are  $2 \times 2$  binned).

The first submovie shows the best frame of each full 100-frame burst. These bursts took 30 sec, but the movie cadence is 1 minute since the other 30 sec were used for the KvdL mode. The second panel shows the same sharpest frames, but co-aligned using the 100-frame averages per burst. This is only full-frame alignment, comparable to tip-tilt correction in active optics. There is still much rubber-sheet frame-to-frame warping visible.

The third panel clockwise shows the results from the full speckle reconstruction for the same bursts, after cube alignment. For each, the superimposed Fried parameter specifies the seeing quality determined from the synchronous burst in the blue continuum. It varied from 6 cm to 11 cm, with an overall increase as seen on the corresponding G-band seeing quality plot taken from the chronological DOT data index. The improvement over the sharpest-frames movies is striking. Above Fried = 10 cm the restoration quality becomes very good, reliably resolving fine structure at the 0.3 arcsec diffraction limit.

The fourth panel clockwise shows the line-center results from the KvdL reconstructions of the 20-frame/burst wavelength-scans collected in the first half of each minute, also after cube alignment. The quality is significantly lower than for full reconstruction, but still much better than what is obtained by frame selection. The KvdL advantage is that these images can be directly compared with, or subtracted from, the companion images sampling the same scene in the other four Halpha wavelengths and in the red-continuum images. In addition, all of these can be precisely co-aligned with the simultaneously taken blue continuum and G-band image sequences via the red-continuum sequence.

**Explanation.** The DOT speckle reconstruction starts by aligning all frames per burst with the sharpest one through cross-correlation, and then obtain their average. The field of view covered by the camera is then tessellated into about 1000 overlapping isoplanatic patches of  $64 \times 64$  px or  $4.4 \times 4.5$  arsec (for the blue cameras). Each subfield is speckle-reconstructed independently, obtaining speckle transfer functions from atmospheric turbulence modeling using spectral-ratio Fried parameter evaluation and applying statistical bi-spectral phase estimation in speckle masking, as developed over the years by Weigelt, von der Lüche, de Boer, and others. The restored patches are then assembled by cross-correlation of their overlaps, using the burst average as template, into the full-field speckle-reconstructed image. This diagram by P. Sütterlin illustrates the scheme. The isoplanatic tessellation is an key part of speckle reconstruction that makes it wide-field in nature, in contrast to on-axis adaptive optics. The matching errors in the re-assembly are usually far smaller than the original rubber-sheet deformations. The resulting sequence of speckle-reconstructed images is then often aligned into a 3D (x,y,t) data cube to facilitate analysis and movie production.

In the case of full speckle reconstruction each camera registers speckle bursts of about 100 short-exposure frames, and each such burst is reconstructed independently. Since all cameras start their exposures synchronously, the resulting multiple-camera sequences are simultaneous. However, at each wavelength the wavefront corrections are determined and applied independently. In particular, when the Lyot filters for Halpha and Ba II 4554 are sequentially tuned to sample these lines at different wavelengths, the successive bursts undergo independent restoration. Each wavelength sample then has had its own seeing with its own restoration. The resulting data cubes must

yet be aligned with each other. This is difficult when the scenes differ much, as between Halpha line center and red continuum.

In the case of two-channel KvdL registration and restoration with a tunable filter, only the parallel wide-band continuum camera registers full speckle bursts of 100 frames that undergo full speckle reconstruction. Within the same time, the tunable-filter camera takes shorter bursts, down to only 20 frames/burst, and is tuned in between taking these. For example, a five-wavelength "scan" through Halpha is taken at 20 frames/burst per profile sampling, while the wide-band red-continuum camera collects a full 100-frame burst in synchronous 20-frame segments. The exposure pairs are strictly synchronous between the two cameras, starting and ending simultaneously, and so they saw exactly the same seeing. The KvdL restoration then consists of normal speckle reconstruction for the complete wide-band burst, followed by application of the resulting wavefront deformation matrix as a deconvolution operator for the five retuned narrow-band bursts. The resulting narrow-band images have considerably lower quality than for full-burst reconstruction, but since they share the same wavefront deformation matrix they "have seen the same seeing" and can, for example, be subtracted to produce Dopplergrams. KvdL splitting into subbursts can also be used to speed up the cadence, at the DOT to as fast as 2 sec when sampling a single wavelength without tuning waits.

Note that the common KvdL wavefront correction also shares the rubber sheet correction inherent in the isoplanatic patch tessellation and re-assembly of the wide-band burst. The different profile samplings are therefore perfectly co-aligned and so are the resulting data cubes. Halpha line center and the other profile samplings are then easily aligned to the G-band data via the red-continuum images and to Ba II 4554 Dopplergrams using the barium broad-band continuum images, since these all show the granulation in common. Only the alignment with Ca II H remains difficult since its scene differs much from all others.

**Further remarks.** The movie also demonstrates how terribly (or beautifully) fast the quiet-Sun Halpha scene changes. The slow movie cadence obviously undersamples the intrinsic dynamical time scales. For comparison see this 1-sec cadence movie, presented in 2008ESPM...12..7.1R and made from data taken a year later by L. Ruppe van der Voort at the twice larger SST. Traditional estimates of the solar change time specified the 7 km/s sound speed as limiter, yielding 30 sec for the DOT diffraction limit at Halpha. This is a comfortable duration, much in excess of the seeing freezing time of 10 msec and so permitting collection of complete seeing statistics. However, 30 sec cadence appears much too slow for Halpha scenes. Their faster time scales imply that only KvdL restoration can be used to make Dopplergram movies; full bursts take too long and sample inconstant solar-tmosphere conditions.

The demonstration movie therefore also displays the major limitation of speckle reconstruction for chromospheric imaging. Its advantages are that it is a robust method and corrects the whole field of view, but its disadvantage is that it requires a large number of frames per burst that must independently sample the seeing to ensure validity of the assumed Kolmogorov statistics. Too many frames, so taking too long, for chromospheric imaging. The sound speed is a better solar change time estimator in the deeper atmosphere, making speckle reconstruction a better option for photospheric imaging. But the action is higher up. The short chromospheric time scales make the resulting photon need of fast narrow-band imaging a prime driver for larger solar telescope aperture.

The MOMFBD restoration method developed by Van Noort et al. (2005) for the SST requires far fewer frames per burst, but takes far more subsequent processing and is less robust, necessitating adaptive optics as well. It inherently (via the MO standing for Multi Object) entails multi-channel co-registration as in KvdL restoration. Larger telescopes than the DOT must combine adaptive optics with MOMFBD for chromospheric imaging.

### 7.3 DOT facts

#### Optics

Prime mirror (Cervit): aperture 45 cm, focal length 200 cm

Quality: rms 0.011 micron = wavelength/50

Prime-focus field stop (hole in water-cooled mirror): 1.6 mm

Field of view: 150 arcsec

#### Telescope

Mount: parallactic, brushless push-pull pairs of servo motors

Gears: 1:75000 reduction in four floating-gear steps

Weight: 16 tons

Tower

Design: permits only parallel platform motion, no tilts

Construction: open steel framework

Height: 15 meter

Weight: 13 tons

Canopy

Design: fold-away clam-like shell

Construction: teflon-like-coated PVC fabric on heavy steel ribs

Diameter: 7 meter

Image acquisition system

Blue cameras: Hitachi KP-F100 (1296 x 1030 px, square 6.7 micron px, well depth 16000, 10 bits, 12 frames/s, bad non-linearity)

Field of view: 92 x 73 arcsec, 0.071 arcsec/px

Red cameras: Redlake MegaPlus II ES4020 (2K x 2K px, square 14.84 micron pixels)

Field of view: 113 x 113 arcsec, 0.110 arcsec/px

Fiber links: dual way, custom made (IGF)

DOT speckle processor

Location

Observatorio del Roque de los Muchachos

Instituto de Astrofísica de Canarias

Isla de La Palma, Spain

The DOT is controlled from the SST building of the Institute for Solar Physics of the Royal Swedish Academy of Sciences

Former team

SIU director & solar physics program leader: Prof. Dr. Christoph U. Keller

DOT builder: Dr. Ir. Robert H. Hammerschlag

DOT scientist: Prof. Dr. Robert J. Rutten

DOT engineer: Ir. Felix C.M. Bettonvil

DOT software engineer: Drs. Guus Sliepen

DOT technicians: Piet W. Hoogendoorn, Aswin Jägers

Construction

Workshop Sterrekundig Instituut Utrecht

Centrale Werkplaats Technische Universiteit Delft

Instrumentele Groep Fysica Universiteit Utrecht

Former funding

Sterrekundig Instituut Utrecht (Utrecht University)

Department of Physics and Astronomy (Utrecht University)

Utrecht University

Netherlands Organization for Scientific Research (NWO)

Netherlands Graduate School for Astronomy (NOVA)

Stichting Technische Wetenschappen STW (NWO)

Stichting ASTRON (NWO)

European Solar Magnetometry Network (EC-TMR)

European Solar Magnetism Network (EC-RTN)

North Atlantic Treaty Organization (NATO-CRG)

International Association INTAS

Stichting Optisch Zonneonderzoek in Utrecht (SOZOU)

Stichting N. van Ballegooijenfonds

Pieter Langerhuizen Lambertuszoon Fonds

U.S. National Science Foundation, via Helio Research

DOT websites

DOT: <http://www.staff.science.uu.nl/rutte101/dot> = <http://www.dot.iac.es>

DOT database: <ftp://dotdb.strw.leidenuniv.nl>

DOT search engine: <http://dotdb.strw.leidenuniv.nl/search>

DOT observer wiki: <http://dotdb.strw.leidenuniv.nl/wiki>

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