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Proxy magnetometry with the Dutch Open Telescope

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Abstract. Superb movies from the Dutch Open Telescope (DOT) on La Palma have proven the validity of the open concept of this innovative telescope for high-resolution imaging of the solar atmosphere. A five-camera speckle-burst registration system is being installed that should permit consistent and synchronous speckle reconstruction at multiple wavelengths including the G band, Ca II K and Hα, and provide tomographic high-resolution imaging of the magnetic topology of the solar atmosphere up to the transition region. Other plans include use of a birefringent Ba II 4554 filter built at Irkutsk. However, the DOT funding remains insecure.

1. DOT now

The Dutch Open Telescope (DOT) is an innovative telescope which achieves high angular resolution through combining openness (avoiding internal seeing not through telescope evacuation but through wind flushing of the mirror and telescope interior) with an open support tower (avoiding the excitation of local turbulence by wind blocking) and an excellent site (close to the Swedish solar telescope building from which the DOT is operated) on La Palma where the trade winds are often sufficiently strong to keep the ground-heated layer of turbulent convection below the 15 m DOT tower height and to keep the telescope clean from internal turbulence.

The DOT has demonstrated that the open-telescope concept can successfully replace the vacuum solution to internal seeing that has been used sofar in high-resolution solar telescopes. This success is of obvious importance to the US ATST project and is already copied in the German GREGOR project.

A selection of photographs from the DOT website[1] in Fig. 1 illustrates the open structure of the DOT as well as the extraordinary sturdiness of the parallactic telescope mount which enables shake-free observation even under heavy wind buffeting, a necessary property for an open telescope at a windy site. The support tower consists of an open tubular frame to minimize wind disturbance. Its parallel-triangle geometry inhibits platform tilts and so delivers pointing stability for sources at infinity.

[1] http://dot.astro.uu.nl

Figure 1. DOT photographs, along rows from top left: • DOT observing, water tank for prime-focus cooling in foreground. South is to the left. • covered mirror, focus support struts, suction hoses. • initial imaging-system tube. • clamshell canopy closed. • hour angle wheel, covered mirror in the upper right. • focus alignment within the canopy. • Seykora-Beckers scintillometer with anti-falcon spike.

The optical scheme is simple: a parabolic mirror of 45 cm diameter and 200 cm focal length projects a 2 cm solar image on a tilted mirror which reflects most of it away and passes only the field of observation (up to 3 arcmin) through a tiny hole. The mirror is water-cooled to ambient temperature. Careful laser alignment (bottom-left photograph) has served to position the pinhole with large accuracy.

The post-focus imaging system consisted sofar of a slender tube containing the prime-focus field stop, re-imaging optics, interference filter (usually G band but Ca II K has been tried), and a video camera. The images were transfered through a modem link to the Swedish telescope building and digitized in a PC with an 8-bit frame grabber. This simple hardware was used to verify the open principle, and also to test speckle restoration as a means to get rid of the remaining atmospheric seeing above the telescope. The latter technique proved so successful even at intermediate seeing that most DOT observing is now in speckle mode (see contribution by Süetterlin et al. elsewhere in these proceedings). Movies from these initial observing runs are available on the DOT website and are highly recommended —- they are truly superb!

Example snapshots are shown in Fig. 2, but the movies really bring the message home that with speckle restoration the DOT provides high-resolution imaging *over extended durations*. Even at La Palma the seeing is not always superb, but the combination of a windswept site, an open telescope and consistent speckle restoration permits imaging close to the diffraction limit (0.2 arcsec) whenever the seeing is reasonable. At La Palma such seeing often stays for the whole day, a characteristic in which La Palma differs intrinsically from most other mountain sites.

At present a much more elaborate post-focus system is being implemented. It will consist of five digital (10 bit) cameras with 1300×1030 pixels and a sufficiently fast frame rate to permit taking speckle exposures at the atmospheric freeze time (10 ms or less) in speckle bursts within the solar freeze time (10–20 s per 0.1 arcsec pixel). Digital fiber links transport these speckle bursts to the Swedish solar telescope building where they are stored on tape, up to 400 Gbyte per observing day. The cameras will be fed through elaborate secondary optics systems, mostly mounted besides the incoming beam, that re-image different wavelengths at the diffraction limit with large telecentric spaces for filter placement. The spectral diagnostics that we aim to use are the G band around (λ = 430.5 nm) at 1 nm bandwidth, the Ca II K core at 0.1 nm, Hα through a 0.025 nm tunable Zeiss Lyot filter formerly used by V. Gaizauskas at the Ottawa Solar River Observatory, and the Ba II 455.4 nm line through a very narrow (0.008 nm) tunable Lyot filter built by V. Skomorovsky and co-workers at Irkutsk. The new system and a test of the Dopplergram capabilities of the Ba II 455.4 filter-and-line combination are described by Sütterlin et al. elsewhere in these proceedings.

2. DOT history

The DOT history was described already at the previous Sacramento Peak Summer Workshop (Rutten 1999), but it seems fitting to mention the role which the Sacramento Peak Observatory has played in the DOT conception — because to

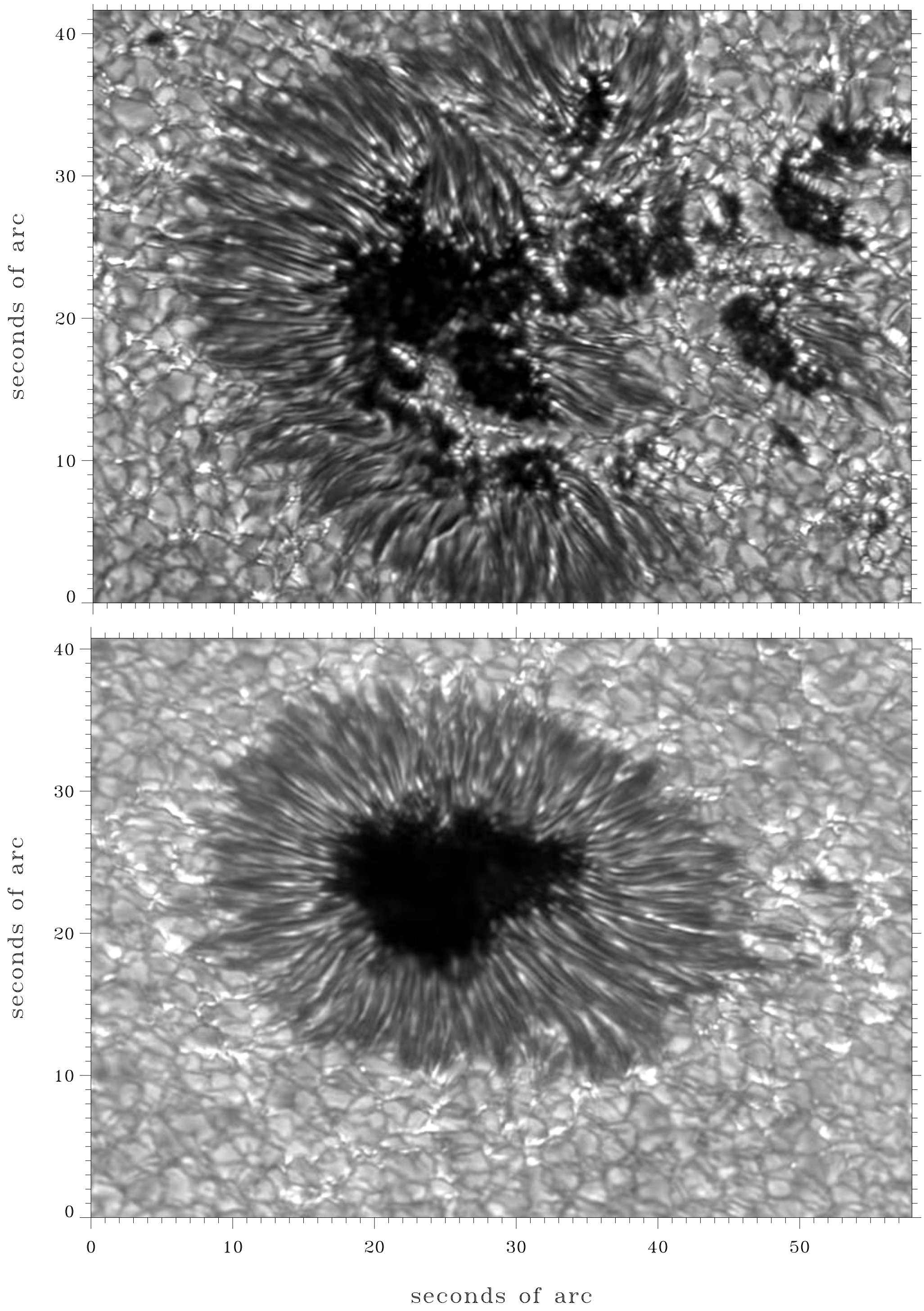

Figure 2. DOT G-band images, with different greyscaling to highlight different structures. Top: AR 8739 on October 23, 1999, 10:04:44 UT. Bottom: AR 8704 on September 20, 1999, 11:01:13 UT. A highly compressed movie of this sunspot featured as *Astronomy Picture of the Day* on February 23, 1999.

a considerable extent, the DOT has originated from Kees Zwaan's experiences at Sac Peak. Zwaan died much too early in June 1999. Much of his work on cool-star magnetism has been reviewed by himself in Schrijver & Zwaan (2000), completed while he was already ill; the JOSO background to the DOT story has been described elsewhere (Rutten 2000).

Kees and Prisca Zwaan came to Sac Peak, then an Airforce facility under the charismatic leadership of Jack Evans, in 1966 after Zwaan completed his Utrecht thesis on sunspot spectra under Minnaert. The Zwaans took very much to the Southwest, to the Sunspot community, and to the spirit of frankness (which perhaps Dutch scientists seem to share more with American colleagues than with their European ones). The year and a half they spent at Sunspot influenced Zwaan's interests decisively. He spent much time studying the extensive Big Dome film collection, giving him his encyclopedic feel of "how active regions behave" on which much of his later research was based including the notion of a magnetic "hierarchy" from slender fluxtubes to full-scale umbrae, and he spent much time discussing observing strategies with Dick Dunn, who was then designing his vacuum tower telescope.

Zwaan's later involvement (as chairman of the site testing working group) in JOSO's extensive quest for the best solar site in Europe stems from this Sac-Peak-generated interest. His JOSO experience led to the formulation of the open tower and telescope, initially envisaged to be transportable and check out sites for LEST (as the ATST team may now envisage to use the DOT to verify the eventual ATST site). The open concept was born in creative Zwaan-style discussions with Hammerschlag who became sufficiently motivated to make the open telescope his chief project — which it has been ever since.

3. DOT future

At present the DOT is funded for a three-year "verification period" in which the simple analog image registration that served to demonstrate the open principle is being expanded into the five-camera system summarized above and described in more detail by Sütterlin et al. in these proceedings. This system plus the success of the open concept should put the DOT squarely on the solar physics map as a multi-wavelength high-resolution imager. We hope to have the system working and the DOT capability for high-resolution solar physics proven when the current funding runs out by next autumn (2001).

The observational niche that the DOT fills with its new camera system consists of long-duration image sequences at high resolution over a wide field. The post-detection speckle processing that we have opted for brings two disadvantages compared with the adaptive optics that is being adopted elsewhere[2]: substantial data processing (but that gets faster all the time) and no possibility to feed a spectrograph slit without seeing. But it also brings a very important advantage: in speckle reconstruction, *the whole field* is optimally restored rather than just the central isoplanatic patched sensed by the wavefront detector. The

[2] Here at Sac Peak at the DST, elsewhere in particular at the New Swedish Solar Telescope which will replace the already dismantled SVST before you can say Göran Scharmer.

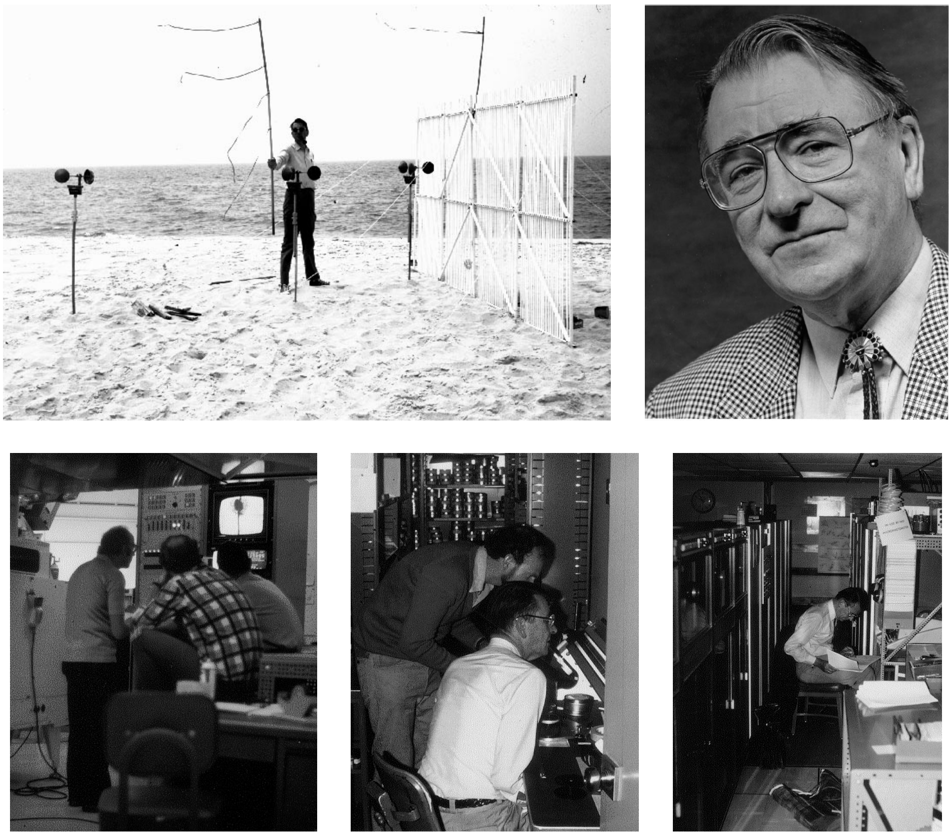

Figure 3. Kees Zwaan (July 24, 1928 — June 16, 1999).
The beach shot was taken by Hammerschlag in 1973 on the Portuguese island Barreta, long championed by Zwaan as an alternative site to the Canary Island volcanos. The oceanic breeze is as strong but at sea level there is more atmosphere including the inversion layer. The wind screen was described by Hammerschlag & Zwaan (1973). The portrait was taken by a Utrecht University photographer at Zwaan's official retirement in 1993. The farewell party concluded the Soesterberg workshop (Rutten & Schrijver 1994) but Zwaan continued working full-time, in particular writing *"Solar and Stellar Magnetic Activity"* with Karel Schrijver. The three pictures below were taken at Sac Peak in 1979. Left: Horst Mauter, Lawrence Cram and Kees Zwaan observing a sunspot with the Echelle Spectrograph. Zwaan put a drawing made from this photograph on the cover of his Utrecht University farewell lecture. Middle: Cram and Zwaan inspect the (photographic!) spectrograms. Right: digitizing the film with the Sigma-5 and the fast microdensitometer. The spectra formed the material for the thesis by Hans Brants (1985).

effectiveness of speckle reconstruction (and phase-diverse reconstruction) diminishes for increasing aperture and is probably no option for meter-class telescopes, but at the DOT speckle processing brings the very important advantage of sharpening large-area images.

The science niche that the DOT will fill consists of atmospheric tomography at high resolution, with emphasis on "proxy-magnetometry" since the diagnostics portray the unsigned magnetic field topology. We give a brief summary of the diagnostics here; more general background is given in Rutten et al. (2000).

The G-band is described in multiple contributions in this volume as the best diagnostic to identify the tiny magnetic elements ("fluxtubes") that make up the magnetic network. The DOT capability to collect day-long sequences will permit to track these features over extended periods to study the assembly and shredding of the network. Obviously, the same holds for active regions.

Ca II K imaging delivers the chromospheric network. It is fuzzier than the G band bright-point clusters which make up the photospheric network but the Ca II K network is a direct indicator of magnetic heating, through spectral line formation that is relatively simple and fairly well understood. In addition, ground-based Ca II K imaging is very valuable for exact co-alignment with coronal image sequences from TRACE because the TRACE 170 nm passband produces look-alike images that correlate very well (Rutten et al. 1999).

High-resolution image sequences in Hα may constitute the most valuable DOT contribution to solar physics. At present there is a large gap between MHD studies of photospheric fluxtubes and MHD and plasmaphysics studies of coronal loops. Both fields progress thanks to new observing techniques (particularly infrared Stokes polarimetry and TRACE) and thanks to steady advance in numerical simulation capability — but it seems that there is a missing realm, at the level of the "magnetic canopies" between the upper photosphere and the low corona. Hα represents about the only diagnostic that can fill this gap. Quantitative interpretation of Hα filtergrams is notoriously difficult because the line mixes Dopplershifts with brightness modulation and is awkwardly sensitive to NLTE population mechanisms because its lower level is so very detached from the ground state. The tactic chosen by the THEMIS group at Meudon to invert bi-dimensional MSDP spectra using extensive Hα profile modeling is an excellent approach, but with all due respect it is clear that THEMIS will not compete with the DOT in terms of angular resolution until it gets adaptive optics, and then it will do so only over a very small field whereas the crucial property of Hα is that it shows *where* the fibrils and mottles that make up magnetic canopies actually go — but to map where they go requires sharpness over a large field.

The Ba II 455.4 nm test described by Sütterlin et al. in these proceedings is very promising with respect to Dopplershift mapping. In addition, J. Trujillo Bueno has during this meeting forcefully emphasized that high-resolution polarimetry with this line should be worthwhile; it has the highest linear polarization near the limb of all lines in the second solar spectrum.

As mentioned above, the present DOT funding runs out by the autumn of 2001. It was cornered in 1998 with much-appreciated help from well-known colleagues and also by the DOT First Light Ceremony in 1997 being a high-level affair featuring Prince of Orange Willem-Alexander. It will be harder to conquer DOT support in the absence of royal attention. We may need your support —

not only to keep the DOT alive but also to keep solar physics in Utrecht alive. That presently consists primarily of the authors to this contribution (of whom two are temporally employed). You are also quite welcome to contribute to foundation SOZOU which Kees Zwaan bequested to support the DOT (secretary P. Hoyng).

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