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OPENING THE DUTCH OPEN TELESCOPE

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ABSTRACT

We hope to "open the DOT" to the international solar physics community as a facility for high-resolution tomography of the solar atmosphere. Our aim is to do so combining peer-review time allocation with service-mode operation in a "hands-on-telescope" education program bringing students to La Palma to assist in the observing and processing. The largest step needed is considerable speedup of the DOT speckle processing.

1. INTRODUCTION

The Dutch Open Telescope (DOT, photograph in Fig. 1) is an innovative solar telescope on La Palma, achieving high-cadence (20 s) solar imaging with 0.2 arcsec angular resolution over long durations (multiple hours) and wide fields of view (90×70 arcsec).

The beautiful DOT movies (http://dot.astro.uu.nl) dramatically convey the dynamical nature of the magnetically-dominated structure of the solar atmosphere. They demonstrate forcefully that long-duration high-cadence high-resolution observation is an absolute must in solar physics. The DOT is the first groundbased solar telescope regularly producing such movies.

The DOT is presently being equipped with a multi-wavelength imaging system which turns it into a tomographic mapper sampling the solar atmosphere from the deep photosphere to the high chromosphere. At 0.2 arcsec such diagnostic imaging opens exciting opportunities to study the magnetic coupling between the solar interior and the solar corona.

However, the DOT data production rate is presently limited to only a few observing campaigns per year. They suffice for our own Utrecht University research needs, but severely underexploit the enormous DOT science potential. The main bottleneck is the very time-consuming speckle processing – multiple months per observing day. If we manage to speed it up we intend to make DOT observing available to the wide solar physics community. Details below.

2. DUTCH OPEN TELESCOPE

The superb DOT image quality results from:

- favorable site: strong laminar oceanic trade wind, low inversion layer, absence of jet-stream shear;
- open design: wind flushing of the telescope interior and primary mirror, non-blocking support tower, stable platform above ground-heated turbulent boundary layer;
- advanced image processing: synchronous speckle burst registration at all cameras, large-volume speckle data collection, off-line speckle reconstruction at all wavelengths.

Further details are given in *e.g.,* Rutten *et al.* (2001a, 2001b). The DOT science strategy and niche are discussed extensively in Rutten (2001). These publications as well as many others and various DOT evaluation and progress reports are electronically available at the DOT website (http://dot.astro.uu.nl).

3. TOMOGRAPHIC MAPPING

The DOT engineers (the last two authors above) are presently constructing optomechanical hardware that will turn the DOT into a tomographic mapper which, when co-observing with TRACE, will diagnose the magnetic coupling between different regimes in the solar atmosphere from the deep photosphere to the EUV corona. The spectral diagnostics are:

- continuum (4320 Å): deep photosphere, showing convective granulation;
- G band (4305 Å): CH lines which brighten in magnetic elements through CH dissociation, showing intergranular magnetism at enhanced contrast;
- Ca II H (3968 Å): brightens in magnetic areas, showing low-chromosphere topology similarly to (but sharper than) ultraviolet images from TRACE;
- H-alpha (6563 Å), rapidly tuned: unique diagnostic of low-lying loops, showing actual magnetic canopies and their dynamics (cf. Rutten 2001);
- Ba II (4554 Å), rapidly tuned with polarization analysis: large-mass ion resonance line, showing velocity fields with extraordinary definition (Sütterlin et al. 2001) and likely to be an excellent mapper of upper-photosphere Zeeman splitting and Hanle depolarization;
- EUV Fe IX (171 Å) from space: bright thermal emission at 10^6 K and dark bound-free scattering absorption at 10^4 K, showing coronal loops and their dynamics.

Such synchronous multi-diagnostic image gathering is illustrated in Fig. 2 with older SVST-plus-TRACE

Figure 1: The Dutch Open Telescope at the Roque de los Muchachos Observatory. The 15 m high tower as well as the telescope itself are open to the trade wind from the North (to the right). When it blows strongly it skims off the solar-heated turbulent boundary layer and flushes the telescope itself. The parallactic telescope mount is extraordinarily stiff to avoid image shake from wind buffeting. A clamshell foldaway dome protects the telescope from (sometimes very) inclement weather. The DOT presently has a 45 cm parabolic primary mirror with 200 cm focal length. The prime-focus image is mostly reflected away with a water-cooled mirror containing a 1.6 mm hole which transmits the field of view. The structure at the top of the telescope contains this light stop, the focusing mechanism, re-imaging optics, the G-band filter and the G-band camera in a slender on-axis tube, a phase-diverse video imaging system for focus control branched off on one side of the incoming beam, the near-G continuum filter and camera on the other side. The Ca II Hα and Ba II 4554 Å filters and cameras will be mounted there as well. The speckle frames from each camera are transported via optical fibers to the large-capacity (360 GByte) specklegram acquisition system in the DOT control room in the nearby New Swedish Solar Telescope (NSST) building.

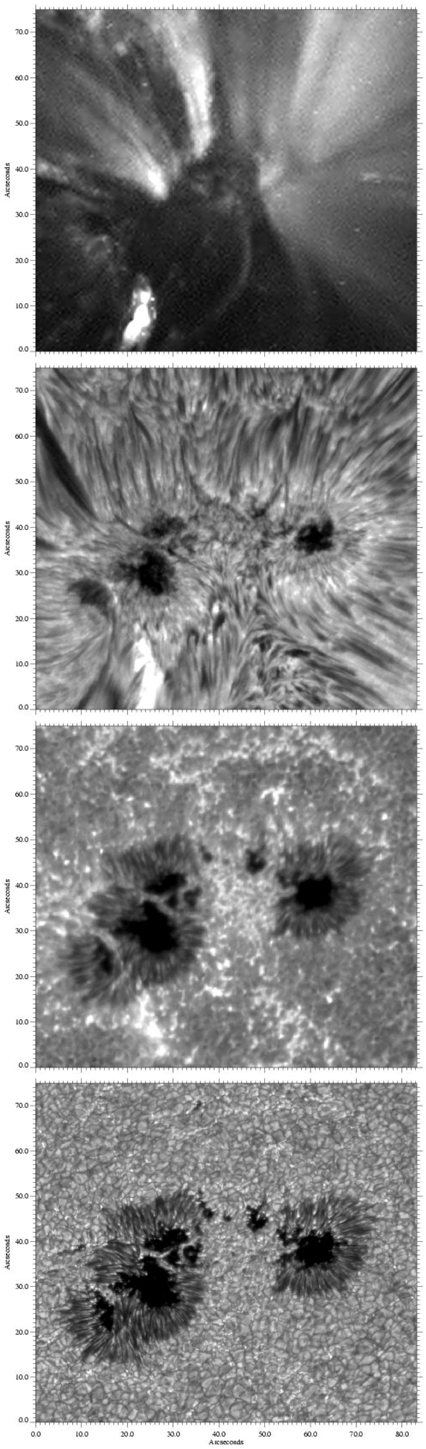

Figure 2: Tomographic mapping: famous quartet from the multi-wavelength images taken with TRACE (top, 171 nm) and the SVST (Hα center, Ca II K center, G band) by B. de Pontieu. This ubiquitous quartet was put in perspective to add observational perspective to the theme of this meeting. It aptly illustrates the forthcoming DOT multi-wavelength capabilities. The message of this contribution is that the DOT will collect comparable but long-duration and very homogeneous multi-wavelength tomography movies, and that it may do so as context imager for many solar observing programs including YOUR programs — if we solve our speckle processing bottleneck problem. Courtesy T.E Berger.

images collected by T.E. Berger. We aim to turn the DOT into a machine which regularly and frequently collects such composites at high cadence in long-duration sequences. Figure 3 shows a two-channel example.

The consistent speckle reconstruction applied at the DOT brings important advantages:

- large field of view: only limited by the size of the camera chip. Speckle reconstruction is an image-plane technique that is not limited to one isoplanatic patch for optimal restoration. It starts by dividing the field of view into many such patches, which are separately reconstructed and put back together in the end. Pupil averaging over multiple r_0-size subapertures makes speckle signal/noise diminish with aperture size, but with the 45 cm diameter of the DOT primary seeing quality $r_0 \approx 7$ cm suffices to obtain restoration down to the 45 cm diffraction limit;
- excellent homogeneity: the seeing on La Palma is frequently better than $r_0 \approx 7$ cm over long durations. This means that the resulting DOT speckle movies are homogeneous in quality, an important asset for time-sequence analysis;
- achromaticity: speckle reconstruction permits synchronous diffraction-limited co-spatial image gathering at widely different wavelengths. The seeing changes with the wavelength, but the restoration is achieved independently at each.

The narrow-band filters that will be installed at the DOT (for Hα and Ba II 4554 Å, a Lyot filter in both cases) will probably require two-channel speckle restoration as described by Keller & von der Lühe (1992). Since the broad continuum passband must lie close to the narrow line passband in order to sample the same wavefront perturbations, we are adding a continuum channel close to Hα.

The science value of such multi-wavelength diagnostics at high cadence over a wide field and during long durations to studies of magnetic structuring, magnetism-constrained dynamics, and various types of magnetic coupling is obvious and large. In principle the DOT may fill this niche at least until Solar-B operates.

4. SPECKLE PROCESSING

Speckle reconstruction is an important contributor to the superb quality of the DOT movies but it also poses a large problem: a speckle data glut. At present we have two cameras running synchronously. In the future there will be five or even six. When taking 100-frame speckle bursts at 30 s cadence they will fill the 360 GByte speckle storage in about two hours (corresponding to one "benchmark run" in the graph in Fig. 4). The subsequent speckle reconstruction using all six DOT computers on La Palma will take as long as three months.

Only very few such runs per year can therefore be processed. Our corresponding strategy is to observe somewhat more frequently, archive each run on tape, and select the very best run for processing and subsequent analysis. This strategy fulfills our rather modest science needs at Utrecht. One good run can easily furnish a good part of a PhD thesis!

However, this tape-and-select "science for Utrecht" mode implies a large loss of potential science by the worldwide solar physics community. As noted above, the DOT represents an ideal high-resolution context observer to virtually every solar physics program addressing issues in which magnetic topology plays a role. Frequently, such programs are executed as topic-oriented campaigns of one to a few weeks duration combining many telescopes. The DOT strengths of high resolution over extended duration, relatively large field of view, and tomographic multi-wavelength capability constitute desirable assets to any such campaign.

Effectively the speckle processing achieves hundredfold data compression from 100 frames per speckle burst to a single wavefront-restored image. The final size of a multi-hour multi-camera run therefore amounts to less than 4 GByte and can easily be mailed to a DOT customer on a single DVD. We believe that many solar physicists would be quite happy to receive such DVD's for the solar region they have observed with other instruments. This belief is our motivation to try to open the DOT.

Frequent DOT participation in international campaigns is viable only if the speckle processing delivers the product (the DVD with restored image sequences) not long after each campaign. Since speckle reconstruction involves tessellating the observed field into about a thousand isoplanatic subfields which are each processed independently and then rejoined, parallel processing is an obvious technique to consider. An effort to achieve this has recently culminated in a test demonstration of a parallel version of the DOT speckle code on a temporary 12-node cluster. The speckle reconstruction itself parallelized nearly perfectly, the tessellation and rejoining reasonably.

Figure 4 shows estimates for the required DOT cluster size in terms of turnaround time, based on our parallel-code tests. The conclusion is that we need a sizable cluster, preferably combined with a multi-processer computer to speed up the preprocessing. The cost, including non-trivial housing on La Palma, amounts to 200–300 k€. The present DOT funding is insufficient to realize such a solution. Thus, we are in need of outside funding to realize fast speckle processing turnaround.

5. SERVICE MODE TIME ALLOCATION

If we manage to speed up the speckle processing to a turnaround of only a week or shorter we intend to open the DOT to others as a "common-user" facility from which observing time can be requested through a peer-review proposal mechanism. The DOT must then be manned a much larger fraction of the time

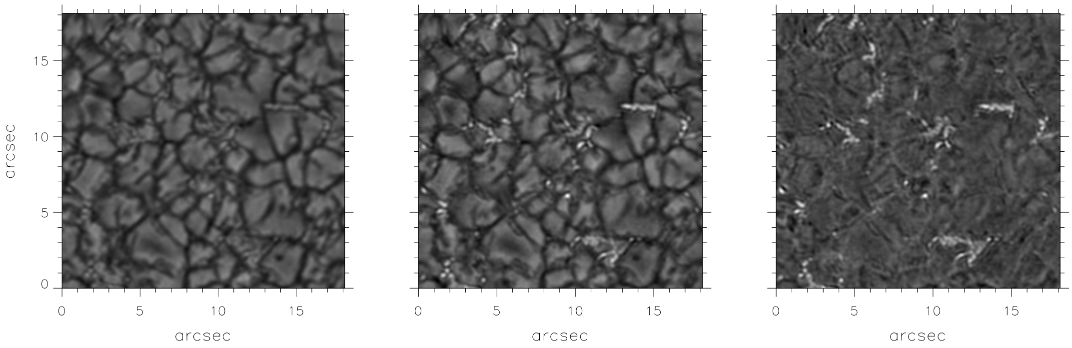

Figure 3: Example of synchronous DOT imaging. Small cutouts from a 100-minute 63×73 arcsec^2 two-camera sequence of AR 9669 taken October 19, 2001. First panel: continuum (λ = 4320 Å). Second panel: synchronous G-band (λ = 4305 Å). Third panel: "magnetic image" isolating the magnetic elements in the intergranular lanes through an algebraic combination of the two images. Such high-resolution image sequences permit studies of magnetic-element buffeting, twisting and braiding as well as studies of deeper-than-granulation fluxtube anchoring (cf. van Ballegooijen et al. 1998). The double movie is available in mpeg at http://dot.astro.uu.nl, as FITS files on CD-rom from P.Suetterlin@astro.uu.nl.

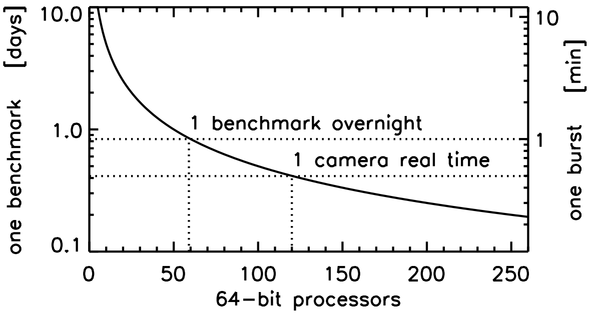

Figure 4: Cluster size estimate for DOT speckle processing. Horizontal: number of 64-bit CPU's, assuming next-generation specifications. Vertical at left: days needed to process one "benchmark" of 360 GByte speckle data. Vertical at right: minutes needed to reconstruct a single speckle burst. The graph is probably erring on the optimistic side because the preprocessing (frame alignment and tessellation) does not accelerate linearly with the CPU number. The preprocessing may be done more efficiently on a multi-processor computer than on a Beowulf cluster.

than for Utrecht-only usage. This may be done by involving the proposer, but an attractive alternative is to add service operation by students in traineeships at the telescope. They will gain hands-on experience with state-of-the-art data acquisition and reduction techniques in international campaigns at the major astronomical observatory in Europe. We think in terms of bringing a few dozen students to La Palma each observing season (May–October) for two-week stints at the telescope.

In view of the large decline in the number of students choosing physics at our university (a dramatic trend all over Western Europe), we believe that the attractiviness of such a program to students will also be attractive to the Utrecht Faculty of Physics and Astronomy, the main DOT sponsor. Since the present DOT funding expires over two years, we hope to realize a "student-on-the-DOT" program soon enough to exert a favorable influence on future Faculty decisions regarding the DOT future. Our largest problem is to find funding for the speckle processor.

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