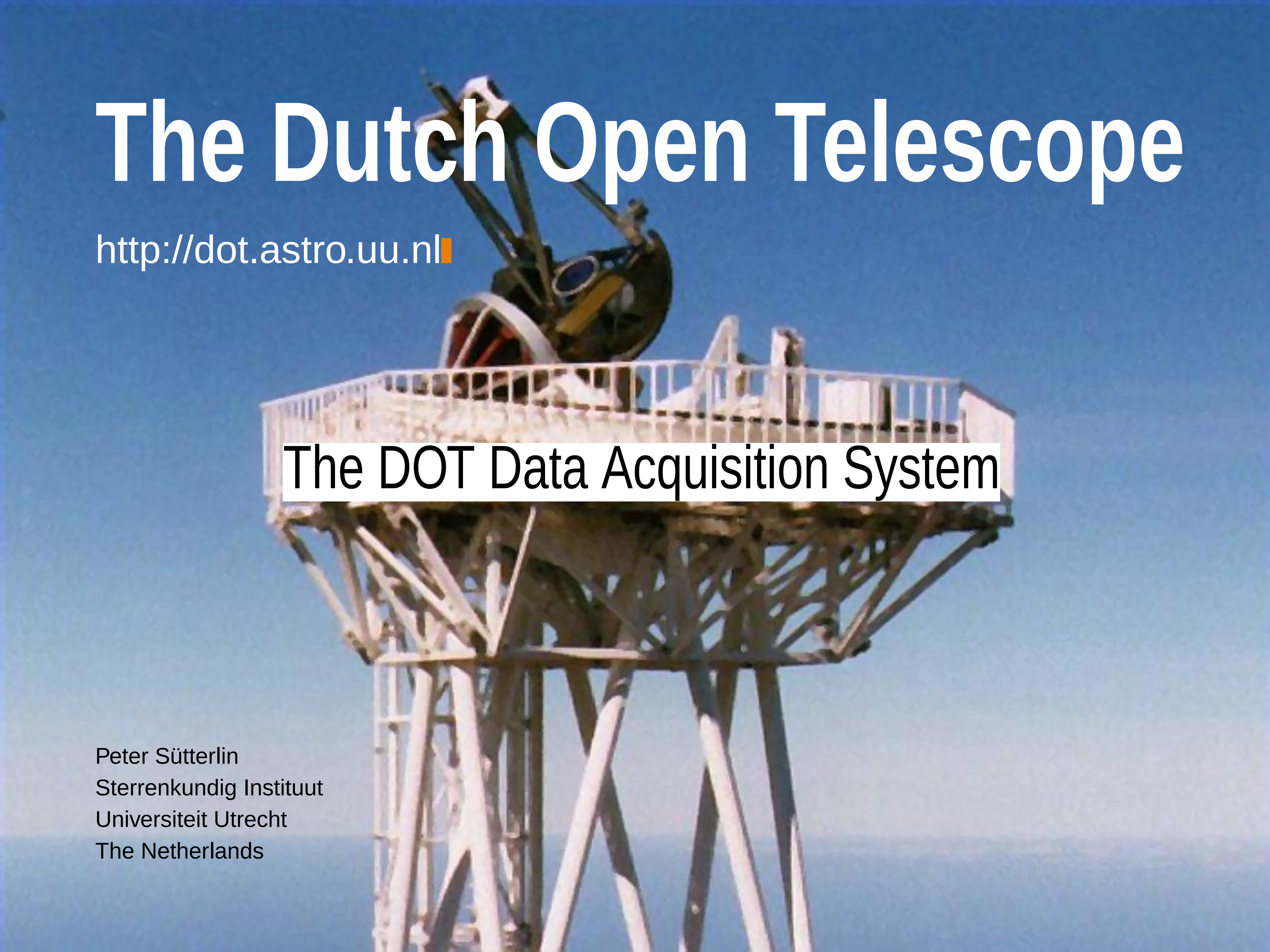

The Dutch Open Telescope

http://dot.astro.uu.nl

The DOT Data Acquisition System

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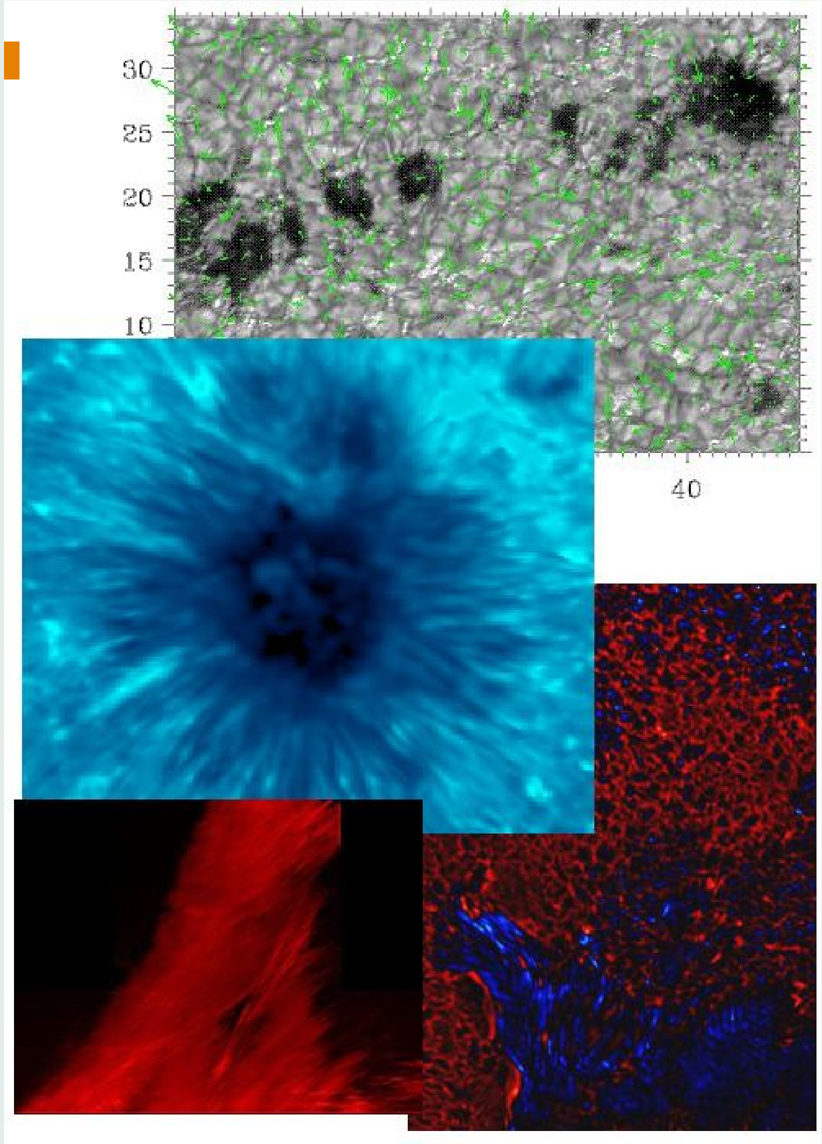
Outline

- Hardware
  - Cameras
  - Fiber link
  - Computer
- Software
  - Acquisition
  - Post processing
- Results
- Conclusions



The CCD Cameras

- Hitachi KPF-100 machine vision camera
- Chip Sony ICX-085
  - ⋆ 1296×1030 px
  - ⋆ Pixel size $6.7 \times 6.7\,\mu m^2$
  - ⋆ Full Well Capacity $\approx 17\,000\ e^-$
  - ⋆ High quantum efficiency in the blue
- 10 bit, 20.2 MHz ADC (12 fps)
- RS 242 digital readout
- Programmable exposure time (80 μs steps)
- Currently only 6 fps
- Automatic dark adjust

The Fiber Link

Cameras and acquisition computers are separated by more than 150 m. This distance is bridged by an *bidirectional* optical fiber link (2 lines/camera). Concepted and realized by the IGF, the link has several functions:

- Data link Camera $\longrightarrow$ Computer
- Control link Computer $\longrightarrow$ Camera
- Uses off-shelf Hotlink receivers
- Timing and synchronization of cameras:
  - ⋆ Clock pulse generation
  - ⋆ Enabling master/slave mode
- Hardware abstraction layer

Computer I: The Acquisition Computer

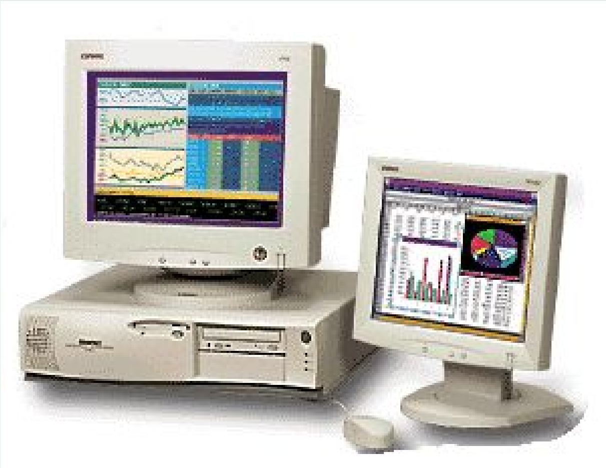
One computer per camera, a total of 5 mounted in a 19-inch rack.

- Compaq Proliant ML350
- Dual P III-600
- 512 MB RAM
- RAID 0 (striping) system, 4×18 GB = 72 GB
- IC4-DIG16 digital frame grabber
- Operating system Linux

Computer II: The Control Workstation

All operation is controlled by one computer. The main acquisition software is running there, in addition (when not observing) it can be used for standard work.

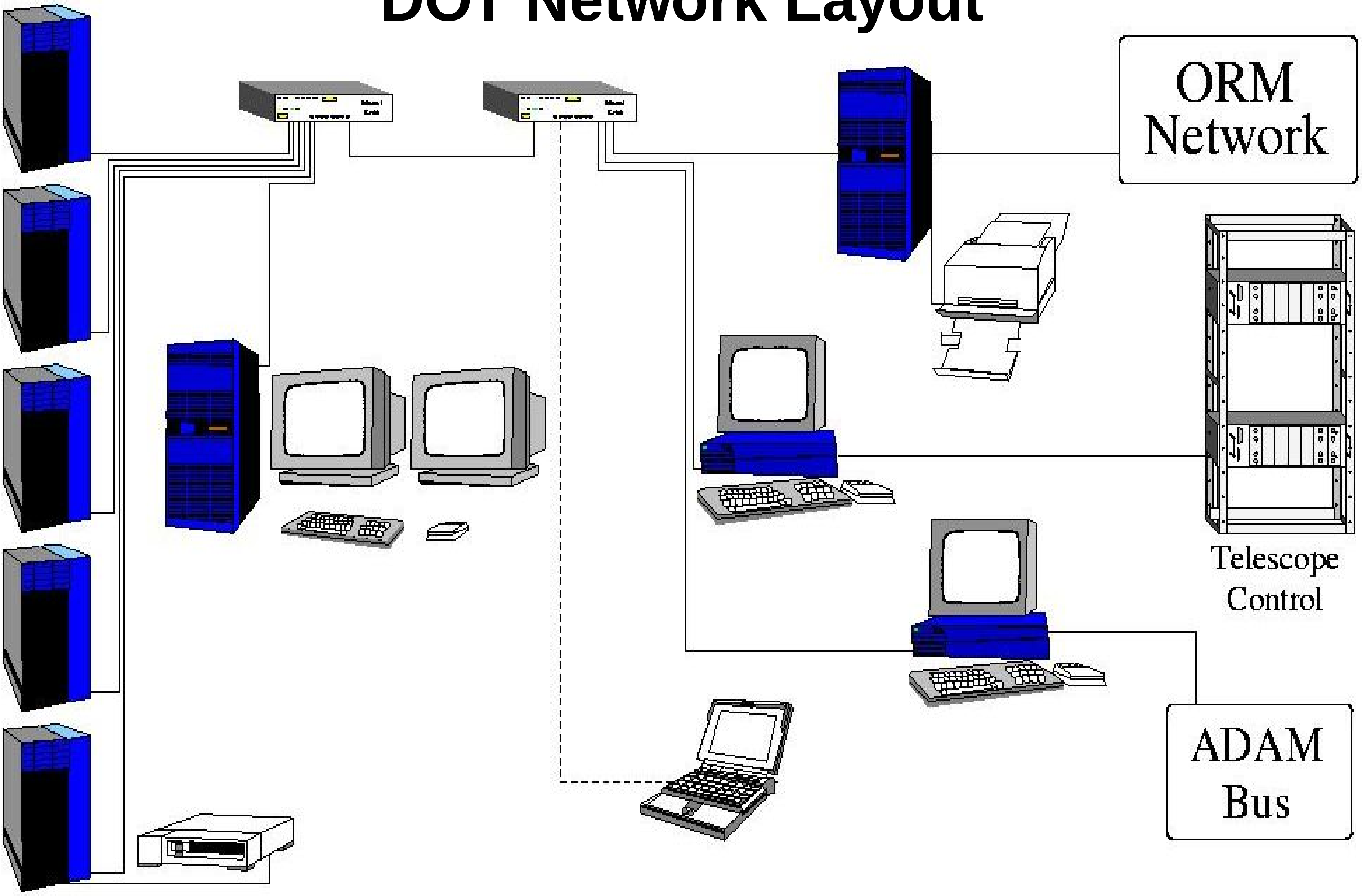
- Compaq Workstation AP 400
- Dual P III-600
- 512 MB RAM
- RAID 1 (mirror) system, 2×18 GB = 18 GB
- Dual screen (21″ and 19″)
- Operating system Linux
- IDL, LaTeX etc.



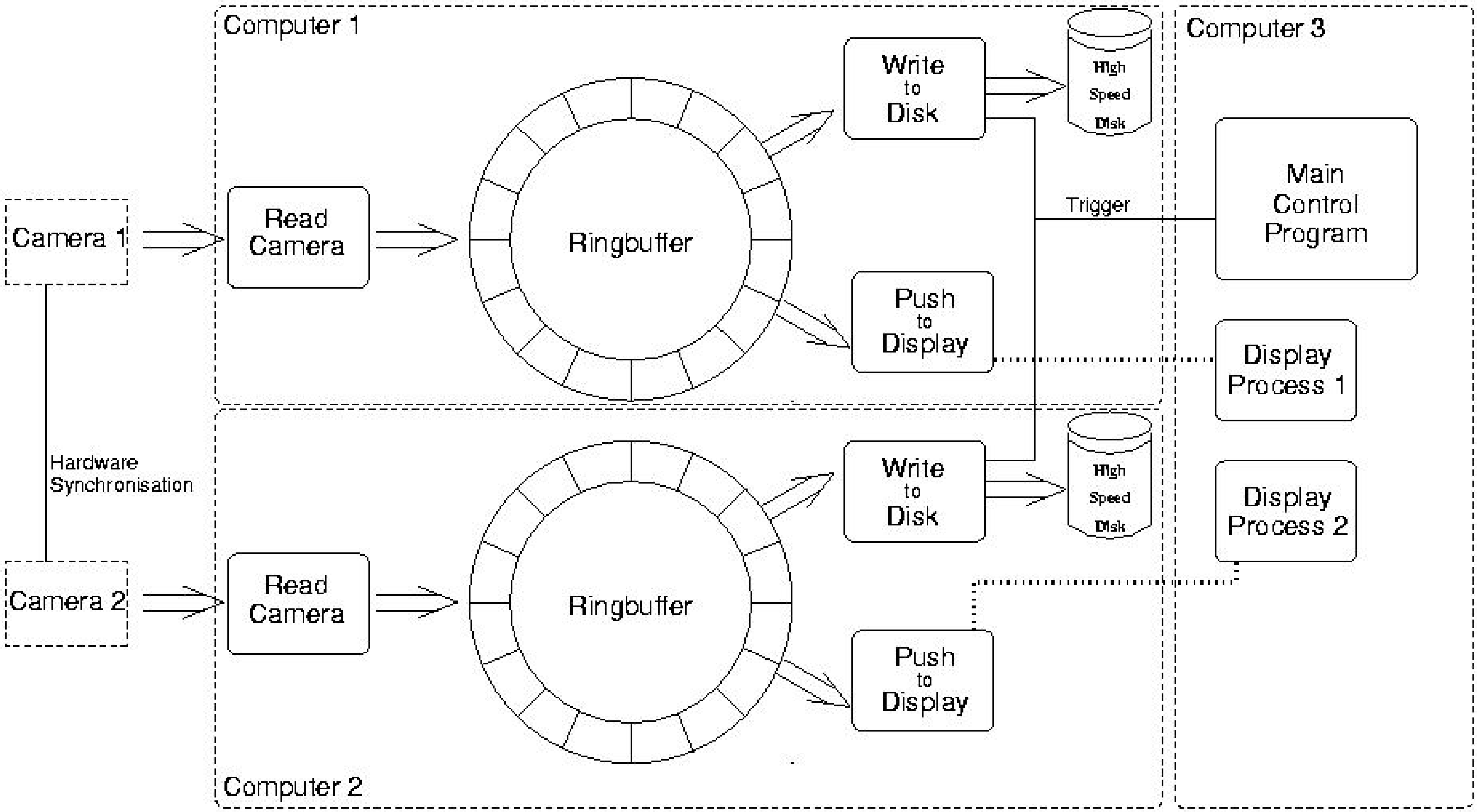
Computer III: Backup

- A speckle burst (100 frames) is 254 MB. The disk capacity is 290 bursts. For the standard observation cadence (30 s) the disks are full after 2 h 25 min
- Data are saved to tape (Exabyte EZ17 tape library with Mammoth2 drive):
  - ⋆ 7 tape autoloader
  - ⋆ 150 GB (60 uncompressed)/tape
  - ⋆ Write speed 12 MB/s
  - ⋆ Network limit 10 MB/s
- Backup of 5×72 GB takes 10 h
- ca. 100 $/tape

DOT Network Layout

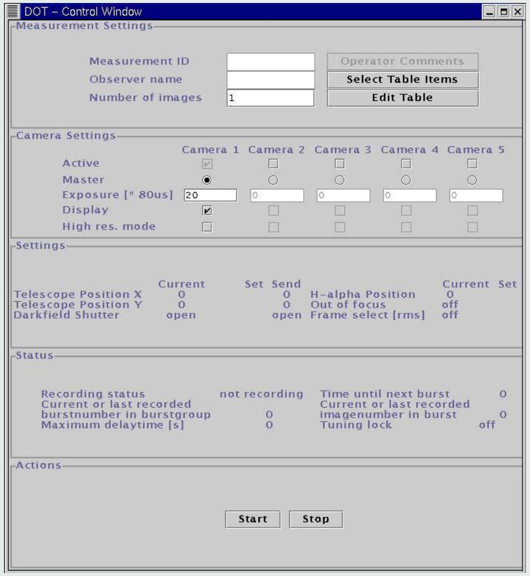


Control Layout



The Main Control Software

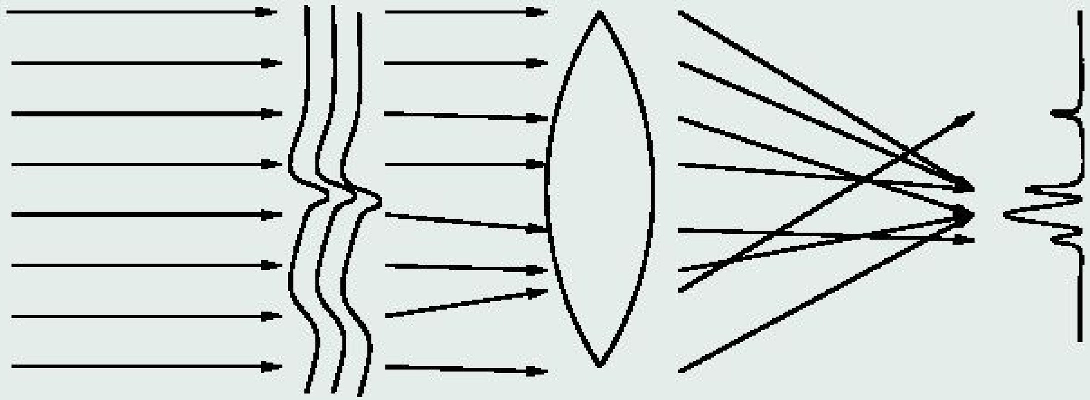
- Select cameras to use
- Specify exposure times
- Take single frames or bursts
- Take time series
- Frame select mode
- Point telescope
- Change focus
- Close shutter
- Tune Hα filter

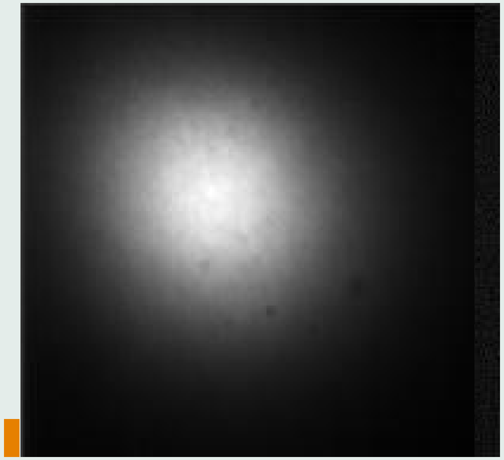


Post Processing

Influence of the Atmosphere

Fluctuation of the temperature causes local variation of the refraction index on a typical timescale of 10–20 ms.





For the isoplanar case we can write

$$f_i(\vec{x}, t_i) = f_0(\vec{x}) \otimes PSF(\vec{x}, t_i)$$

$$\Longleftrightarrow$$

$$F_i(\vec{k}, t_i) = F_0(\vec{k}) \cdot OTF(\vec{k}, t_i)$$

Restoring the powerspectrum is easy:

$$\left\langle \left| F(\vec{k}) \right|^2 \right\rangle = \left| F_0(\vec{k}) \right|^2 \cdot \left\langle \left| OTF(\vec{k}) \right|^2 \right\rangle$$

The second term on the right side is called the Speckle Transfer Function; it corresponds to the PS of a point source and can be measured or computed from models of the atmosphere.

Models for the STF

The currently best model for the STF has been derived by Korff:

$$\left\langle |S(\vec{q})|^2 \right\rangle = \int\int\int\int W(\vec{r})W^*(\vec{r}-D\vec{q})W^*(\vec{r})W(\vec{r}-D\vec{q}) \cdot \exp\{-\mathcal{D}(D\vec{q}) - \mathcal{D}(\vec{r}-\vec{r}') + \frac{1}{2}[\mathcal{D}(\vec{r}-\vec{r}'+D\vec{q}) + \mathcal{D}(\vec{r}-\vec{r}'-D\vec{q})]\}d\vec{r}d\vec{r}'$$

$\vec{q} = \vec{k}/k_{Nyq}$; D: aperture of telescope; $\mathcal{D}$: phase structure function

The function only depends on the Aperture function of the telescope, $W(\vec{r})$, and the normalized Fried parameter $\alpha = r_0/D$.

Thus, the problem is reduced to determining the value of α. This is done using the *Spectral Ratio Technique*.

The Spectral Ratio

Summing the fourier transforms of the observed images in two different ways and building the ratio yields

$$\frac{|\langle F(\vec{q})\rangle|^2}{\left\langle |F(\vec{q})|^2 \right\rangle} = \frac{|F_0(\vec{q})|^2}{|F_0(\vec{q})|^2} \cdot \frac{|\langle S(\vec{q})\rangle|^2}{\left\langle |S(\vec{q})|^2 \right\rangle} =: \mathcal{E}(\vec{q})$$

Computing $\mathcal{E}(\vec{q})$ using the Korff model reveals a power law between α and the value of $\vec{q}$ where a specific value of $\mathcal{E}$ is reached:

$$\alpha_{\mathcal{E}} = A \cdot q_{\mathcal{E}}^{B}$$

This allows to estimate α by evaluating the measured $\mathcal{E}(\vec{q})$.

Speckle Masking

To restore the full FT of the object,

$$F_0(\vec{q}) = |F_0(\vec{q})| \cdot \exp[i\varphi(\vec{q})]$$

also the phase information is needed. *Direct* averaging does not work, the phases are evenly distributed over the unit circle and cancel out. Instead, the Speckle Masking Bispectrum is computed:

$$F^3(\vec{q}, \vec{p}) = F(\vec{q}) \cdot F(\vec{p}) \cdot F^*(\vec{q} + \vec{p})$$

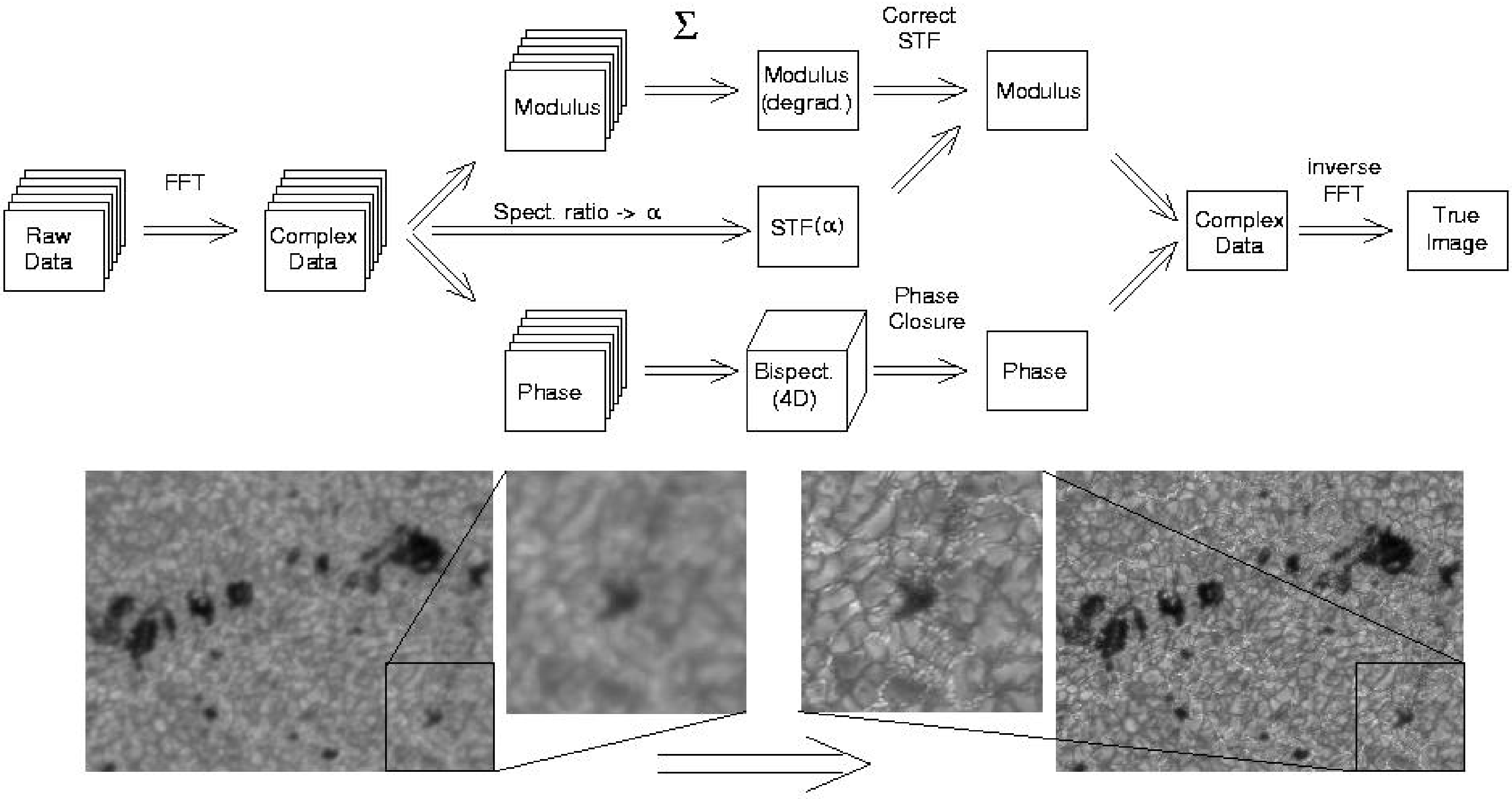
Using the phase information Φ of the averaged bispectrum, the object phase can recursively be restored:

$$\exp[i\varphi(\vec{q}+\vec{p})] = \exp[i\varphi(\vec{q})] \cdot \exp[i\varphi(\vec{p})] \cdot \exp[-i\Phi(\vec{q}+\vec{p})]$$

Here 2 starting points are needed: Zero for $\vec{q} = 0$ (real point) and the phase for the first neighboring point. That one is assumed to be not affected by the seeing ($|\vec{q}| \ll \alpha$) and taken from the averaged FTs.

Now modulus (from the averaged power spectrum, corrected with the STF) and phase can be combined and a backward Fourier transformation reveals the true object information.

Schematic View



Computational Demands

- Standard: dark subtract, gain correction
- Correct image shift
- Split into (overlapping) subfields
- Estimate and subtract noise
- correct subfields
- reassemble subfields

For the new cameras, the whole process of reconstructing *one* image needs

- 980 subfields of size 64×64
- > 400 MB RAM
- ~ 2 GB temporary disk space
- ~ 9 CPU-hours on a 600 MHz P III

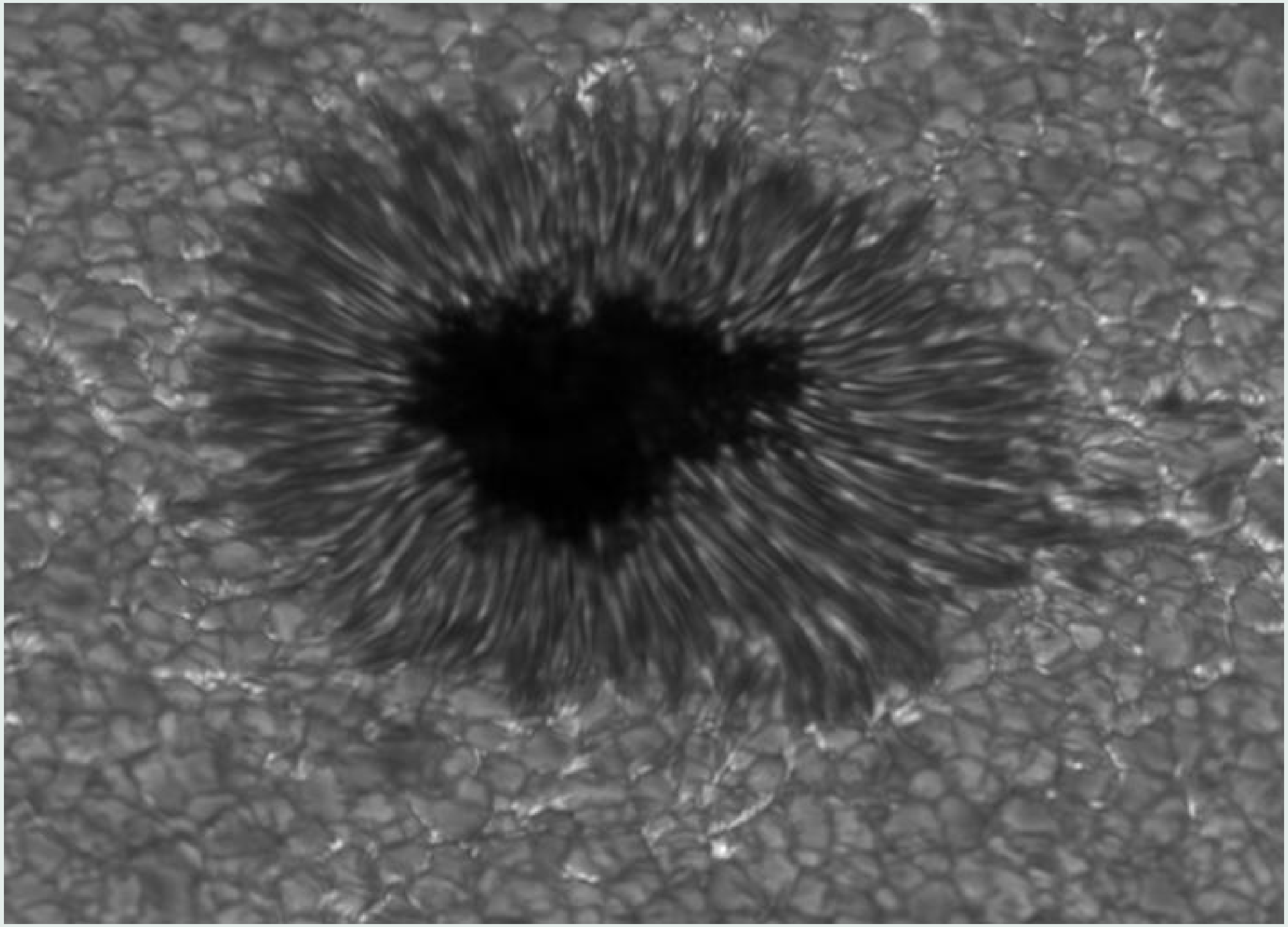
DOT Results

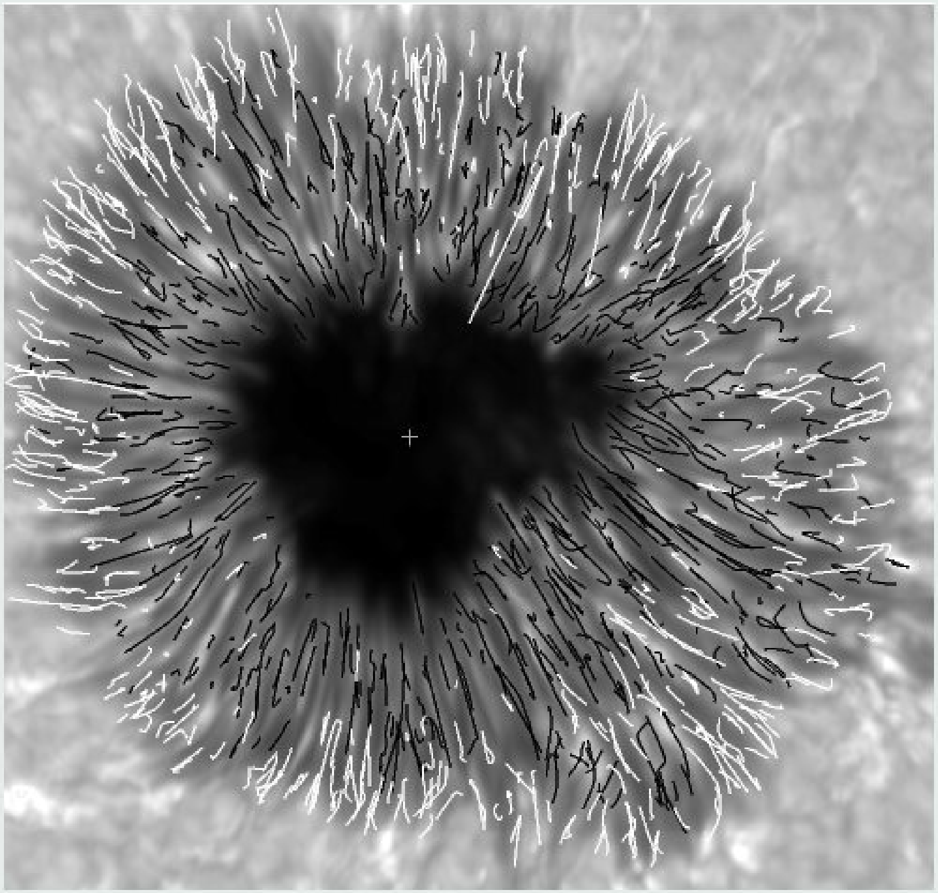
The DOT had the first scientific observation campaign in September 1999, already as part of an international campaign (JOP097) with other ground and space based observatories.

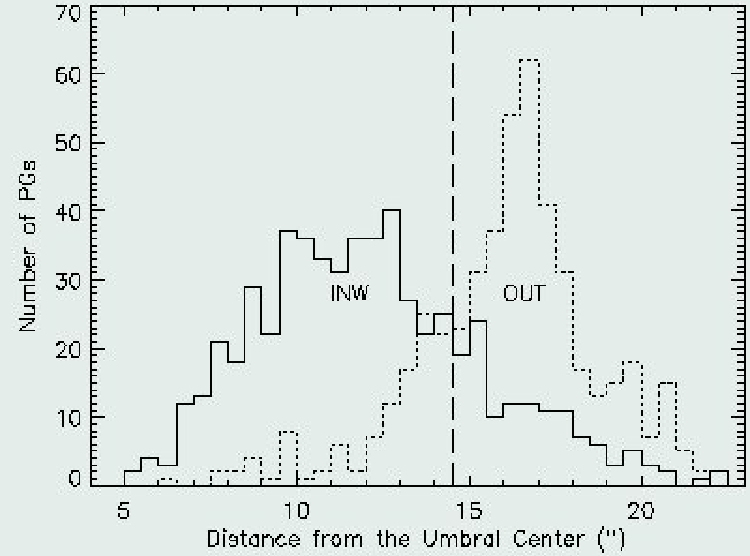
Equipped with a G-band filter, during this and the following observation campaigns many time series of solar structures could be recorded - thanks to the speckle reconstruction, all at or close to the telescopic resolution limit of 0.2 arcsec.

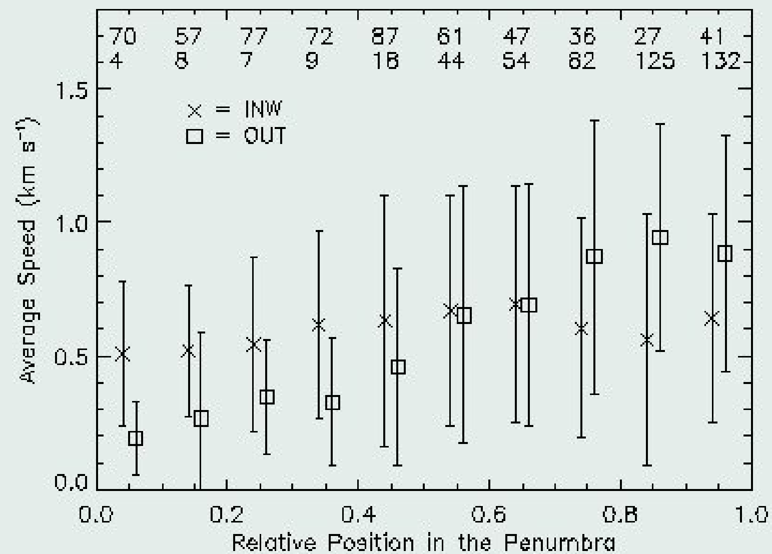
All DOT data are accessible via the DOT web site http://dot.asto.uu.nl and, following the open data policy, can be requested by anyone interested in using them for own research.

Results I: AR 8704



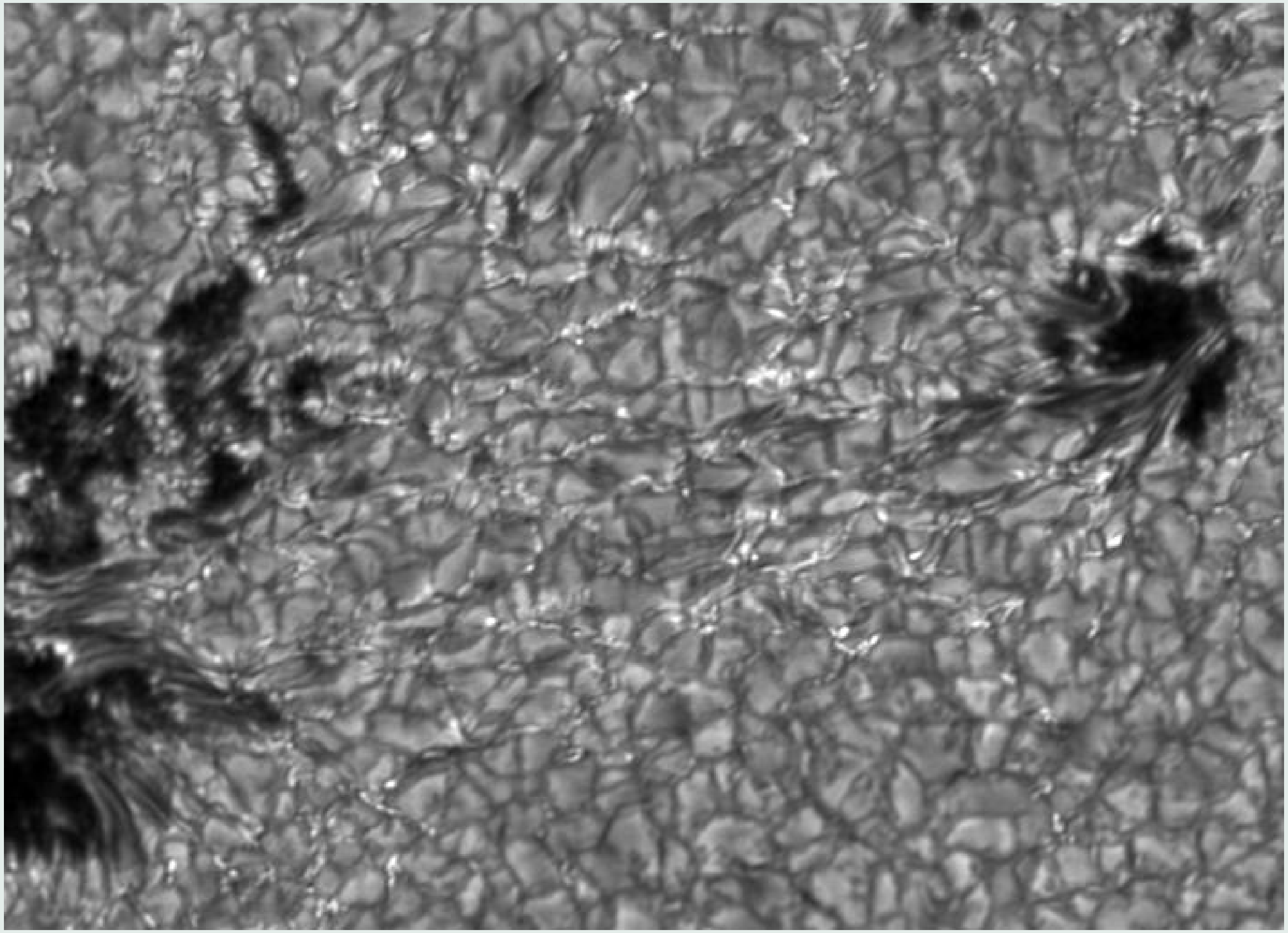






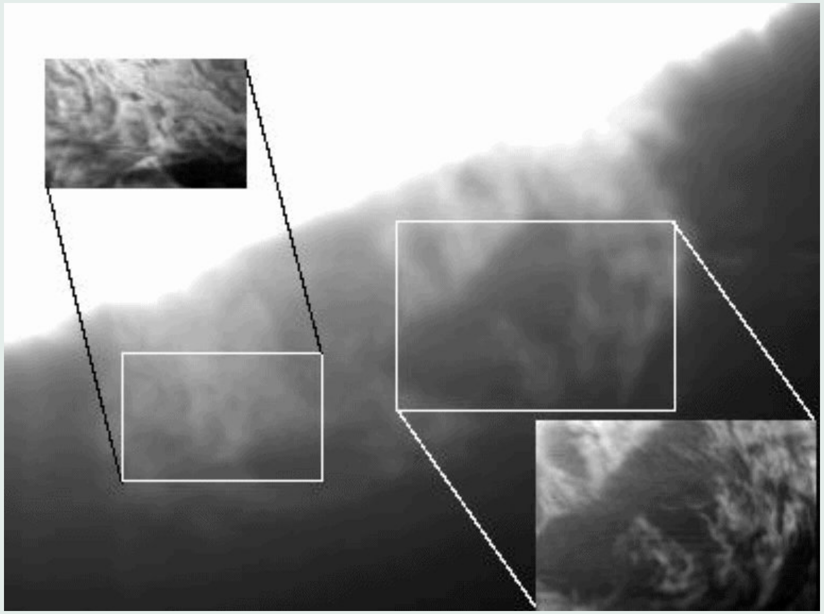
M. Sobotka, P. Sütterlin, Themis Workshop Rome 2001

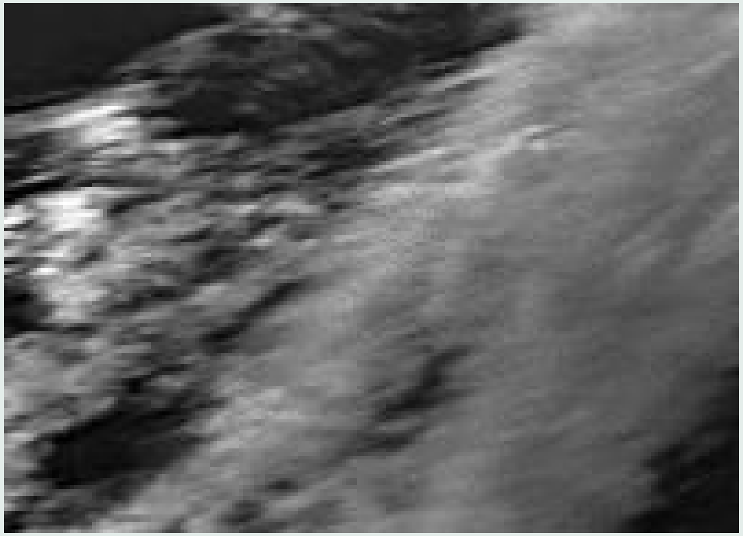
Results II: AR 8737



Results III: Prominence

July 2000: Test of Hα imaging capabilities of the DOT in a joint campaign (VTT/GCT/SVST/DOT). 3 Å filter.

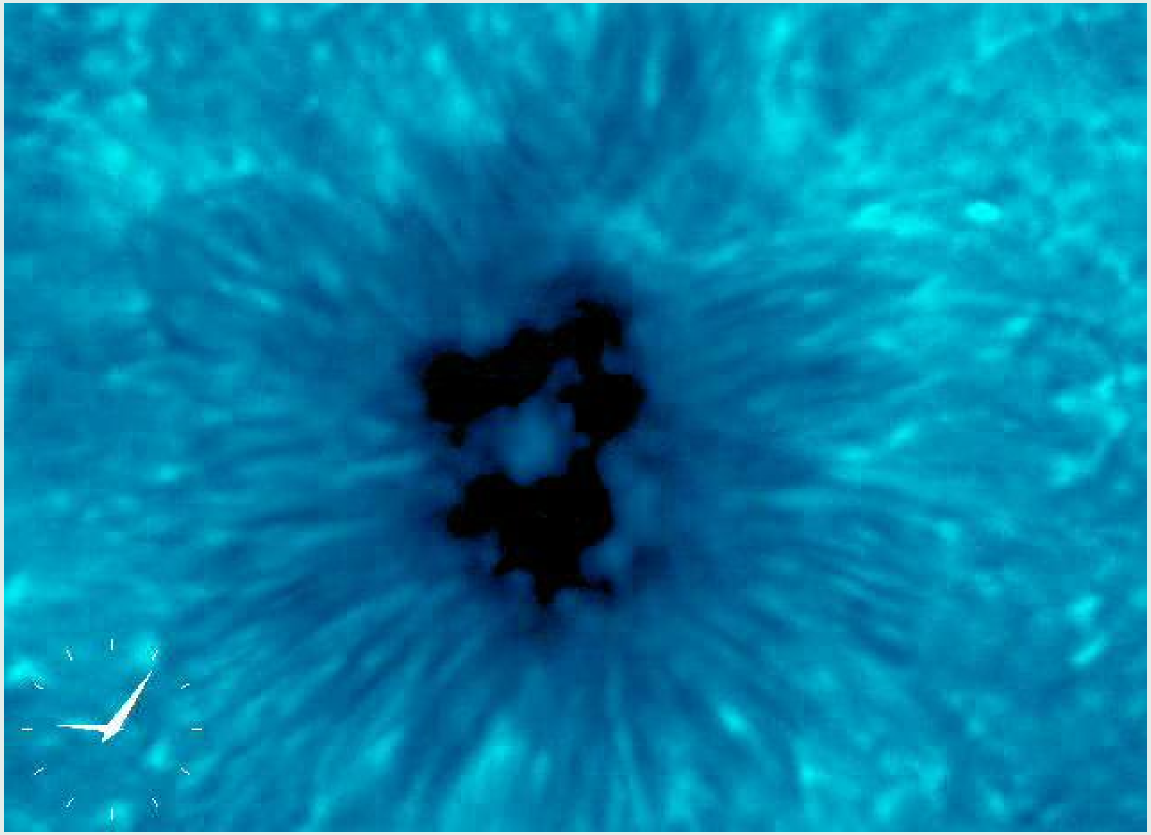


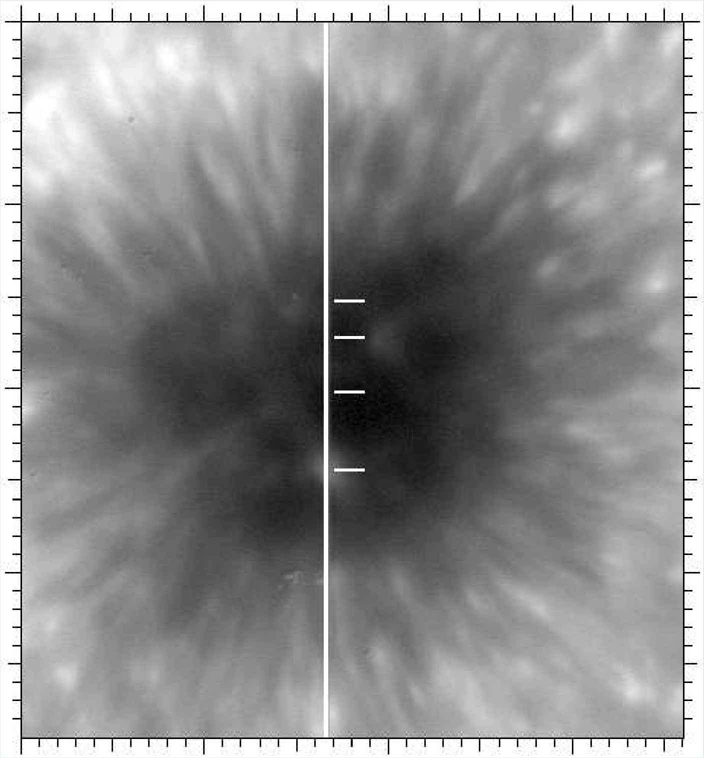


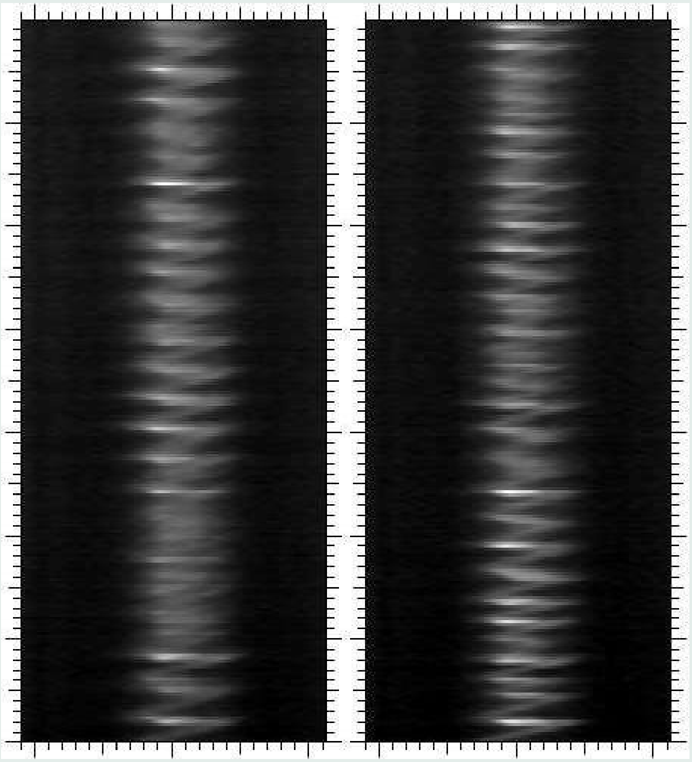
The material will be the basis for a graduation work in Nijmegen.

Results IV: Umbral Flashes in Ca II H

November 2000: Test of Calcium imaging capabilities of the DOT in collaboration with the KVA Stockholm. 1 Å filter.

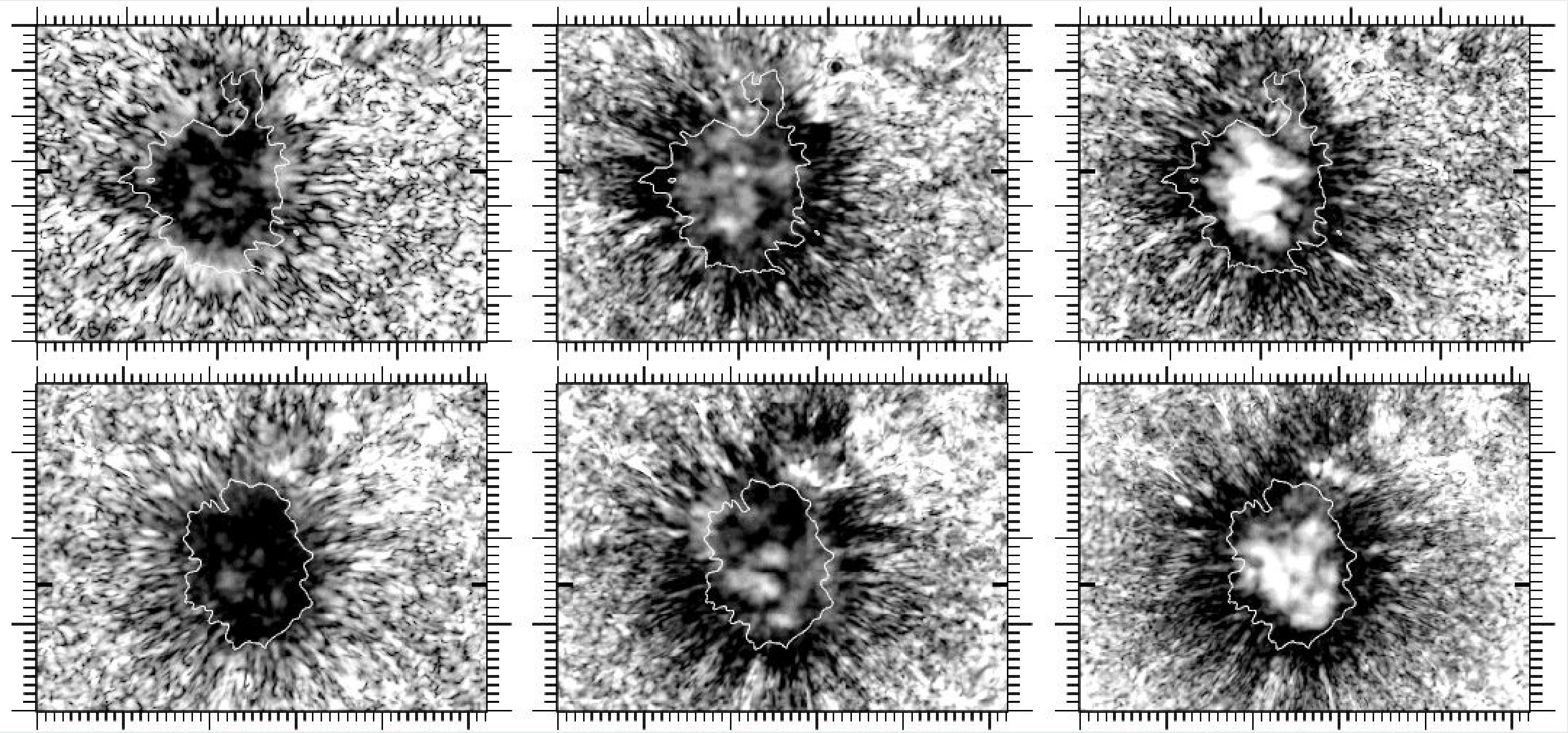






Left: Slitjaw image, vert. line=slit, hor. dashes mark points of time slices. **Right:** Ca II H line core vs. time

SVST spectra by Luc Rouppe van der Voort show velocity oscillations with high amplitude (10 km/s). Same in Hα (K. Tziotziou) and He I 10830 (M. Collados). The apparent velocities in the movie are much higher and due to wave interference.



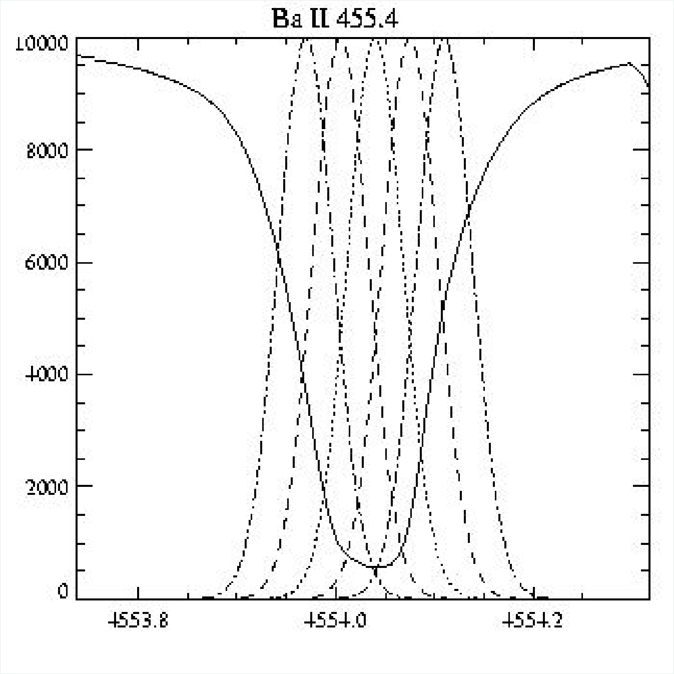
Powermaps of the DOT time series in 5 (left), 3 (middle), and 2 min (right).

The DOT time sequences have been analyzed by J. Sloover (A&A, in preparation). He finds power peaks in the 3 minute band above the umbra as well as ring-like concentrations at the border to the penumbra. A comparison of SVST Ca and G-band data showed no correlation.

Results V: Ba II 4554

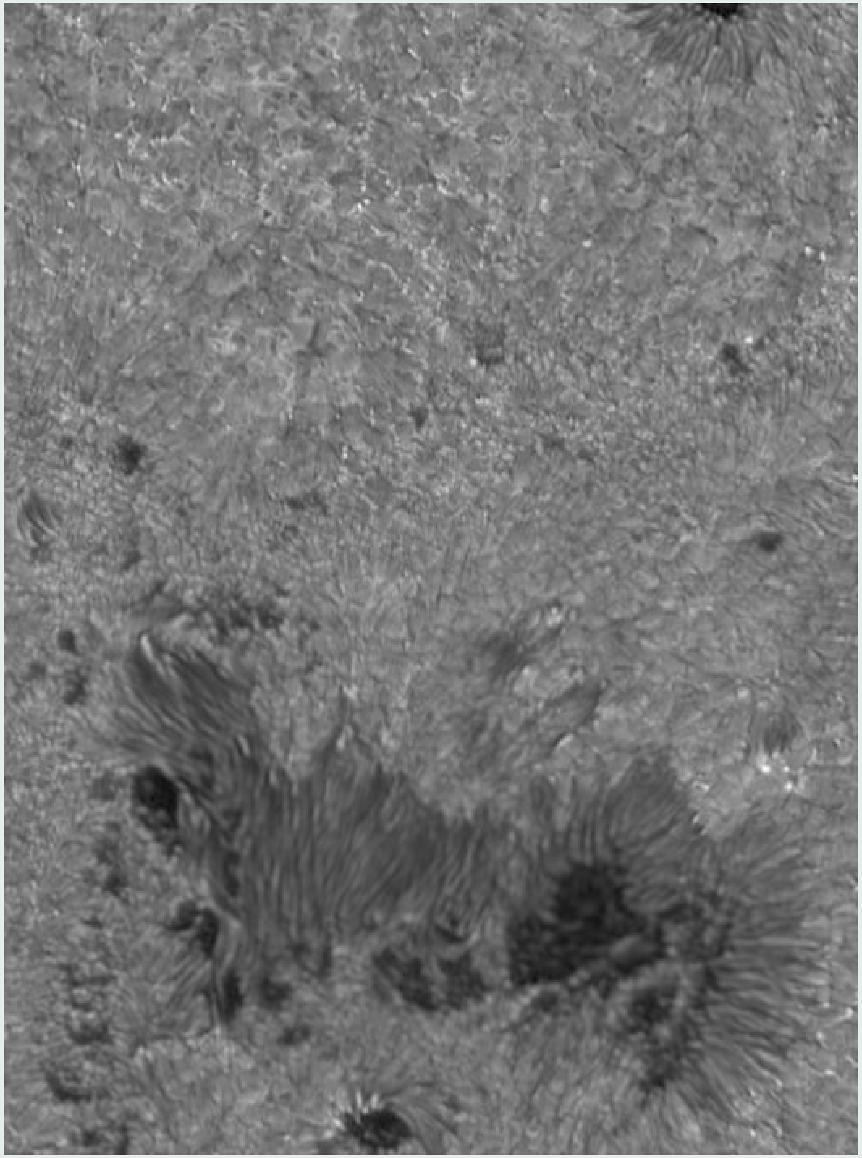
In July 2000 a feasibility test was carried out at the SVST in La Palma. Main objective was to test if a Siberian Lyot-type filter for the Barium resonance line at 455.4 nm would be an option for the DOT. The Ba line is interesting in many respects:

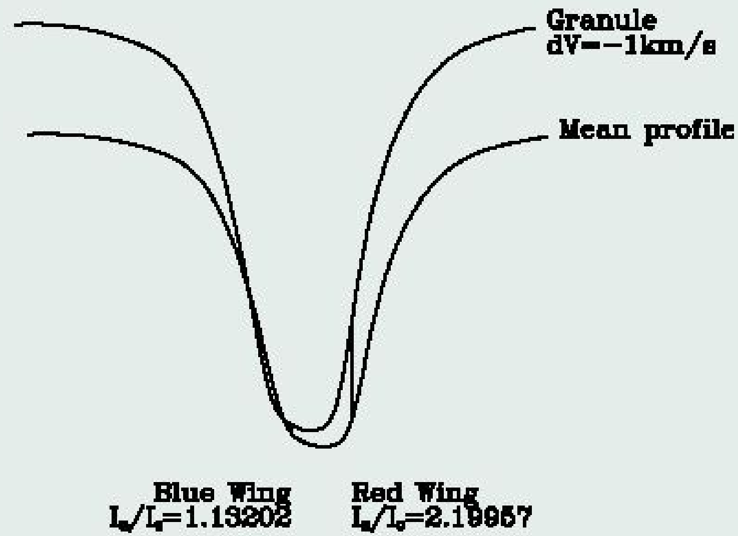
- ⋆ Same atomic configuration as Ca II K
- ⋆ Almost completely ionized – low T-sensitivity
- ⋆ High atomic weight – low (Doppler) T-sensitivity
- ⋆ Landé-factor 1.16
- ⋆ strongest line in second solar spectrum



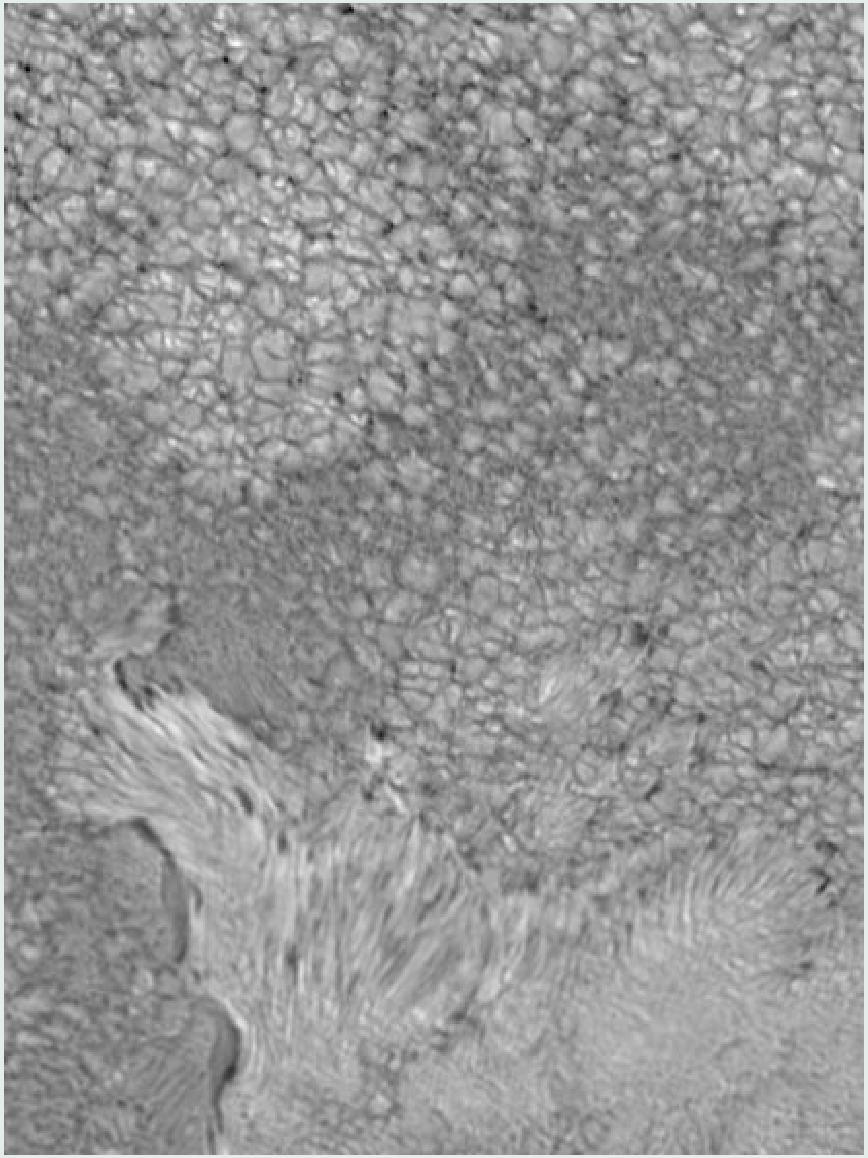
Left: V. Skomorowsky and G. Domishev with their filter at the SVST. **Right:** Passband of the filter.

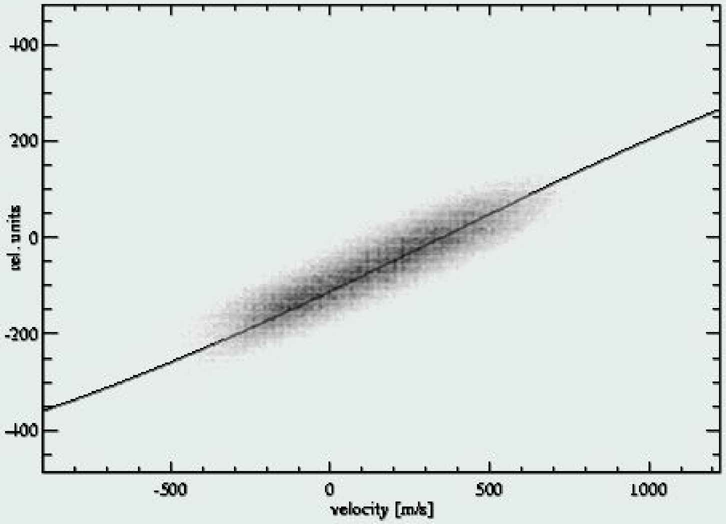
The filter has an extremely narrow passband of 80 mÅ (equivalent width of the Ba line is 159 mÅ), still the transmission is good enough to allow speckle reconstruction when using the DOT cameras.





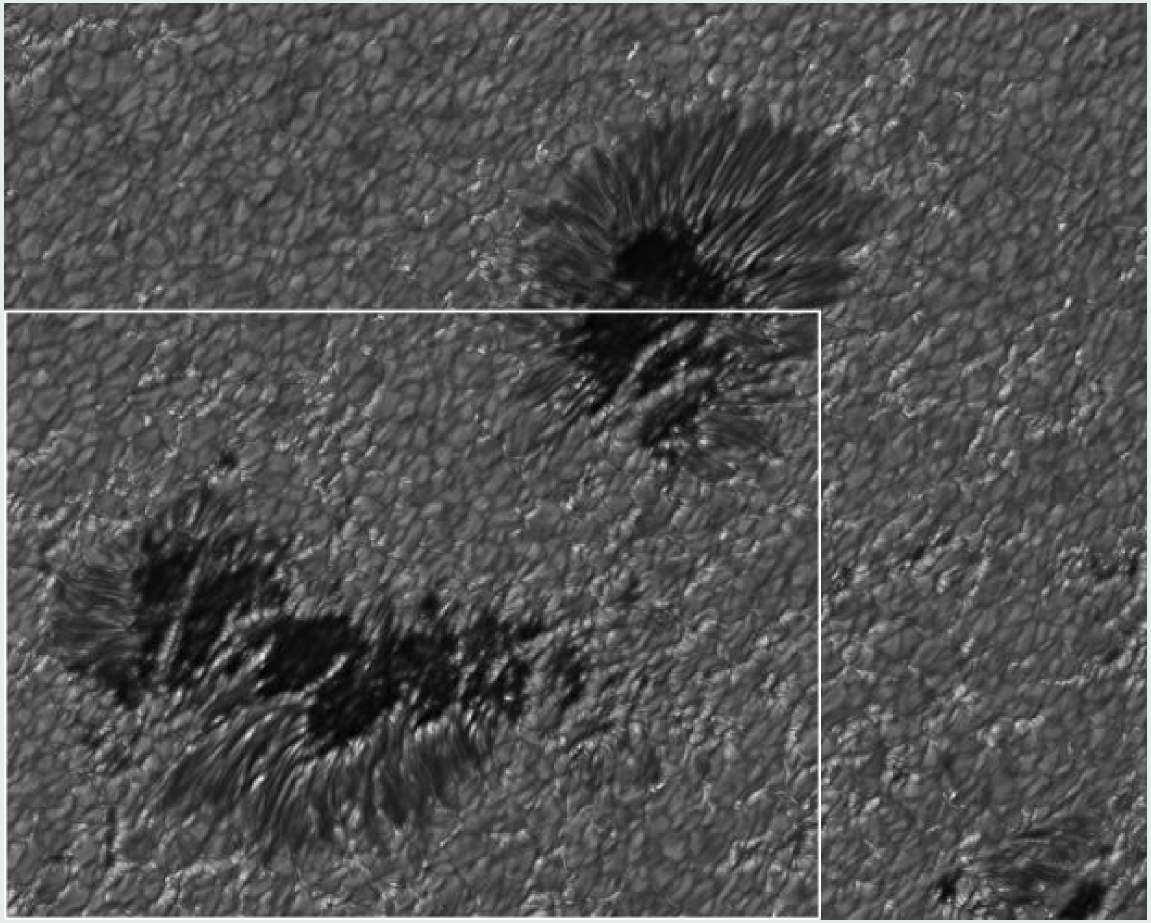
A positive correlation of velocity and intensity leads to enhancement and cancelation effects in the line wing. In the blue line wing (left), hot structures with downflows show high contrast, granulation (hot upward) is almost invisible.





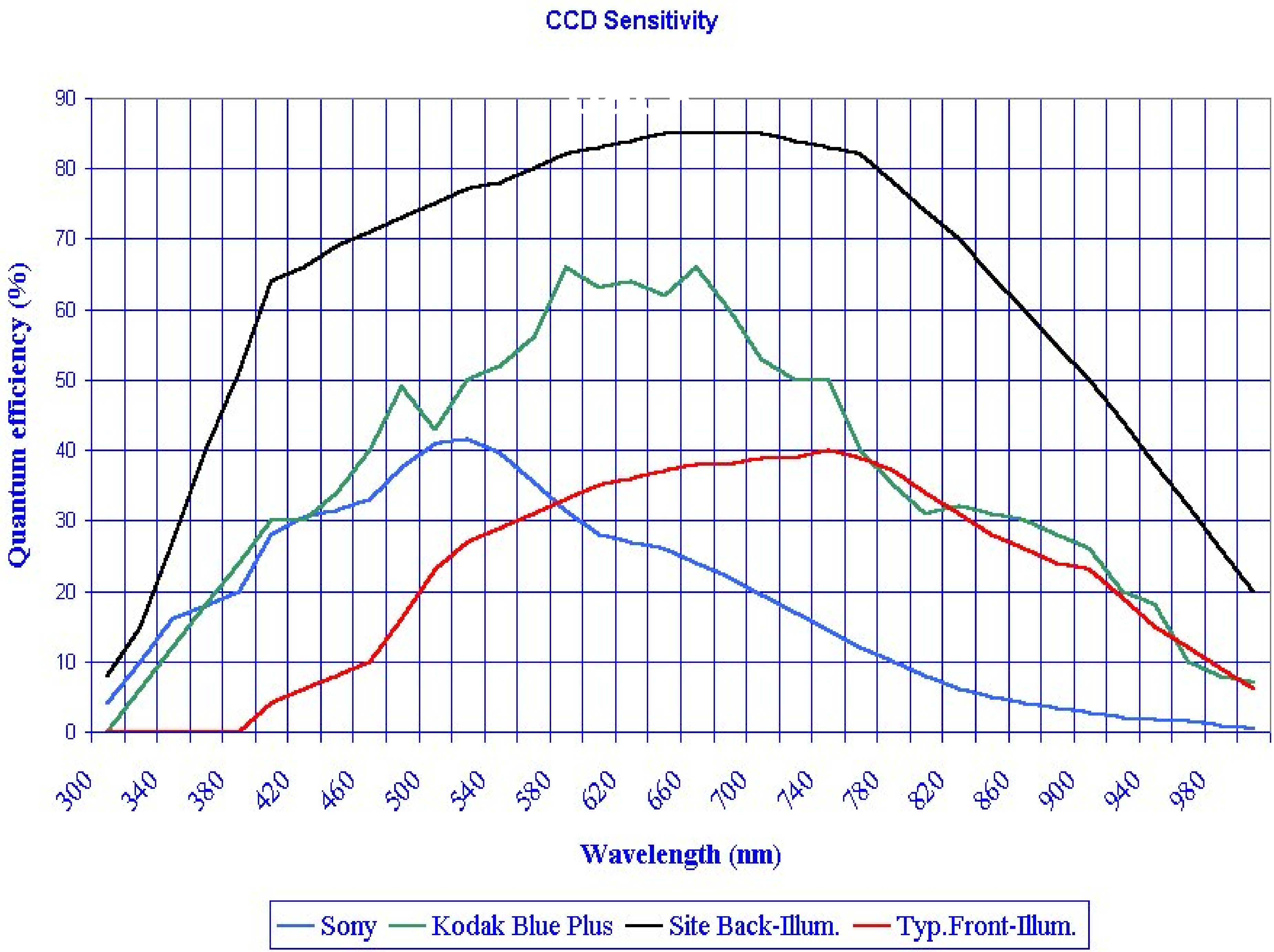
Left: Dopplergram made from two line wing filtergrams. **Above:** Comparison of velocities derived from two and five wavelength points. The line shows the theoretical curve.

Results VI: The New Camera



Conclusions

- The combination good site + open telescope + speckle reconstruction delivers an unprecedented amount of high resolution data.
- Already with one channel, the DOT starts producing valuable scientific output.
- Full science will start this summer when two or more channels are available simultaneously.
- The current setup is budget-limited. But the system can easily be upgraded (larger and more sensitive cameras, more disk space, faster computers).



CCD Sensitivity
Quantum efficiency (%)
0
10
20
30
40
50
60
70
80
90
300
340
380
420
460
500
540
580
620
660
700
740
780
820
860
900
940
980
Wavelength (nm)
Sony
Kodak Blue Plus
Site Back-Illum.
Typ.Front-Illum.

DOT: Aperture and typical STF