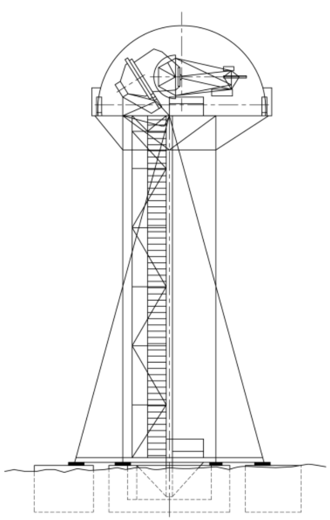
Transmission profile of the Dutch Open Telescope Hα Lyot filter

J. Koza, R.H. Hammerschlag *, J. Rybák, P. Gömöry, A. Kučera, P. Schwartz

Astronomical Institute, Slovak Academy of Sciences, Tatranská Lomnica, Slovakia
* Leiden Observatory, Leiden, The Netherlands



SKALNATÉ PLESO

Sterrewacht Leiden

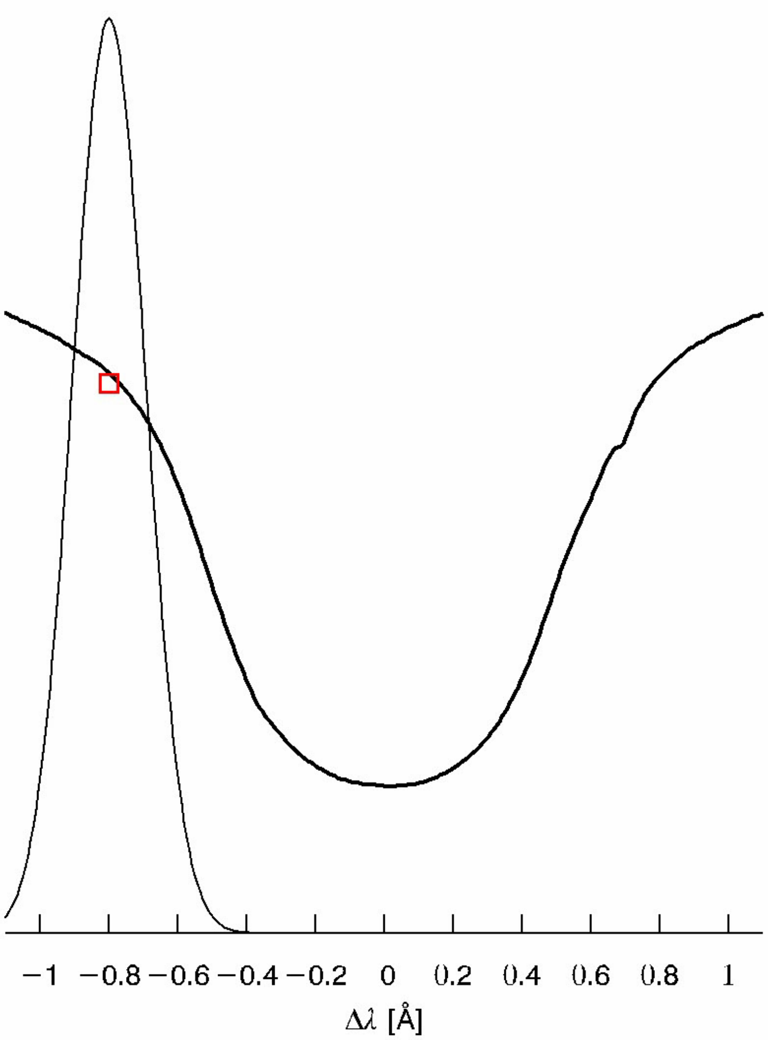
SLOVAK RESEARCH AND DEVELOPMENT AGENCY

DUTCH OPEN TELESCOPE

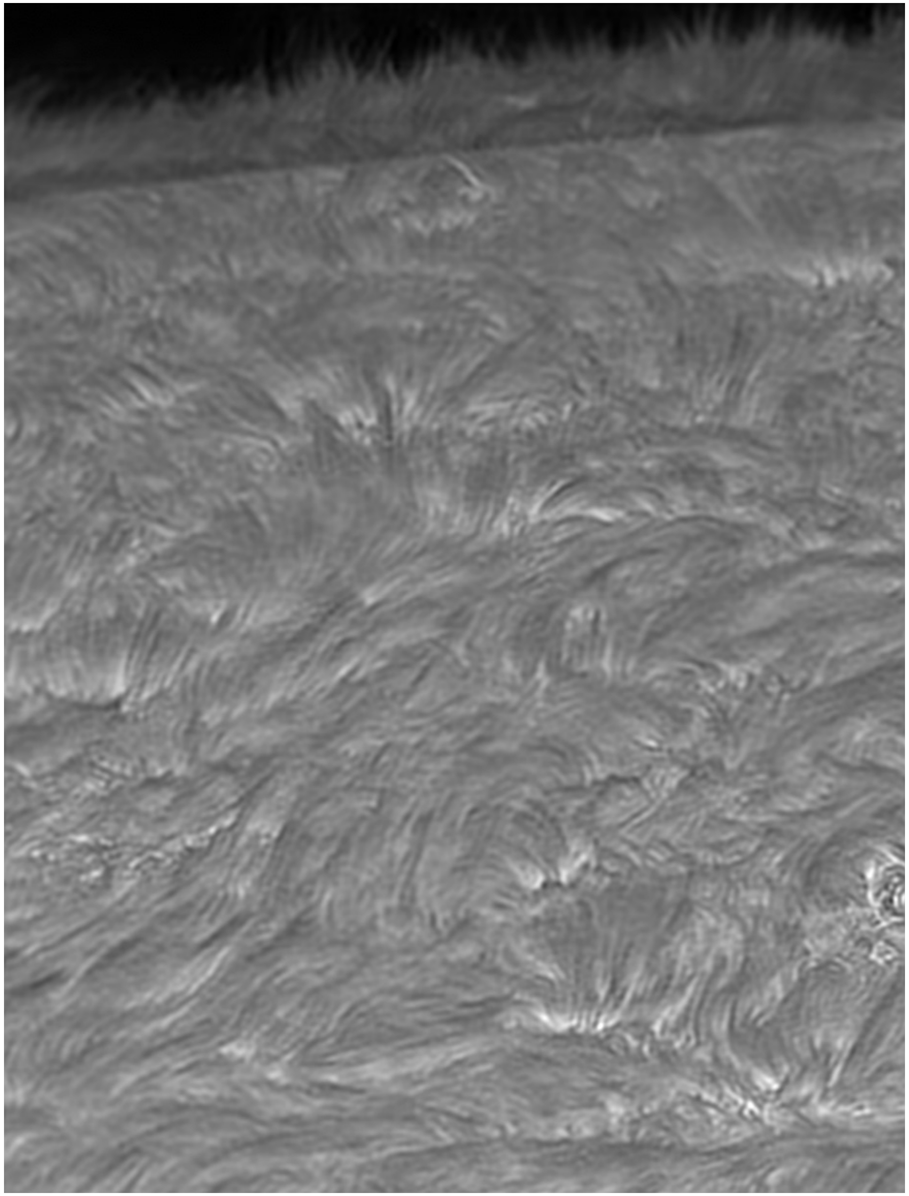
Imaging spectroscopy

quasi-simultaneous acqusition of wide-field images in many wavelengths in a spectral line profile

Dutch Open Telescope Hα Lyot filter at $\Delta\lambda$ = –0.8 –0.6 –0.4 –0.2 0 0.2 0.4 0.6 0.8 Å



Imaging spectroscopy



Instruments employing:

Lyot filter

Dutch Open Telescope (Hα, Ba II 4554 Å)

Narrowband Filter Imager at Hinode

CoMP at Mauna Loa Observatory

CoMP-S at Lomnicky Peak Observatory

ChroTel at Tenerife

ChroMag at High Altitude Observatory

Fabry – Pérot interferometer

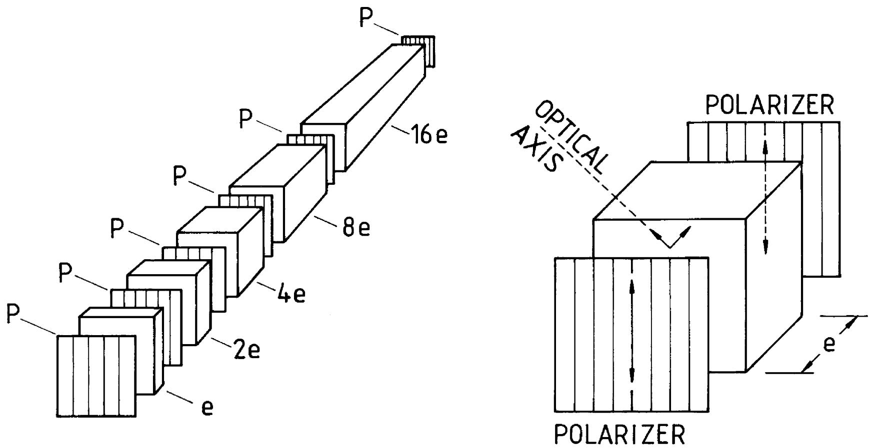
IBIS at Dunn Solar Telescope

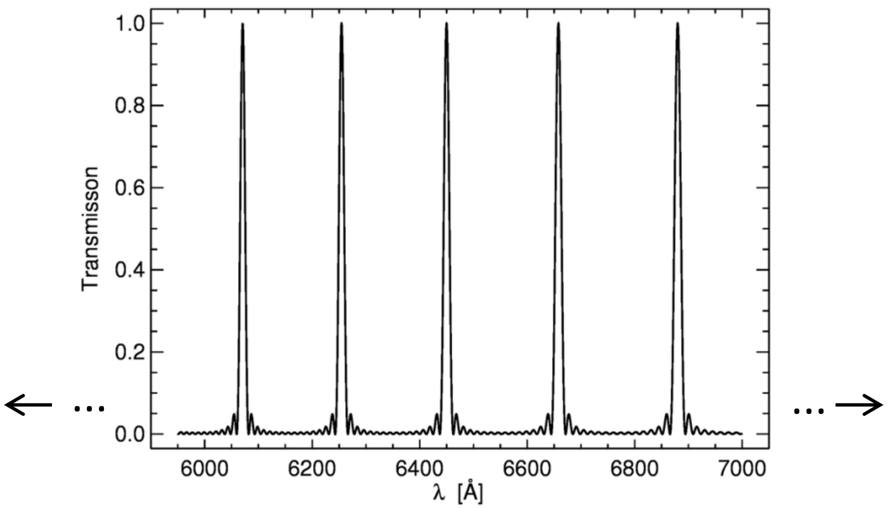
CRISP at Swedish 1-m Solar Telescope

GFPI at GREGOR

TESOS at Vacuum Tower Telescope

Lyot filter in brief



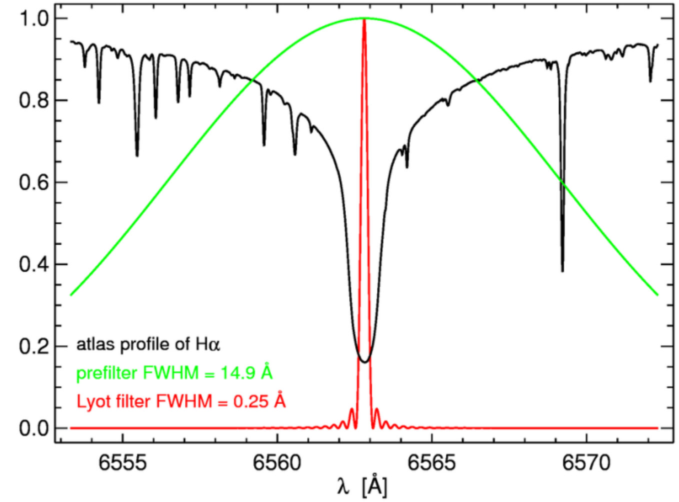


- a sequence of polarizers P and birefringent crystals of thickness *e*, 2*e*, 4*e*, 8*e*, 16*e*, ...
- periodic transmission profile with multiple peaks
- selection of a spectral range by a broad-band prefilter

Theoretical transmission profile:

$$T = \prod_{k=1}^{N} \cos^2 \frac{2^{k-1}\pi e J}{\lambda} = \frac{\sin^2 \frac{2^N \pi e J}{\lambda}}{4^N \sin^2 \frac{\pi e J}{\lambda}}$$

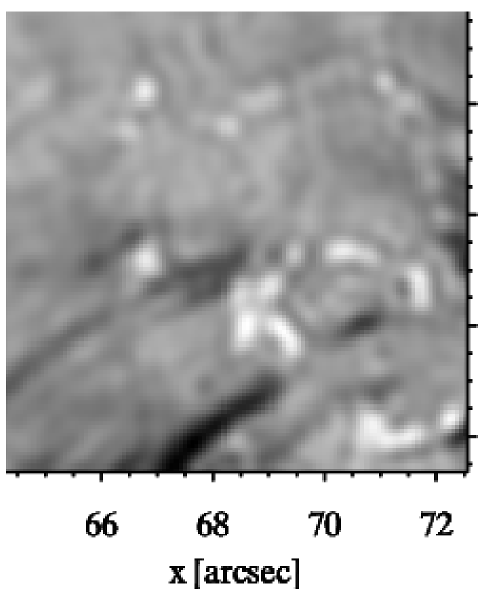
N – number of polarizer-crystal stages
e – thickness of the thinnest crystal plate
J – birefringence of crystal



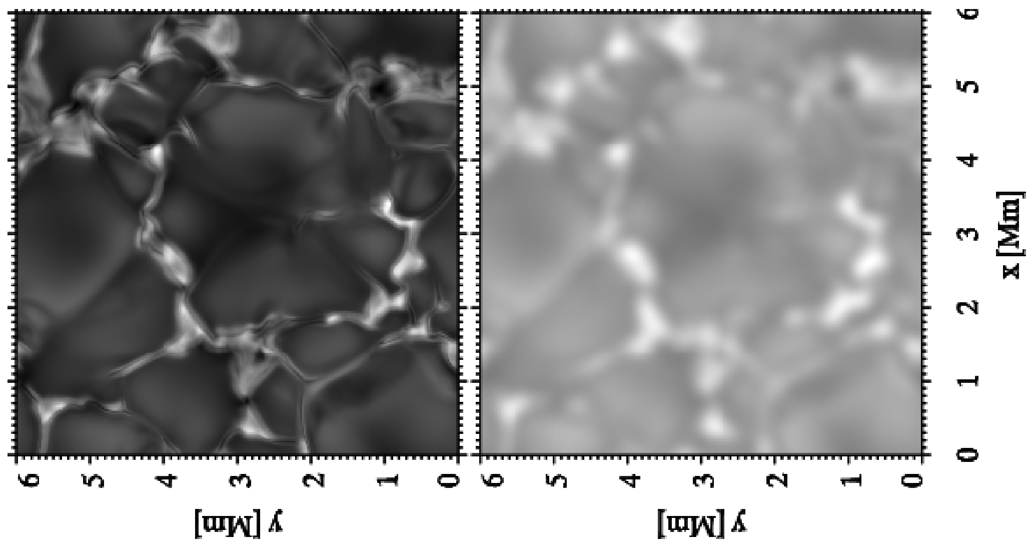
In practice, the transmission profile of a single peak is often **approximated by a Gaussian**.

Application
of the DOT Hα Lyot filter transmission

Comparing of **observations** with results of **simulations**



DOT observation of bright points in 2004 Oct 6 in the blue wing of Hα at $\Delta\lambda = -0.8$ Å.

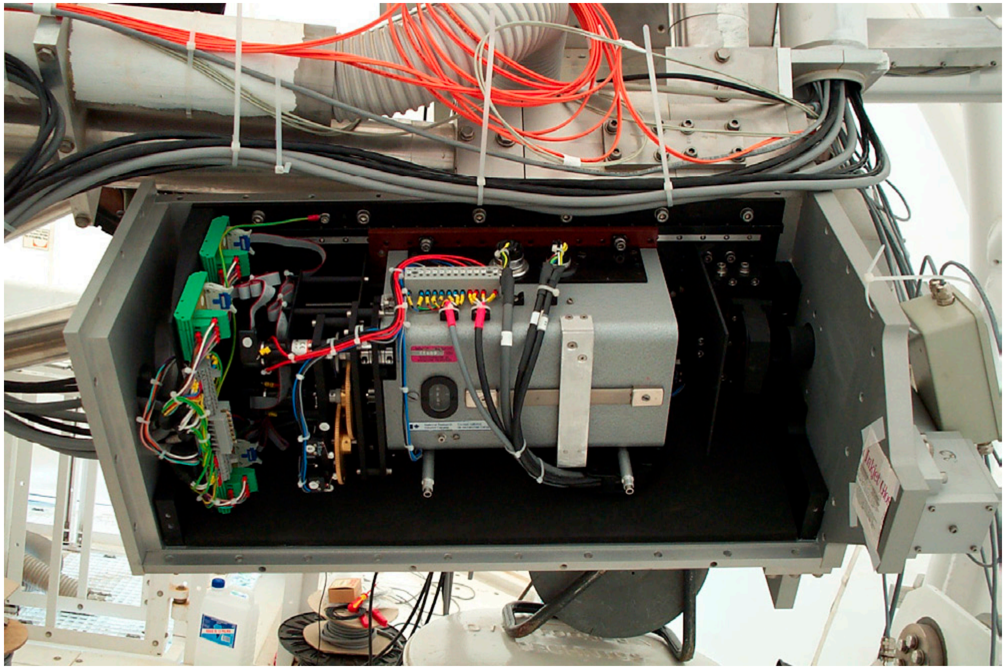


Emergent intensity in the Hα blue wing at $\Delta\lambda = -0.8$ Å resulting from 3D MHD LTE simulation after convolving with the DOT Lyot filter transmission approximated by Gaussian (left) and Airy function (right).

Leenaarts et al. 2006: A&A 449, 1209

Aims

Understanding an instrument may be vital for correct interpreting of data.



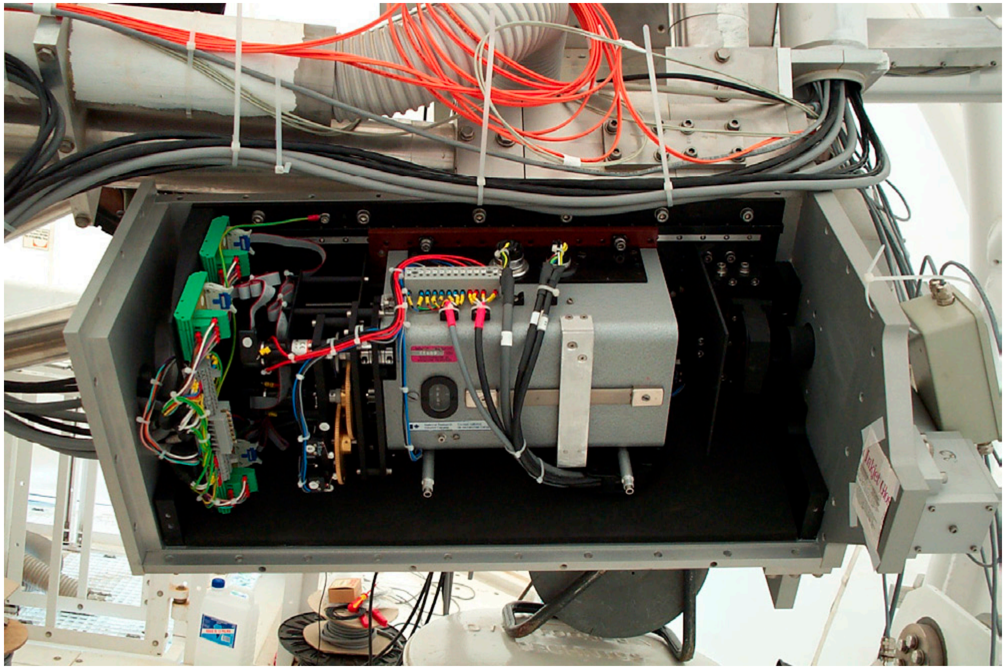
the DOT Hα Lyot filter in deployment

[Bettonvil et al. 2006: Proc. SPIE Conf. Series 6269]

Aims

Understanding an instrument may be vital for correct interpreting of data.

- to summarize available facts about the transmission profile of the DOT Hα Lyot filter
- to confront them with observations and suspicions on the leak of parasitic light
- to reconcile discrepancy between limb observations and spectroscopic measurement of filter
- to present a method for indirect testing of transmission profiles of Lyot filters
two new theoretical transmission profiles of the DOT Hα Lyot filter



the DOT Hα Lyot filter in deployment

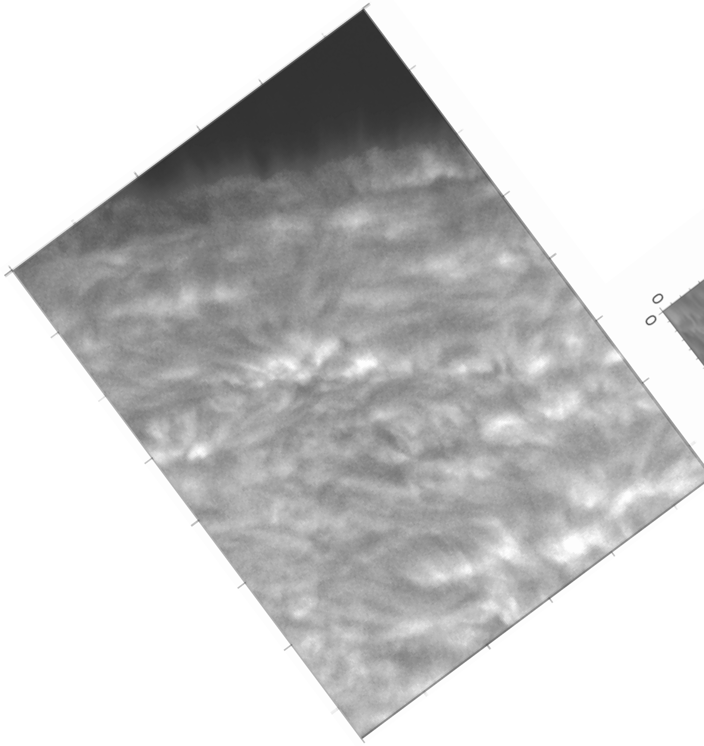
Bettonvil et al. 2006: Proc. SPIE Conf. Series 6269

Problem 1: DOT limb image *versus* images from other instruments

DOT Hα center
speckle-reconstructed image

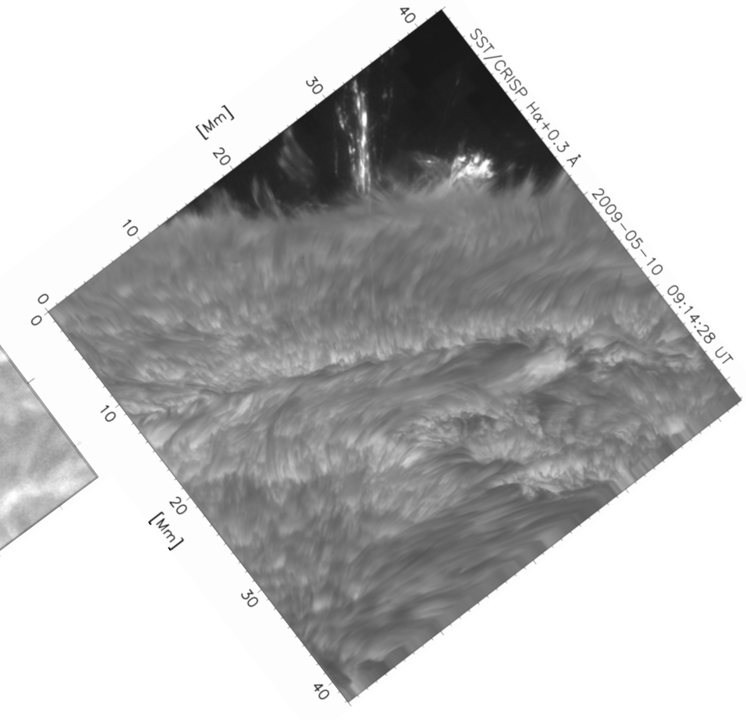
[Rutten 2007: ASPC 368, 27](#)
[Rutten 2013: ASPC 470, 49](#)

FPI / VTT Hα center
AO, raw image



[Puschmann et al. 2006: A&A 451, 1151](#)

CRISP / SST Hα +0.3 Å
AO + MOMFBD



[Antolin & Rouppe van der Voort 2012: ApJ 745, 152](#)

"I doubt that the double limb is caused by parasitic light (continuum leak outside the Hα passband)."
[from "Observing the Solar Chromosphere" (Rutten 2007: ASPC 368, 27)](#)

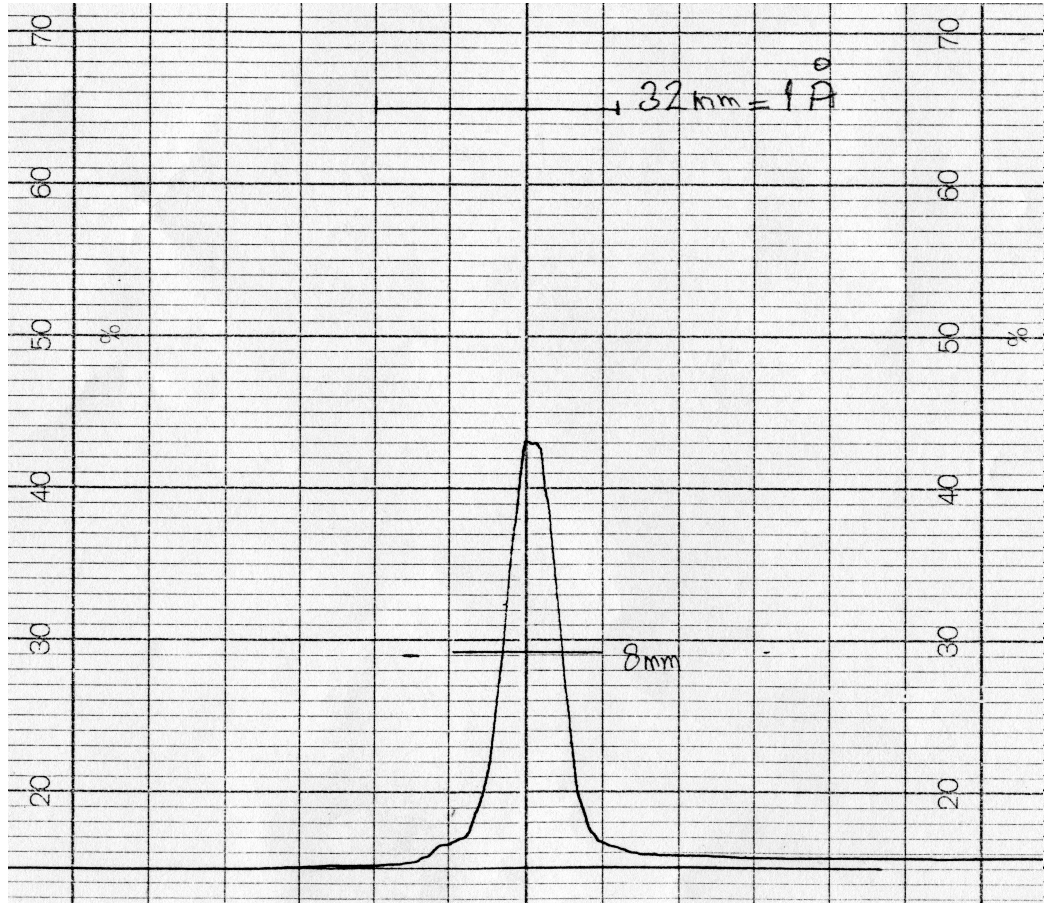
"The sharp limb is probably parasitic continuum light (cf. Bray & Loughhead 1974)."
[from "Twists to Solar Spicules" (Rutten 2013: ASPC 470, 49)](#)

DOT limb image shows the sharp limb what is not the case of images from the other instruments.
The DOT sharp limb may be due to parasitic light.

Problem 2: DOT limb image *versus* spectroscopic measurement of filter

DOT Hα center
speckle-reconstructed image

Rutten 2007: ASPC 368, 27
Rutten 2013: ASPC 470, 49

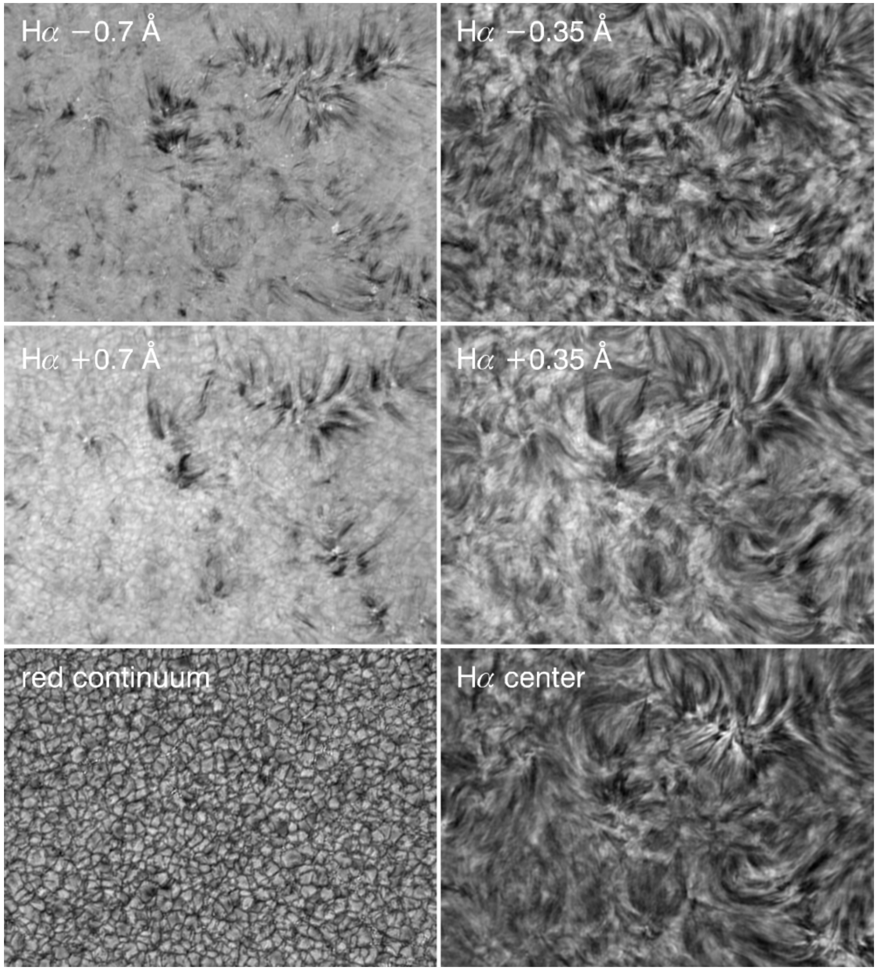


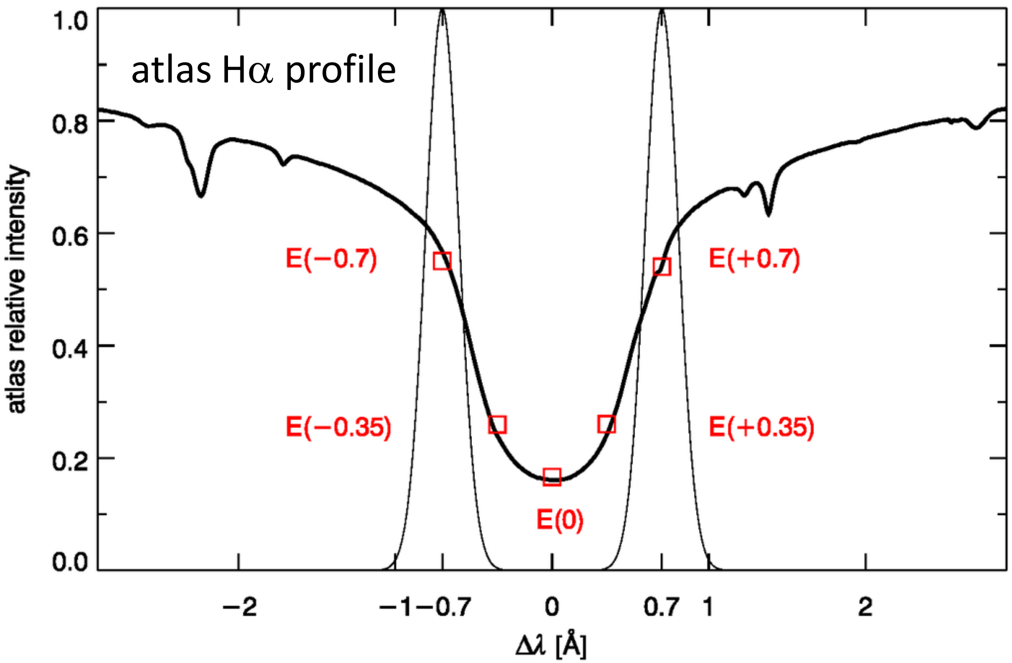
Measured transmission profile of the DOT Hα Lyot filter.

The spectroscopic measurement of the filter showed:

- almost symmetric and Gaussian-like transmission profile with FWHM = 250 mÅ without subsidiary maxima or far-center sidelobes **ruling out a leak of unwanted parasitic light**
- invariance of the profile in tuning

Indirect testing the filter transmission





- Large discrepancy of observed and anticipated ratios.
- An indication of presence of parasitic light in DOT Hα images supporting the suspicions in Rutten 2007 and 2013?

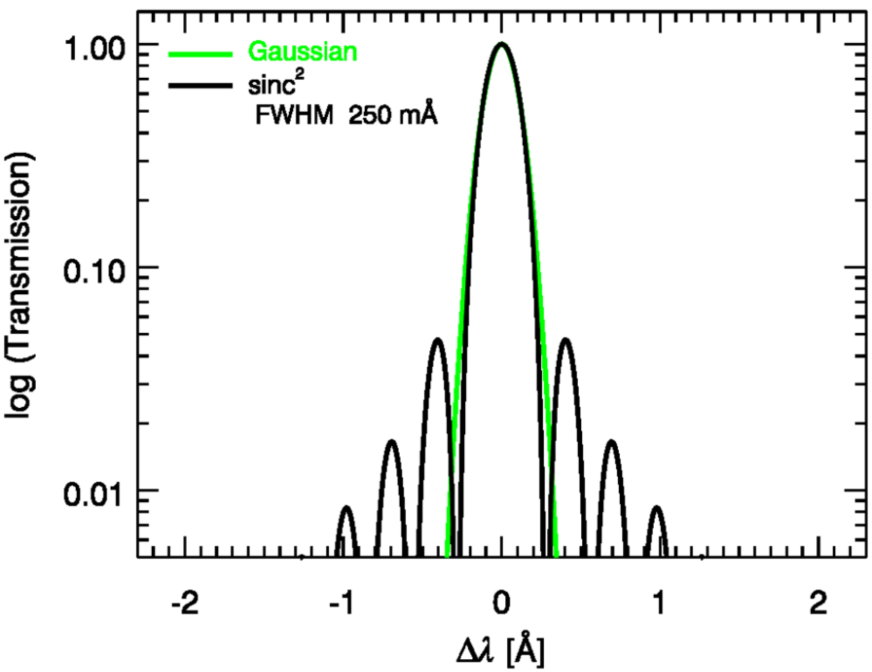
DOT observation of quiet Sun at disk center 2005 Oct 19 taken by Hitachi camera

similar scene on 2007 Sep 28 but taken by RedLake camera

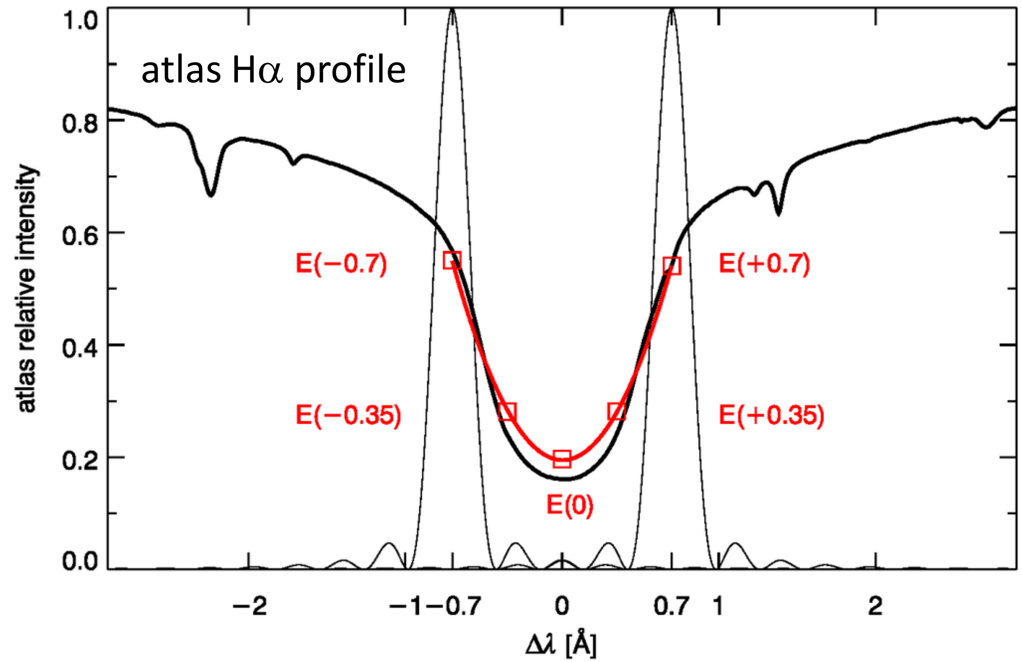
Observed *versus* anticipated wing-to-center ratios

Ratio	DOT Hα Observations 2005 Oct 19	DOT Hα Observations 2007 Sep 28	Atlas Hα Profile + + Gaussian
E(±0.7) / E(0)	2.32	2.34	3.28
E(±0.7) / E(±0.35)	1.75	1.75	2.10
E(±0.35) / E(0)	1.33	1.34	1.56

Indirect testing the filter transmission



approximation for transmission profile of a single peak of Lyot filter



$$T = sinc^2(\Delta\lambda) = \left(\frac{\sin \pi x}{\pi x}\right)^2, x = 2k\frac{\Delta\lambda}{FWHM}$$

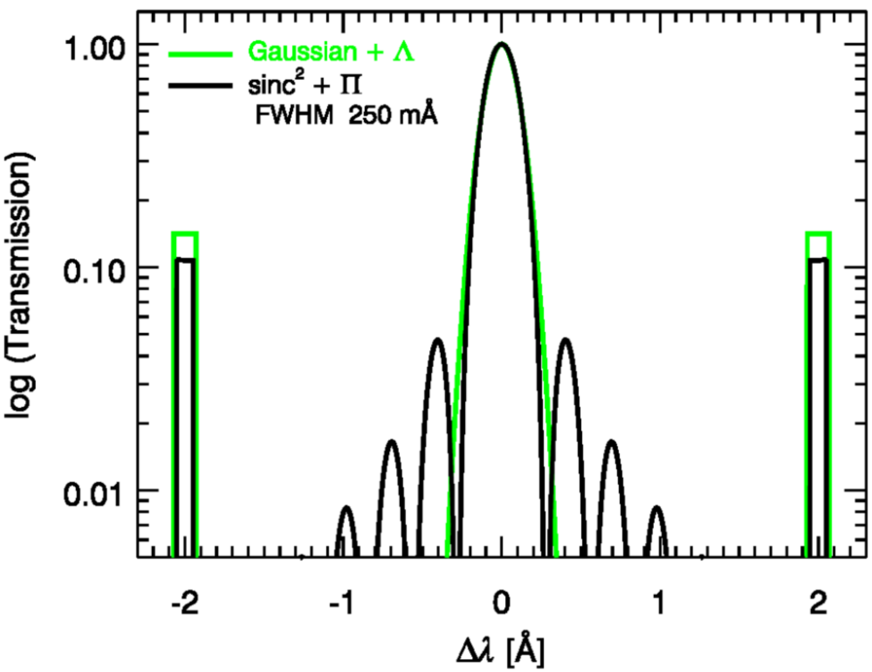
Gaizauskas 1976, JRASC 70, 1
Koza et al. 2014: AN 335, 409

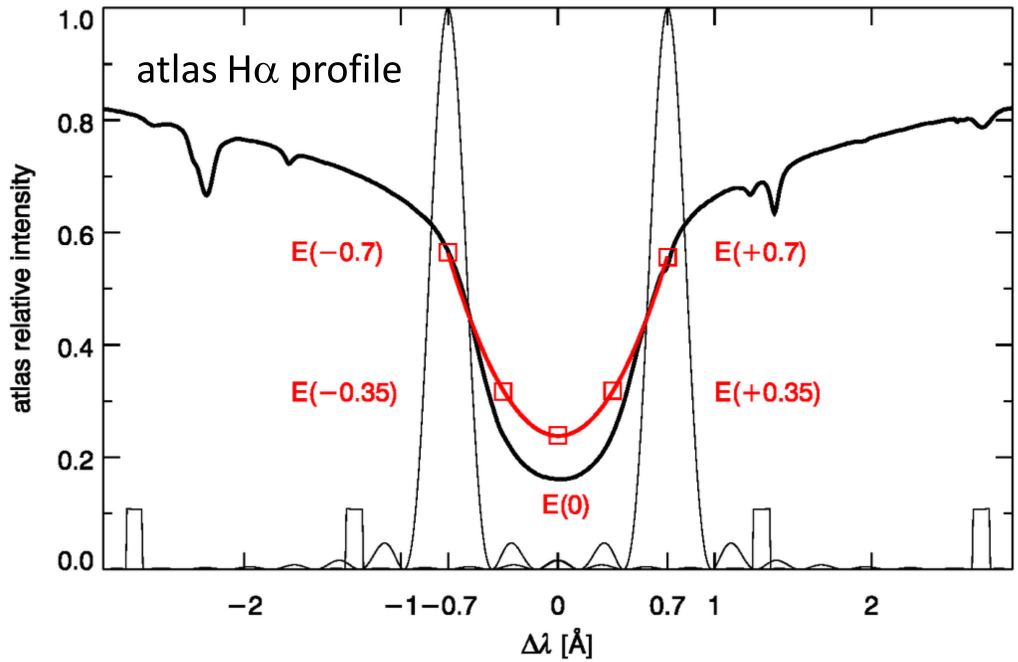
- Gaussian and sinc² models yield ratios significantly exceeding the observed ones.
- It suggests in contradiction with the spectroscopic measurement of the filter that its real transmission profile might have larger throughput than these models.

Observed *versus* anticipated wing-to-center ratios

Ratio	DOT Hα Observations		Atlas Hα Profile +	
	2005 Oct 19	2007 Sep 28	+ Gaussian	+ sinc²
E(±0.7) / E(0)	2.32	2.34	3.28	2.78
E(±0.7) / E(±0.35)	1.75	1.75	2.10	1.94
E(±0.35) / E(0)	1.33	1.34	1.56	1.43

New transmission models





Ad hoc rectangular extensions Λ and Π of the Gaussian and sinc² function at Δλ = ± 2 Å

Rectangle	Area [mÅ]	Width [mÅ]	Height
Λ	20.0	141	0.141
Π	11.5	107	0.107

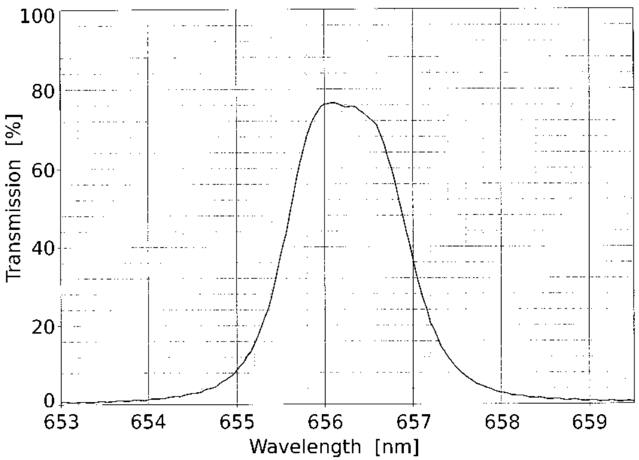
Observed *versus* anticipated wing-to-center ratios

Ratio	DOT Hα Observations		Atlas Hα Profile +			
	2005 Oct 19	2007 Sep 28	+ Gaussian	+ sinc²	+ Gaussian + Λ	+ sinc² + Π
E(±0.7) / E(0)	2.32	2.34	3.28	2.78	2.35	2.35
E(±0.7) / E(±0.35)	1.75	1.75	2.10	1.94	1.77	1.76
E(±0.35) / E(0)	1.33	1.34	1.56	1.43	1.33	1.34

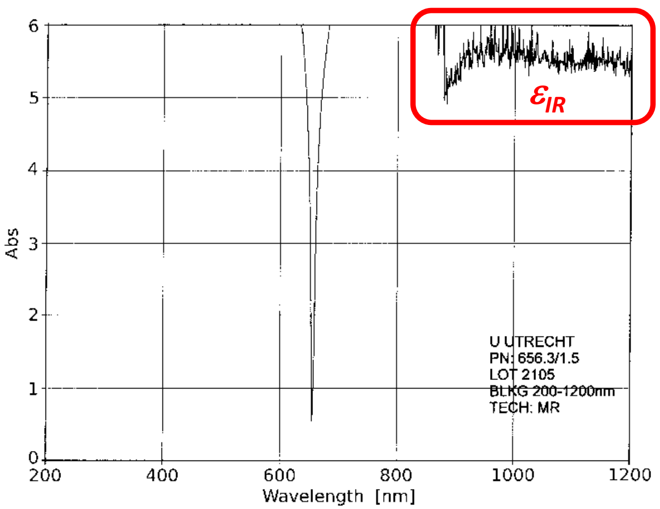
Discussion

Discriminating a source of the parasitic light

Transmission of prefilter (FWHM = 14.9 Å)
of the DOT Hα Lyot filter



The logarithm of the prefilter transmission
(The transmission decreases upward)



Symptoms of a leak of the parasitic light:

1. dissimilarity of limb images
2. discrepancies of the wing-to-center ratios

Two likely gateways:

1. IR window in the prefilter transmission (broadband transmission of $10^{-5.5}$ at 870 - 1200 nm)
2. the main passband of the Lyot filter itself

Considering an extreme situation that the polarisers in the Lyot filter are completely ineffective in IR wavelengths, estimated IR leak ε_{IR} is only 1.3% from the total parasitic light.

$$\varepsilon_{IR} \approx \frac{F_{IR}}{F_{H\alpha}} \frac{P_{IR}}{P_{H\alpha}} \frac{S_{IR}}{S_{H\alpha}} \Delta\lambda_{IR}$$

Then virtually all parasitic light leaks through the main passband of the prefilter and the Lyot filter.

Conclusions

- accurate knowledge of filter transmission is important, in particular in comparing observations with simulated data
- discrepancy: measured Gaussian-like transmission
  versus
  two independent indications of a possible leak
  of parasitic light into DOT Hα images
- to reconcile the discrepancy, two theoretical transmission profiles of the DOT Hα Lyot filter were suggested combining the Gaussian and a square of sinc function with two ad hoc rectangle functions
- using of the two suggested transmission profiles allows comparing of DOT Hα observations with simulated data
- decisive answer can give spectroscopic re-measurement of the filter
- potential users should not be discouraged from using of the DOT Hα data
- current URL of the public-open DOT database offering many ready-to-use Hα data sets:

http://dotdb.strw.leidenuniv.nl/DOT/

Further application of the method of wing-to-center ratios:

Indirect testing of transmission of any filter, e.g., at NFI / Hinode.

Koza et al. 2014: Astronomische Nachrichten 335, 409