Measurements of Photospheric Magnetic Fields

Spectro-Polarimetry at High Spatial Resolution

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SOLARNET IV

Lanzarote

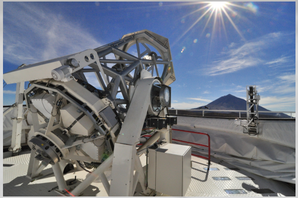
January 2017

MAX-PLANCK-GESELLSCHAFT

Small-scale photospheric magnetic structures

direct measurements are now possible:

- AO development
- space / balloon observatories
- DKIST/EST will open new frontiers

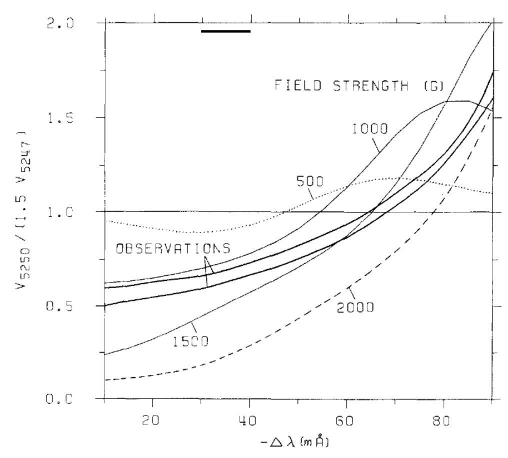


Sub-resolution analysis techniques

Example: Stenflo (1973)

The fine-structure of the magnetic network

- Zeeman signal of two lines formed under same conditions (Fe I 5247/5250 Å)
- determination of true field strength possible
- network fields concentrated in 100–300 km regions of ≈2 kG



Stenflo (1984)

Hi-res B-measurements

Hi-res B measurements: Typical work flow

1. observe
   hi-res, hi-S/N, low straylight
2. calibrate, reduce & improve the data
3. invert data (get B, γ, χ)
4. interpret & publish results

Approach #1

try to decouple steps (1,2,3)
as much as possible

Approach #2

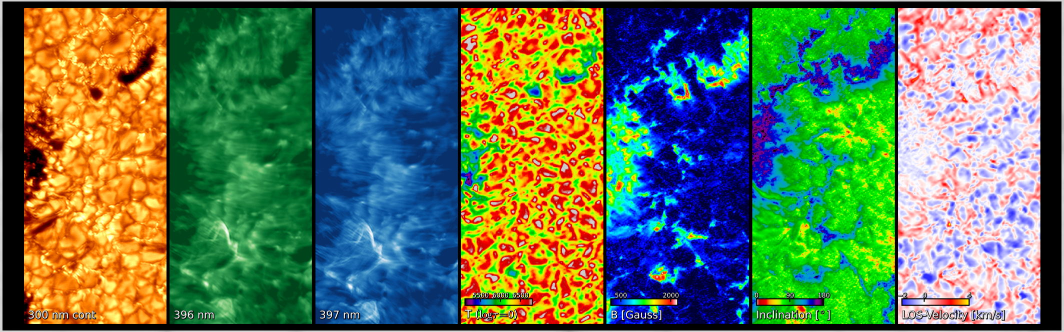
treat (1,2,3) in a single,
strongly coupled step

Magnetic field measurements at diffraction limit

Sunrise
seeing-free @ 0.1″

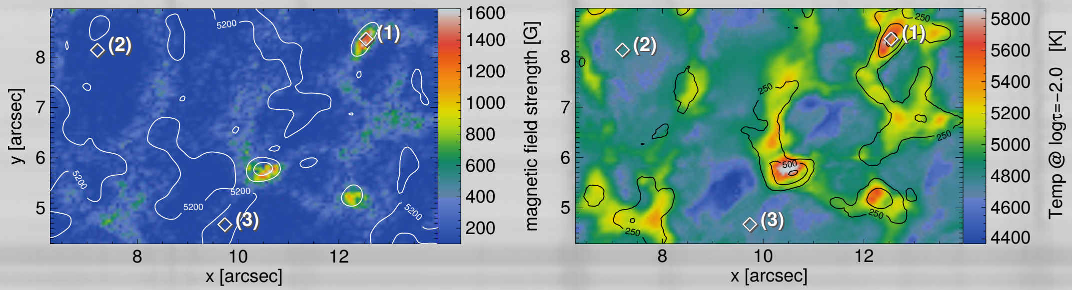
Hinode
seeing-free 0.3″

SST/GREGOR
with seeing 0.1–0.4″



SUNRISE-2, 2013

kilo-Gauss flux tubes in quiet Sun



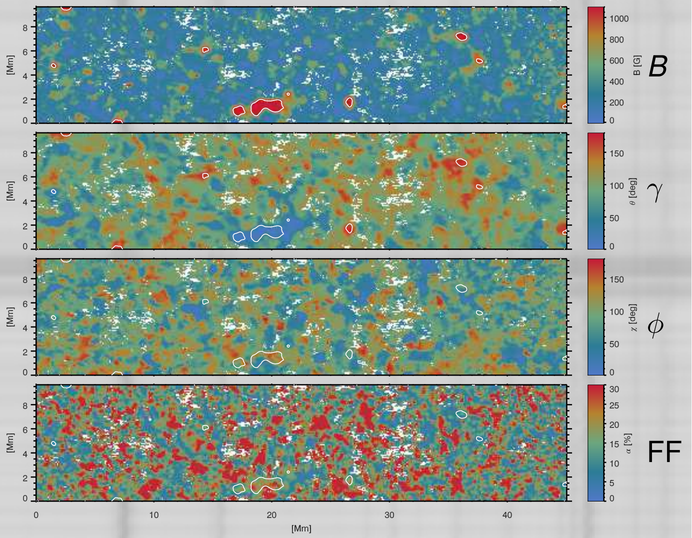
SUNRISE-1: resolved flux tubes (Lagg et al., 2010)

- resolution sufficient for direct determination of field strength in flux tubes
- no filling-factor required

Magnetic landscape of very quiet-Sun regions

GREGOR - GRIS
Martínez González et al. (2016)

- spatial resolution $0.4''$
- extremely high magnetic sensitivity:
  - Fe I 15650 lines, high Landé factor
  - low noise level ($5 \cdot 10^{-4}$ range)
  - $\rightarrow$ almost all pixels contain signal $\geq 3\sigma$



Magnetic landscape of very quiet-Sun regions

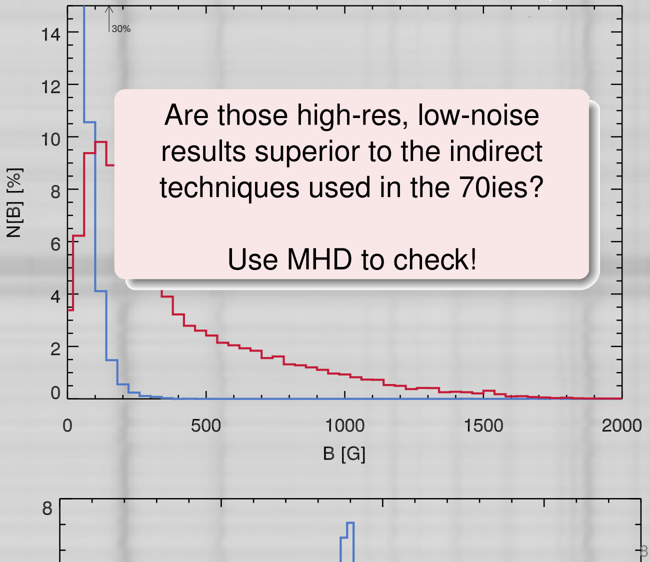
GREGOR - GRIS
Martínez González et al. (2016)

2 atmospheric components:

- dominant component
- minor component

Field strength:

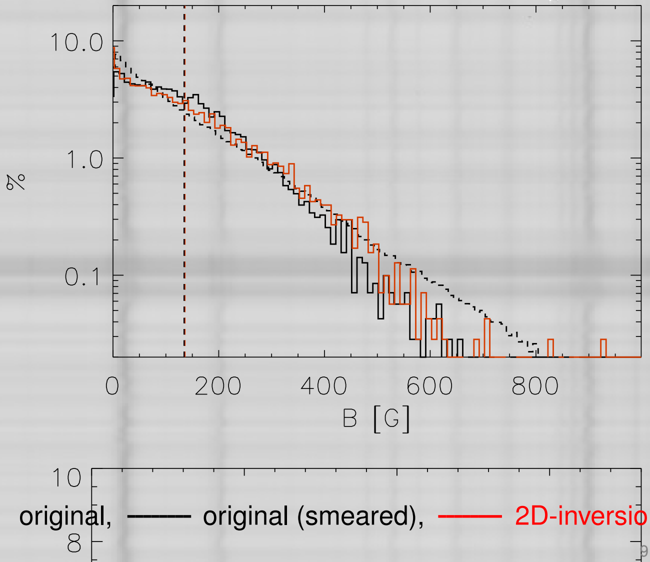
- few kG fields, concentrated in patches
- dominated by weak



Are those high-res, low-noise results superior to the indirect techniques used in the 70ies?

Use MHD to check!

Magnetic very quiet-Sun regions

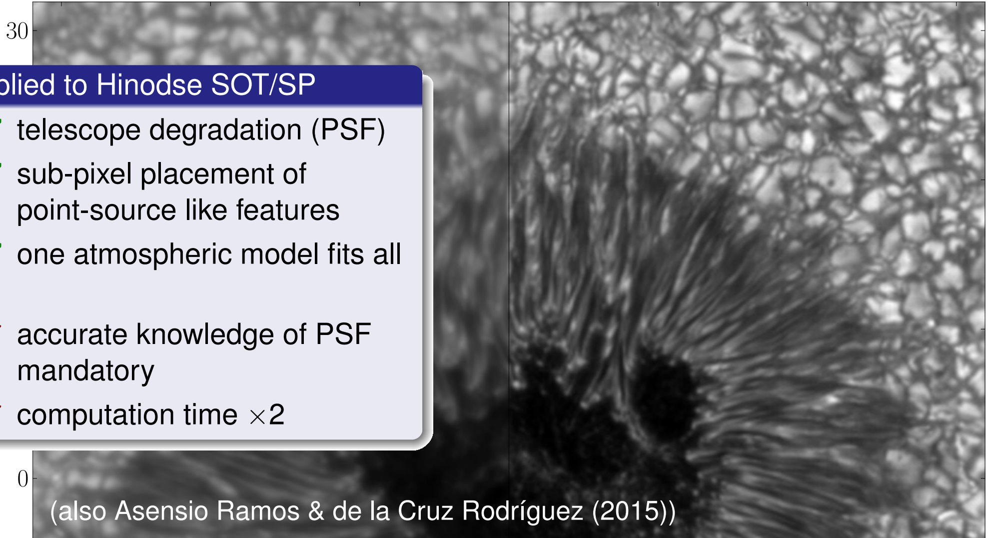


Comparison with MHD
Danilovic et al. (2016)

- simulate measurement by applying spatial PSF
- retrieve B and γ using 2D inversions

→ discrepancies demonstrate

The power of 2D inversions (van Noort, 2012)



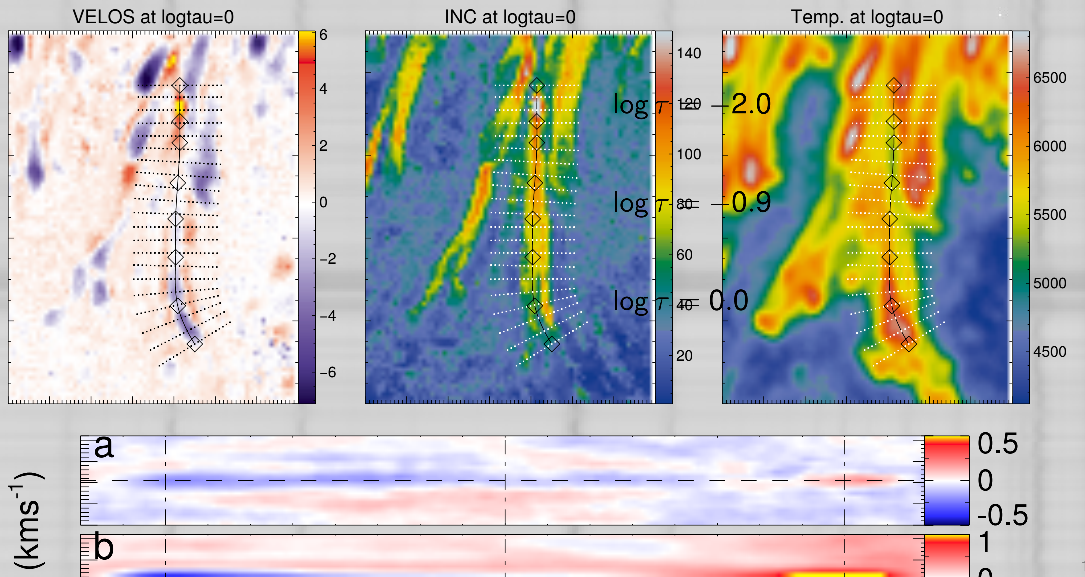
Applied to Hinodse SOT/SP

- ✔ telescope degradation (PSF)
- ✔ sub-pixel placement of point-source like features
- ✔ one atmospheric model fits all

- ✘ accurate knowledge of PSF mandatory
- ✘ computation time $\times 2$

(also Asensio Ramos & de la Cruz Rodríguez (2015))

Remarkably uniform penumbral filaments (Tiwari et al., 2013)

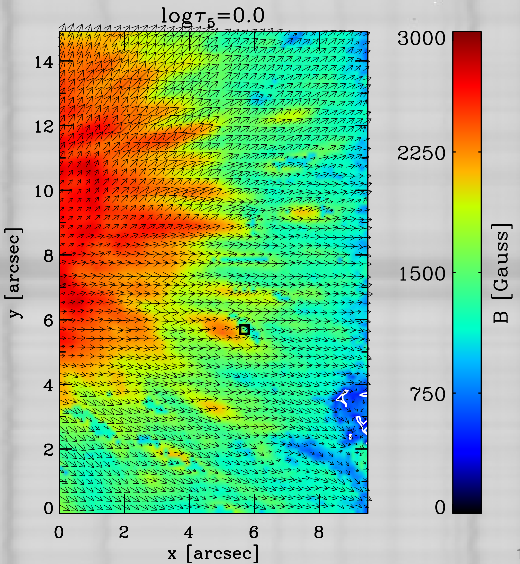


Field-free gaps in penumbra?

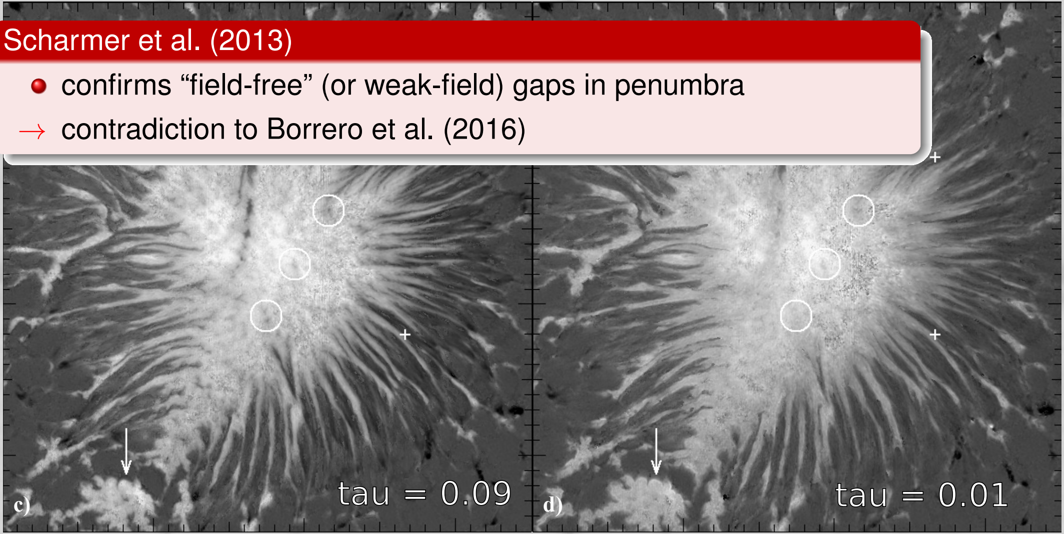
Borrero et al. (2016)

- GRIS Fe I 1.56μm lines
- deepest observable layers
- thorough straylight analysis

- no evidence for field free gaps
- robust against various straylight assumptions



Field-free gaps in penumbra?



Scharmer et al. (2013)

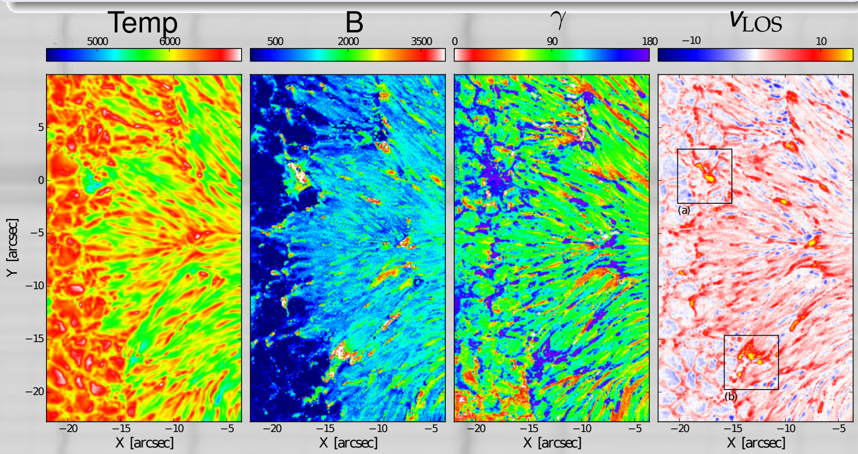
- confirms "field-free" (or weak-field) gaps in penumbra

→ contradiction to Borrero et al. (2016)

Discovery of extremes (1)

Peripheral downflows (van Noort et al., 2013)

7 kG @$\log \tau = 0$, downflows of $> 20\,\mathrm{km\,s^{-1}}$



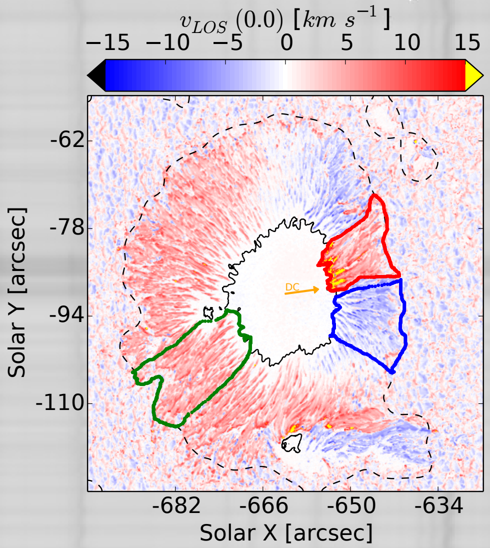
Discovery of extremes (2)

Counter-Evershed Flow (Siu-Tapia et al., 2017, soon!)

- “normal” looking penumbra containing flow towards umbra
- $>$ 5 kG supersonic flows towards umbra

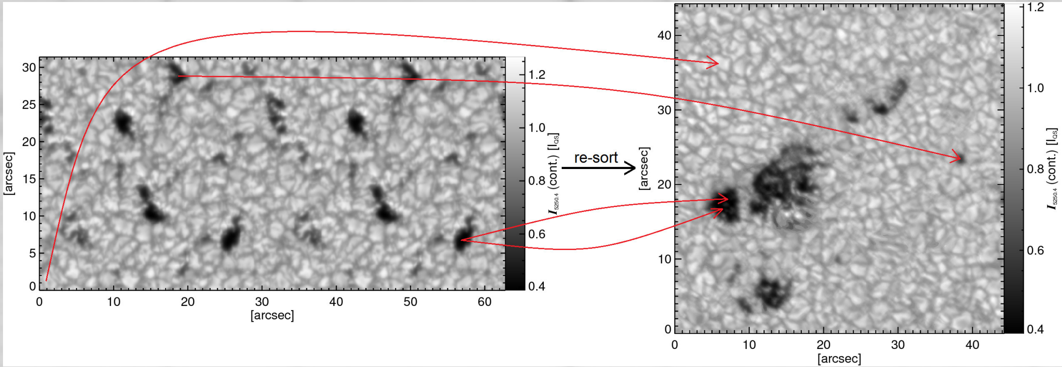
Are these results trustworthy?

✔ check with MHD!

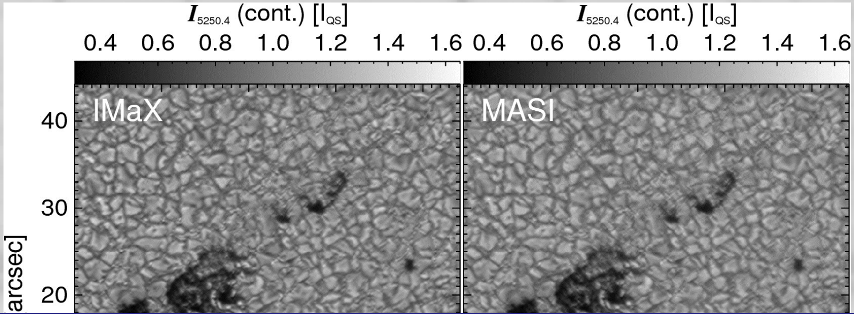


MHD Assisted Inversions (MASI, Riethmüller et al., 2016)

1. take representative MHD snapshot
2. degrade MHD snapshot: spatial & spectral PSF
3. re-sort MHD profiles to observations
4. use (3) as initial condition for MHD run
5. repeat (3-4)



MHD Assisted Inversions (MASI, Riethmüller et al., 2016)



MASI - a first step towards an integration of the MHD equations into the Stokes inversion of a time series

- create MHD simulations very similar to an observation
- allows the creation of new MHD simulations with interesting solar targets (e.g., light bridges)
- can be used as a first-guess atmosphere for a traditional Stokes inversion technique

Current status of high-res magnetometry

- Observations & analysis techniques have reached a high level of sophistication
- Awareness of importance to treat all instrumental effects carefully (spatial & spectral PSF, straylight, seeing fluctuations, . . .)
- Insight into magnetic structure on smallest spatial scales increased significantly during the last decade

BUT: we still produce contradicting / controversial results!

Is this caused by

- the Sun itself? ("not all penumbrae are equal")
- the selection of spectral lines? (we simply measure different things)
- the mis- / over-interpretation of our data?

What is needed to solve this problem?

What is needed to solve this problem?

You are in the right meeting to hear about this!

Understand observations

- know your instrument
- couple your workflow: treat everything altering the photon / EM wave from its generation on the Sun until it becomes a byte on your disk **in a single step**
- simulate observations using MHD simulations
  realism of simulations of minor importance
- good examples: 2D-inversions, SOPHISM (Blanco & PHI-team, 2017)

Improve instrumentation

- increase spatial resolution
  EST: Sarah Matthews (Friday, 11:30)
  DKIST: Valentin Martínez-P. (Friday, 12:00)
- increase height resolution
  Sunrise-3: Hans-Peter Doerr (Friday, 12:40)
- spectro-polarimetry at diff. limit:
  FSP: Francisco Iglesias (Friday 14:50)
  CHROMIS: Goran Scharmer (Friday, 15:20)
  GRIS: Andrés A. Ramos (Friday, 16:50)
  Michiel van Noort (Friday, 17:05)

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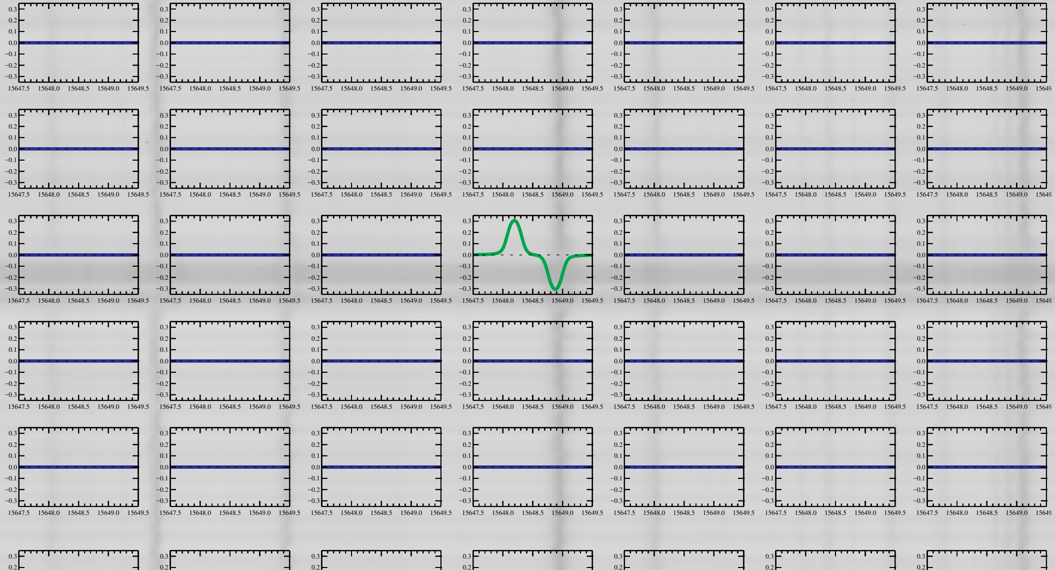
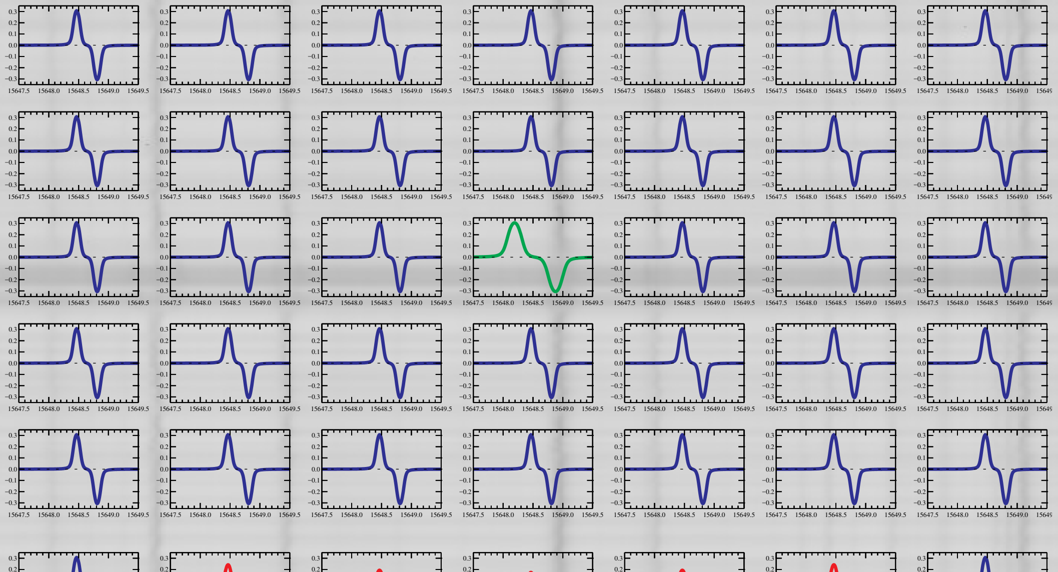
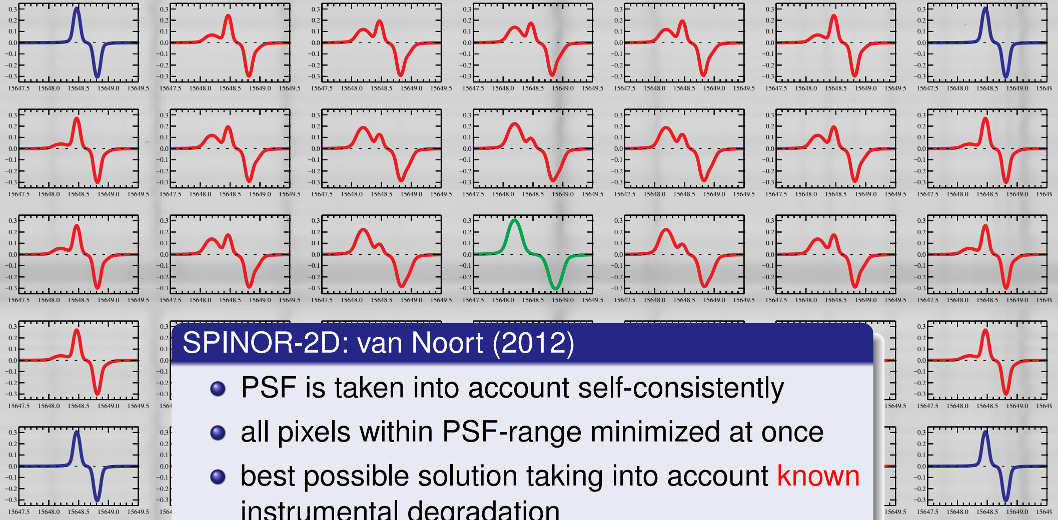
PSF influence - magnetic pixel in QS - nowith PSF



PSF influence - magnetic pixel in weak *B* environment - nowith PSF





SPINOR-2D: van Noort (2012)

- PSF is taken into account self-consistently
- all pixels within PSF-range minimized at once
- best possible solution taking into account known instrumental degradation