Imaging Spectro-Polarimetry with Long Exposure Times

T. A. Waldmann

CASSDA Workshop, 18.02.2014

Motivation and approaches

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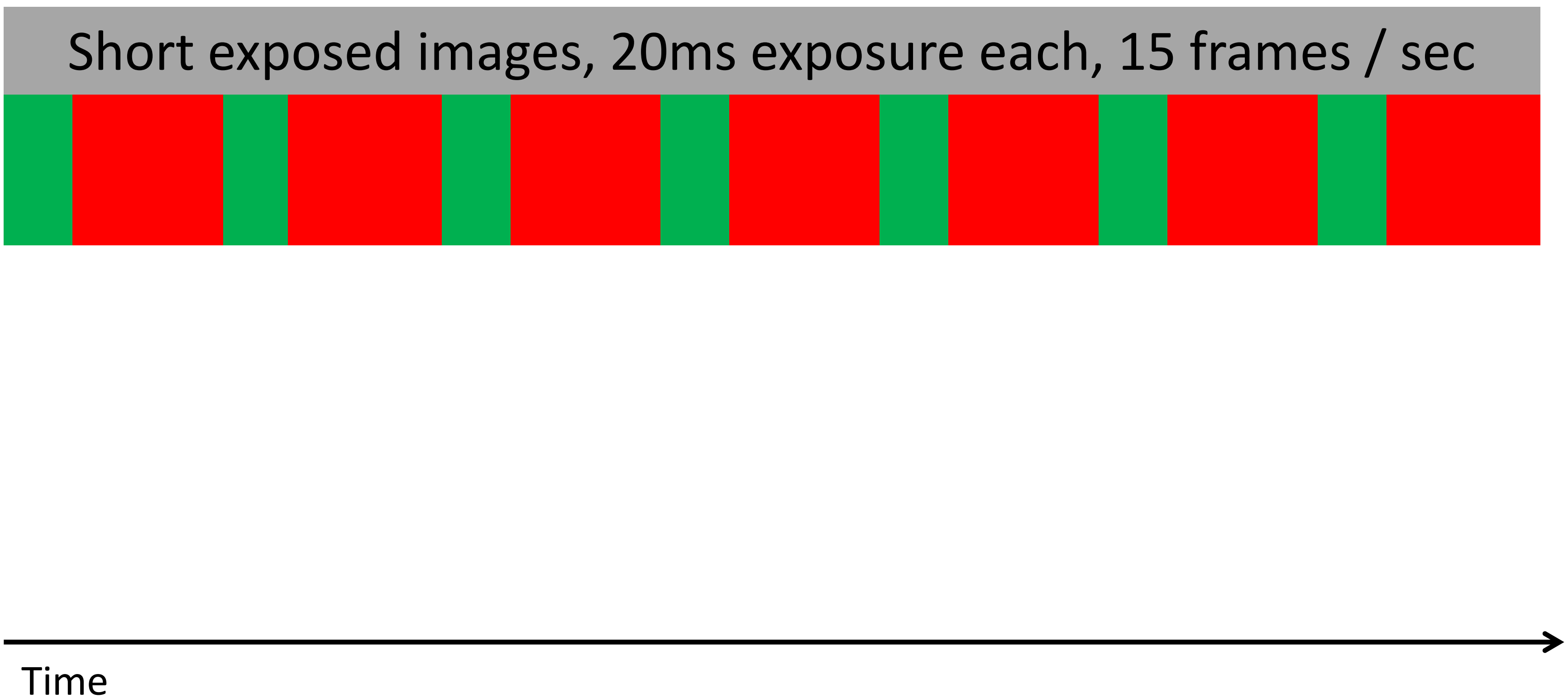

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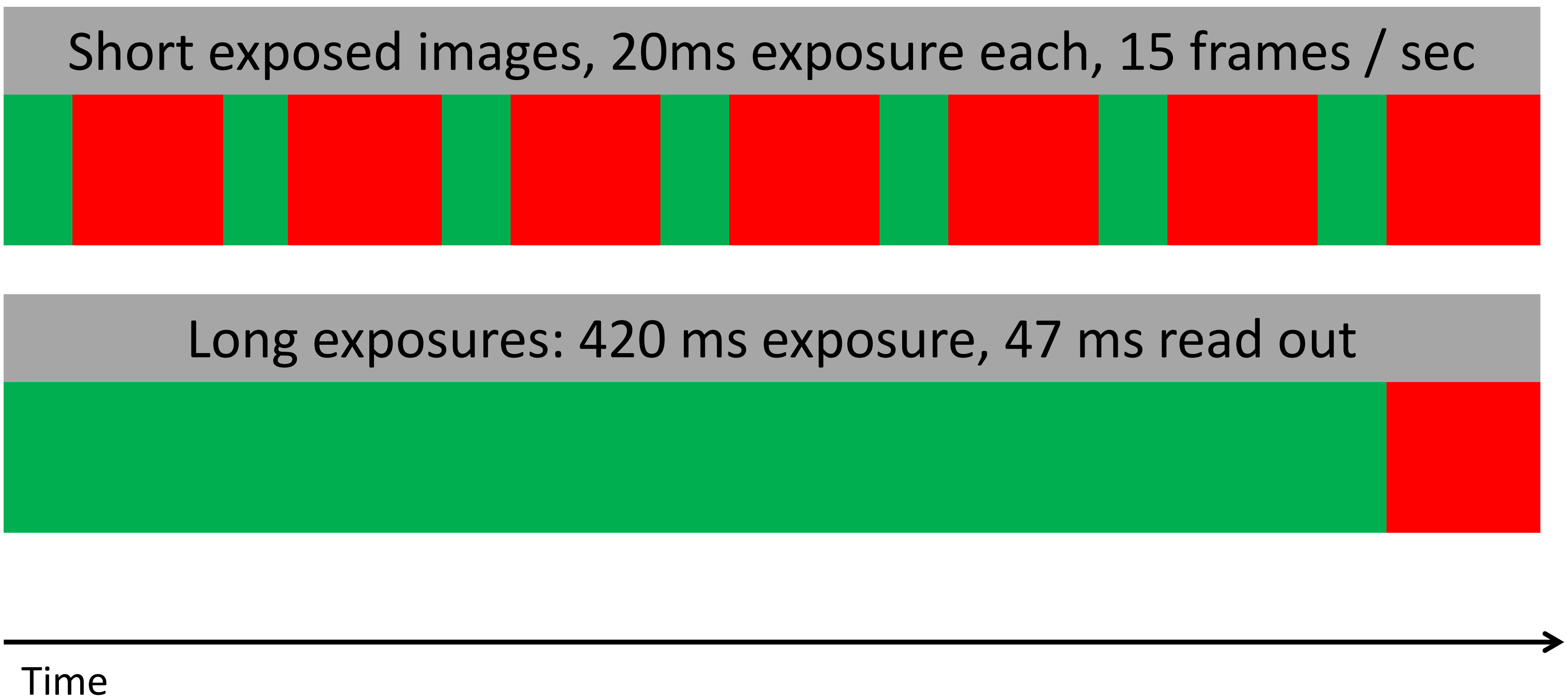

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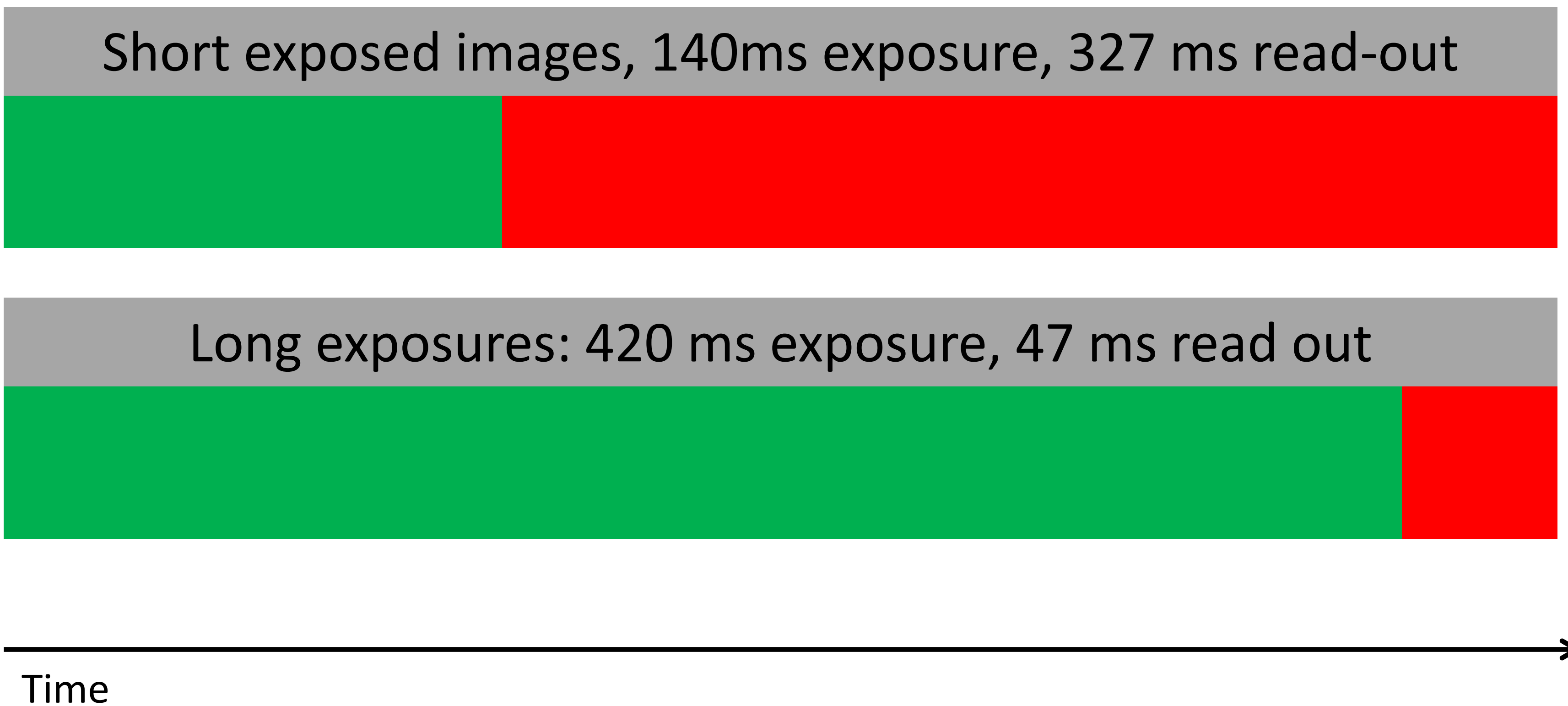

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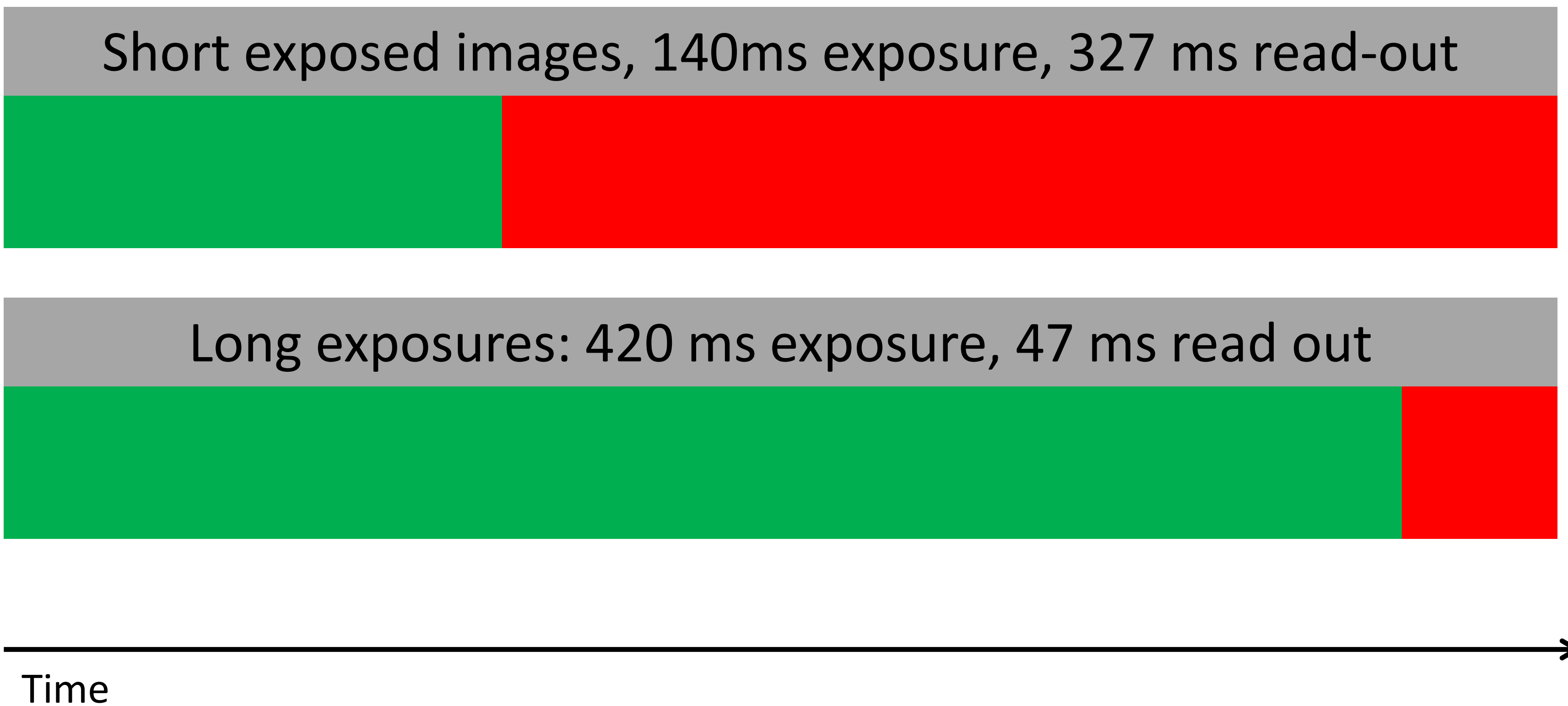

Long-exposure PSF needed to deconvolve the frame!

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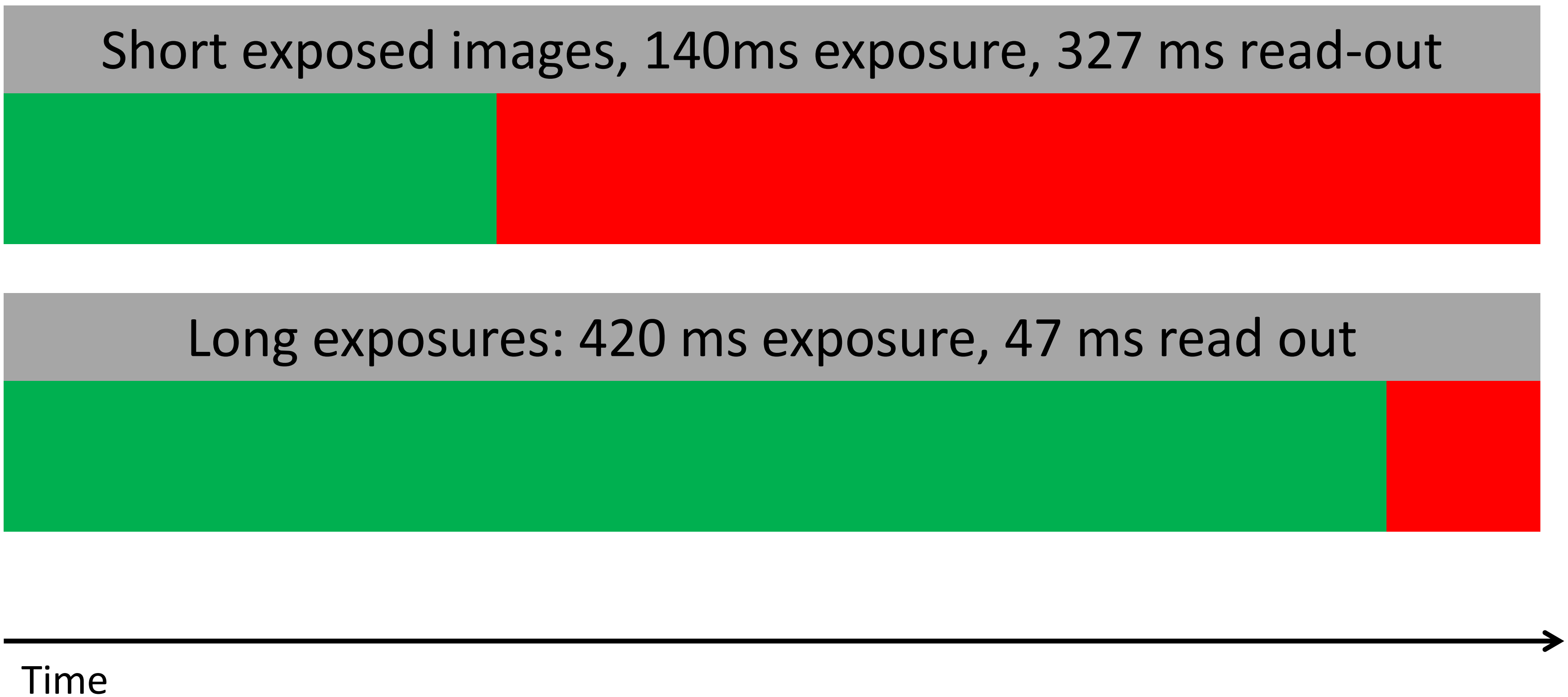
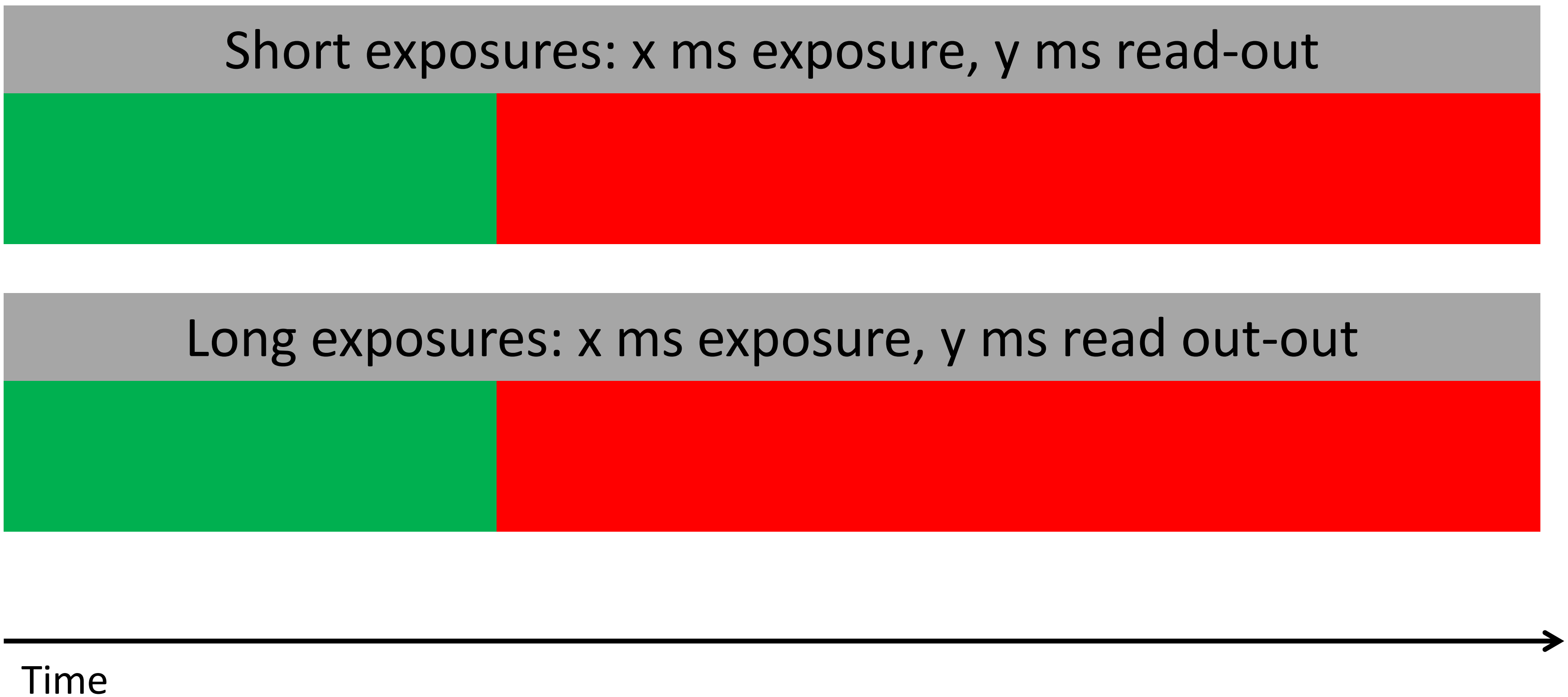


Comparisons during this workshop



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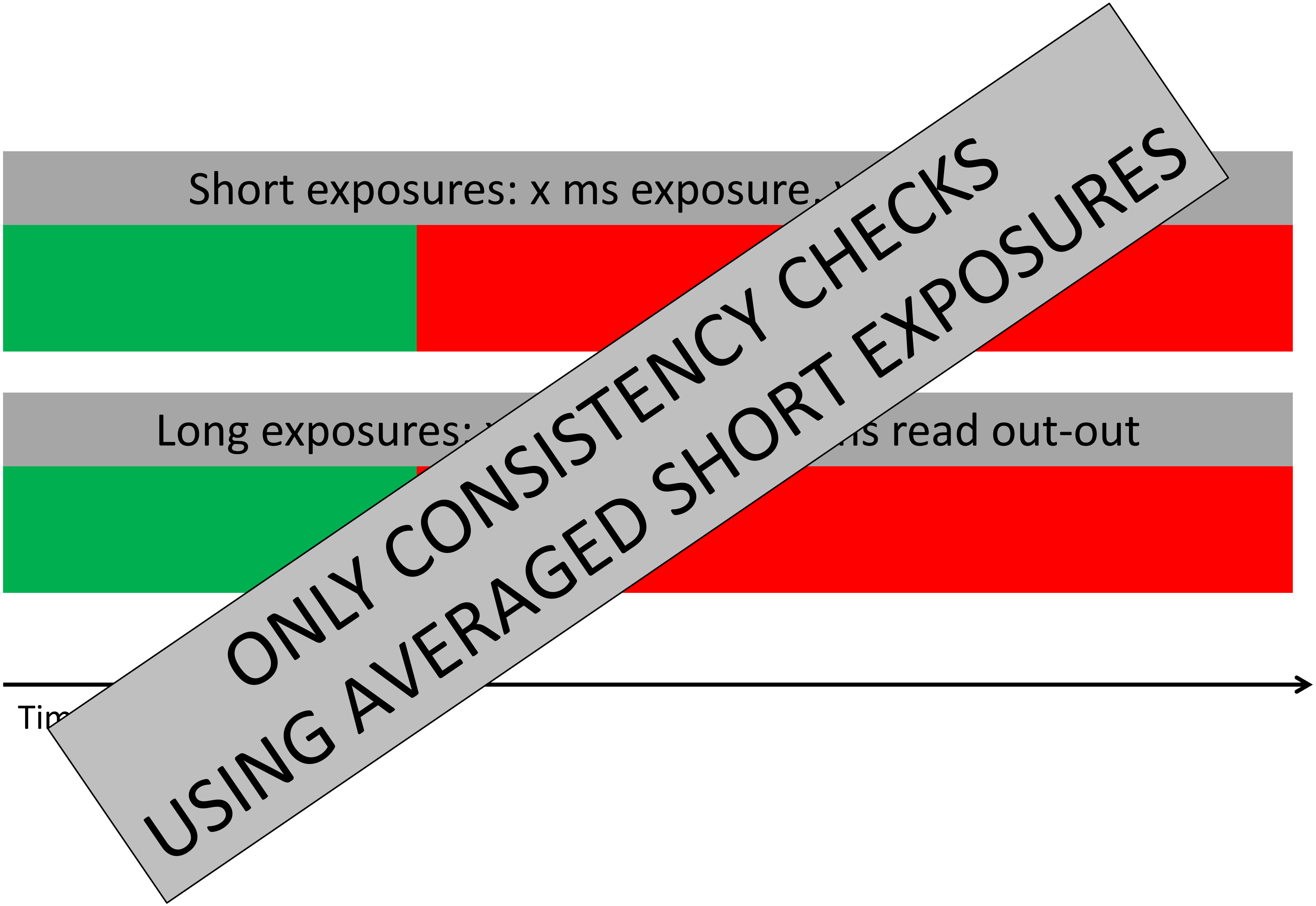
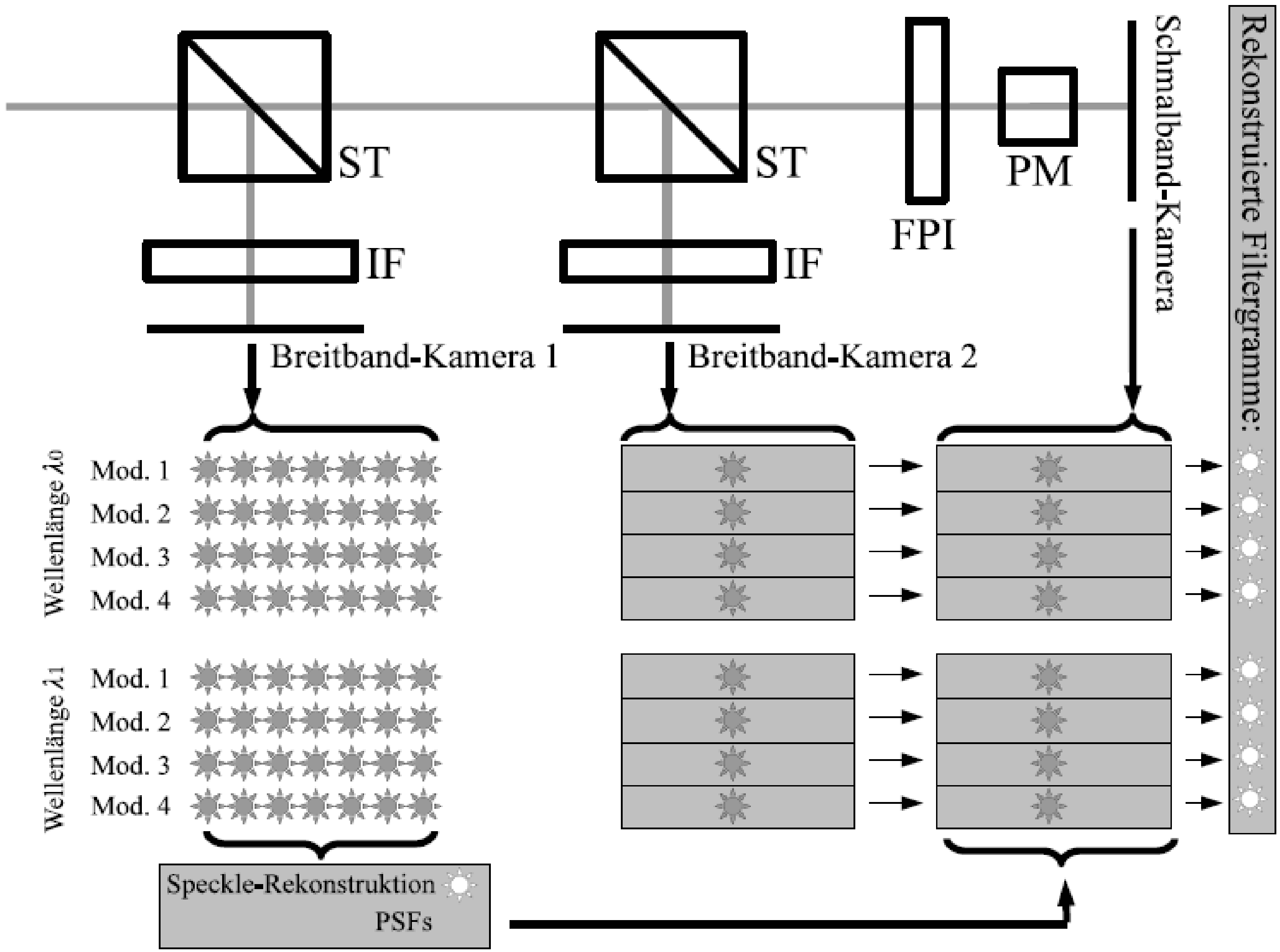


Long-exposure PSF estimation

- Methods include, but are not limited to:
  - Use AO-telemetry data (e.g. Marino, 2007).
  - Use data from an additional imaging channel (e.g. Waldmann, 2011).
  - More sources available (e.g. Jollisant, 2004)…

PSF Estimation using an additional imaging channel



PSF Estimation

- PSF estimation is based on comparing the individual BB-images with a Speckle-Reconstruction of the BB-images.
- Photometry of Speckle-Reconstructions has been proven to be accurate *(Wöger et al. 2008)*.

PSF Estimation

- Method introduced by Friedrich Wöger, 2007:
  - Iterative, regularized, constrained division in the Fourier-domain.
  - Gaussian shape of long exposure PSF.
  - PSF is non-negative.
  - MTF is limited by the MTF of the ideal telescope.
  - Division only if SNR exceeds a certain treshhold.

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  - Model PSF via wavefront phase at the telescope pupil.
  - Use simulated annealing to estimate a set of Zernikes that minimizes an error function.

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  - Slow.
  - No guarantee that the result is a (local, global, any…) minimum of the error function.

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COMPARABLE RESULTS

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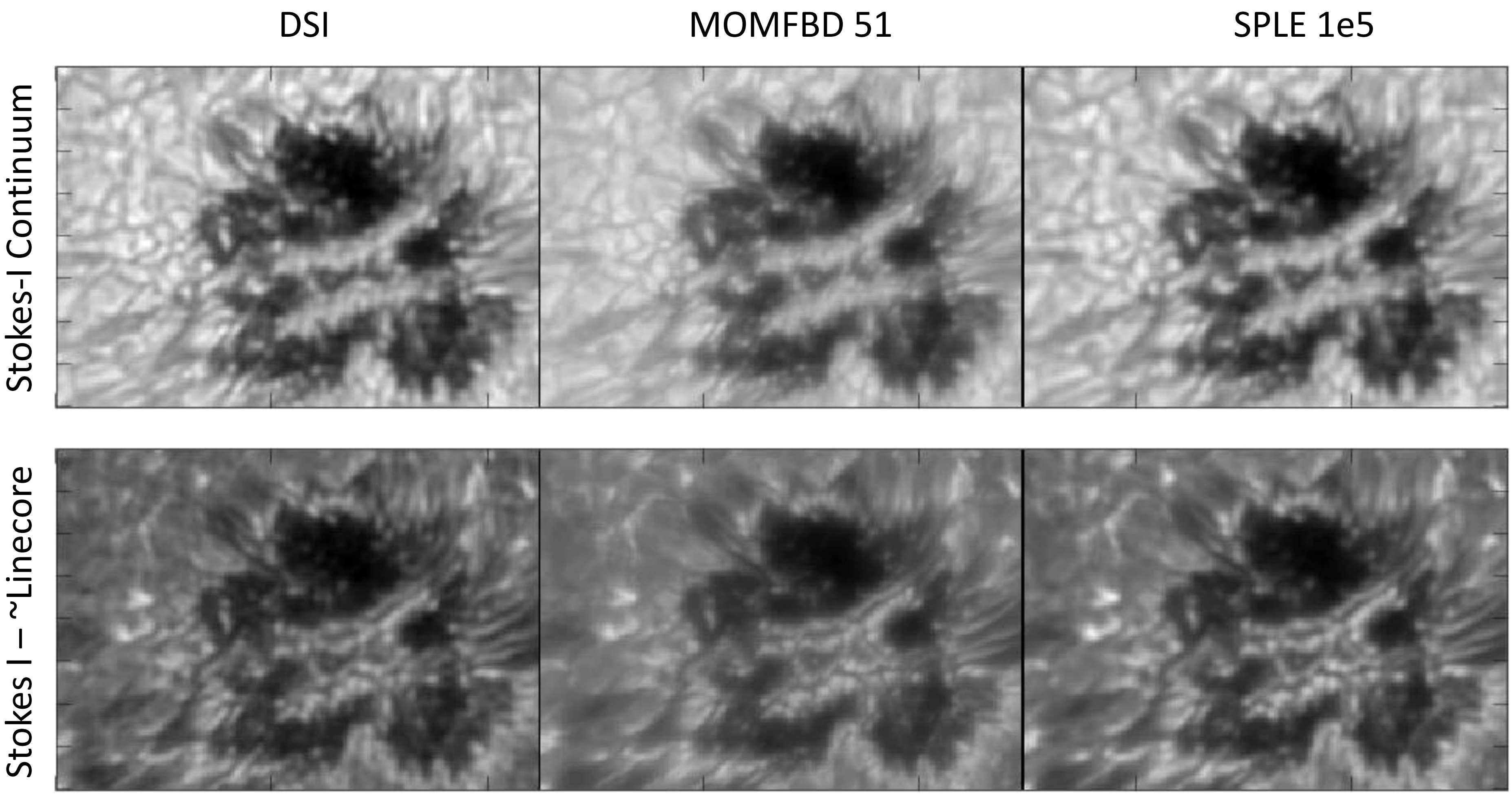
TO BE IMPROVED

Exemplary Results

- GFPI at VTT: Simulated long exposures (8*20 ms) and compared with MOMFBD and DSI.



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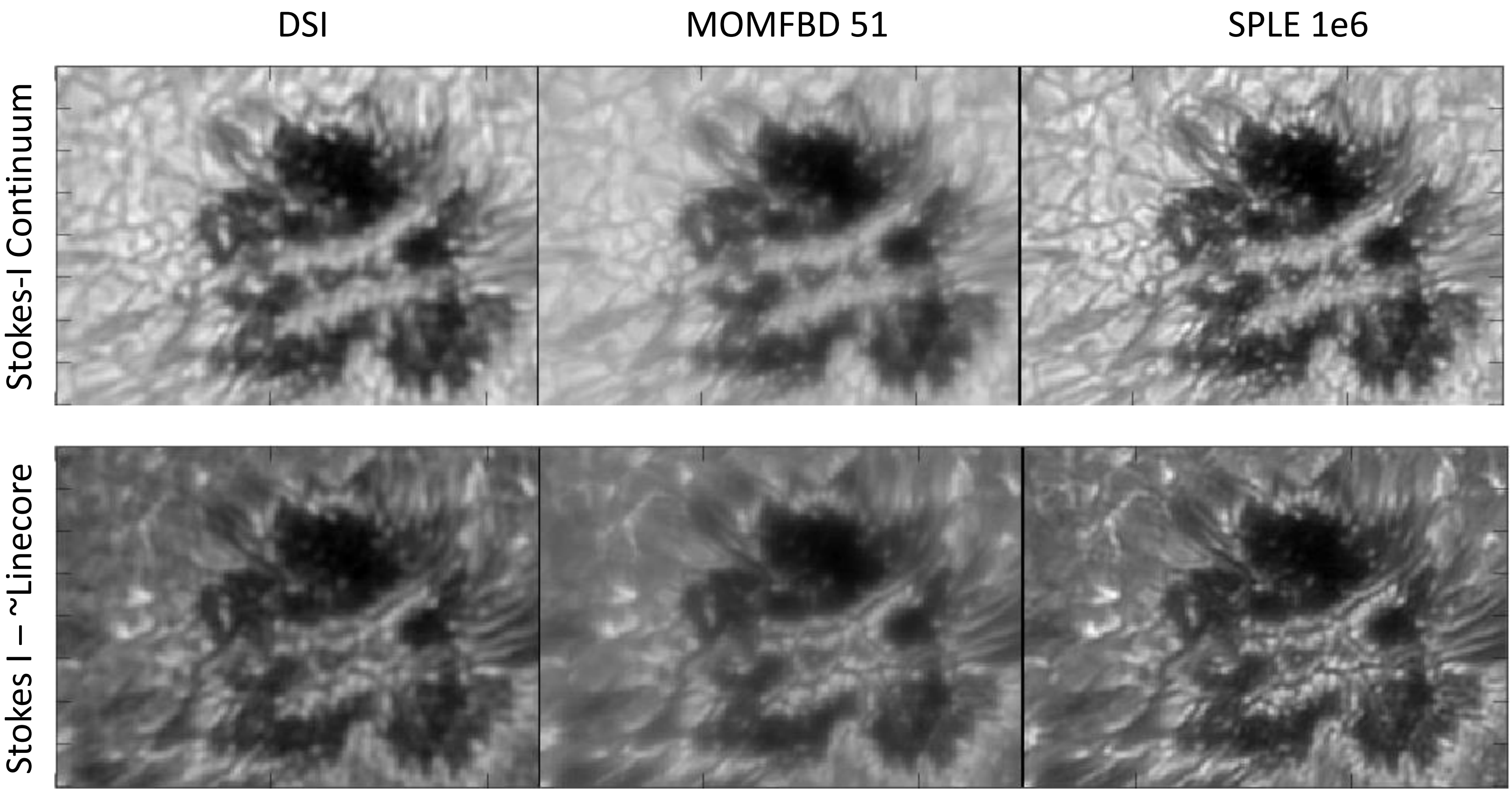

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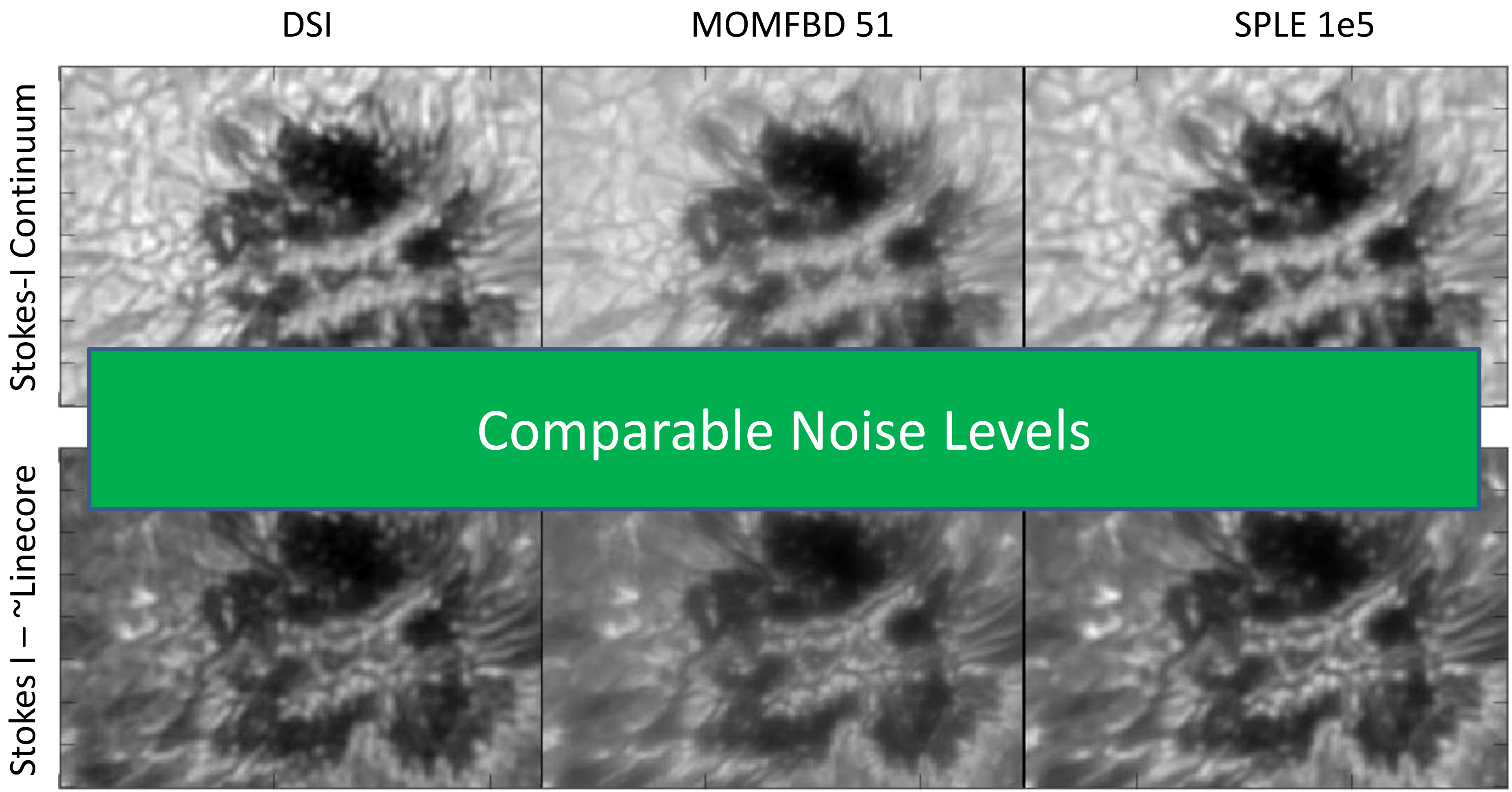

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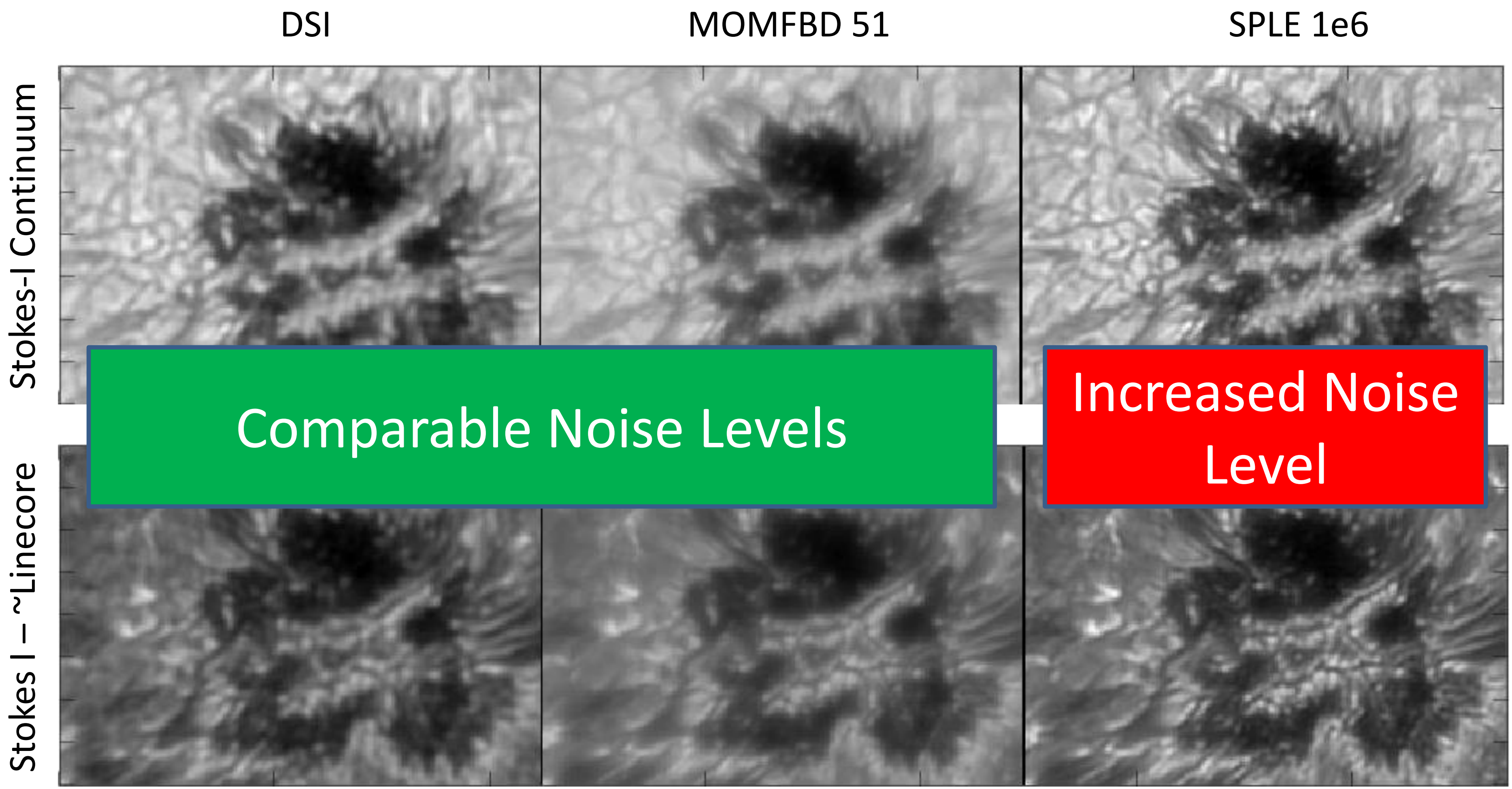
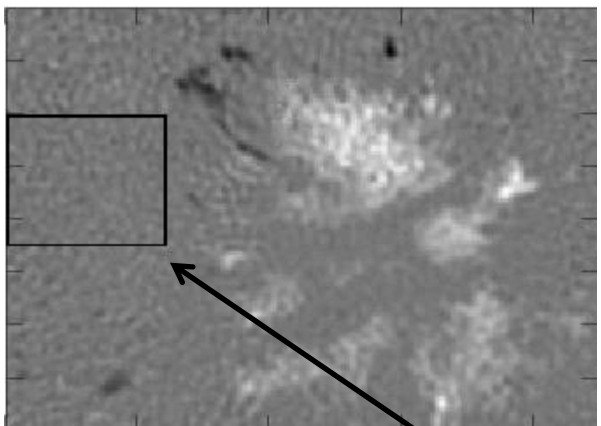
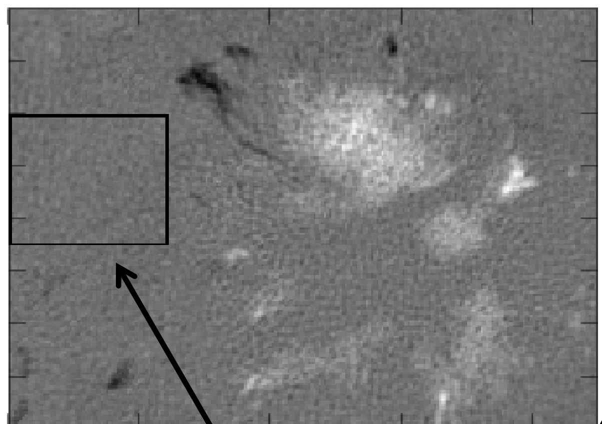


Exemplary Results: Noise Levels

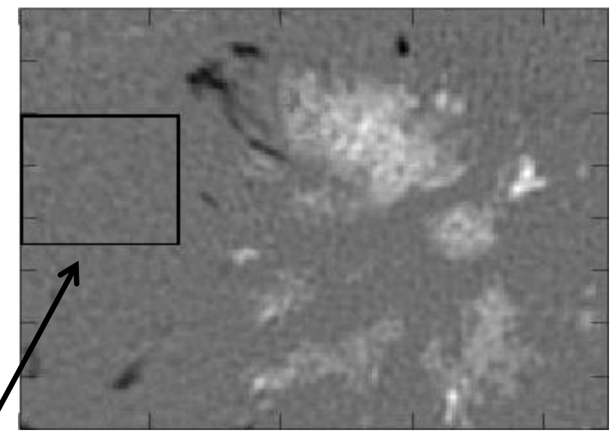
Stokes – V Continuum - DSI



Stokes – V Cont.- MOMFBD



Stokes – V Cont.- SPLE 1e5



Compute Standard Deviations for Stokes -Q, -U, -V.

Exemplary Results: Noise Levels

DSI noise levels:
Stokes-Q: 0.004
Stokes-U: 0.004
Stokes-V: 0.003

MOMFBD noise levels:
Stokes-Q: 0.004
Stokes-U: 0.004
Stokes-V: 0.003

SPLE„soft" deconvolutions noise levels:
Stokes-Q: 0.003
Stokes-U: 0.003
Stokes-V: 0.002

SPLE„hard" deconvolutions noise levels:
Stokes-Q: 0.010
Stokes-U: 0.010
Stokes-V: 0.007

Regarding the numbers shown here, please note the last slide of this presentation*

Exemplary Results: Noise Levels

DSI noise levels:

Stokes-Q: 0.004

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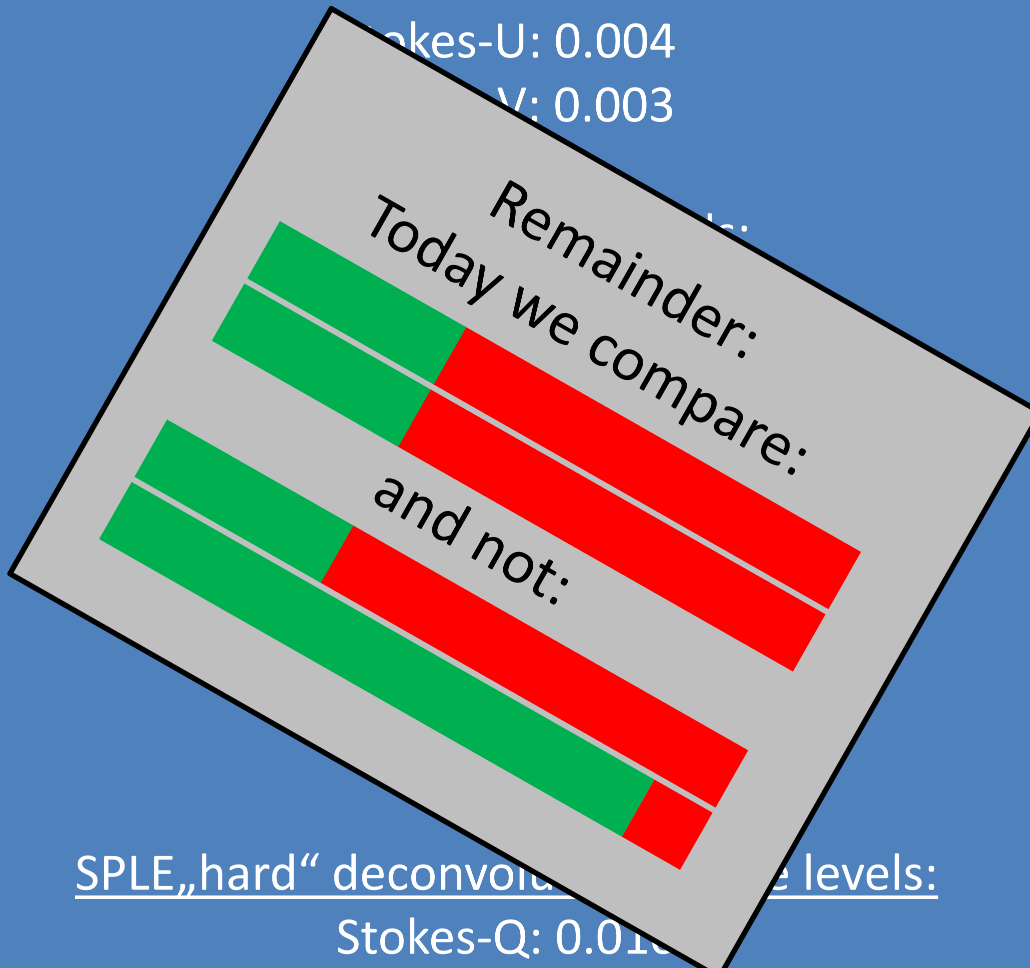

SPLE„hard“ deconvolu... ...e levels:

Stokes-Q: 0.01...

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Exemplary Results: Noise Levels

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MOMFBD noise levels:

ALL IS WELL

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PIPE-PSF Estimation: *Flaws* and <u>Justifications</u>

- *VTT pupil was modelled with Zernikes only (i.e. no secondary, no spider).*
  - <u>No pupil images were available.</u>
  - <u>Pupil-arrays were small (64x64 to 128x128 Pixel).</u>
  - <u>Results compared well with the Wöger-Method.</u>
  - <u>Results compared well with Speckle-Deconvolution results.</u>

- *Finally, only 25/(50) Zernikes were used.*
  - <u>In simulations, no big difference between using 25 and up to 50 Zernikes was seen.</u>
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We wanted to <u>proof the concept,</u>
not optimize the details!

PIPE-PSF Estimation: Things to do better!

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<u>Two Possibilities:</u>

a) Use code of Peter F. Perroni to estimate PSFs
b) Use more thorough model for a long exposure PSF

PIPE-PSF Estimation: How to do it better!

- Work of Peter F. Perroni, 2013:
  - Use GPUs instead of FPUs and a Cooperative Particle Swarm Optimization algorithm instead of simulated annealing.
  - Code publicly available, can be downloaded and tested: *http://web.inf.ufpr.br/vri/alumni/peter-frank-perroni-msc-2013*

- More thorough model for a long exposure PSF:
  - See, for example, the work of Jose Marino, 2007.
  - Other possibilities ?!
  - Note: if the *statistics* of the wavefront are used, a long exposure is an exposure in the order of > 0.5 seconds (cf. Marino, 2004).

Summary

- Spectro-Polarimetry with long exposure times can yield results close to the diffraction limit…
- … at the lock point of the adaptive optics system…
- …, i.e. size of field-of-view limited by anisoplanatism.
- SPLE using an additional imaging channel: proof-of-concept done…
- … but methodology should be optimized …
- … and possible advantages taken that have not been used up to now.

Summary

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MCAO SYSTEMS WILL BE AVAILABLE

- SPLE using an additional imaging channel: proof-of-concept done…
- … but methodology should be optimized…
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Some Comments

- Whatever PSFs you will use to deconvolve your data, deconvolution will enhance the contrast.

- Under- / Over-correction can lead to false deduction of physical parameters.

- Possible consistency checks:

  - Compare your results with independent findings (e.g. *Sharmer et al, 2011*).

  - Used a BB-Speckle-Reconstruction to estimate PSFs?
    > Check what happens when you deconvolve the raw BB-images (e.g. *Waldmann, 2011*).

  - Cross-check with other methods (e.g. *this workshop, Waldmann, 2011; Marino, 2007*).

  - Other possibilities ?

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  - Cros… methods (e.g. *this workshop, Waldmann, 2011; Marino,* 2…
  - Ot… ilities ?

PROOF OF CONCEPT DONE.
LIMITS OF USABILITY TO BE DETERMINED.

Final conclusion

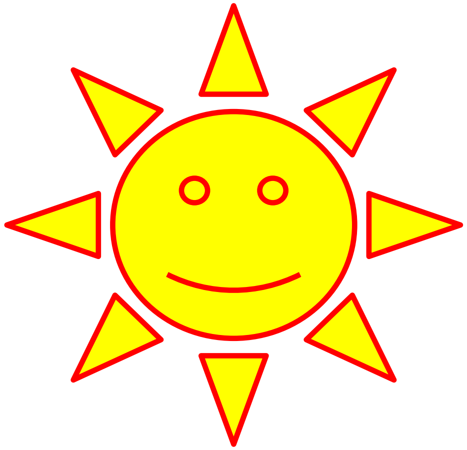
```
if faster_cameras_available_nowadays then begin

        long_exposures=maybe_obsolete

endif else begin

        long_exposures=worthwhile_trying

endelse
```



Thank you for your attention.

Bibliography

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- Marino, 2004: *Point spread function from adaptive optics loop data,* Presentation slides, Center for Adaptive Optics, Workshop on Adaptive Optics PSF Reconstruction.
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* The noise levels of the Stokes parameters shown here are different than the numbers given in Waldmann, 2011. This is due to a re-computation of the demodulation matrix of the GFPI polarimeter. Please contact CASSDA team members for details.