AIP Leibniz-Institut für Astrophysik Potsdam

High-Resolution Spectroscopy with PEPSI/SDI

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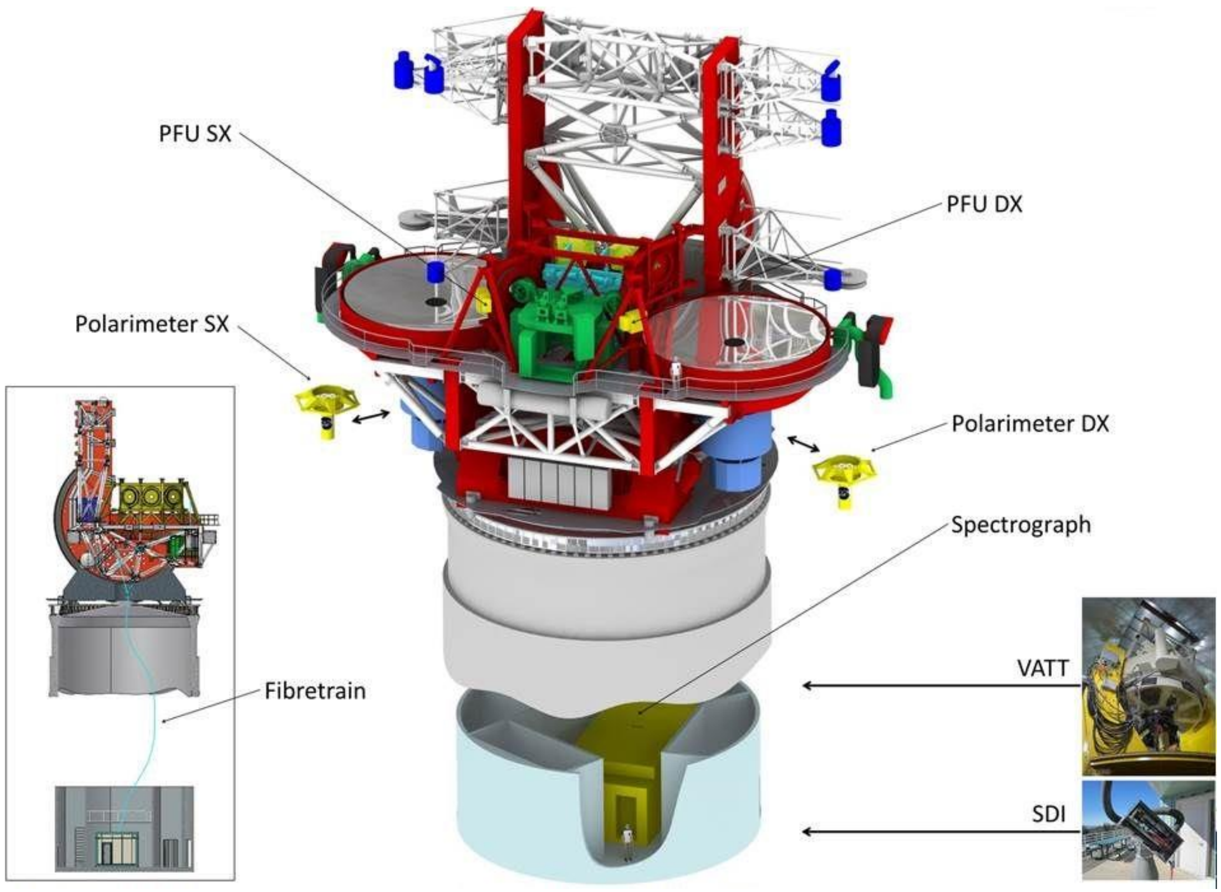
Outline

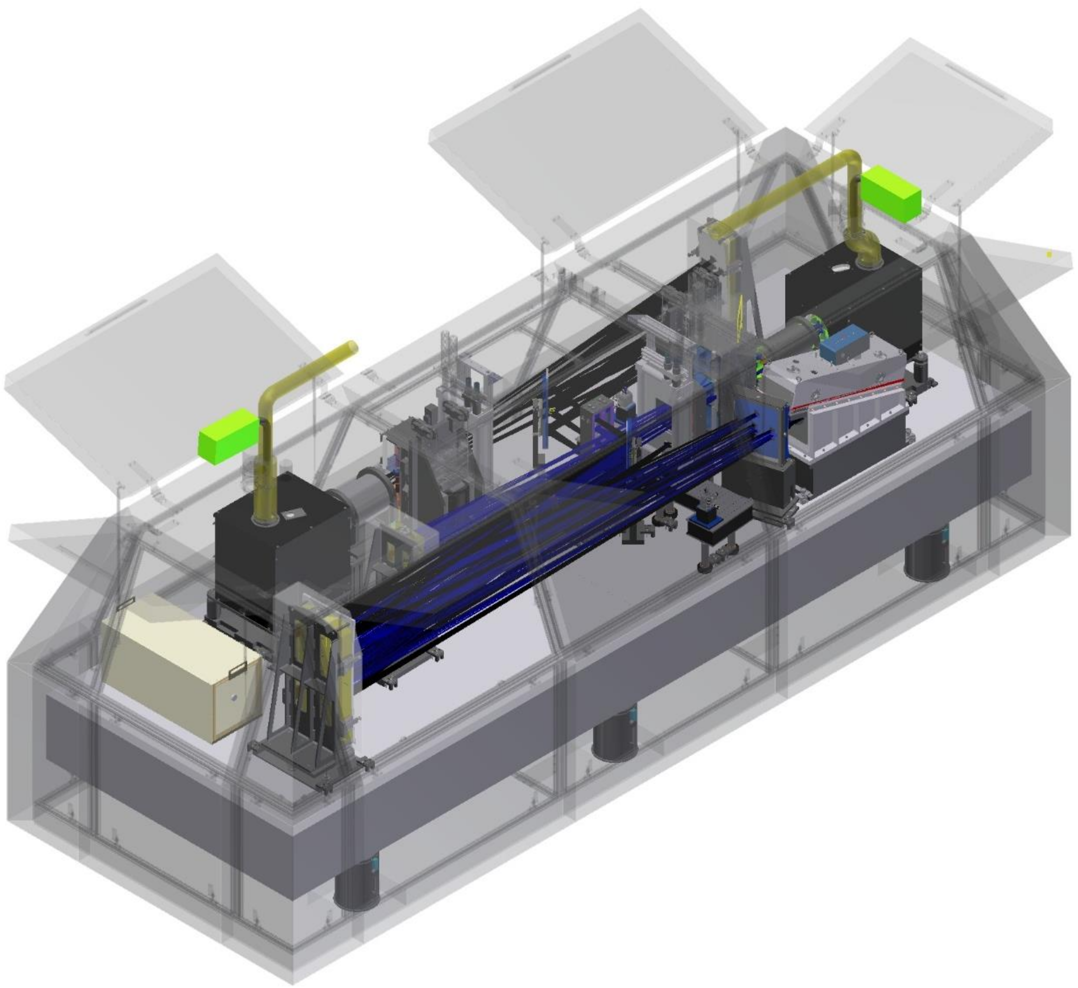
- Potsdam Echelle Polarimetric and Spectroscopic Instrument (PEPSI) for the Large Binocular Telescope (LBT)
- The Solar Disk-Integrated Telescope (SDI)
- Scientific objectives
- Sun-as-a-star spectroscopy
- First results – Ca II K line
  - Continuum calibration using the NSO FTS atlas
  - Cross-comparison with SOLIS/ISS – quality check
  - Comparison of Sun-as-a-star spectra with synoptic full-disk images and magnetograms
- Future work

Potsdam Echelle Polarimetric and Spectroscopic Instrument



- State-of-the art, thermally stabilized, fiber-fed, high-resolution spectrograph
- Spectropolarimeter for the Large Binocular Telescope in Arizona, USA
- PEPSI receives light from three separate telescopes (LBT, SDI, and VATT)

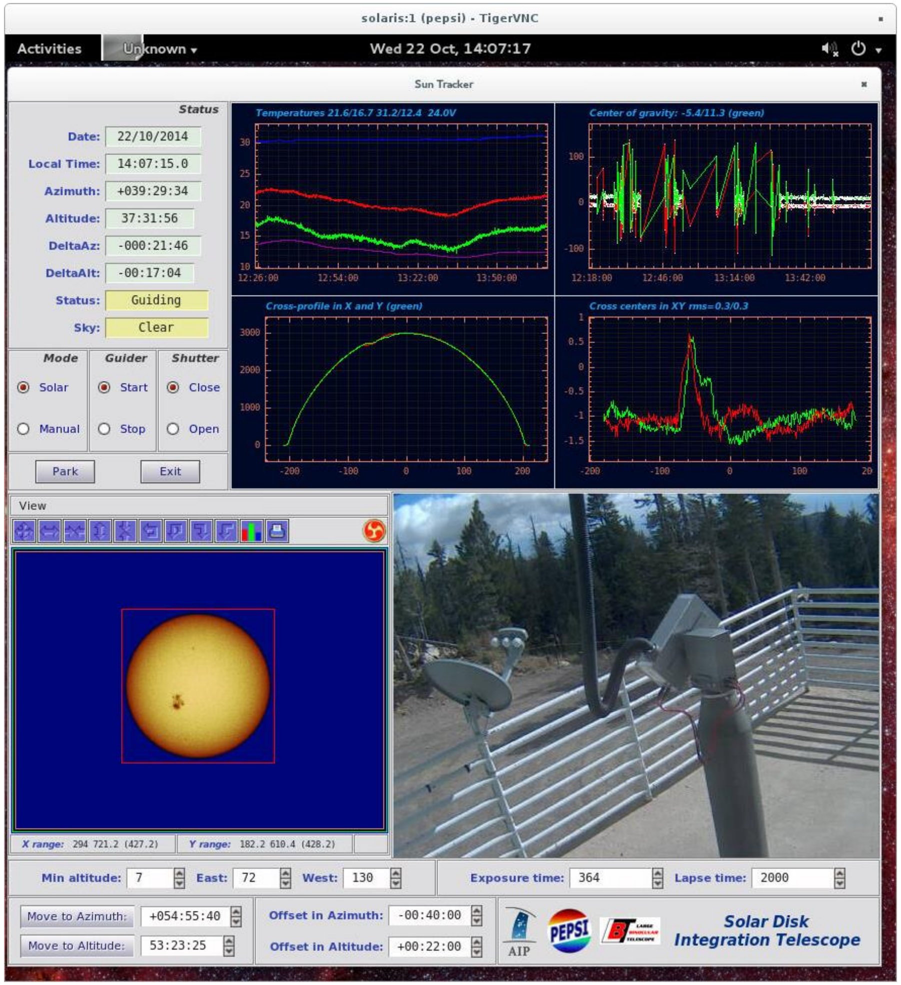
Spectrograph Design



- Asymmetric, white-pupil, two-arm (red and blue) spectrograph design with 200 mm beam diameter
- Largest available, monolithic echelle grating
- Two cameras, each equipped with single 10.3 k × 10.3 k CCD, record a total of 92 echelle orders
- Spectral resolution *R* depends on the choice of feeding fibers: *R* = 43000, 120000, and 270000
- Instrument is placed in a pressure- and temperature-stabilized chamber in the LBT basement .

Solar Disk-Integrated (SDI) Telescope

- 10-millimeter diameter, fully automated binocular telescope
- Feeds spectrograph with disk-unresolved sunlight via two 300 µm-core fibers
- Main goals:
  - Technical: provide external comparison source for the PSF
  - Scientific: long-term monitoring of the Sun (at least one solar activity cycle)
- Three consecutive exposures in the blue and red arm to cover the wavelength range (380–900 nm)
- On a good day, 300 exposures per day, approx. 600 images (approx. 134 GB per day)

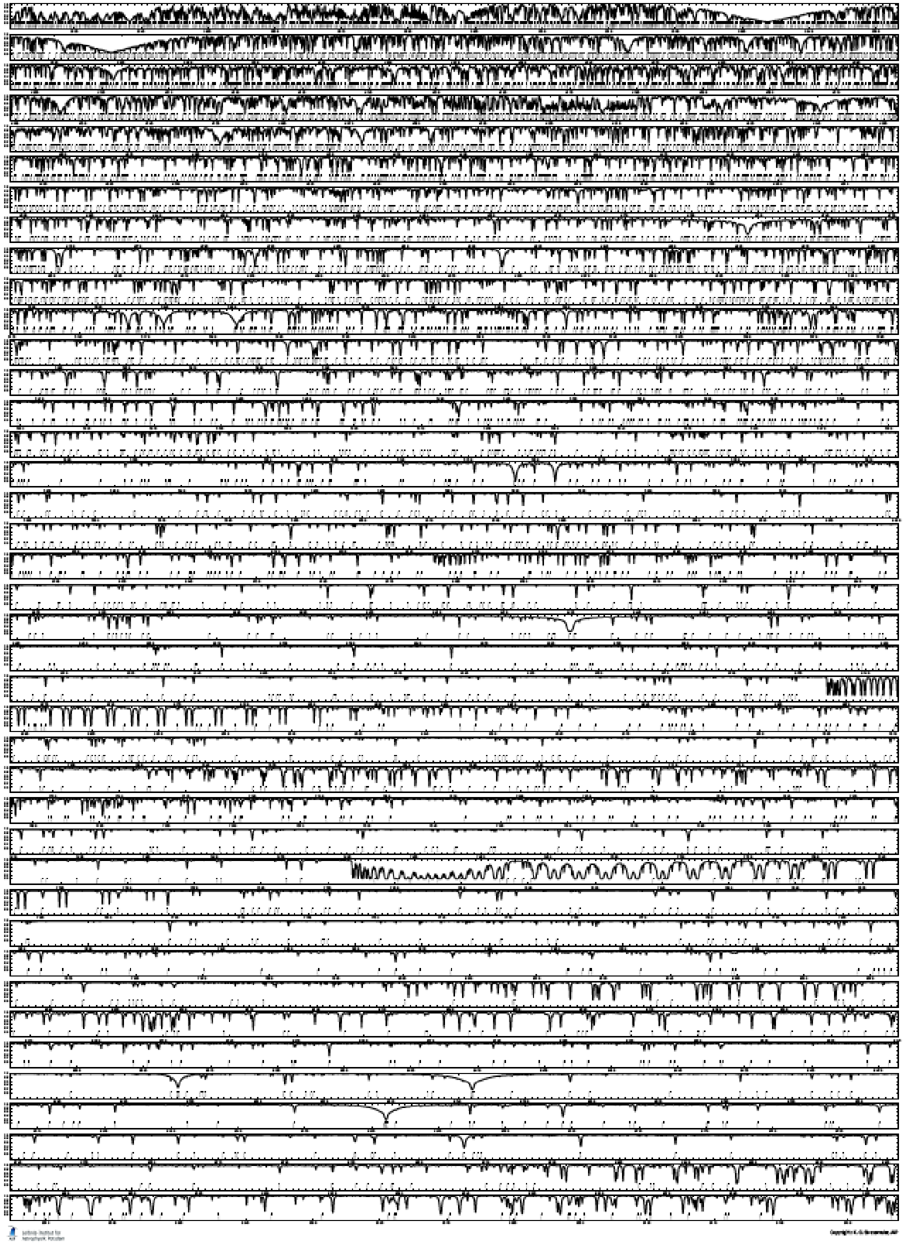


Science Objectives

- Sun-as-a-star – understanding our star and its effects on Earth and the near-Earth environment
- Long-term monitoring of the radiative output of the Sun-as-a-star in a broad wavelength range (380 – 910 nm)
- Solar activity – surface magnetic field variations – proxy → strong chromospheric absorption lines (e.g., Ca II K & H)
- Bisectors – asymmetry variations during the solar cycle due to varying surface magnetic fields, which affect photospheric convection
- Variations of the solar atmospheric as quantitative input for more accurate atmospheric models
- Investigating spectral signatures of solar flares and searching for a spectral response to white-light flares (maybe too ambitious for the declining phase of solar cycle No. 24)

Sun-as-a-Star Spectroscopy

- SDI uses the highest spectral resolution of up to R = 270000
- Signal-to-noise ratio for one spectrum (one exposure) is approx. 1000:1, which gives a S/N ratio of up to 5000:1 for co-added spectra
- Final data product: quasi-continuous, long-term, disk-integrated solar spectra with high spectral and temporal resolution
- Standard data reduction (S4S package) includes: dark and flat-field corrections, scattered light subtraction, wavelength and flux calibrations, etc.

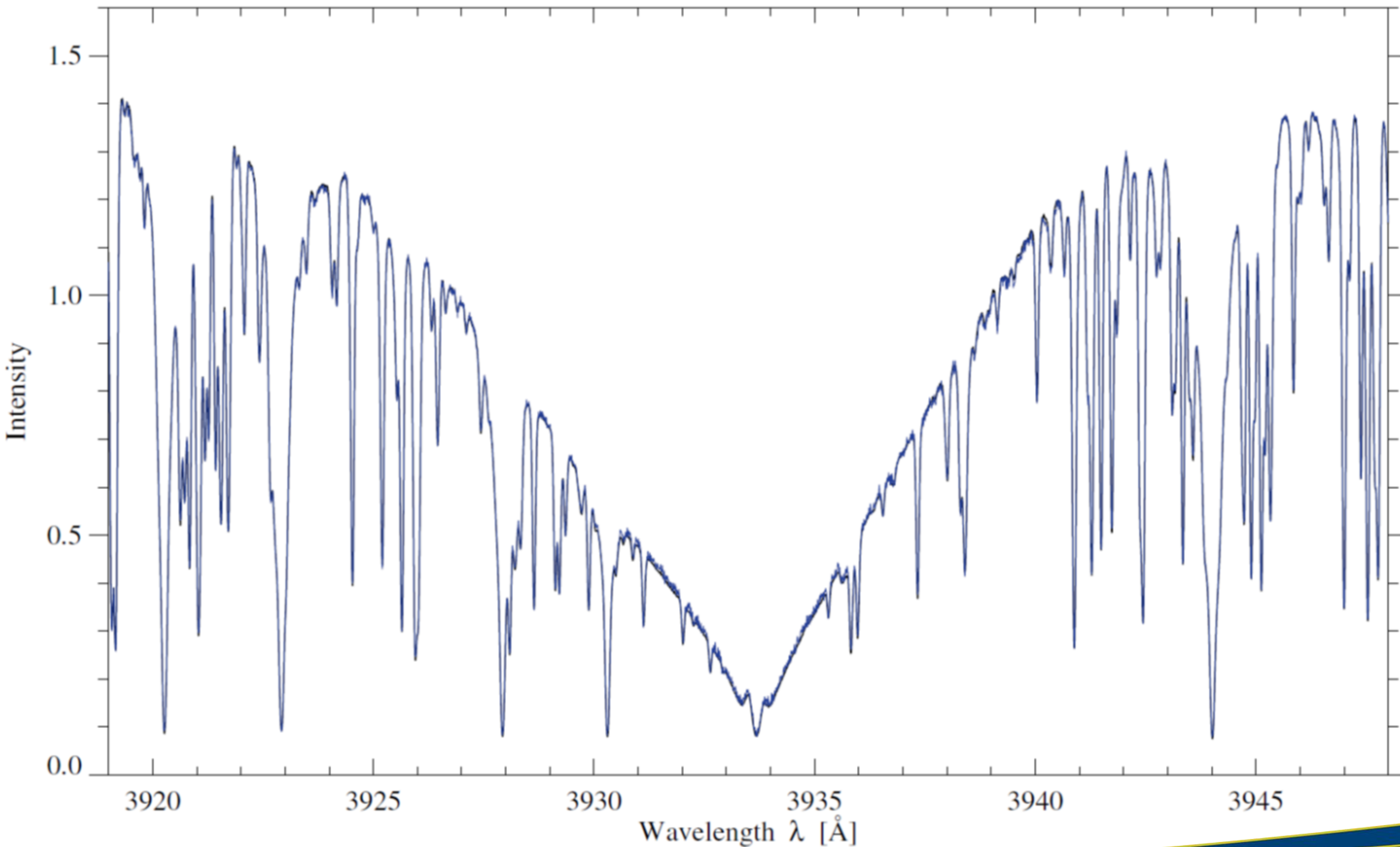


First Results

- **Tools**
  - Data pipeline for extraction, calibration, and analysis of PEPSI/SDI spectroscopic data based Interactive Data Language (IDL)
  - sTools – data reduction pipeline developed by the Optical Solar Physics Group at AIP for high-resolution solar observations taken with the GREGOR solar telescope (imaging and near-infrared spectroscopy, image restoration, spectral line fitting, etc.)

- **Techniques**
  - Continuum calibration:
  - Align all spectra taken over the course of a day
  - Compute the average spectrum for a day to reduce the noise
  - Determine the continuum level by comparison with the NSO FTS atlas
  - Assume the continuum correction contains only a low-frequency trend
    → approximate the ratio of average observed and atlas spectrum by a Fourier decomposition
  - Restore the trend from the Fourier components and correct the observed spectrum
  - This corrected daily spectrum serves as input for further analysis.

Single Exposure vs. 100 Co-Added Spectra



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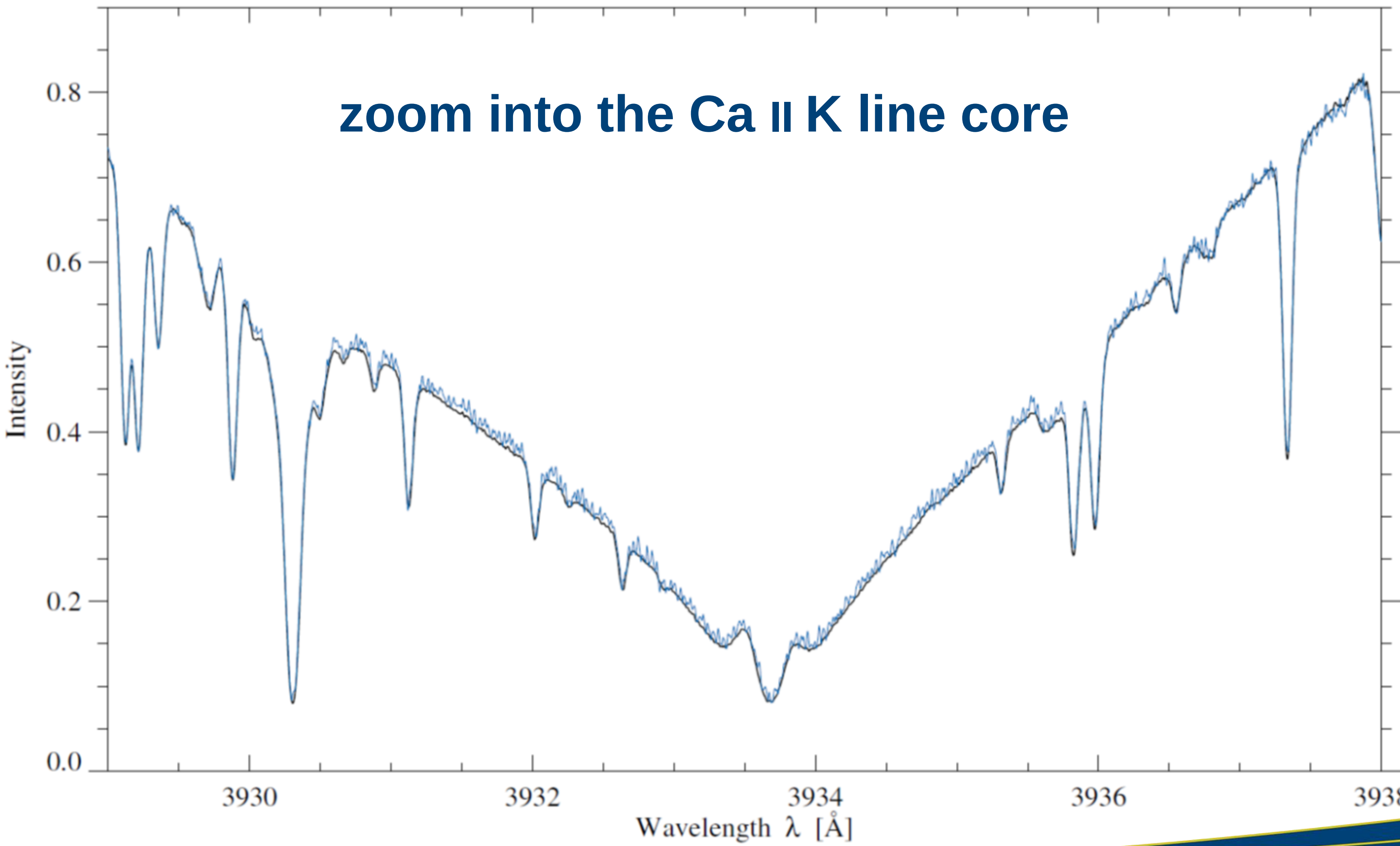
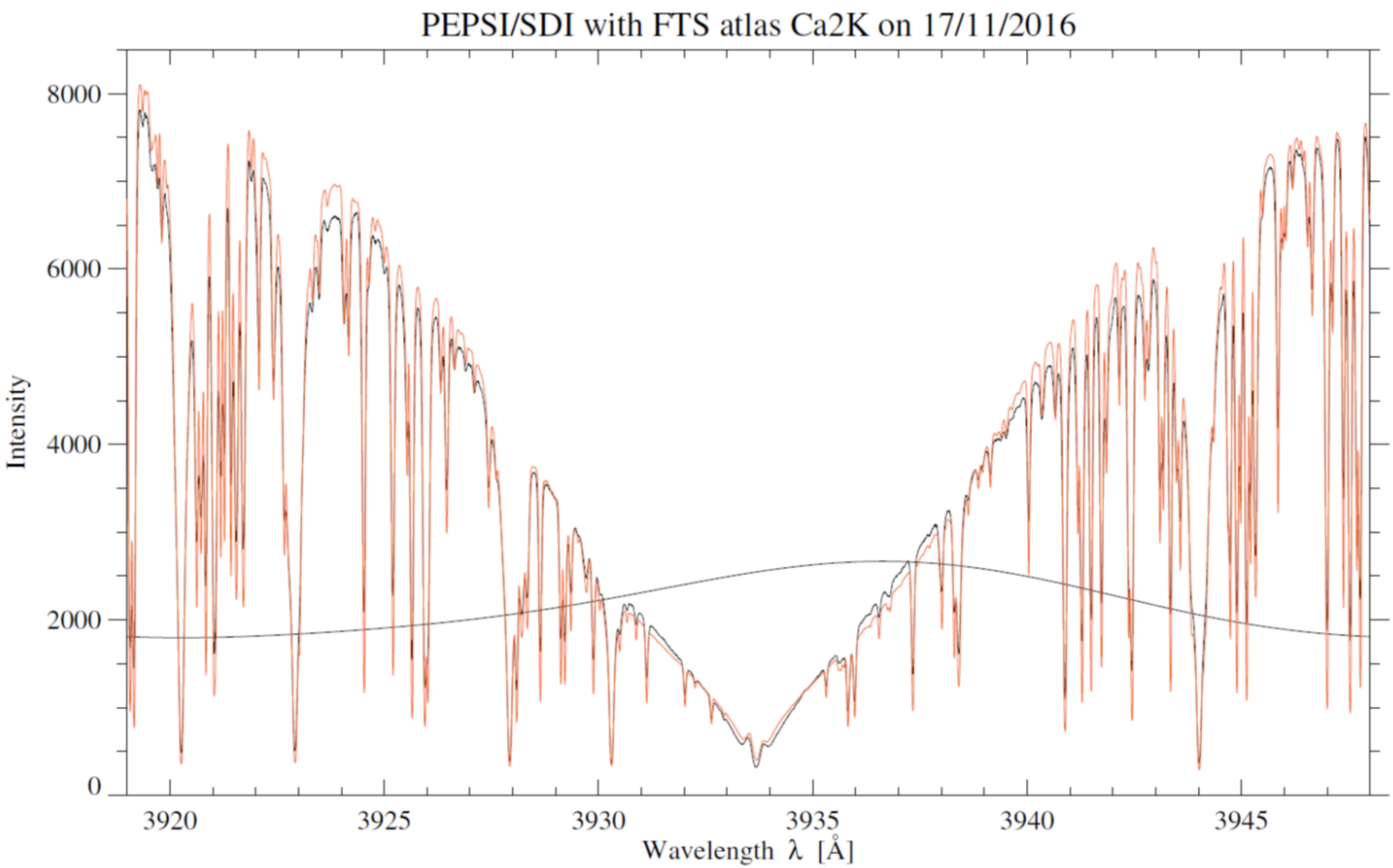
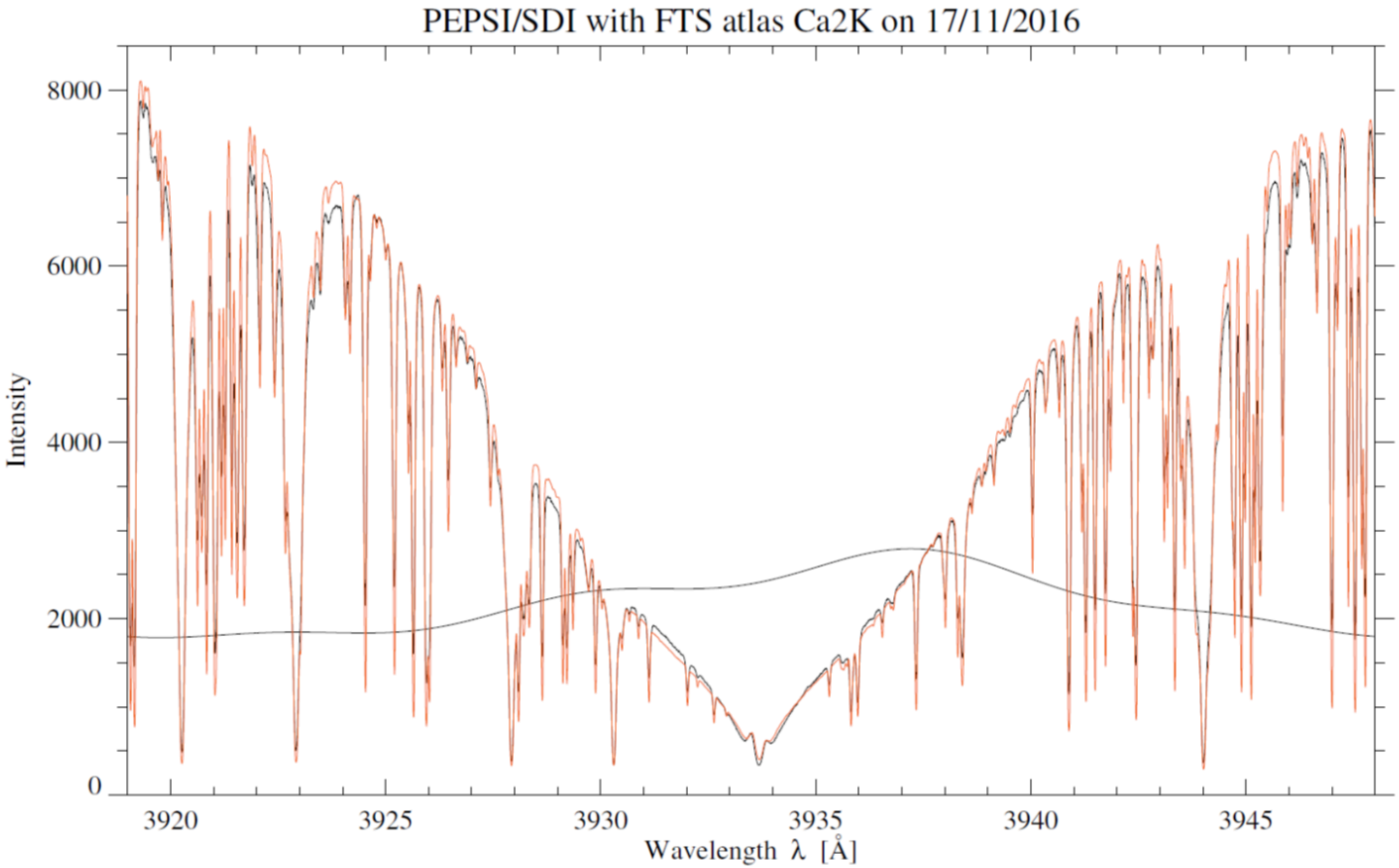


Continuum Fitting



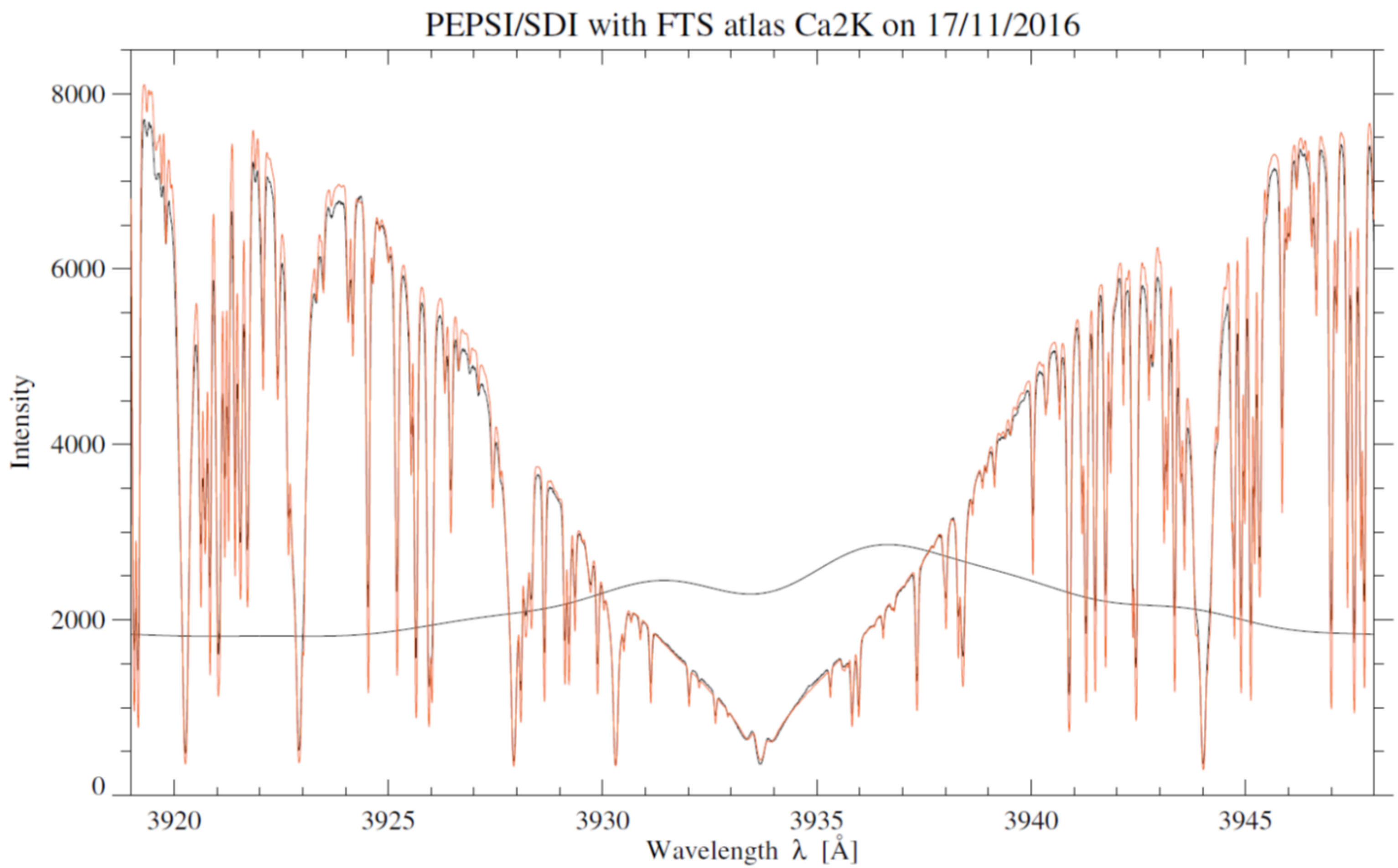
Continuum calibration curve reconstructed from two Fourier coefficients.

Continuum Fitting



Continuum calibration curve reconstructed from four Fourier coefficients. The inner line wings and the periphery is well fitted.

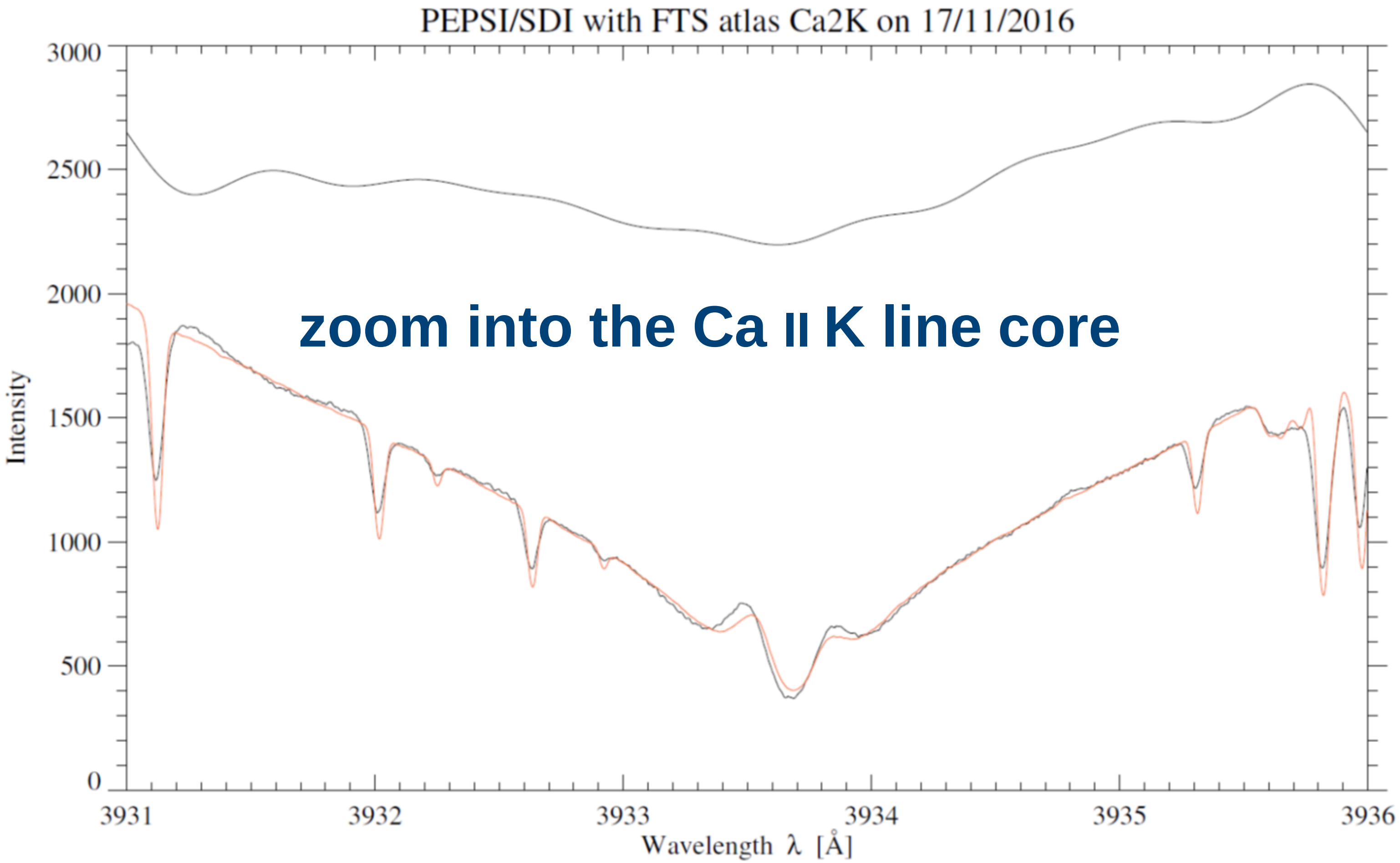
Continuum Fitting



Continuum calibration curve reconstructed from eight Fourier coefficients. The line core is well fitted, too. Is there an upper limit?

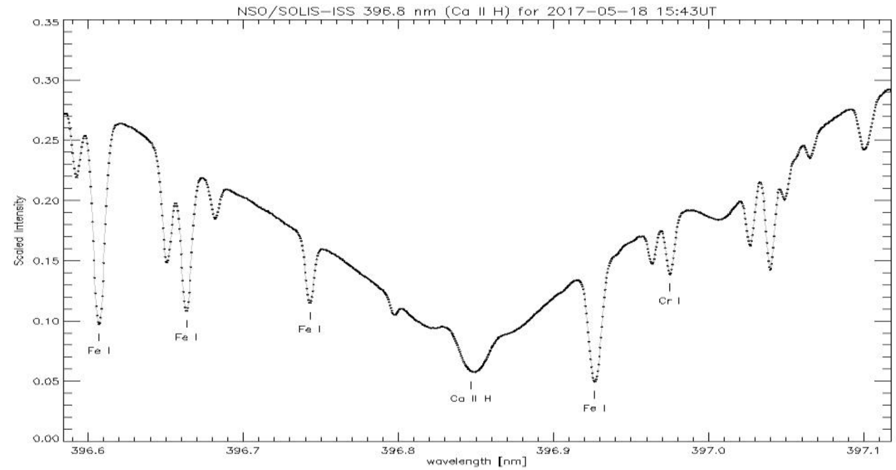
Continuum Fitting

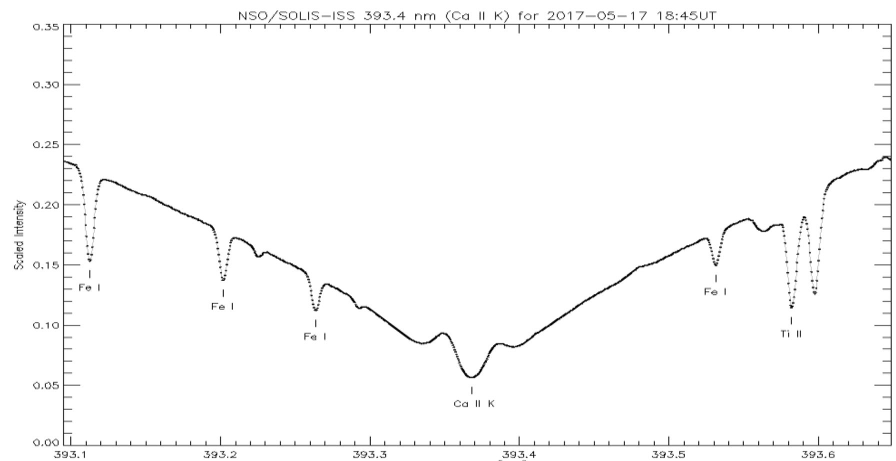
Comparison with FTS Atlas



Continuum calibration curve reconstructed from eight Fourier coefficients. The line core is well fitted, too. Is there an upper limit?

Synoptic Optical Long-term Investigations of the Sun (SOLIS)





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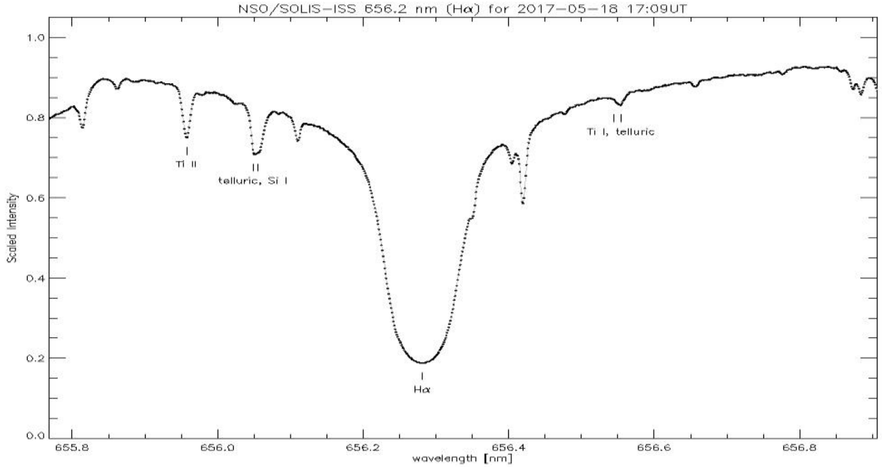
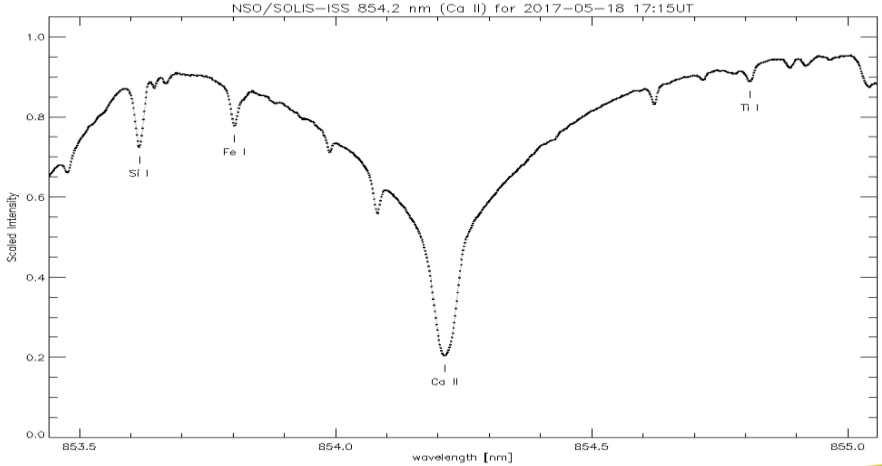
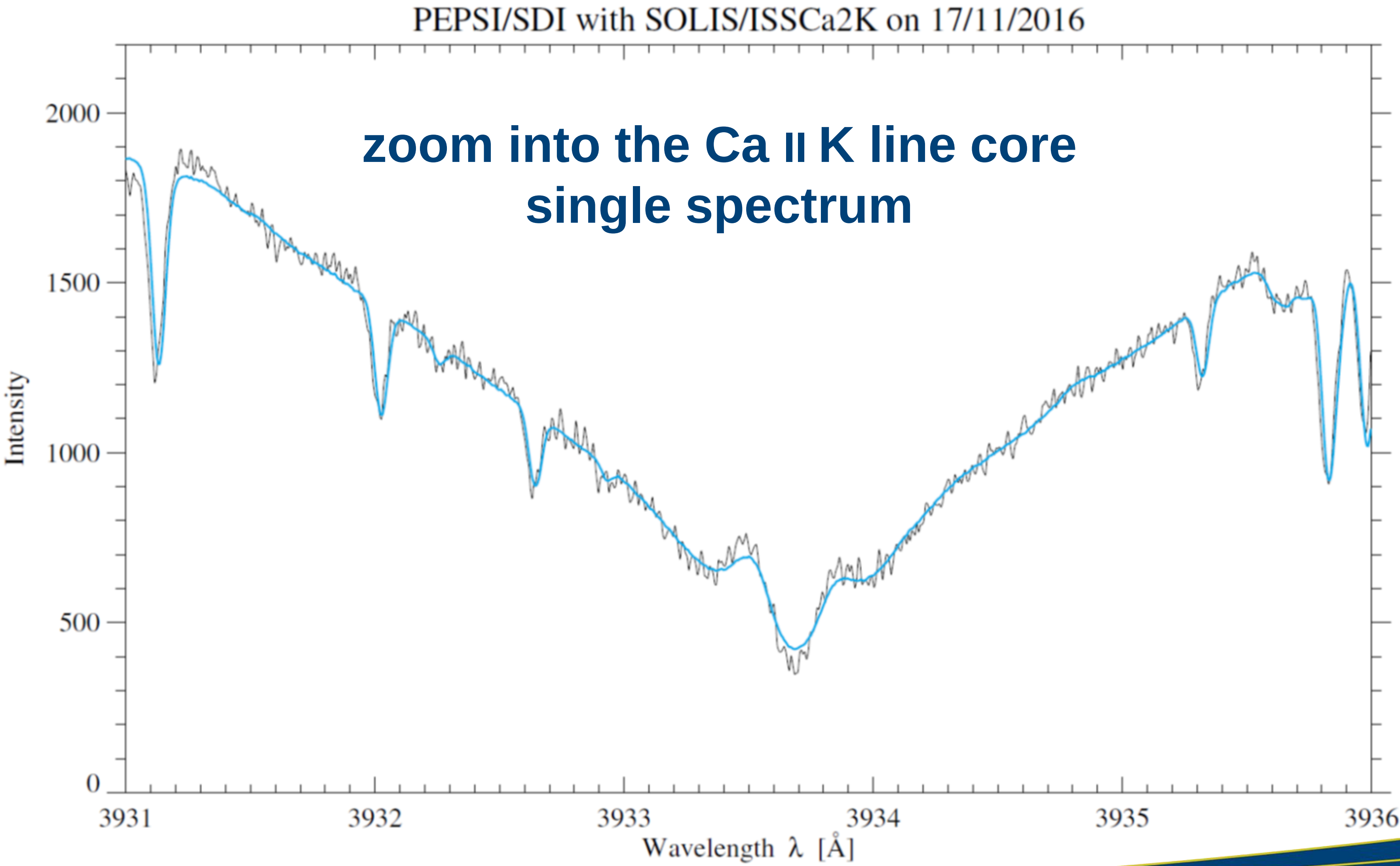
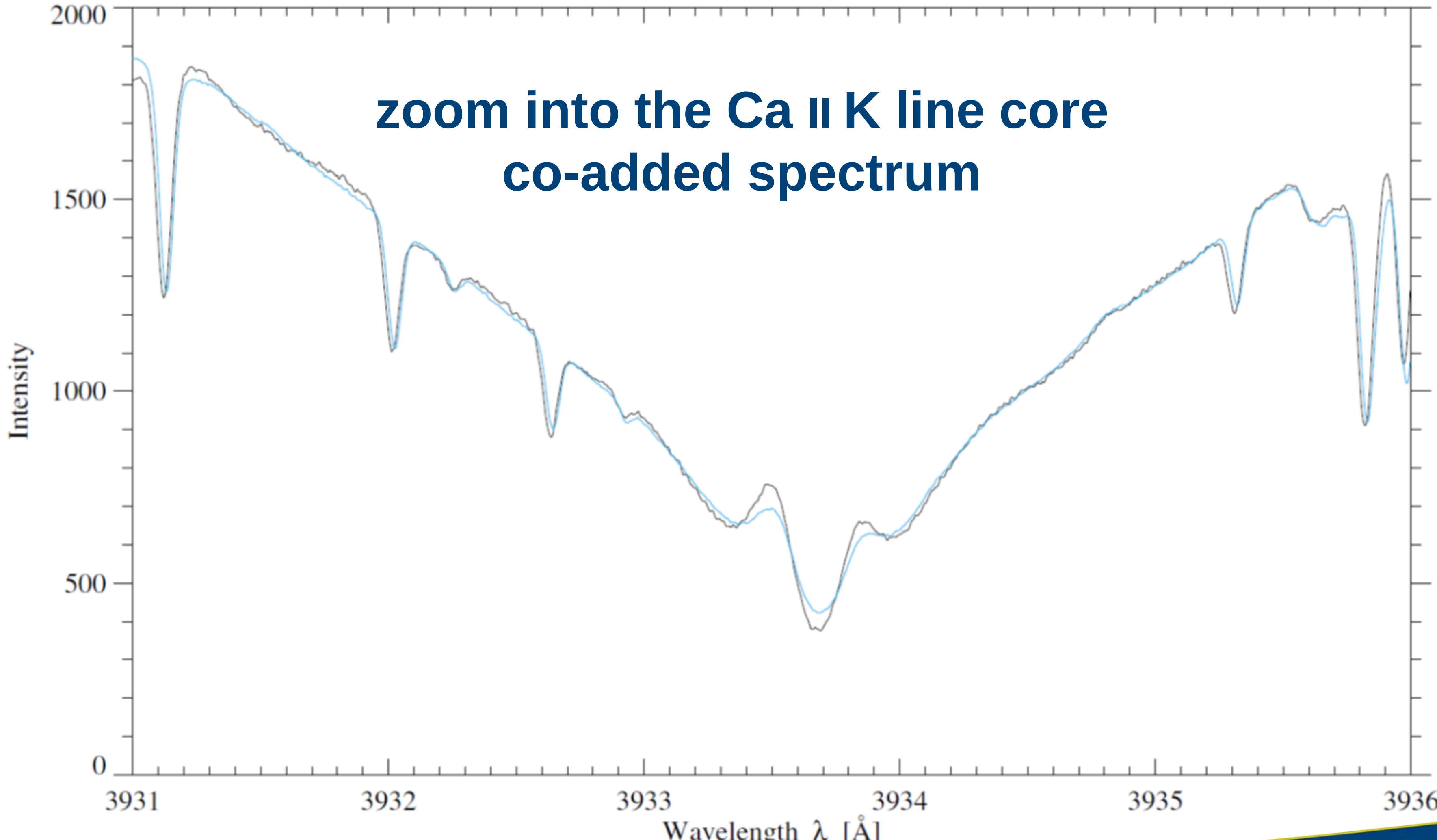




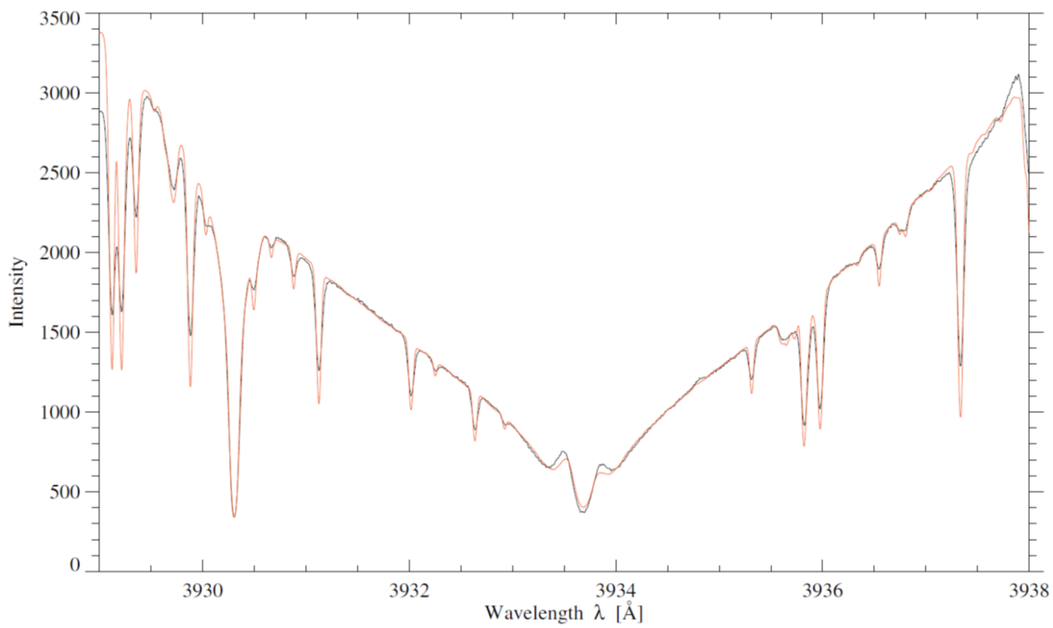
Comparison with SOLIS/ISS

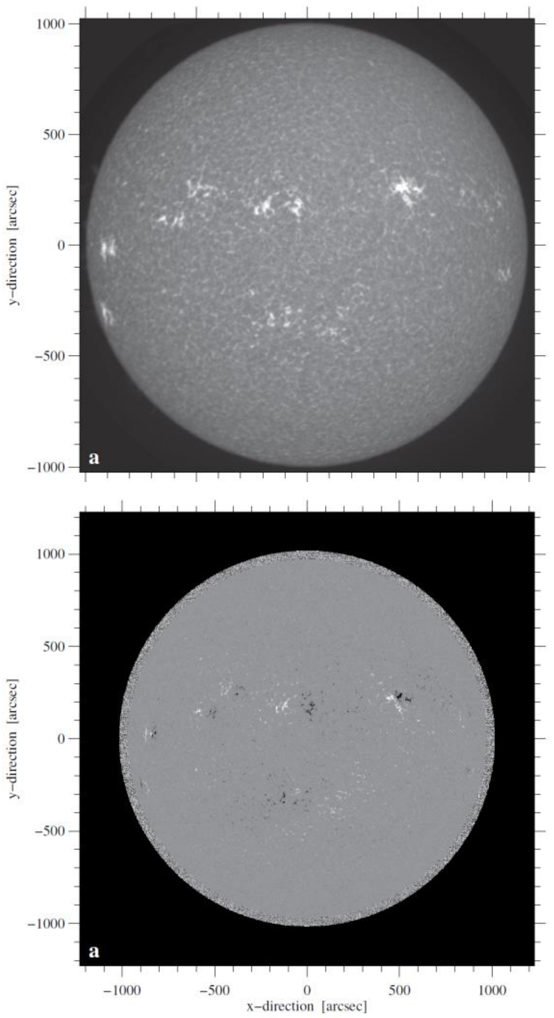


Comparison with SOLIS/ISS



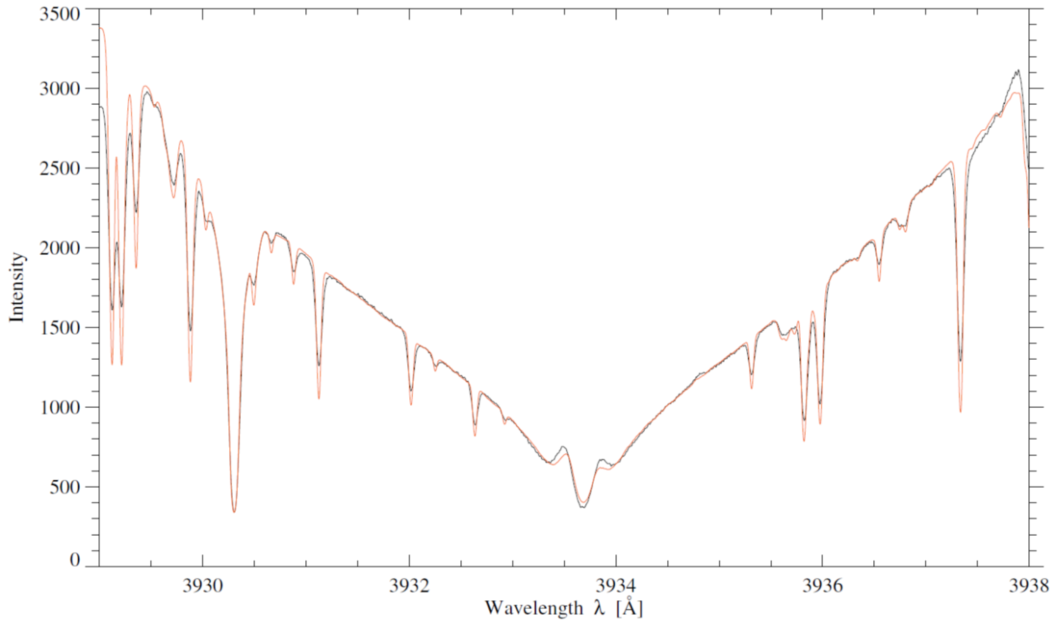
Comparison with ChroTel Images and HMI Magnetograms

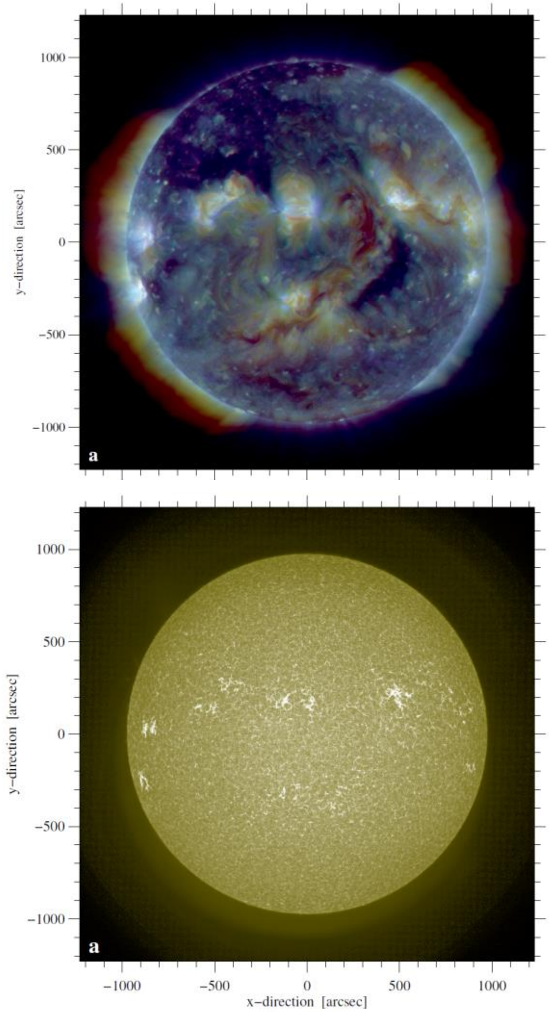




Comparing solar spectra with full-disk images and magnetograms allows us to determine the relation between phenomena of the active Sun and specific spectral features.

Comparison with AIA UV and EUV Full-Disk Images





Comparing solar spectra with full-disk images and magnetograms allows us to determine the relation between phenomena of the active Sun and specific spectral features.

Future Work

- Further development of the PEPSI/SDI data pipeline.
- Derive meaningful solar activity indices and trace solar activity variation on different time-scales.
- Investigate the variation of solar atmospheric properties on time-scales ranging from daily changes to annual and decadal trends.
- Investigate the center-to-limb variation of the solar spectrum during the 2017 solar eclipse.
- Compare Sun-as-a-star with spatially resolved spectra.
- There is a small chance to catch energetic or even white-light flares. Do they leave signatures in the total and/or spectral irradiance?

References

- **Strassmeier, K., Ilyin I., Järvinen, A., et al. 2015:** PEPSI: *The High-Resolution Échelle Spectrograph and Polarimeter for the Large Binocular Telescope.* Astron. Nachr. **336**, 324
- **Keller, C., Harvey, J., Giampapa, M. 2003:** *SOLIS: An Innovative Suite of Synoptic Solar Instruments.* in: Innovative Telescopes and Instrumentation for Solar Astrophysics, S.L. Keil, S.V. Avakyan (eds.), Proc. SPIE **4853**, 194
- **Kurucz, R., Furenlid, I., Brault, J., Testerman, L. 1984:** *Solar Flux Atlas from 296 to 1300 nm.* National Solar Observatory, Sunspot, New Mexico
- **Kuckein, C., Denker, C., Verma, M., et al. 2017:** *sTools – A Data Reduction Pipeline for the GREGOR Fabry-Pérot Interferometer and the High-Resolution Fast Imager at the GREGOR Solar Telescope.* in: Fine Structure and Dynamics of the Solar Atmosphere, S. Vargas Domínguez, A.G. Kosovichev, L. Harra, P. Antolin (eds.), IAU Symp. **327**, in press

Thank you for your attention!