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PEPSI/SDI Sun-as-a-star Observations of the 2017 August 21 Solar Eclipse

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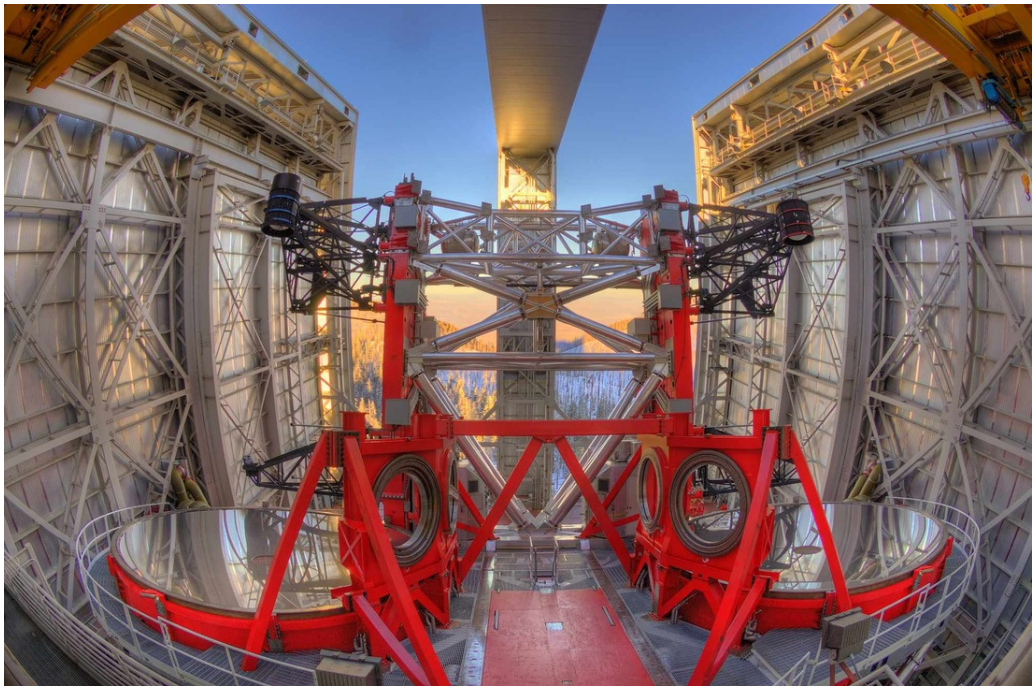
Outline

- Motivation
- Potsdam Echelle Polarimetric and Spectroscopic Instrument (PEPSI)
- Solar Disk-Integrated Telescope (SDI)
- 2017 August 21 Solar Eclipse
- Observations
- Eclipse model and simulated Na D$_1$ & D$_2$ profiles
  - Full-disk with limb-darkening, no rotation
  - Full-disk with rotation → Doppler broadening of the simulated profiles
- Discussion and future development

Motivation

- Eclipse spectrum with the most powerful spectrograph
- Analysis of the temporal evolution of solar Na D_1 & D_2 chromospheric lines
- Develop a simplified model of the solar chromosphere from synthetic Sodium spectra:
  - limb-darkening
  - differential rotation (with respect of latitude)
  - eclipse scenario
- Compare observational results with synthetic line profiles

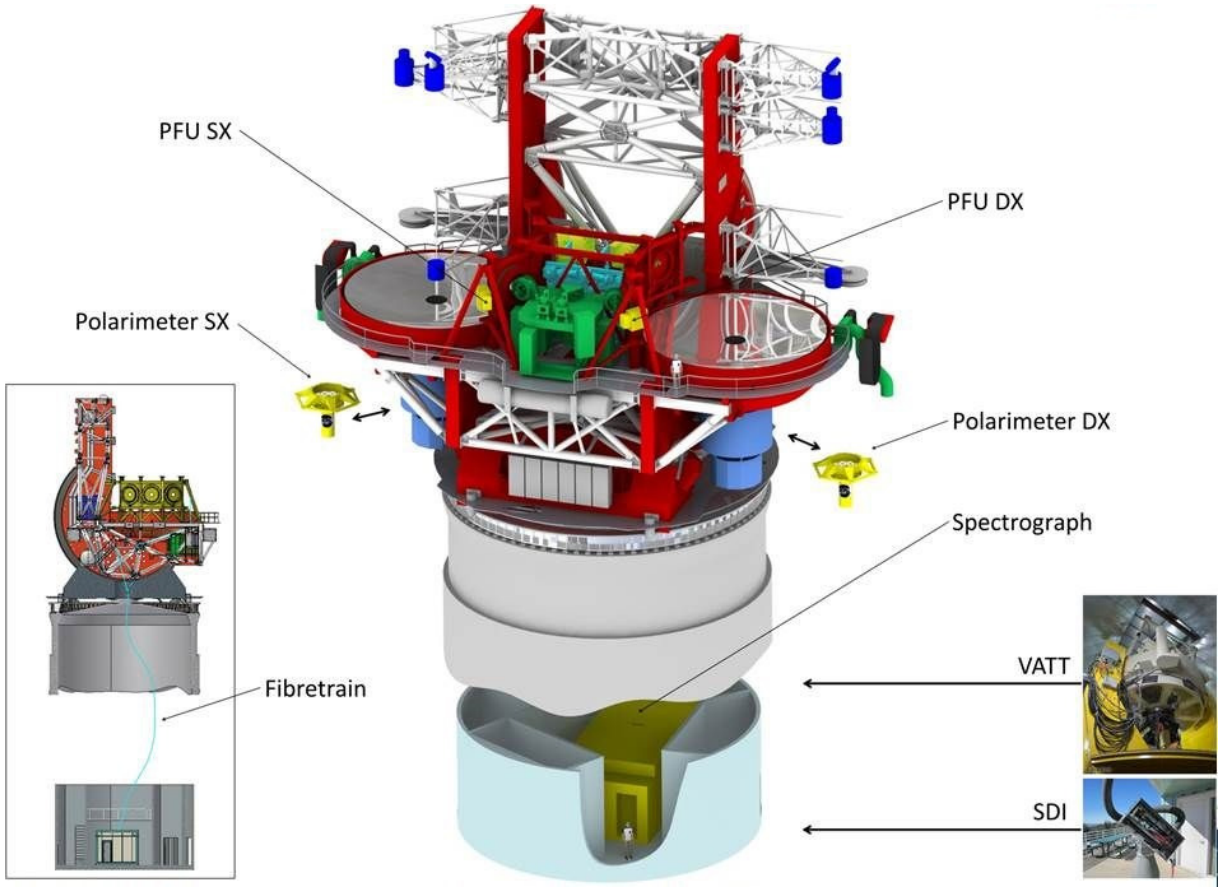
Large Binocular Telescope at Mt. Graham International Observatory



- Location: Mount Graham, Arizona, US
- Altitude: 3,221 m
- Class: optical telescope
- Diameter: 8.4 m
- Spatial resolution of a 22.7m telescope

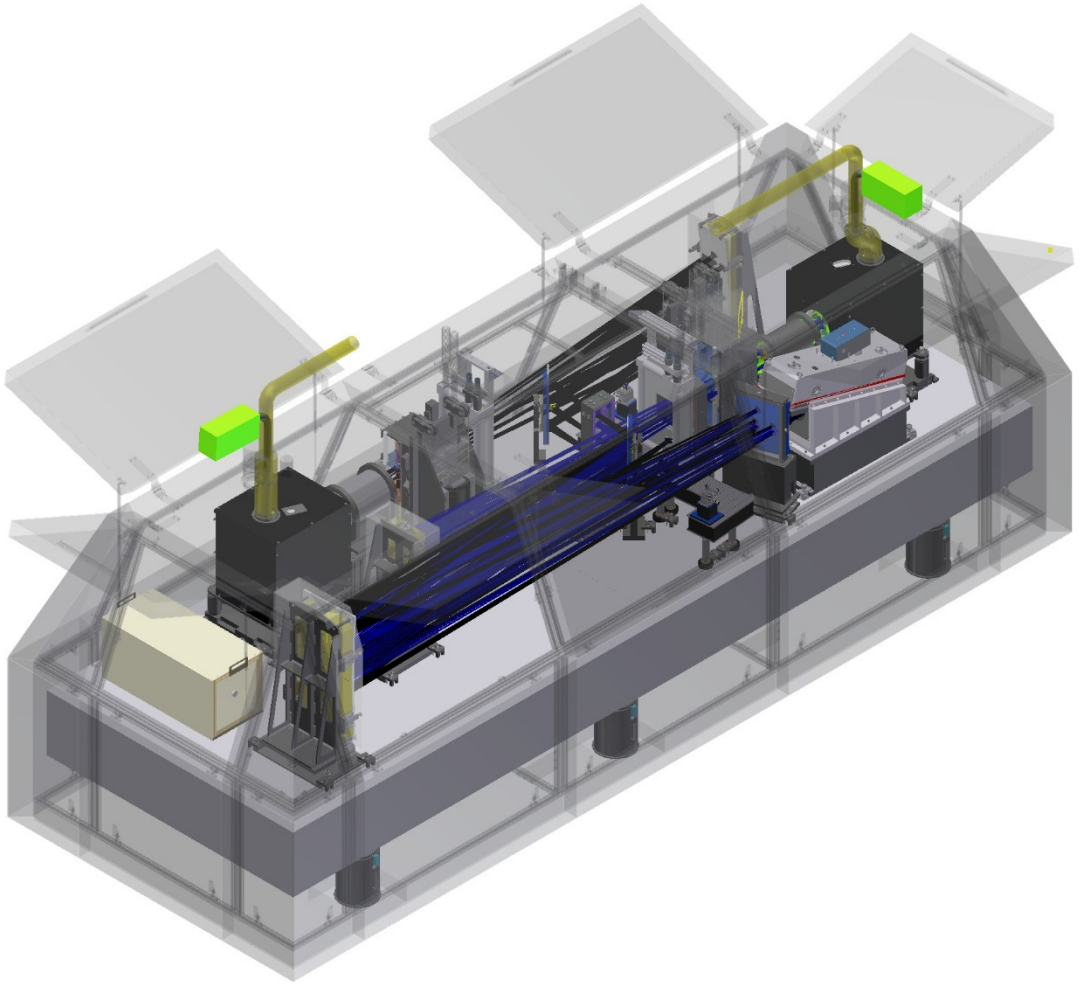
“Aspiring to be the first of the ELTs and one of the leading 8-m class telescopes, LBTO must offer, state-of-the art instruments that efficiently and reliably deliver high-quality data to the users of the observatory, thus enabling excellent science at the forefront of astronomy”

Potsdam Echelle Polarimetric Spectroscopic Instrument



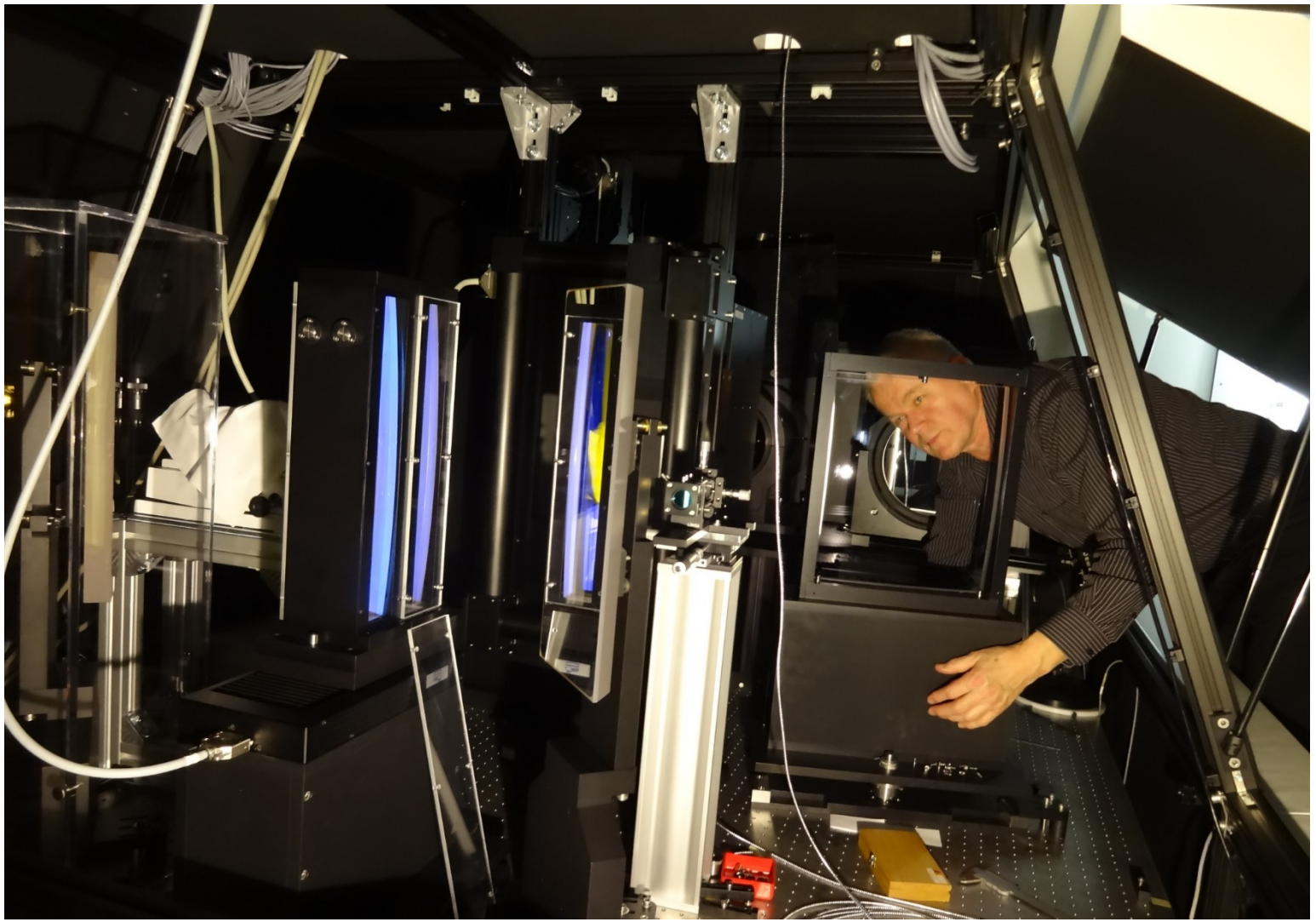
- State-of-the art, thermally stabilized, fiber-fed, high-resolution spectrograph
- Spectropolarimeter for the Large Binocular Telescope in Arizona, USA
- PEPSI receives light from three separate telescopes (LBT, SDI, and VATT)

Mechanical Design of the Spectrograph



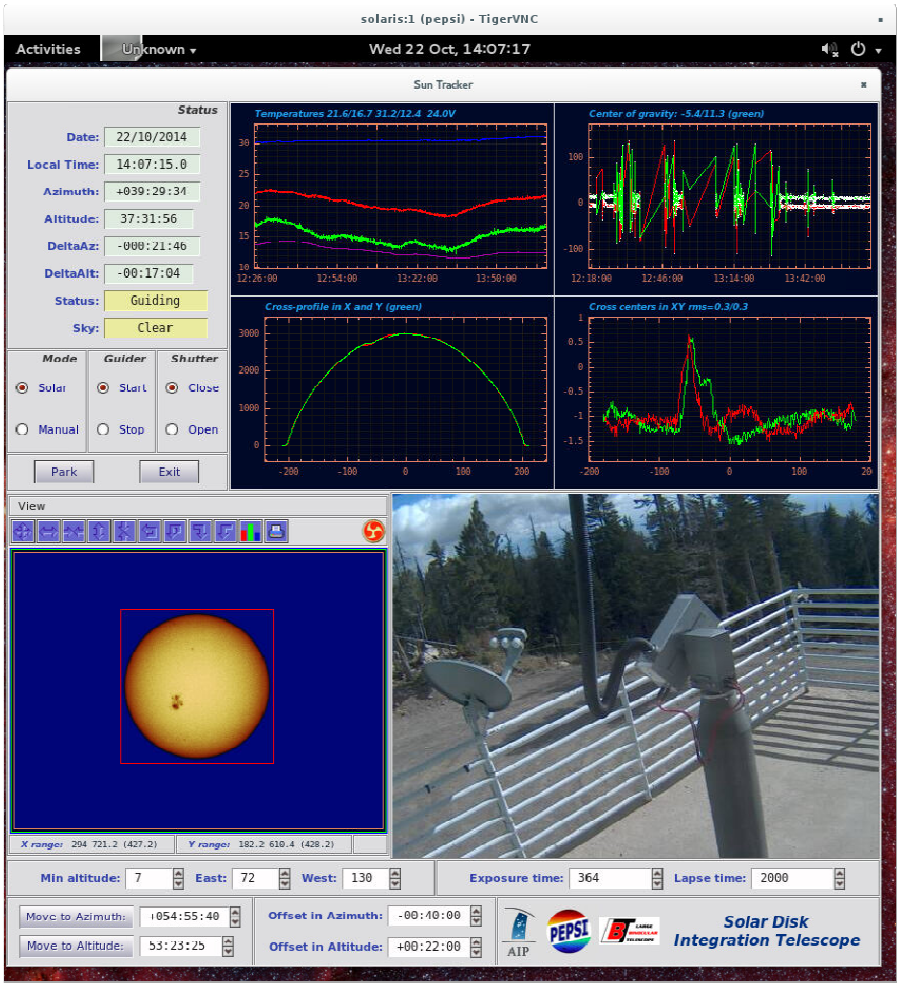
- Asymmetric, white-pupil, two-arm (red and blue) spectrograph design with 200 mm beam diameter
- Largest available, monolithic echelle grating
- Two cameras, each equipped with single 10.3 k × 10.3 k CCD, record a total of 92 echelle orders
- Spectral resolution *R* depends on the choice of feeding fibers: *R* = 43000, 120000, and 250000
- Instrument is placed in a pressure- and temperature-stabilized chamber in the LBT basement .

Inside look of PEPSI

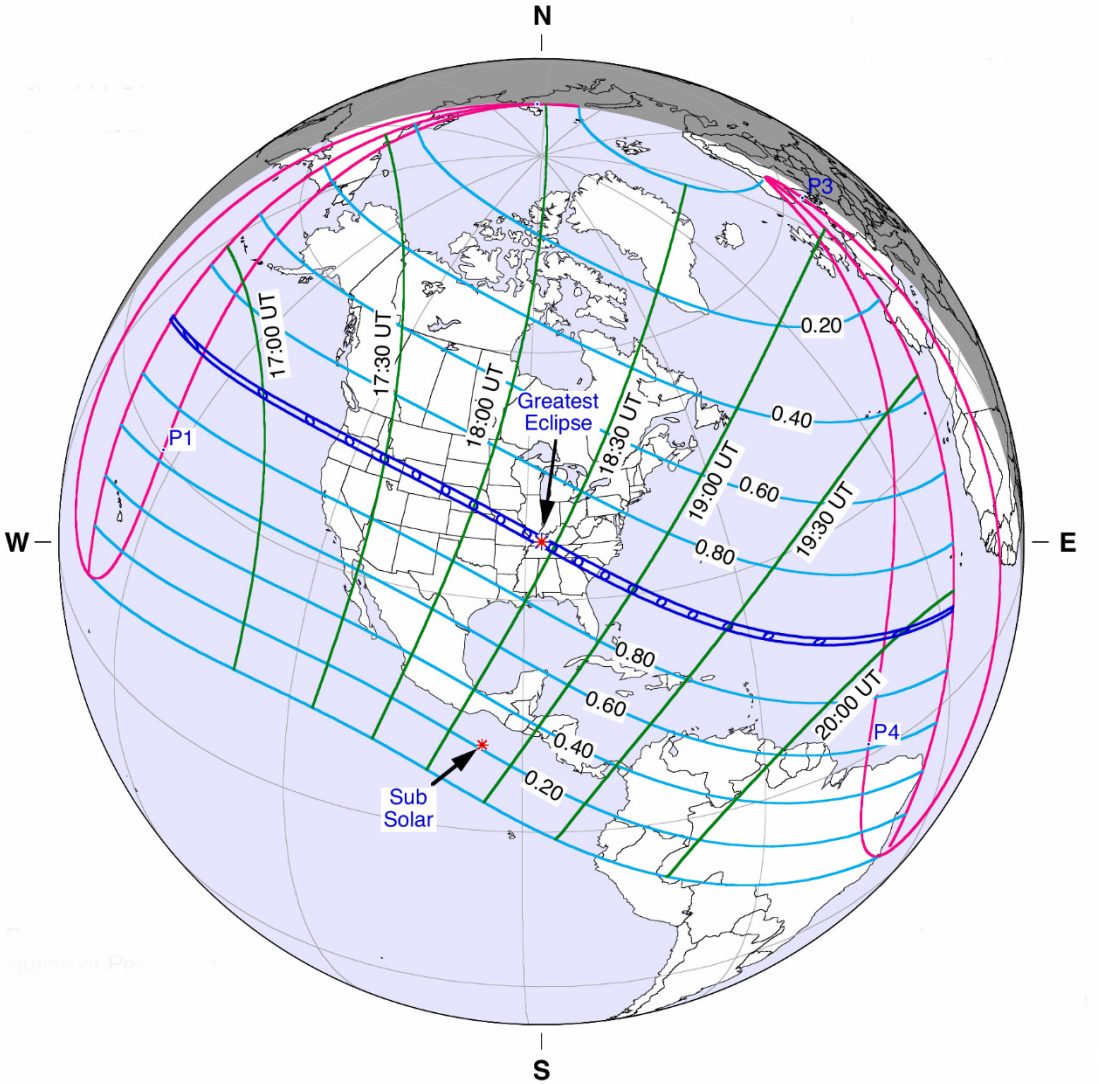


Solar Disk-Integrated Telescope (SDI)

- 10-millimeter diameter, fully automated binocular telescope
- Feeds spectrograph with disk-unresolved sunlight via two 300 μm-core fibers
- 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)



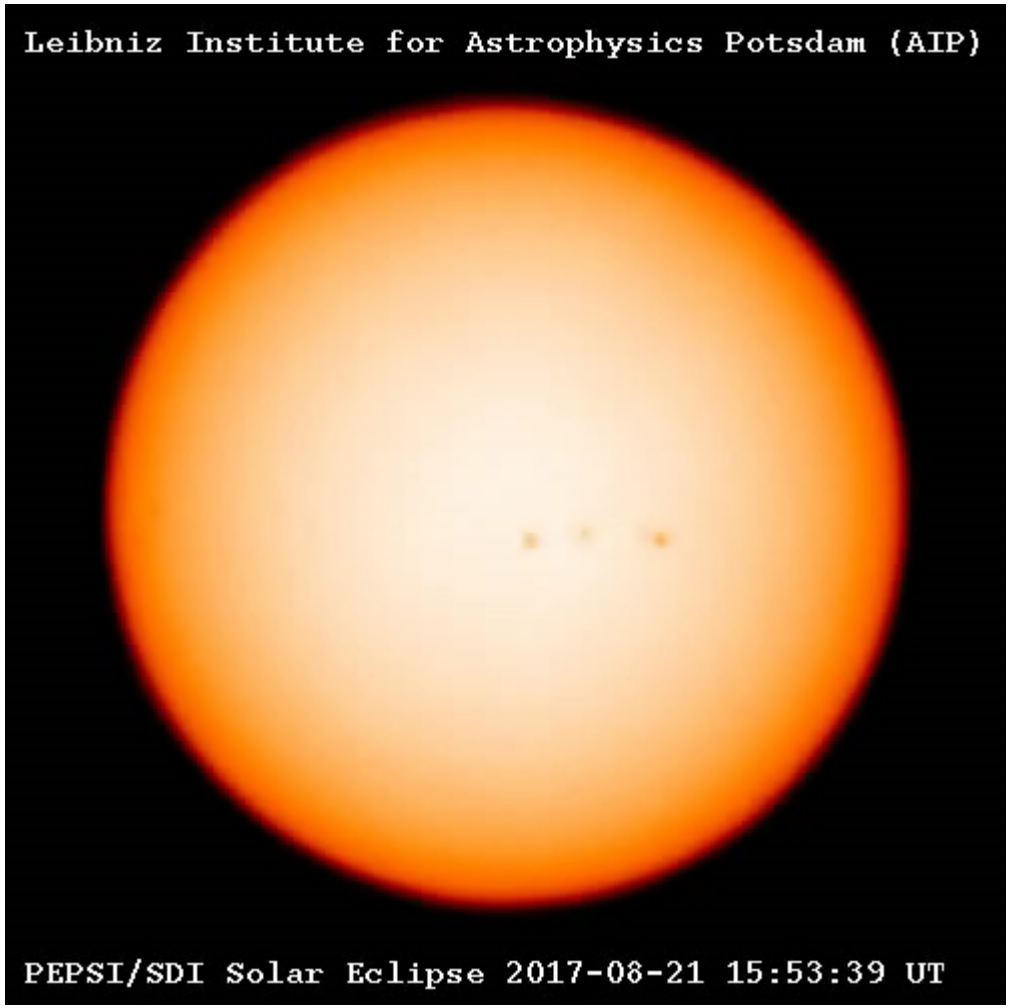
Total Solar Eclipse 2017 August 21



- First total eclipse for the mainland United States since 1979
- Path of totality crossed 14 states
- Maximum total eclipse duration: 2m 40s
- Magnitude: 1.03
- Highest degree of media representation in the human history
- Social science projects
- Impact on solar power generation

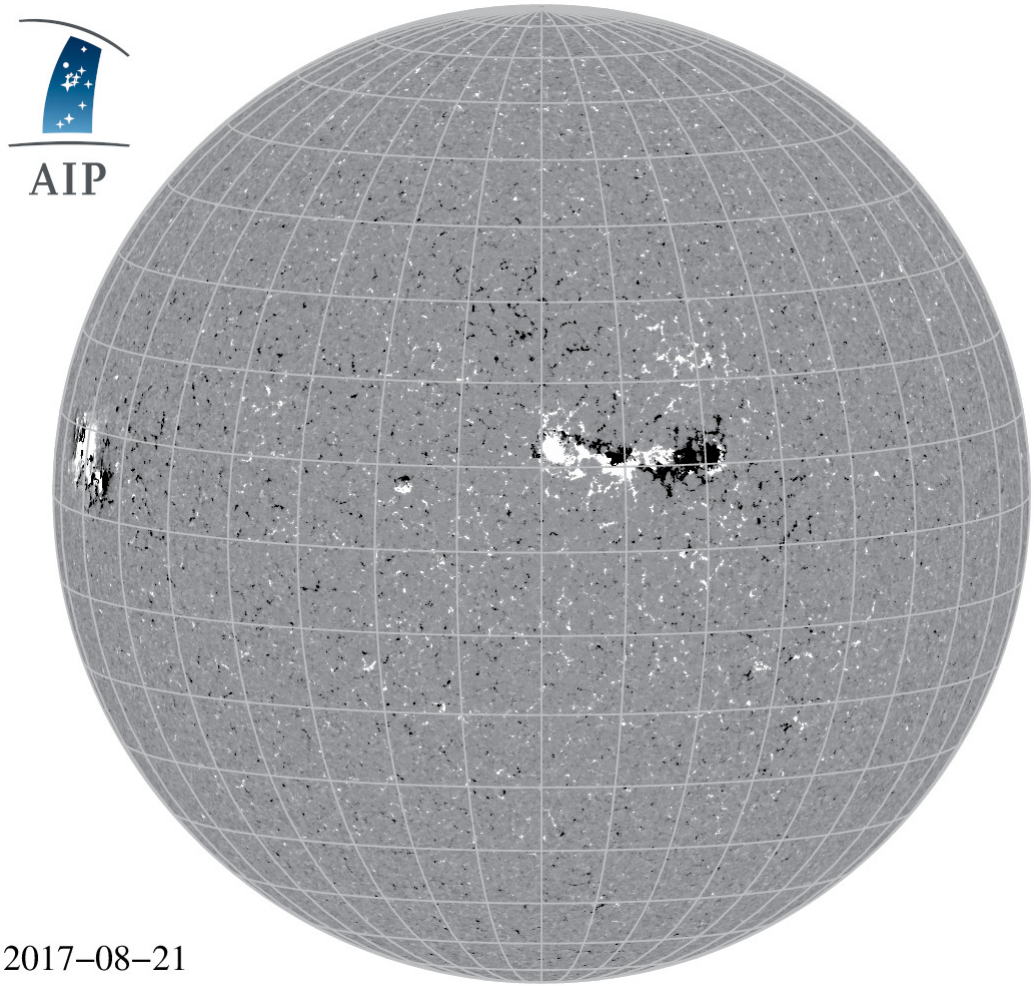
More info and images at: EclipseWise website

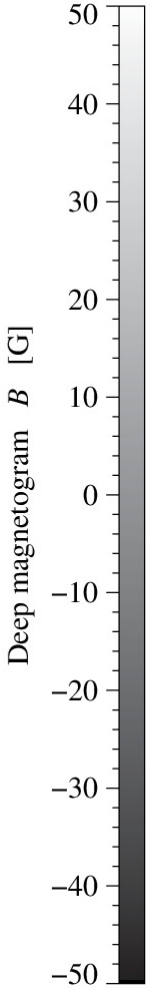
Observing the Solar Eclipse



- Number of Frames: 907
- Observing conditions: clear sky with exception of few clouds
- Duration: 16:15 – 19:00 UTC
- Total obscuration: 61.6%
- Total Number of spectra recorded in the range between 4200Å – 4800Å and 5300Å – 6300Å was 100
- Exposure time: 0.3□s
- Interval between consecutive scans: ≈70□s

Full-Disk SDO/HMI Magnetogram



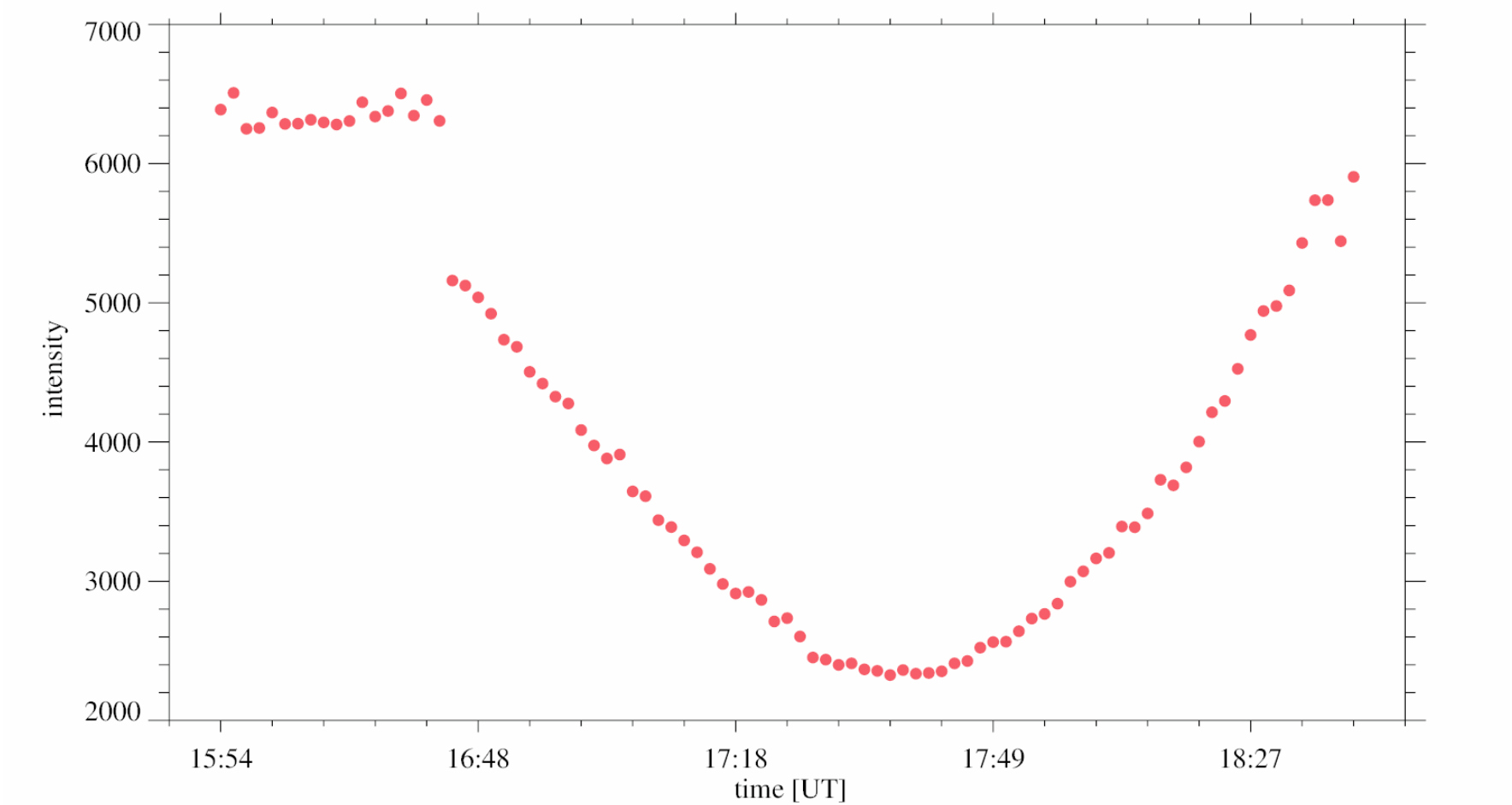


Two bipolar active regions are visible on the solar surface with the following properties:

- location: close to the solar equator
- number of sunspots:
  - NOAA12672 - 4
  - NOAA 12671 - 20
- flares: 3-4 C-class flares

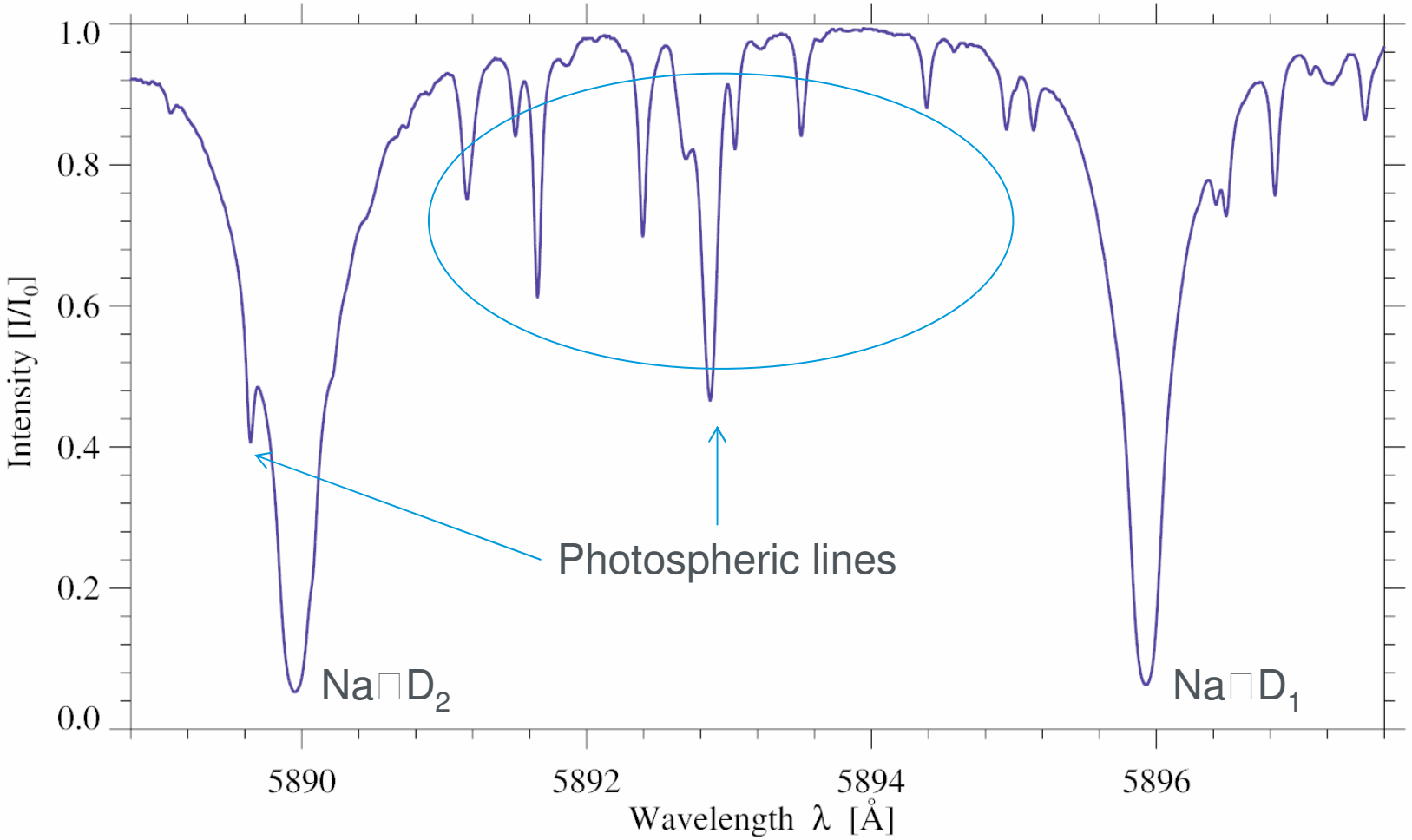
Amongst other effects active region spectral signatures can influence the disk-integrated spectral line profiles due to the different local velocities.

Light-Curve Derived from Spectra



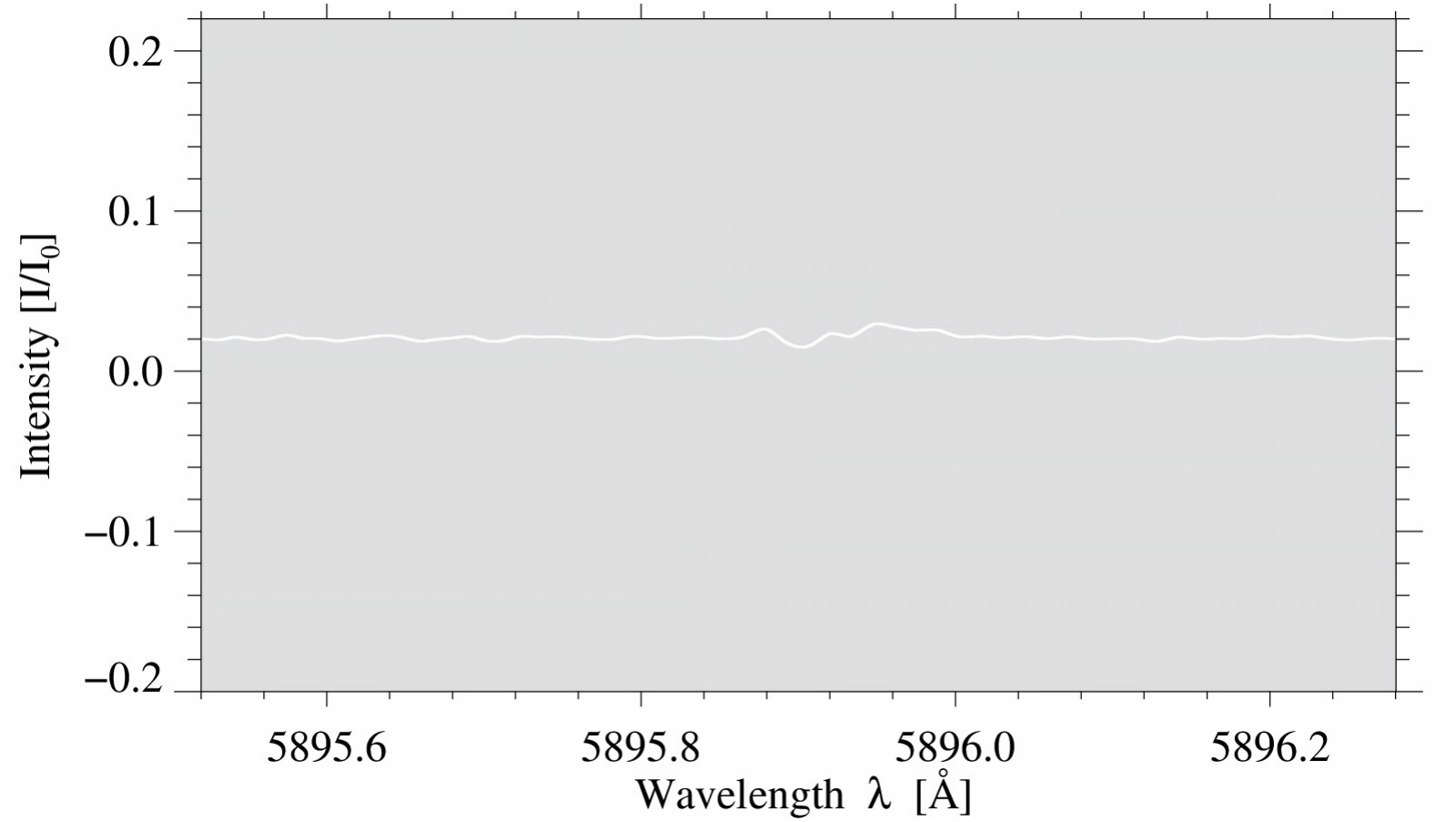
Variation of the flux intensity in the wave-range between 5300Å – 6300Å (PEPSI red).

Sodium doublet in the solar chromosphere



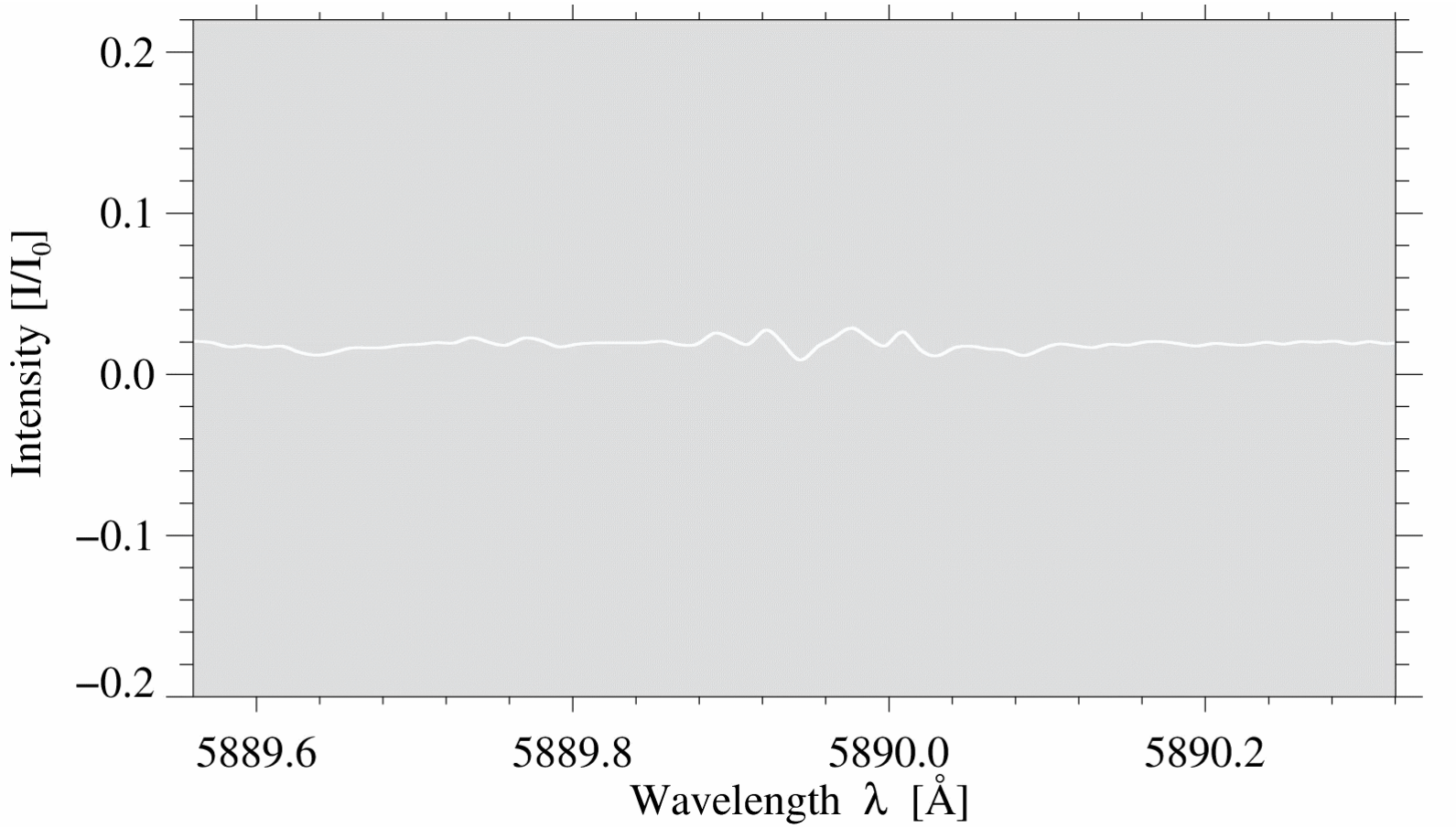
Standard data reduction (SDS4PEPSI) includes: dark and flat-field corrections, scattered light subtraction, wavelength and flux calibrations, etc.

Contrast Profiles Na D$_1$



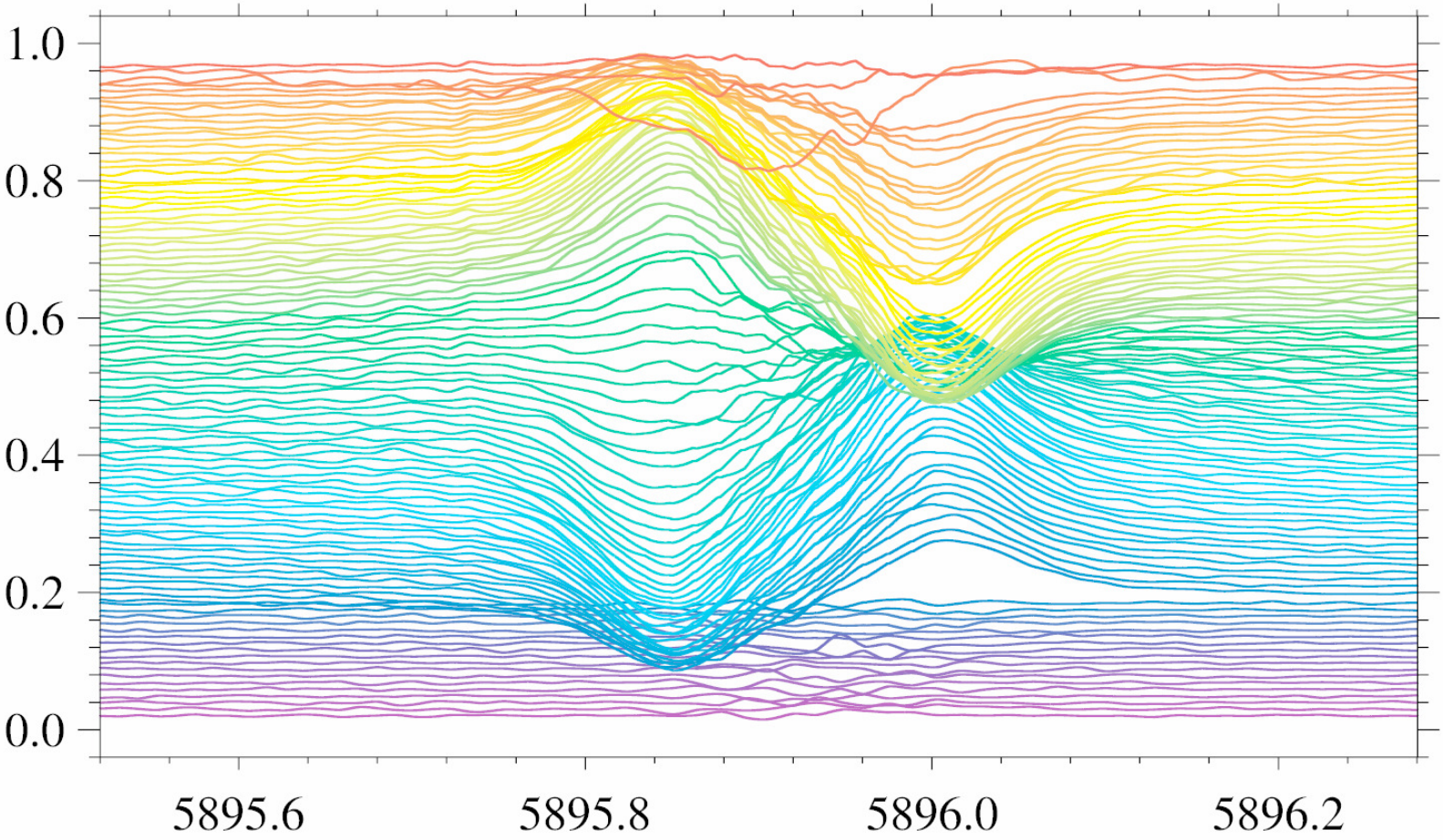
Comparison between 100 Na D$_1$ disk-integrated absorption line profiles recorded during the eclipse and one average (quasi-)quiet sun profile.

Contrast Profiles Na D_2



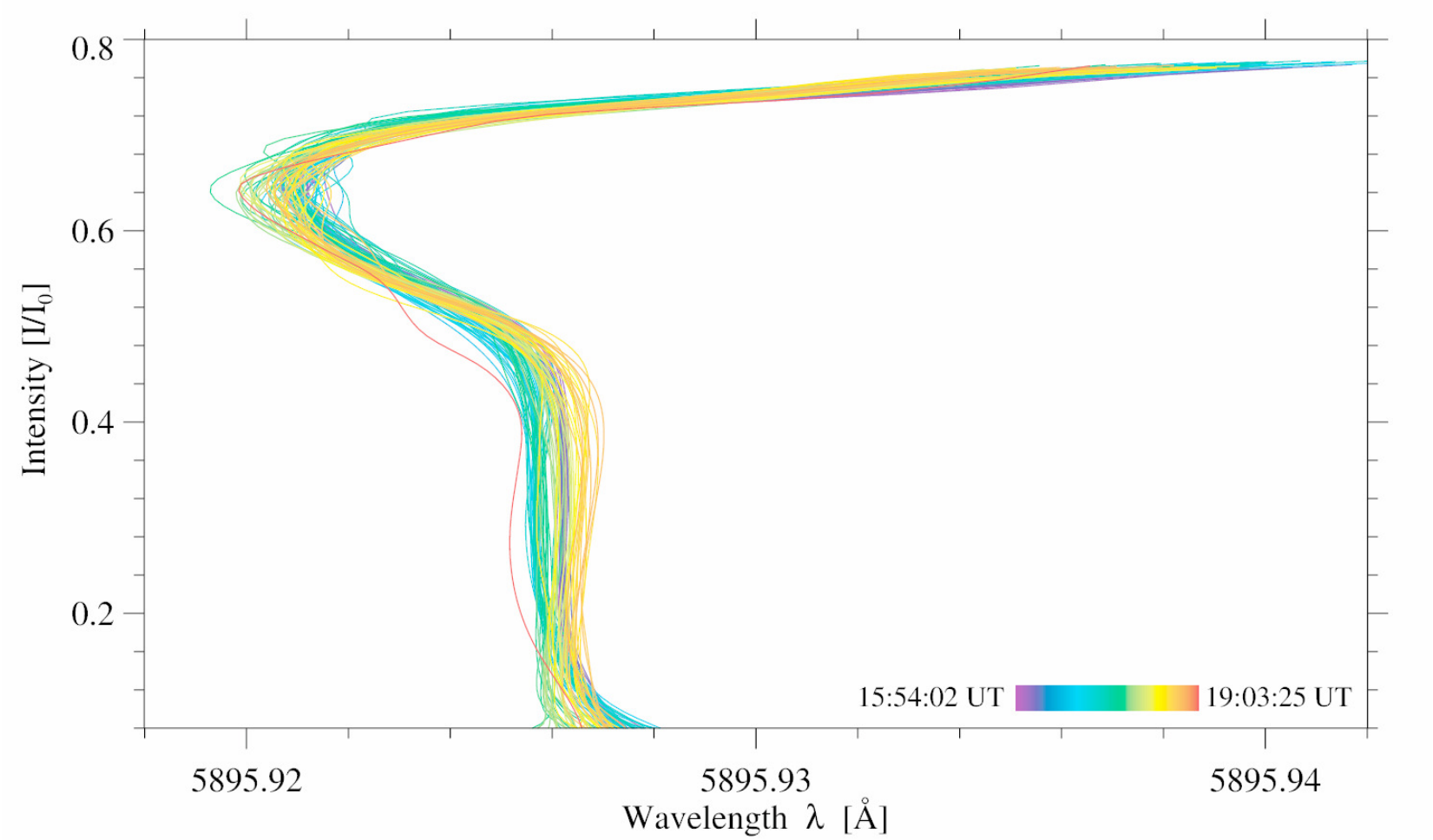
Similar representation of the D_2 line profiles where we also observe contamination from the photospheric Fe absorption line.

Contrast Profiles Na D_1 – variation with time



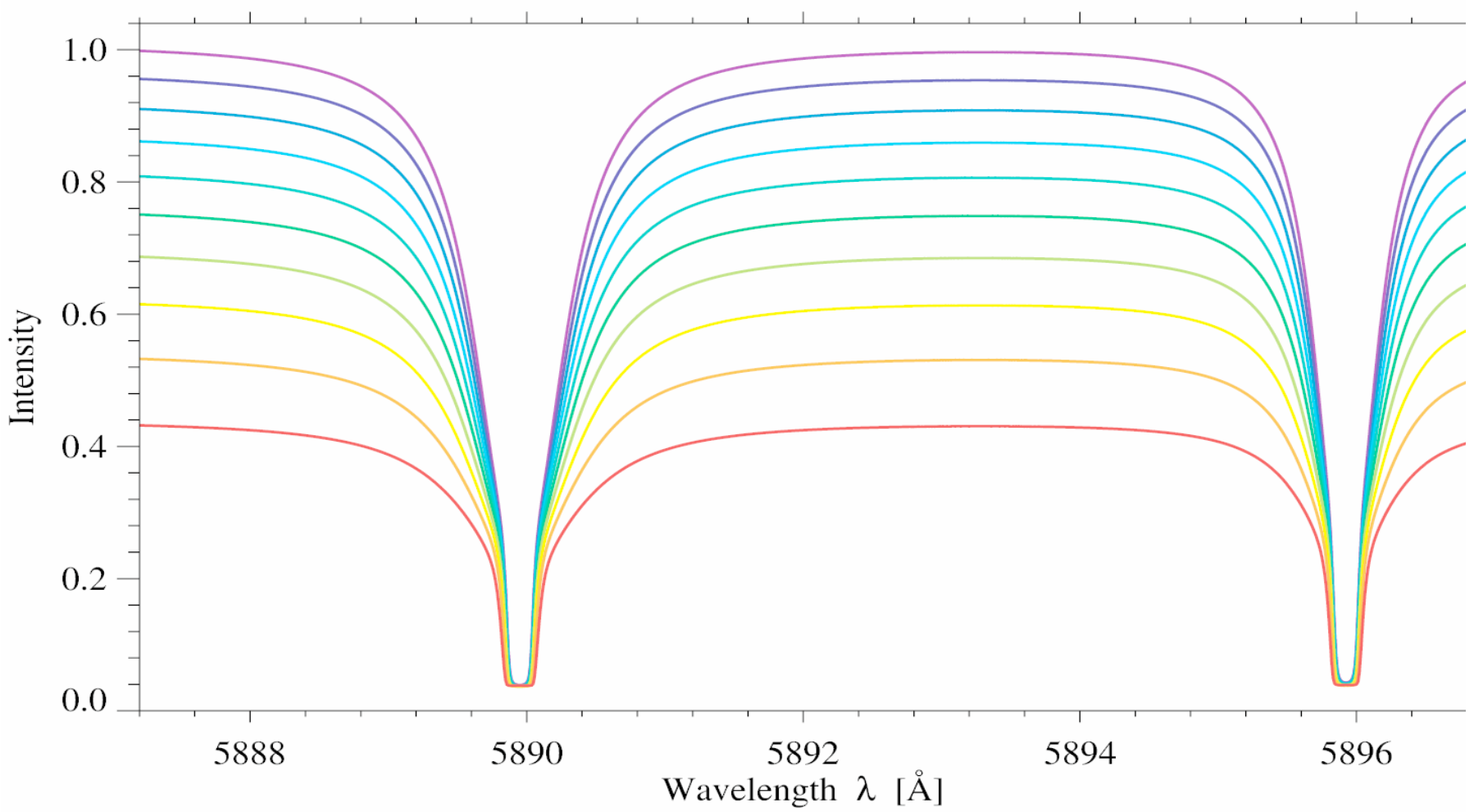
Contrast profiles comparison between quiet sun and eclipse spectra, spaced with a constant for a better visibility.

Na□D$_1$ line bisector series



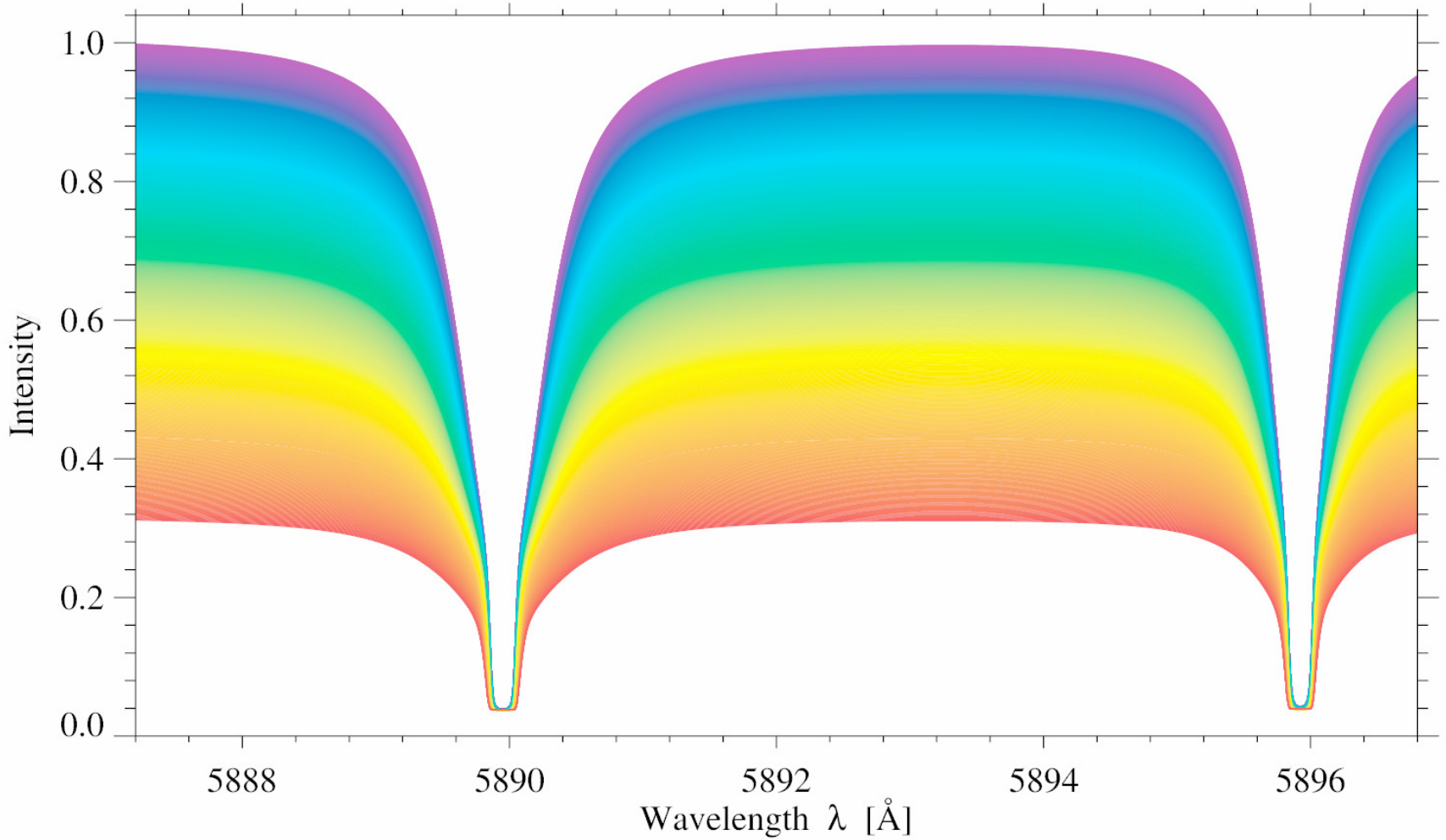
Na D_1 bisector evolution in time color-coded matching the observation interval. The asymmetry providing quick overview of velocity gradient with height.

Synthetic Sodium Doublet – Stage 1



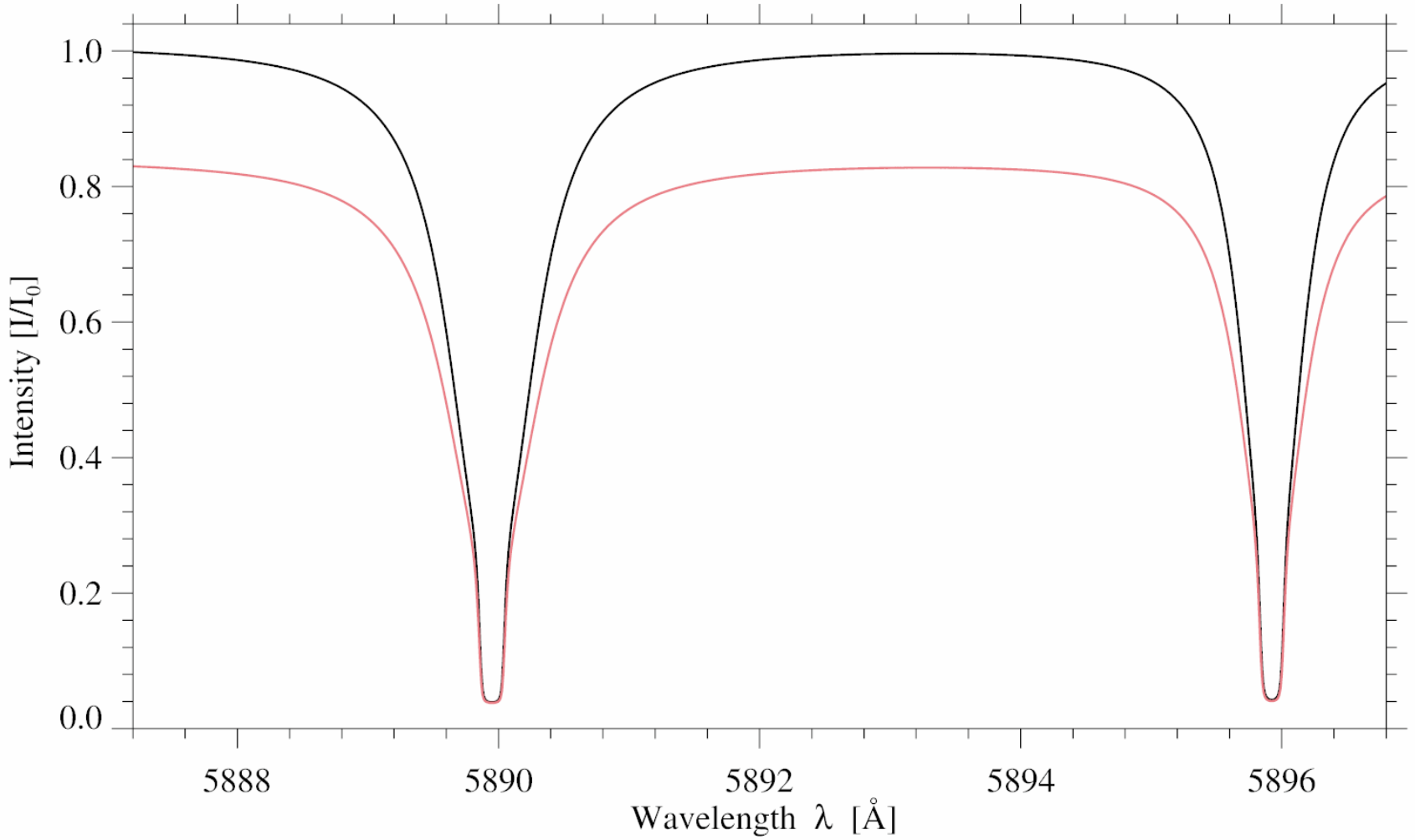
The initial10 profiles with respect to distance from disk center, created with 1D FALC model.

Synthetic Sodium Doublet – Stage 1



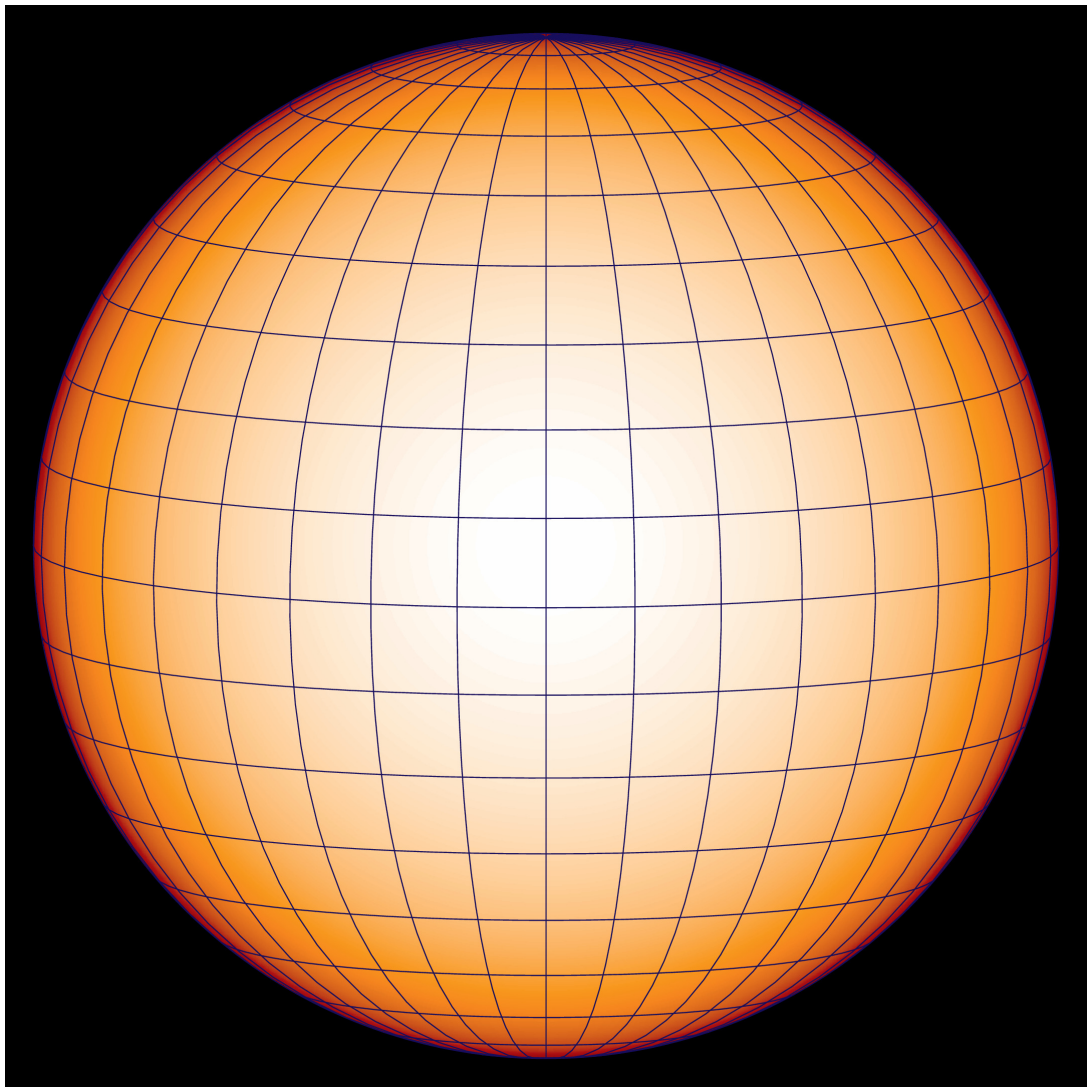
After deriving CLV curve from the initial 10 profiles we are able to obtain set of 1001 spectra with higher μ(=*cos(θ)*) resolution.

Model: disk-center vs disk-integrated profile



Red profile represents disk-integrated average profile where black profile corresponds to disk-center spectral profile.

Model: Full-Disk Image – Stage 2

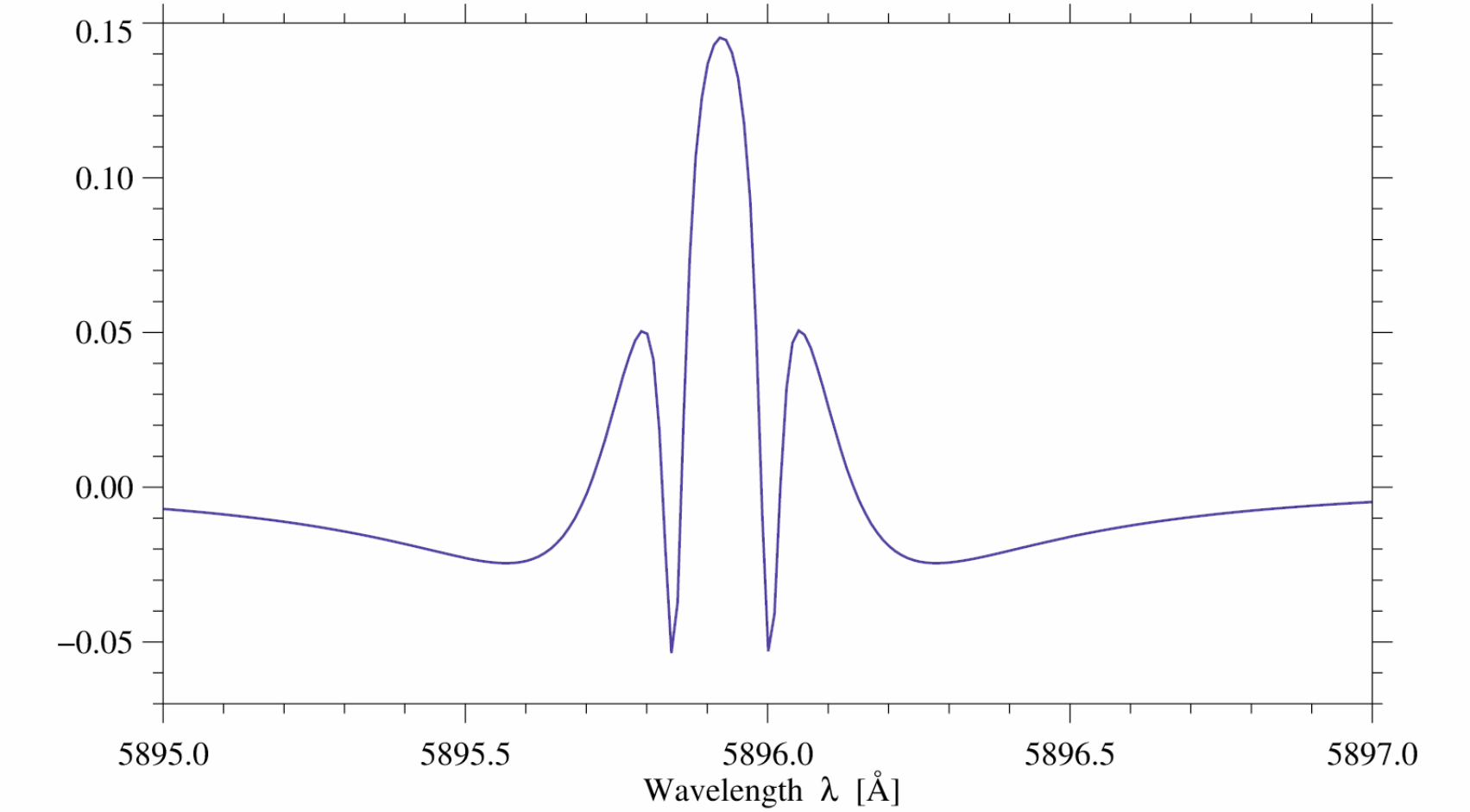


Using the newly obtained 1001 line profiles we are able to create a 2D map of the solar atmosphere at chosen height in the chromosphere.

Model properties:

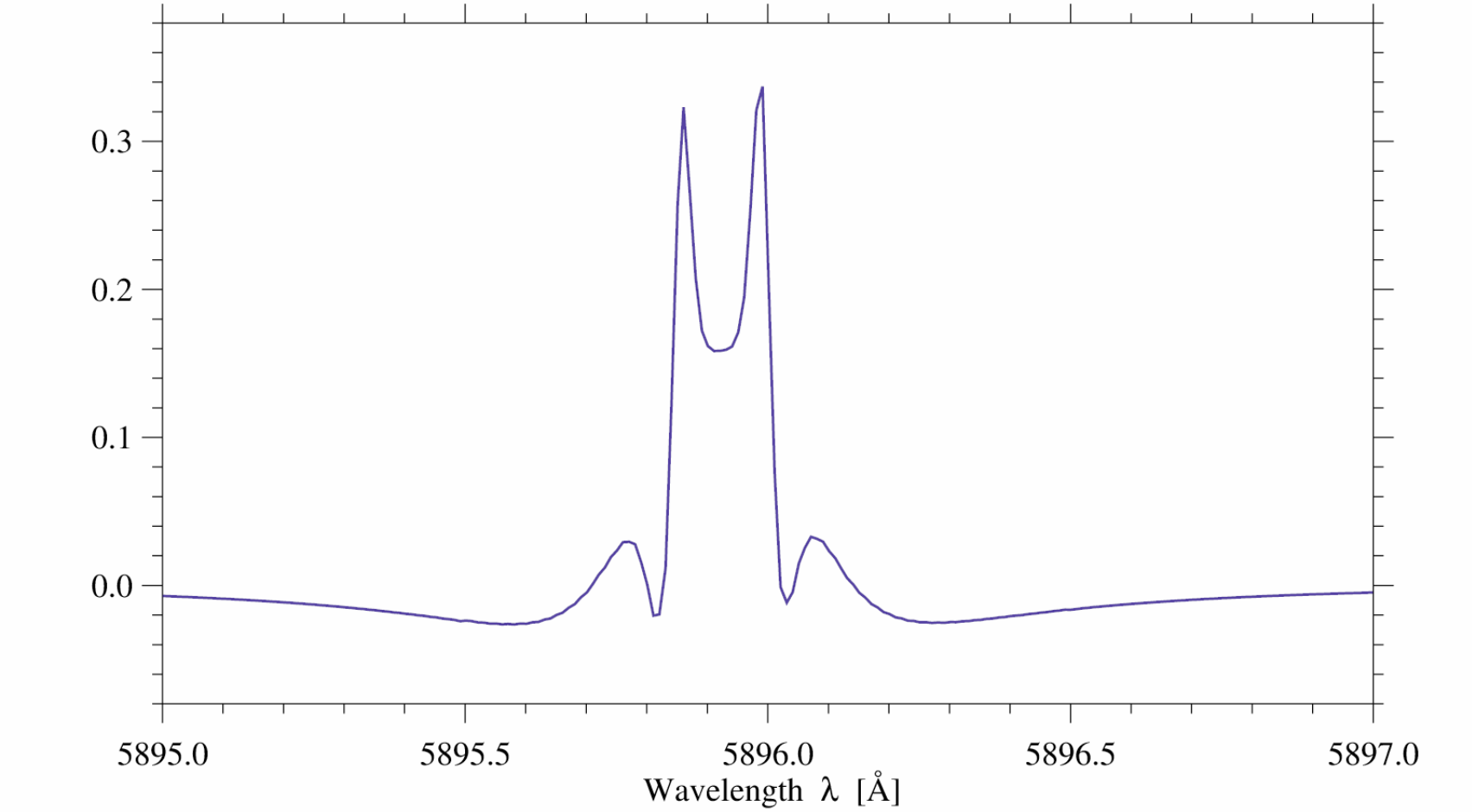
- limb-darkening effect
- differential rotation with respect to position on the sun
- no velocity gradient with distance from solar surface

Model: Without Doppler effect



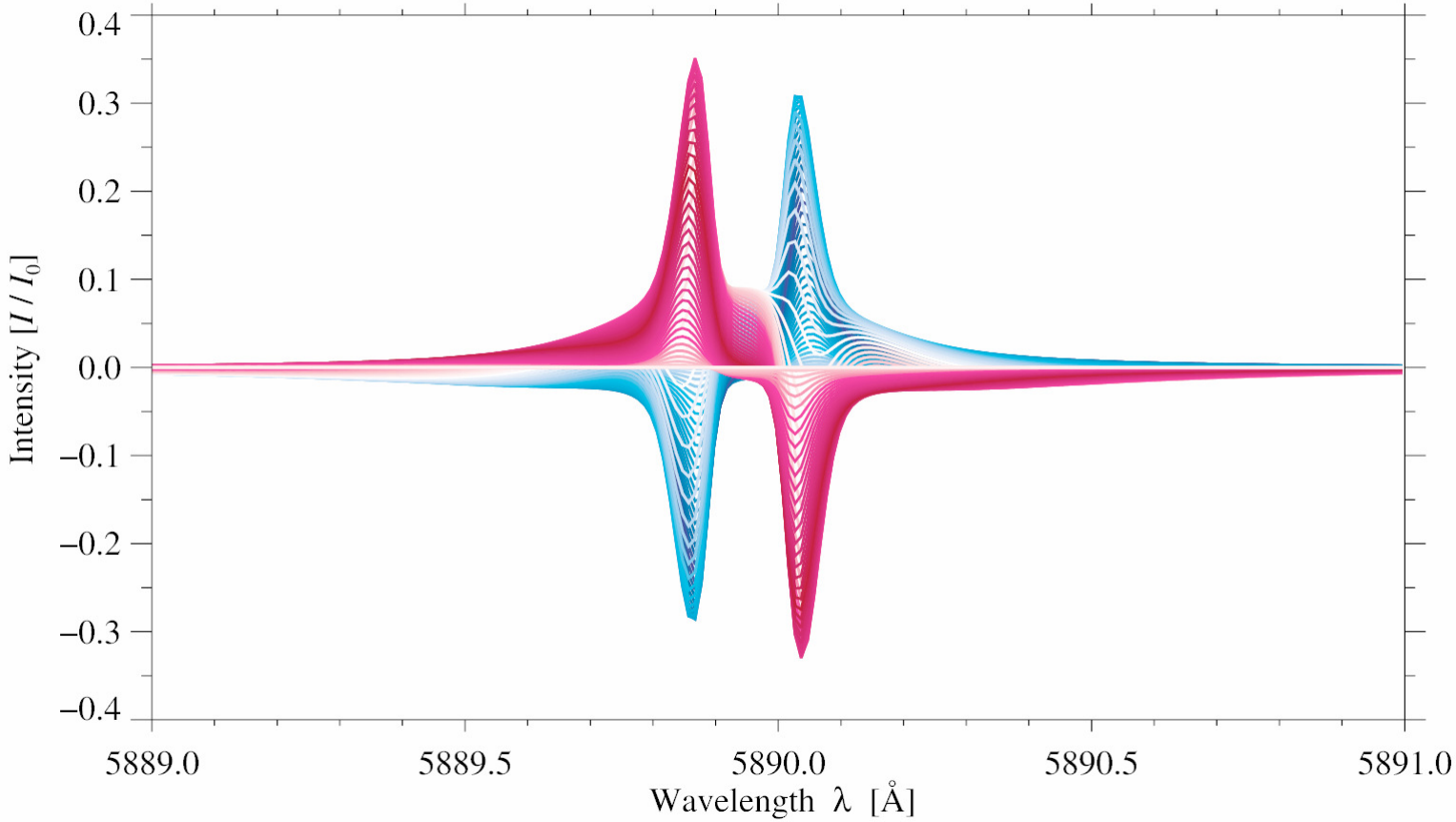
Contrast profile showing the comparison between quiet sun and disk-centered profile without doppler effect.

Model: Contrast profile



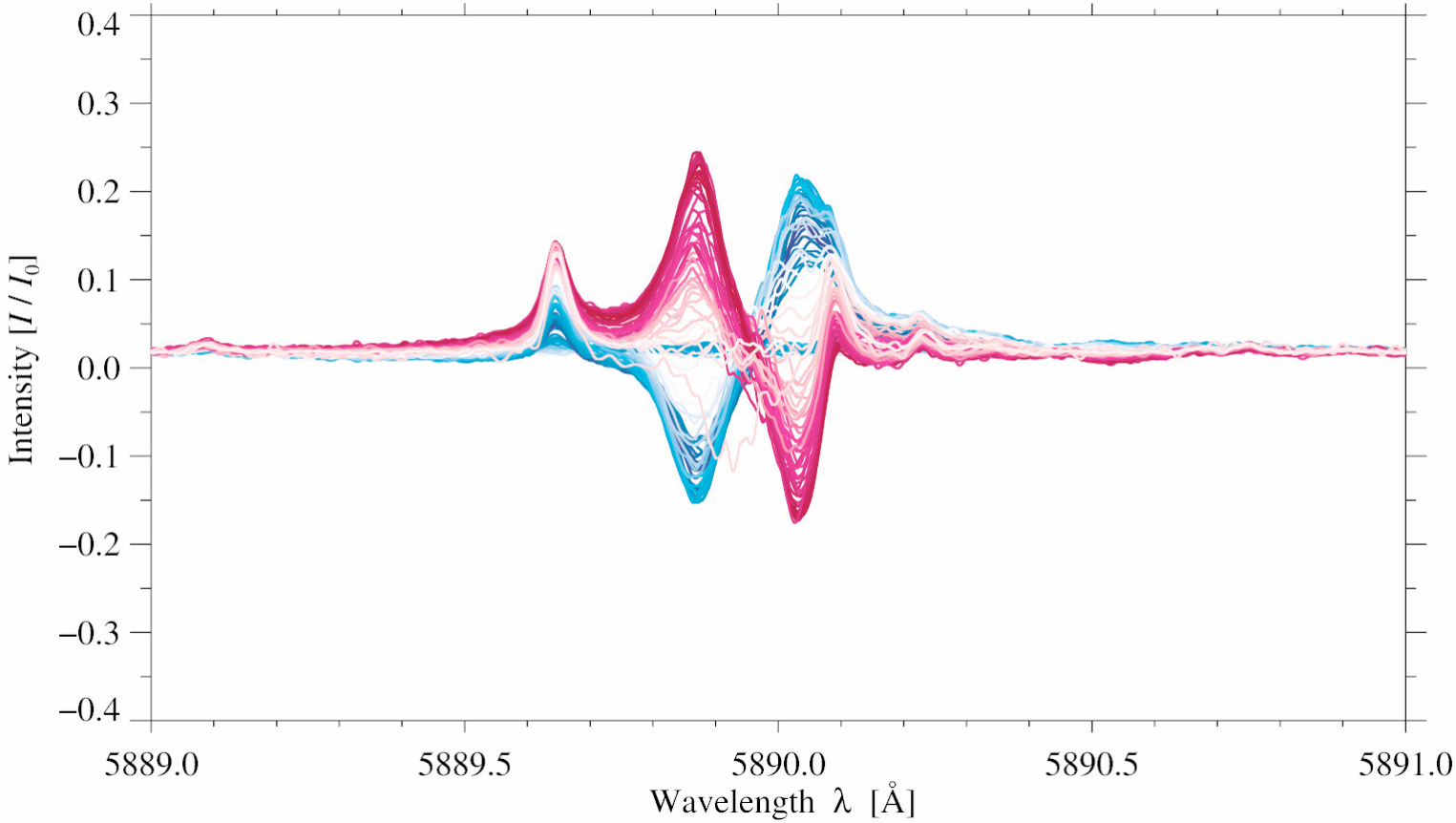
Contrast profile showing the comparison between quiet sun with and disk-centered profile added doppler broadening.

Comparison between observations and synthetic data



Contrast profiles showing the comparison between a quiet sun profile without eclipse and spectra shifted to the blue or red part of the spectrum due to lunar disk covering different part of the solar disk.

Comparison between observations and synthetic data



Contrast profile obtained from PEPSI/SDI observations of the eclipse, where we can see the contamination from photospheric lines. We observe the same effect of switching from blue to red shift in the wavelength .

Conclusions and Future Work

- We used fast cadence observation with high spectral resolution to study the temporal evolution of the chromospheric Sodium doublet during the 2017 Solar Eclipse.
- Ten initial spectra simulated with a 1D FALC model were used to obtain a full-disk 2D maps in order to compare with observed spectra.
- Differences between observational and simulated disk-integrated spectral profiles occurs due to:
  - different position angel of pole and inclination
  - no contamination from photospheric absorption lines
  - correct solar/lunar ephemeris
- Further development of the model and investigation:
  - observations: D_1 bisector and LOS velocity measurements with respect to distance from the solar surface
  - model: possibility of including active regions and velocity gradient

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
- **Strassmeier, K., Ilyin I., and Steffen, M., 2017:** *PEPSI deep Sepctra. I.The Sun-as-a-star.* Astron. Astrophs. **612**, 15
- **Reiners, A., Lemke, U., Bauer, F., et al. 2016:** *Radial velocity observations of the 2015 Mar. 20 eclipse. A benchmark Rossiter-McLaughlin curve with zero free parameters.* Astron. Astrophs., **595**, 13
- **Fontenla, J. M., Avrett, E. H., and Loeser, R., 1993:** *Energy balance in the solar transition region. III - Helium emission in hydrostatic, constant-abundance models with diffusion.* Astrophys. J., **406**, 319


Thank you for your attention!