LARS – the Laser Absolute Reference Spectrograph at the VTT

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The LARS project

LARS is an Absolute Reference Spectrograph. It performs fiber-coupled solar observations with the high-resolution Echelle Spectrograph of the Vacuum Tower Telescope (VTT) at the Observatorio del Teide on Tenerife. The scientific instrument is operated by the Kiepenheuer Institute for Solar Physics, Freiburg.

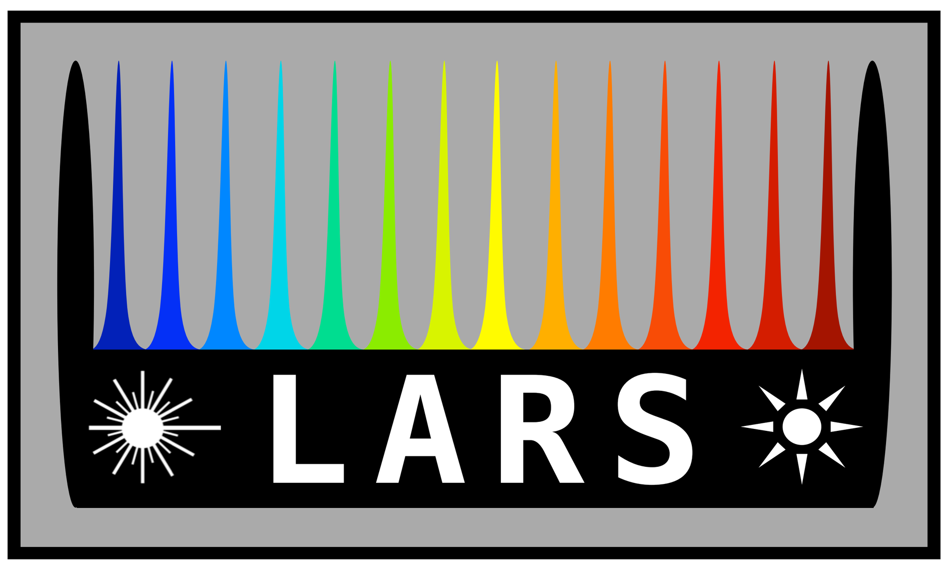

Figure 1. LARS logo

The spectral observation is supported by a Laser Frequency Comb which serves as an absolute ruler for the wavelength calibration of the solar spectrum. This novel technique of spectroscopic observations allows the determination of absolute velocities in the solar atmosphere with the best accuracy (m s^{-1}).

LARS @ VTT

The Vacuum Tower Telescope (VTT) is designed to perform high-quality solar spectroscopy. It is equipped with an Adaptive Optics system to compensate for atmospheric wavefront distortions. The **Echelle Spectrograph** enables observations with a spectral resolution of ≥700,000. The novel **Laser Frequency Comb** tops off the unique system for high-precision solar spectroscopy.

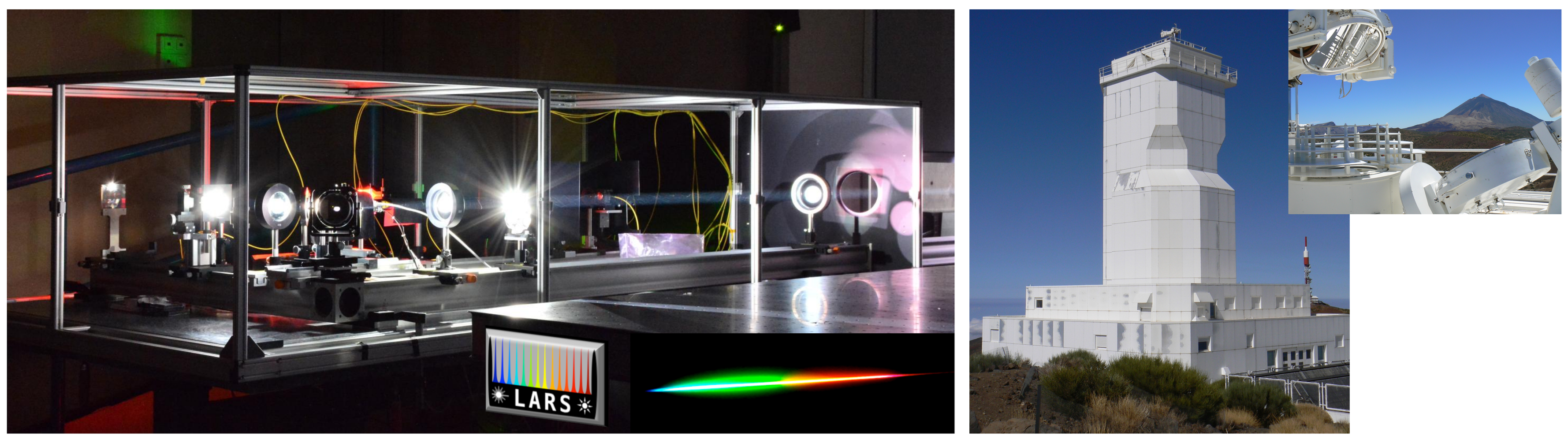

Figure 2. Left: LARS optics and Frequency Comb spectrum. Right: VTT building and Coelostat.

Instrumental setup

LARS consists of several instrumental components which are illustrated in Fig. 3:

- ✧ **Laser Frequency Comb**: Pulsed, mode locked fs-Laser at 1060 nm; emission spectrum is filtered with two FPCs to a free spectral range of 8 GHz; spectral broadening[2] with a tapered Photonic Crystal Fiber to the range 480 – 1500 nm
- ✧ **Solar channel optics**: Beam splitter sends 10% of the light to the Context Imager and 90% to the fiber coupling unit (1”,3”,10”) for spectral observations
- ✧ **Artificial light sources**: HeNe laser, Hollow cathode lamps, Flatfield lamp
- ✧ **Spectrograph and fiber switch**: Light channels are coupled to a fiber switch The output fiber is connected to the Echelle Spectrograph of the VTT.

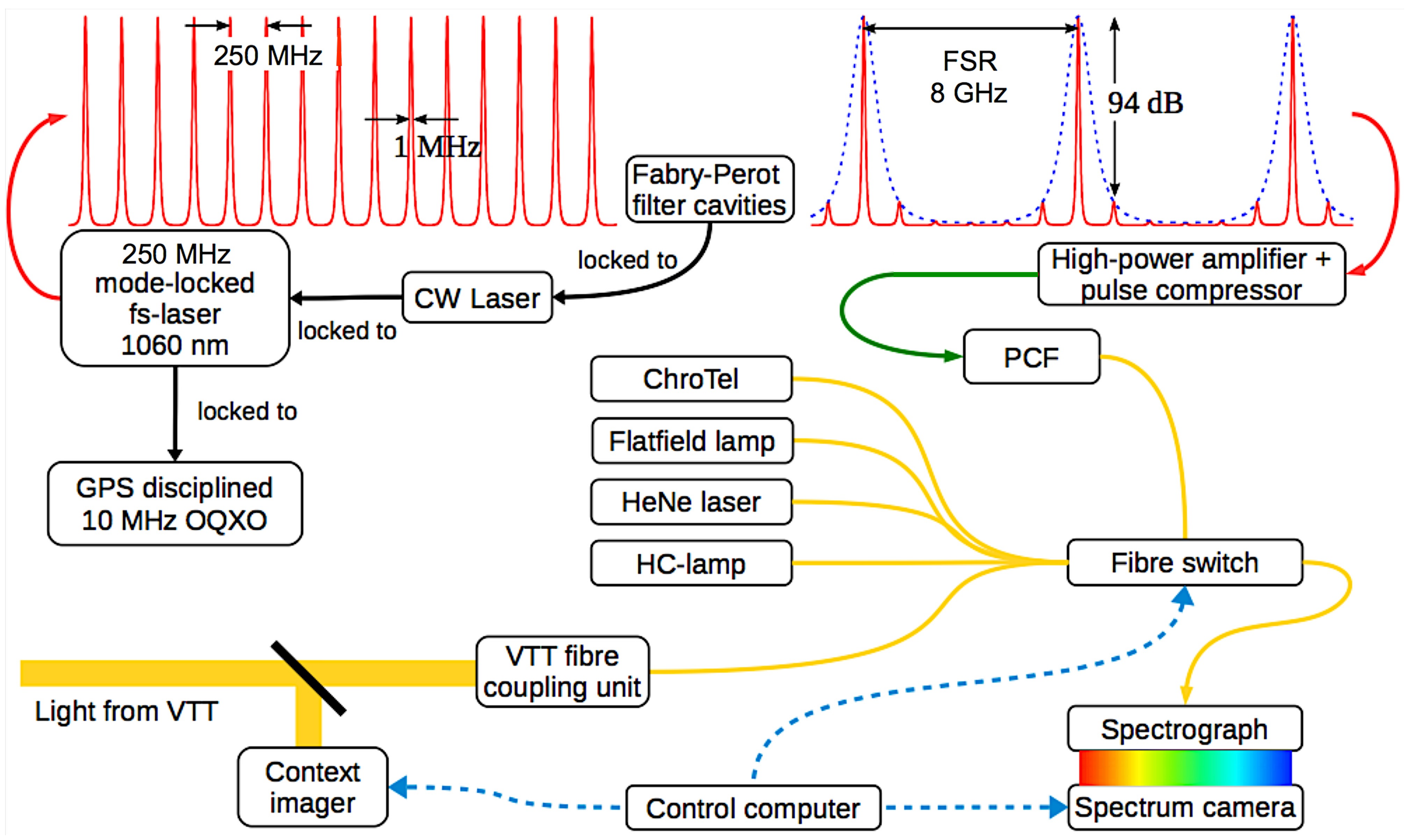

Figure 3. Instrumental setup of LARS. The upper half illustrates the Laser Frequency Comb, the lower half sketches the setup for solar observations with the spectrograph. All light sources are coupled by single-mode fibers to a fiber switch (adapted from Doerr, H.-P. 2015, PhD thesis).

Acknowledgements: The Laser Frequency Comb was developed by Menlo Systems GmbH and MPQ Garching, and implemented at the VTT by Dr. Tilo Steinmetz [3]. The LARS instrument was designed and installed at KIS by Dr. Hans-Peter Doerr and Dr. Thomas Kentischer. The Post-Doc project of the author was applied by Prof. Dr. Wolfgang Schmidt and is funded by the Deutsche Forschungsgemeinschaft DFG.

Data

✧ LARS observes the Sun simultaneously in two channels:

1) **Context images**: 2D: field-of-view with 2048 × 1536 pixel (100” × 75”)
2) **Integrated spectrum**: Alternating observation of the solar and comb spectrum
   Integrated solar light of a selected region (1”, 3”, 10”)
   1D: Vertical binning over the illuminated sensor region

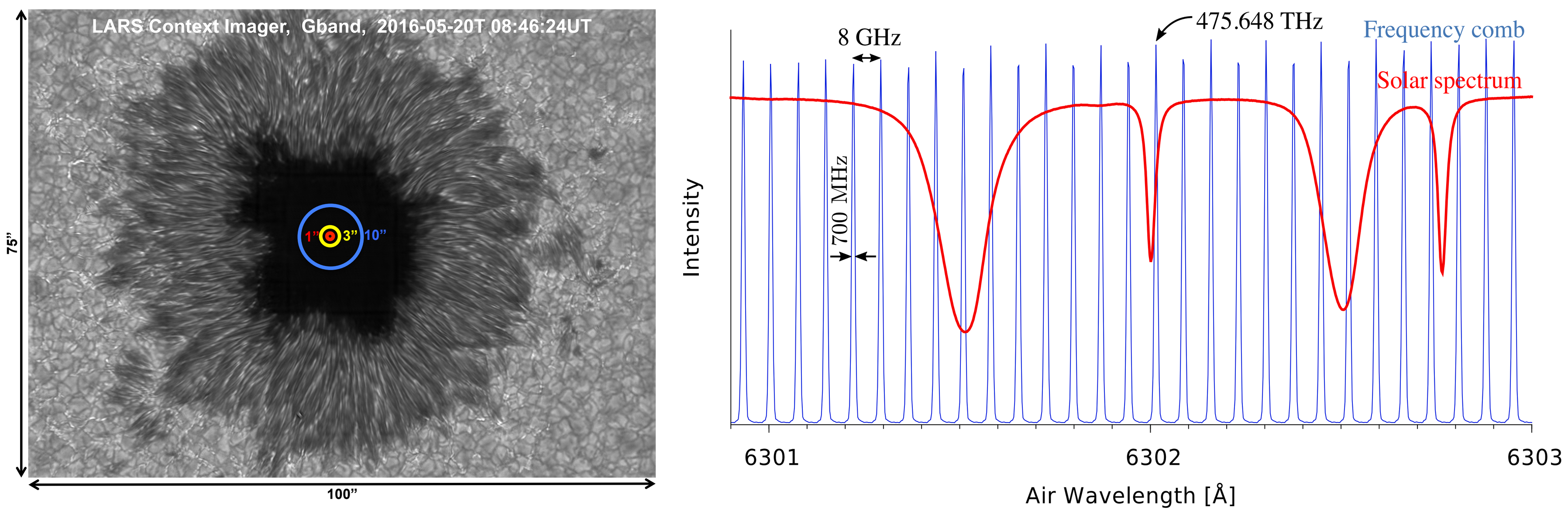

Figure 4. Context image (left panel) and solar/comb spectrum (right panel[1]) observed with LARS.

- ✧ Effective spectral working range from 480 – 710 nm
- ✧ Temporal cadence of seconds and below
- ✧ Absolute wavelength calibration of the solar spectrum with the comb spectrum
- ✧ Accuracy of the spectral calibration of ≤ m s^{-1}
- ✧ Data calibration with a semi-automatic data pipeline (H.P. Doerr)

Science

- ✧ **Absolute velocities** in the solar atmosphere at highest accuracy
- ✧ **Precise line asymmetries**:

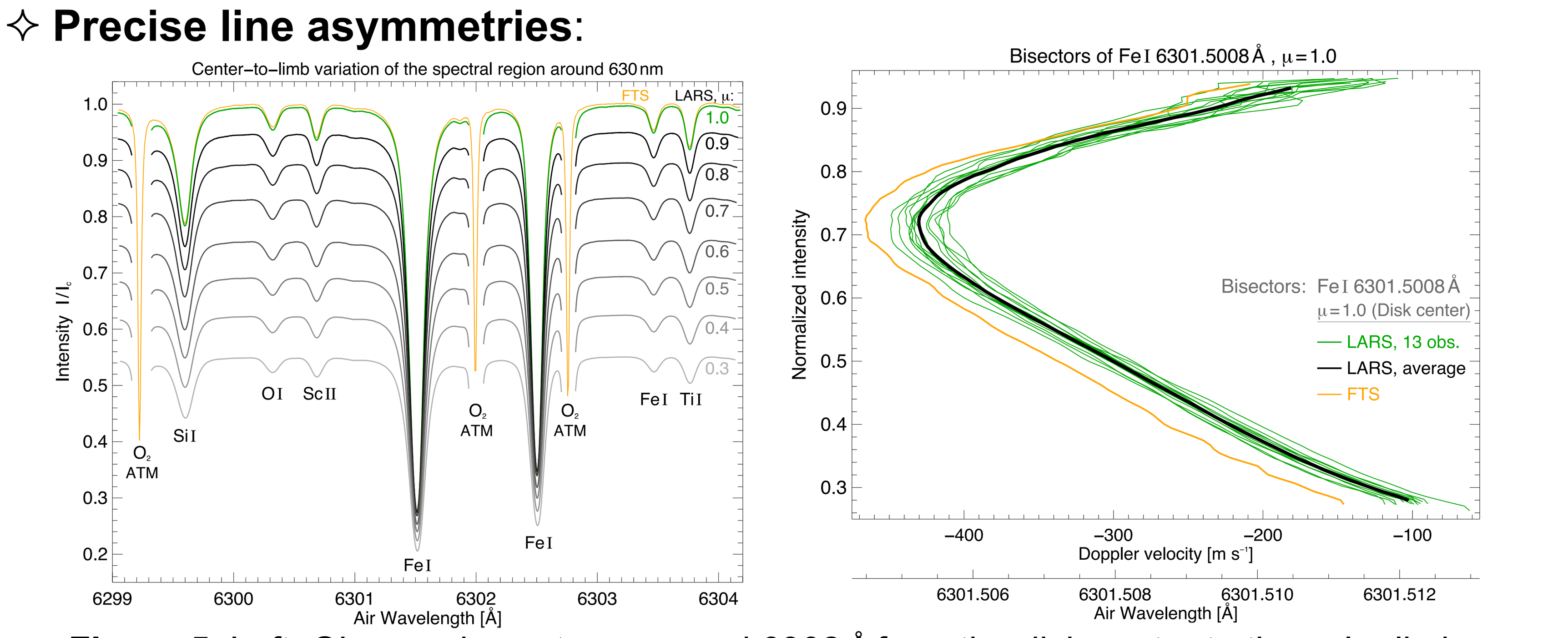

Figure 5. Left: Observed spectrum around 6302 Å from the disk center to the solar limb. Right: Bisector analysis of Fe I 6301.5 Å at disk center revealing the C-shaped velocity curve.

✧ **Center-to-limb variation of the convective blue-shift**:

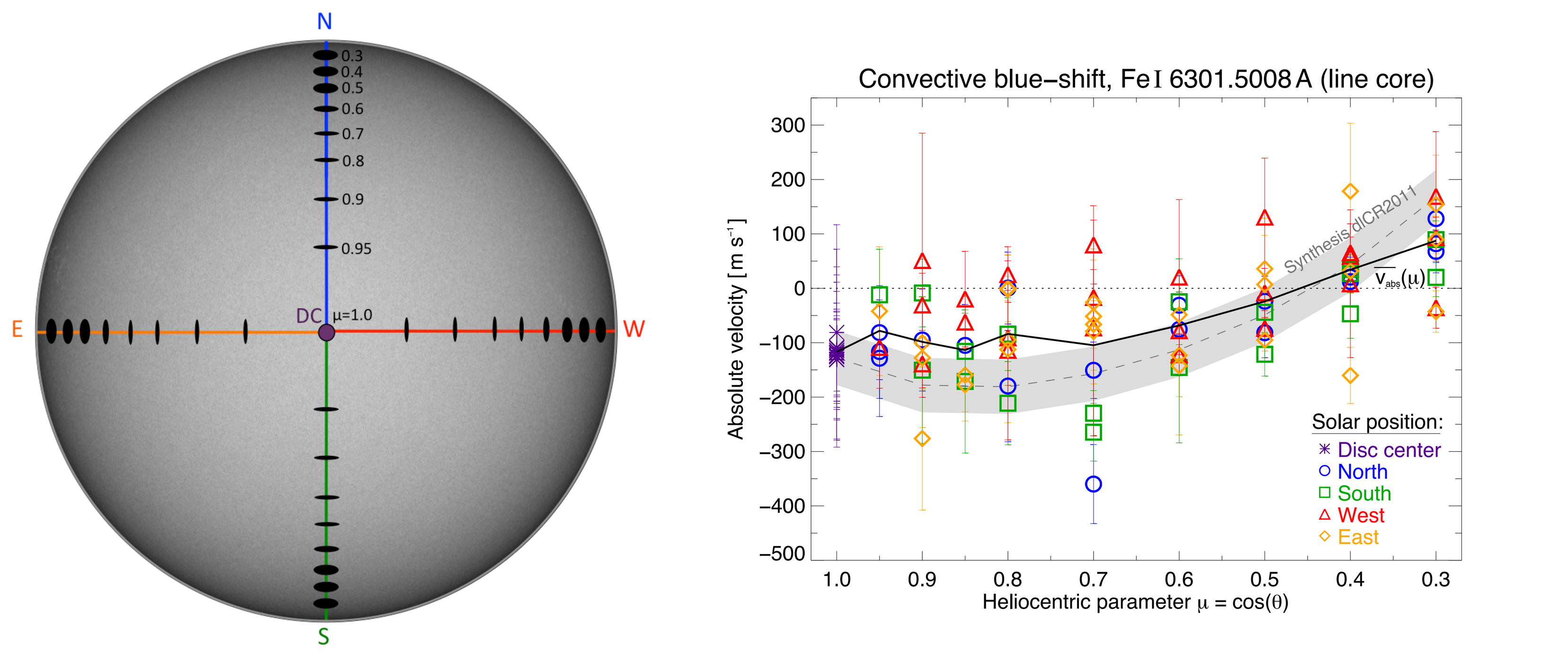

Figure 6. Systematic scanning across the solar disk (left) and velocity results for the line core of Fe I 6301.5 Å (right). The black line shows the average trend from the disk center to limb.

✧ **Sunspot waves and p-modes:** Absolute velocities and Helioseismology

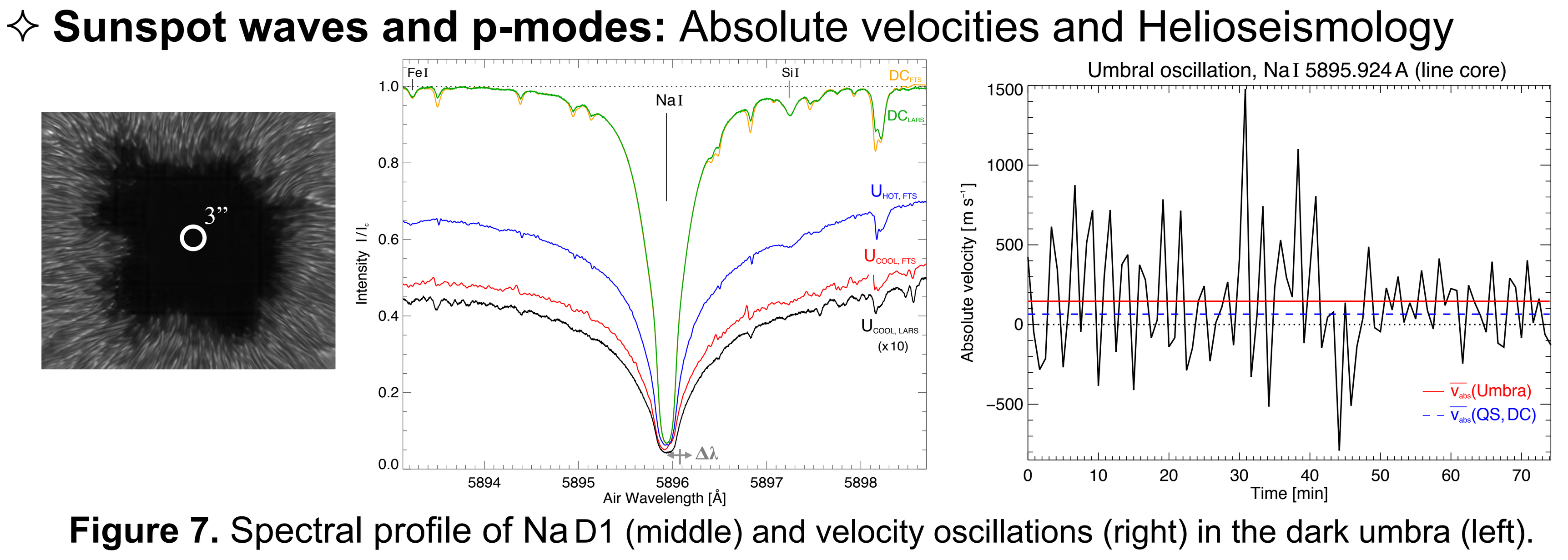

Figure 7. Spectral profile of Na D1 (middle) and velocity oscillations (right) in the dark umbra (left).

- ✧ **Spectral atlases** for the Sun with highest accuracy (disk center, limb, spots)
- ✧ **Atomic transitions**: Determination of laboratory wavelength with HC-lamps

References:

(1) Doerr, H.-P., 2015, PhD thesis, University of Freiburg
(2) Probst, R. A.; Wang, L.; Doerr, H.-P.; et al., 2015, New Journal of Physics, 17, 023048
(3) Steinmetz, T.; Wilken, T. ; Araujo-Hauck, C.; et al., 2008, Science, 321, 1335
(4) Doerr, H.-P.; Steinmetz, T.; Holzwarth, R.; Kentischer, T.; Schmidt, W., Solar Physics, 280, 663