The FISS Spectro-Polarimeter (FISS-SP) at GST with diffraction-limited* imaging capability

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Abstract

To understand the magnetic nature of small scale events we need spectro-polarimetric information at high spatial and spectral resolutions. Only with image restoration of solar spectra [4] we can reach the diffraction limit of modern large aperture high resolution ground based telescopes. Combining the signal of many spectral lines improves the signal to noise ratio and hence allows a more robust extraction of information on solar features.

To explore the possibilities and performance of such an image restoration on data sets with high spatial & spectral resolution we temporary extended the Fast Imaging Solar Spectrograph (FISS) instrument [1] installed at the 1.6 meter Goode Solar Telescope (GST) at the Big Bear Solar Observatory (BBSO) with polarimetric capabilities and two fast large FOV cameras.

Setup

The FISS Spectro-Polarimeter (FISS-SP) with diffraction-limited imaging capability

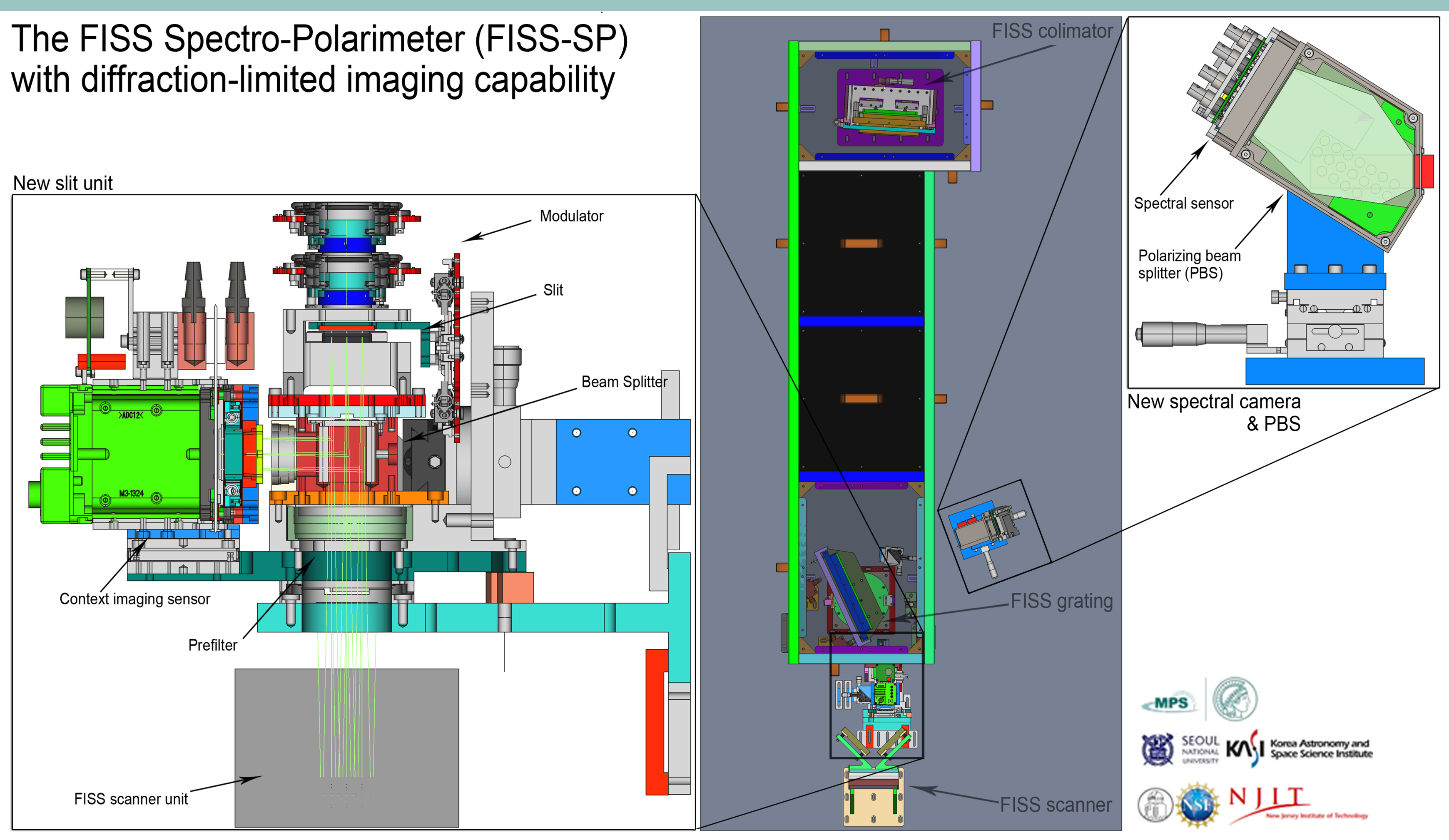


Figure: CAD drawing of the FISS-SP assembly using the existing FISS spectrograph (center), the new FISS-SP slit unit (left) and the new spectral camera and polarizing beam splitter (PBS) (right).

We extended the FISS instrument with polarimetric capabilities (modulator with two FLCs), a slit library with slits from 8 to 32 µm, a 98:2 beam splitter to feed the fast context imaging sensor. The new spectrograph camera unit is equipped with a large format sensor attached to a PBS. Both sensors are thermally stabilized using vibration free water-cooled Peltier devices.

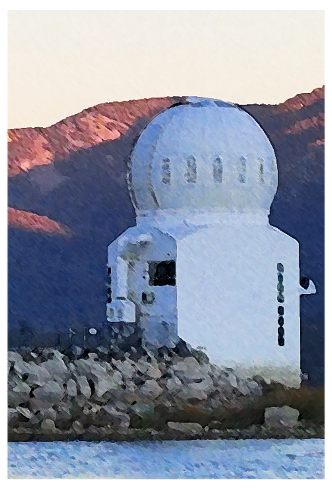


Table: Properties of the FISS-SP sensors

	Spectrograph Camera	Context Imager
Frame rate	30 Hz	360 Hz
Modulation cycle	7.5 Hz	-
Temporal noise	8.8 e-	13 e-
Pixel pitch	4.6 µm^2	5.5 µm^2
Pixel scale X	4.19 mÅ/px	0.027 ''/px
Pixel scale Y	0.023 ''/px	0.027 ''/px
Usable FOV	58.65'' × 33.06Å	63.18'' × 20.25''
Data Rate (compressed)	1 160 MB/sec	1 164 MB/sec

Data Reduction

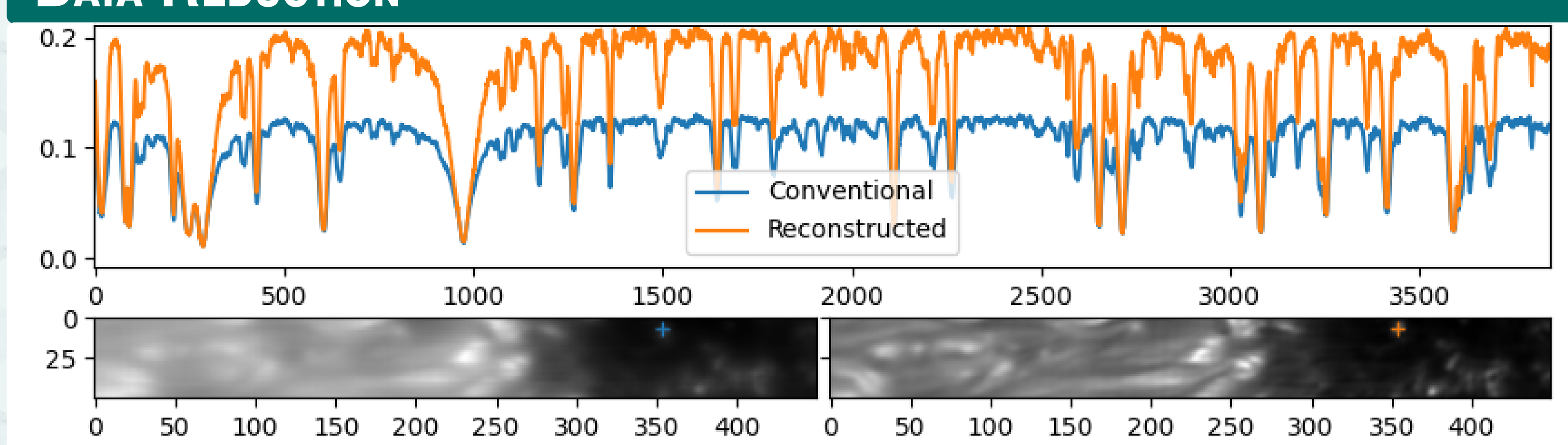


Figure: Comparison of a conventional with a restored spectrogram. Top plot shows single spectra at the marked locations in the images below. Noise and signal are amplified in the process and contribution from neighboring features is removed in a deconvolution-like process. Lower row shows ROIs from conventional (left) and restored (right) spectrograms averaged over 0.2 Å.

We use `spectroflat` [2] (Poster #44) for flat fielding and `specrestore` [4, 5] to reduce the SPC data. We use `MOMFBD` [6] for the restoration of the SJC data.

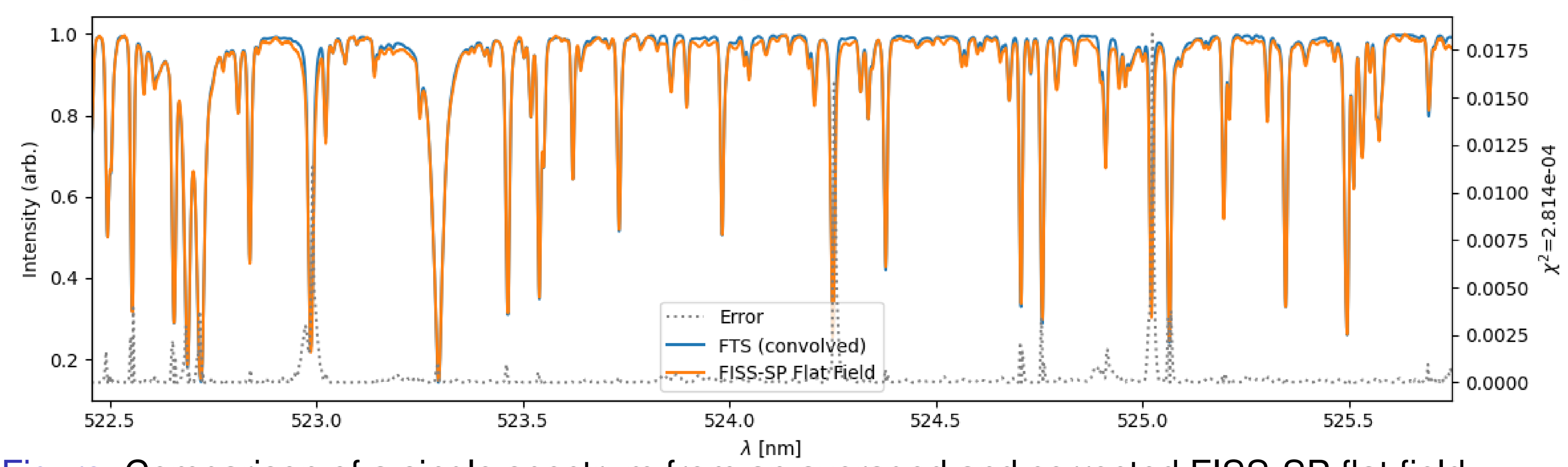


Figure: Comparison of a single spectrum from an averaged and corrected FISS-SP flat field measurement with a disc-center spectral atlas (Kitt-Peak FTS) after convolution with the FISS-SP SPSF. The error curve is the square difference between the convoluted FTS and the measured profile. The calibrated average FISS-SP profile reproduces the reference atlas well.

First Results

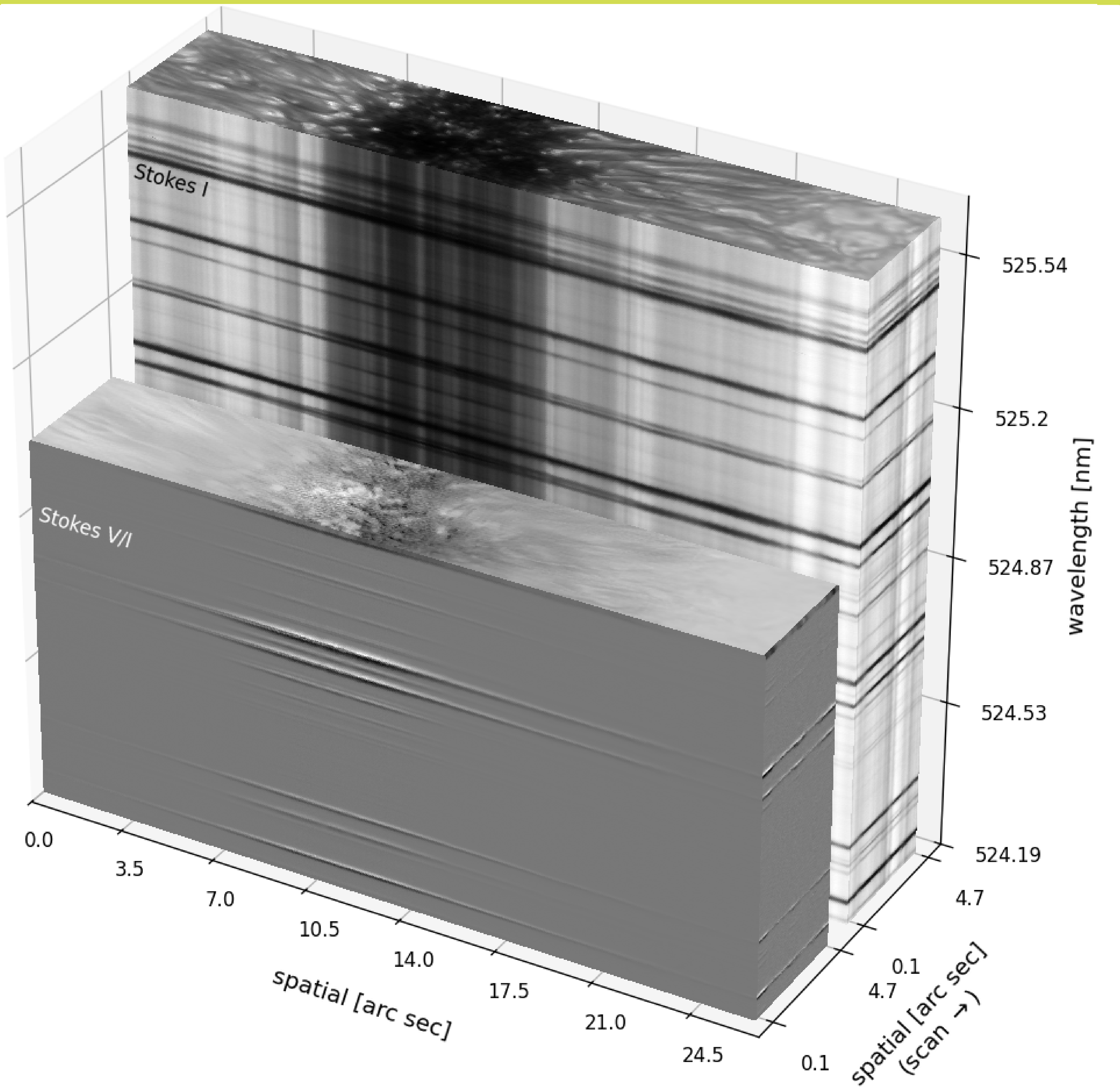


Figure: Restored scan of active region NOAA 13 111. The cube in the back shows the Stokes I hyperspectral cube (cut at a continuum position) while the one in front shows Stokes V/I (cut at the red wing of the 5250.2 Å line). Both cubes show only a fraction of the recorded wavelength range. Please refer to the movie for an animation through the full cube with all Stokes parameters.

After reconstruction the resulting data sets are the highest resolution spectro-polarimetric full Stokes scans so far achieved. The spatial resolution of the spectrally integrated scans can compete with that of the restored context images and reaches the GST diffraction limit*. The spectral range is more than 30 Å and includes more than 150 solar lines with a resolution of up to $R \approx 560\,000$.

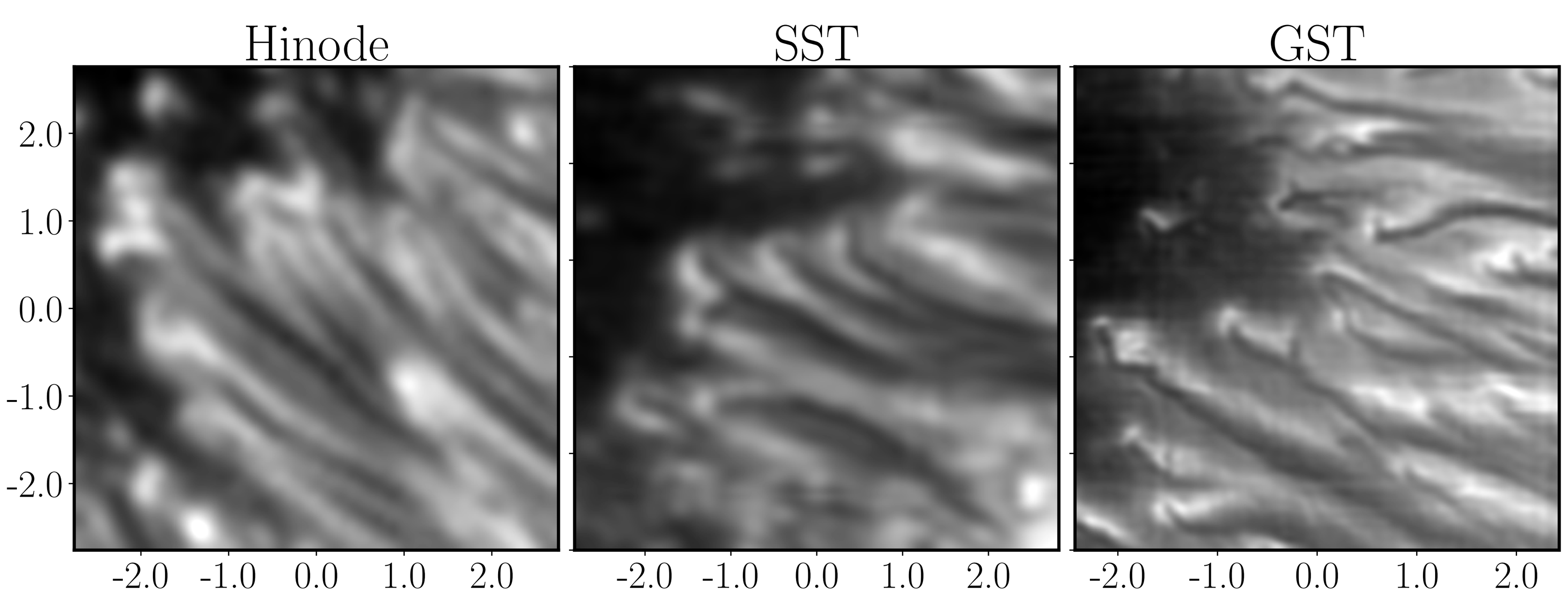
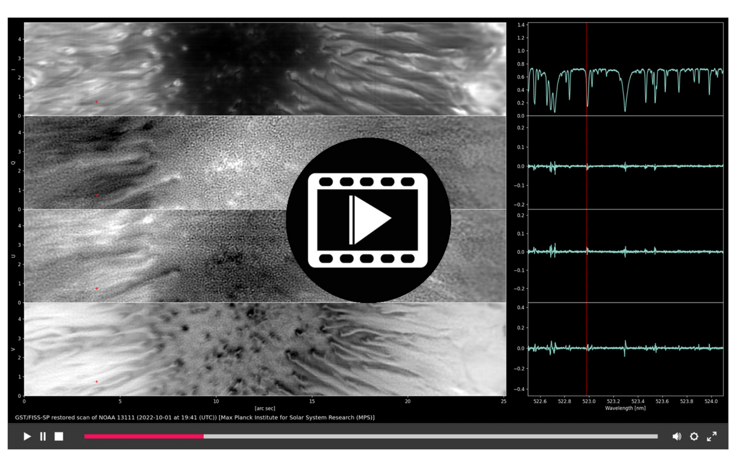


Figure: Spectrograph scans of similar penumbral filaments, acquired with HINODE SP (0.5m, 6301.5 Å, deconvolved) TRIPPEL-SP@SST (0.98m, 6310.5 Å, restored) and FISS-SP@GST (1.6m, 5250.6 Å, restored). All images show a spectral average over 0.15 Å of the respective hyperspectral cubes, tick marks are labeled in arc-seconds.

Extraction of information on solar features using a many line inversion technique [3] is currently ongoing.

Movie download

Scan QR-code to download a movie of the restored scan!



Sunspot of **NOAA 13111** at µ = 0.89
Oct. 1st 2022 at 19:41 (UTC)

References

[1] Chae, Jongchul, et al. "Fast Imaging Solar Spectrograph of the 1.6 Meter New Solar Telescope at Big Bear Solar Observatory," *Sol. Phys.*, *288*(1):1–22 (November 2013).
[2] Hölken, J., et al. "Spectroflat: A generic spectrum and flat-field calibration library for spectro-polarimetric data," *A&A*, *687*:A22 (2024, See also ESPM-17 Poster #44).
[3] Riethmüller, T. L. and S. K. Solanki. "The potential of many-line inversions of photospheric spectropolarimetric data in the visible and near UV," *A&A*, *622*:A36 (February 2019).
[4] van Noort, M. "Image restoration of solar spectra," *A&A*, *608*:A76 (December 2017).
[5] van Noort, M. and H. P. Doerr. "Data reduction and restoration of spectropolarimetric microlensed hyperspectral imager data," *A&A*, *668*:A151 (December 2022).
[6] Van Noort, Michiel, et al. "Solar Image Restoration By Use Of Multi-frame Blind De-convolution With Multiple Objects And Phase Diversity," *Sol. Phys.*, *228*(1-2):191–215 (May 2005).

*) GST diffraction limit is 0.068" at 5250 Å using the Rayleigh criterion ($1.22\,\lambda/D$)

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