Leibniz-Institut für Astrophysik Potsdam

Multi-line Spectroscopy of a Sunspot with a Strong Light Bridge

R. Kamlah[1, 2], M. Verma[1], I. Kontogiannis[1, 2, 3], C. Denker[1]

[1] Leibniz-Institut für Astrophysik Potsdam (AIP), Potsdam, Germany
[2] Universität Potsdam, Institut für Physik und Astronomie, Potsdam, Germany
[3] Eidgenössische Technische Hochschule Zürich, Zürich, Switzerland
[4] Istituto Ricerche Solari Aldo e Cele Daccò (IRSOL), Locarno, Switzerland

Abstract: A detailed spectroscopic study was conducted on a mature, unipolar, round sunspot with a fully developed penumbra. The sunspot was observed on 2019 May 15, using the echelle spectrograph at the Vacuum Tower Telescope (VTT) at the Observatorio del Teide in Tenerife, Spain. During its evolution, the sunspot developed light bridges that divided the umbra into three distinct cores of negative polarity. The spectroscopic dataset comprises spatially resolved scans of the Cr I, Hα, and Hβ lines and covers a field of view of 104″ × 194″. These high-resolution, ground-based observations are complemented by full-disk synoptic data from the Helioseismic and Magnetic Imager (HMI) on board the Solar Dynamics Observatory (SDO). Spectroscopic diagnostics provide insights into line-of-sight (LOS) velocities and other spectral line properties from the photosphere to the chromosphere. Applying Background-subtracted Solar Activity Maps (BaSAMs) to the Cr I data reveals a ring of enhanced photospheric activity surrounding the sunspot, which is consistent with SDO observations. In the chromosphere, an extensive and stable Hα filament, as confirmed by Hα BaSAMs, is present throughout the VTT observations. The spectroscopic analysis indicates height-dependent velocity gradients, with increasing Doppler velocities from the photosphere to higher layers. The light bridge exhibits persistent, near-zero redshifts at photospheric heights, while a related, jet-like feature is blueshifted. The opposite sides of the penumbra exhibit red- and blue-shifted flows that reverse in the chromosphere, particularly in Hβ. Blueshifts dominate both the umbra and the light bridge in both Hα and Hβ, with the strongest values in the moss region and the associated jet. These results underscore the effectiveness of multi-line spectroscopy in probing the interaction between magnetic and flow structures in sunspots across atmospheric layers.

Formation of a Light Bridge

- Evolution and decay of the sunspot tracked over several days using SDO.
- Development of a prominent light bridge - divides umbra into three parts.

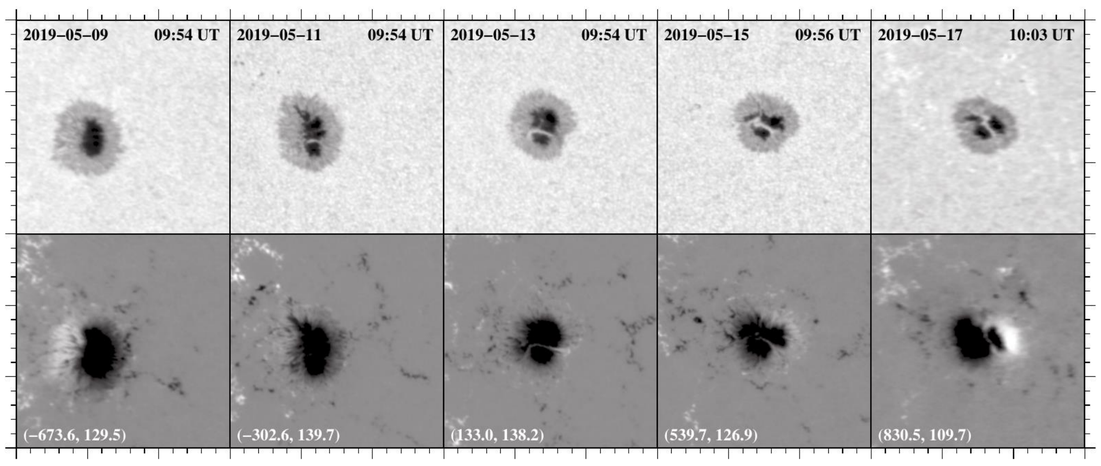

Fig. 1: Synoptic HMI continuum images (top) and LOS magnetograms (bottom) showing the evolution and disc passage of active region NOAA 12741 from 2019 May 9 to May 17. The FOV covers 150″× 150″. The magnetograms are displayed in the range of ±1000 G.

Morphology in the Chromospheric Hα line

- Trace structures at different heights in the atmosphere.
- Indicates strong vertical coherence of the light bridge and moss regions.
- Locations of major variability change with height.
- Enhanced activity in the surrounding observed at ±0.5 Å and 0.0 Å, consistent with chromospheric dynamics.
- Suggests local non-thermal disturbances or dynamic structuring.

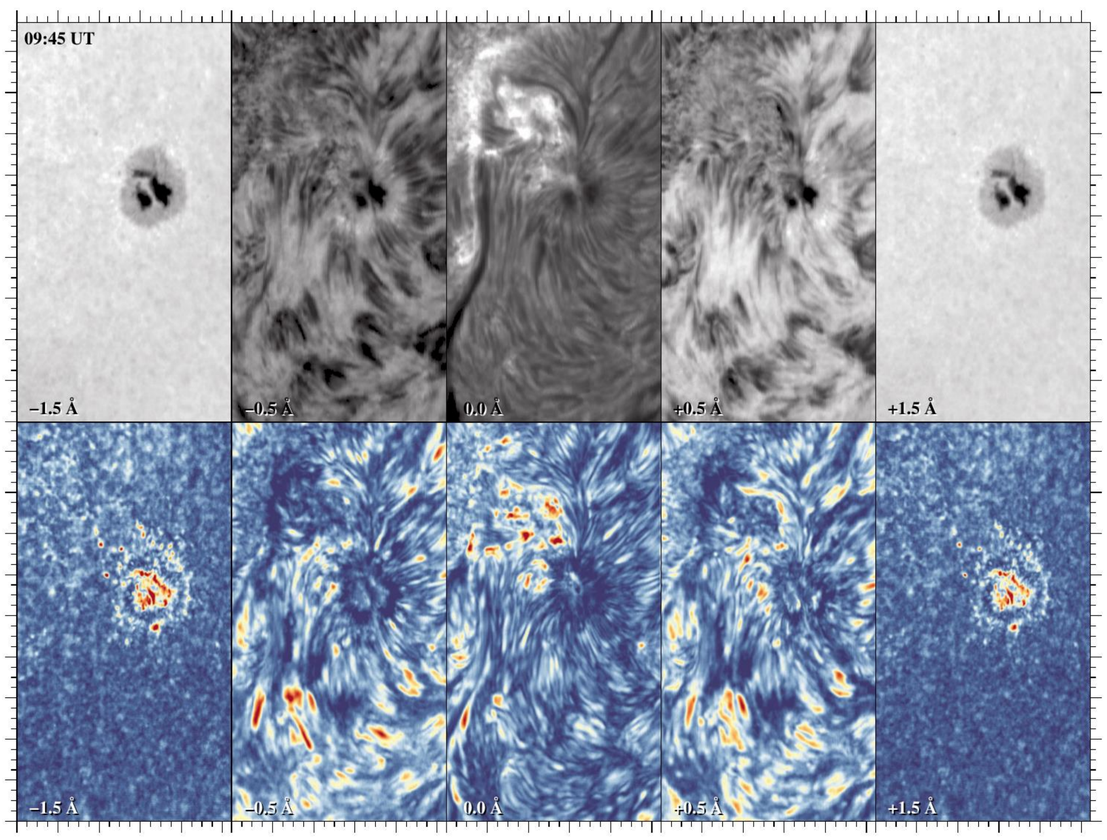

Fig. 2: Slit-reconstructed 2D maps at 5 wavelength positions of the Hα line recorded at 09:45 UT (top) and BaSAMs of the entire dataset (bottom). The wavelength positions with respect to the Hα line core is given in the lower left corner of each panel. The FOV covers 104.40″ × 194.40″ (major tick marks are separated by 20″).

Vertical Flow Asymmetries in Cr I, Hβ, and Hα

- Cr I: up- and downflows in the light bridge observed in the photosphere.
- Hβ: blueshift in the light bridge core and reversal of photospheric flow.
- Hα: opposing redshifts, suggesting vertical flow inversion.
- Confirms presence of bidirectional mass motions.

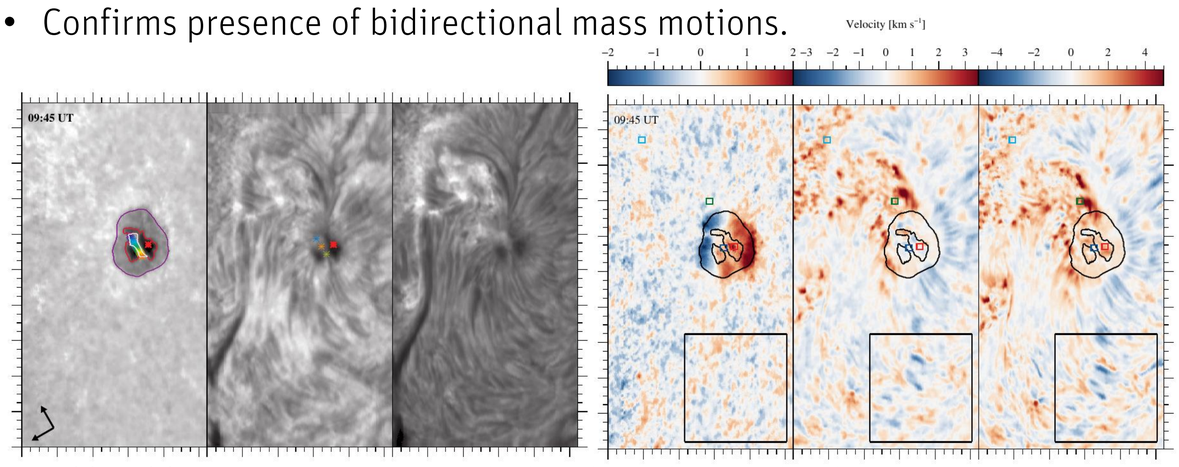

Fig. 3 (L) & 4(R): Line core velocities of Cr I - (left), Hβ (middle), and Hα (right). The colored squares highlight areas from which velocities have been extracted, such as the umbra (red), a jet feature (green), and the moss region (light blue), and the light bridge (dark blue).

Spectral Signatures of the Light Bridge

- Profiles sampled along the light bridge axis.
- Hβ: Partially below umbra - calibration effects cannot be excluded.
- Cr I and Hα: smooth gradients from umbra to quiet Sun.
- Indicates opacity or thermal anomalies within the bridge.

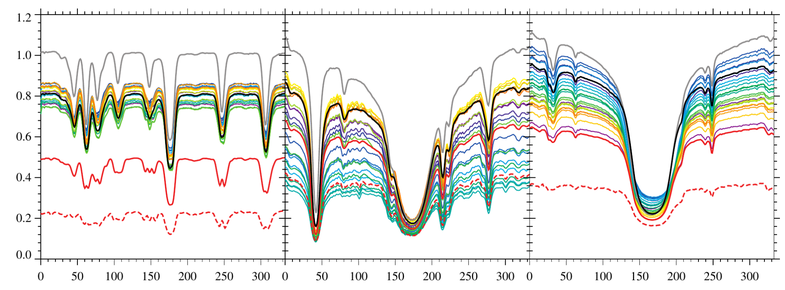

Fig. 5: 3 × 3 pixel average of spatial spectra along the light bridge. Color scheme progresses from purple at the north-east to orange at the south-west as indicated in the left panel of Figure 3. Dashed red line: umbra; solid thick lines: quiet sun (gray), penumbra (black), and umbra (red).

Temporal Evolution at Chromospheric Heights

- Hβ and Hα: progressive line-core deepening and asymmetry.
- Cr I: mostly static, confirming changes originate higher in the atmosphere.
- Suggests ongoing chromospheric restructuring, possibly linked to heating or mass motions.

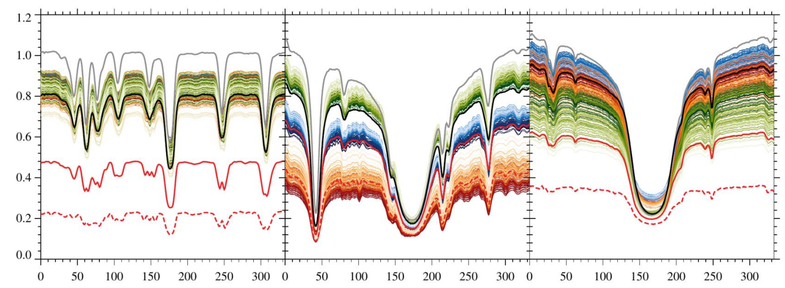

Fig. 6: 3 × 3 pixel average of temporal spectra at three fixed positions along the light bridge as indicated in the middle panel of Figure 3. Temporal evolution is indicated by colored lines in orange, blue, and green – become lighter with time. Dashed red line: darkest part of the umbra. Solid, thick lines represent the quiet sun (gray), penumbra (black), and umbra (red).

Conclusion

- Signatures of vertical atmospheric coupling, with opposing flow directions in the photosphere and chromosphere.
- Hβ proved particularly sensitive to localized absorption effects, displaying unusually deep line cores and dynamic temporal evolution.
- BaSAMs and Hα filtergrams indicate stable structuring above the light bridge.
- The combination of velocity maps and spectral diagnostics indicates that the light bridge is an active site of energy redistribution and magnetic reconfiguration.
- Although likely rooted in subsurface processes, the observed restructuring manifests predominantly in the chromosphere - only minor signatures in photosphere.