Cluster analysis for two solar physics problems: Stokes parameters & NUV spectra

J.S Castellanos-Durán[1] & L. Kleint[2]

1. Departamento de Física, Universidad Nacional del Colombia, Bogotá, Colombia, 2. Lockheed Martin Solar and Astrophysics Laboratory

Contact: jscastellanosd@unal.edu.co

Group of Solar Astrophysics
Observatorio Astronómico Nacional
Universidad Nacional de Colombia

Abstract: By studying spectral profiles and their polarization state, we are able to investigate the solar atmosphere and its physical properties, such as temperatures, velocities, densities and magnetic fields. For this purpose, we applied a cluster technique to identify and catalog different kinds of profiles for two solar physics problems. First, using polarimetric data at 6302 Å (photospheric line) taken by IBIS, we determined how the Stokes parameter V varies during a small solar flare. Secondly, using state-of-the-art solar data taken by the recently launched NASA mission IRIS, we made a catalog of the NUV MgII lines in different region of the solar atmosphere.

Polarimetry

Stokes parameters are used to describe the state of polarization of an electromagnetic wave

$$\frac{E_i}{E_{0i}} = \mathrm{Re}\left[e^{i\left(\omega t - \frac{2\pi z}{\lambda} + \delta_i\right)}\right], \quad i = x, y \quad (1)$$

The four Stokes parameters I, Q, U and V can be defined either in terms of the electric field or as quantities that are measurable, i.e. intensities using linear (Q and U), circular (V) polarization, or without any polarizer (I). The analytical expressions are given by

$$(2)\quad \begin{aligned} I &= E_{0x}^2 + E_{0y}^2 \\ Q &= E_{0x}^2 - E_{0y}^2 \\ U &= 2E_{0x}E_{0y}\cos(\delta_y - \delta_x) \\ V &= 2E_{0x}E_{0y}\sin(\delta_y - \delta_x) \end{aligned} \qquad (3)\quad \begin{aligned} I &= I \\ Q &= I_{0^\circ} - I_{90^\circ} \\ U &= I_{45^\circ} - I_{45^\circ} \\ V &= I_{rhc} - I_{lhc} \end{aligned}$$

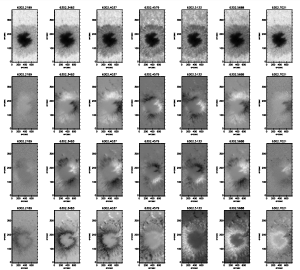


Fig 1. The Stokes parameters I, Q, U and V (respectively) at different wavelength steps of the photospheric line at 6302 Å taken by the Interferometric Bidimensional Spectrometer (IBIS) in Sunspot, NM.

Micro flares on October 15, 2011

A series of micro flares occurred between 15:00 – 16:00 UT, simultanously with polarimetric observations by IBIS. In order to determine which of the active regions produced each explosive event, we calculated the solar flux for each AIA channel, taking different numbers of square subregions as shown in Fig. 2.

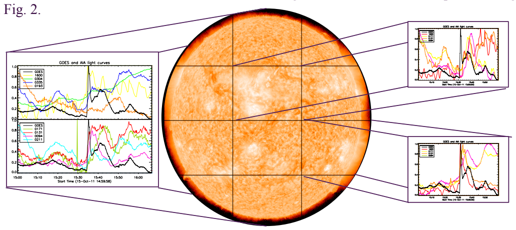
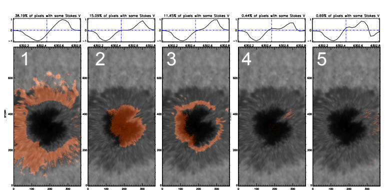


Fig 2. AIA light curves of the entire full disk (left), subregions (right) and overplotted is the GOES 1-8 Å light curve.

Analyzing a small flare with the cluster technique

To determine if the photosphere contributed to the micro flare, we searched for different kinds of profiles of the Stokes parameter V using the cluster technique. The V parameter was chosen because it is proportional to the line-of-sight magnetic field (see eq. 4).



$$V = -\mu\lambda_0^2 g_L B_{\|}\frac{dI_0}{d\lambda} \quad (4)$$

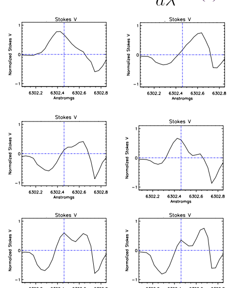


Fig 3. (Top): Stokes V Profiles and their location (orange pixels) over the solar photosphere.
Fig 4. (Right): Profiles that were observed during the micro flare at the line at 6302 Å taken by IBIS.

Profiles classes that were found:

- Doppler shifted (e.g. image 1)
- Strong magnetic field (e.g. images 2-4)
- Sum of profiles (e.g. image 5)
- Opposite sign in the magnetic field
- Strange profiles (e.g. fig 4)

Cluster technique

The technique works with k random initial profiles and then, iteratively moves items between clusters, minimizing variability within each cluster and maximizing variability between clusters.

- Step 1: K random initial profiles.
- Step 2: Choose K final profiles that have the most different shapes between each other.
- Step 3: Assign all the profiles (total pixel per image) to one of the K categories.

Interface Region Imaging Spectrograph (IRIS):

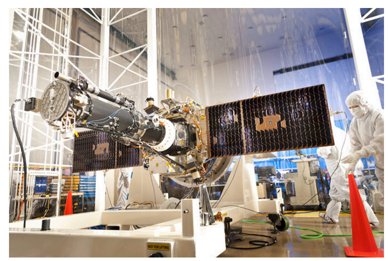


Fig 5. Photograph of the Interface Region Imaging Spectrograph (IRIS)

The Interface Region Imaging Spectrograph (IRIS) was launched on June 27, 2013. This spacecraft is a multi-channel imaging spectrograph with a 20 cm UV telescope (Figure 5). IRIS is obtaining Ultra Violet spectra (figure 6, left) and slit-jaw images (Figure 6, right)

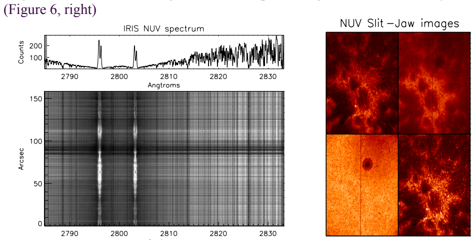


Fig 6. Sample of IRIS observations: NUV solar spectrum (left), NUV Slit-jaw images (right)

MgII line profiles using IRIS data

To identify the locations of different physical conditions in the solar chromosphere, it is desirable to create a catalog of the Mg II line-profiles. For this purpose, we use the cluster technique on the high resolution spectra from IRIS.

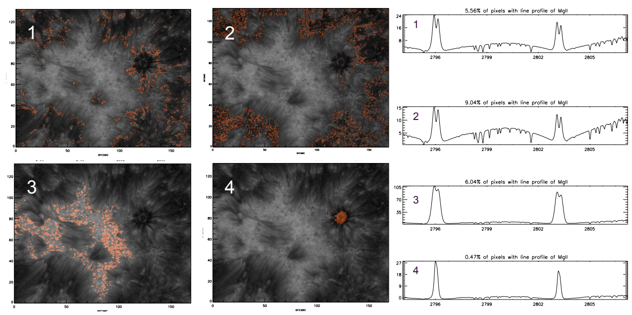


Fig 7. The background image shows the Sun at the wavelength of the maximum of the blue peak of the MgII K line. The orange pixels are the regions which have similar line profiles with their average profile shown on the right of the image.

We identified that fibrils, quiet sun, umbra, penumbra and the edge between features have different kinds of profiles (see Figure 7). Furthermore, some profiles have very strong asymmetries, or different intensity levels between the two Mg II lines. At the limb, we found profiles with a red-enhanced asymmetry, in contrast to the blue-enhanced asymmetries shown in Fig. 8.

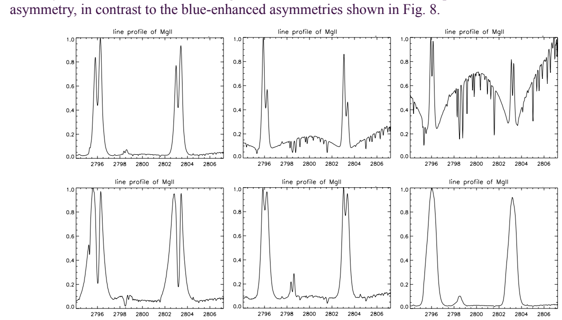


Fig 8. Sample of asymmetric profiles that were found in areas with different solar features, such as bright points, high temperatures, and magnetic fields, or near to the limb.

Acknowledgments

Sincere thanks and acknowledgement to Dr. Lucia Kleint for all her support and to Lockheed Martin Solar and Space Physics Laboratory team.

reference

De Pontieu, B. and Lemen, J. *IRIS Technical Note 1: IRIS operations*. **2013.**
Stenflo, J. *Theory of solar polarization*. **2008.**
Nitta, N. V. et al. *Soft X-ray Fluxes of Major Flares Far Behind the Limb as Estimated Using STEREO EUV Images*. **2013**
Leenaarts, J. et al. *The formation of IRIS diagnostics II. The formation of the Mg II h&k lines in the solar atmosphere.* **2013**

Summary and future work

- We classified the Stokes parameter V of the 6302 Å line in a sunspot that hosted two micro flares. We found some strange profiles near by kernel emission observed by AIA and HMI. The next step would be to combine the classes that were observed over the photosphere with chromospheric observations at 8542 Å, and compare with results of Stokes inversions to determine the atmospheric conditions, which produced these events.
- We classified and located the Mg II line profiles in the chromosphere and transition region. In the future, we are going to compare with simulation results to determine, which conditions of temperatures, velocities, and magnetic fields generated each of these profiles.