In situ detections of Space Weather by the LYRA radiometer on board the PROBA2 satellite

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Abstract

The Large Yield RAdiometer (LYRA) is an ultraviolet irradiance radiometer on-board ESA's PROBA2 micro-satellite. Since its launch, in 2009 it observes the Sun in four different passbands, chosen for their relevance to solar physics, aeronomy and space weather. Flying on an altitude of 725 km, LYRA proved to be an excellent flare monitor and is involved in the analysis of the atmospheric composition of the Earth.

One of the most peculiar and intriguing results of LYRA is the detection of short, strong, bursts that do not directly correlate with solar coronal events, nor with pointing of the instrument to Earth's upper atmosphere, but correlate well with high Ap index on Earth's surface. The location of the PROBA2 spacecraft during those detections also correlates well with the Earth's magnetic field lines with a Mcilwain L-value of three and and above six, providing an independent confirmation of the magnetic origin of these detections. Most intriguingly those Mcilwain surfaces correspond to areas between the Van Allen belts and outside the outer radiation belt.

As LYRA has the ability to observe in four different UV bandpasses, using filters and detectors of different technology, the comparison between these filters allows us to pin down the aforementioned detections as caused either by high energy electrons or hard EUV/soft X-ray photons.

1 The PROBA2 orbit

The characteristics of the PROBA2 orbit:

- Heliosynchronous
- Polar
- Dawn-dusk
- 725 km altitude
- 100 min duration
- Crosses the auroral oval 4 times an orbit

2 The LYRA instrument on board the PROBA2 satellite

The LYRA instrument consists of three different redundant units each containing four different UV and EUV channels. Below is a table of the different filters, bandpasses and detector technologies for the three LYRA units.

Channels (bandpasses)	Lyman-α (120-123 nm)	Herzberg (190-222 nm)	Aluminum (17-80 + <5 nm)	Zirconium (6-20 + <2 nm)
Unit 1:	MSM (diamond)	PIN (diamond)	MSM (diamond)	P-N (silicon)
Unit 2:	MSM (diamond)	PIN (diamond)	MSM (diamond)	MSM (diamond)
Unit 3:	P-N (silicon)	PIN (diamond)	P-N (silicon)	P-N (silicon)

3 The detections

The algorithm for the automatic detection of the disturbances is (also see Fig. 1):

- The time series is smoothed with a window of 100 sec (the typical length of the disturbances)
- The smoothed time series is extracted for the original
- The σ value of the extracted time series is calculated
- The number of points of the extracted time series that have values above a limit of 4σ is counted
- If there are more than 10 points that have values above the average by more than 4σ, then we count a detection

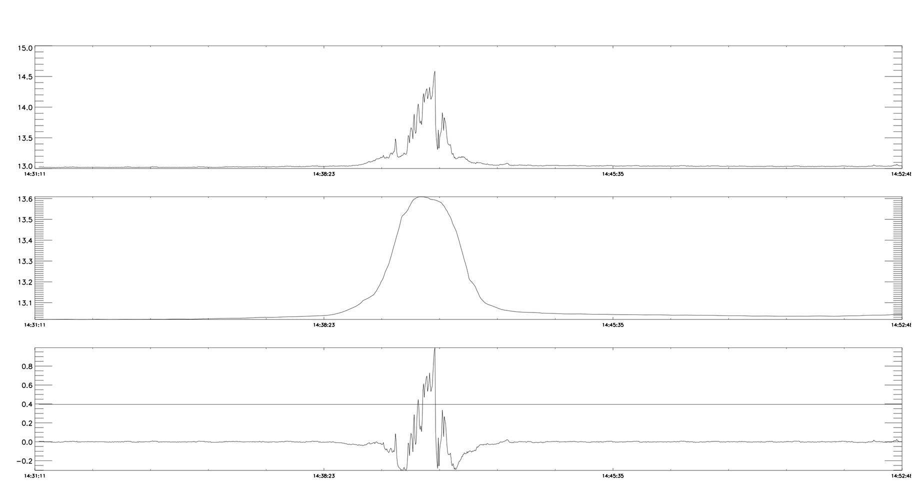

Figure 1: An example of the application of the algorithm for the automatic detection of the disturbances. The first time series is the original, the second is the smoothed and the third is the extracted. In this example the extracted time series has more than 10 instances where the counts exceed the 4 σ threshold, therefore this is a "disturbed" time series. The horizontal line on the third panel corresponds to the 4 σ level.

4 Disturbances vs Ap Index

The authors correlated the 3-hour, geomagnetic Ap index (as published by the NASA's National Geophysical Center) with the frequency of detection of a disturbancy by all four channels of LYRA's unit two for the period of April 2010 to December 2013. The Lyman-α and Herzberg channels only exhibit a very small number of detections that are probably false detections due to noise. Also the frequency of those detections is not effected by the value of the Ap index. The Aluminum and Zirconium channels exhibit a far more interesting behavior as they contain a large number of detections that also correlate extremely well with the Ap Index. Figures 2 & 3 illustrate the correlation between the frequency of detection of those events, for the aforementioned channels, with the geomagnetic activity on Earth's surface. The frequencies that correspond to Ap values of $\sim$10 or less are very close to the detection errors of the algorithm and should be considered practically zero. The "saturation" that appears above Ap values of $\sim$100 can either correspond to a physical limit of the observed phenomenon or to a limit of the PROBA2's orbit (ie the spacecraft only passes through the affected areas, for the given time window, therefore a very limited number of times therefor it cannot observe the phenomenon more frequently than that, even if the phenomenon is stronger).

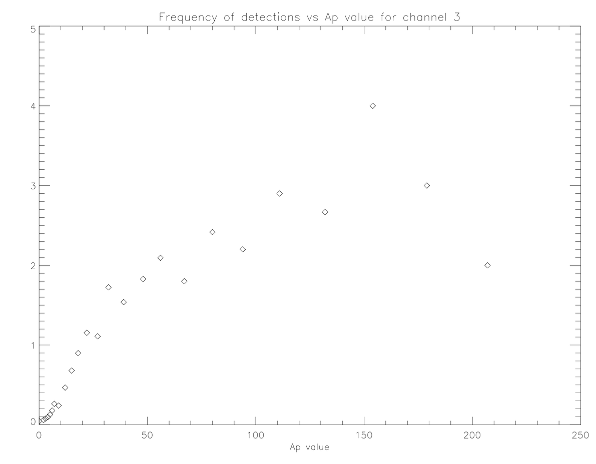

Figure 2: The frequency of occurrence of a disturbance in the Aluminum channel versus the Ap index for the same 3-hour window

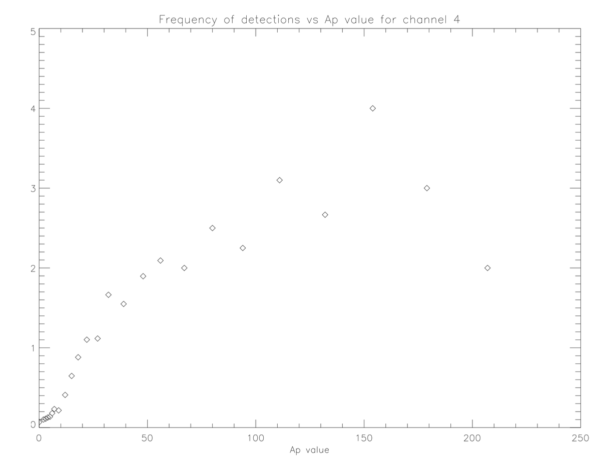

Figure 3: The frequency of occurrence of a disturbance in the Zirconium channel versus the Ap index for the same 3-hour window

5 Geographical distribution of the disturbances

An independent confirmation of the correlation between the disturbances observed by LYRA and Earth's magnetic activity can be achieved by plotting the positions of the satellite where more than two detections were obtained over the April 2010 to December 2014 period.

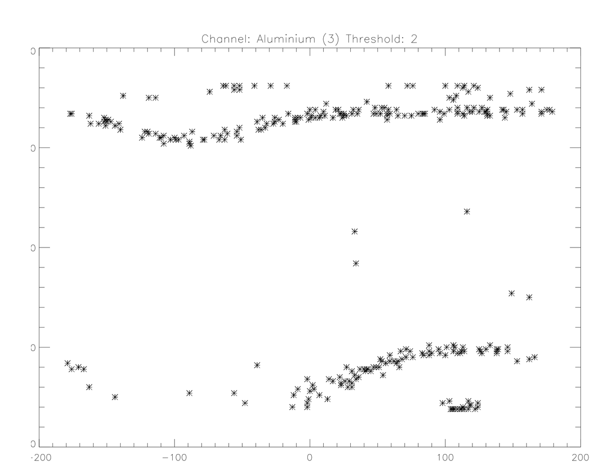

Figure 4: Map of the geographical locations where more than two detections of disturbances were made for the period 1/4/2010 to 31/12/2013, for the Aluminum channel.

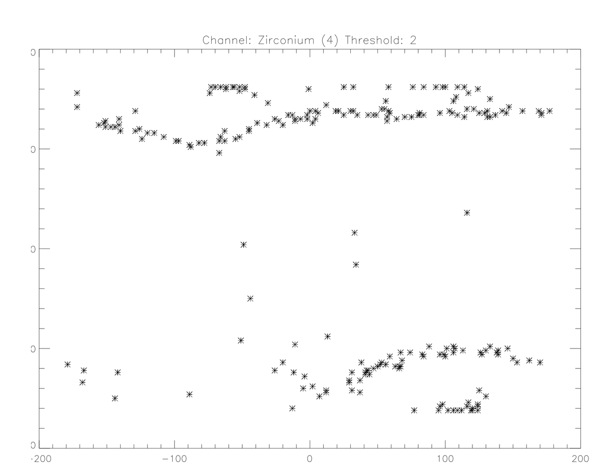

Figure 5: Map of the geographical locations where more than two detections of disturbances were made for the period 1/4/2010 to 31/12/2013, for the Zirconium channel.

Both Figures 4 & 5 correlate very well with the Mcilwain L-shell surfaces for values L=3 and L> 6 as can be seen in Figure 6. As the L=3 surface extents to the area between the van Allen radiation belts and the L> 6 surfaces extent to the area outside the van Allen outer radiation zone, the authors suggest that the observed disturbances are created in those areas.

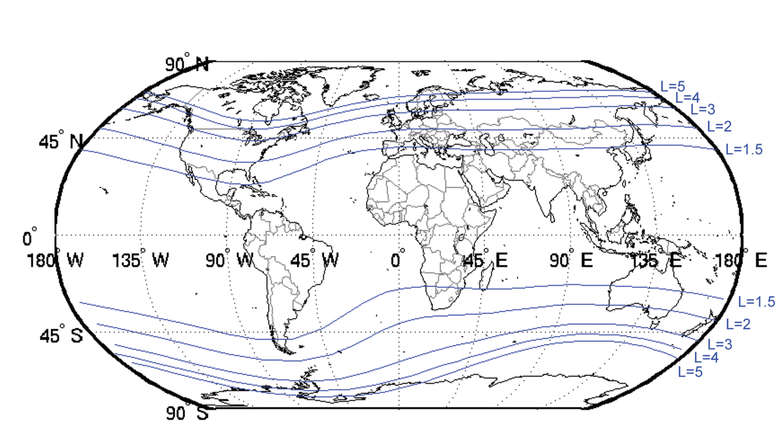

Figure 6: Map of the Mcilwain L-shell surfaces at sea level for L values of: 1.5, 2, 3, 4 and 5

6 Future Work

The next very important step for this project will be the identification of the nature of the disturbances. Although the magnetic origin of the effect is well established, the nature of the effect itself remains unknown. Since the Lyman-α and Herzberg channels of LYRA cannot observe the effect, there are two distinct possibilities of what the Aluminum and Zirconium channels observe: either hard photons such as EUV or soft X-rays or electrons with high energy. Comparisons with other instruments, such as SWAP (also on board PROBA2) and the Soil Moisture and Ocean Salinity (SMOS) mission (in a similar orbit to PROBA2) will help us to identify the nature of these events.