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 radiometer on-board ESA's PROBA2 micro-satellite. Since its 2009 launch 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, neither with the 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 5.8±0.8, providing an independent confirmation of the magnetic origin of these detections. Most intriguingly the $L = 6$ Mcilwain surface extends to an area well inside the outer Van Allen belt.

The same events are also observed by the Energetic Particle Telescope (EPT), an energetic particle detection instrument, on board ESA's PROBA-V mission. Similar detections made by the 2.4-8 MeV electrons channel, providing us with the identification of the cause of the detections.

1 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 100 points that have values above the average by more than 4σ, then we count a detection
- The length of the detection (i.e. the time difference between the first point above 4σ and the last) is measured. If found more than 200 sec or less than 50 sec then the detection is rejected

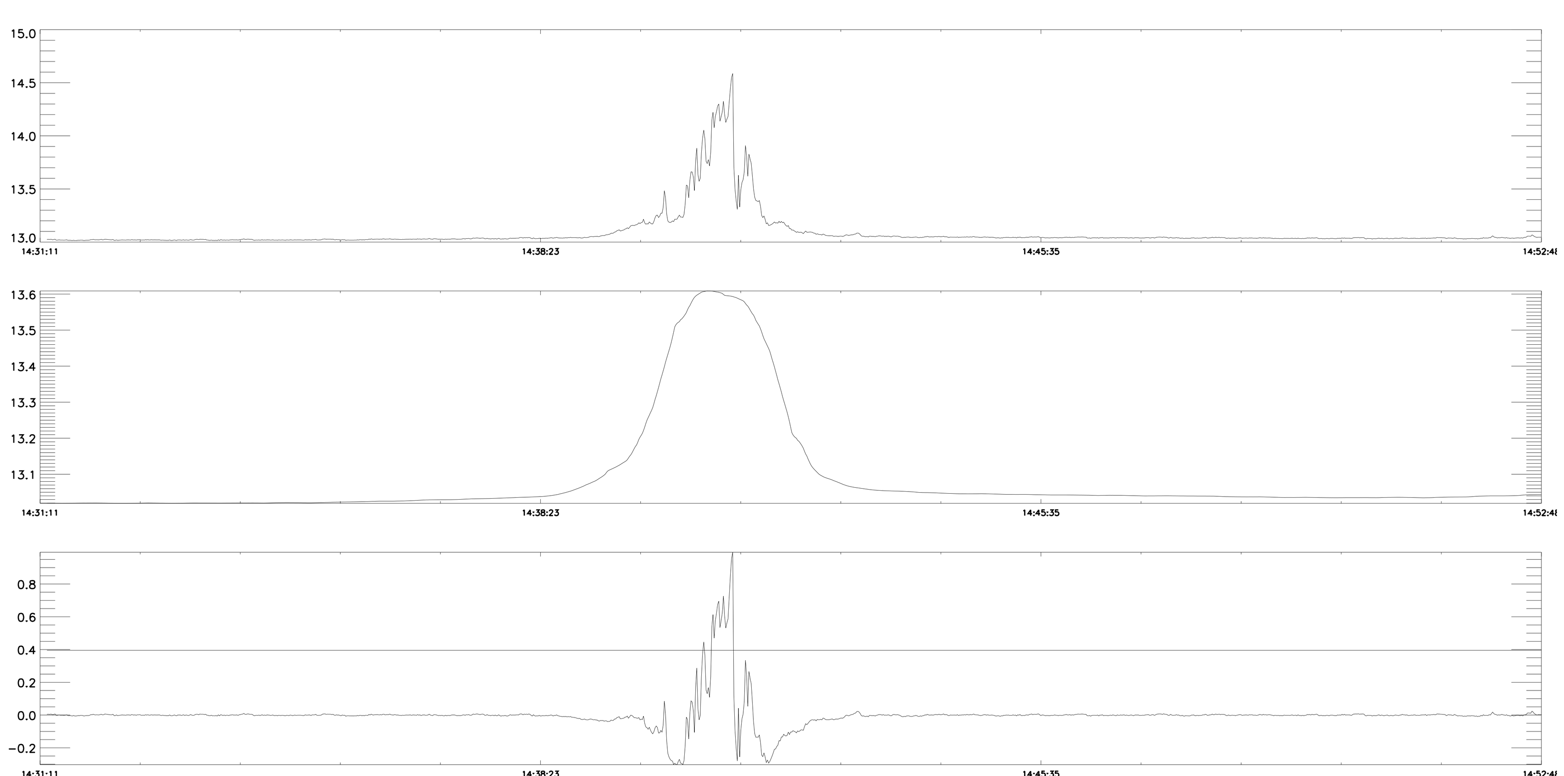

Figure 1: An example of the application of the algorithm for the automatic detection of the disturbances. The first time series is the original, the second is the smoothed and the third is the extracted. In this example the extracted time series has more than 100 points where the counts exceed the 4 σ threshold, therefore this is a "disturbed" time series. The horizontal line on the third panel corresponds to the 4 σ level.

2 Disturbances vs Ap Index

The authors correlated the 3-hour, geomagnetic Ap index (as published by the NASA's National Geophysical Center) with the likelihood of detection of a disturbancy by all four channels of LYRA's unit two for the period of April 2010 to December 2014. The Lyman-α and Herzberg channels do not exhibit any detections while the Aluminum and Zirconium channels contain a large number of detections that correlate extremely well with the a_p Index. Figure 2 illustrates the correlation between the likelihood of detection of those events, for the aforementioned channels, with the geomagnetic activity on Earth's surface. The wide spread of points for high a_p values can be explained by the small numbers of samples used for those points. The drop in the likelihood observed for $a_p = 180$ is due to the detections lost as the signal from the events is much weaker than the signal from solar flares (during geomagnetic storms the possibility of solar flares is also very high).

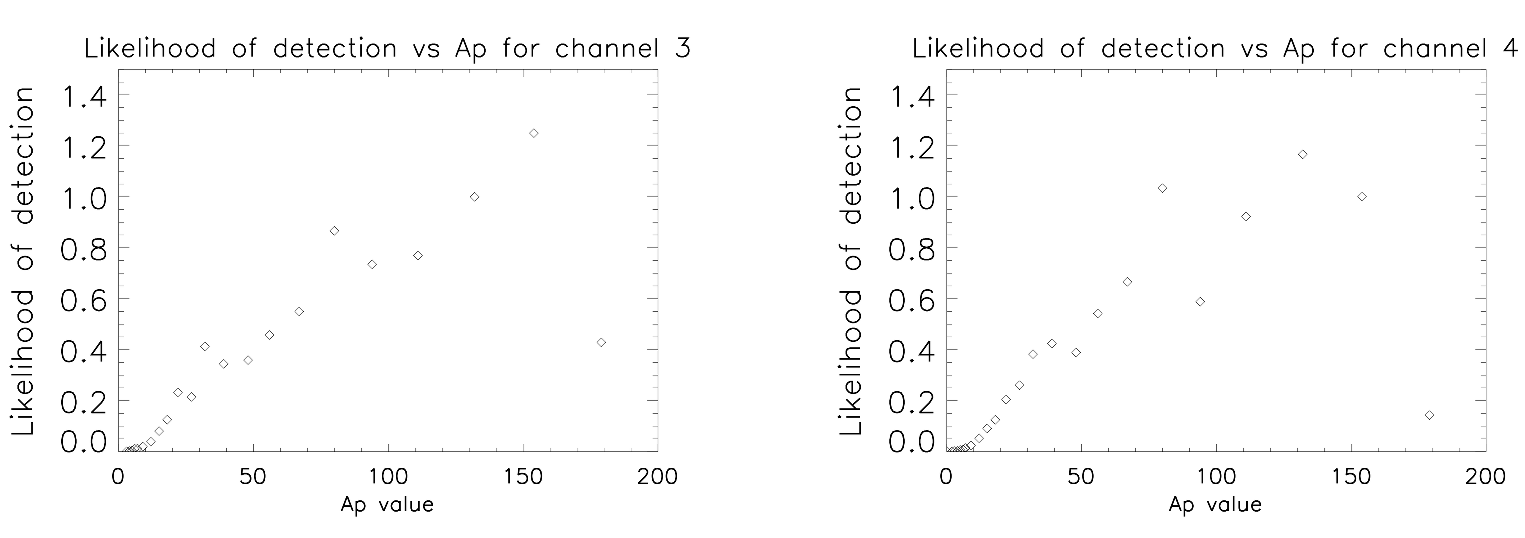

Figure 2 The likelihood of occurrence of a disturbance in the Aluminum (left) and Zirconium (right) channels versus the Ap index for the same 3-hour window

3 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 when the detections were obtained.

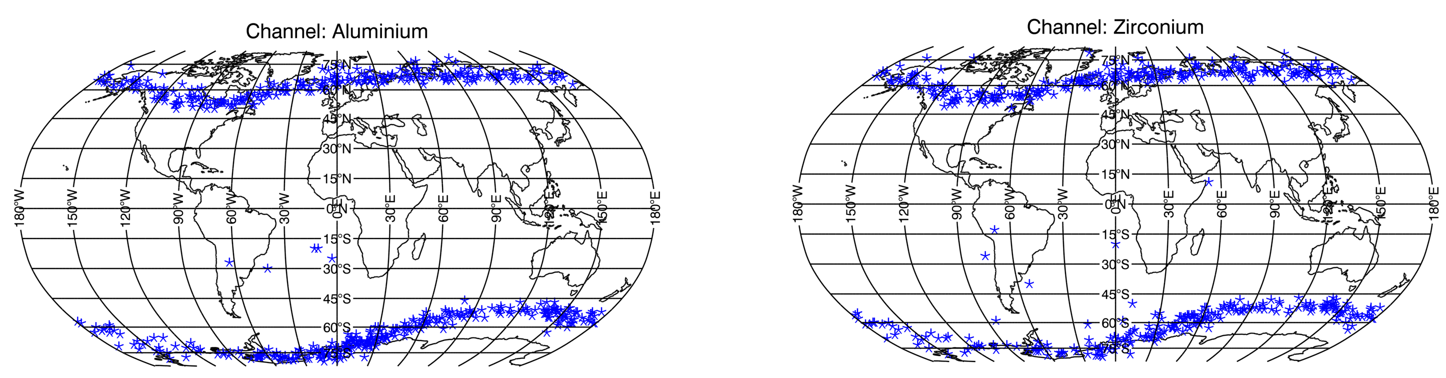

Figure 3. Maps of the geographical locations of the satellite during all the detections that occurred between April 2010 and December 2014. Left is channel 3 (Al) and right is channel 4 (Zr).

Both maps of Figure 3 correlate very well with the Mcilwain L-shell surfaces and the mean L-values of the positions of the detections (for both hemispheres) are 5.8±1.4 for channel 3 (Al) and 5.7±1.4 for channel 4 (Zr). While if we average the L-shell value of the positions of all LYRA detections (ie from both channels 3 & 4, and both LYRA units 2 & 3), the average values is 5.8±0.8. As the magnetic field lines that correspond to the Mcilwain L-shell 5.8 close inside the outer Van Allen radiation belt, the authors suggest that the observed phenomenon originates from plasma particles accelerated in that zone during electromagnetic activity and reach the altitude of the satellite via Earth's magnetic field.

4 EPT detections

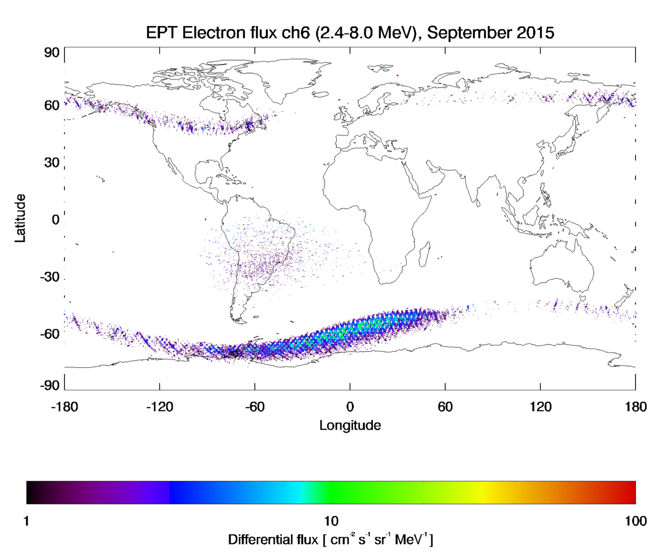

Figure 4. Map of EPT detections of channel 6 for September 2015. Channel 6 is sensitive to electrons of the 2.4-8 MeV energy range.

ESA's PROBA-V mission is dedicated to Earth's observation and in-situ measurements of space weather. EPT is an instrument designed for the detection of barionic charged particles of various energy ranges. Figure 4 shows a map of the detections made by channel 6 of EPT that is sensitive to electrons of energy range 2.4-8 MeV. This map is in agreement with the maps of Figure 3 with the only exception of the detections of the South Atlantic Anomaly (SAA) made by EPT. As such, it confirms the identification of the reported observations as electrons of the range of 2.4-8 MeV. The lower part of the range (ie 2.4 MeV) is a conservative estimation as the detections of the SAA made by EPT do not have LYRA counterparts and lower energy particles are know to penetrate the atmosphere in the SAA area more easily. Thus the energies of the electrons detected by LYRA are probably significantly higher than 2.4 MeV

5 Dawn vs Dusk detections

The PROBA-2 satellite flies constantly on a polar, dawn/dusk orbit, and thus, can detect any significant difference in the likelihood of an event taking place in the dawn or dusk part of the orbit.

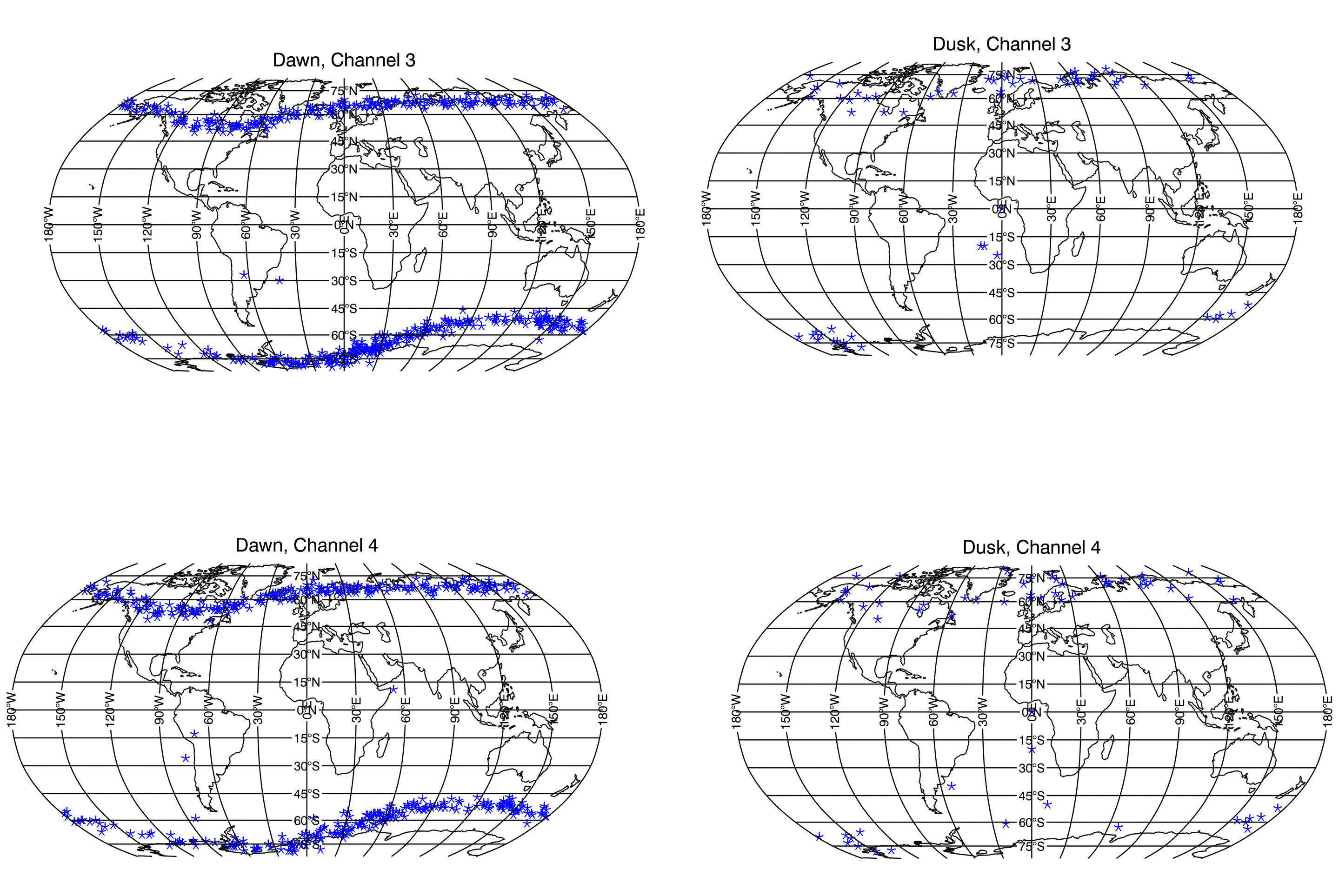

Figure 5. The geographic distribution of the detections that took place during the dawn (left-hand side maps) and dusk (right-hand side maps) for both channels 3 (top maps) and 4 (bottom maps).

Figure 5 reveals the much higher likelihood of a detection during the "morning" part of the orbit than the "afternoon". The number of detections for channel 3 are 509 and 63 for dusk and dawn, while for channel 4, 463 and 63 respectively. Thus, it is approximately 8 times more likely to have a detection during dawn than dusk and this is consistent for both channels. This is a significant and yet unexplained find that requires further investigation.