Automatic solar burst detection and classification

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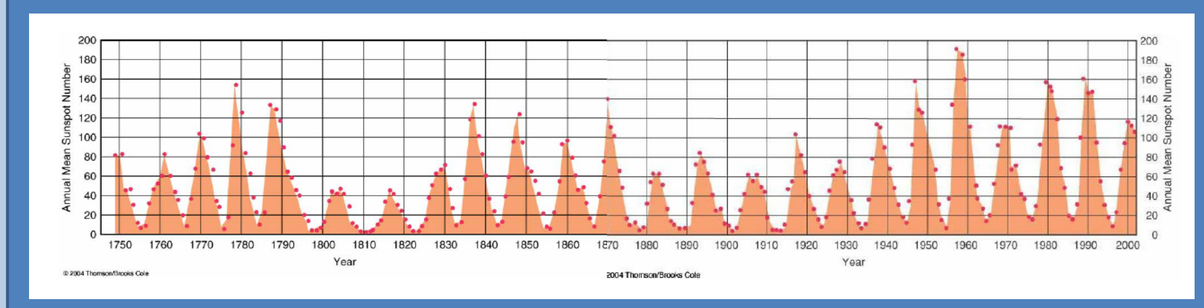
1 Introduction

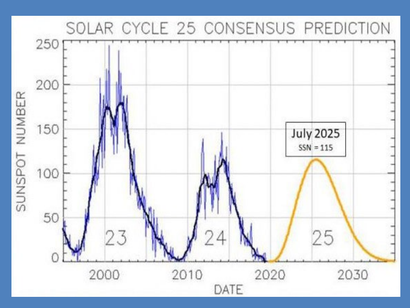
This work presents a system for automatic detection and classification of solar radio bursts (SRBs) based on deep neural networks. Specifically, YOLO (v4) has been trained, through manual labeling, with solar events reported since 2020, resulting in a model that allows for their detection on high-contrast spectrograms. Radio bursts from the solar corona provide key information in order to predict space weather hazards posed by the so-called coronal mass ejections (CME): high-energy charged particles in solar CMEs penetrating the Earth's magnetosphere will cause interference in circuitry and signals, particularly in satellites, and affect the electromagnetic spectrum on the Earth surface, thereby dooming communication and power lines among many other important infrastructures.

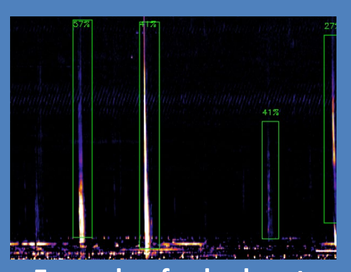
- **Given the importance of this phenomenon and recent technological advances, regular monitoring of radio bursts has increased, and large observational data sets have been produced. Therefore, their manual identification and classification is becoming unmanageable, calling for automatic methods like the one presented here.**

Why now?

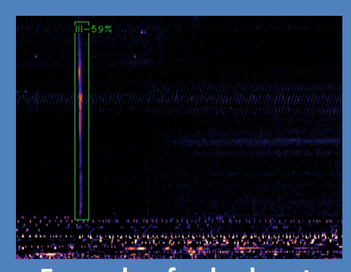
- **Solar cycles: approximately every 11 years there is a quasi-periodic change in the Sun's activity, measured in terms of variations in the number of sunspots observed on the solar surface.**
- **Sunspots: observed since the early 17th century, the sunspot time series is the longest continuously recorded of all natural phenomena.**







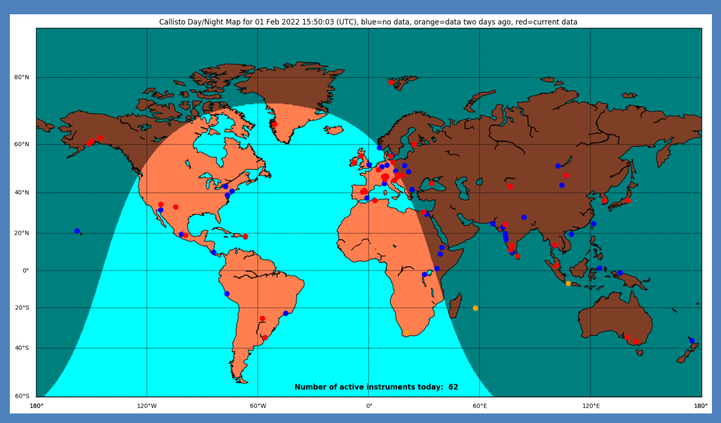
Example of solar burst detection



Example of solar burst classification

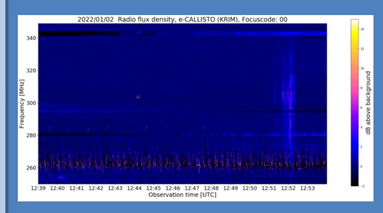
2 Data Source

- **e-Callisto Network: a network of low-cost radio receivers (radio-spectrometer) distributed around the globe to capture sporadic radio emissions from the Sun (Solar Radio Bursts-SRB).**
- **SRBs: are considered to be precursors to more explosive events on the Sun such as solar storms or CMEs, which makes them another element in what is known as Space Weather.**
- **Wide coverage: a large number of stations at different geographical longitudes in order to obtain observations 24 hours a day.**

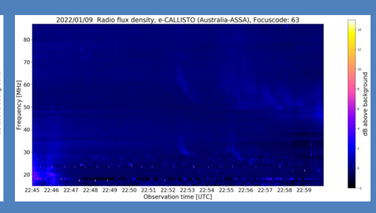


3 Data description

Based on the morphology and frequency-drift rates in the dynamic spectrograms, there are five primary types of radio bursts (types I to V) as well as other more complex bursts that are often observed.



Type I



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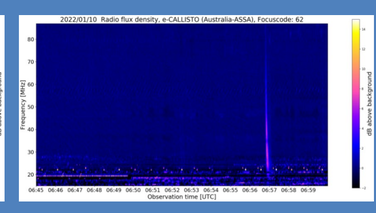

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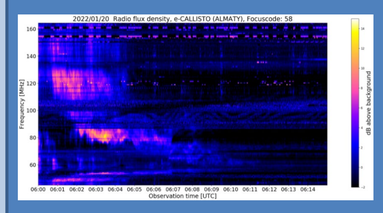
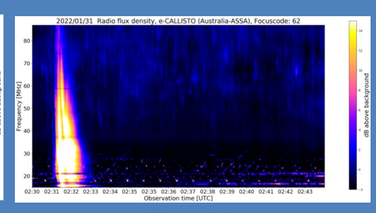
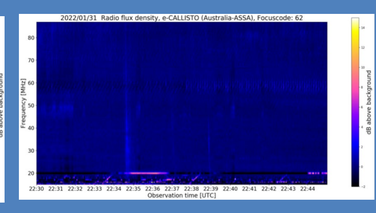


Type IV



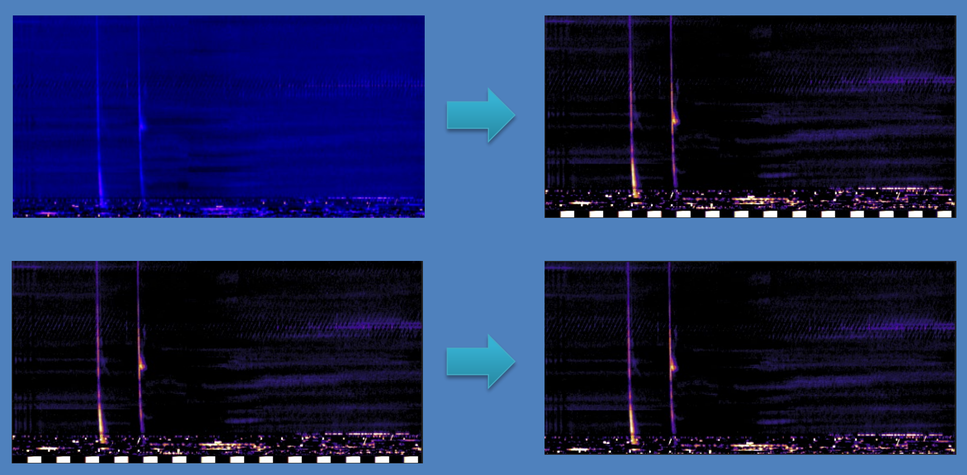
Type V



Type VI

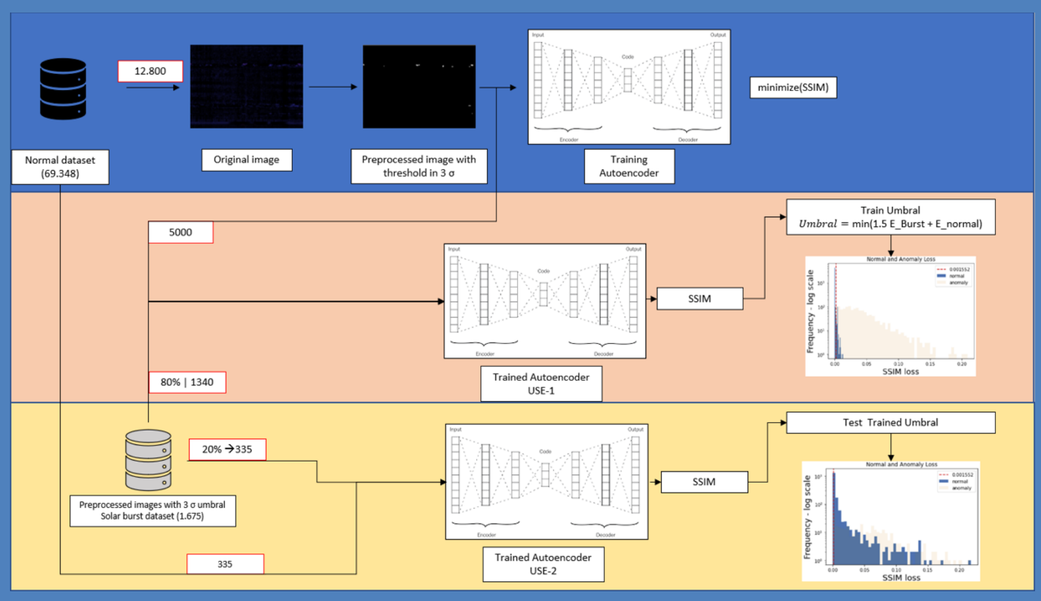
4 Data Preprocessing

Due to the nature of the problem, noise is an intrinsic factor that must be treated in the best possible way to achieve satisfactory results. Specifically, multiple frequency channels have been removed due to white spots appearing in the image, a background cancellation operation has been applied and finally high contrast images have been generated to make solar events more easily detectable.



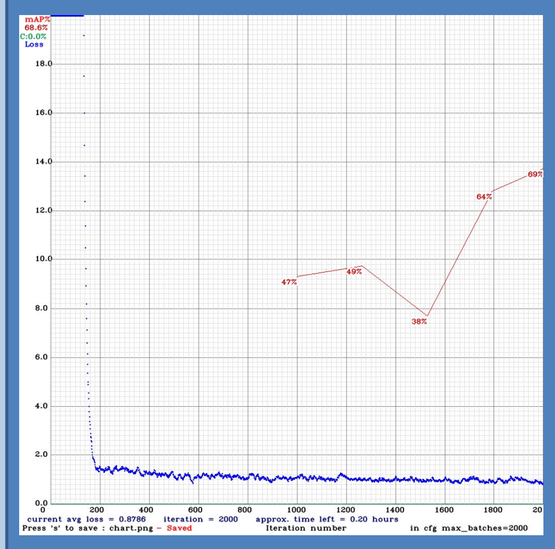
5 Approaches

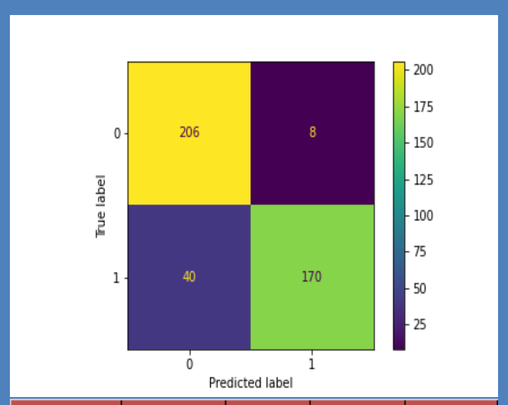
For this problem multiple approaches have been tested, from unsupervised, using classical architectures such as autoencoders and SVM OC, to supervised using state-of-the-art models for object classification via transfer learning.



6 Best Approach

After many approximations, the best results were obtained with YOLO V4, a single-stage object detector. For this purpose, 520 solar events from a single station were first labeled and predictions were made on all those offered by the e-Callisto menu, a tool we specifically developed for this work. Finally, another training was performed adding the false positives obtained by the predictions of the first model and labeling the rest of the solar events of that station, being now a total of 1400. The results for all the stations are shown below:

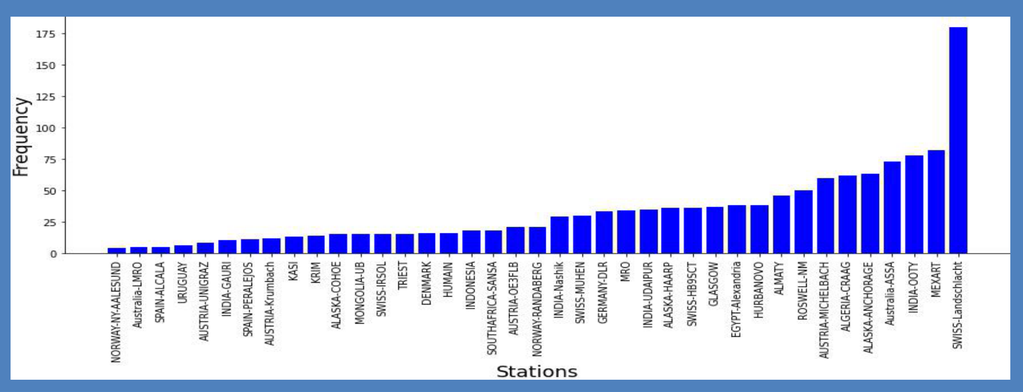




	precision	recall	f1-score	support
No Burst	0,837	0,963	0,896	214,000
Burst	0,955	0,810	0,876	210,000
accuracy	0,887	0,887	0,887	0,887
macro avg	0,896	0,886	0,886	424,000
weighted avg	0,896	0,887	0,886	424,000

7 Conclusions

These results are undoubtedly a breakthrough in the problem of detecting solar events. This is so for multiple reasons. First, the metrics achieved for a single station are at the same level as the latest advances reported in the field. However, it is hard to say which approach is best due to differences in the databases used (station, time range, labeling zones, etc.). Second, the results shown, are derived from images that are very difficult to classify, in some cases even by humans. In addition, there are three other added values, firstly the ability to label several zones (events) in a single spectrogram allows for more informative, easier-to-generate event reports for the scientific community. Secondly, since confidence values are given for each labelled event, optimization of the confidence threshold (set to 0.25 in the results shown here) is an extra handle on discrimination power. Finally, the possibility of analyzing the distribution of solar events of each station based on the predictions made.



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