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A New Deep Learning Model to Detect Gamma-Ray Bursts in the AGILE Data

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ABSTRACT

AGILE space mission was launched in 2007 to study X-ray and gamma-ray astrophysics. AGILE operated in spinning mode from 2009 until 14 February 2024, when it re-entered the Earth's atmosphere. We analyzed the data acquired by the AGILE Aanti-coincidence system (ACS), which is designed to reject charged background particles. It also detects X-ray photons in the 50 - 200 KeV energy range and saves each panel count rate in the telemetry as ratemeter data, a time series with a resolution of 1.024 sec. The project aims to develop a new method to detect Gamma-Ray Bursts (GRB) in the data acquired by the AGILE/ACS. This method was implemented in two phases. First we developed a Deep Learning model to predict the background count rates of the AGILE ACS top panel (perpendicular to the pointing direction of the payload detectors) using the satellite's orbital parameters as input. Second we implemented an algorithm that can detect GRBs when the real count rates acquired by the ACS are significantly higher than those predicted by the model. After training, the model can predict the ACS count rates with a mean reconstruction error of 3.8%. We evaluated the method using the ACS's light curves extracted from the AGILE archive using the list of GRBs present in the GRBweb catalog. The model detected 39 GRBs with a significance greater than 3 sigma. Results contain four GRBs detected for the first time in the AGILE data. This activity is also funded with an INAF Mini-Grant 2022.

1. AGILE context

AGILE [1] is a space mission of the Italian Space Agency (ASI) devoted to high-energy astrophysics, launched in 2007 and which terminated its operation in 2024. Since 2009, the AGILE satellite spins around its sun-pointing axis with an angular speed of about 0.8 degrees/sec, thus completing a rotation every ~7 minutes. This work uses data acquired during this so-called "spinning mode" observing period. AGILE has an anti-coincidence system (ACS) comprising five independent panels surrounding all AGILE detectors to reject background-charged particles efficiently. The ACS detects hard-X photons in the 50 - 200 KeV energy range and continuously stores each panel count rate in the telemetry as ratemeters data, with 1.024 sec resolution. We developed a new method based on a Deep Learning (DL) model to detect Gamma-ray bursts (GRB) in the ACS top panel data. The DL model predicts the background value of the AGILE ACS top panel using the satellite's orbital and attitude parameters. The output of this model is used to calculate the difference between the count rates acquired by the ACS and the predicted ones. This value is called anomaly score. When the anomaly score is higher than a predetermined threshold we detect a GRB.

2. Deep Learning model

The DL model executes a regression task and is implemented with a dense neural network of three hidden layers of 512, 256 and 128 neurons each. We used dropout layers with a dropout rate of 2% as a regularization technique. The input values of the model are 17 parameters representing the AGILE orbital and attitude configuration (e.g., detector pointing, altitude, etc.). The model output is the predicted count rate of the ACS top panel. We created a dataset of more than 80 million orbital parameters configurations extracted from the 2020 data archive with the associated ACS top panel ratemeters (the labels of the dataset). We split the dataset into training, test, and validation datasets. The orbital parameters and the ACS ratemeters are normalized between 0 and 1 to improve the computations.

We excluded from the dataset the passages into the South Atlantic Anomalies and the time windows with known GRBs to analyze background-only time windows. We trained the model with the Nadam optimizer and the Mean Absolute Error loss function for 109 epochs. Fig. 1 shows the ACS top real (blue) and predicted (red) count rates for one AGILE orbit. The mean reconstruction error is 3.8%. We calculated the p-value distribution of this model using 20 million background-only orbital parameters. The p-value distribution is used to define thresholds on the anomaly score for different sigma levels.

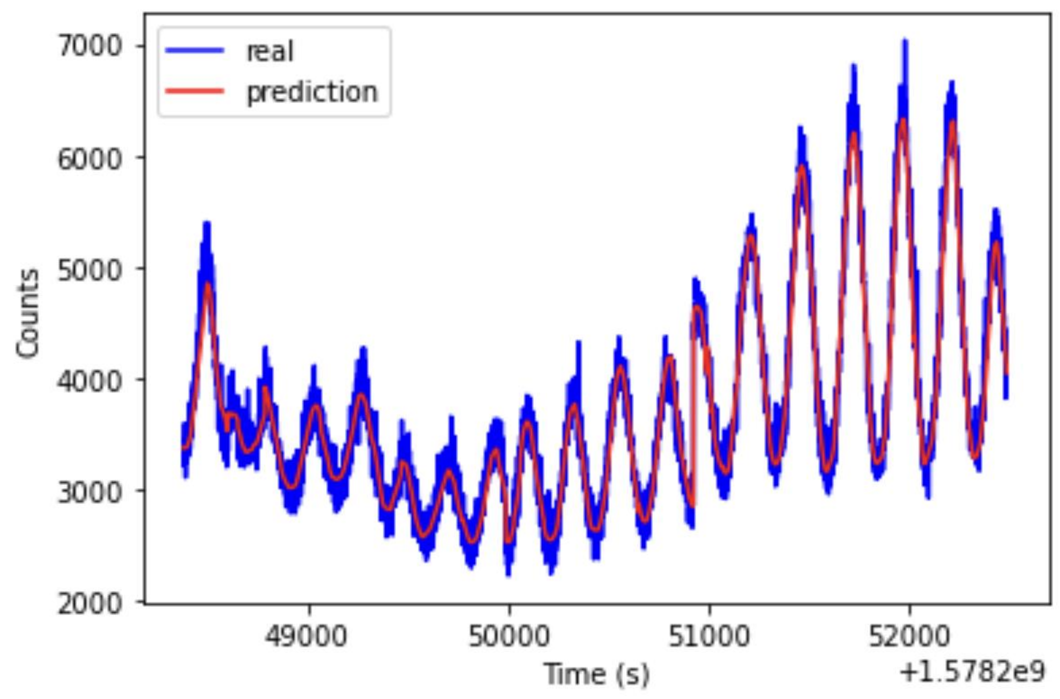

Fig. 1: Example of real ACS count rates (blue) and predicted ones by our deep learning model (red). Adopted from [3].

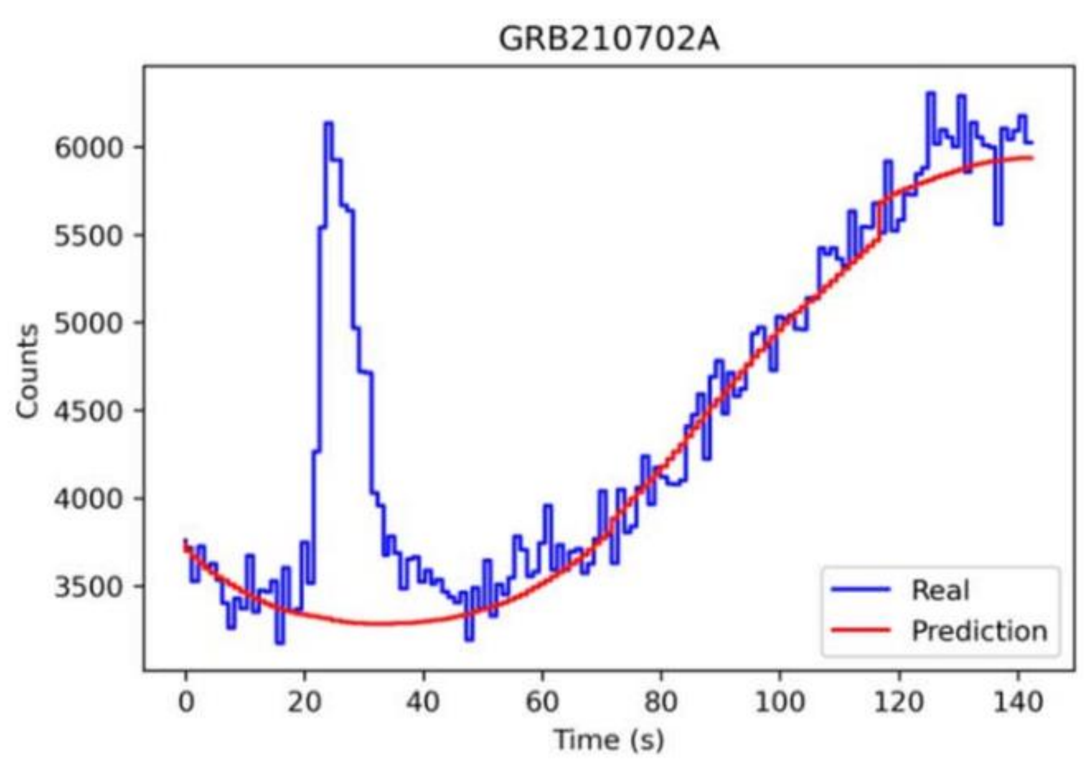

Fig. 2: Example of GRB detected by the ACS ratemeters. The difference between the predicted count rates and real ones can be used to detect the GRBs. Adopted from [3].

3. Results

We created a GRB dataset using the GRBweb catalog and extracting data from the AGILE ACS archive using the trigger times in the catalog. The model detected 39 GRBs with sigma ≥ 3. Figure [2] shows the ACS acquired (blue) and predicted (red) light curves related to GRB210702A. We detected four GRBs never detected in the AGILE data with previous analyses. Results prove an improvement in the detection capability compared to previous analysis methods.

4. Conclusions and Future Works

We developed a deep neural network trained with millions of AGILE orbital parameters configurations to perform a regression task predicting the background count rates of the AGILE ACS top panel. Results show that this model can predict the ACS count rates with a mean error of 3.8%. We developed an anomaly detection method [3] to detect GRBs when the differences between predicted and acquired count rates exceed a predefined threshold. The advantage of this method is that it does not need a detrending algorithm as other detection methods [2] that can introduce artificial anomalies in the data. The model detected 39 GRBs. Four GRBs are new detections in the AGILE data. We plan to use this method to train models to predict the background level of other detector instruments.

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