Deep Learning Method for AGILE-GRID GRB Detection

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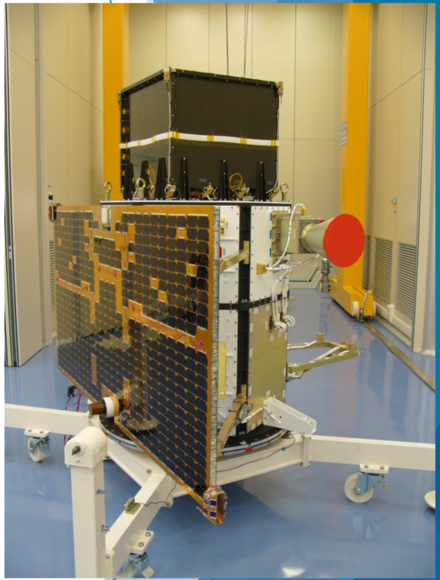
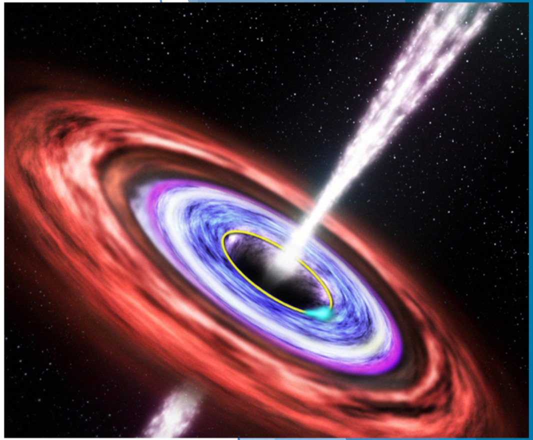
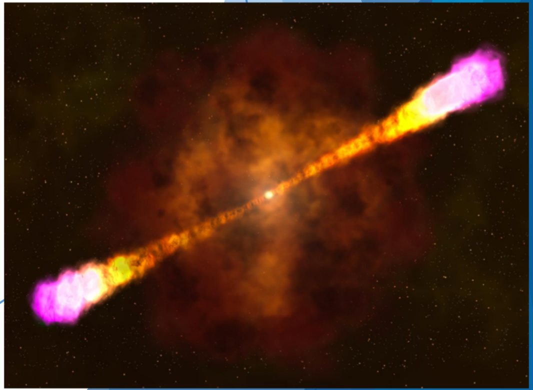
- AGILE is an Italian Space Mission funded by INAF, ASI and INFN
- AGILE is observing the Gamma-Ray sky since its launch on 23 April 2007
- AGILE has on board three instruments: Gamma Ray Imaging Detector (GRID), SuperAGILE and Mini-Calorimeter
- The instrument used for this work is the GRID instrument, with an energy range between 100MeV and 10 GeV



Gamma Ray Burst

- GRBs are extremely energetic explosions that occur in distant galaxies (Billions of light years).
- They are the brightest electromagnetic events known in our universe
- GRBs have a collimated emission of energy into a narrow jet, to see them the GRB needs to be pointed in the observer direction
- The prompt energy emission usually has a duration in the scale of seconds.





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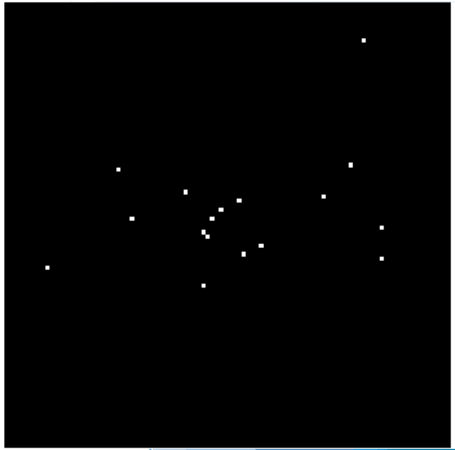
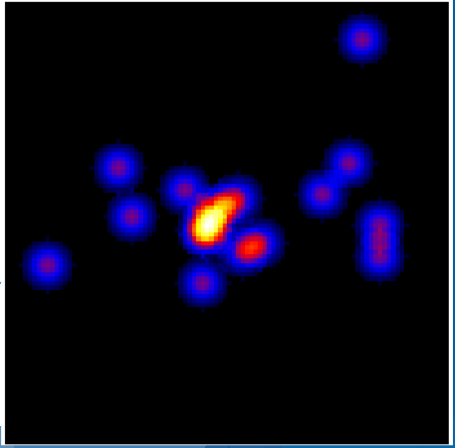
AGILE and GRB

- AGILE is able to detect GRB using all its three instruments
- This work is focused on the GRID instrument that produces maps of the sky called counts maps
- The count map show the gamma-ray photons detected by the GRID instrument, binned inside the image pixels
- After a Gaussian Smoothing the image is clearer
- The GRID can detect GRB in its energy range, we developed a new method to improve the detection performances





GRB and Multi-messenger era

- The GRB detections are shared with the Scientific Community through the Gamma-Ray Coordinates network (GCN)
- Using this network all astrophysical missions share the coordinate of detected GRB to allow other mission to point their instrument and follow the GRB event
- The GCN network is used to exchange informations helpful to find a relationship between Gravitational Waves and GRBs
- With this new method we want to detect short GRBs as counterpart of Gravitational Wave events

AGILE and Multi-Messenger era

- AGILE sends to the Community an alert when a new GRB is detected from MCAL data with a significance over a threshold
- AGILE also receives alerts from external instruments to search inside the AGILE instruments data the same event
- The AGILE Team developed a pipeline for the Real-Time Analysis and response to these alerts
- This new method for the GRB detection will be implemented as an analysis tool of the AGILE Real-Time pipeline

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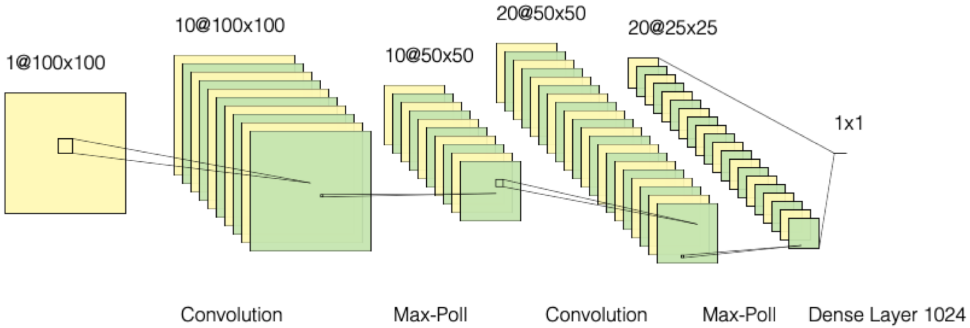
Why Deep Learning?

- Standard methods to evaluate GRB detection uses the list of photons selected in a radius from the GRB position
- We developed this new method to detect GRB directly from the counts maps, analyzed like an image composed of a pixels matrix
- We decided to implement a Convolutional Neural Network to classify maps searching for maps with a GRB inside
- The CNN is the class of Deep Learning used to classify images, it has different convolutional layer

CNN Implementation



- We implemented the CNN with convolution and max-polling layers.
- Starting from an image of 100x100 pixels we got at the end of the convolution layers a dense layer of 1024 values.
- After a dropout operation the CNN output is a vector of two values ranging between 0 and 1, this is the result

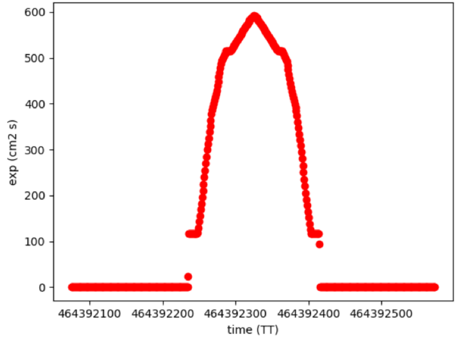
AGILE Observing Pattern

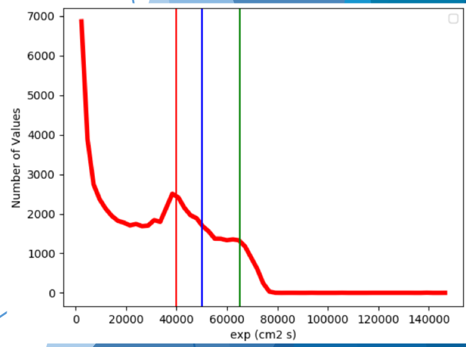
- Since November 2009 AGILE is operating in ”spinning-mode”, the satellite axis sweeps a 360° circle in the sky. This observing mode provides an unique capability for transient discoveries

- First of all we have studied the AGILE complex observing pattern during the satellite spins.

- We calculated the exposure of a fixed point in the sky during a spin to find the temporal variability. We also calculated the mean exposure value during a year for 200s integration

- From the first analysis we decided to search GRB in 200s counts maps





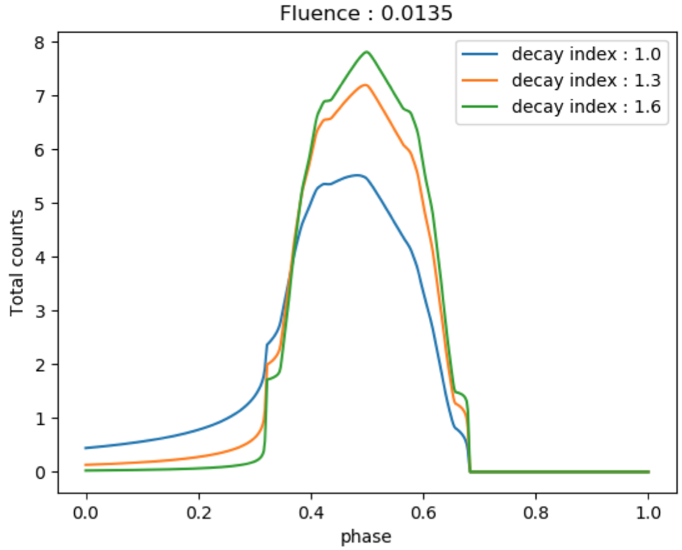
GRB Model

- We started from the Fermi-LAT GRB catalog[1] to define model of the GRB that AGILE-GRID can detect

- From this catalog we calculated a mean GRB fluence that can be detected by AGILE

- Using exposure and background level we calculated the number of photons that we expect from a GRB

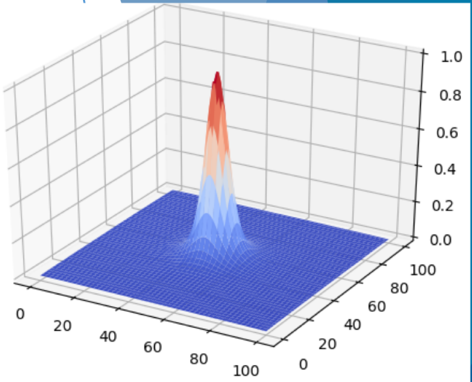
- We used this number of photons to simulate the datasets for the CNN training and testing

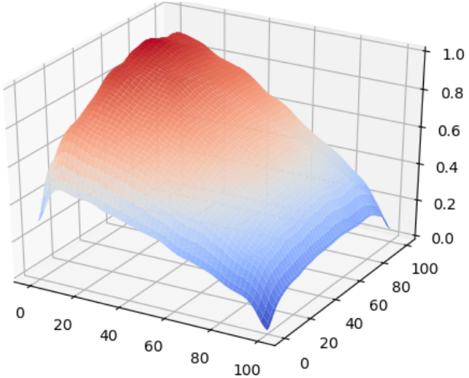


[1] M. Ajello et al. A Decade of Gamma-Ray Bursts Observed by Fermi -LAT, ApJ, 878, 1 (2019)

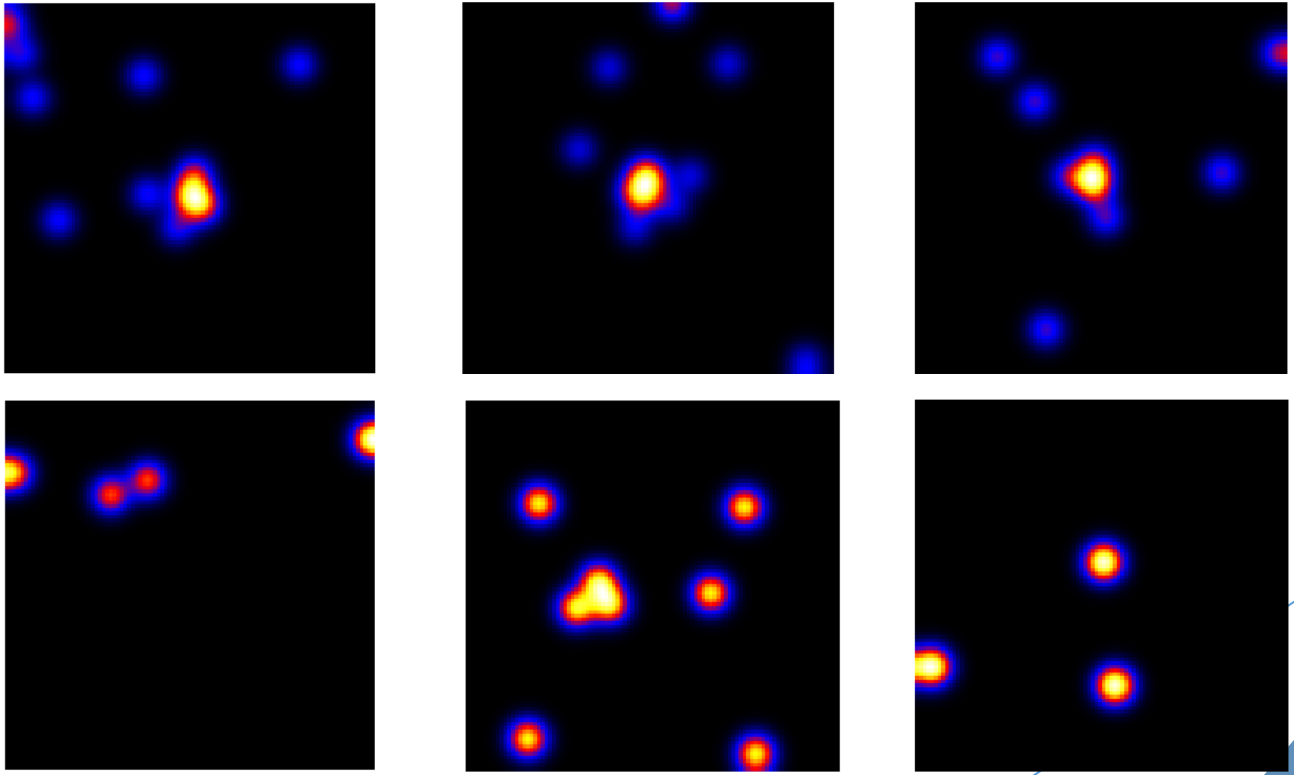
Datasets Creation

- ➢ In order to train and test the CNN we created two datasets, composed of 200 000 labeled simulated counts maps
- ➢ These datasets contain half of maps with just background and other half with a simulated GRB in the center of the map
- ➢ The simulated GRBs are centered because the context of this work is a pipeline for the analysis of external alert were time and position are known in advance
- ➢ We calculated histograms to check the datasets





AGILE-GRID Simulated Maps

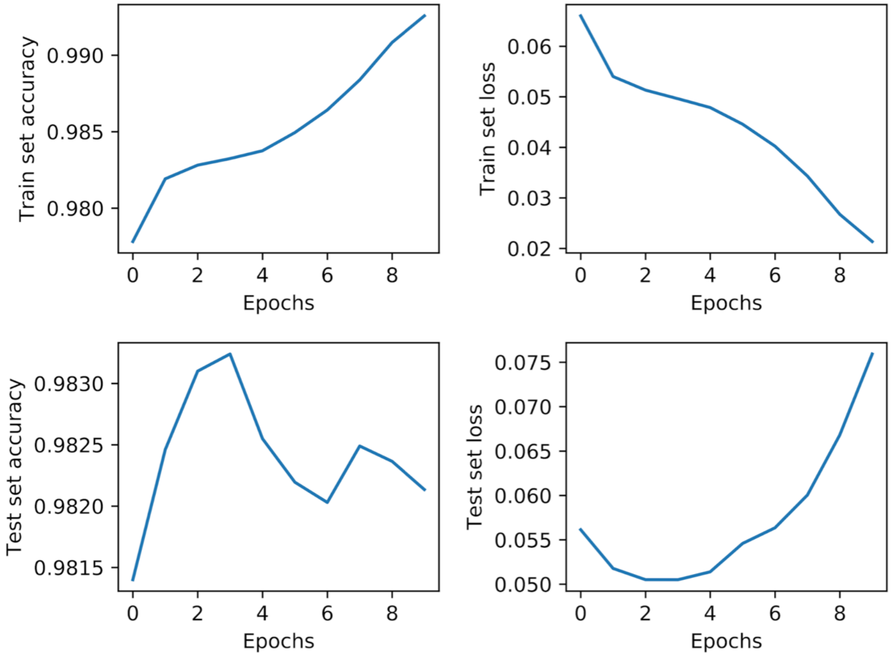


CNN Training and Test

- The CNN was trained for 10 epochs but after 3 epochs the accuracy decreases so we stopped the training on the third epochs

- The Accuracy reached on the test set is about 0.982 %

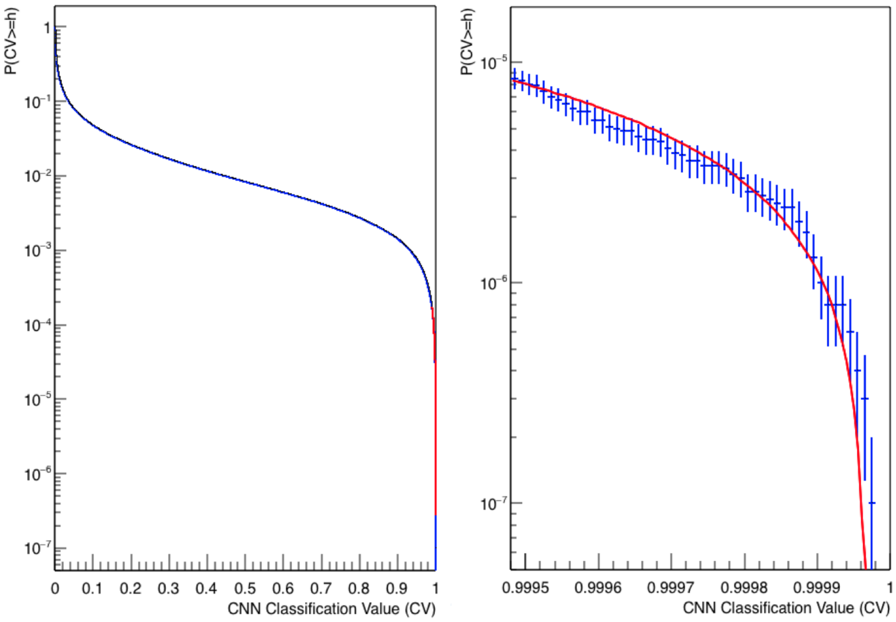
- Now we need to find the statistical significance of this CNN classification because we want to **minimize the false positive**



P-Value distribution

- The CNN will be used inside the AGILE pipeline for external alert, for this reason the CNN will work in different observing conditions

- We defined three different background and three different exposure levels and for each combination of them we calculated the p-value distribution of the CNN output values evaluating 10 millions of background maps



P-Value and Statistical Significance

		$g_{iso} = 5$			$g_{iso} = 10$			$g_{iso} = 15$		
σ	p-values	$exp = 40$	$exp = 50$	$exp = 65$	$exp = 40$	$exp = 50$	$exp = 65$	$exp = 40$	$exp = 50$	$exp = 65$
3	1.35×10^{-3}	2.9×10^{-1}	2.7×10^{-1}	2.5×10^{-1}	2.1×10^{-1}	1.9×10^{-1}	1.3×10^{-1}	1.5×10^{-1}	9.6×10^{-2}	4.8×10^{-2}
3.5	2.32×10^{-4}	5.8×10^{-2}	5.8×10^{-2}	5.0×10^{-2}	4.2×10^{-2}	3.4×10^{-2}	2.0×10^{-2}	2.4×10^{-2}	1.4×10^{-2}	6.0×10^{-3}
4	3.17×10^{-5}	1.6×10^{-2}	1.3×10^{-2}	9.6×10^{-3}	6.5×10^{-3}	5.5×10^{-3}	2.9×10^{-3}	3.1×10^{-3}	2.0×10^{-3}	7.7×10^{-4}
4.5	3.40×10^{-6}	2.7×10^{-3}	2.4×10^{-3}	1.6×10^{-3}	1.3×10^{-3}	7.7×10^{-4}	3.3×10^{-4}	4.3×10^{-4}	2.6×10^{-4}	1.0×10^{-4}
5	2.86×10^{-7}	1.1×10^{-3}	5.0×10^{-4}	2.3×10^{-4}	3.0×10^{-4}	1.8×10^{-4}	6.0×10^{-5}	8.0×10^{-5}	3.0×10^{-5}	1.0×10^{-5}

- To define the statistical significance of a GRB detection with the CNN we used the p-value thresholds for the different sigma level to find the thresholds of the CNN output value in the different observing conditions.

Real GRB Evaluation

- We tested the CNN on real AGILE data simulating the external alert from GRBs catalogs: Fermi-LAT[1], Fermi-GBM[2] and Swift-BAT[3]. A total of 595 GRBs are selected from catalogs

- For each GRB of these catalogs we created the AGILE-GRID counts maps with an integration time of 200s and with the trigger time and position of the catalogs

- We classified these counts maps with the CNN detecting 20 counterparts with sigma >3 , 10 of them with sigma >=4 and 15 of them are new announce by AGILE

[1] M. Ajello et al. A Decade of Gamma-Ray Bursts Observed by Fermi -LAT, ApJ, 878, 1 (2019)
[2] Swift-BAT Online Catalog https://swift.gsfc.nasa.gov/archive/grb_table/
[3] Fermi GBM Burst Catalog https://heasarc.gsfc.nasa.gov/W3Browse/fermi/fermigbrst.html

AGILE-GRID GRB counts maps

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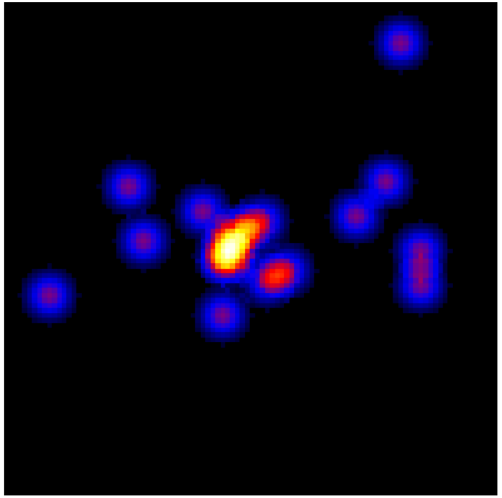

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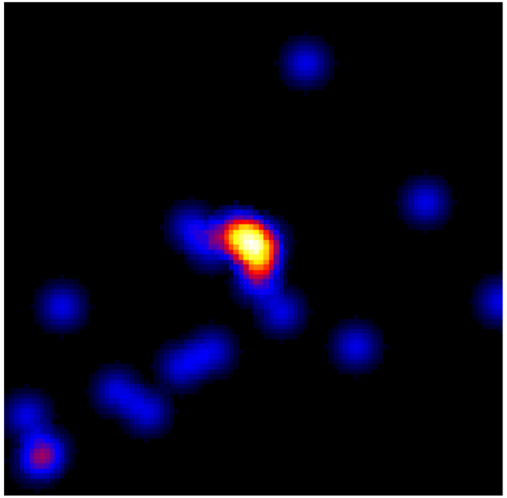

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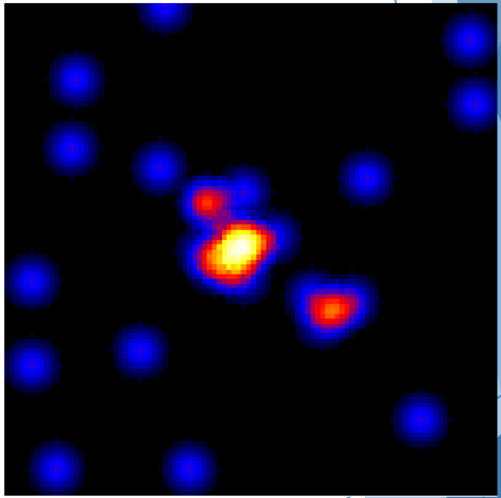

Conclusion

- We developed this new CNN method to detect a GRB inside the AGILE-GRID counts maps when an external alert is received
- We trained and tested the CNN network creating datasets of simulated maps, we also calculated the p-value distributions
- Using Fermi and Swift catalogs we evaluated real GRB and the CNN detects 20 GRB, 15 of which are a new announce
- We compared the results of this method with results of the standard method used by AGILE Team founding a significant improvement in this specific context of an automated pipeline. A publication is in progress