Event Selection Technique of Multi-layer Si-CdTe Compton Camera onboard Hitomi

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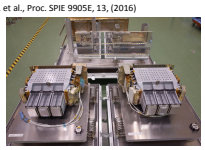
The soft gamma-ray detector (SGD) onboard Hitomi, which has a unique design concept of combination of "narrow-field multi-layer semi-conductor Compton camera" and active shielding, realizes astronomical observations in 60—600 keV energy band with high sensitivity. Development of optimum event selection criteria is essential to derive the best observational performance of SGD but it is challenging because many parameters such as detected photon energy, Compton scattering angle, distance of each hit ..etc. would be correlated non-linearly. Here, we propose a new method to distinguish the signal from the background from multi parameter space utilizing machine learning approach. We found the possibility that this approach could be a good guide for the physical understandings for a optimum event selection of Compton camera by the preliminary result using both on-ground experimental data with good photon statistics and flight data with a real in-orbit background and signal data.

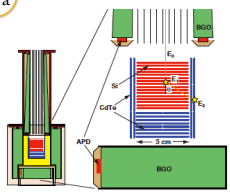
1. Introduction

S. Watanabe, et al., Proc. SPIE 9905E, 13, (2016)



Soft Gamma-ray Detector (SGD) onboard Hitomi

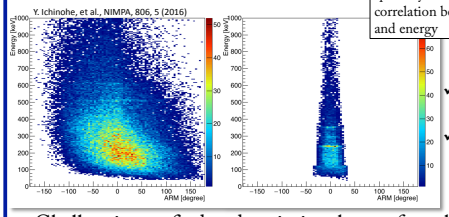
- Multi-layer Si-CdTe Comton camera+ active shield
  - ➔ extremely low BGD
- Anisotropy of Compton scattering azimuthal angle
  - ➔ polarization measurement
- First time in-orbit operation for Si-CdTe Compton camera



It is essential to distinguish the signal from the background for measurement of energy and polarization from astronomical object. Optimum combination from many parameters such as detected energy, Compton scattering angle, each hit position, ..etc. should be investigated.

We developed a "primary cut" using on-ground calibration data, which is based on the angle between Compton reconstructed direction and line-of-sight (OFFAXIS). Dependence of energy and distance of hit is taken into account non-linearly.

Y. Ichinohe, et al., NIMPA, 806, 5 (2016)



"primary cut" applies correlation between OFFAXIS and energy

Open questions

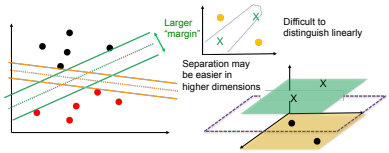
- ✓Are there any other parameter correlation for better cut ?
- ✓Is this still valid for in-orbit signal and background ?

Challenging to find and optimize the cut from huge set of multi-parameters, which could have non-linear correlations by human eyes. Any new ideas ?

2. New approach for multi-parameter event selection

Problem: To distinguish the signal to the background utilizing multi-parameter relations which could be correlated non-linearly.

Solution: Non-linear classification with machine learning. Classification that maximize Figure Of Merit (FOM) could provide guide to physical understanding



Concept of Support Vector Machine for linear classification. Green boundary is preferred rather than orange one because of larger "margin"

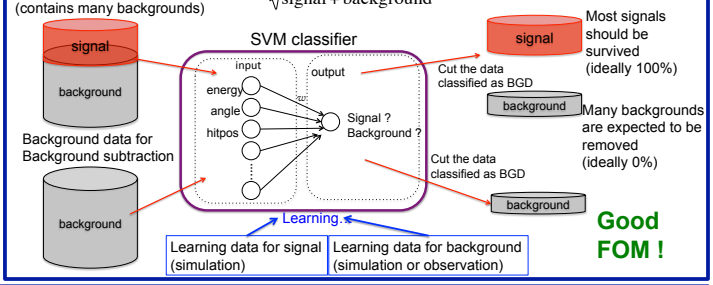
Linear boundary in the higher dimension is projected to non-linear boundary with Kernel method

Support Vector Machine (SVM)

One of the classifier using supervising learning. It determines the boundary of two (or multi) groups by maximize the "margin", which means the shortest distance between the data and boundary.

Complicated non-linear boundary can be projected to simpler one by utilizing Kernel function.

$$FOM = \frac{\text{signal}}{\sqrt{\text{signal} + \text{background}}}$$



3. Application of the new event selection

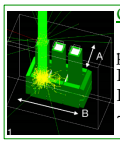
Application 1: Thermal-vacuum test on-ground

First of all, we applied our new event selection based on non-linear SVM classification to the on-ground calibration data.

Enough photon statistics are available but not identical data to in-orbit background.

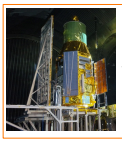
➔ Good application for verification of the method and study of the SVM characteristics

	Signal	background
Learning data	Crab simulation	On-ground data
Apply data (different data set from learning data)	Crab simulation	On-ground data



Crab Simulation

photon index = 2.1
Flux = 3.4x10^{-8} erg/s/keV
E=40-1000 keV
~40 Ms exposure

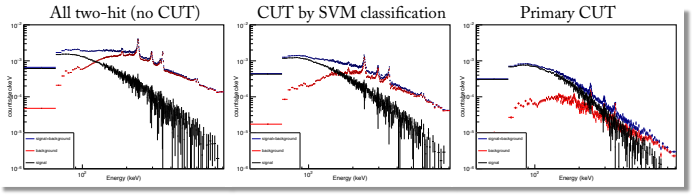


Thermal Vacuum test

Jun. 26 ~ July. 04 2015
Mainly background measurements
~3.4 Ms exposure

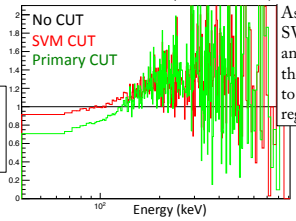
Spectral analysis procedures

1. SVM learning by energy-binned learning data
2. Use SVM for energy-binned apply data
3. Evaluate FOM for each energy bin
4. Compare FOM to other cut conditions



- ❖New SVM event selection works well and signal spectrum can be obtained
- ❖Background reducing ratio of SVM cut looks reasonable and more signal survives compared with standard "primary CUT"

Ratio of FOM (noCUT=1)



Looser, even NO cut is still effective at signal dominant regime because of definition of FOM.

As the signal decreases, new SVM cut defeats looser cut and it could be better than the standard primary cut up to less photon statistics regime.

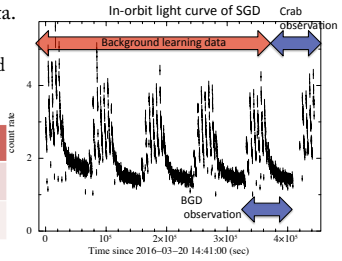
Our SVM cut looks OK as the first step. To be continued further optimization (signal acceptance, SVM hyper-parameters, other signal model ..etc.) and detailed understanding of SVM cut characteristics using this high statistics data.

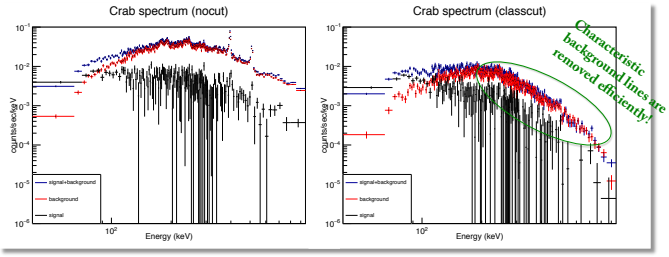
Application 2: Crab observation data in orbit

After validating our new event selection by Application 1, we applied this method to in-orbit Crab observation data.

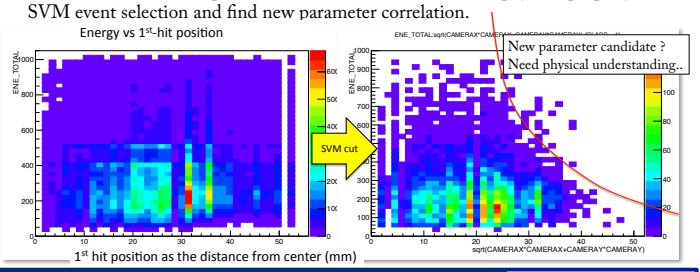
Limited exposure time (~5ks) is problem for both learning and apply data. But background and astronomical data obtained by Si-CdTe Compton camera in orbit.

	Signal	background
Learning data	Crab simulation	In-orbit all BGD (~ 300 ks)
Apply data	Crab observation (~5ks)	BGD observation for Crab (~5ks)





Re-visit to check multi-parameter distribution to understand physical property of SVM event selection and find new parameter correlation.



4. Conclusions

- New event selection technique using multi-parameter classification with SVM is being developing to maximize performance of S-iCdTe Compton camera
- Consistent result with standard cut is obtained and possibility of new parameter correlation is found
- Further optimization/understanding are needed for future application