Gamma-ray bursts detection with Wild binary segmentation algorithm

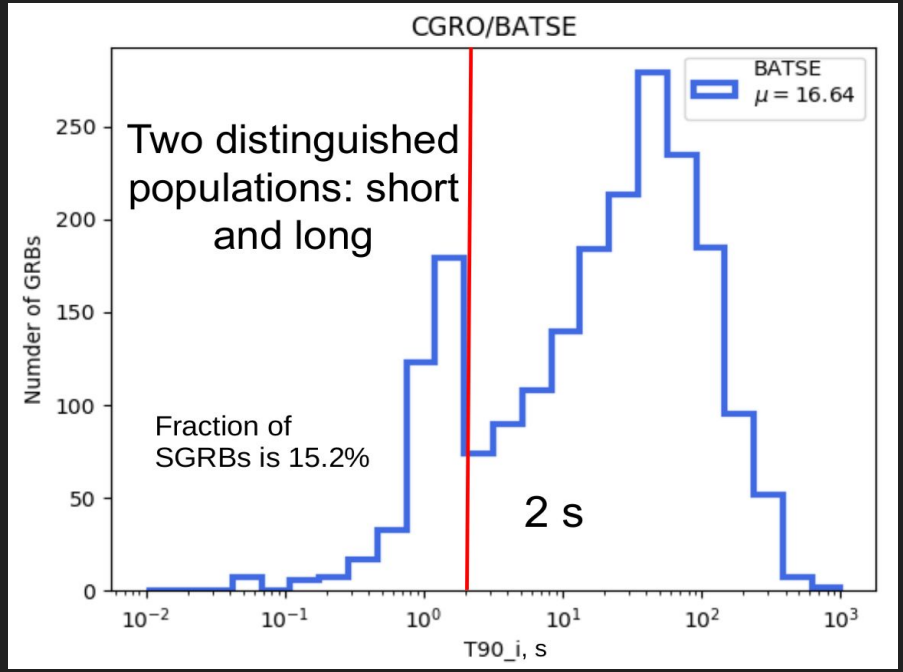
(daily data from SPI-ACS)

Kateryna Barynova
master student at TSNUK
supervisors: PhD S. Antier,
PhD B. Cordier

Gamma-ray bursts (GRBs)

GRBs:

- from γ-rays to radio (prompt + afterglow)
- average rate 1/day
- cosmological distances
- short and long GRBs:
  - 2 s band
  - different progenitor systems



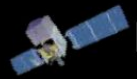
Open questions in GRB physics

GRB studies

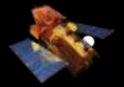
- Progenitors and central engines
- The physics of the relativistic ejecta
- Multi-messenger emission

Using GRBs as a tool for cosmology

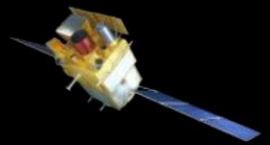
- Spectroscopy of the line of sight
- Host galaxies
- Very distant GRBs : first stars/reionization of the intergalactic medium ?



Fermi : short GRBs and excellent coverage of the prompt emission



- Swift : study of the afterglow and measurement of the redshift



Build a homogeneous sample of GRBs with a good time and spectral coverage With redshift measurement

Gamma-ray bursts searches

Fermi / GBM

- 12 NaI detectors, 2 BGO detectors
- 4.4 keV - 2 MeV (NaI)
- Semi-major axis 6 900 km, period 95 min.
- Daily tte data

INTEGRAL / SPI-ACS

- 19 HPGe detectors
- 75 keV - 2 MeV
- Semi-major axis 88 000 km, period 72 hours
- Already binned data in single energy bond

FWBS offline pipeline

Frylewitz P. et al (2014) https://arxiv.org/pdf/1411.0858.pdf

1. smaller sample that it could be on detector's sensitivity -> new weaker GRBs
2. new analysis to detect gamma-ray counterparts

Offline detection of GBM (SPI-ACS) gamma-ray transients (weak and highly variable, different population) with an independent (new concept) approach from the on-board GBM (SPI-ACS) pipeline

Confirmation of GBM (SPI) triggers

- Estimation of their significance
- T_{start} , T_{stop} , duration of the GRB
- Detectors involved (GBM)
- Search for precursors

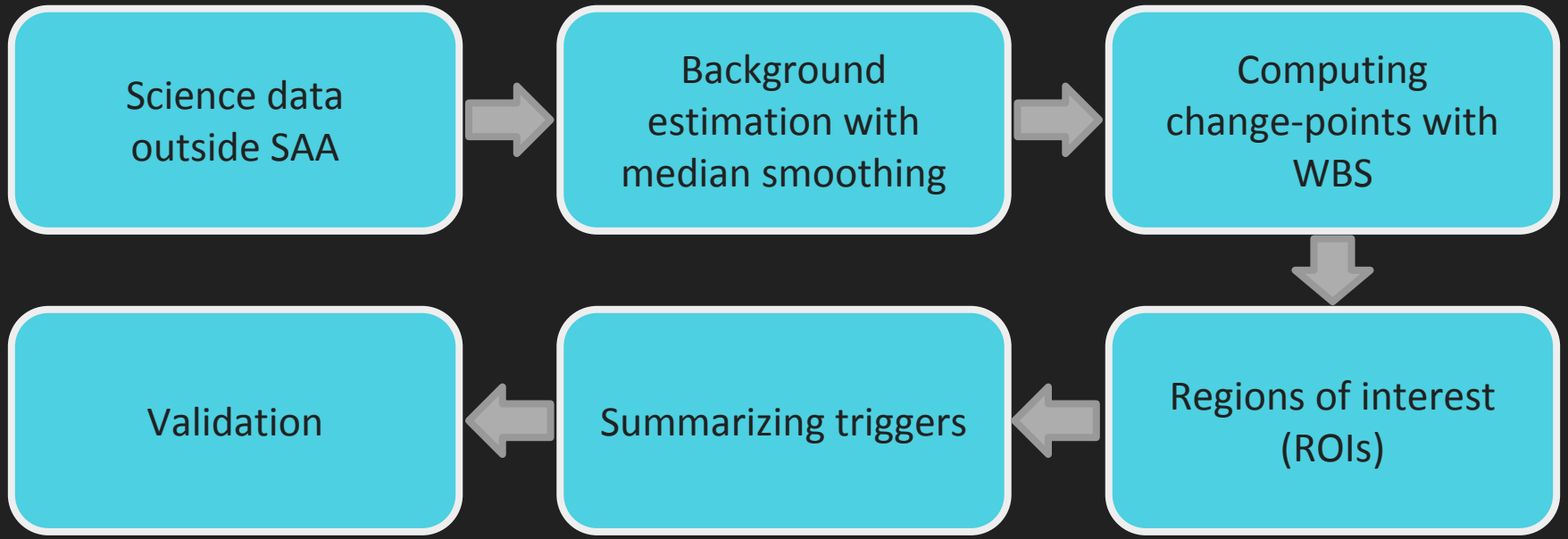
New triggers

- Short, Long
- Increase of the GRB statistics, estimate total rate
- Localization of GRBs

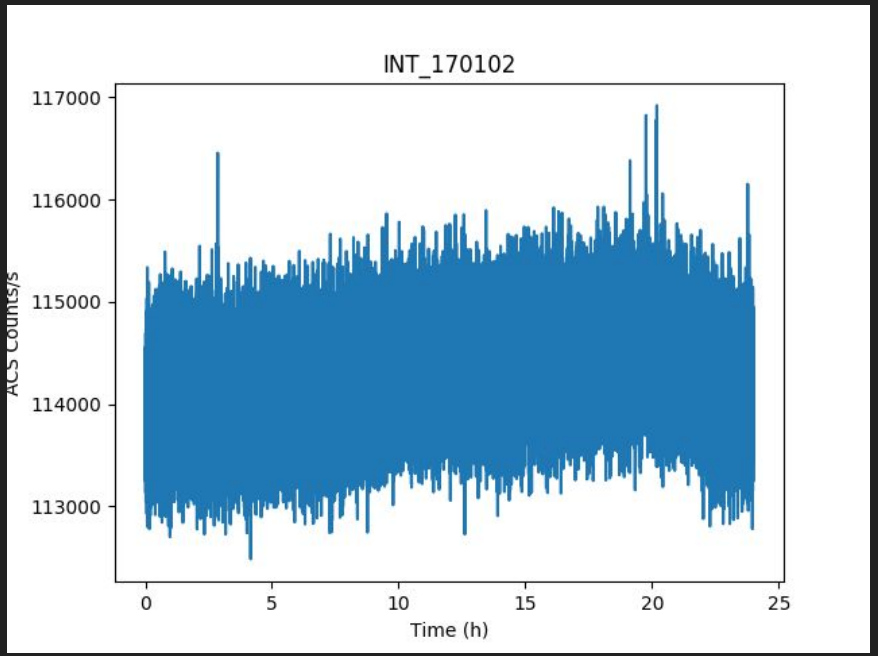
Close to linear computational time

Not a {0.128,0.256,0.512,1.024, ..s} multi-scale resolution

FWBS offline pipeline



INTEGRAL input data, parameters



- HPGe 75 - 2000 keV energy band
- 1 Jan 2017 - 31 Dec 2018 (2 years)
- Outside RB ➡ duty cycle < 100%
- 0.2 s binning F-WBS analysis
- 6 parameters:
  - binning = 0.2 s,
  - kernel median = 800 s,
  - random time intervals = 5000,
  - number of CPs = 10,
  - maximum duration of trigger = 200 s,
  - SNR threshold = 5.0

Signal: $\forall t \in [1, T], \; X_t = f_t + b_t$

Background estimation

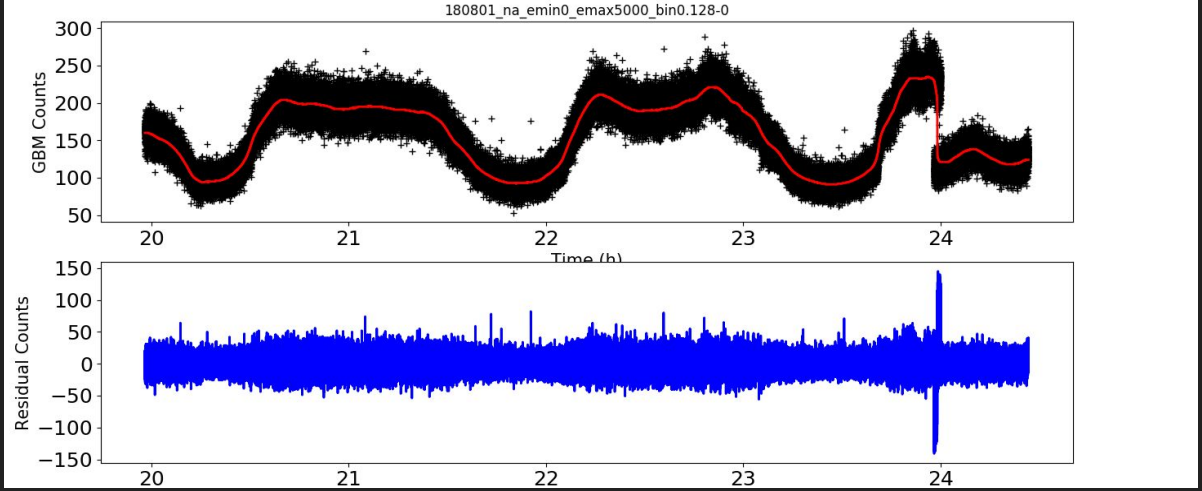
Median smoothing, kernel optimization related to the binning

- Timing resolution of { X_t } = 200 ms
- Median smoothing kernel K = 800 s
- adaptable

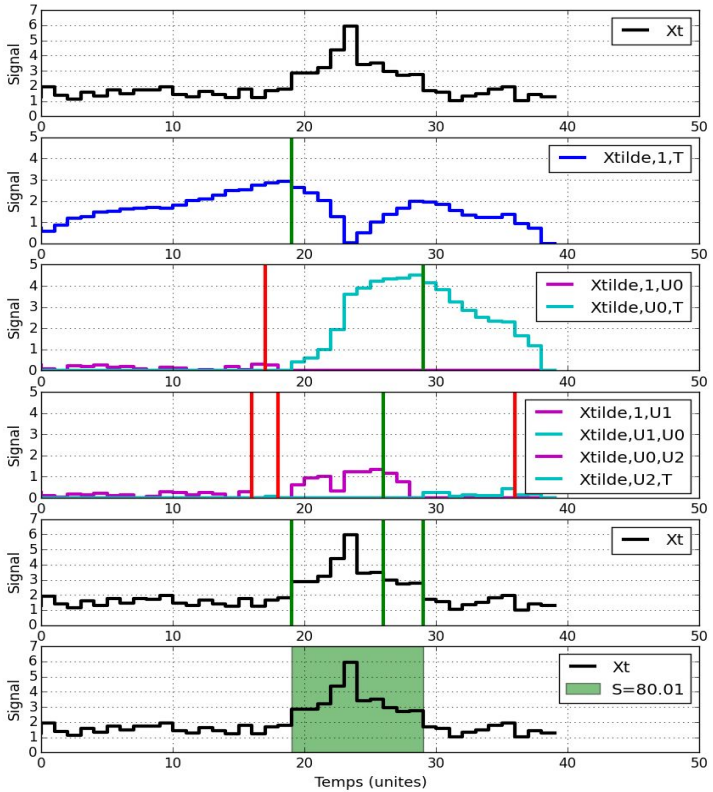
Contaminants:

- galaxy sourses
- SAA, Earth atmosphere

$$\tilde{E}(b_t) = \widehat{\{X_i\}}_{i \in [t - \frac{K-1}{2}, t + \frac{K-1}{2}]}, \forall t \in [\frac{K-1}{2} + 1, T - \frac{K-1}{2}]$$



WBS procedure



LC (time series, randomly defined)

Figure of Contrast $\tilde{X}_t$ to highlight change points (Antier et al. 2016)

Iteration from left and right side of the CP candidate

Stopped when did not detect any more candidates

List of change points candidates

Estimation of the GRB interval

WBS procedure

Frylewitz P. et al (2014) https://arxiv.org/pdf/1411.0858.pdf

1. M random intervals
2. For each interval compute contrast weights vector

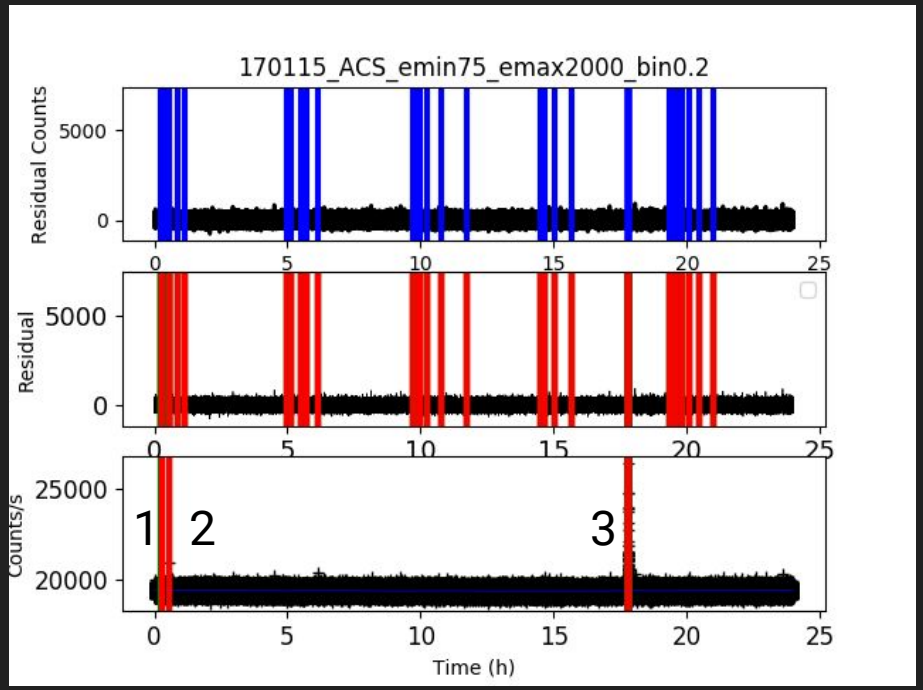
$$\tilde{X}^{u}_{s_m,\,e_m} = \sqrt{\frac{e_m - u}{n\,(u - s_m + 1)}} \sum_{t=s_m}^{u} X_t - \sqrt{\frac{u - s_m + 1}{n\,(e_m - u)}} \sum_{t=u+1}^{e_m} X_t \,.$$

$$\forall u \in [s_m, e_m],\ n = e_m - s_m + 1,$$

3. Significance of ROI with SNR

$$\mathrm{SNR}_{\tilde{\tau}_i,\tilde{\tau}_j} = \frac{\sum_{t=\tilde{\tau}_i}^{t=\tilde{\tau}_j} X_t - \tilde{E}(b_t)}{\sqrt{\sum_{t=\tilde{\tau}_i}^{t=\tilde{\tau}_j} \tilde{E}(b_t)}}$$

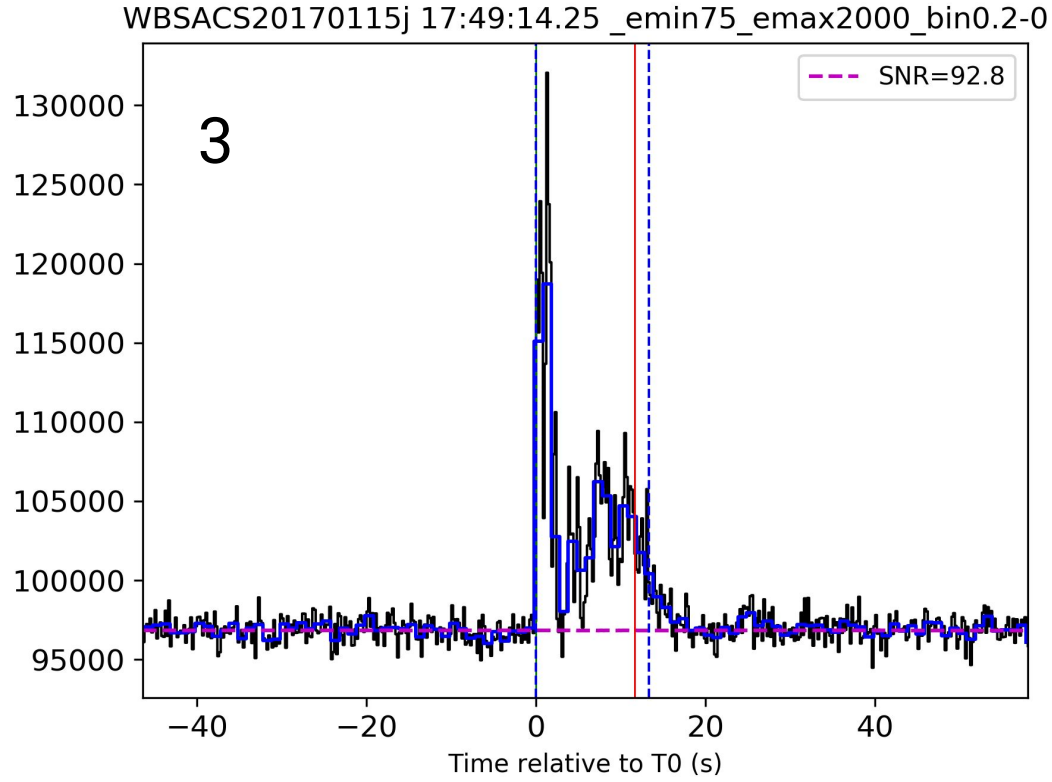
WBS procedure

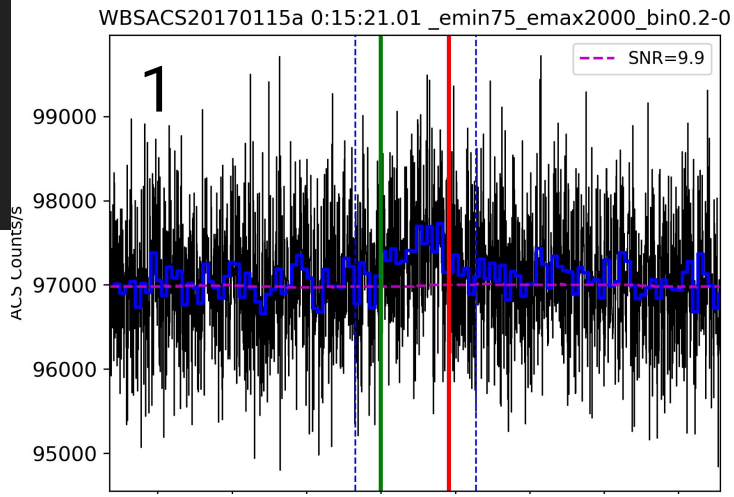


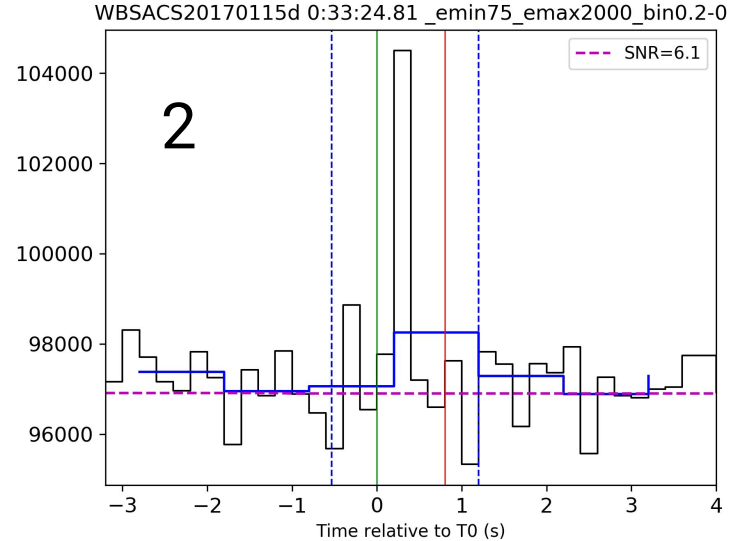
Residual SPI-ACS LC for 15 Jan 2017

- Blue - change-points by WBS
- Green/red - list of ROIs with start- and end-point
- Third plot - selection of individual ROIs that passed the threshold SNR > 5 (background not removed)

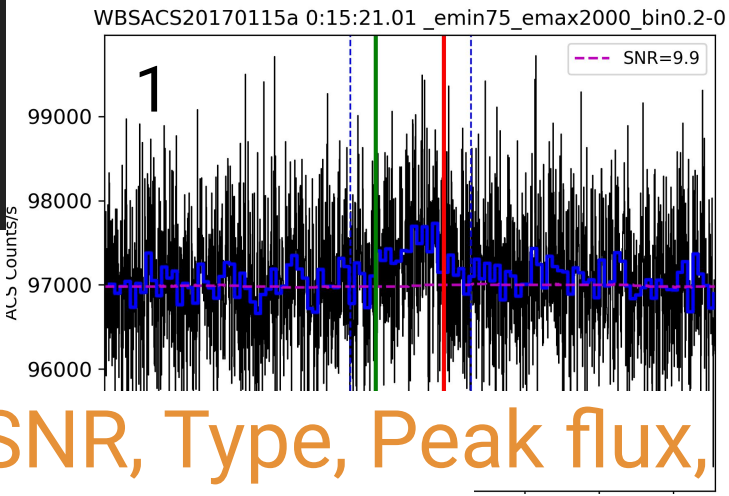
WBS procedure

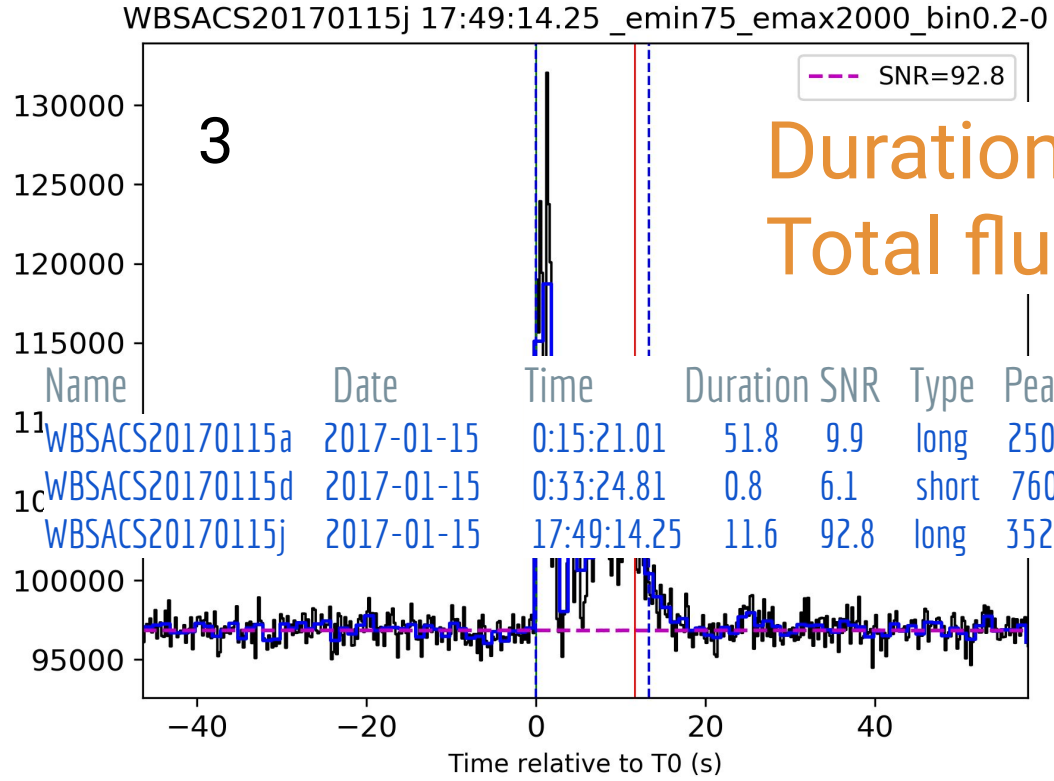




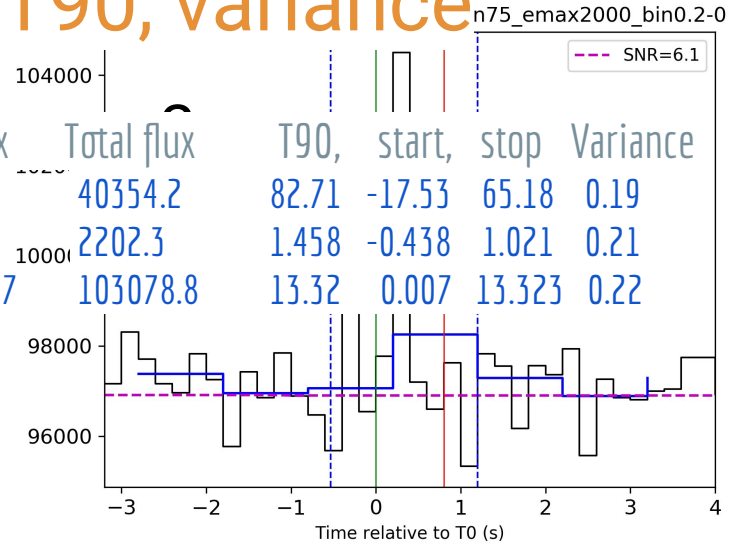


WBS procedure





Duration, SNR, Type, Peak flux, Total flux, T90, variance



Name	Date	Time	Duration	SNR	Type	Peak flux	Total flux	T90,	start,	stop	Variance
WBSACS20170115a	2017-01-15	0:15:21.01	51.8	9.9	long	2500.384	40354.2	82.71	-17.53	65.18	0.19
WBSACS20170115d	2017-01-15	0:33:24.81	0.8	6.1	short	7600.0	2202.3	1.458	-0.438	1.021	0.21
WBSACS20170115j	2017-01-15	17:49:14.25	11.6	92.8	long	35212.367	103078.8	13.32	0.007	13.323	0.22

Gamma-ray bursts searches: FWBS pipeline

Fermi/ GBM

INTEGRAL / SPI-ACS

Proof of concept

60 days (in 2017, 2018)

- ✘ 42/44 GRBs in coincidence with Fermi/GBM standard method
- ✘ 1.2 event/day in E > 50 KeV
- ✘ 19 events / day in E < 50 KeV

Full 2017, 2018, 2019 analysis

- ✘ 3 events per day
- ✘ 130 GRBs in coincidence with Fermi/GBM
- ✘ 60% of GRB supplement detection than classical INTEGRAL methods

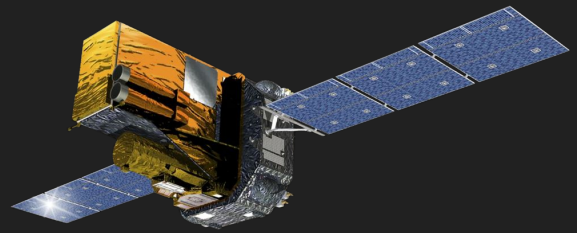
Detection of gamma-ray transients with wild binary segmentation

https://arxiv.org/abs/1909.10002

S. Antier[1,2], K. Barynova[2,3], P. Fryzlewicz[4], C. Lachaud[1], G. Marchal-Duval[2]

Summary

- F-WBS method can be applied for analyzing data from various gamma-ray telescopes due to it's flexibility and computational simplicity
- Paper with results on Fermi/GBM F-WBS 60 days blind search for MNRAS is submitted (authors: S. Antier, K. Barynova, P. Fryzlewicz, C. Lachaud, G. Marchal-Duval)
- To be done very soon: check the coincidence for INTEGRAL with other catalogs, except GBM
- 61 new trigger in coincidence with Fermi/GBM over 2 years



Thank you for your attention.....