# The EXTra(S) Sky of XMM-Newton
## Aperiodic Short-term variability



Martino Marelli
on behalf of the Work Package 2 – EXTraS
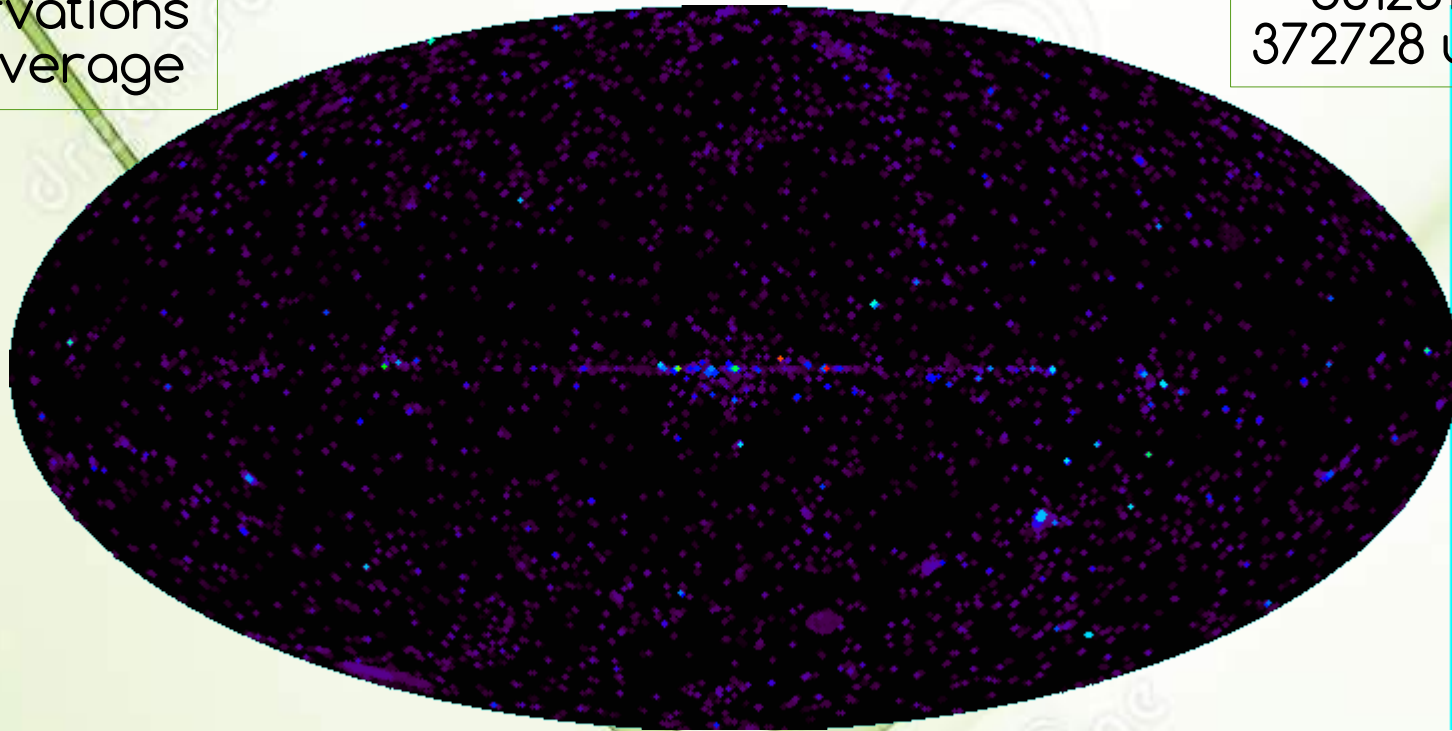Marelli M. Salvetti D. Belfiore A.

# Introduction

M. Marelli - EXTraS group

# The Third XMM-Newton catalog

DR4 : Automated analysis of observations before 2013:
source detection & characterization

7427 observations
1.9% sky coverage

531261 sources
372728 unique srcs

- Basic timing analysis of <u>bright sources</u> in <u>low background</u>
- No sistematic search for periodicity
- No dedicated analysis of weak flaring sources
- No analysis of year-timescale variability

M. Marelli - EXTraS group

# Aperiodic Short-Term Variability

We describe irregular variations..

..within a single XMM-Newton exposure..

..of rates and spectra..

..of each source already detected into the third XMM-Newton catalog

3XMM

Periodic Short Term Variability (IAPS Roma)

Aperiodic Long Term Variability (Leicester)
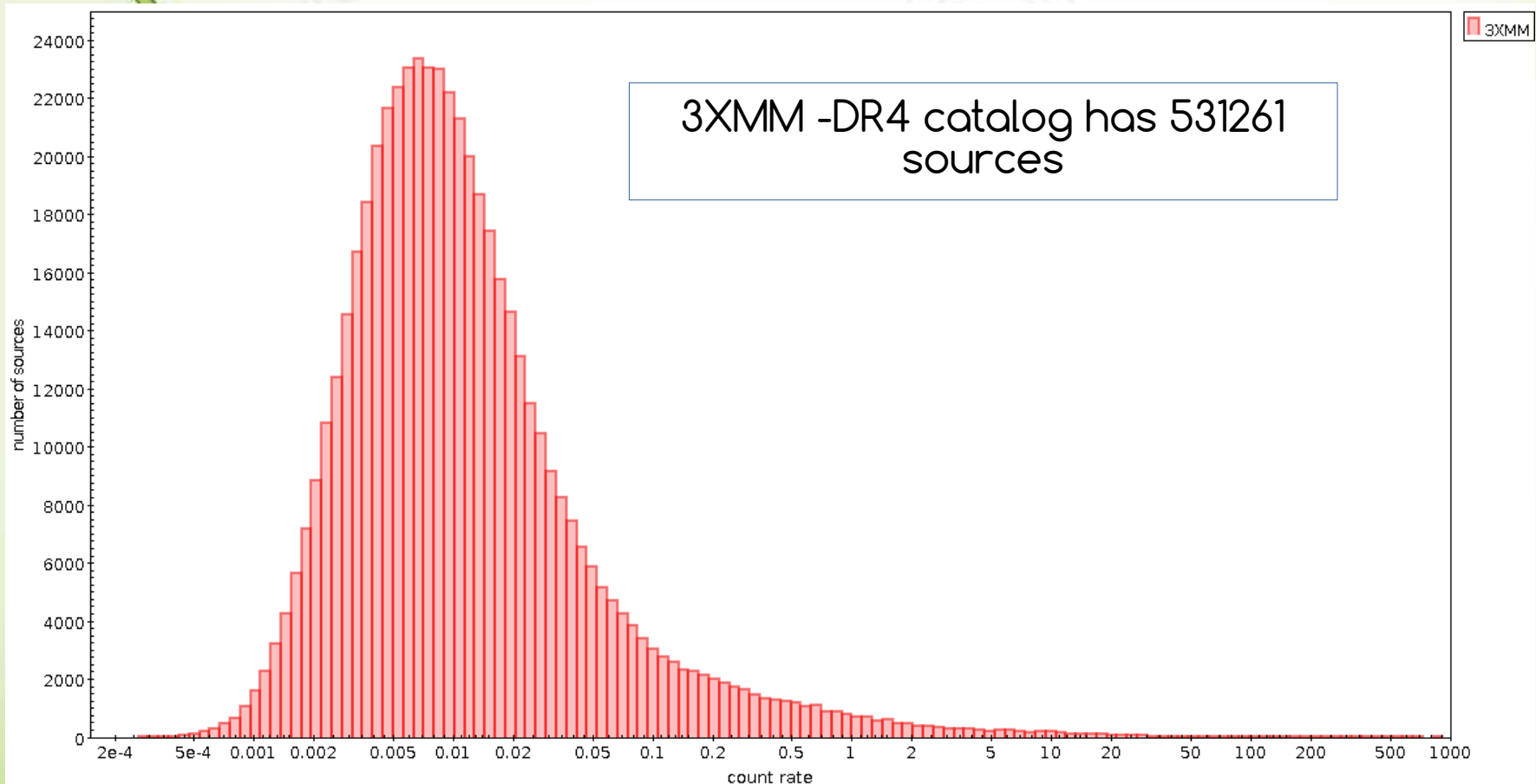
Search for new transient sources (IUSS Pavia)

Astrosiesta 02/02/2017

M. Marelli - EXTraS group

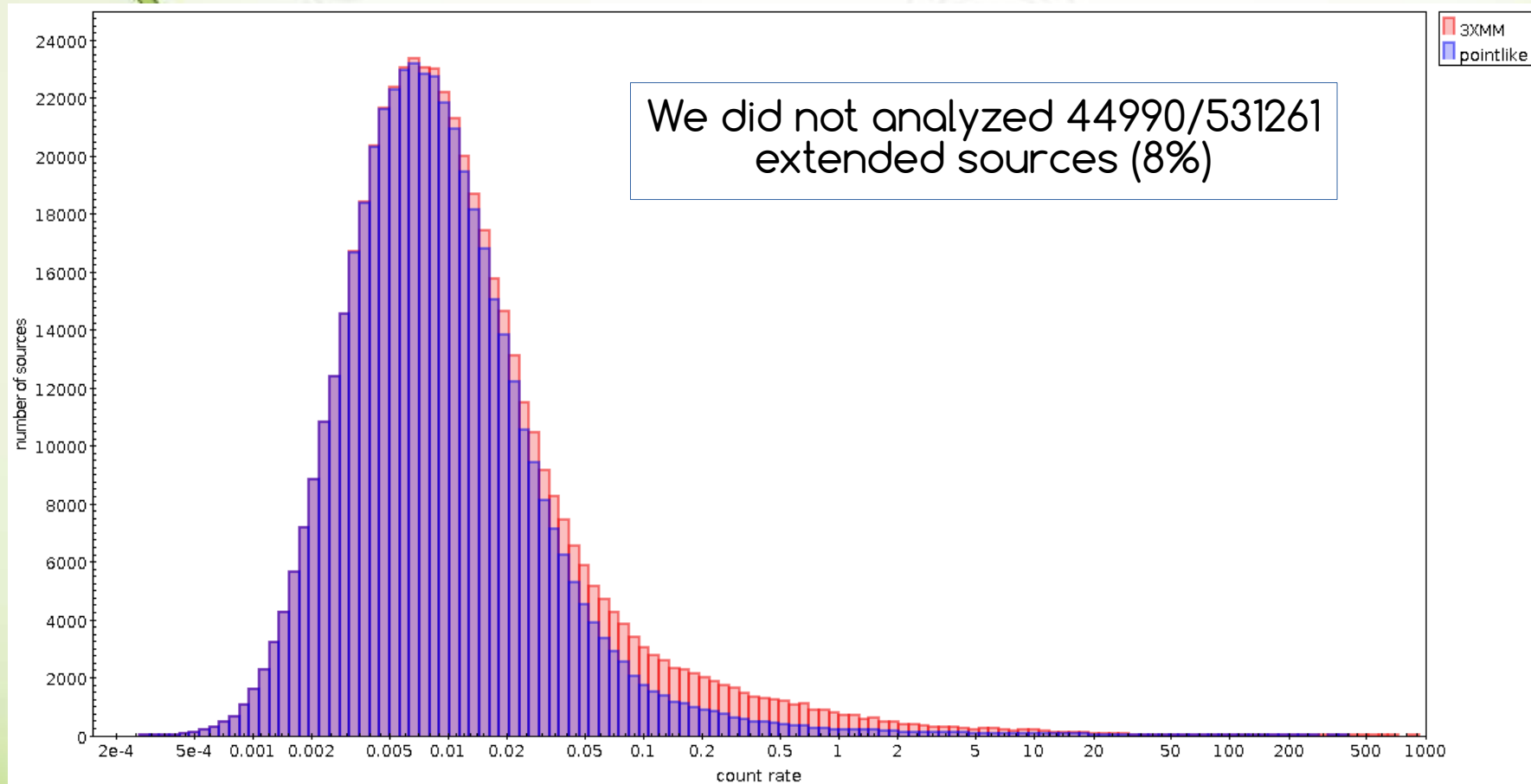# Methods & Improvements

M. Marelli - EXTraS group
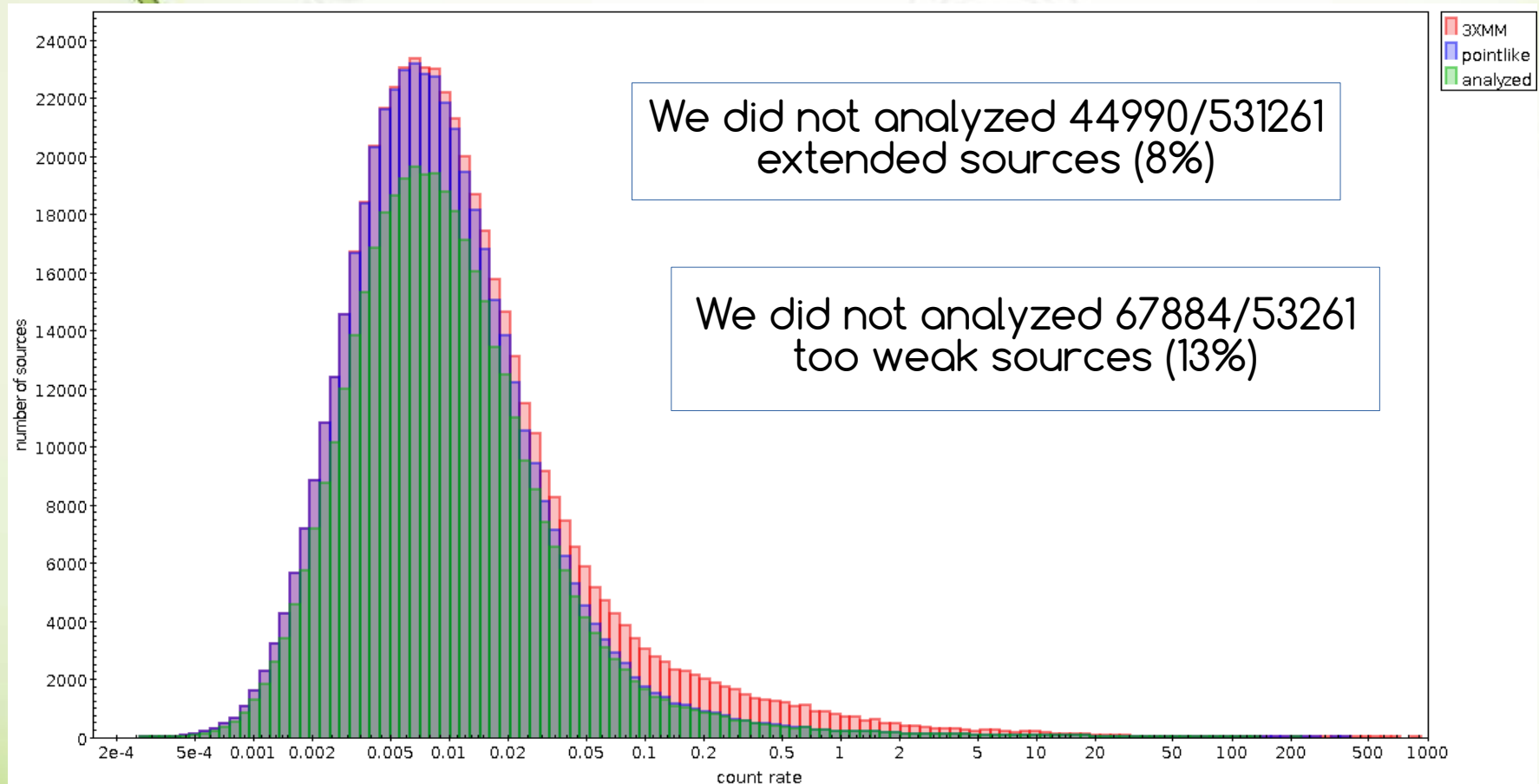
# Methods & Improvements

## - We did time analysis of most of 3XMM sources

- We do not rely on SAS - We use optimized regions & global background
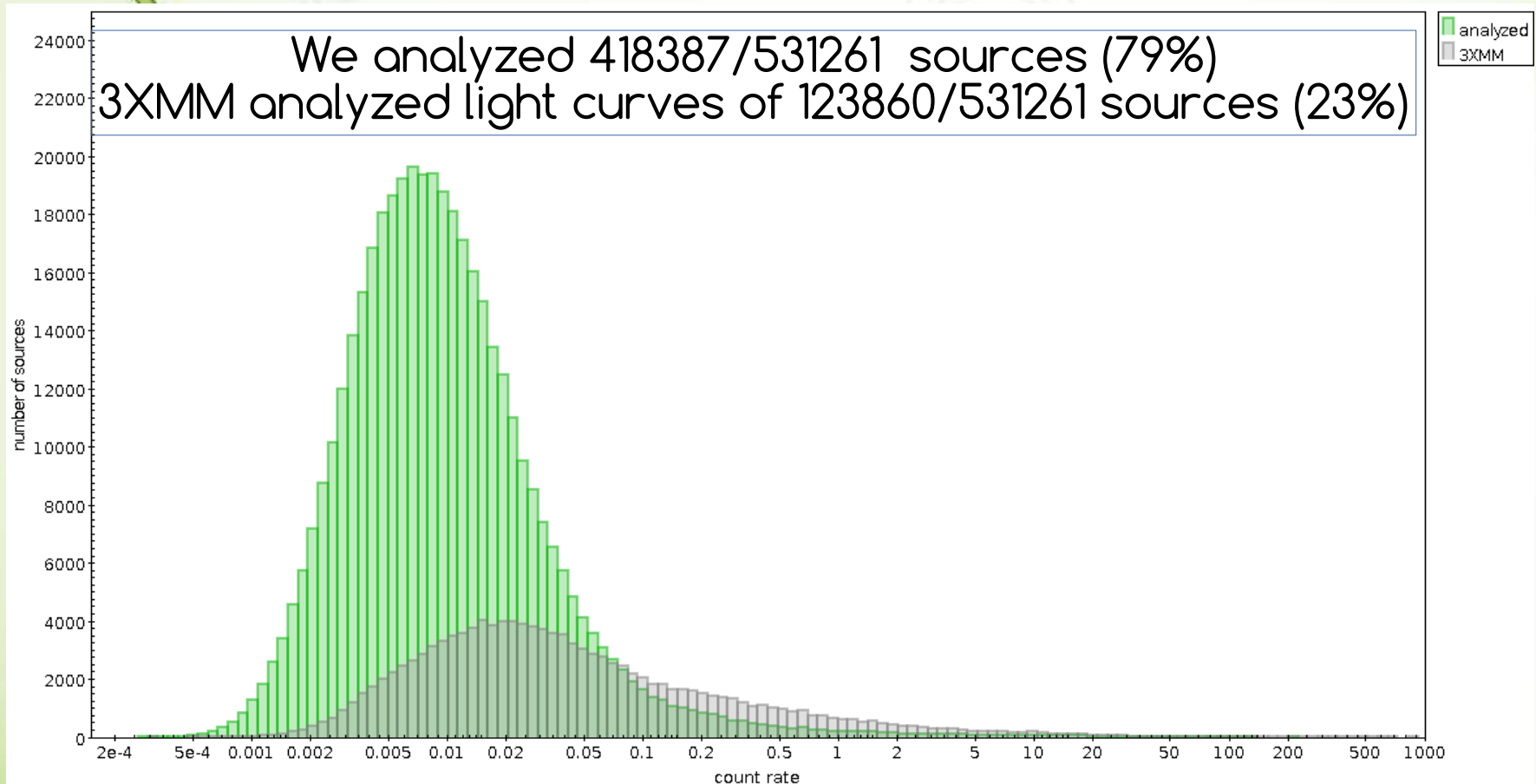- We are able to treat high background - We make use of Bayesian Blocks



3XMM -DR4 catalog has 531261 sources

# Methods & Improvements

## - We did time analysis of most of 3XMM sources

- We do not rely on SAS - We use optimized regions & global background
- We are able to treat high background - We make use of Bayesian Blocks

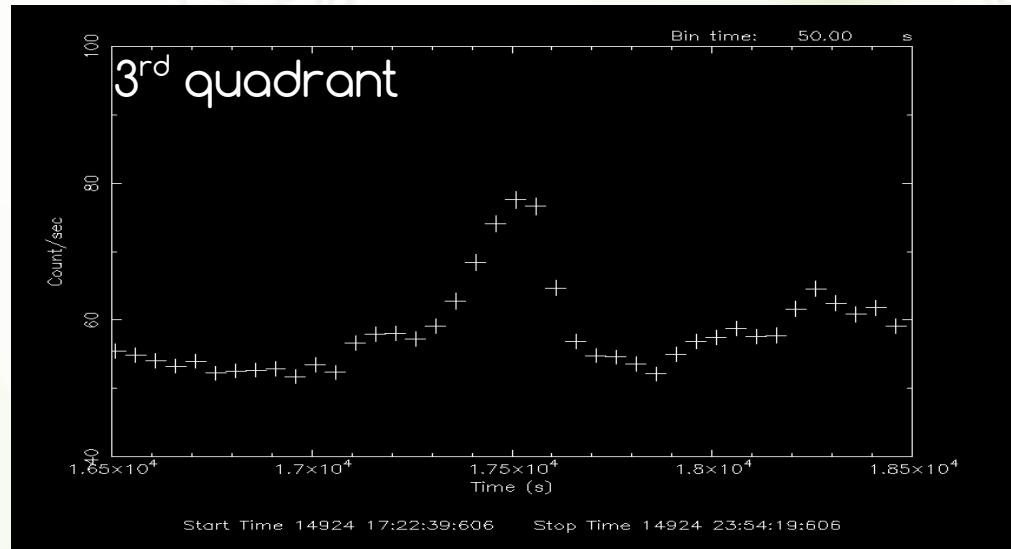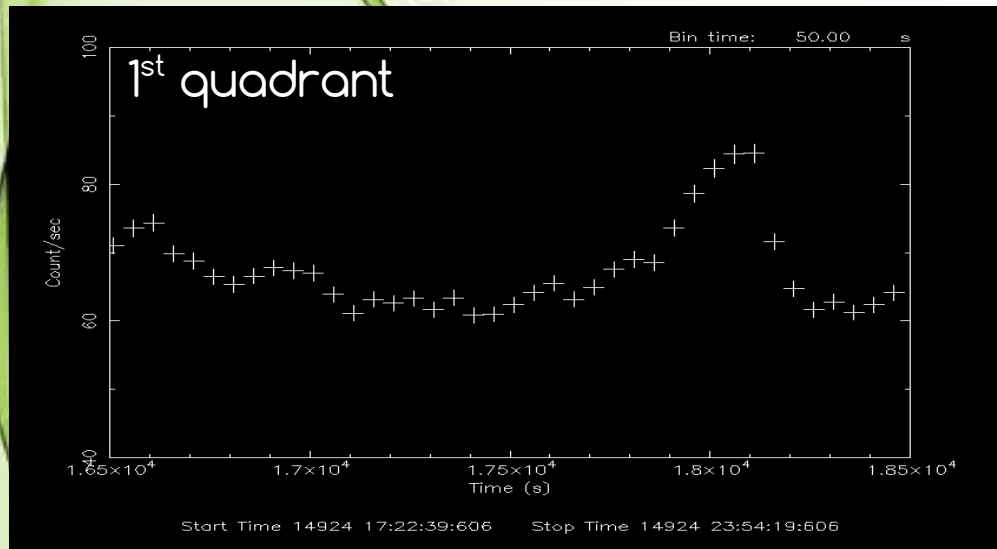We did not analyzed 44990/531261 extended sources (8%)

# Methods & Improvements

## - We did time analysis of most of 3XMM sources

- We do not rely on SAS - We use optimized regions & global background
- We are able to treat high background - We make use of Bayesian Blocks



We did not analyzed 44990/531261
extended sources (8%)

We did not analyzed 67884/53261
too weak sources (13%)

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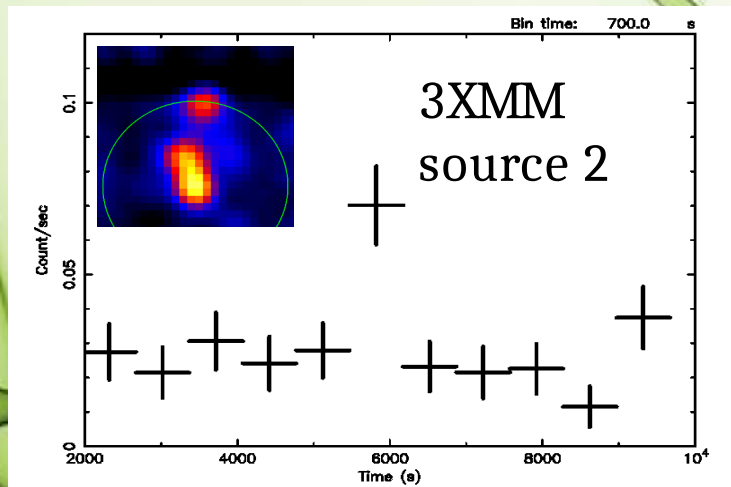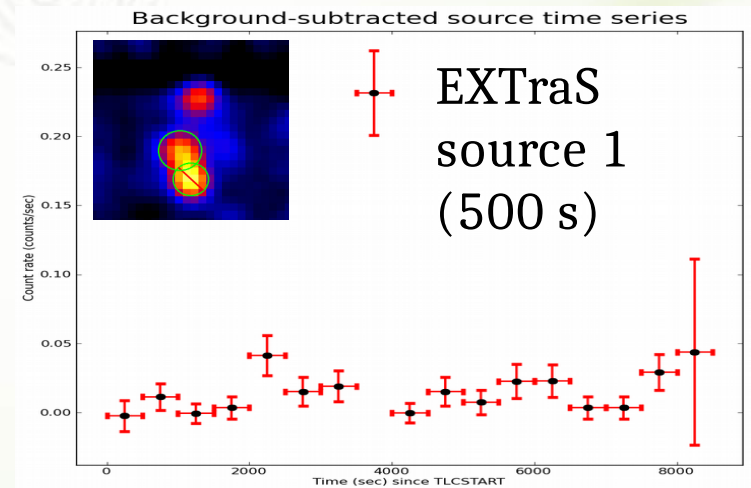
# Methods & Improvements

## - We did time analysis of most of 3XMM sources

- We do not rely on SAS - We use optimized regions & global background
- We are able to treat high background - We make use of Bayesian Blocks

We analyzed 418387/531261 sources (79%)
3XMM analyzed light curves of 123860/531261 sources (23%)



We analyzed about three times the time series of 3XMM!
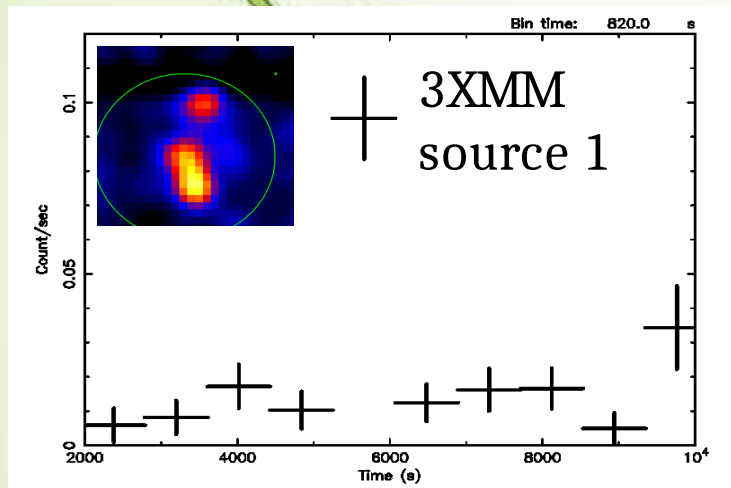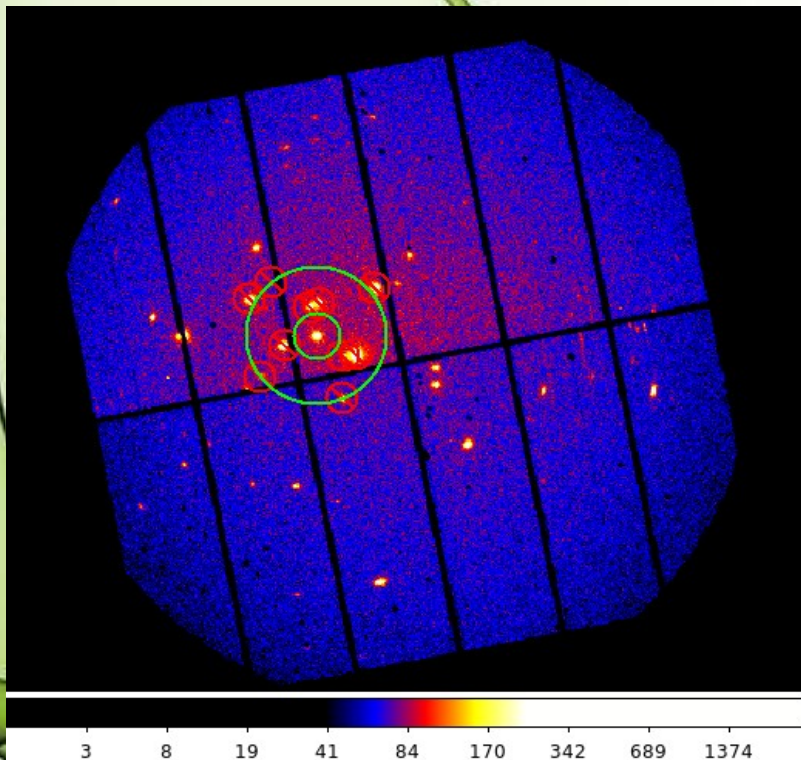
# Methods & Improvements

- We did time analysis of most of 3XMM sources
## - We do not rely on SAS
- We use optimized regions & global background - We are able to treat high back - We make use of Bayesian Blocks

Before SAS v.14 (2014), for about 27% of PN observations time of arrivals were not correctly reconstructed and artificially shifted by 10s-10000s at least in one quadrant



The problem is critical when:
- source & background are not on the same CCD
- we want to know the exact TOA of events
- we search for periodicity

## We created new, SAS-indipendent tools!
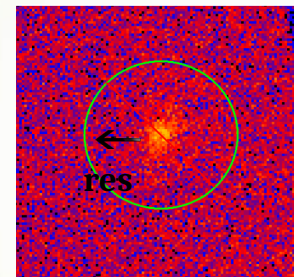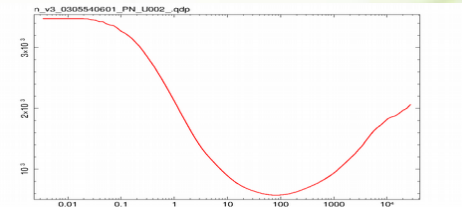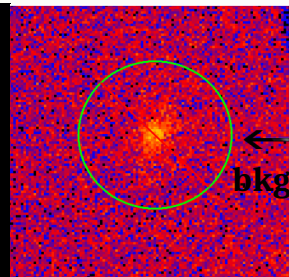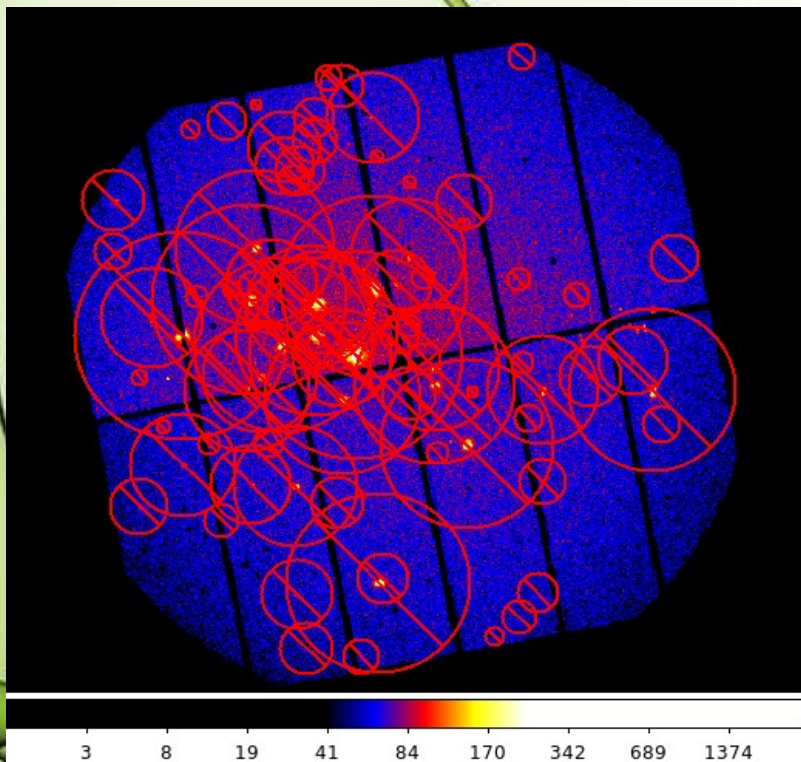
# Methods & Improvements

- We did time analysis of most of 3XMM sources - We do not rely on SAS
- We use optimized regions & global background
- We are able to treat high back - We make use of Bayesian Blocks

"Source data were extracted from a circular aperture of fixed radius (28"), centred on the detection position" (3XMM web site)
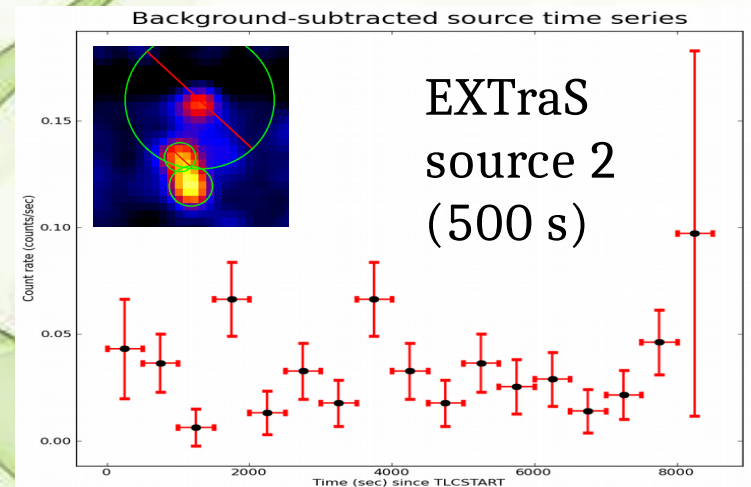
# Methods & Improvements

- We use optimized global background

" For each source .. a co-centred annular region with inner and outer radii of 60" and 180", respectively. Other sources that lay within or overlapped the background region were masked during the processing" (Rosen et al. 2016)

3XMM



3  8  19  41  84  170  342  689  1374

"..however, in some cases, the background region could comprise very little usable background." (Rosen et al. 2016)

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# Methods & Improvements

- We use optimized regions & global background

"We build background region by carefully excising all 3XMM sources from the entire FoV ... minimizing the error bar on the background estimate, balancing the need to minimize leakage and increase statistics" (WP2 deliverable D2.3)

x20 counts!

EXTraS
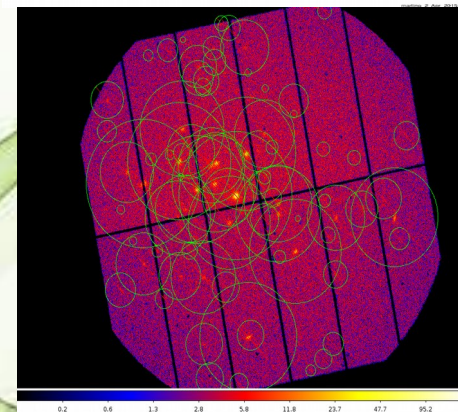


- Always background counts >10% of total
- Always sources residual counts <7% of background

# Methods & Improvements

- We did time analysis of most of 3XMM sources - We do not rely on SAS
- We use optimized regions & global background
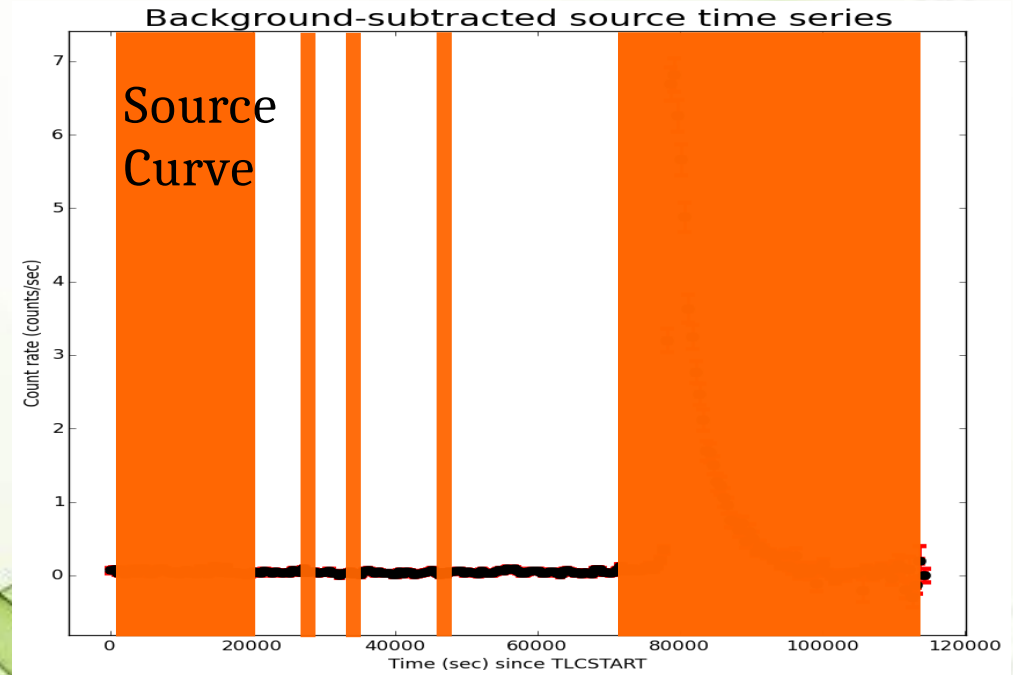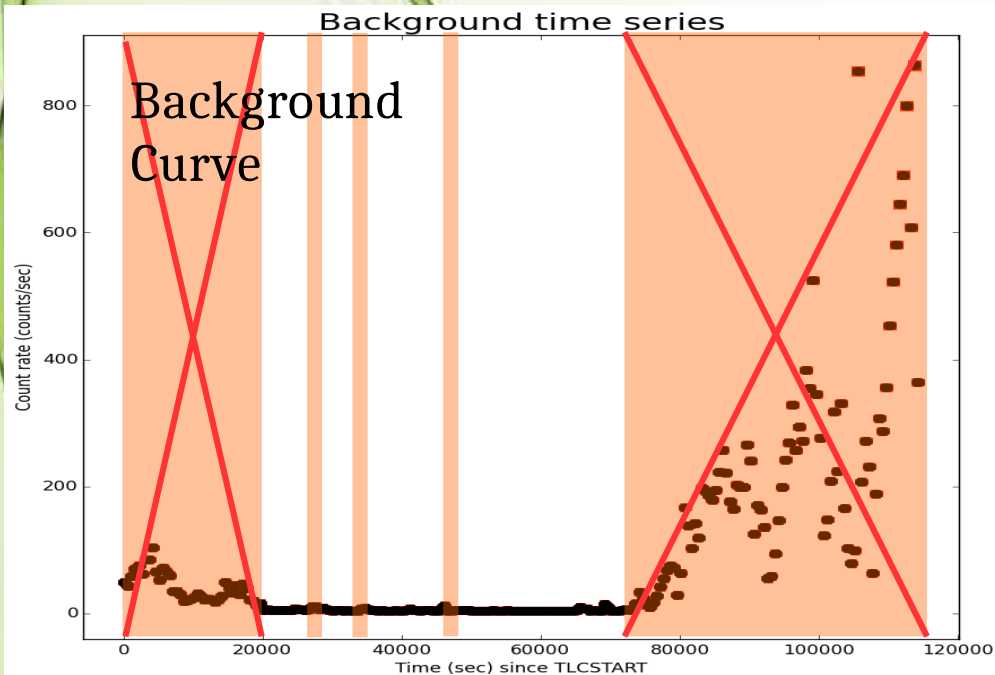- We are able to treat high back - We make use of Bayesian Blocks

" ..Instead of dealing with a background that looks just the same as where the source is, we prefer to model the background ... and obtain an accurate estimate wherever the source is." (WP2 deliverable D2.3)
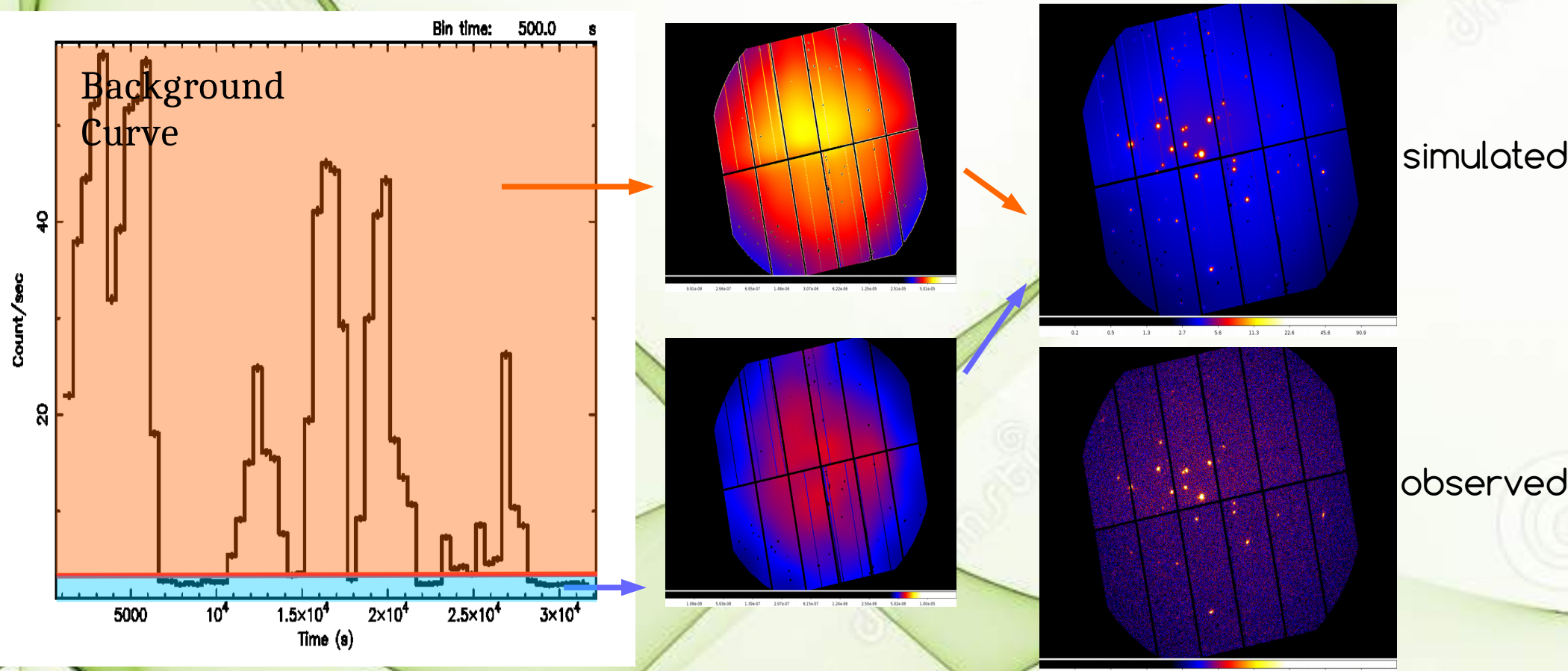
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# Methods & Improvements

## - We are able to treat high background periods

Tipically "high-background periods" are discarded.
As defined by SAS tools, ~27% (164 Ms) of 3XMM-4 time is affected, and therefore never analyzed by automatic/literature analysis
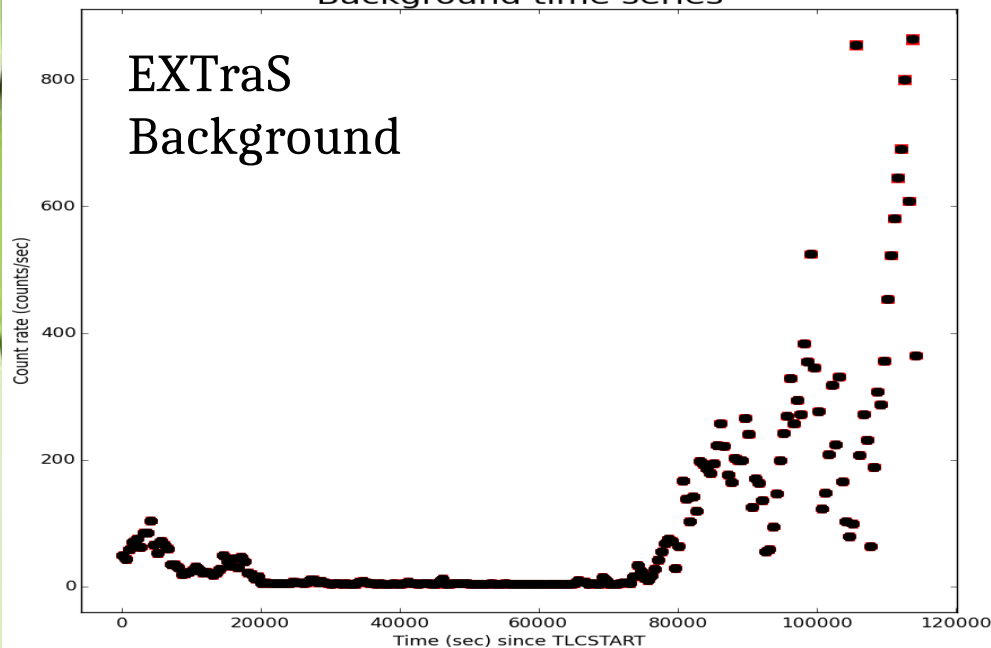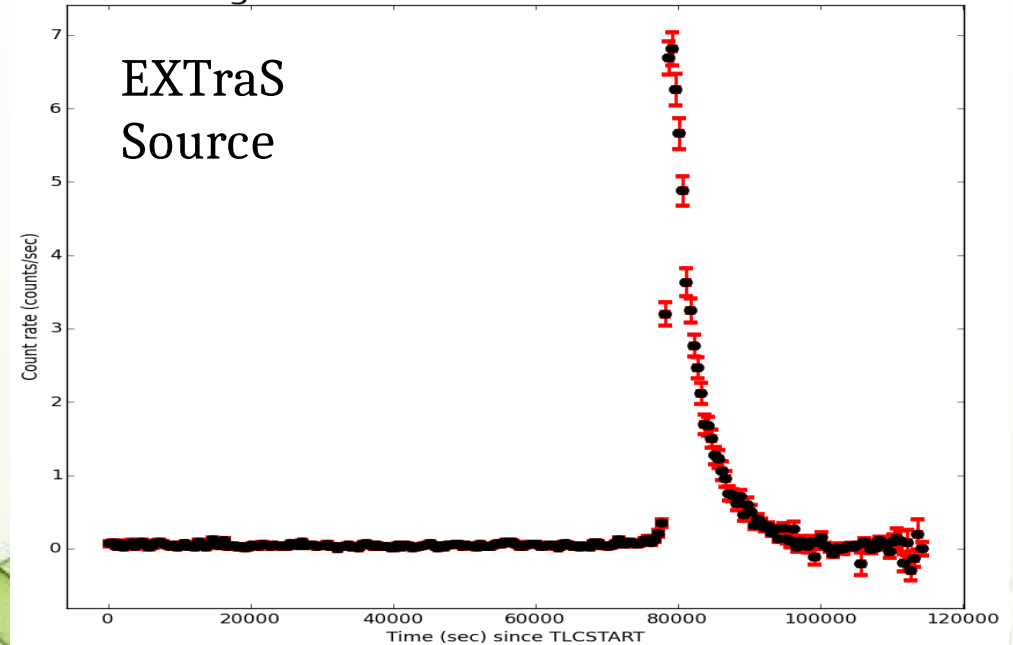


Background time series

Background-subtracted source time series

**3XMM null hypotesis probability for constant fit 0.14!**

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# Methods & Improvements

- We did time analysis of most of 3XMM sources - We do not rely on SAS
- We use optimized regions & global background
- We are able to treat high background periods
- We make use of Bayesian Blocks

Thanks to our modelization of the two components of the background we are able to consider the different vignetting of the quiescent component and the variable component



EXTraS null hypotesis probability for constant fit <$10^{-50}$!

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# Methods & Improvements

## - We make use of Bayesian Blocks

"Adaptive binning … that finds the optimal segmentation of the data in the observation interval" (Scargle 2013)
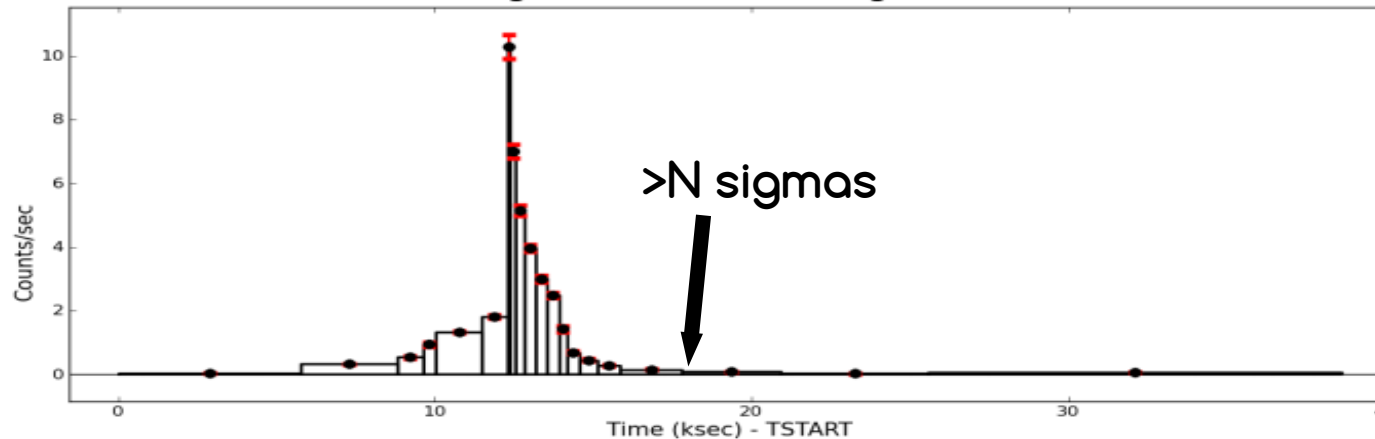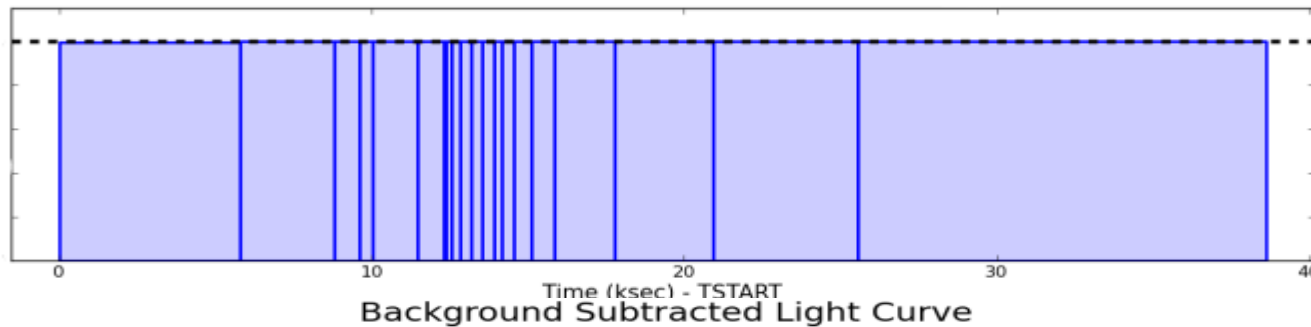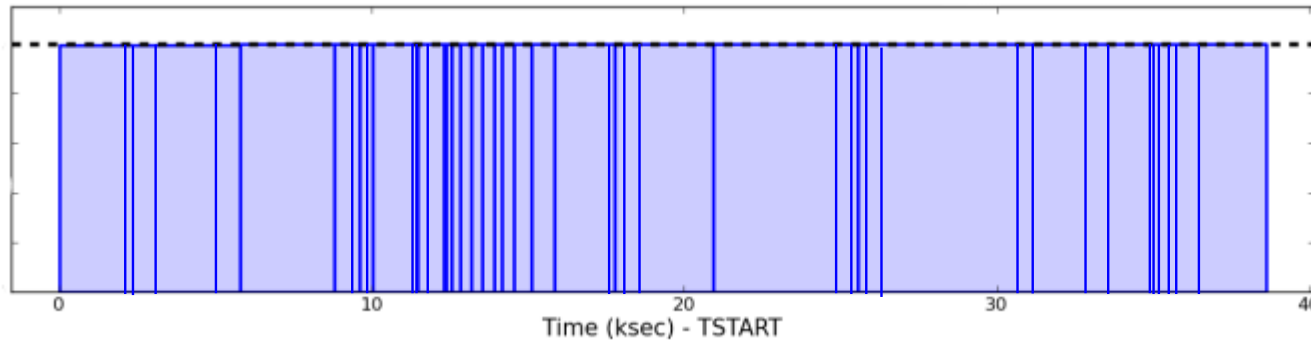
Our newly-implemented technique is perfect for testing the variability of sources with a priori unknown behaviour



Background Subtracted Light Curve

>N sigmas

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# Methods & Improvements

- We did time analysis of most of 3XMM sources - We do not rely on SAS
- We use optimized regions & global background - We are able to treat high background periods
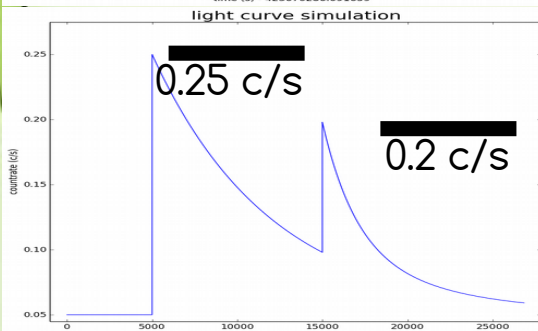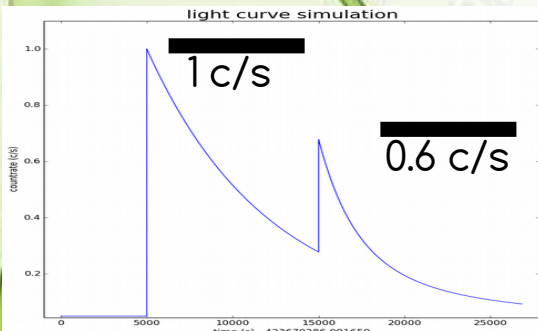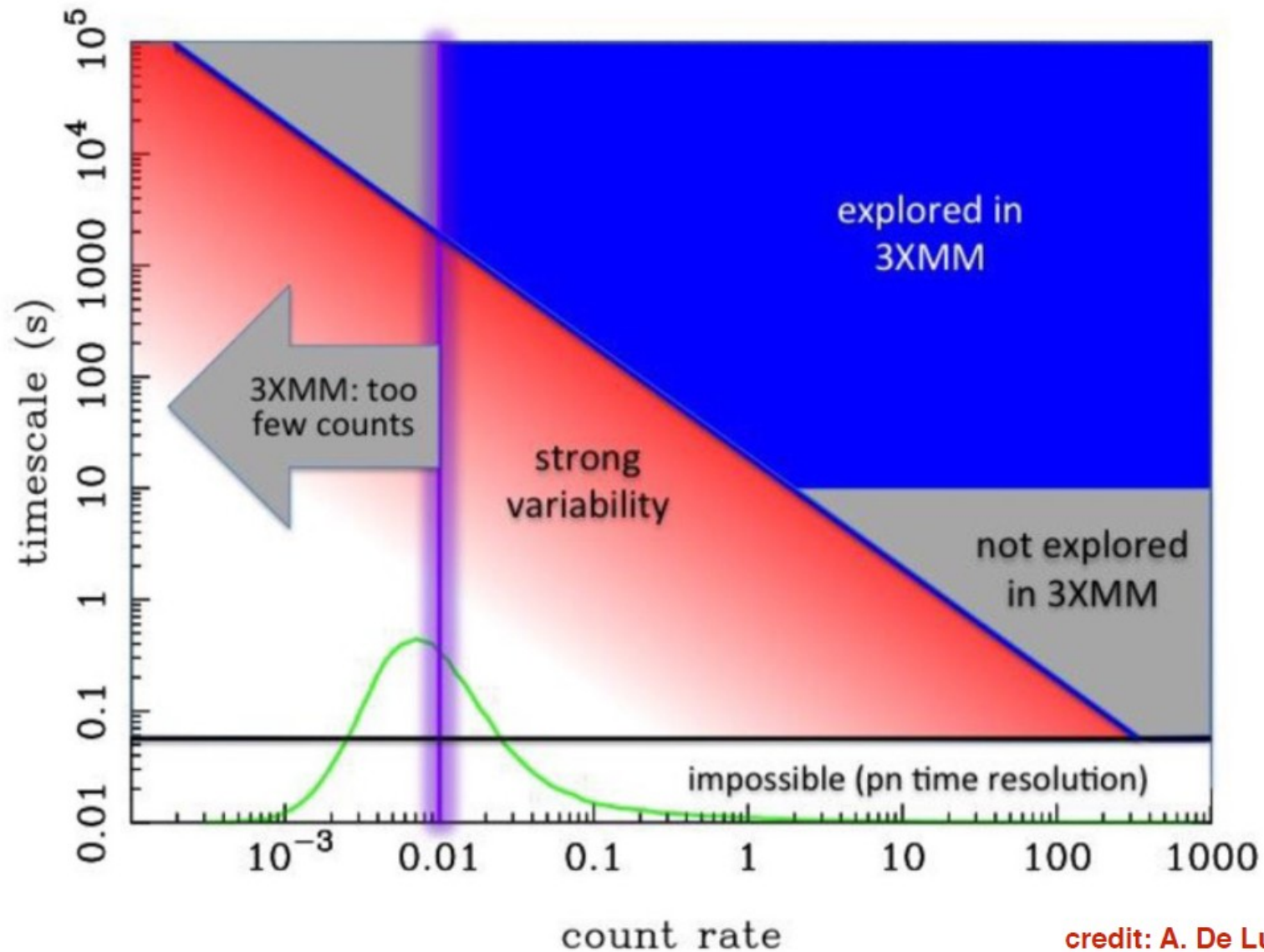## - We make use of Bayesian Blocks

Our newly-implemented technique is perfect for testing the variability of sources with a priori unknown behaviour

M. Marelli - EXTraS group

# Products & Results

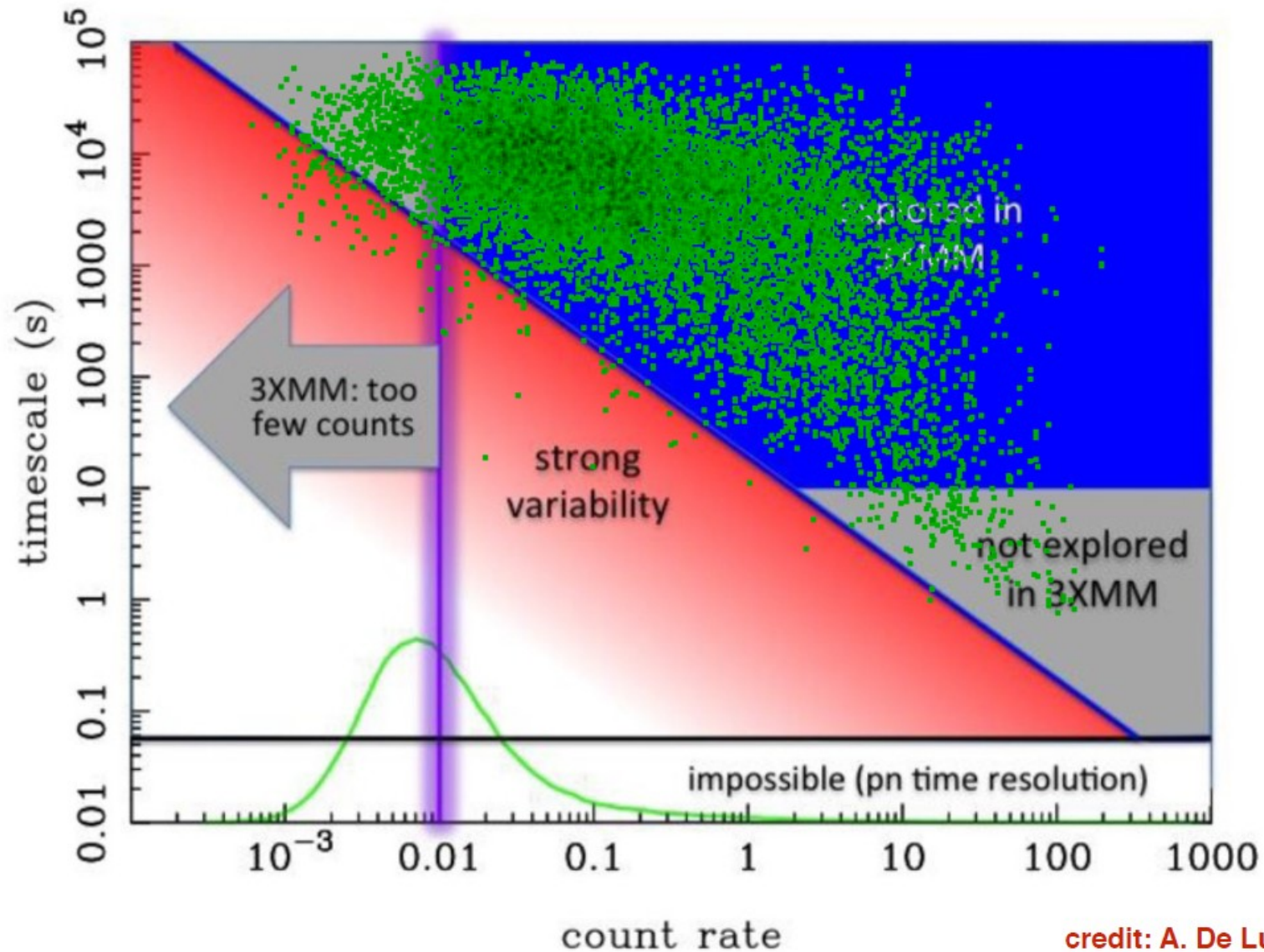M. Marelli - EXTraS group
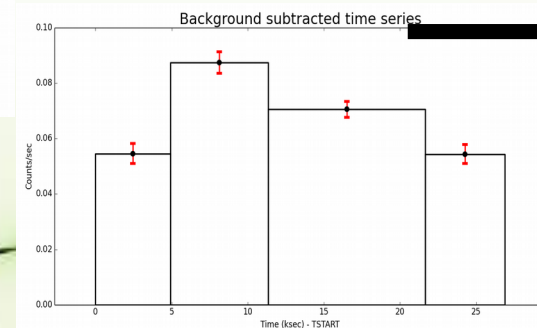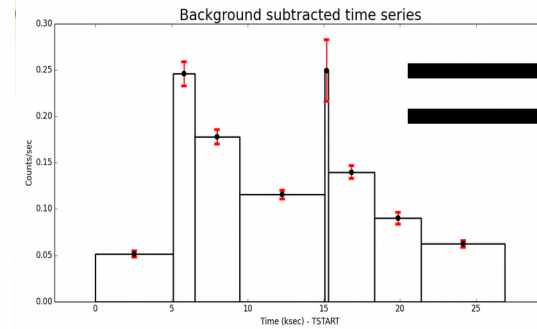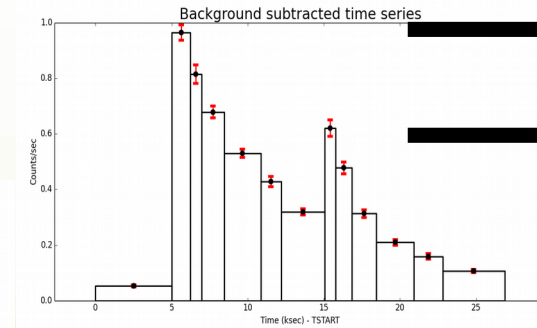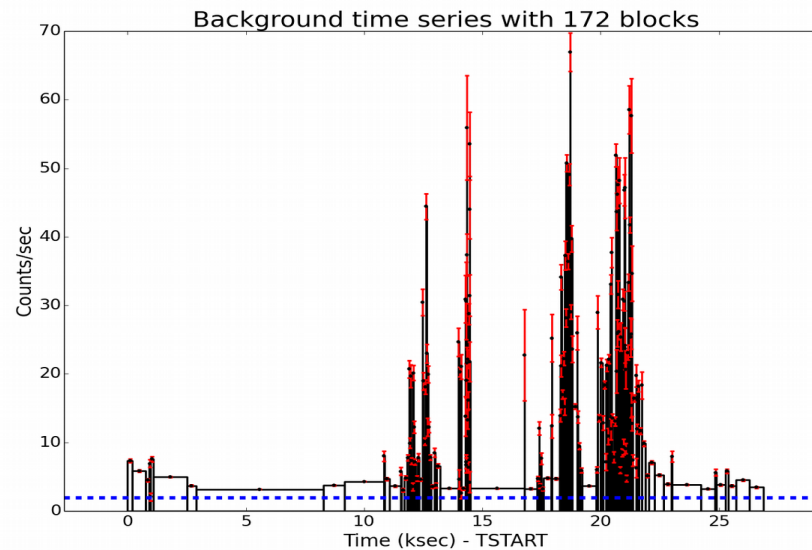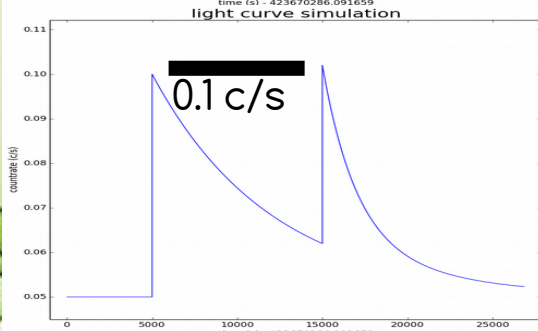
# Results

credit: A. De Luca

# Results

From 3XMM 3696 variable unique sources to EXTraS 9180 variable unique sources



credit: A. De Luca

# Products

For each observation, camera, exposure, source

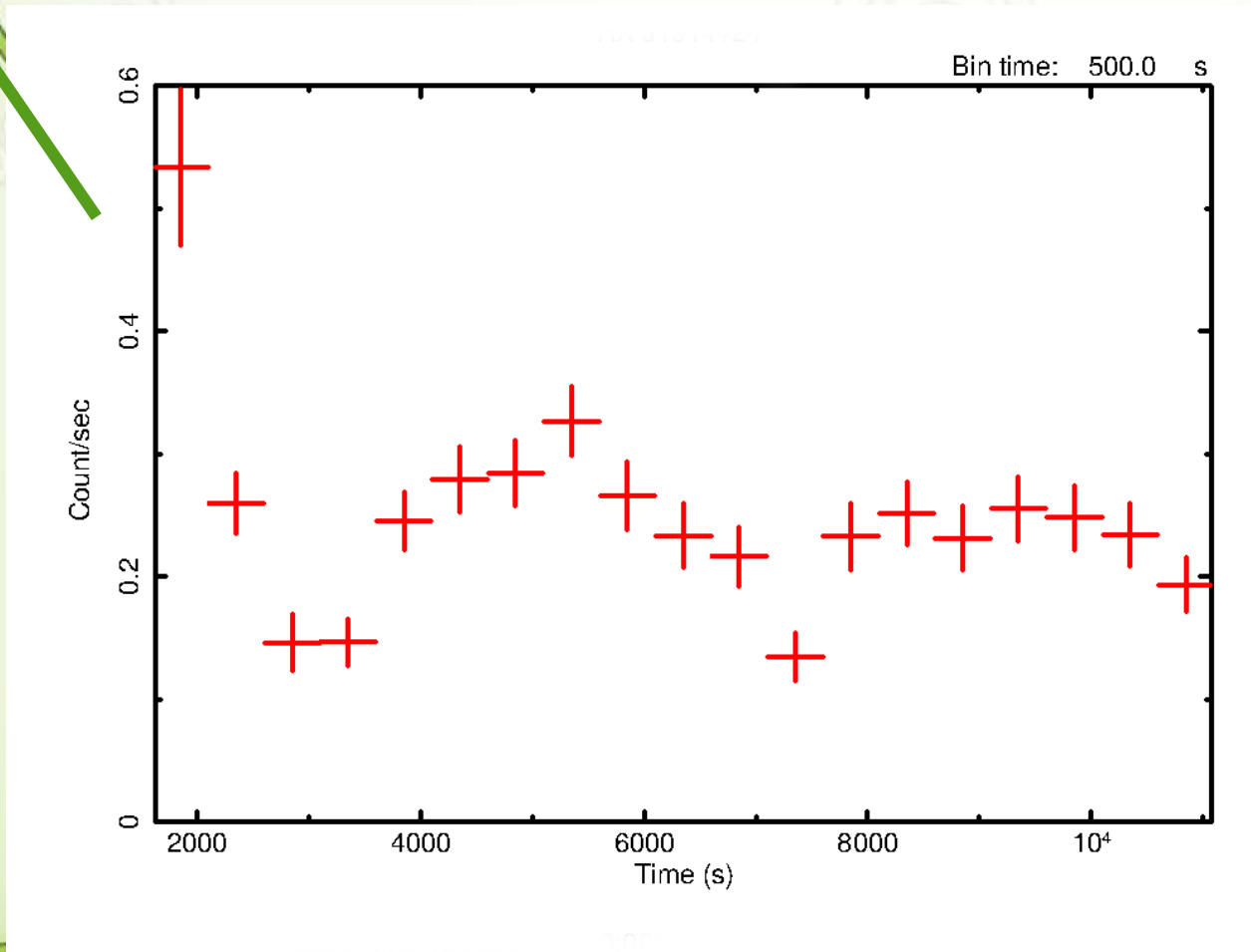| Standard Light Curve | Uniform Bin Light Curve | Bayesian Blocks Light Curve |

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# Products

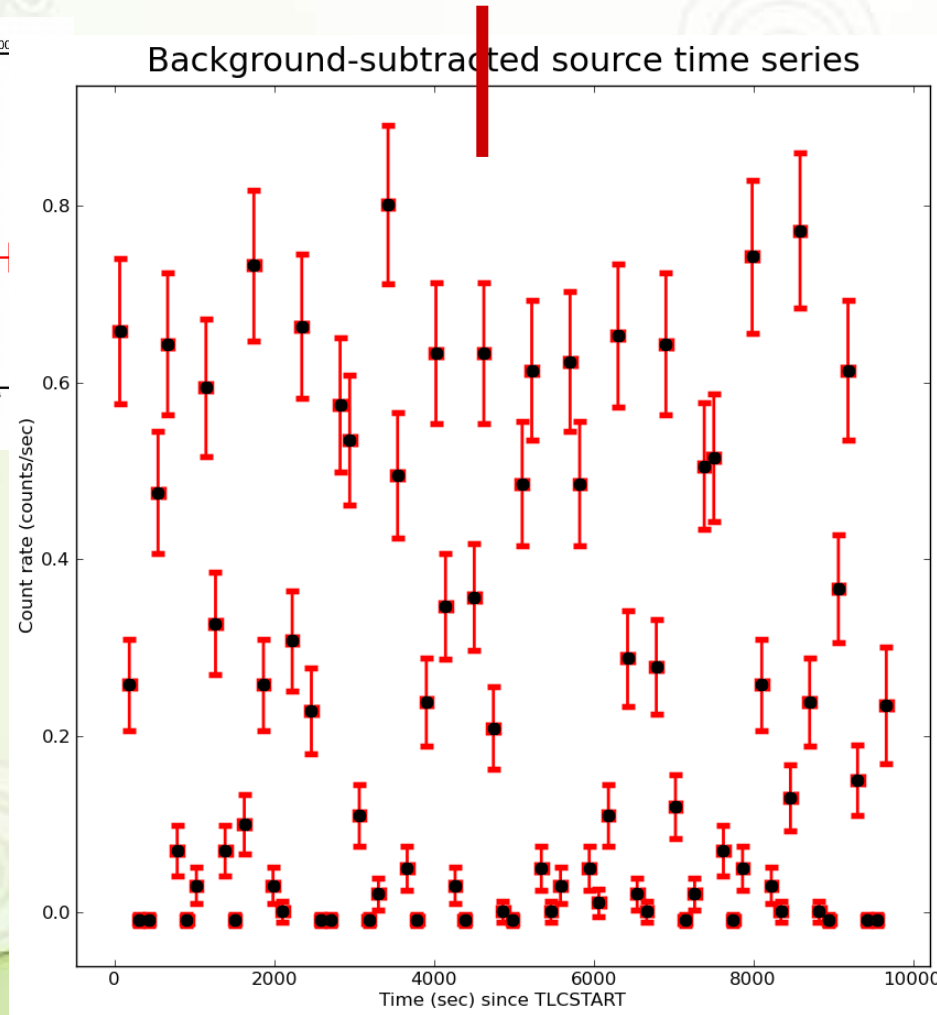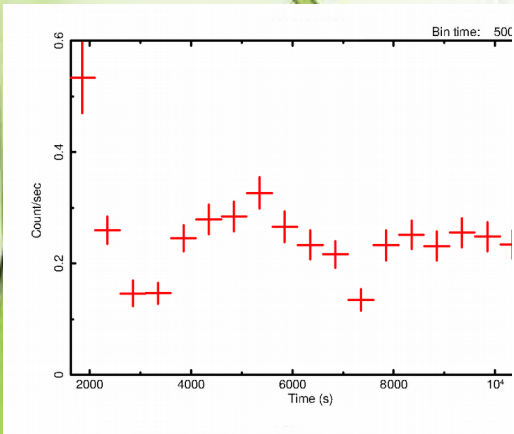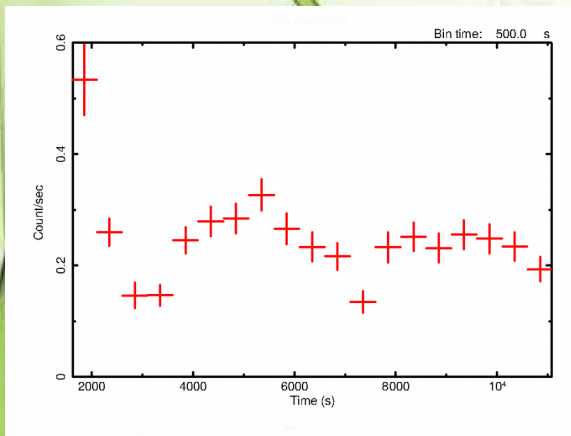| Standard Light Curve | Uniform Bin Light Curve | Bayesian Blocks Light Curve |
|---|---|---|

# Products

ubXX_obs_exp_src_dt.fit

| Standard Light Curve | Uniform Bin Light Curve | Bayesian Blocks Light Curve |
|---|---|---|



Background-subtracted source time series

# Products

Standard Light Curve

Uniform Bin Light Curve

Bayesian Blocks Light Curve

bbXX_obs_exp_src_sig.fit

# Products

stdXX_obs_exp_src_dt.fit

**Standard Light Curve**
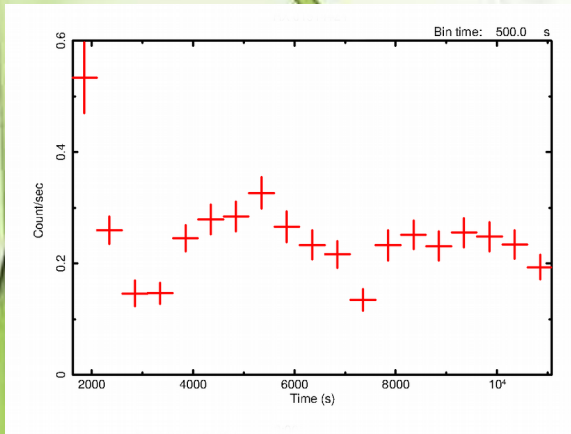


| 500 s | Variable |
|-------|----------|

ubXX_obs_exp_src_dt.fit

**Uniform Bin Light Curve**
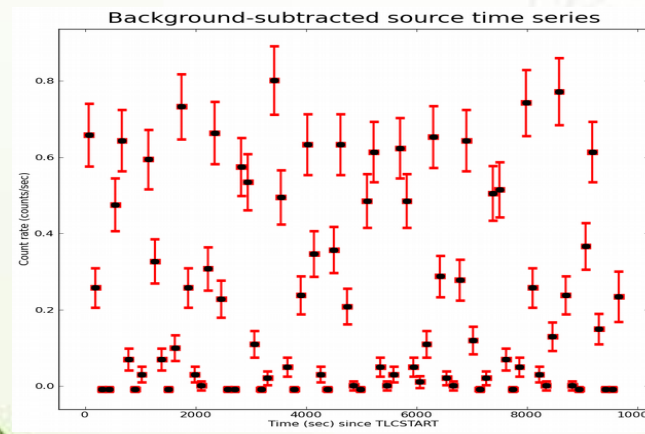


| 500 s | Variable |
|-------|----------|

bbXX_obs_exp_src_sig.fit
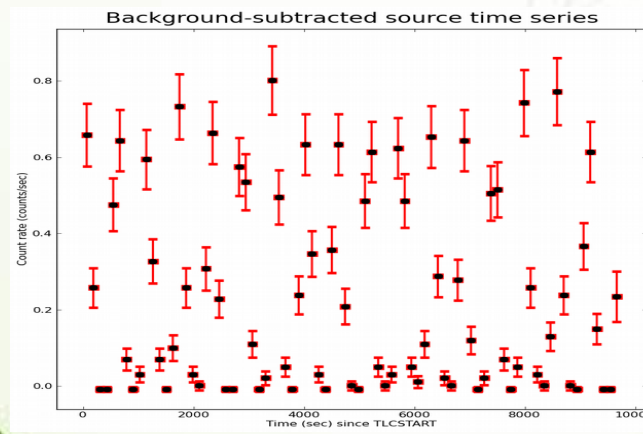
**Bayesian Blocks Light Curve**



| 3 sigma | 4 sigma |
|---------|---------|

# Products



## Standard Light Curve

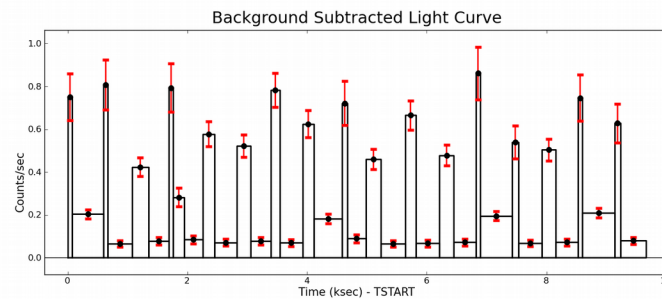## Uniform Bin Light Curve

## Bayesian Blocks Light Curve
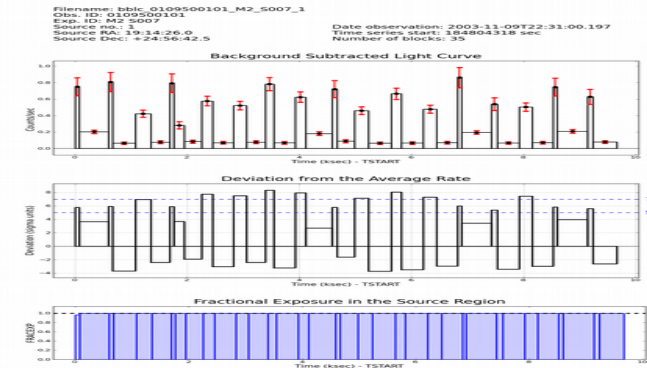
| 500 s | Variable |
|---|---|

| 500 s | Variable |
|---|---|

| 3 sigma | 4 sigma |
|---|---|

| 0.2-12 keV | 0.2-1 keV | 1-2 keV | 2-12 keV |
|---|---|---|---|

| 0.2-12 keV | 0.2-1 keV | 1-2 keV | 2-12 keV |
|---|---|---|---|

XX_SL.fit , XX_LO.fit, XX_HI.fit

| 0.2-12 keV | 0.2-1 keV | 1-2 keV | 2-12 keV |
|---|---|---|---|

| 0.2-12 keV | 0.2-1 keV | 1-2 keV | 2-12 keV |
|---|---|---|---|

# Products

## Standard Light Curve
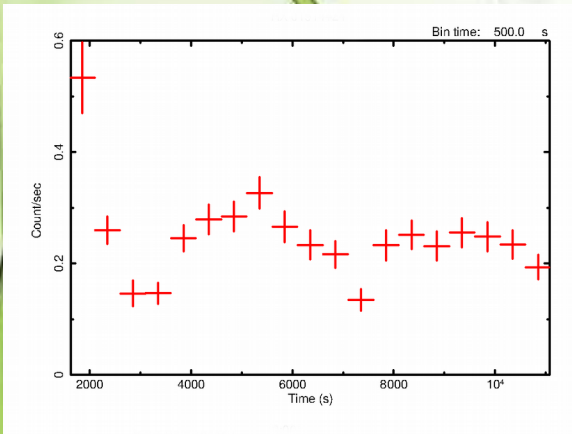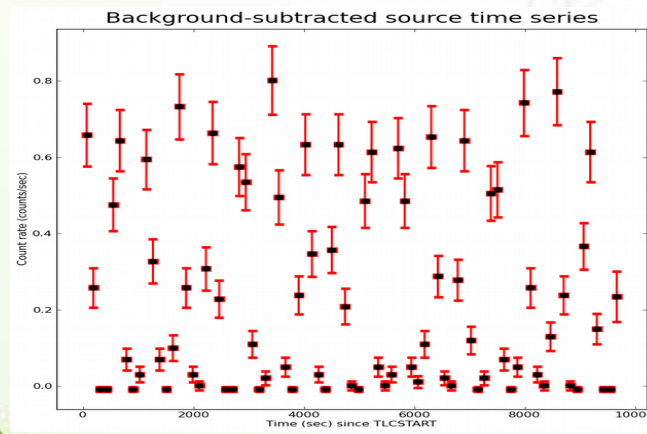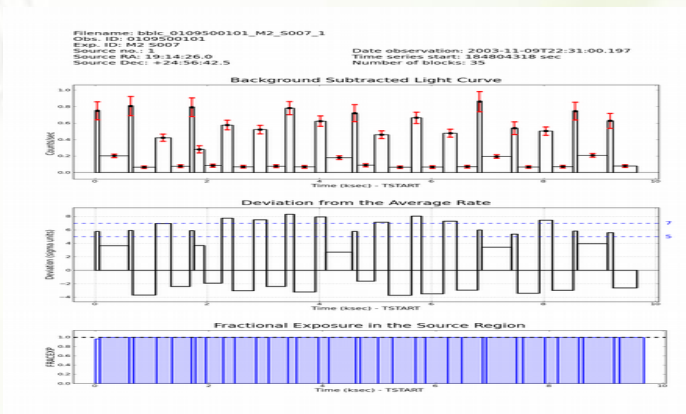


## Uniform Bin Light Curve



## Bayesian Blocks Light Curve



| 500 s | Variable | | 500 s | Variable | | 3 sigma | | 4 sigma | |
|---|---|---|---|---|---|---|---|---|---|

| | | 0.2-12 keV | 0.2-1 keV | 1-2 keV | 2-12 keV | 0.2-12 keV | 0.2-1 keV | 1-2 keV | 2-12 keV |
|---|---|---|---|---|---|---|---|---|---|

| | | 0.2-12 keV | 0.2-1 keV | 1-2 keV | 2-12 keV | | 0.2-12 keV | 0.2-1 keV | 1-2 keV | 2-12 keV |
|---|---|---|---|---|---|---|---|---|---|---|

XXlc_obs_exp_src_dt.fit
XXcdf_obs_exp_src_dt.fit
XXhr_obs_exp_src_dt.fit

| | Light Curve | Cumulative Distribution Function | Hardness Ratio | | Light Curve | Cumulative Distribution Function |
|---|---|---|---|---|---|---|

# 17,500,000 files

AstroSiesta 02/02/2017

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# Catalog

All the results from headers are stored in a single catalog file

| MAIN CATALOG FILE |
|---|
| 2.3 GB |
| 802,075 rows |
| 754 columns |

| LIGHT CATALOG FILE |
|---|
| 0.6 GB |
| 802,075 rows |
| 194 columns |

**Miscellaneous**
Source ID (obs/exp/cam/num/IAU/3XMM4)
Coordinates (Celestial/Galactic)
Instrumental
3XMM Main Results

**UB (500&Opt)/BB (3s&4s)**
Average
Standard Deviation
Median
Fractional Excess Variance
Skewness
Kurtosis
Amplitude
**Model fitting**
Constant
Linearl
Quadraticl
Exponential
Flarel
Eclipse
**Cumulative**
Time Fraction <3s
Time Fraction >3s
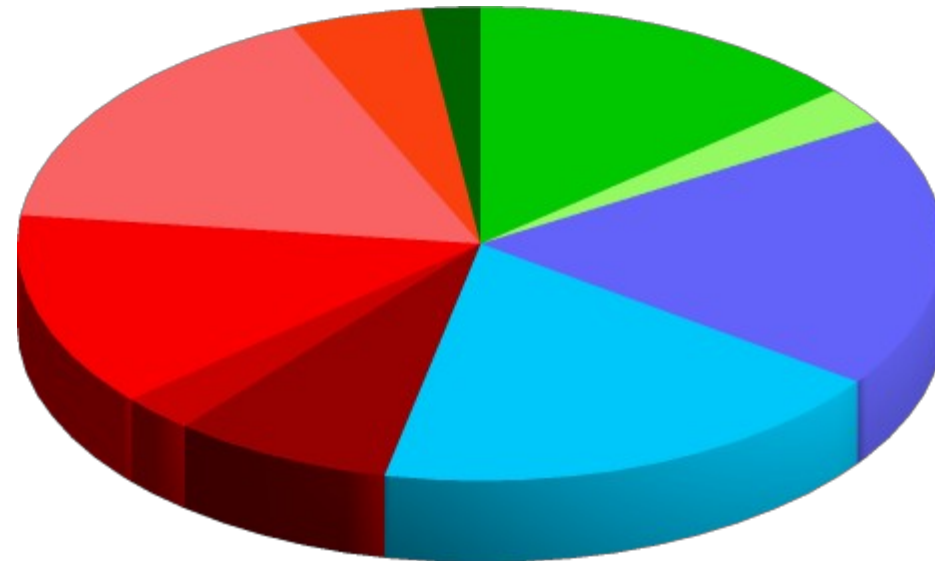Central 90% range
Central 20% asymmetry

**BB (3s&4s)**
Min&Max Rate
Gradient
Dou/Hal Time
Neg/Pos
Deviation
Fragmentariness
Steadiness

**UB (500&Opt)**
HR Constant
Model
HR Linear Model

**Flags**
Quality
Bayesian Blocks
Attitude
BB Spurious



- Source ID
- Available prod
- UB Curve 500s
- UB Curve Opt
- UB Curve FFT
- UB Curve HR
- BB Curve 3s
- BB Curve 4s
- Flags
- Instrument

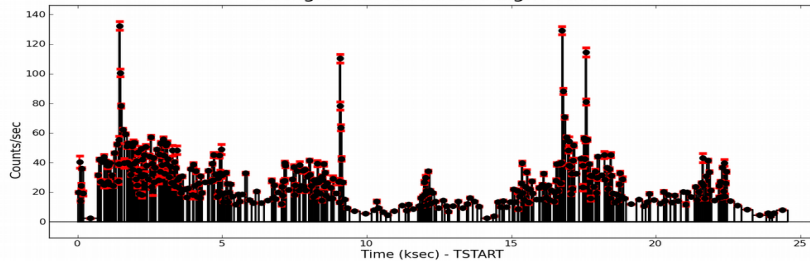More than enough..

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# Some Examples

# Some Examples (fragm)..

LMXB : EXO 0748-676

Filename: bblc_0119710201_PN_S009_1
Obs. ID: 0119710201
Exp. ID: PN S009
Source no.: 1
Source RA: 07:48:33.8
Source Dec: -67:45:07.2

Date observation: 2000-03-05T20:39:03.300
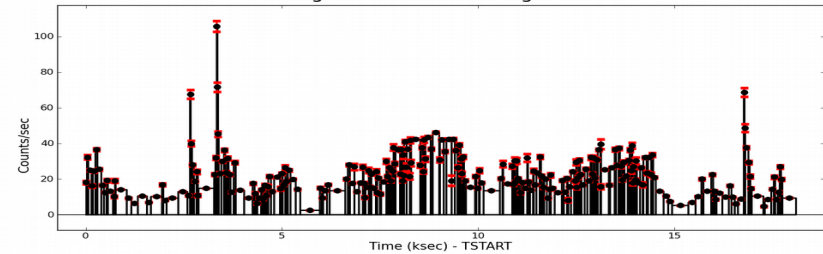Time series start: 68676005 sec
Number of blocks: 379


Background Subtracted Light Curve

Filename: bblc_0123500101_PN_S001_1
Obs. ID: 0123500101
Exp. ID: PN S001
Source no.: 1
Source RA: 07:48:33.7
Source Dec: -67:45:07.7

Date observation: 2000-04-21T04:00:13.140
Time series start: 72676876 sec
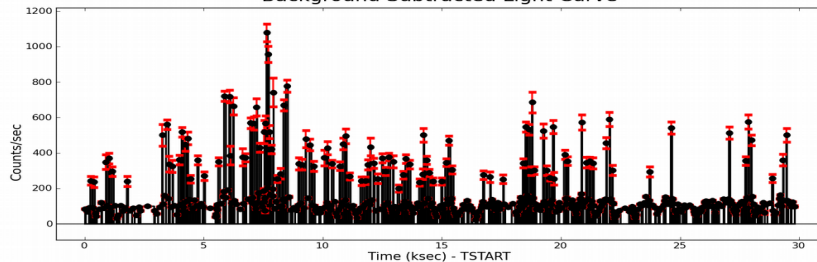Number of blocks: 248


Background Subtracted Light Curve

HMXB : X Persei

Filename: bblc_0151380101_PN_S002_1
Obs. ID: 0151380101
Exp. ID: PN S002
Source no.: 1
Source RA: 03:55:22.9
Source Dec: +31:02:44.9

Date observation: 2003-02-25T17:27:08.269
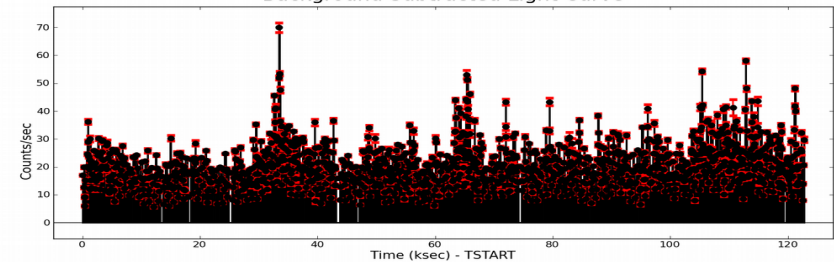Time series start: 162581291 sec
Number of blocks: 497


Background Subtracted Light Curve

Filename: bblc_0600980101_M2_S002_1
Obs. ID: 0600980101
Exp. ID: M2 S002
Source no.: 1
Source RA: 03:55:22.9
Source Dec: +31:02:45.2

Date observation: 2010-02-23T15:12:40.067
Time series start: 383325222 sec
Number of blocks: 1293


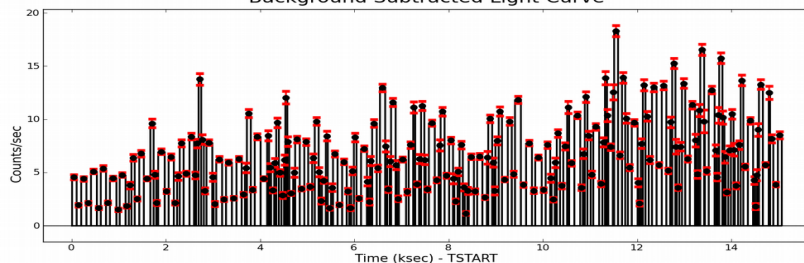Background Subtracted Light Curve

HMXB : LS V +44 17

LMXB : CRTS J135716.8-093238

Filename: bblc_0653660101_PN_S003_1
Obs. ID: 0653660101
Exp. ID: PN S003
Source no.: 1
Source RA: 04:40:59.3
Source Dec: +44:31:50.8

Date observation: 2011-03-18T10:57:43.629
Time series start: 416833128 sec
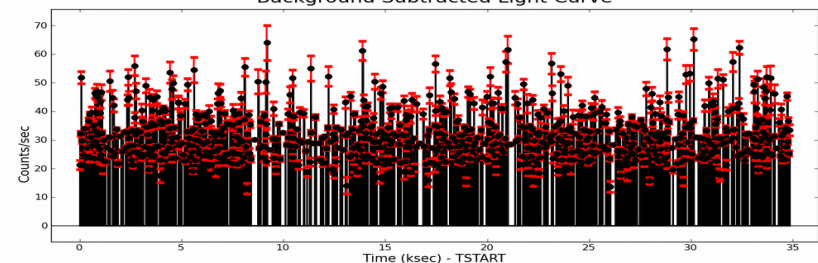Number of blocks: 211


Background Subtracted Light Curve

Filename: bblc_0674580101_M1_U002_1
Obs. ID: 0674580101
Exp. ID: M1 U002
Source no.: 1
Source RA: 13:57:16.8
Source Dec: -09:32:38.3

Date observation: 2011-02-05T15:56:34.815
Time series start: 413308656 sec
Number of blocks: 739
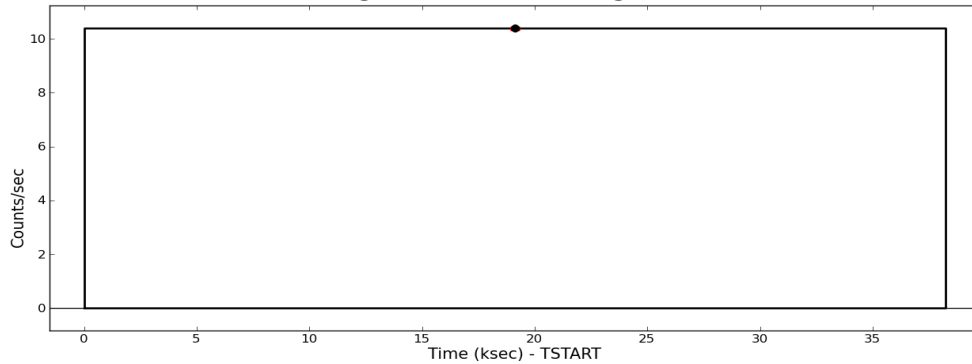

Background Subtracted Light Curve

# Some Examples (steady)..

## PSR: Vela

Filename: bblc_0111080101_M1_S001_1
Obs. ID: 0111080101
Exp. ID: M1 S001
Source no.: 1
Source RA: 08:35:20.6
Source Dec: -45:10:34.3

Date observation: 2000-12-01T23:50:05.223
Time series start: 92101866 sec
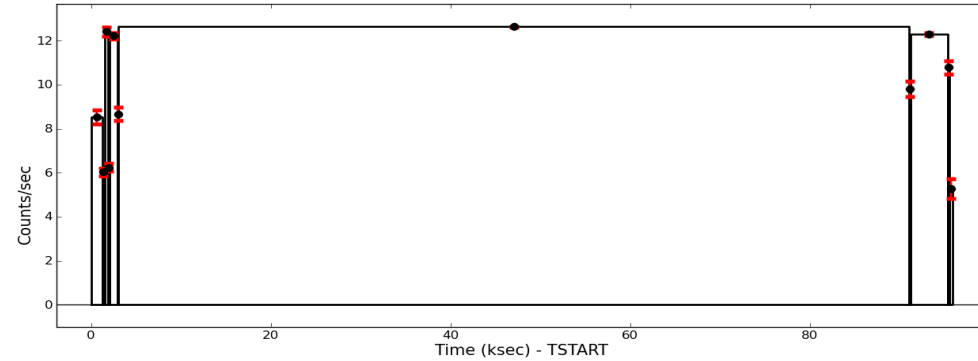Number of blocks: 1

**Background Subtracted Light Curve**

## AGN : M86

Filename: bblc_0200920101_M2_S002_1
Obs. ID: 0200920101
Exp. ID: M2 S002
Source no.: 1
Source RA: 12:30:49.4
Source Dec: +12:23:29.4

Date observation: 2005-01-10T02:48:09.209
Time series start: 221712549 sec
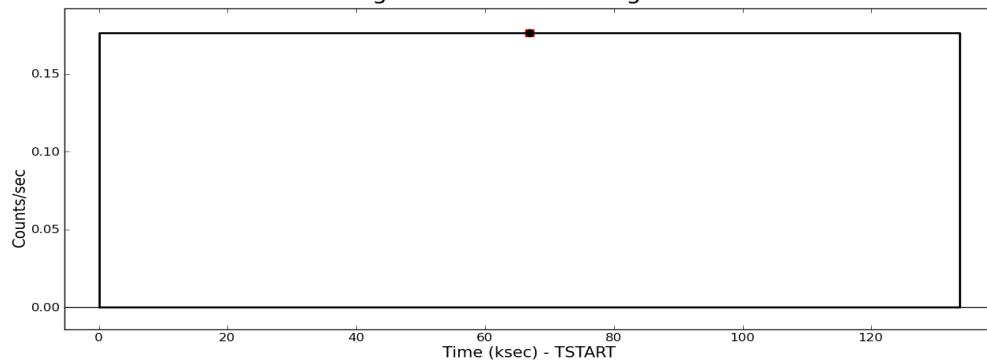Number of blocks: 11

**Background Subtracted Light Curve**

## Starburst Galaxy: NGC 3256

Filename: bblc_0300430101_M1_S001_1
Obs. ID: 0300430101
Exp. ID: M1 S001
Source no.: 1
Source RA: 10:27:51.3
Source Dec: -43:54:13.4

Date observation: 2005-12-06T20:10:52.777
Time series start: 250287113 sec
Number of blocks: 1

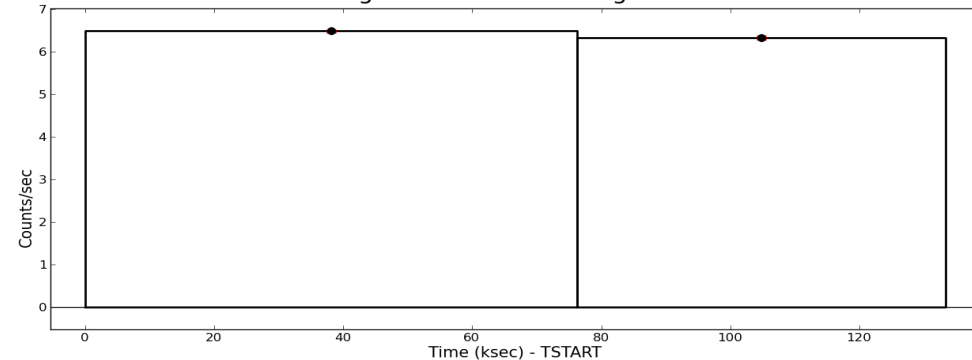**Background Subtracted Light Curve**

## Seyfert I Galaxy: MR 2251-178

Filename: bblc_0670120201_M1_S001_1
Obs. ID: 0670120201
Exp. ID: M1 S001
Source no.: 1
Source RA: 22:54:05.9
Source Dec: -17:34:55.4

Date observation: 2011-11-11T18:53:09.843
Time series start: 437424852 sec
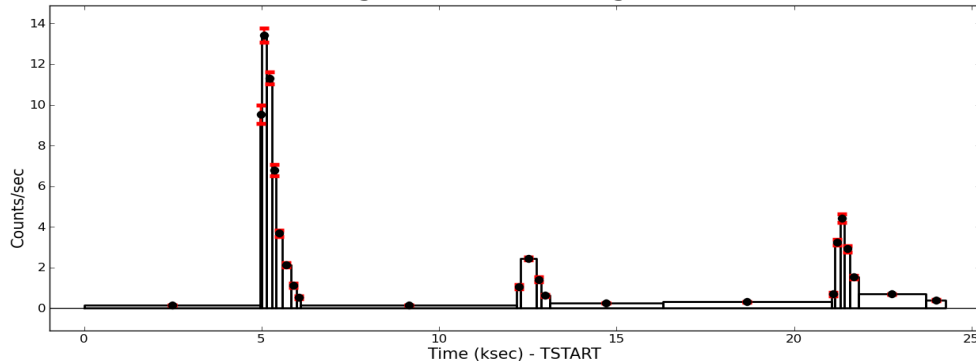Number of blocks: 2

**Background Subtracted Light Curve**

# Some Examples (DOU time)..

Filename: bblc_0200530501_M2_S002_1
Obs. ID: 0200530501
Exp. ID: M2 S002
Source no.: 1
Source RA: 10:56:27.2
Source Dec: +07:00:36.1

**Star: Unassociated**

Date observation: 2006-05-19T22:26:12.602
Time series start: 264464830 sec
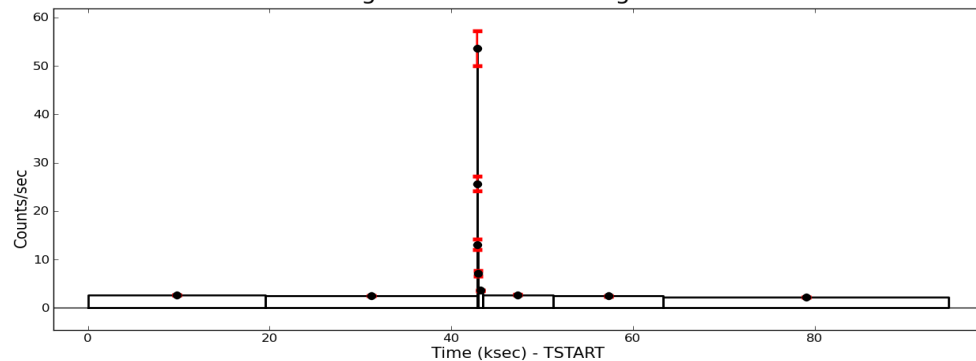Number of blocks: 23



Background Subtracted Light Curve

Filename: bblc_0402430301_M2_S003_2
Obs. ID: 0402430301
Exp. ID: M2 S003
Source no.: 2
Source RA: 17:45:02.3
Source Dec: -28:54:50.0

**LMXB: 2XMM J174502.1-285450**

Date observation: 2007-04-01T14:47:41.500
Time series start: 291826123 sec
Number of blocks: 10



Background Subtracted Light Curve

M. Marelli - EXTraS group

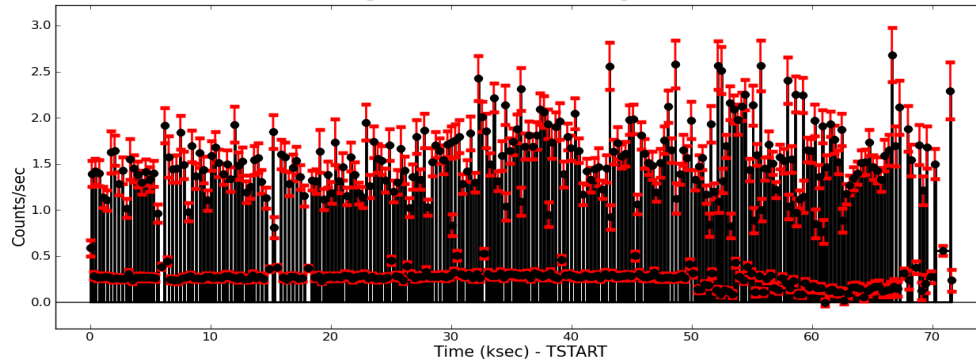# Some Examples (HAL time)..



Filename: bblc_0206100101_PN_U002_1
Obs. ID: 0206100101
Exp. ID: PN U002
Source no.: 1
Source RA: 08:06:22.9
Source Dec: +15:27:31.1

### X-ray Binary: RX J0806.3+1527

Date observation: 2004-11-05T17:16:59.825
Time series start: 216062282 sec
Number of blocks: 446
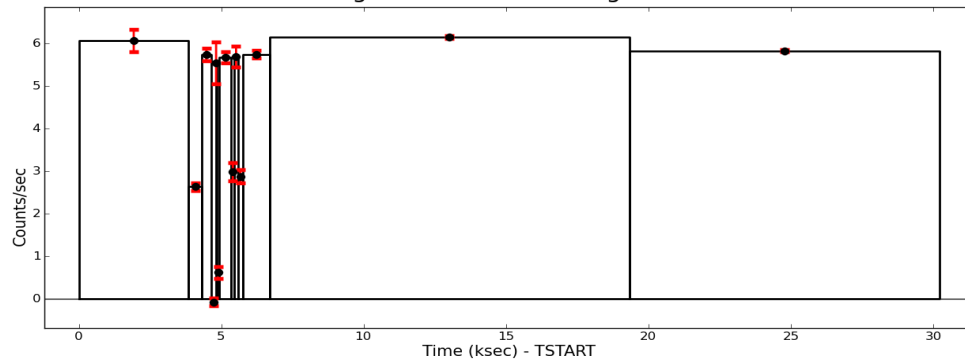
**Background Subtracted Light Curve**



Filename: bblc_0503750301_M2_S007_1
Obs. ID: 0503750301
Exp. ID: M2 S007
Source no.: 1
Source RA: 19:21:14.1
Source Dec: -58:40:12.8

### Seyfert I Galaxy: ESO 141-55

Date observation: 2007-10-09T23:46:38.272
Time series start: 308360858 sec
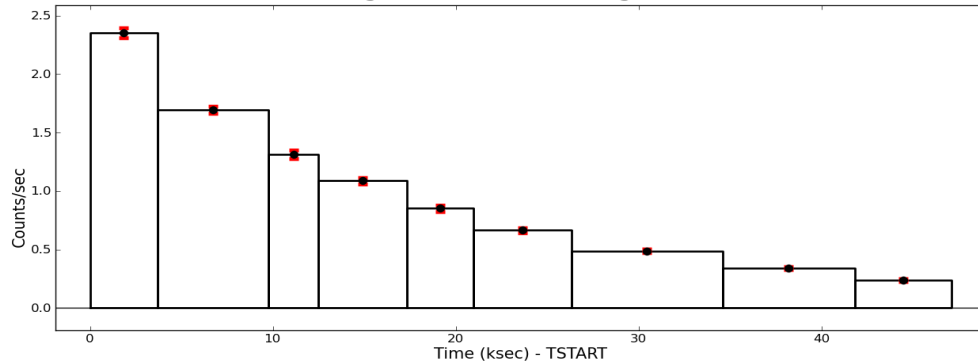Number of blocks: 13

**Background Subtracted Light Curve**

# Some Examples (exponential)..

T-Tauri Star: EM SR 4

Filename: bblc_0109060101_PN_S004_3
Obs. ID: 0109060101
Exp. ID: PN S004
Source no.: 3
Source RA: 16:25:56.2
Source Dec: -24:20:48.2

Date observation: 2000-09-11T21:10:19.898
Time series start: 85093882 sec
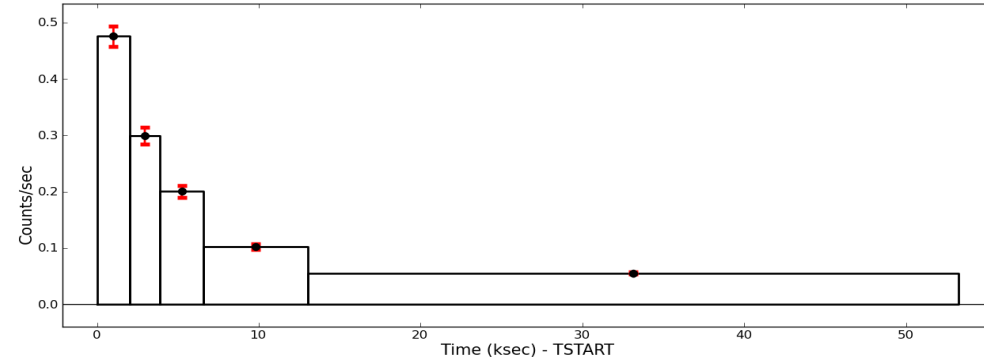Number of blocks: 9


Background Subtracted Light Curve

Brown Dwarf:
J161401.73-225848.7

Filename: bblc_0109060201_M1_S002_3
Obs. ID: 0109060201
Exp. ID: M1 S002
Source no.: 3
Source RA: 16:14:01.6
Source Dec: -22:58:46.2

Date observation: 2000-08-24T20:23:44.261
Time series start: 83535880 sec
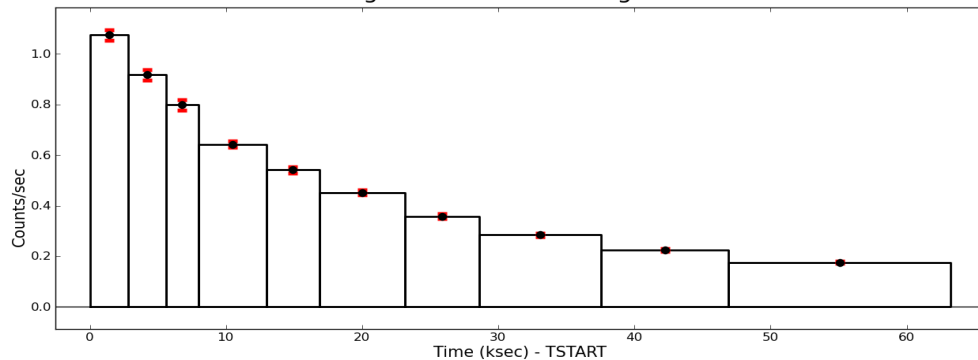Number of blocks: 5


Background Subtracted Light Curve

Gamma-ray Burst:
GRB 080723B

Filename: bblc_0560191401_M2_S003_1
Obs. ID: 0560191401
Exp. ID: M2 S003
Source no.: 1
Source RA: 11:47:20.0
Source Dec: -60:14:27.8

Date observation: 2008-07-23T18:48:16.648
Time series start: 333226157 sec
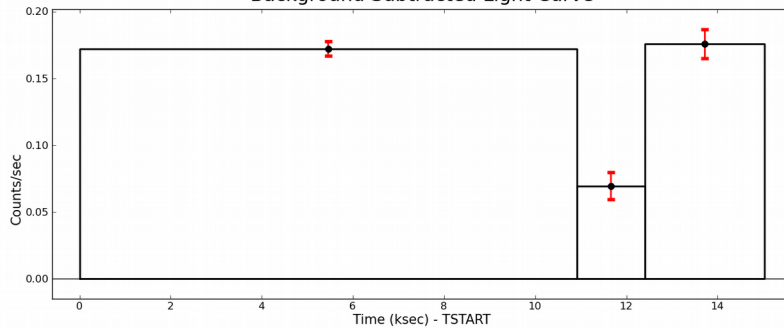Number of blocks: 10


Background Subtracted Light Curve

# Some Examples (eclipse)..
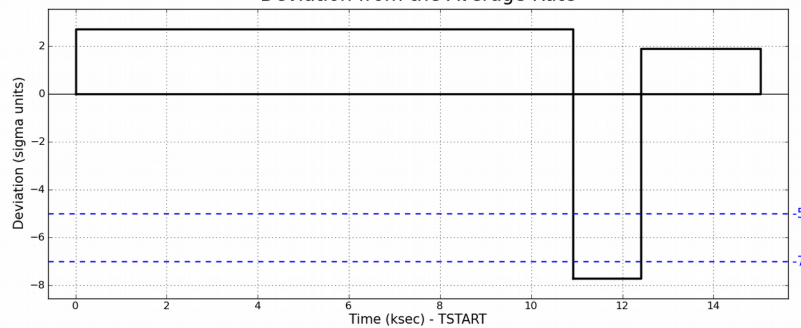


**X-ray Binary Candidate in M31: HPH2013 75**

Filename: bblc_0405320901_PN_S001_23
Obs. ID: 0405320901
Exp. ID: PN S001
Source no.: 23
Source RA: 00:42:32.2
Source Dec: +41:13:14.0

Date observation: 2006-07-02T13:41:13.539
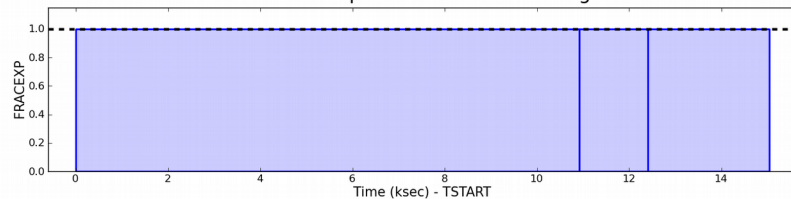Time series start: 204702668 sec
Number of blocks: 3

Background Subtracted Light Curve

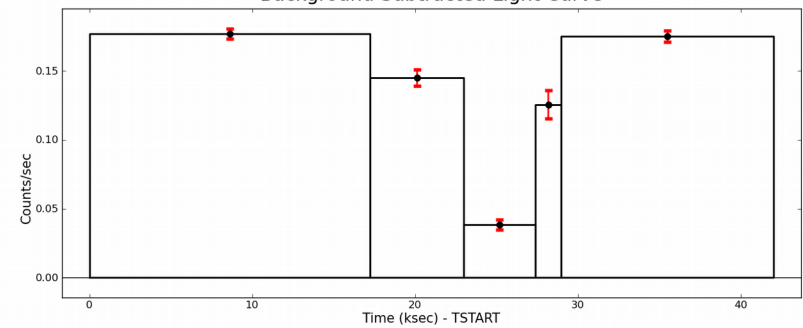Deviation from the Average Rate

Fractional Exposure in the Source Region

**HMXB: HD 49798**

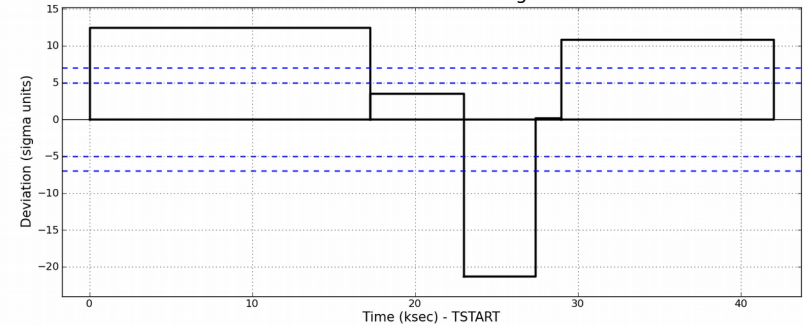Filename: bblc_0555460201_PN_S003_3
Obs. ID: 0555460201
Exp. ID: PN S003
Source no.: 3
Source RA: 06:48:04.7
Source Dec: -44:18:58.4

Date observation: 2008-05-10T21:29:03.453
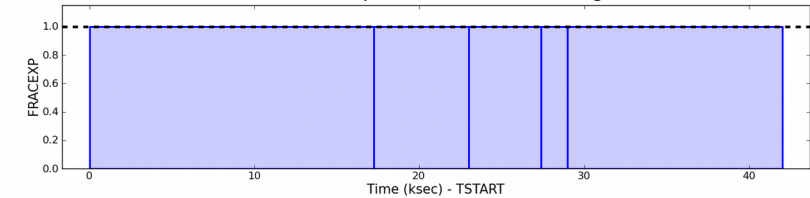Time series start: 326842206 sec
Number of blocks: 5

Background Subtracted Light Curve

Deviation from the Average Rate

Fractional Exposure in the Source Region

Conclusions

Please help us in making Science!