XMM2ATHENA

Long-term transient alerts

Natalie Webb
In collaboration with
IRAP, AIP, MPE, CEA, ObAS, Leicester

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101004168

INTRODUCTION

- Already ~15000 observations with XMM-Newton

Long-term variability

- Sources vary on the long term, no systematic study made in X-ray
- Some sources already detected >90 times
- But some sources observed and not detected
- Time domain astronomy becoming important
- XMM-Newton could continue until 2030s and could provide transient alerts

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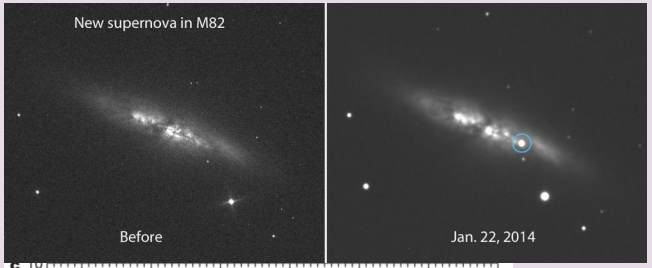
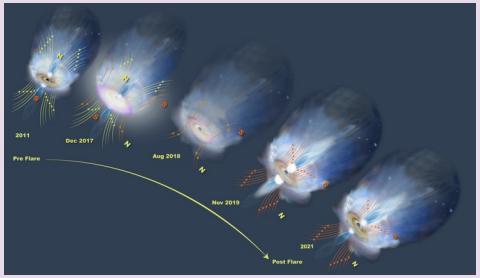
INTRODUCTION

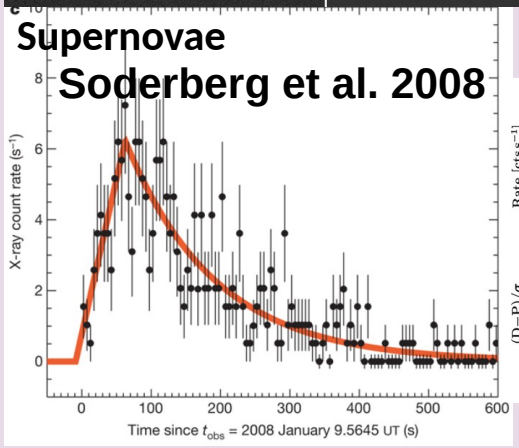
Long-term variability



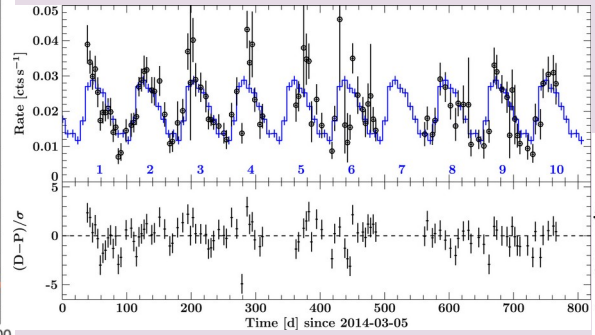


Supernovae

Soderberg et al. 2008



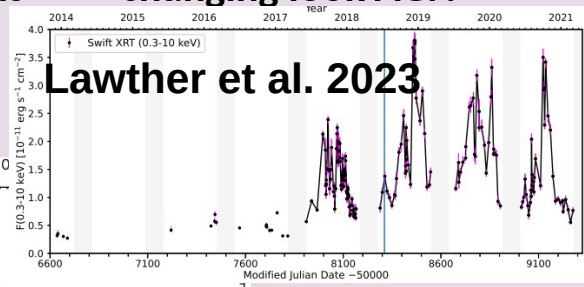
ULX state changes



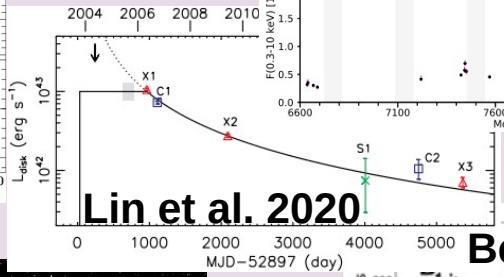
Walton et al. 2016

tidal disruptions

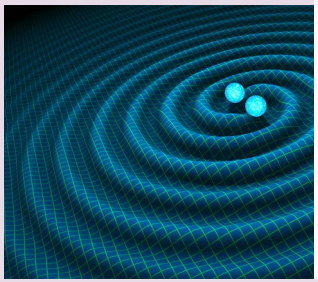
changing look AGN

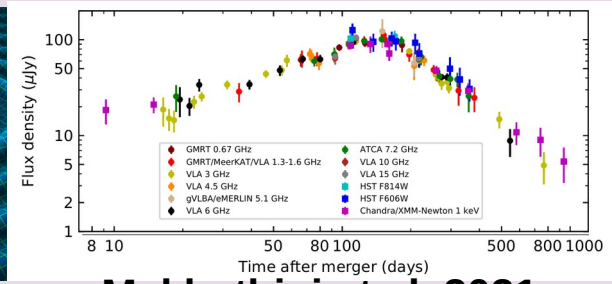


Lawther et al. 2023

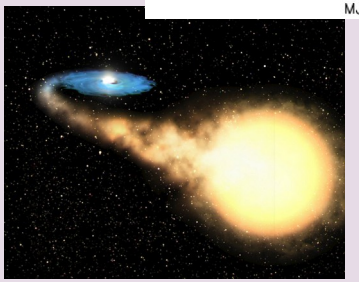


Lin et al. 2020



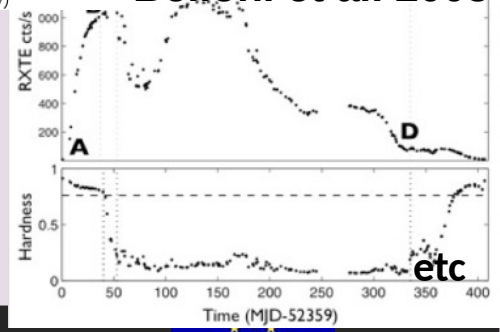


Makhathini et al. 2021



X-ray binary/ CV outbursts

Belloni et al. 2005



etc

Grav. wave events

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EXAMPLE OF SCIENCE QUESTIONS THAT CAN BE ANSWERED FOR TDES CAUGHT EARLY

Have TDEs played an important role in SMBH growth ?
- **rate of TDEs**
- **mass accretion rate (sub/super-Eddington) & mass accreted**
- **what is physical mechanism behind super-Eddington accretion ?**

Why is outburst duration so variable?
- **maybe linked to accreted star mass**
- **or inefficient circularisation of debris stream, so high fallback**

Why do some TDEs have hard spectra instead of thermal spectra?
- **possibly due to jets (e.g. Auchettl et al. 2017)**
- **or e.g. shocks in accretion flows (Hryniewicz & Walter 2016)**

Why are some TDEs detected at some wavelengths and not others?
- **possibly from reprocessing of X-ray emission from the disc**
- **or from shocks between the debris streams as they collide**
- **or a combination of both**
- **or due to viewing angle, obscuration by dust, or something else**

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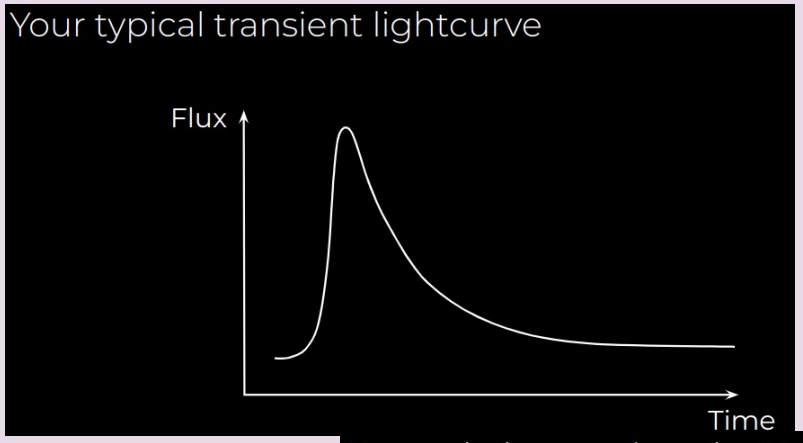
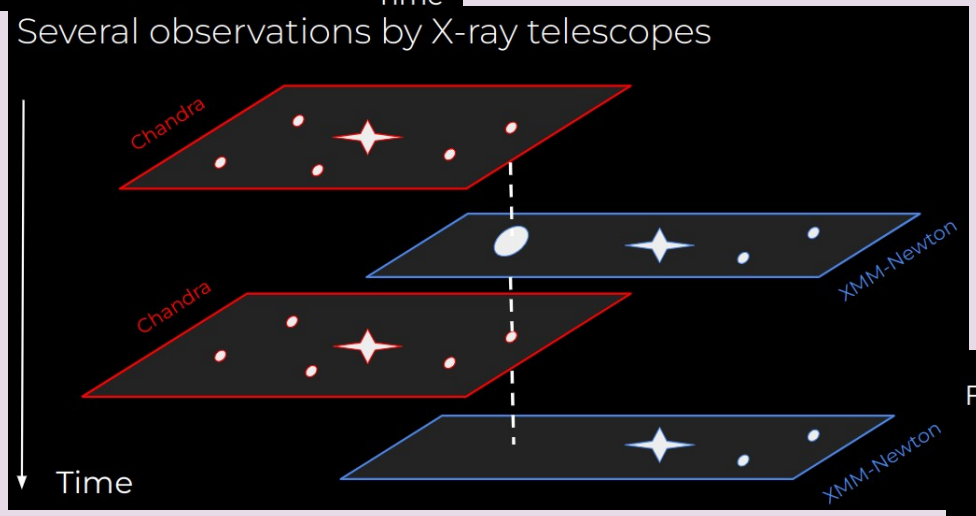
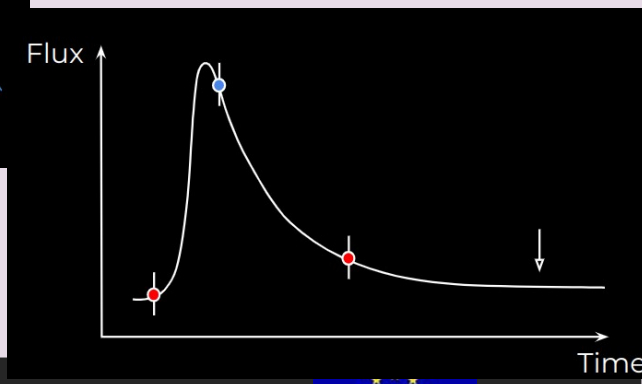
LONG TERM VARIABILITY







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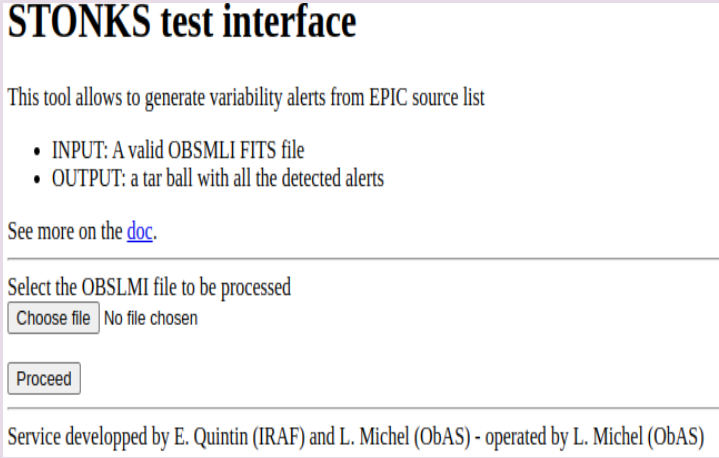
Long-term variability

- 6 X-ray catalogues added to 4XMM catalogue to increase timeline + data points
- Catalogues include the : Chandra Source Catalogue (CSC 2.0, Evans et al. 2020b), Swift X-ray Points Source catalogue (2SXPS, Evans et al. 2020, Rosat All Sky survey (2RXS, Boller et al. 2016), ROSAT pointed pointed survey, (WGACAT, White et al. 1995), XMM-Newton slew survey (XMMSL2, Saxton et al. 2008) & early release Erosita data (eFEDS, Brunner et al. 21)
- Included XMM upper limits using RapidXMM (Ruiz et al. 2022)
- Developed matching algorithm based on Salvato et al. (2018)
- Determined X-ray band(s) and spectral model to use
- Pilot study on 2 months of data to determine variability criteria
- Extended search to investigate spectral variability
- Incorporated optical/UV data from OM telescope
- Tested the algorithm reliability, documentation written
- Code published : https://github.com/ErwanQuintin/STONKS
- Cross-correlation of new sources with ADS



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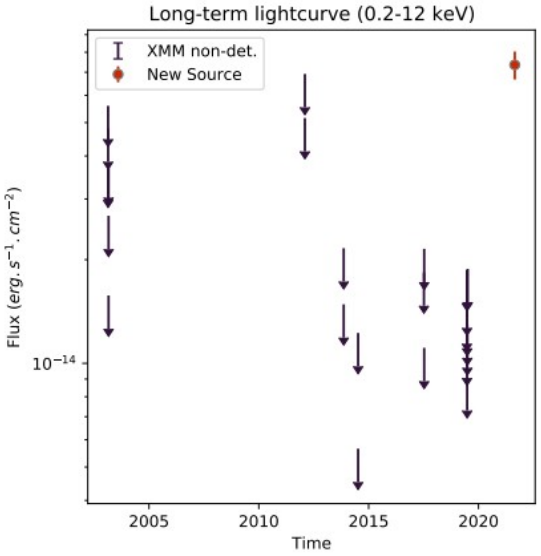
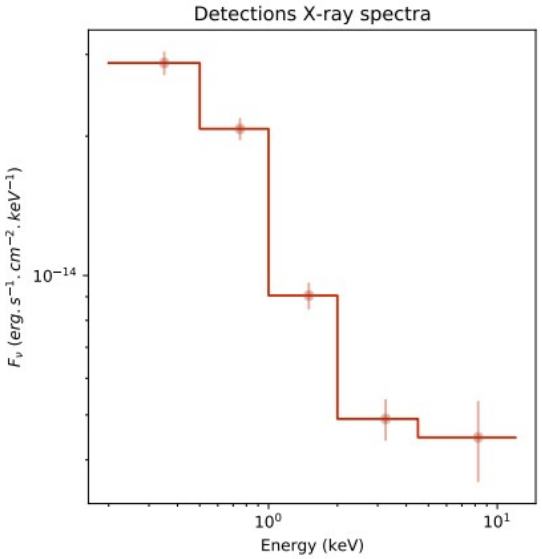
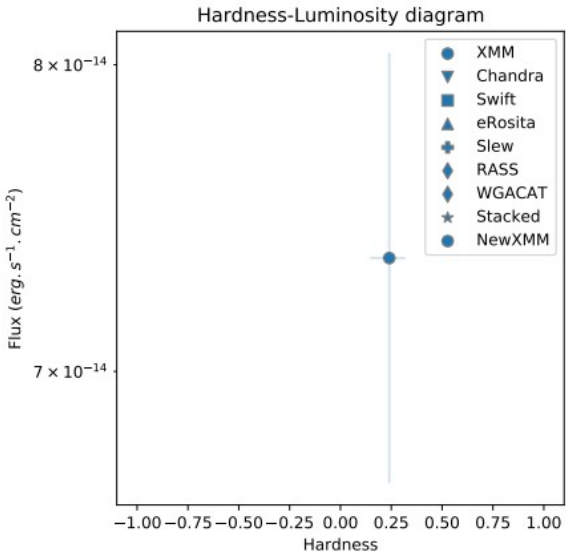
TESTING ALGORITHM

- Online interface used to insert into XMM-Newton pipeline at Strasbourg to identify quasi-real time transients
- Improvement of the speed of the code in order not to slow down pipeline activities
- Output optimised to provide useful data
- A paper describing method & some results written (Quintin et al. to submit)
- Work done to identify new rare objects using the long term variability software (Quintin et al. 2021, Quintin et al. submitted)







ObsID 0891801501
Date Obs 2021-08-27T09:15:57
Target Name ..... NGC 5907 ULX1

SRCNUM 8
Source RA ..... 228.7902 / 15:15:09.6373
Source Dec ..... 56.2301 / +56:13:48.2012
Position Error ..... 0.27"
Off-axis Angles ..... PN: 6.9", M1: 8.0", M2: 7.9"
Instruments DetML .....
PN: 1183.8, M1: 394.5, M2: 327.9, EP: 1902.7

Type of Alert ..... First Detection
Long-term Variability 11.8
Short-term Variability ..... False
Simbad type ..... Not Checked

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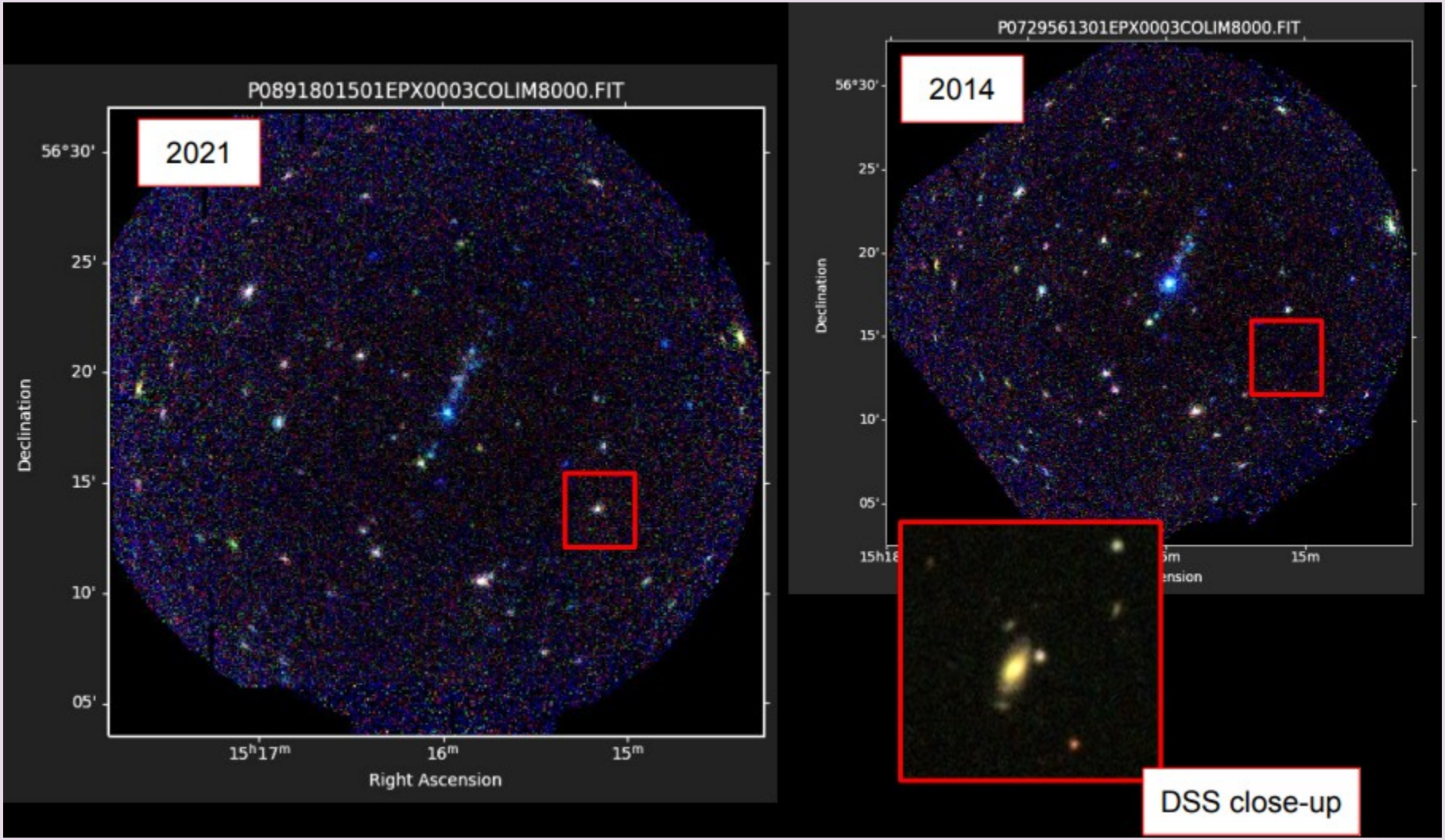
MULTI-WAVELENGTH VIEW OF SOURCE SHOWN ON SLIDE 7



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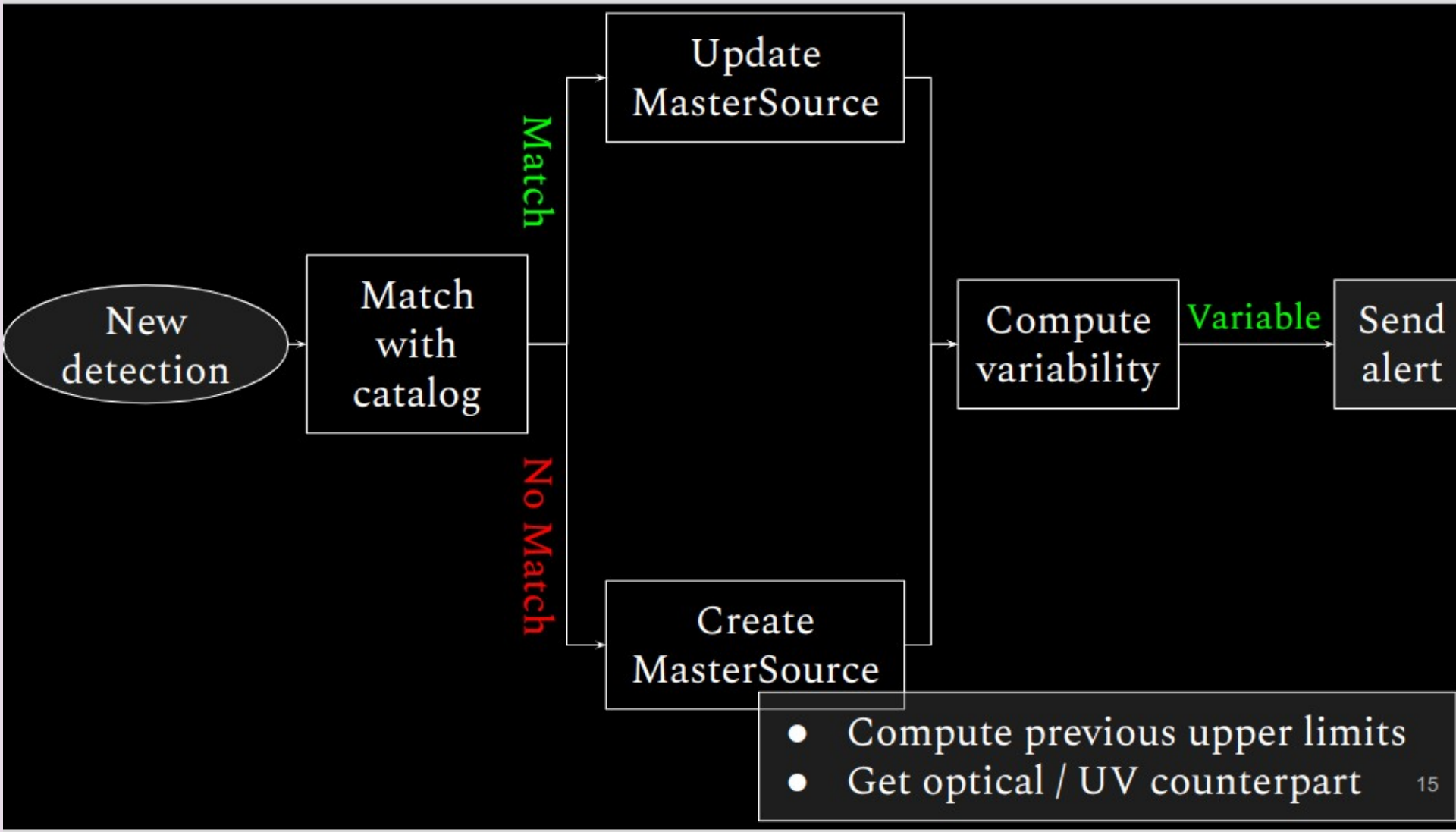
FLOW DIAGRAM OF TASK DEVELOPED



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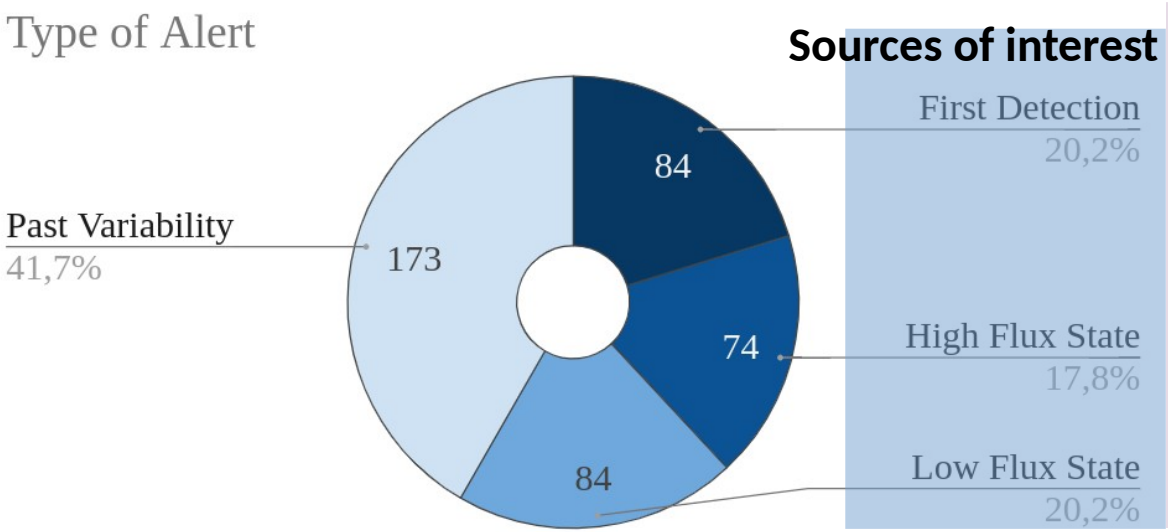
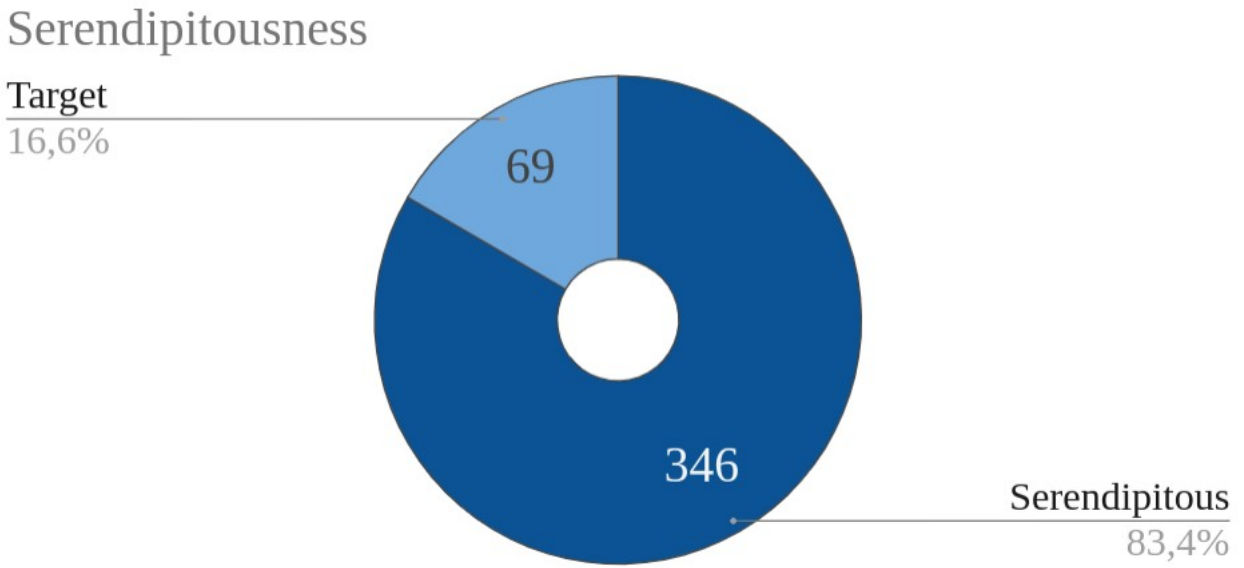
TYPES OF ALERT



- Test on 1 year of data
- 540 observations
- Variability > factor 5
- Detections screened manually
- 242 sources of interest
- On average, 1 alert every 2 days
- Many more transients to be discovered once eRASS published



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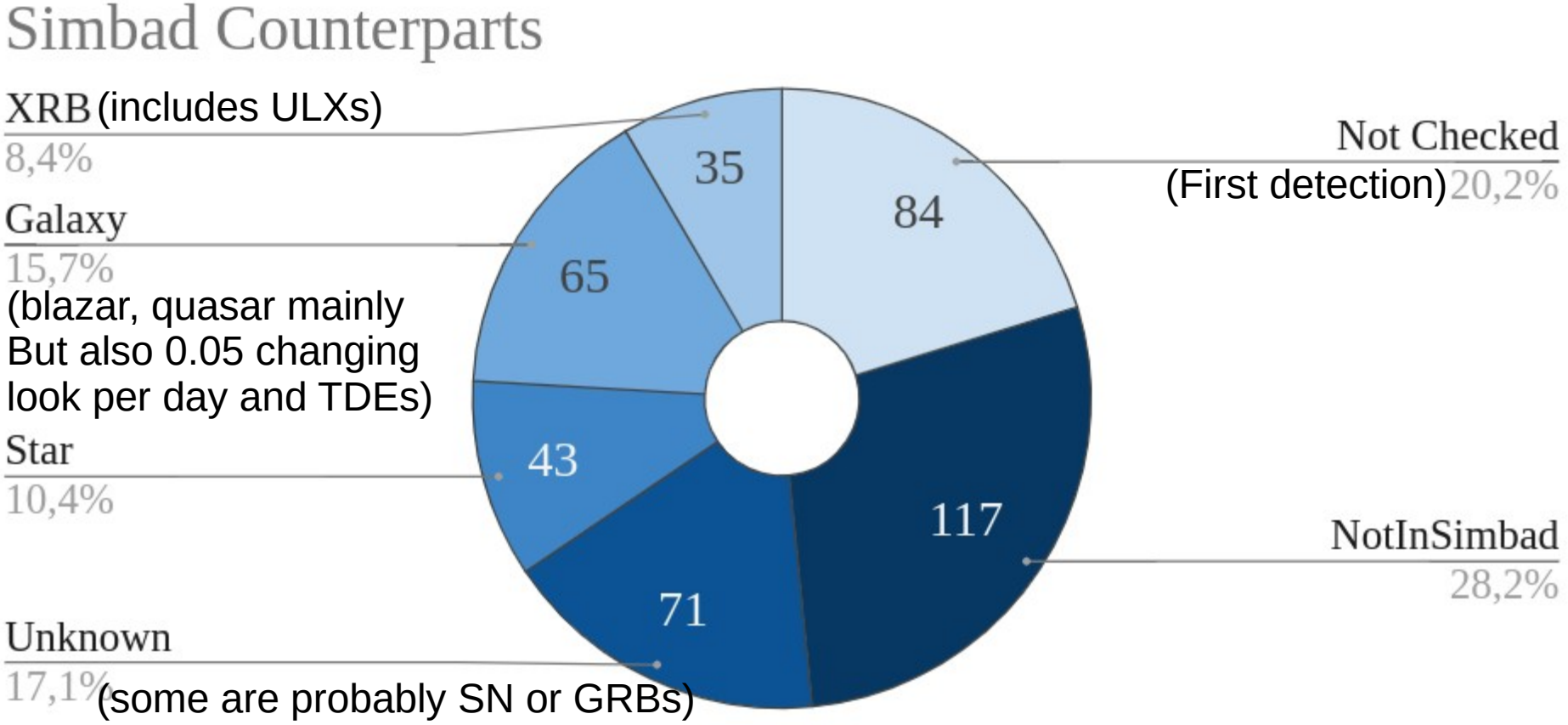
SOURCE NATURE



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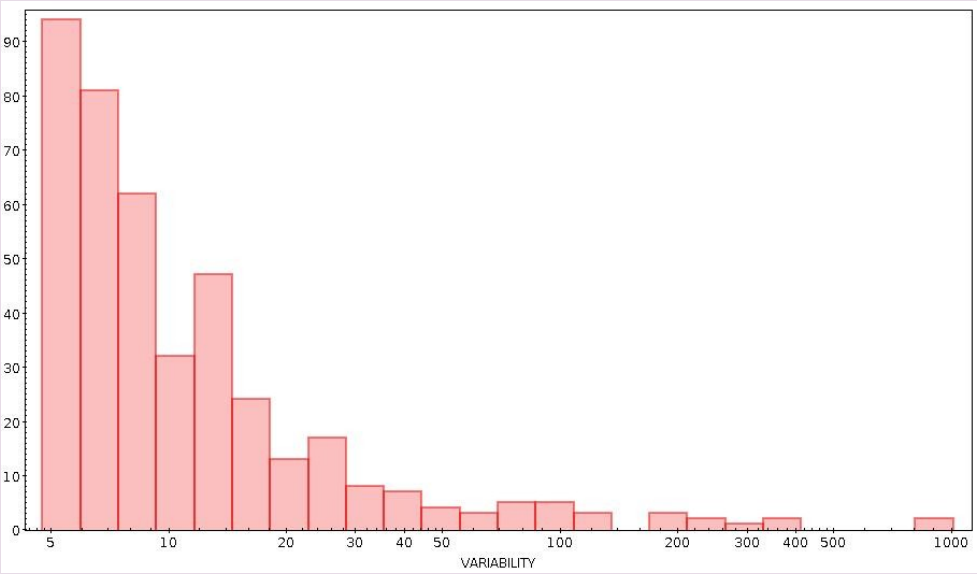
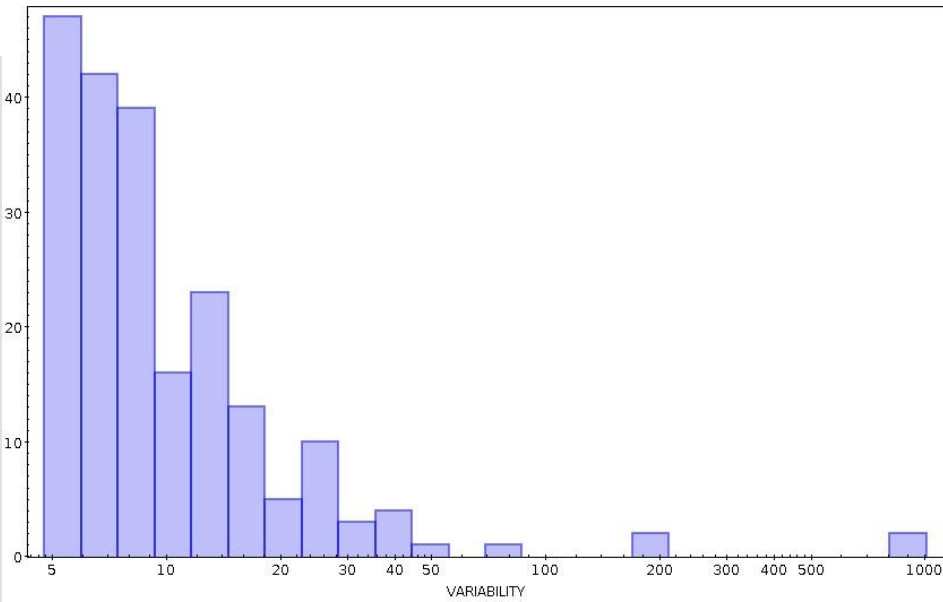
VARIABILITY



All sources

Sources of interest



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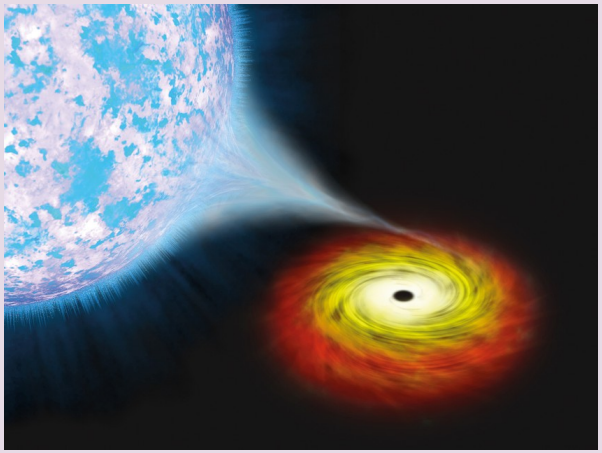
DISCOVERIES OF RARE SOURCES WITH THE SOFTWARE



- Origin of the very high luminosity observed from ultra luminous X-ray (ULX) sources unclear
- 7 showing accelerating pulsations implying a neutron star (NS) compact object
- 8th candidate NS ULX found in galaxy with one other NS ULX (Quintin et al. 2021)
- Supports idea that many ULXs may host NS, implying emission is beamed and generated through fan beam geometry (Gnedin & Sunyaev, 1973)

- Quasi periodic eruptions (QPEs) discovered from massive black holes (Miniutti et al. 2019)
- Five such systems known, two associated with tidal disruption events (TDEs)
- A new strong candidate discovered (Quintin et al. Submitted), also associated with a TDE
- Suggests TDEs may be at the origin of QPEs and data gives constraints on the time from TDE to QPE
- Data helps understand the form of the eruption profile

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HOW COULD ALERTS BE PROVIDED ?

- Code already in place in Strasbourg (ACDS), but no call from pipeline
- PI ticks a box when responding to an AO to say that he is happy for a strongly variable, serendipitously detected (i.e. not the target) source to have information about position, flux variability and nature made public before the end of the proprietary period
- Screeners validate the variable nature, the PI agreement and that the source is not the target, before allowing it to become public
- Medium for providing the alert : webpage / ATEL / GCN / ….
- Typical timescales for the alert are of the order 3 weeks after the observation

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CONCLUSIONS

- **Time domain astronomy is becoming important (see workshop at ESAC in 2018, but also ZTF, gravitational wave events, Rubin, …)**
- **Code already in place (no call yet from pipeline) to find highly variable sources in XMM-Newton data**
- **Alerts could be provided within 3 weeks – good for supernovae, ULXs, TDEs, changing look AGN, gravitational wave events, X-ray binaries, etc**
- **1 new highly variable transient detected every two days – will probably double after publication of eRASS**
- **Very rare objects discovered, could facilitate search for gravitational wave counterparts**

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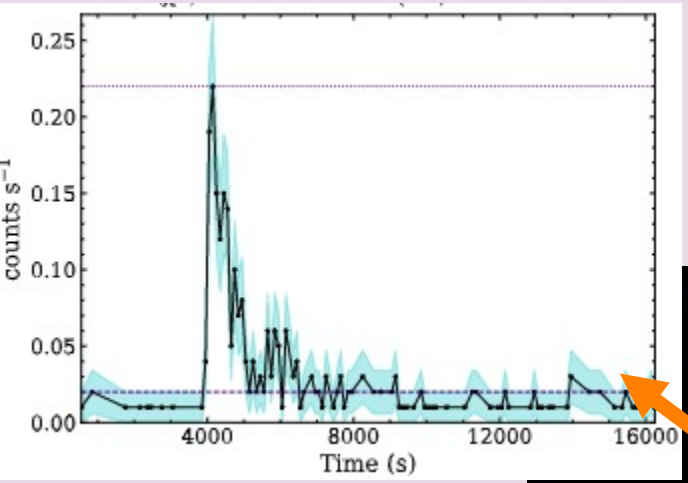
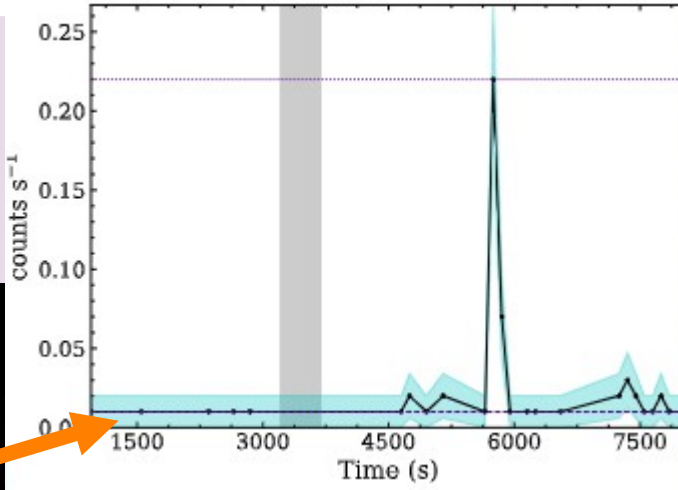
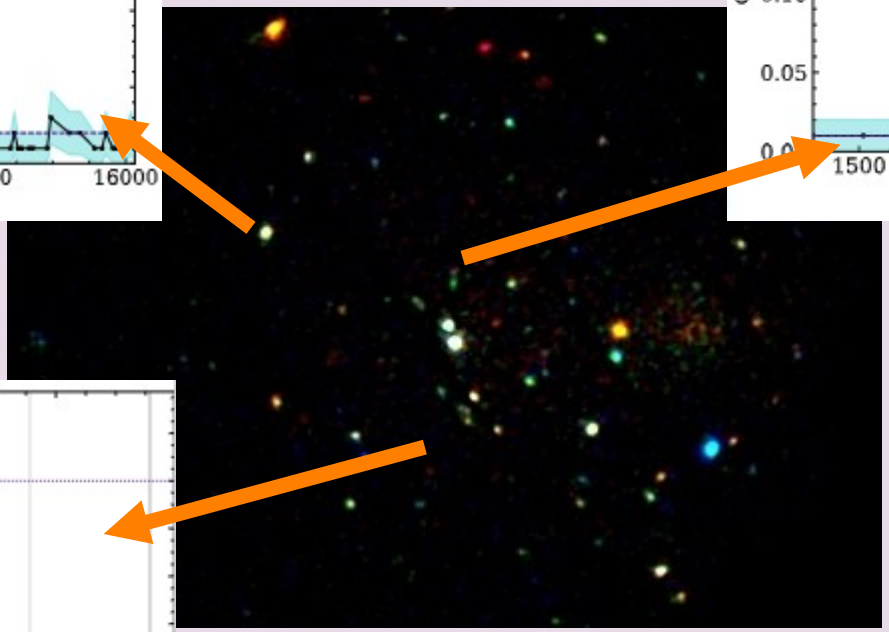
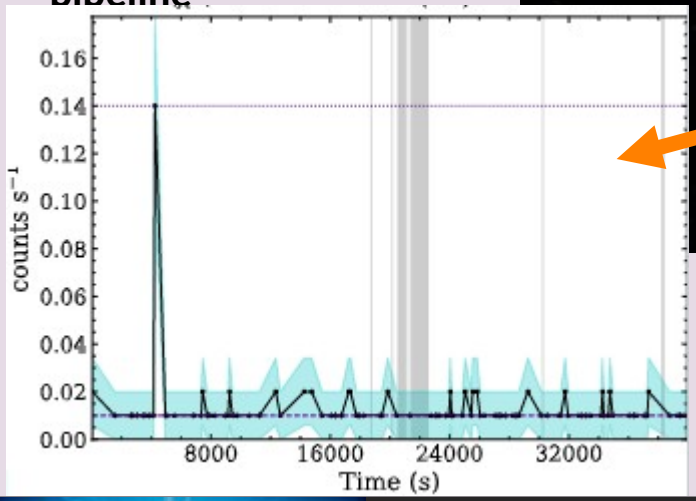
SHORT TERM VARIABILITY







Bright source not identified as variable in pipeline



No source detected with pipeline

HORIZON 2020

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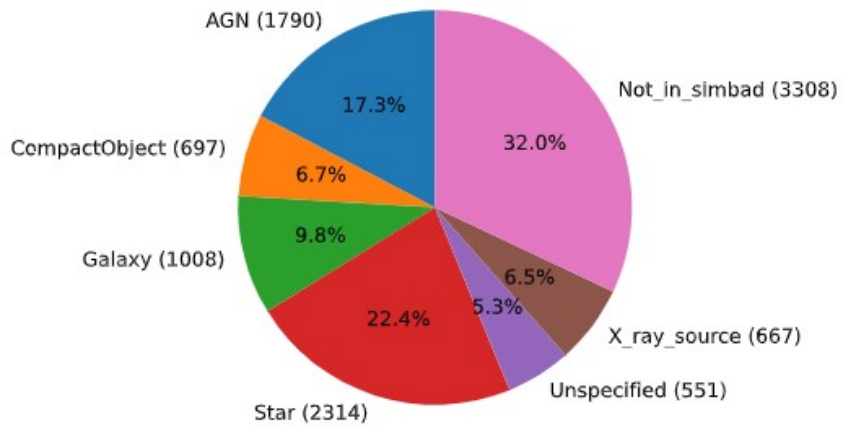
Short-term variability

- Built on preliminary work developed in Pastor-Marazuela et al. (2020)
- Extended use of algorithm to MOS detectors and all modes of MOS and pn
- Improved position determination
- Excluded bright sources & readout streaks to limit false detections
- Investigated full range of detection limits to compare all three cameras
- Tested on specific source types, i.e. FRB fields and Quasi-Periodic Eruptions
- Code also picks out variability from sources with <100 counts & brighter sources, not flagged in pipeline
- Parallelised code + started analysis on all XMM-Newton observations
- **Identified new, faint bursting sources**
- **Identified variability from sources with <100 counts**
- **Identified new short term variable bright sources**
- **Studied different source types (AGN, galaxies, etc)**
- **Work presented at several international meetings**
- **Paper in progress (Gupta et al., to be submitted)**



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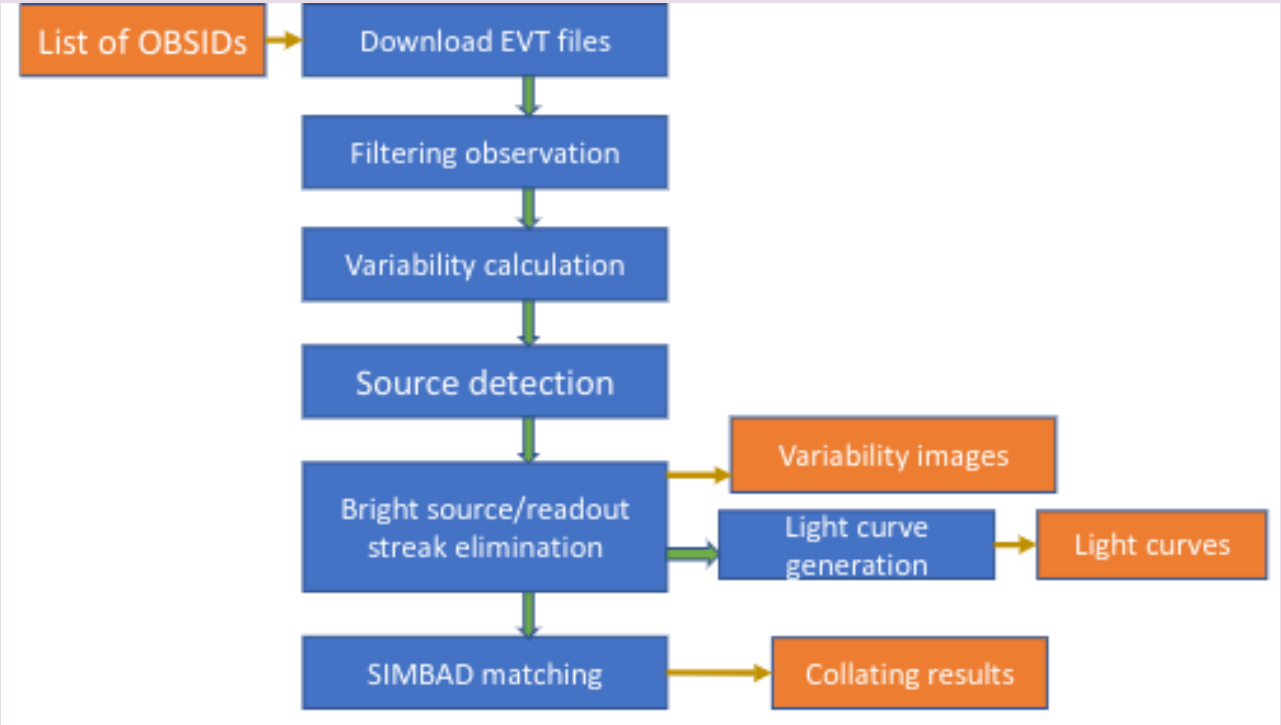
Short-term variability



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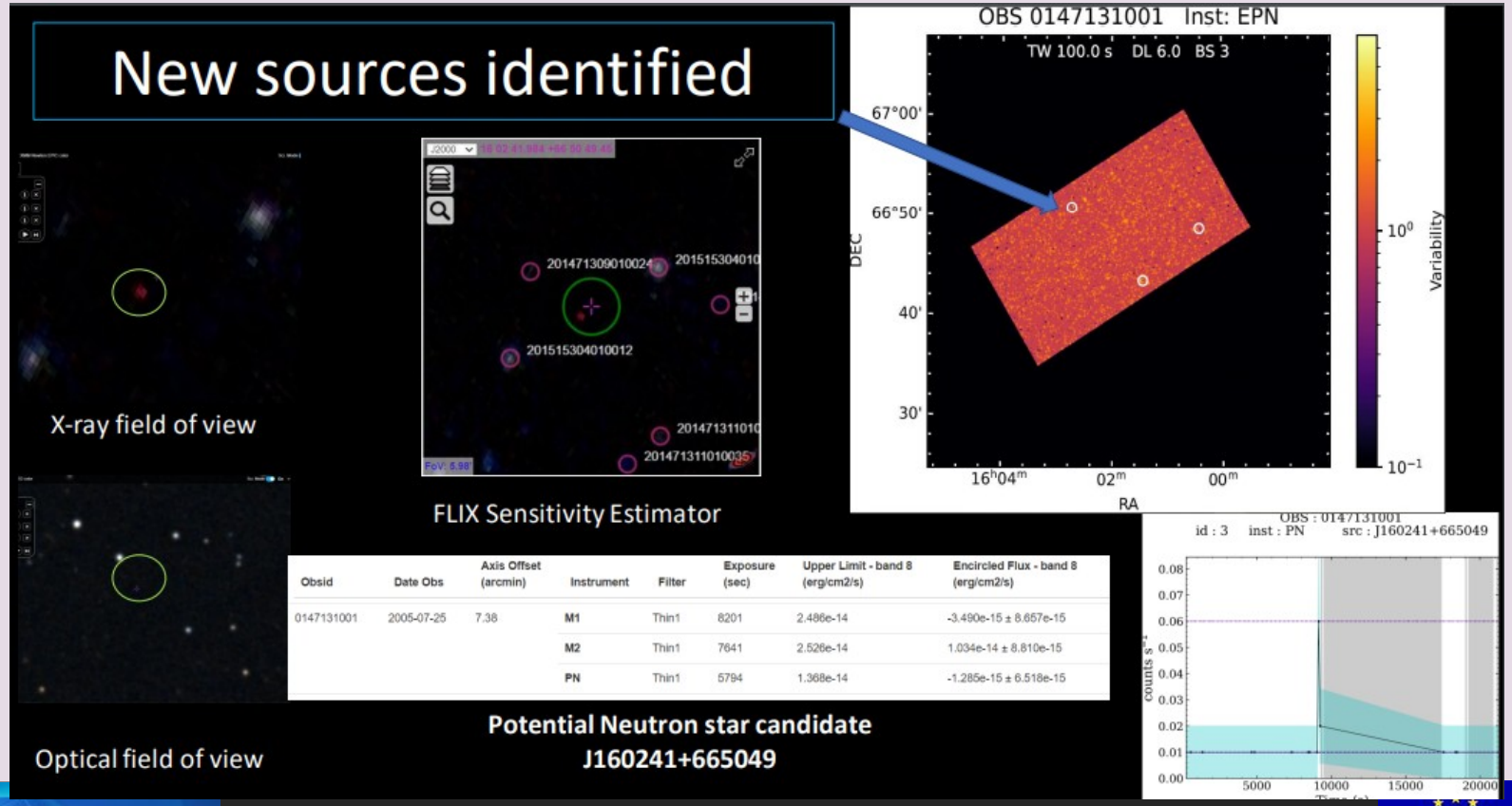
Short-term variability

- Analysed 12210 observations
- 10335 detections identified as variable, 7529 not formally variable in 4XMM-DR11 – doubles number of short term variable sources in the 4XMM catalogue
- About a quarter variable sources can be identified by cross-correlating with Simbad



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