XMM-Newton in the MultiMessenger Astronomy panorama



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XMM-Newton in the MultiMessenger Astronomy panorama

MM sources: transient & persistent Different time scales/luminosities

- Compact object coalescence
 - GRB
- Massive BH merger
- WD-WD, type-I SI
- Fast radio burst
- Core-collapse SNe
- Magnetars
- Isolated neutron stars & PWNe
- Tidal disruption events
- HE neutrino AGN, starburst galaxies, GRBs
- Sources of UHECR

Very sensitive imaging/spectroscopy with good angular and temporal resolution

Needs

Large FoV

Fast reaction fast access to cata

Rich archive

Goals

Detailed characterization of sources

Search for counterparts

Multiepoch information

Outline

- Mission status & future
- XMM capabilities
- Data policies
- Data access & analysis
- Relevant services & tools from SOC, SSC, community

Rejuvenating the mission

XMM-Newton – overview



- Cornerstone ESA mission
- Launched on 10 Dec 1999 into a 48-hr eccentric orbit
- 11m long, 3.8 tonne
- 25 yr of almost flawless operations

Three 15" HEW X-ray mirror modules (~4000 cm2).

Six instruments observe simultaneously:

- Three X-ray CCD cameras (European Photon Imaging Camera, EPIC)
- Two X-ray Refection Grating Spectrometers (RGS)
- An optical/UV monitor (OM)

Aiming for science operations well into 2030s





→ THE EUROPEAN SPACE AGENCY

XMM - The EPIC instrument

Three CCD cameras, observing simultaneously and independently the same FOV r=15'



HEW @1 keV	13″	13″	15"
Aeff @ 1 keV	470 cm2	470 cm2	1200 cm2
Time resol.	2.6 s	2.6 s	73.4 ms
E resol. @ 1 keV	80 eV	80 eV	100 eV

The EPIC instrument – Collecting power



XMM-Newton: observing modes



XMM-Newton: observing modes



XMM-Newton: observing modes



XMM-Newton observing modes: *Slow slew*



XMM Data policies



Products, tools, services from XMM SOC

XMM Data

Observation/Slew Data Files \rightarrow about 8 days after observation CCD-based event lists, containing **uncalibrated quantities ODF** Auxiliary and Housekeeping files, pn/RGS diagnostic images SDF Spacecraft housekeeping Spacecraft attitude showing the satellite star tracker pointing Time correlation le (onboard time and frame counter versus UTC) **Current Calibration Files** CCF collection of all the XMM-Newton calibration files ever made public calibration files are updated continuously



Pipeline Processing System

Top level scientific products → about ~15 days after observation

calibrated clean event files, sky images, source lists, spectra, time series, cross correlation multiwavelength information with archival catalogues SAS

SW

XMM-Newton Science Archive (XSA)



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Starting from https://www.cosmos.esa.int/web/xmm-newton/xsa

From A. Ibarra

COSPAR 2024

XMM Science Analysis Software (SAS)



XMM SAS – 25 yr of experience

 SAS public web page: <u>https://www.cosmos.esa.int/web/xmm-newton/sas</u> (download, installation, information, etc)



Processing from XSA (using RISA)





EGO, October 2024 Т AHEAD2020 Workshop

XMM SAS - future

- New configuration control, build and development system based on Docker technology
- Integration with on-line data processing platforms being pursued (ESA DataLabs)
- Jupyter Lab as user interface, a set of Data Analysis Threads are being prepared



Standard data reduction pipeline for top-level products – run on all new data

Purpose of the pipeline:

- production of top-level scientific products
- quick-look data to users and input to further analysis
- facilitate scientific exploitation of the data
- ensure an homogeneous level in scientific quality
 - produced with the same SAS software package available for users
 - screened and validated following some standards

The top-level products include:

- data from each EPIC, RGS and OM instruments
- calibrated clean event files, sky images, source lists, spectra, time series, cross correlation multiwavelength information with archival catalogues

Products, tools, services from XMM SSC

XMM Serendipitous source catalogue – 4XMM-DR14



XMM Stacked source catalogue



From N. Webb XMMUG meet #25

XMM Slew survey catalogue (to be released)

Endorsement 2022-05-17/14:

- Period : August 2001-August 2023 previous version up to end of 2014
- Catalogue testing under way, release imminent
- 140735 detections (68383 new detections)
- 25695 flagged (18%), mostly high background
- Subsequent versions to be released with the detection/source catalogue(s)

XMM Serendipitous source catalogue – 5XMM

- SOC reprocessed all 17199 observations ready for production of 5XMM
- To include :
 - OM + multi-wavelength counterparts upper limits
 - long-term variability information + OM variability
 - spectral fits
 - classifications
 - photometric redshifts
- Expected for Summer 2025

Further products, tools, services from XMM SSC and external consortia (EU projects)

Useful resources and services

web sites

SSC

XSA

site

web

EXTraS

SED Finder

- allows you to retrieve the SEDs computed for a given XMM source
- Cross-match with >200 catalogues based on algorithm by Pineau+2017 (FP7 ARCHES)
- Keep the 3 most likely correlation patterns
- Compute the SEDs for each pattern
- Generate plots & fits files
- Synchronized with 4XMM-DR13

Temporal domain characterization

- Light curves for ~80% of sources with different time binnings (uniform and Bayesian blocks
- also combining EPIC cameras, all exposure time
- Generation of CDFs
- Thorough caracterization of LCs & CDFs
- Extension of FP7-EXTraS (De Luca+2021), now synchronized with 4XMM-DR13

Source classification

- naive Bayes classification of X-ray sources into four classes - AGN, stars, X-ray binaries (XRBs), and cataclysmic variables (CVs)
- based on spatial, spectral, and timing properties and MWL counterparts
- Algorithm: Tranin+2022 (H2020 XMM2ATHENA)
- Good performance in discriminating stars vs. AGN
- Synchronized with 4XMM-DR12 (+ CSC2, 2SXPS)

X-ray spectral fits

- Synchronized with 4XMM-DR7
- ESA-PRODEX project

Photometric redshifts for extragalactic sources

- Synchronized with 4XMM-DR12
- Based on results of source classification
- ~140,000 AGN/QSO with SDSS/PanSTARRS/ SkyMapper counterparts

sites

web

sites

web

SSC

XSA

Quasi-real time transient finder

Since 2018, running on slew data:

- New detections routinely compared to RASS
- Identifies factor >5 variation in flux
- Results published ~1 week after data collected

XMM SOC web site

New: STONKS, on data from pointed observations

- Flux of new detections compared against <u>any</u> <u>available X-ray data</u> at the given position
- Identifies factor >5 variation in flux
- Implemented in ACDS pipeline, will be run starting April 2025 (PI of GO obs. will be asked in Phase II)
- Alerts issued ~1 week after data collected
- Algorithm & tests in Quintin+2024 (XMM2ATHENA)



Summary

- XMM-Newton: 25 years of successful operations
- Prospects for extending into the '30s
- Very sensitive X-ray imaging spectroscopy
- Huge data archive. Serendipitous source catalogs, characterization of sources in temporal, spectral, MWL domains; classification
- Quasi-real time transient sources
- Relevant for deep follow-up of (faint) MM sources from early to late epochs; also for the search for counterparts; multi-epoch (historical) characterization of persistent sources

XMM-Newton – RGS instrument

- Two of the three XMM telescopes equipped with Reflection grating spectrometers, dispersed X-rays collected by array of CCDs
- high spectral resolution (100 to 500, FWHM) X-ray spectroscopy in the energy range 0.33-2.5 keV or 5-38 Å
- RGS operate simultaneously with EPIC and OM



RGS Observation of Capella - Fe L Complexes

XMM-Newton – OM instrument

- A 30cm Ritchey-Chretien telescope
- coverage between 170 nm and 650 nm of the central 17 sqarcmin region of the X-ray FoV
- Imaging, fast photometry, grism spectroscopy
- OM operates simultaneously with EPIC and RGS



Photometric redshifts



Classification of sources

AGNStarXRB CV \rightarrow AGN183732546149 \rightarrow Star1561971012 \rightarrow XRB801247910 $\rightarrow CV$ 40881 $recall (\%)$ 99.599.488.232.1recision (%)98.997.293.784.6 $_{recore}$ 0.9920.9830.9090.465			.		014	$_$ Truth \rightarrow
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(%) \rightarrow Star_1-score0.9920.9830.9090.465 \rightarrow CV	recision	98.9	97.2	93.7	84.6	→AGN
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→CV	f -score	0.992	0.983	0 909	0.465	→XRB
	1 00010		0.000			→CV

Truth \rightarrow	AGN	Star	XRB	CV	Total cl.					
→AGN	19515	82	25	191	19813					
→Star	44	4628	3	27	4702					
→XRB	140	18	326	17	501					
→CV	9	9	2	124	144					
Total	19708	4737	356	359	Average					
recall (%)	99.0	97.7	91.6	34.5	80.7					
precision (%)	97.0	98.6	90.7	85.5	92.3					
Random Forest on 2SXPS										
Truth \rightarrow	AGN	Star	XRB	CV	Total cl.					
→AGN	5889	7	20	39	5955					
→Star	6	1404	1	3	1414					
→XRB	9	5	83	5	102					
→CV	7	1	1	68	77					
Total	5911	1417	105	115	Average					
recall (%)	99.6	99.1	79.0	59.1	84.2					
precision (%)	96.8	99.2	95.2	87.9	95.2					

Tranin et al. A&A 2022

⇒ better results on XRB + better interpretability