Multi-wavelength counterparts of XMM-Newton sources in the DR13 catalogue

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In collaboration with C. Motch, L. Michel, F-X Pineau and the XMM2ATHENA team
A few numbers

- 983948 detections in the 13243 pointed observations
- 656997 unique X-ray sources
- Coverage ~3% of the sky
- Median flux \(2.2 \times 10^{-14} \text{ erg cm}^{-2} \text{ s}^{-1}\)

Webb et al. 2020, and cats after
What is the nature of these more than 650 000 sources?

- Target of the observation: a well known / studied source
- ~30 to 100 serendipitous sources detected within each observation
- Dedicated spectroscopic follow-up observations at different galactic latitudes and for X-ray bright / and X-ray faint samples (see the XID program)

Nebot et al. 2013
But spectroscopy follow-up can be expensive and is not always so easy

- A too large X-ray positional error
- A too large optical / IR density of sources
- More than one possible counterpart within the positional error is possible
  - Need to prioritize observations at the telescope until the “right counterpart” is found
    - Ranking by X-ray flux? By optical magnitude? By $F_x/F_{opt}$? Or by proximity of the counterpart? Or a combo?
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A way forward:

- Complement as much as possible with existing photometric surveys
- Use a probabilistic approach that can give a weight to matches based on local densities
- Inspect photometric data to classify sources and derive source properties
ObAS with CDS involvement
WP2 deals with multi-wavelength counterparts

The CDS hosts mayor big catalogues. Making it easy to access large catalogues

We chose a set of catalogues:
- cover different wavelengths (UV to radio)
- cover all the locations of the XMM-Newton pointings (not all surveys are all sky)
- cover different deepths (for Galactic versus extragalactic purposes)
MULTIWAVELENGTH CATALOGUES

- UV (GALEX, XMM-SUSS)
- Optical (SDSS, Skymapper, PanSTARRS, Gaia, APASS)
- IR (2MASS, AllWISE)
- Radio (NVSS, FIRST, AKARI)
CROSSMATCH PROCEDURE IN A NUTSHELL

- Based on positions, positional errors and covered area

Hypothesis:

- No systematic offsets between catalogues, accurate positions
- No moving objects (no proper motions)
- At a given area, source properties are homogeneous
- No blending
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We could perform a match per X-ray observation, but...

- We need a large number of sources so as to use a probabilistic approach
- We need to group observations to have enough sources, but...
  - The local density varies from field to field
  - The limiting flux varies from field to field

Applied method to ensure source properties are homogeneous:

- We calculated the optical density of sources in each XMM observation
- We calculated the effective area as a function of the X-ray flux
  - Grouped by similar X-ray flux range and optical source density
~ 1/3 of XMMDR13 sources are not compatible with any other source

Multiwavelength SEDs created for about 400 000 unique X-ray sources

Multiple possible combinations possible (e.g. sol. X alone highest proba Vs X+opt+IR sol.)

Fractions should be treated with caution, given the assumptions made and the limiting fluxes of each survey.
We ingestivate colors

MULTIWAVELENGTH PROPERTIES

- UV-opt
- Opt
- MIR
- X+Opt
- NIR+MIR
- NIR
Compare them with known types of sources

Multi-wavelength photometry can be combined to determine the nature of sources

→ Wednesday morning session
A NEW SERVICE

- One service to retrieve SEDs
  - Query by Source ID
  - Query by Cone Search
  - SED in two formats: FITS & PNG

- See L. Michel presentation

https://xcatdb.unistra.fr/sedfinder/
We provide SEDs that can be accessed, downloaded and visualised

**AGN**: The SED of AGN FBS B 835. With Galex / Apas9 / SDSS12 / Gaia / 2MASS and AllWise fluxes
We provide SEDs that can be accessed, downloaded and visualised.

**CV**: The Cataclysmique Variable QS Vir. The secondary stellar photospheric component dominates the optical / Infrared while the UV (Galex) emission from the accretion disc and from the white dwarf is conspicuous.
- About 20% X-ray sources with SDSS counterpart have a spectroscopic redshift determination

Multi-wavelength photometry can be combined to determine photometric redshifts (classical SED fitting or sophisticated ML techniques)
About 40000 X-ray sources have a good Gaia counterpart with a good distance determination.

Multi-wavelength photometry can be combined to determine stellar parameters (classical SED fitting or using sophisticated ML techniques).

\[ F_X = 10^{-15} \text{ erg cm}^2\text{s}^{-1} \]
GALACTIC POPULATION

- Overdensity of sources in and above the main sequence
- Sources above the main sequence have higher X-ray luminosity

See results from eRASS1 (Freund et al 2024)
See poster from Thomas Oliveira for YSO in Orion & presentation from Pooja Sharma
SUMMARY

- We provide multiwavelength SEDs for X-ray sources
  - Covering from X-ray to radio wavelengths
  - There are more than 25% X-ray source with no counterpart in either survey
  - We have deployed a new service to share these SEDs (via cone search or SRCID)
- Multiwavelength photometry can help us for Galactic and extragalactic studies
  - Determine the nature of the source
  - Derive photometric redshift
  - Derive stellar parameters
- Probabilistic approach is needed to take into account for large errors / high local density of sources, but
  - Probabilities can be difficult to interpret when too many catalogues are involved
  - Watch out with your hypothesis since they will change your results!
    - No moving objects? Gaia... No blending? AllWISE...
➢ Overdensity of sources in and above the main sequence
➢ Sources above the main sequence have higher X-ray luminosity

Nebot et al in prep.
＞ We ingestivate colors of X-ray sources with good matches in all surveys
CROSSMATCH PROCEDURE IN A NUTSHELL

API and scripting mode

ARCHES X-MATCH TOOL
Anonymous Web form

Remote directory
Upload a file:
Choose file No file chosen

File list:
sdss9.174.10491_7.22343_12.3a
galexSais.174.10491_7.22343_12
2mass.174.10491_7.22343_12.3a
3xmm_unicources_v1.2.1ts

X-match script
Script examples
Xmatch galex/sdss/2mass in a cone, with proba

Type, modify or copy/paste here the xmatch script to be executed:

1
2 # Name: galex_sdss_2mass.xme
3 # Description: Perform a probabilistic xmatch between galex, sdss and 2mass
4 # in a given cone of 12 arcminutes. Data is downloaded from VizieR.
5 # input files: none
6 # Output files:
7 # - galex_vot, galex data
8 # - sdss_vot, sdss data
9 # - 2mass_vot, 2mass data
10 # - galex_sdss_2mass_vot: cross-match result
11 # WARNING: the result may not be symetrical using successive full joins
12 # Load galex data from VizieR
13 get VizieRLoader tabname=hi/312/aiz mode=cone center="174.10491 +7.22343" radius=12.0 arcmin allcolumn
14 set pos ra=RAJ2000 dec=DEJ2000
15 set pos type=CIRCLE params=0.6
16 set cols obj.j.J2000/[e_j7][FJ][UV]/
17 prefix galex
18 save galex_vot votable
19 # Load sdss data from VizieR
20 get VizieRLoader tabname=V/139/sdss9 mode=cone center="174.10491 +7.22343" radius=12.1 arcmin allcol
21 where mode=1 & e_RA_ICRS>0.0 & e_DEC_ICRS>0.0 & mag<23
22 set pos ra=RA_ICRS dec=DE_ICRS
23 set pos type=RCD_DEC_ELLIPSE param1=e_RA_ICRS param2=e_DEC_ICRS

Result log

Crossmatch performed with several catalogues from UV to radio