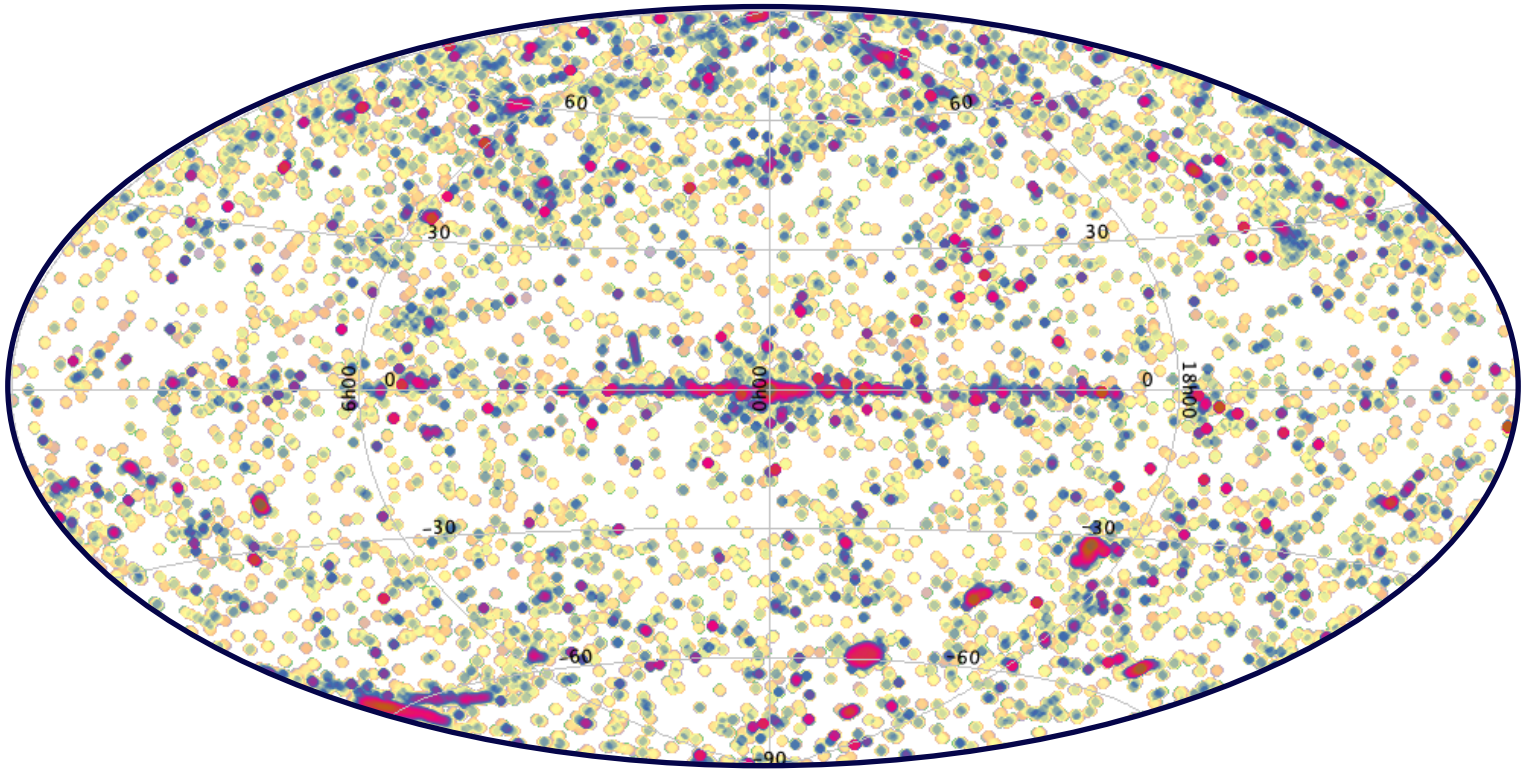
Multi-wavelength counterparts of XMM-Newton sources in the DR13 catalogue

Ada Nebot

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

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

XMM-DR13 CATALOGUE



- A few numbers
  - 983948 detections in the 13243 pointed observations
  - 656997 unique X-ray sources
  - Coverage ~3% of the sky
  - Median flux 2.2 × 10^{-14} erg cm^{-2} s^{-1}

Webb et al. 2020, and cats after

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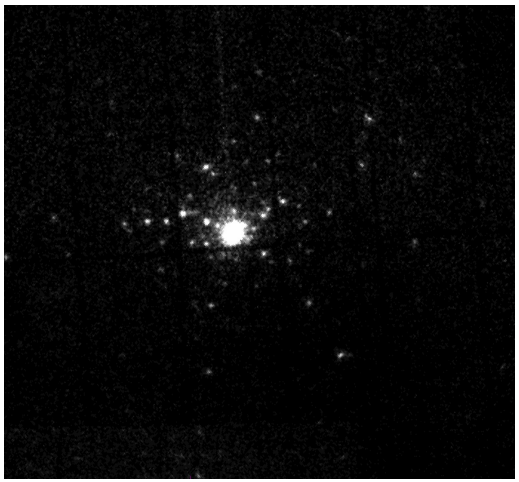
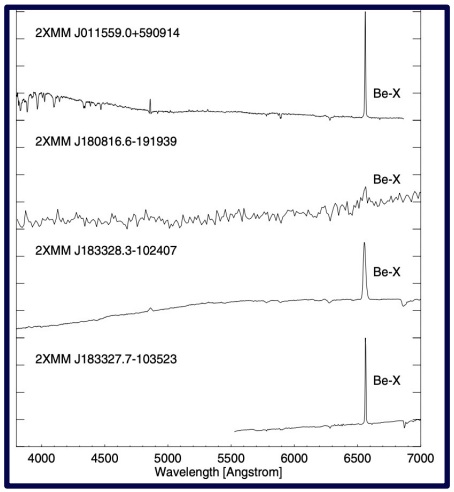
XMM-NEWTON SOURCES

- 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

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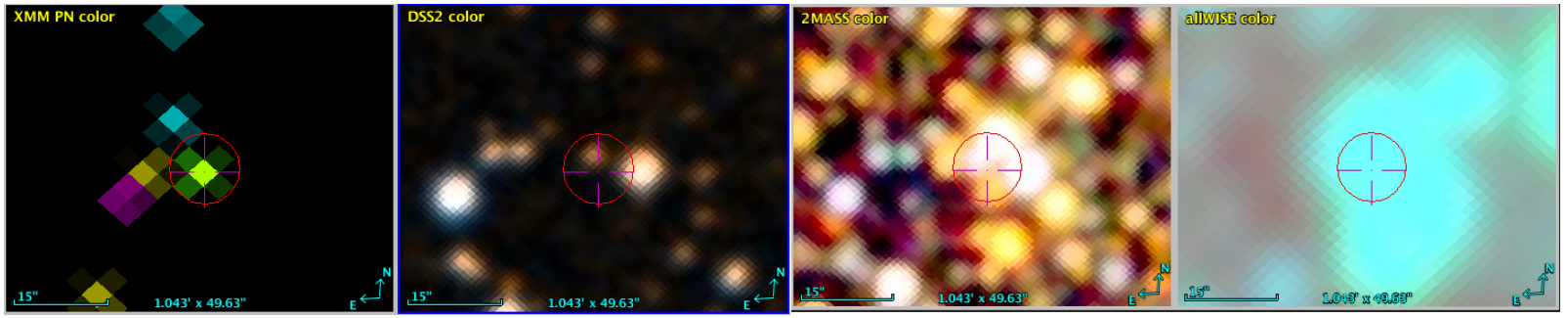
XMM-NEWTON SOURCES

- 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 Fx/Fopt ? Or by proximity of the counterpart? Or a combo?



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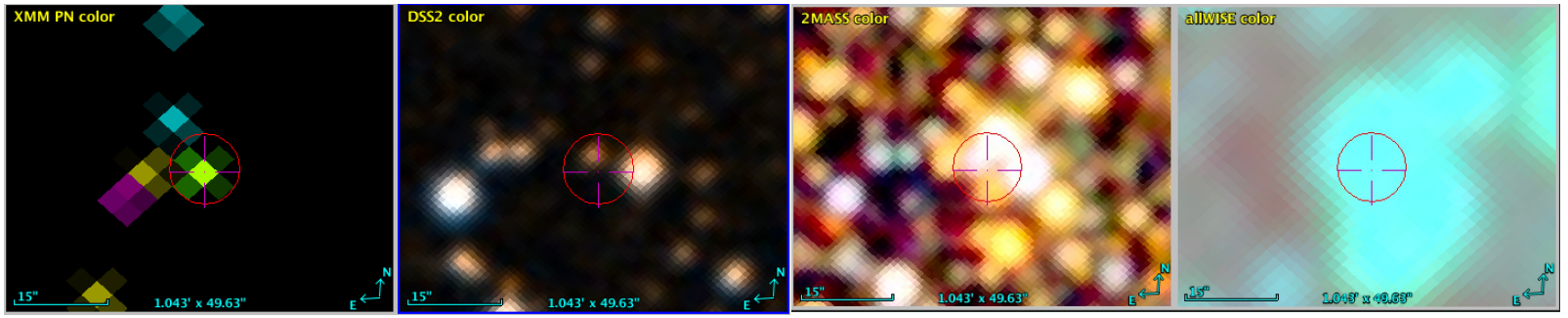

- A way forward:
  - Complement as much as possible with existing photometric surveys
  - Use a probabilistic approach that can give a weight to matches based on local densities
  - Inspect photometric data to classify sources and derive source properties

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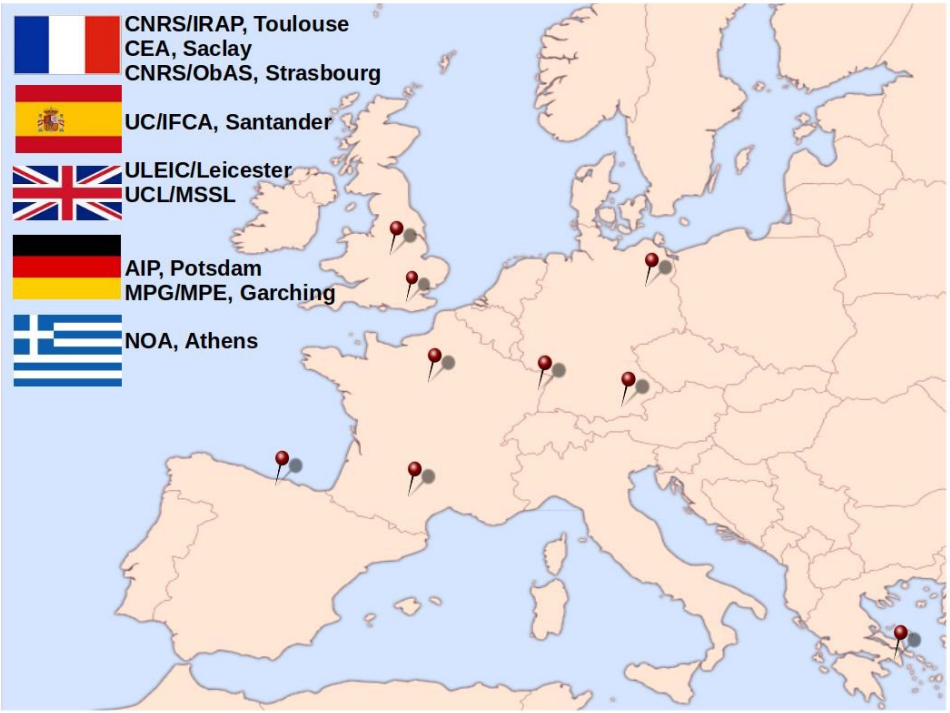
XMM-DR13 CATALOGUE



- ObAS with CDS involvement
- WP2 deals with multi-wavelenth 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)

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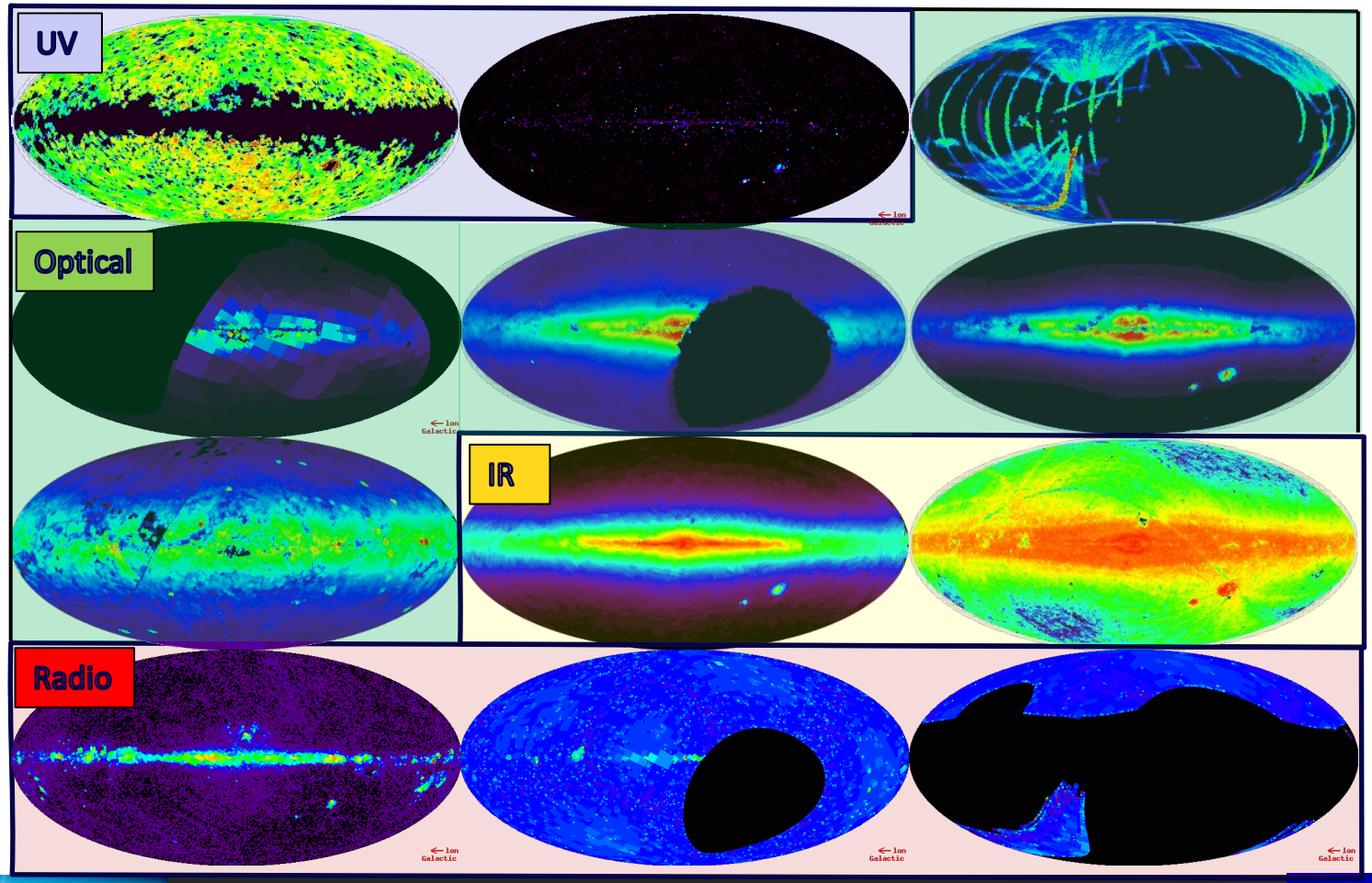
MULTIWAVELENGTH CATALOGUES

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



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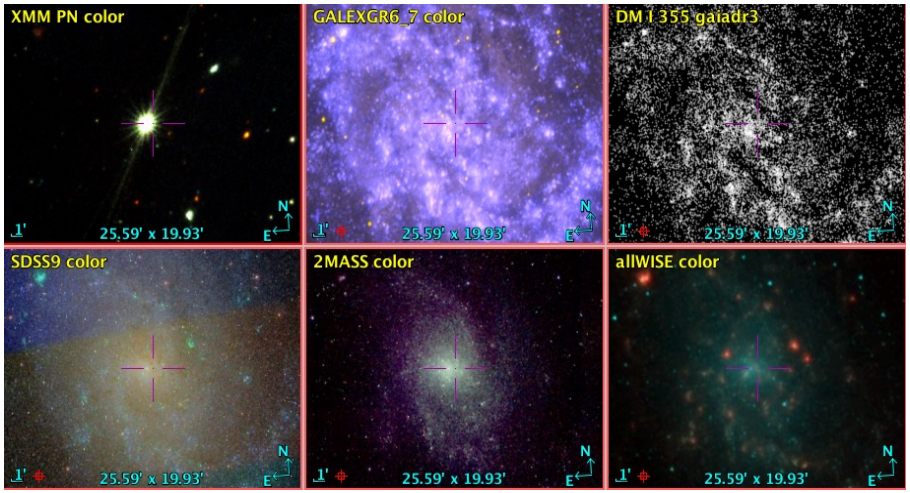
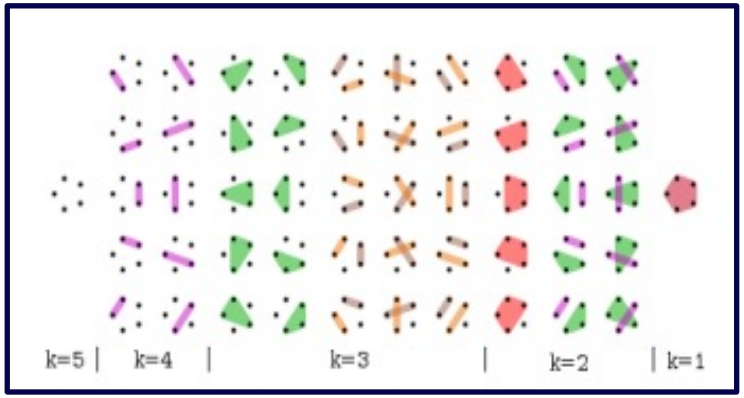
CROSSMATCH PROCEDURE IN A NUTSHELL

- Multi-catalogue probabilistic approach (F.X. Pineau et al. 2017)
- 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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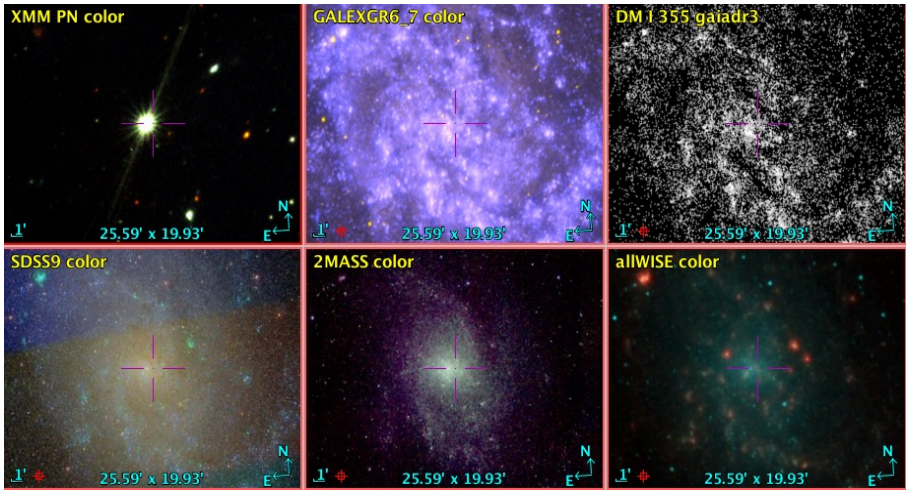

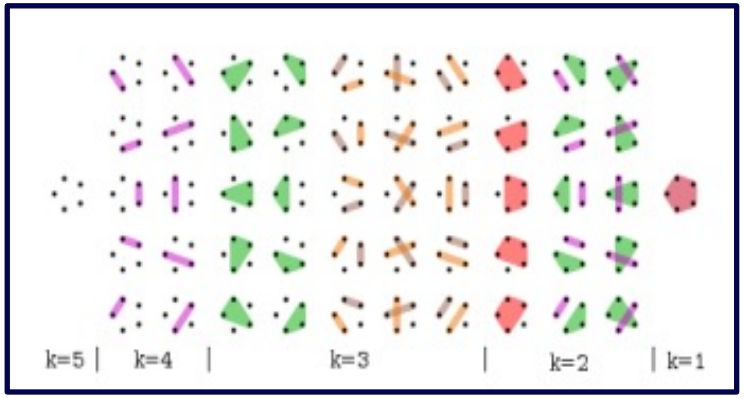

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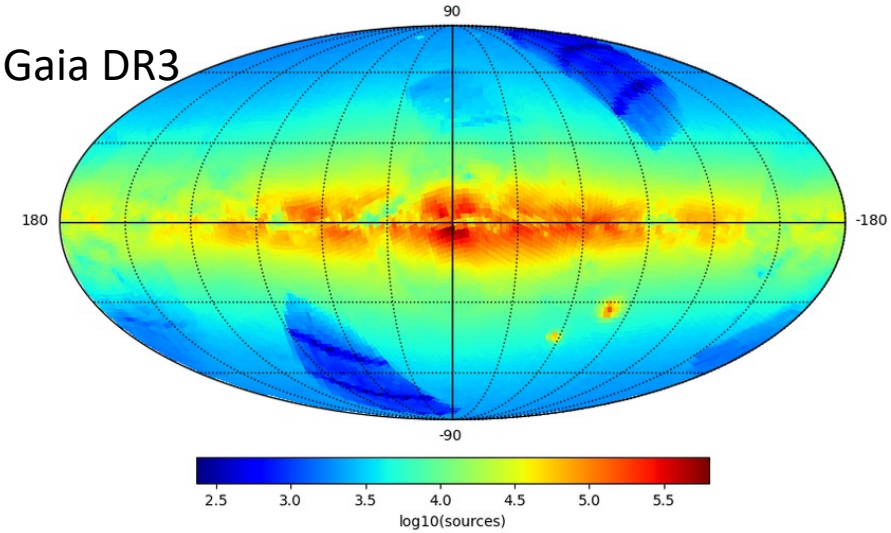
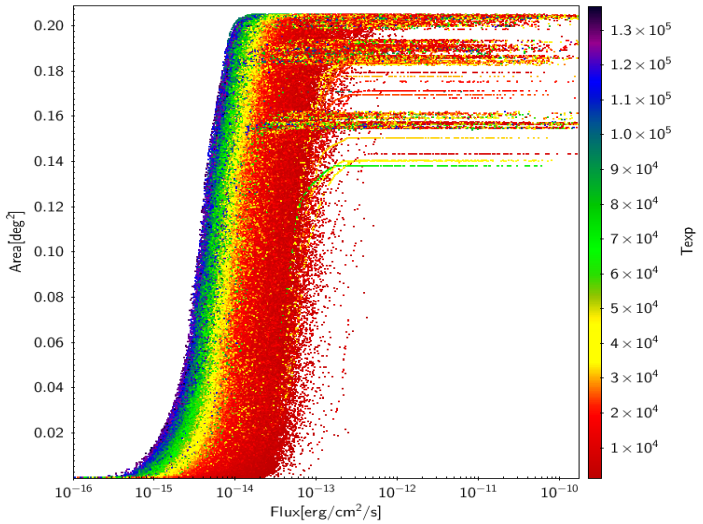
CROSSMATCH PROCEDURE IN A NUTSHELL

- **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

Gaia DR3



XMM Effective area



- **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**

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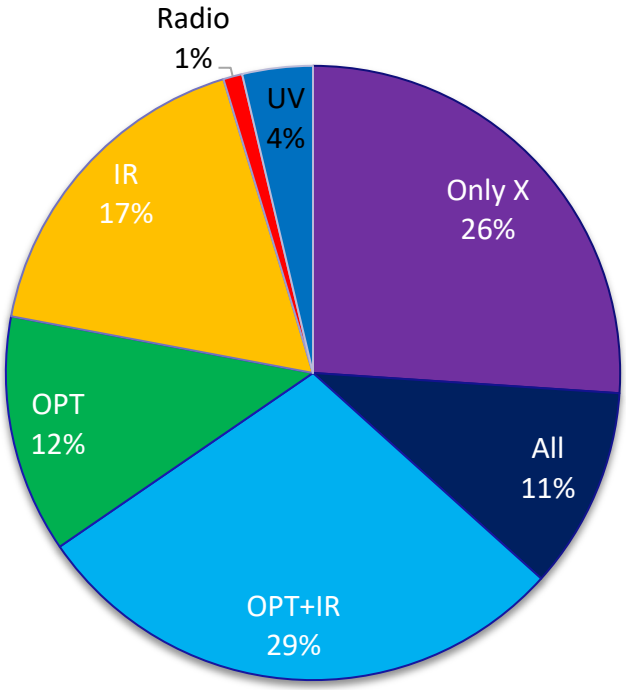
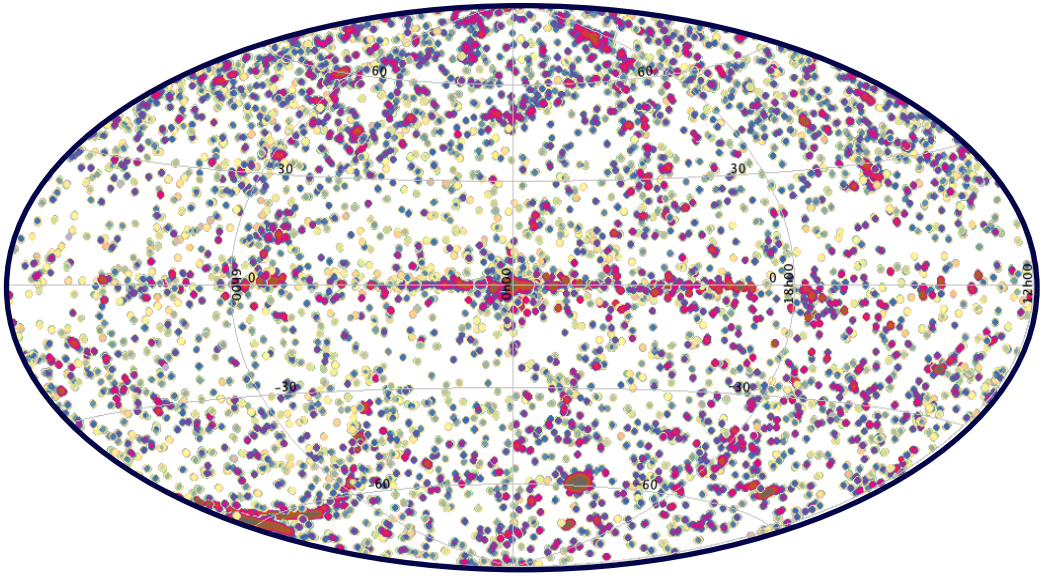
CROSSMATCHES

- ~ 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.)





Only X All OPT+IR OPT IR Radio UV

Frantions should be treated with caution, given the assumptions made and the limiting fluxes of each survey

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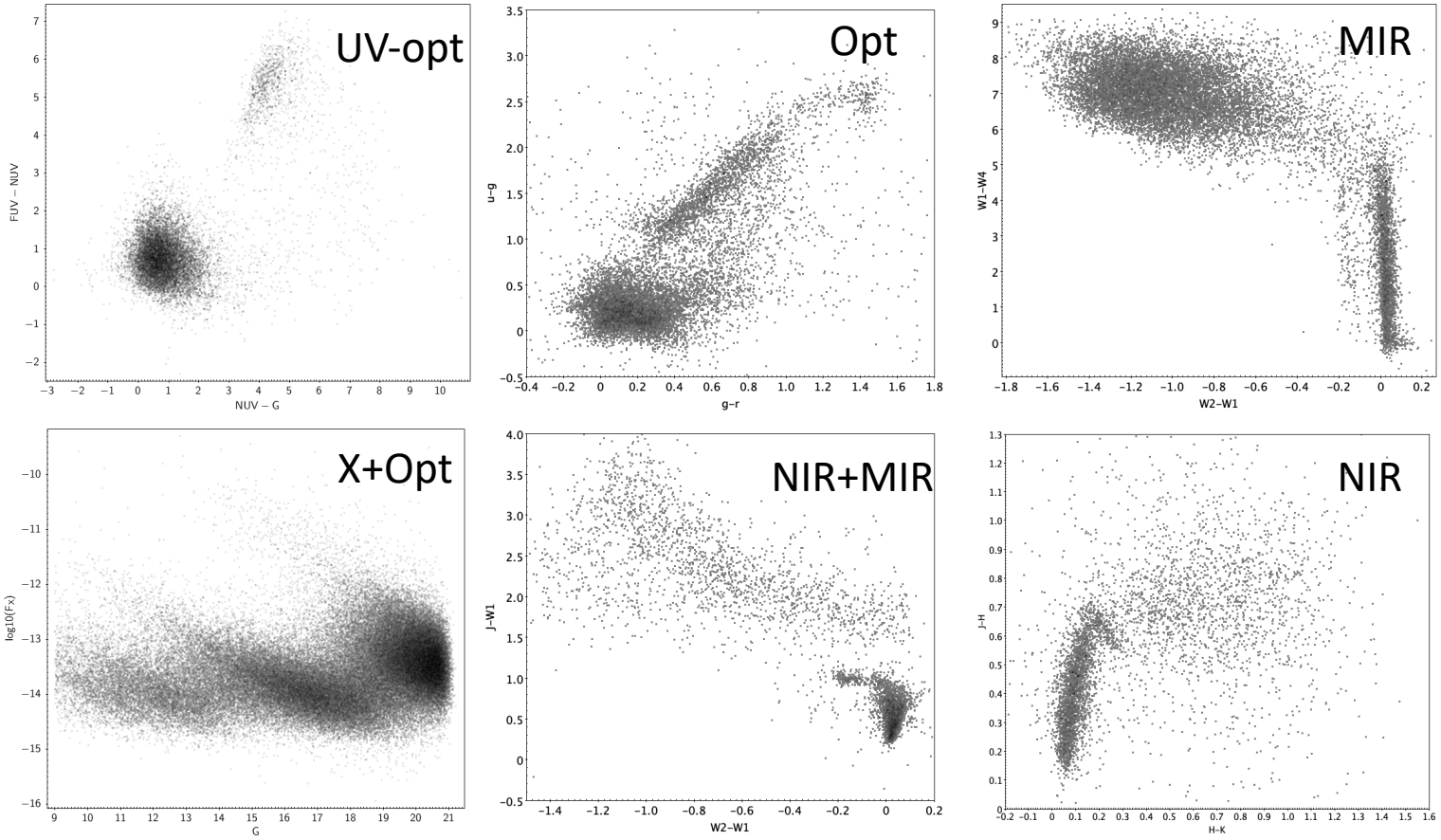
MULTIWAVELENGTH PROPERTIES

- We ingestivate colors



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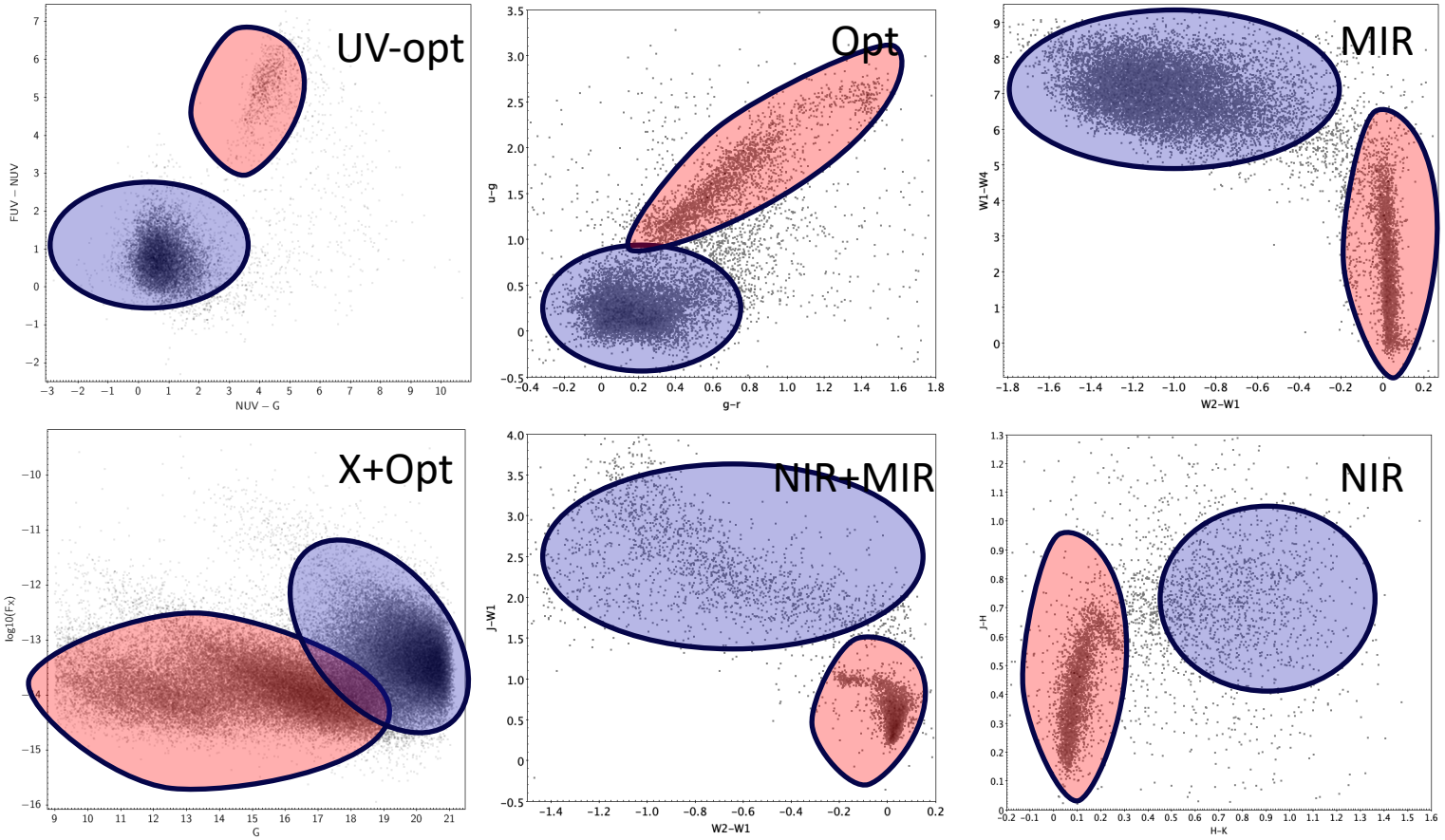
MULTIWAVELENGTH PROPERTIES

➢ Compare them with known types of sources



QSO

STARS

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

→ Wednesday morning session

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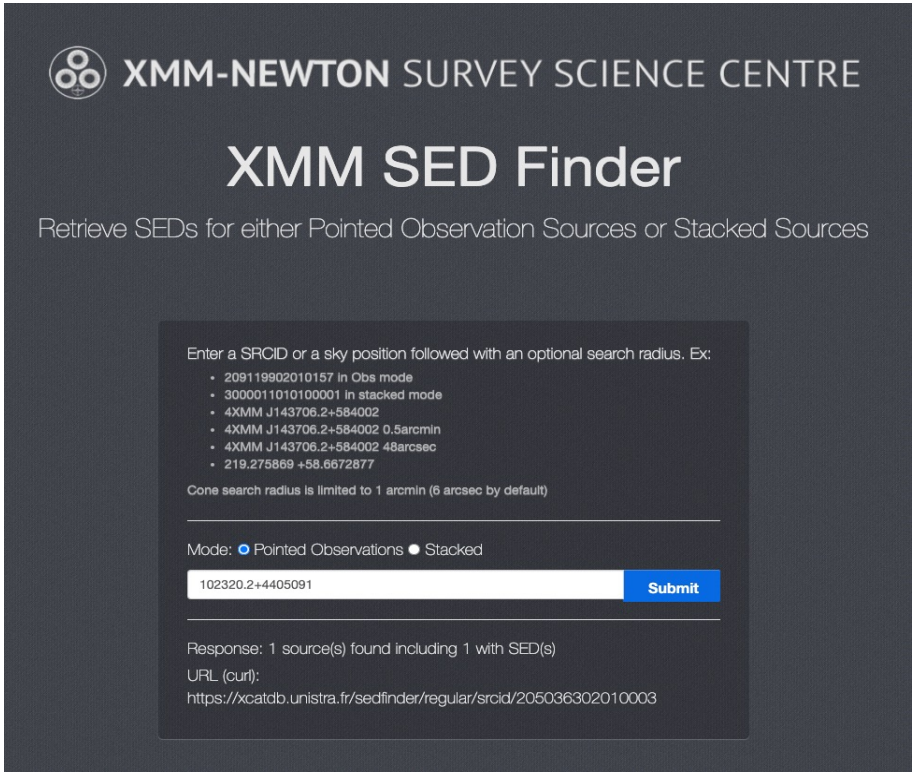
A NEW SERVICE



- **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/

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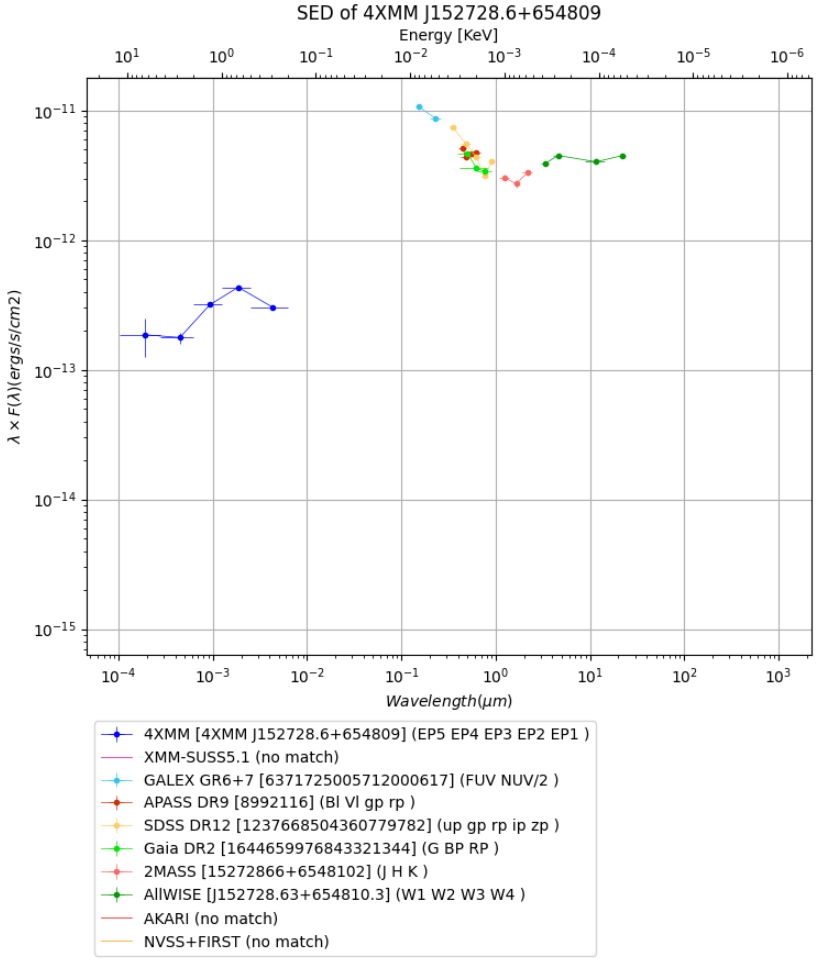
SPECTRAL ENERGY DISTRIBUTIONS

- **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



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SPECTRAL ENERGY DISTRIBUTIONS

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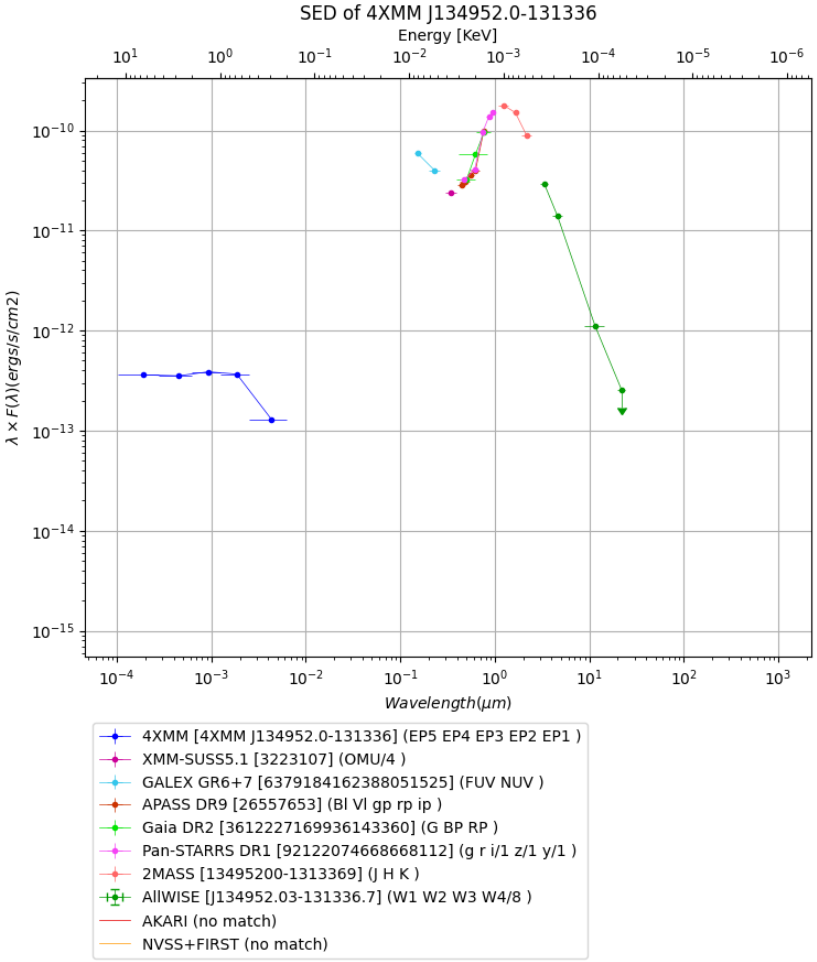
CV : The Cataclysmique Variable QS Vir. The secondary stellar photospheric component dominates the optical / Infrared while the UV (Galex) emission from the accretion disc and from the white dwarf is conspicuous.



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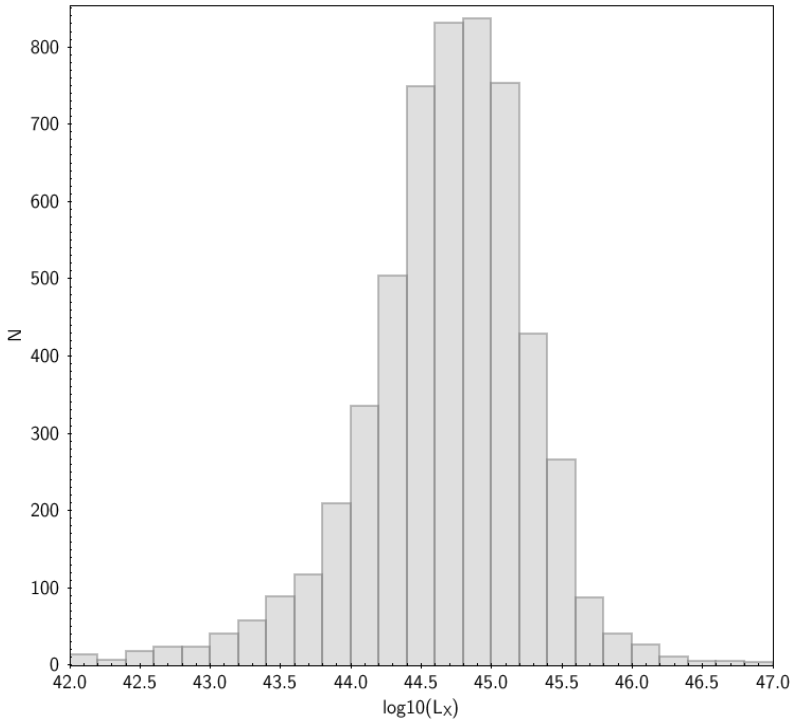
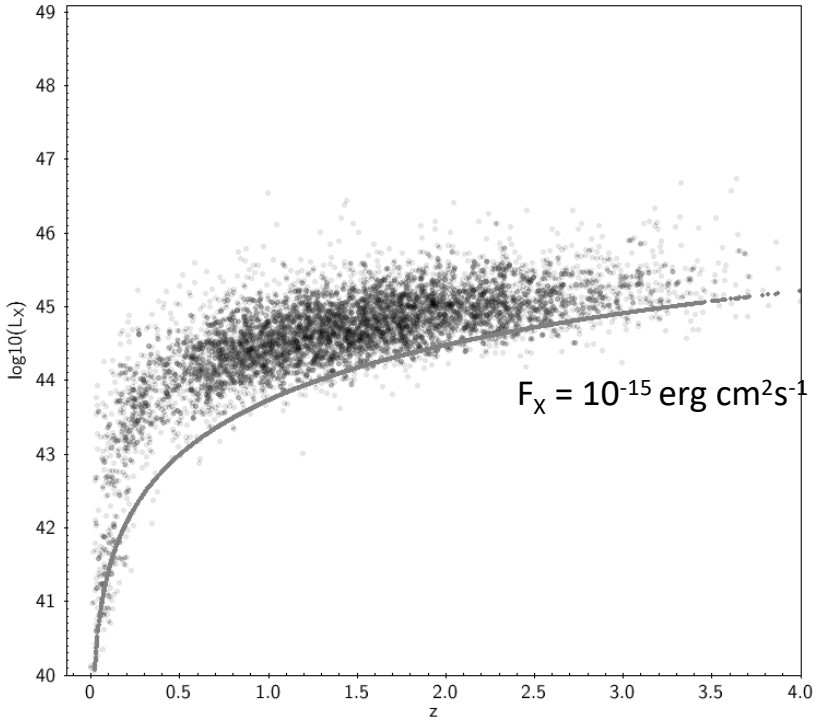
EXTRAGALACTIC POPULATIONS

- 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)

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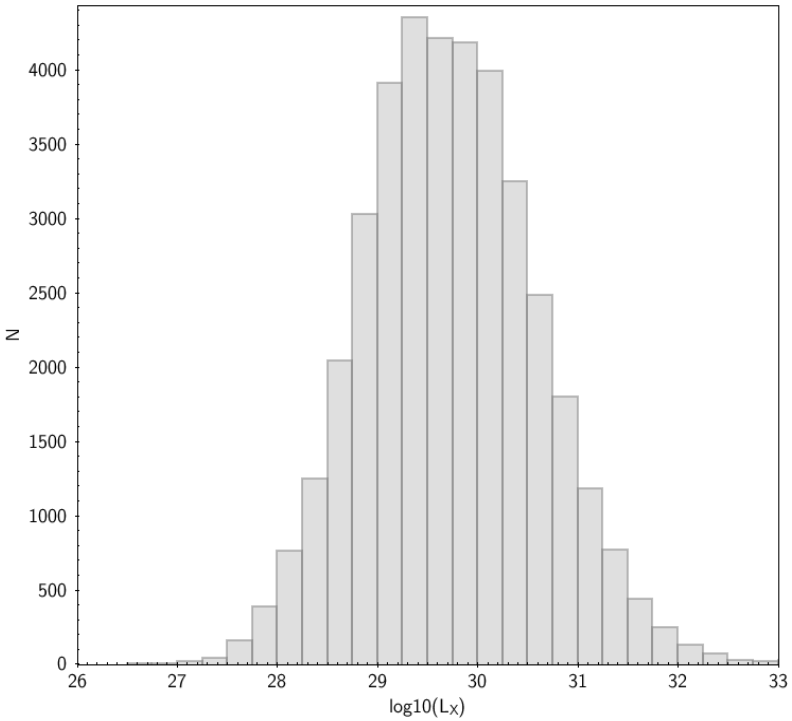
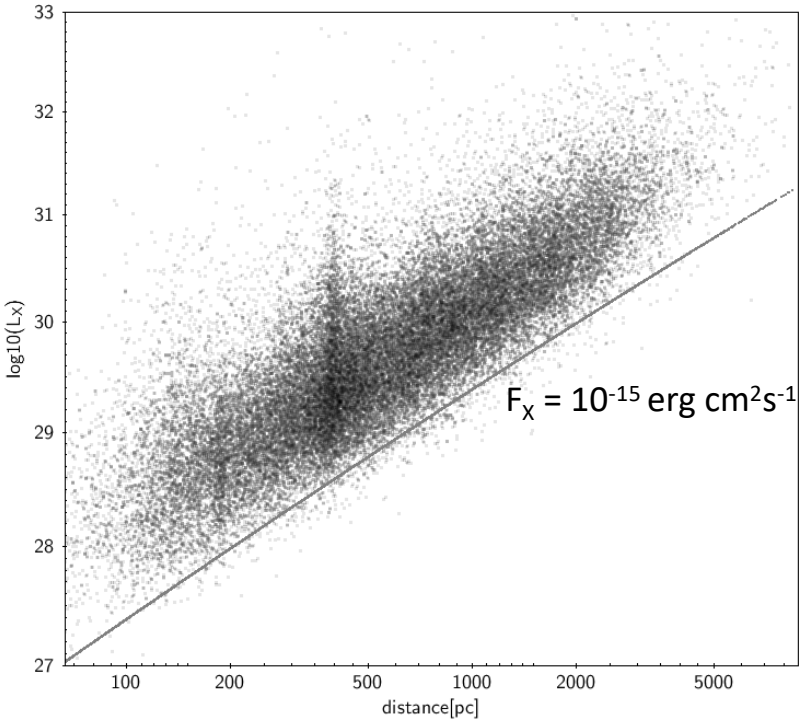
GALACTIC POPULATION

- 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)

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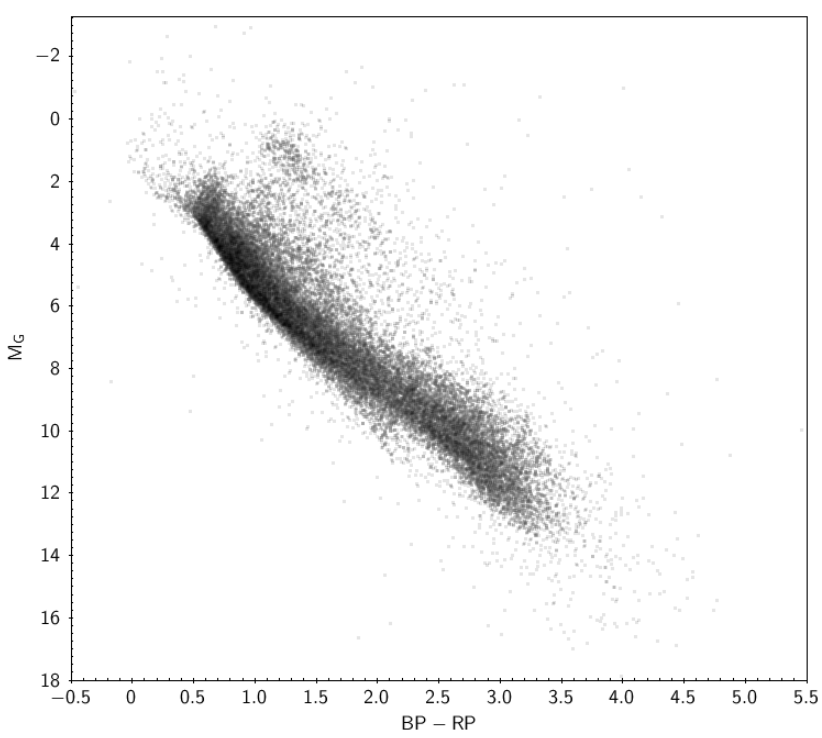
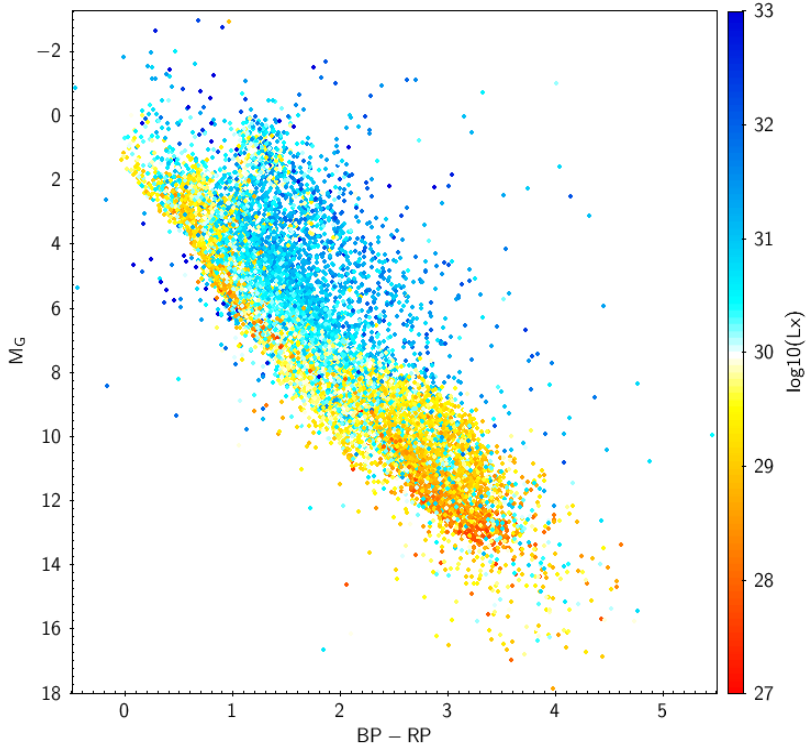
GALACTIC POPULATION

- 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

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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…

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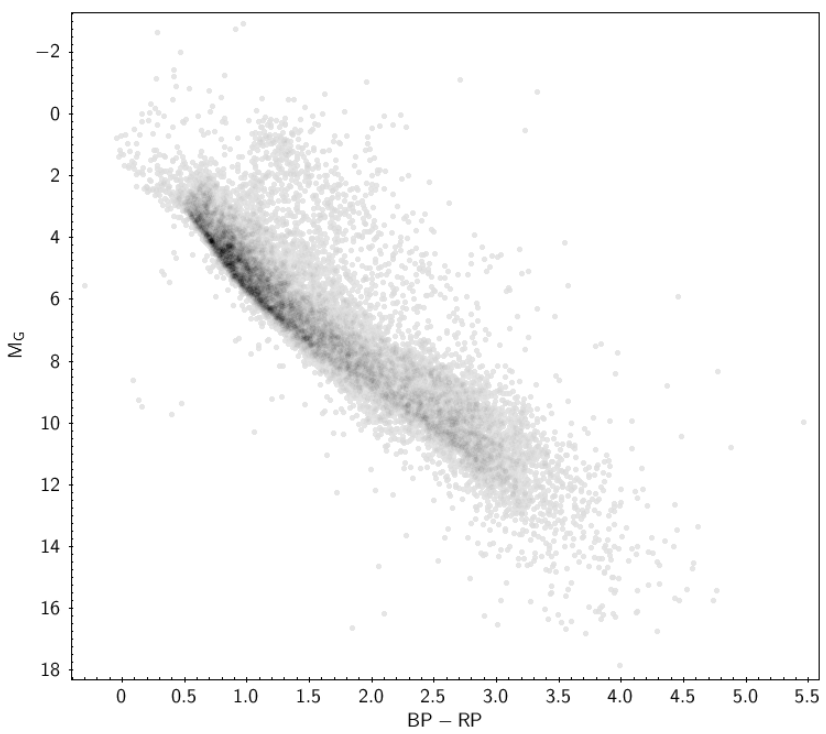

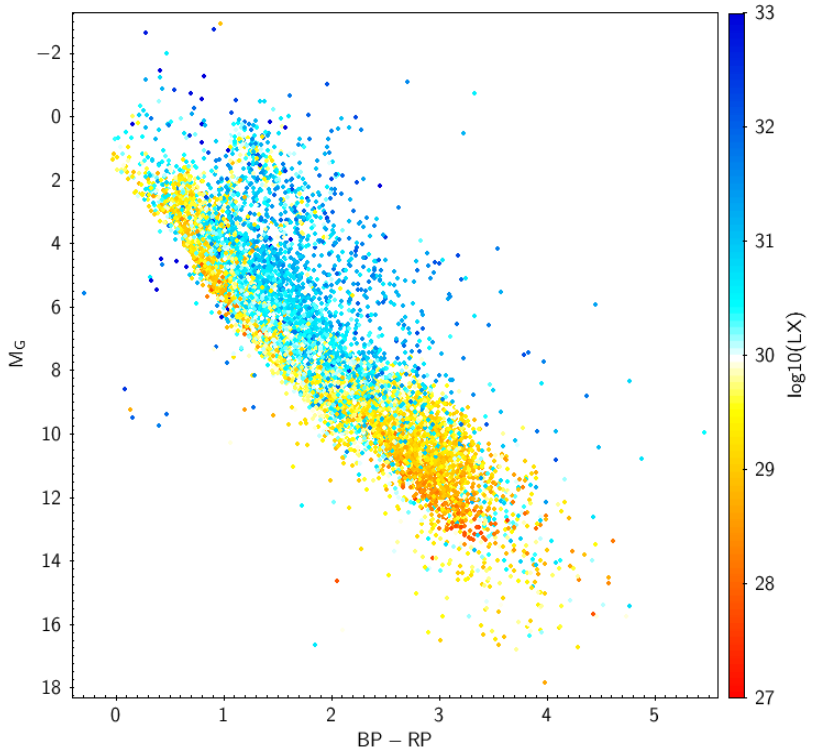

Nebot et al in prep.

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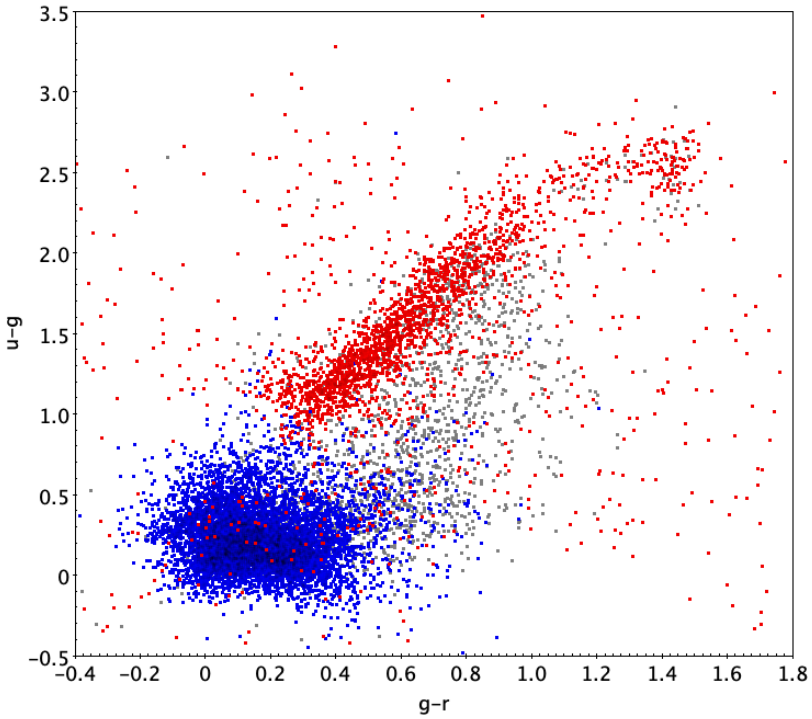
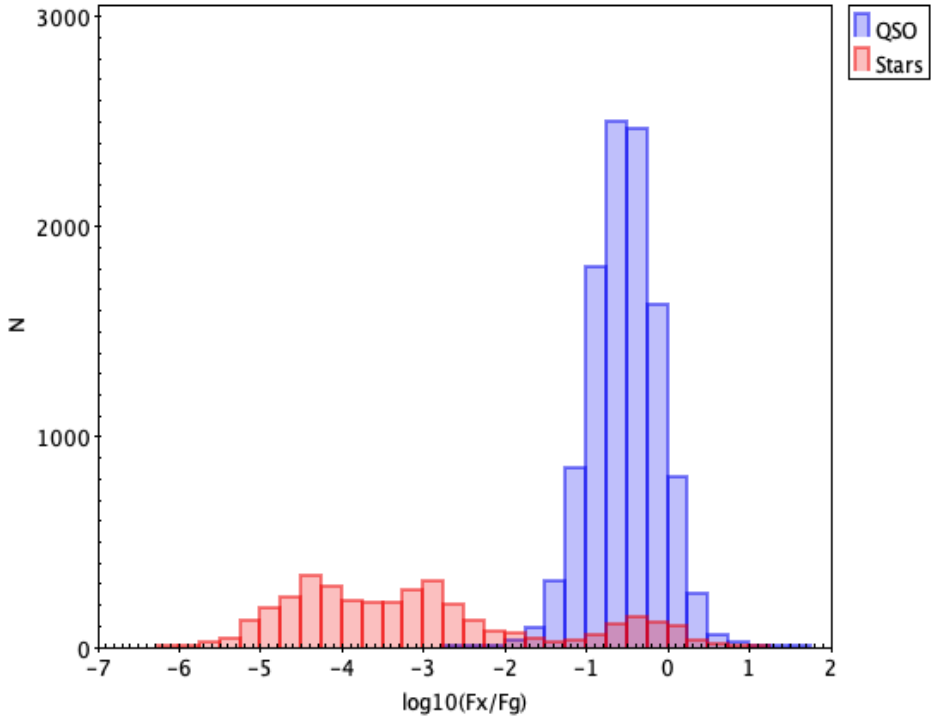
GALACTIC AND EXTRAGALACTIC POPULATIONS

- We ingestivate colors of X-ray sources with good matches in all surveys

SDSS



Fx/Fg



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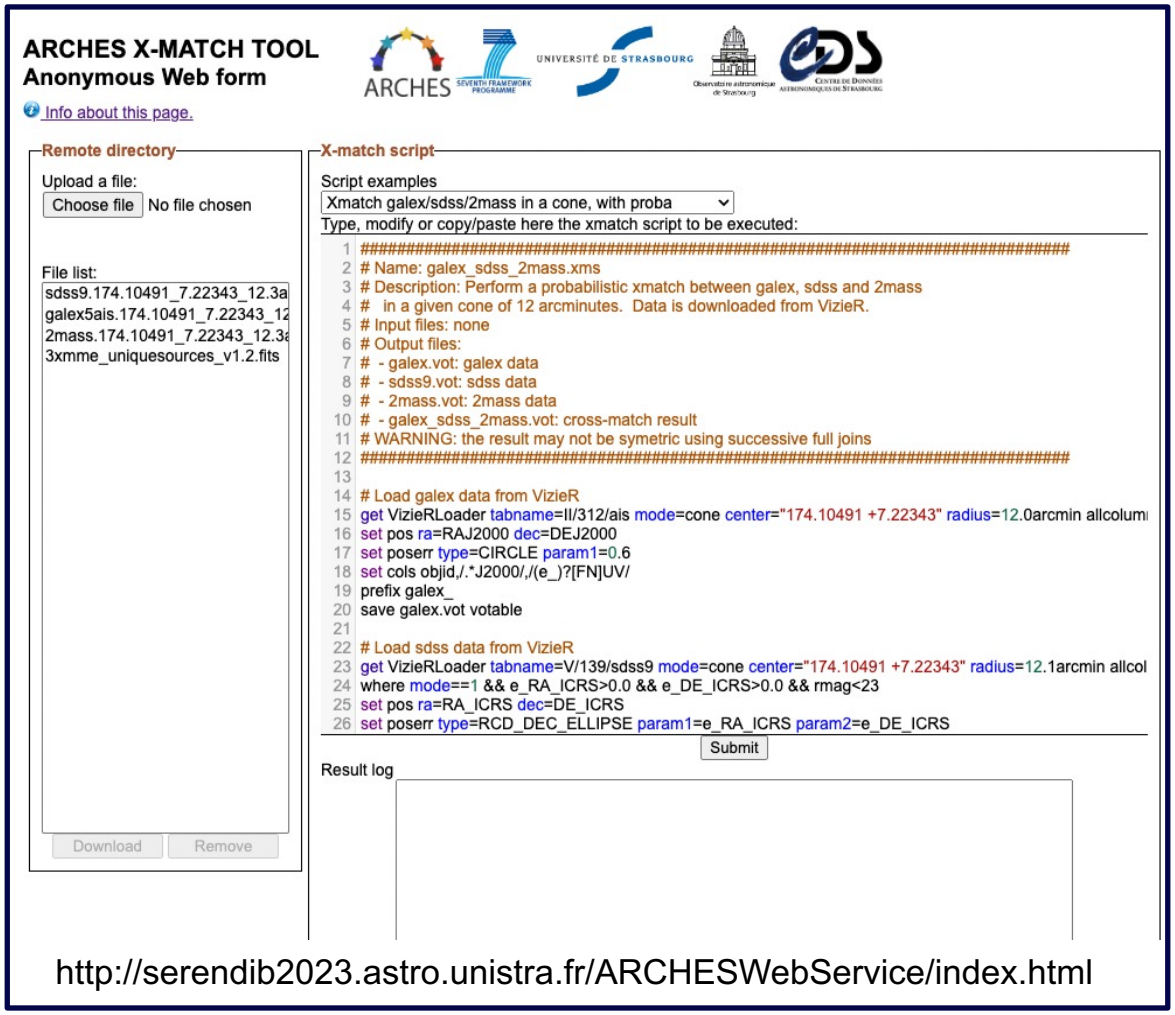
CROSSMATCH PROCEDURE IN A NUTSHELL

- API and scripting mode



http://serendib2023.astro.unistra.fr/ARCHESWebService/index.html

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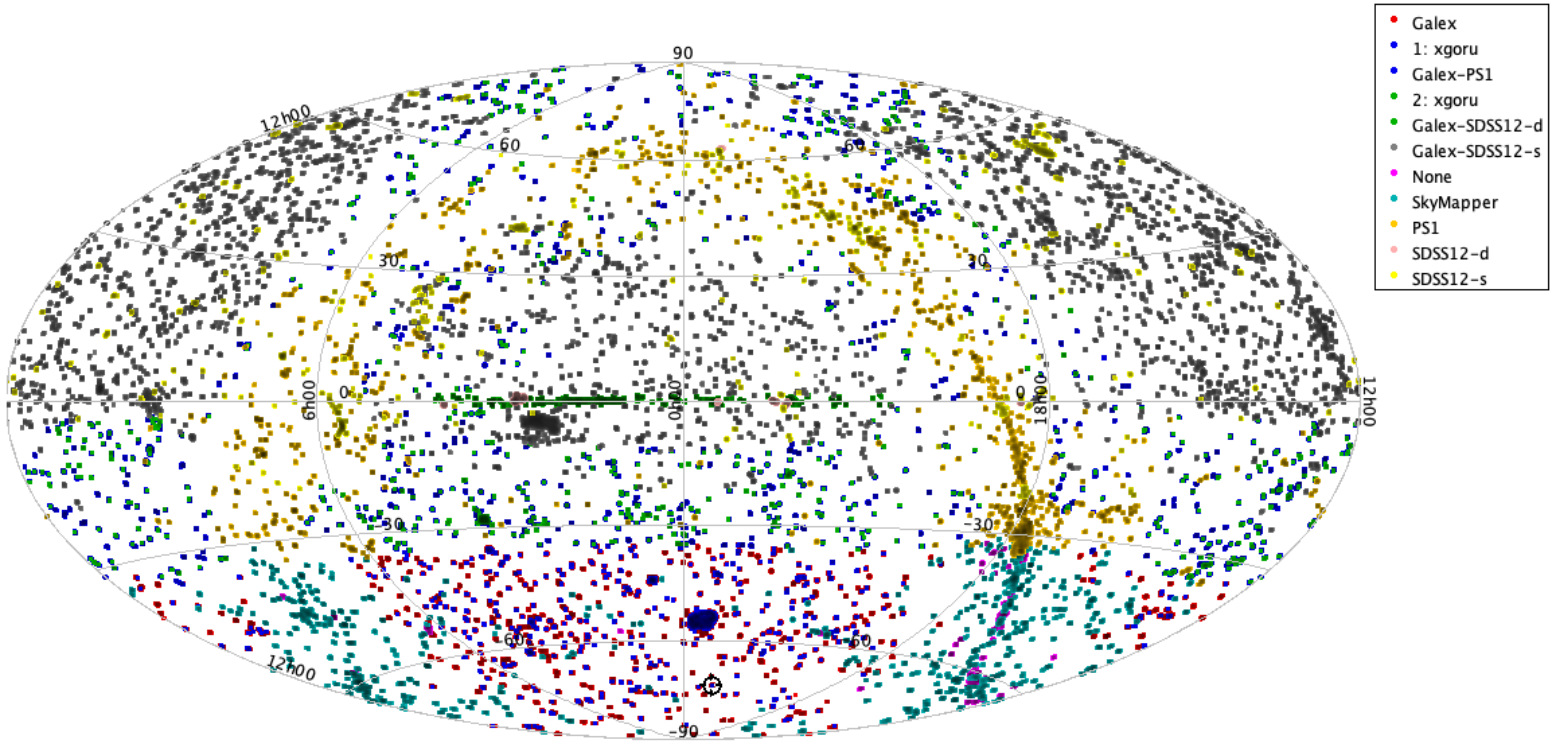
SURVEY CONSTRUCTION

Crossmatch performed with several catalogues from UV to radio



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