Counterparts
determination and classification
in the all-sky surveys era

M. Salvato

with: Johannes Buchner, Tamas Budavari, Tom Dwelly, Andrea Merloni, Marcella Brusa, Sotiria Fotopoulou, Arne Rau, and more
★ What the ALL-SKY surveys can do for you (the case for WISE and GAIA)

★ Surveys are not ALL (a.k.a why we needed, e.g., NWAY)

★ application to ROSAT/2RXS and XMMSLEW2

★ Physical properties of the counterparts

★ Another reason why you want ALL-SKY surveys (a.k.a. photoz!)

★ The power and the risks behind priors (also in view of eROSITA)
Important: every galaxy is/was/will be (?) an AGN

Magorrian+98, Kormendi&Richstone95, Nuker team

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**Important:** every galaxy is/was/will be (?) an AGN
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Census of BH growth requires sampling full luminosity-redshift plane

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(Salvato et. al. 2018, Dwelly, MS, et. al. 1017)

STRIPE82X (Ananna, MS, et. al. 2017)


COSMOS (Marchesi...MS, et. al. 2016)

CDFS (Hsu, MS, et. al. 2014)
ROSAT survey missed in the counting because:

1) Large positional uncertainties
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2) Large uncertainties in the scaling of the counting rates

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ROSAT survey missed in the counting because:

1) Large positional uncertainties

2) Lack of deep enough, homogeneous and wide surveys
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Only the counteparts to bright ROSAT sources in some part of the sky where known (e.g/ Schwope et al. 2000)
Then WISE was launched..
X-ray counterparts identification

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X-ray counterparts identification

Chandra
XMM
ROSAT
eROSITA
XMMSL2

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NWAY in a nutshell

Salvato+ 2018, Dwelly+2017

https://github.com/JohannesBuchner/nway

(i) Matching of N catalogues simultaneously.
(ii) Computation of all combinatorially possible matches, including partial matches across catalogues, i.e. the absence of counterparts in some catalogues
(iv) Taking into account distances, positional uncertainties and the source number densities, computation of the probability of each possible match.
(v) Computation of the probability that there is no match.
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as in Pineau+17
NWAY in a nutshell

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M. Salvato, Toulouse 2018
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(v) Computation of the probability that there is no match.
(vi) Incorporating magnitude distribution, colors, magnitude&colors or other information about the sources of interest, refining the match probabilities.
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For each source of the primary catalogue (in the application from this paper: for each the X-ray source), compute (a) the probability that this source does not have a counterpart and (b), assuming this source has a counterpart, compute the relative probability for each possible match.
Input to NWAY

$X_1 \quad RA_1 \quad Dec_1 \quad \sigma_1$

Xray
Input to NWAY

\[ \chi_1 \text{ RA}_1 \text{ Dec}_1 \sigma_1 \]

\[ Z_1 \text{ RA}_{Z1} \text{ Dec}_{Z1} \sigma_{Z1} \text{ mag}_{Z1} \]

\[ K_5 \text{ RA}_{K5} \text{ Dec}_{K5} \sigma_{K5} \text{ mag}_{K5} \]

\[ \text{B}_2 \text{ RA}_{B2} \text{ Dec}_{B2} \sigma_{B2} \text{ mag}_{B2} \]

\[ \text{B}_3 \text{ RA}_{B3} \text{ Dec}_{B3} \sigma_{B3} \text{ mag}_{B3} \]

\[ \text{B}_4 \text{ RA}_{B4} \text{ Dec}_{B4} \sigma_{B4} \text{ mag}_{B4} \]

\[ \text{B}_5 \text{ RA}_{B5} \text{ Dec}_{B5} \sigma_{B5} \text{ mag}_{B5} \]

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Input to NWAY

$X_1 \ RA_1 \ Dec_1 \ \sigma_1$

$Z_1 \ RA_{z_1} \ Dec_{z_1} \ \sigma_{z_1} \ mag_{z_1}$

$K_5 \ RA_{k5} \ Dec_{k5} \ \sigma_{k5} \ mag_{k5}$

$B_2 \ RA_{B2} \ Dec_{B2} \ \sigma_{B2} \ mag_{B2}$

$B_3 \ RA_{B3} \ Dec_{B3} \ \sigma_{B3} \ mag_{B3}$

$B_4 \ RA_{B4} \ Dec_{B4} \ \sigma_{B4} \ mag_{B4}$

$B_5 \ RA_{B5} \ Dec_{B5} \ \sigma_{B5} \ mag_{B5}$

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<table>
<thead>
<tr>
<th>X cat. entry</th>
<th>Z cat. entry</th>
<th>K cat. entry</th>
<th>B cat. entry</th>
<th>various Probs.</th>
<th>P (X has a ctp)</th>
<th>P (this is the correct ctp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>—</td>
<td>3</td>
<td>...</td>
<td>0.8</td>
<td>0.2</td>
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<td>1</td>
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<td>5</td>
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NWAY output

![Diagram with points labeled Z₁, X, Z, K₅, B₂, B₃, B₄, B₅, B, and X.]
The beauty of NWAY

prior
(e.g due to depth of data)
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\[ P(H|D) \propto P(H) \times P(D|H). \]
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(posterior) prob. of an association, given the data
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separation, pos. uncertainties, number density

(Similar to Pineau et al 2017)

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M. Salvato, Toulouse 2018
The beauty of NWAY

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discriminant(S) between known ctps and field

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M. Salvato, Toulouse 2018
For extragalactic ROSAT/2RXS (Boller+16) and XMMSLEW2: a MIR color-magnitude prior.
Spectral Identification ERosita Sources

PI: Merloni, Nandra

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Bright AGN up to high-z in comparable number as from pencil beam surveys!
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Bright AGN up to high-z in comparable number as from pencil beam surveys!

**Coffey, MS et al. 2018:** SPIDERS DR14 release with physical properties

M. Salvato, Toulouse 2018
first star/AGN classifications
(usefull for spectroscopic follow-up)

Maccacaro+88

See also Mainieri+, Berger+, Civano+

Not-so-subliminal message:
give a try to NWAY

M.Salvato, Toulouse 2018
**first star/AGN classifications**  
(usefull for spectroscopic follow-up)

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Salvato+18
first star/AGN classifications
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See also Mainieri+, Berger+, Civano+

Not-so-subliminal message:
give a try to NWAY

Salvato+18
Same prior will not work in the Galactic plane

XMMSL2 in the galactic plane
XMMSLEW2 GAIA Counterparts classification in the galactic plane

\[ W1 < -1.625 \log(F_{0.5-2 \text{ keV}}) - 8.8 \]
XMMSLEW2 GAIA Counterparts classification in the galactic plane
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- W1 > -1.625 * Log(F_{0.5–2 keV}) - 8.8
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- AGN in Simbad
Accuracy in STRIPE82X photoz comparable to Legacy-COSMOS with SDSS+VHS+WISE (10 bands only)

Ananna, MS et al 2017

Brescia, MS et al 2018

SED fitting

MLPQN

σ=0.06
η=5%

σ=0.02
η=0!

All the best to SPHEREx (Dore’ et al 2018), Euclid and LSST!
Next challenge: the 4 million eROSITA point-like sources
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Prior must be adequate to the depth

I am working on the new prior (stay tuned!)
We developed and released Nway, a code that based on Bayesian statistics allow to consider at once, astrometry, distribution and physical properties of candidate counterparts, opposed to those of field sources. Works also in radio.

For 2RXS (XMMSL2) we defined a MIR color-magnitude prior. Based on a well understood spectroscopic sample we claim a reliable counterpart for at least ~97% of the 106 573 (17 665) X-ray sources, with a small fraction of spurious associations.

The combination of deep pencil beam and shallow all-sky area allowed to determine a better separation between stars ans AGN dominated object in the W1 and Fx plan.

GAIA allowed the determination and classification of the XMMSLEW2 sources in the galactic plane.

For eROSITA, depending on depth and location (e.g. extragal/gal/poles) different discriminators need to be defined (work in progress). NWAY will be also slightly modified.