XMM2ATHENA

A catalogue of photometric redshifts for 4XMM

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& XMM2ATHENA team.

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

INTRODUCTION

- The 4XMM serendipitous catalogue (Webb+2020) is one of the largest X-ray catalogues currently available, with ~630,000 unique sources in data release 12.
- In order to fully untap its scientific potential, distance estimations (i.e. redshifts) are needed.
- Spectroscopic redshifts are available for only a small fraction, and they are observationally very expensive.
- We need to rely on photometric redshifts.

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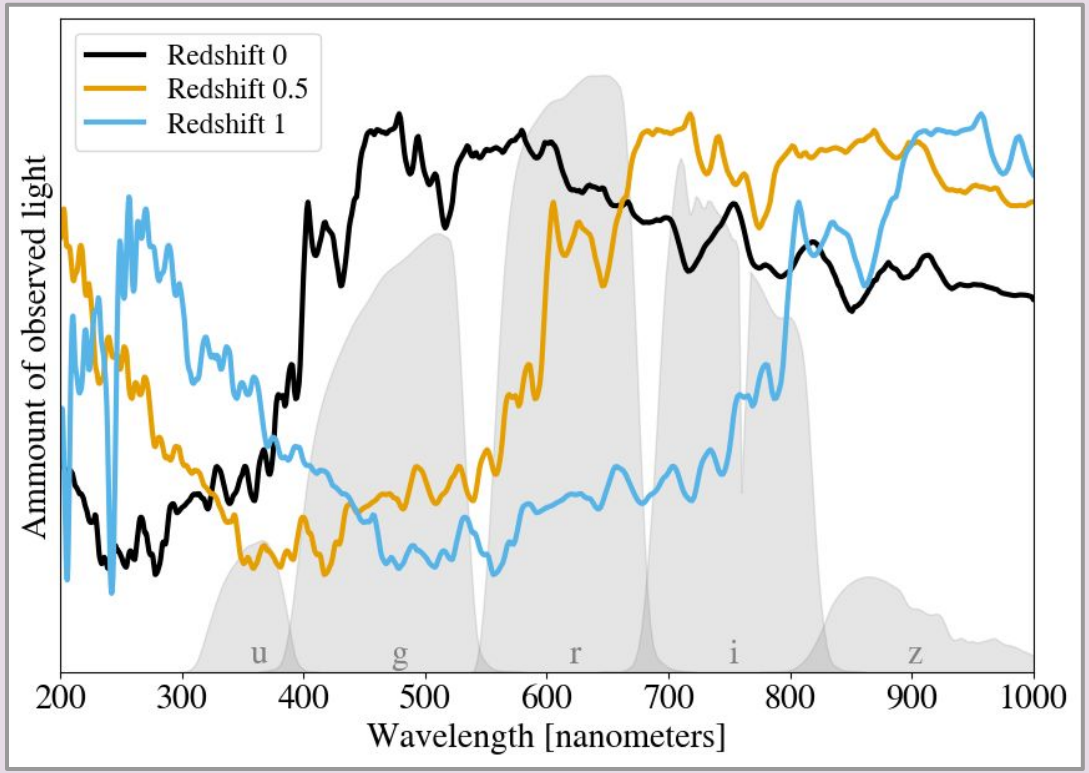
PHOTOMETRIC REDSHIFTS



- **Observed colors for a given galaxy depend on the redshift (and galaxy type)**
- **Two major techniques for photo-z:**
  - Template fitting
  - Supervised machine learning

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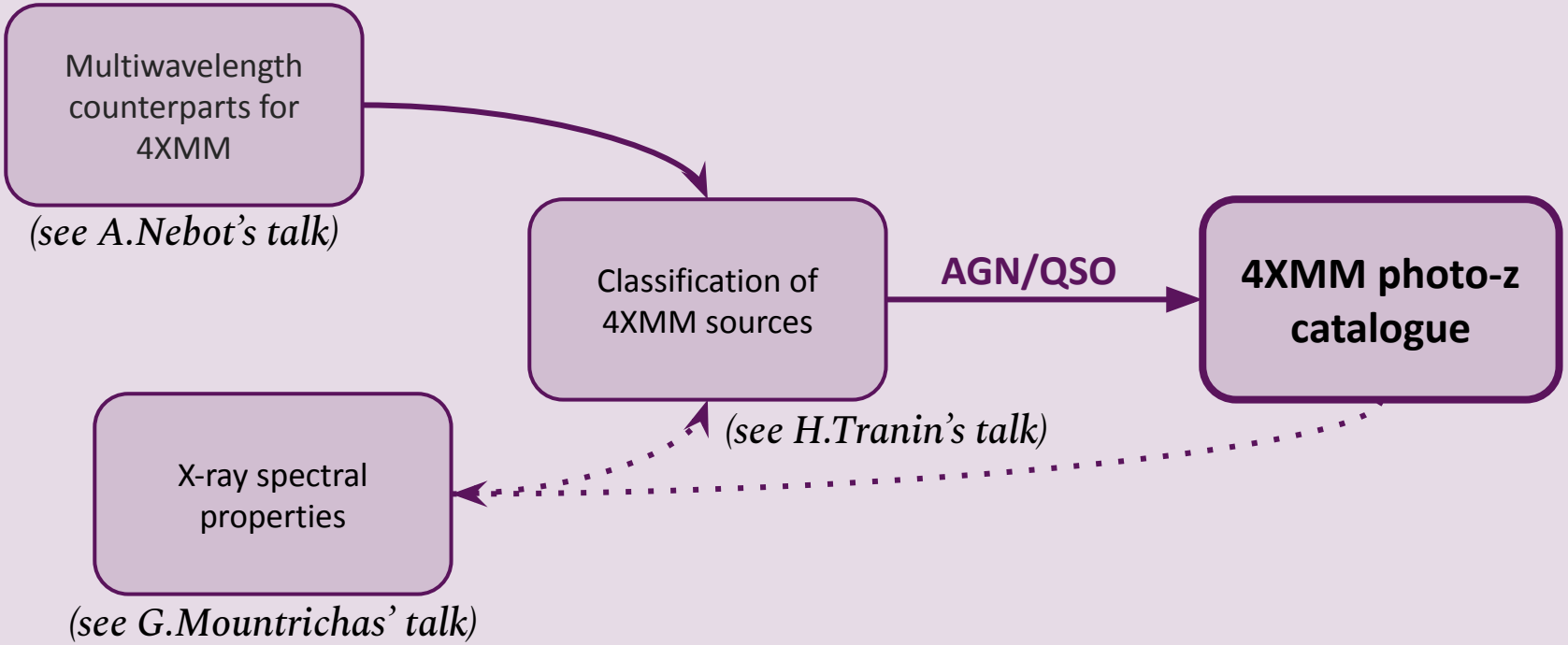
XMM2ATHENA: Photo-z for 4XMM



Development of techniques and tools for 5XMM and future Athena serendipitous catalogues.

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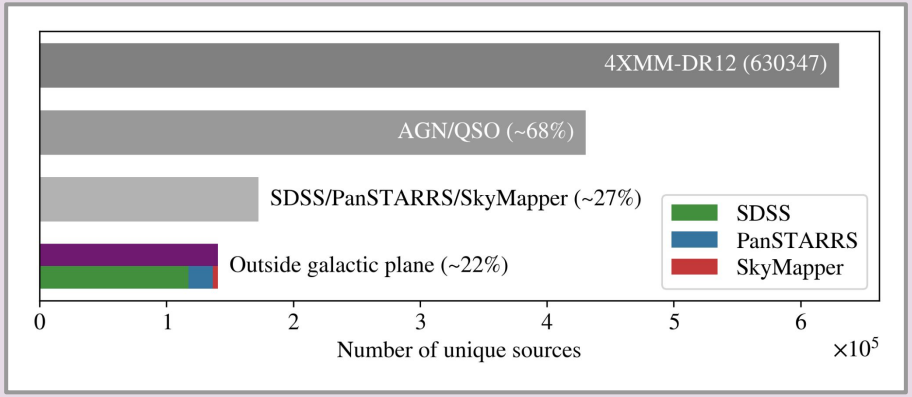
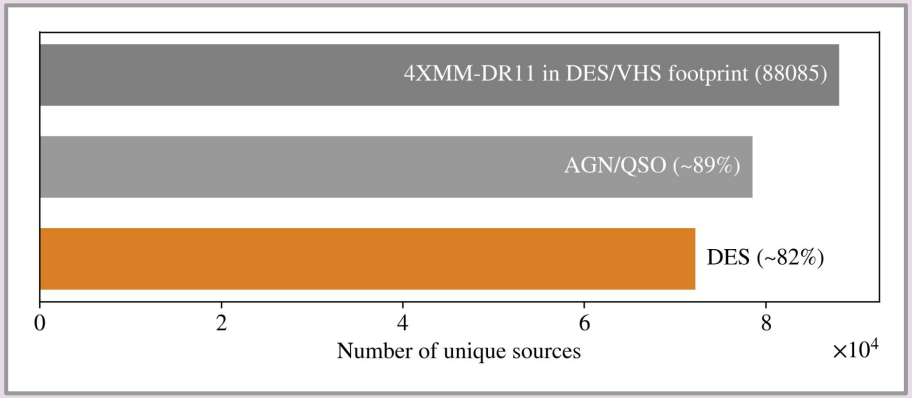
XMM2ATHENA: Selection of 4XMM sources for photo-z

- **4XMM-DR12**
  (full sky, ~1400 deg^2)
  - Classified as AGNs
  - Counterparts in SDSS/PanSTARRS/SkyMapper
  - Outside the galactic plane



- **4XMM-DR11**
  (inside DES/VHS footprint only, ~200 deg^2)
  - Classified as AGNs
  - Counterparts in DES



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XMM2ATHENA: Photo-z Algorithms

We used two different photo-z techniques previously used for X-ray selected sources:

- **MLZ-TPZ** (Carrasco-Kind & Brunner 2013)
  - Supervised machine learning algorithm: **Random forest**
  - Used previously for **XXL-North** (Mountrichas+2017) and **3XMM** (XMMPZCAT, Ruiz+2018)
  - Training sample based on the MORX catalogue
  - Input attributes: **colors** and **optical extension**.

- **LePhare** (Arnouts+1997, Ilbert+2006)
  - SED template fitting code
  - Broadly used in X-ray surveys: **COSMOS** (Salvato+2009, 2011), **CDFS** (Hsu+2014), **Stripe82-X** (Ananna+2017), **eFEDS** (Salvato+2022), **XXL-North** (Pouliasis+2024)
  - Galaxy and AGN templates from eFEDS (Salvato+2022)

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  - Input attributes: **colors** and **optical extension**.

Very good for the bulk of the population.
Needs rich photometry.

- **LePhare** (Arnouts+1997, Ilbert+2006)
  - SED template fitting code
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  - Galaxy and AGN templates from eFEDS (Salvato+2022)

(see E.Pouliasis' talk)

Incomplete photometry.
Rare sources
(e.g. high redshift).

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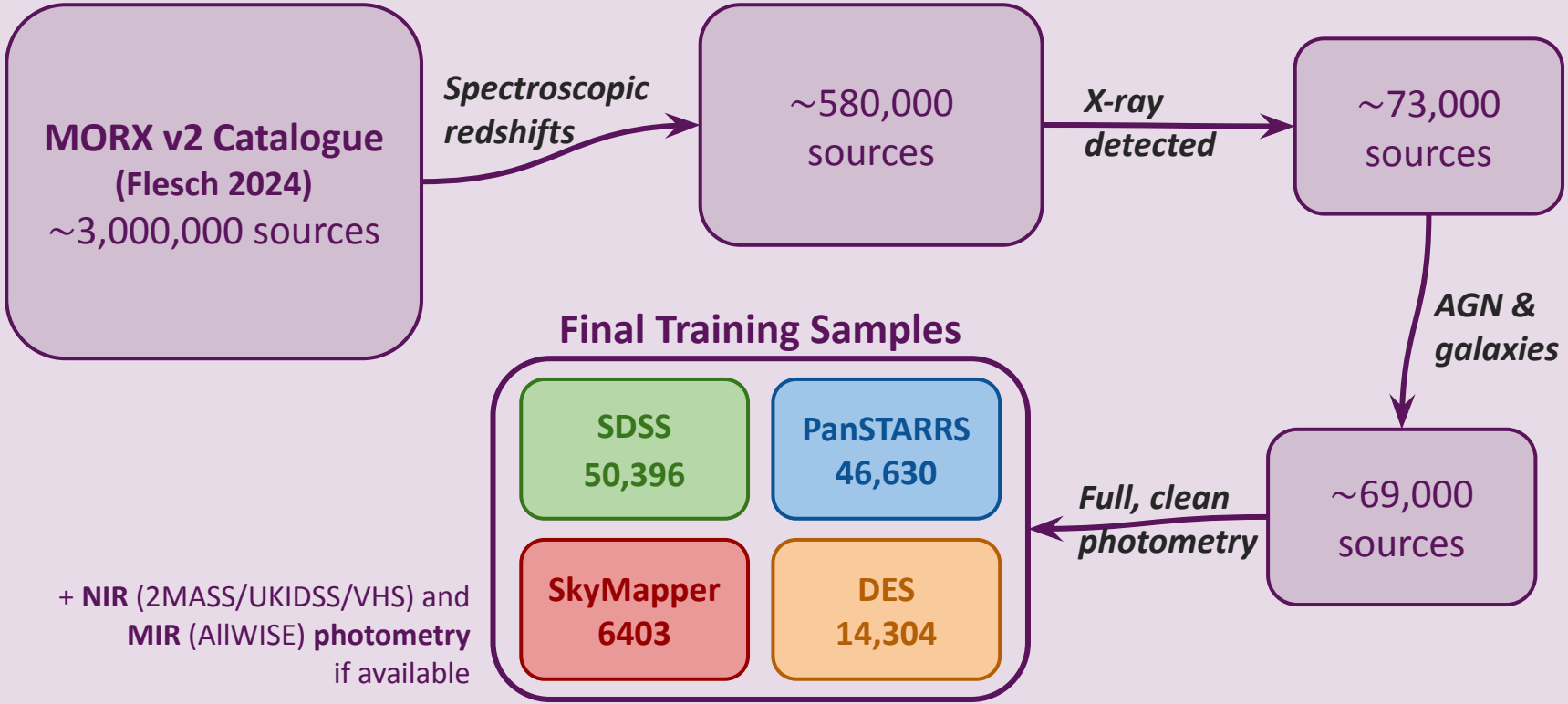
XMM2ATHENA: Training/Validation Sample



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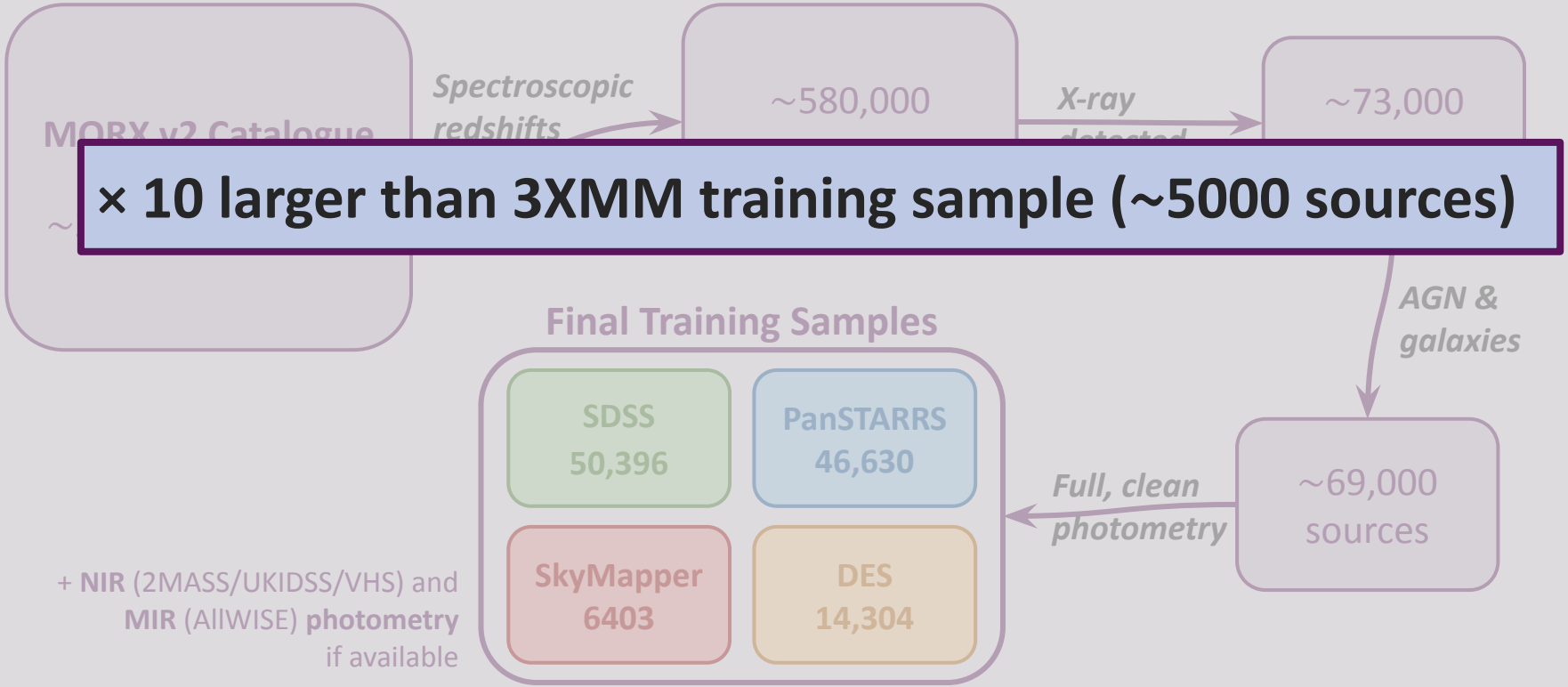

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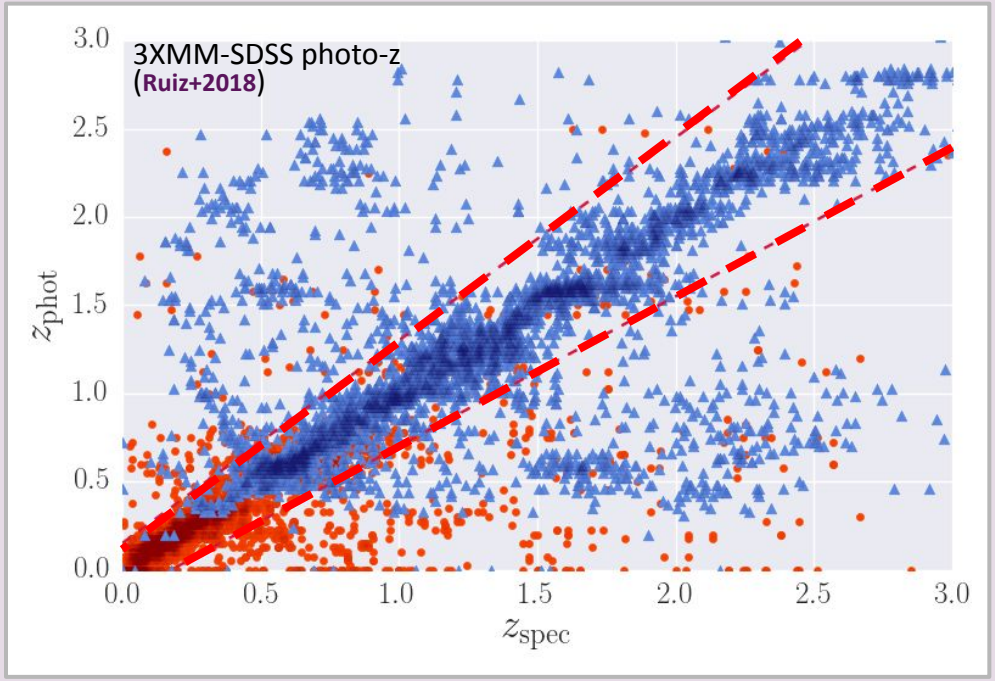
PHOTO-Z RELIABILITY AND ACCURACY



accuracy

$\sigma_{NMAD} = 1.4826 \times \text{Median}(|\Delta z_{norm}|)$

$\eta = 100 \times N_{outliers} / N$

reliability

$\Delta z_{norm} = (z_{spec} - z_{phot}) / (1 + z_{spec})$

outlier if $|\Delta z_{norm}| > 0.15$

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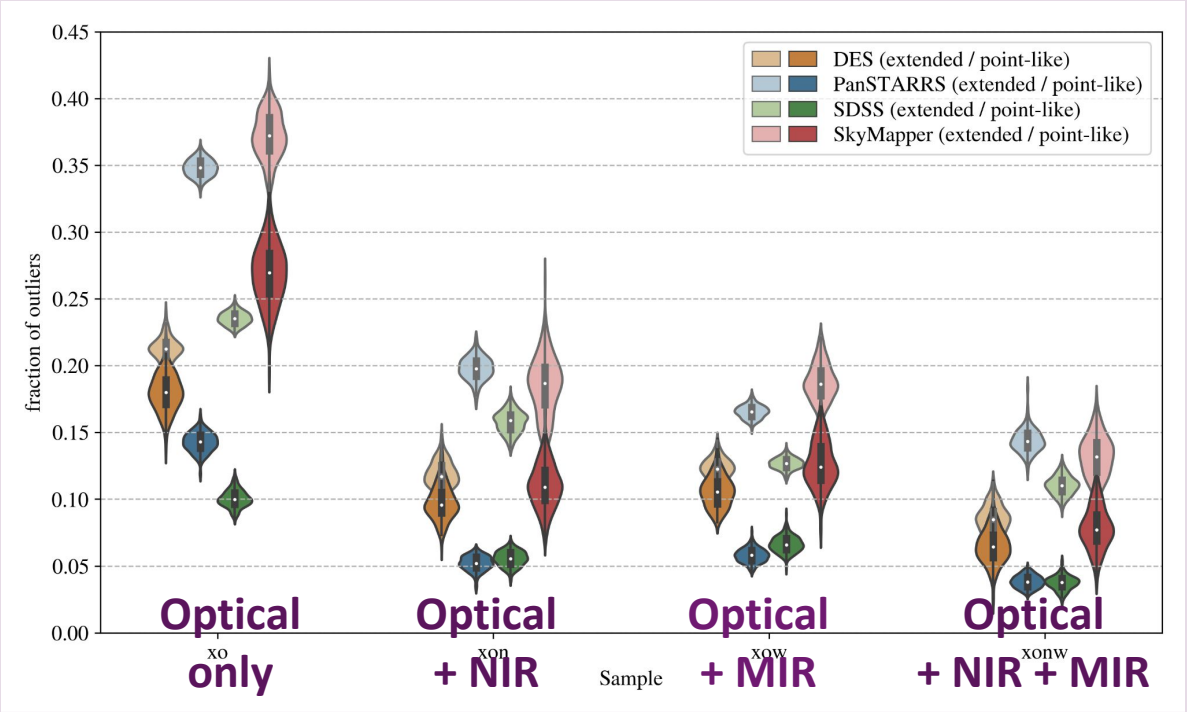
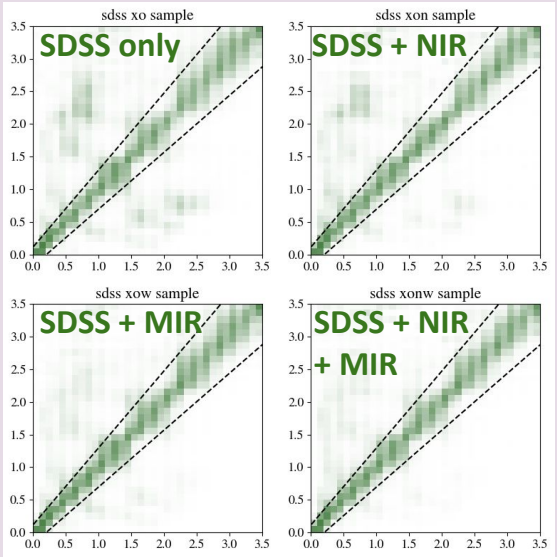
XMM2ATHENA: Photo-z Cross-validation

Results for η using TPZ

(*6-fold cross-validation using the training samples*)



TPZ photo-z versus spec-z



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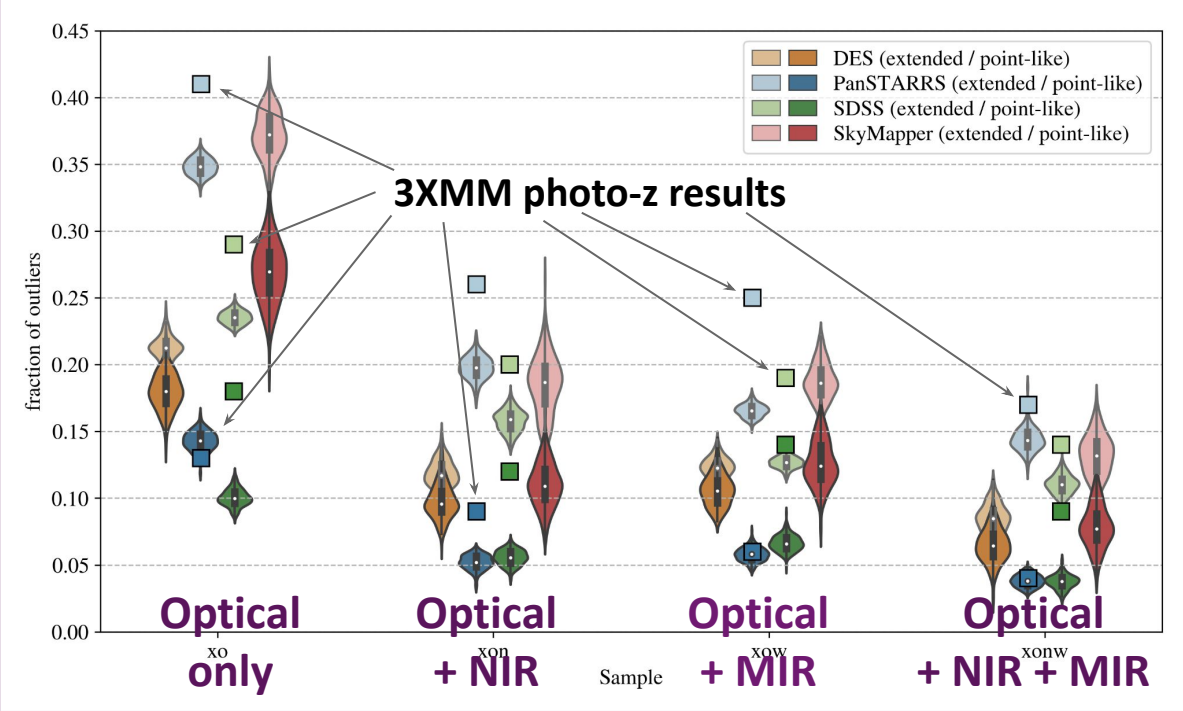
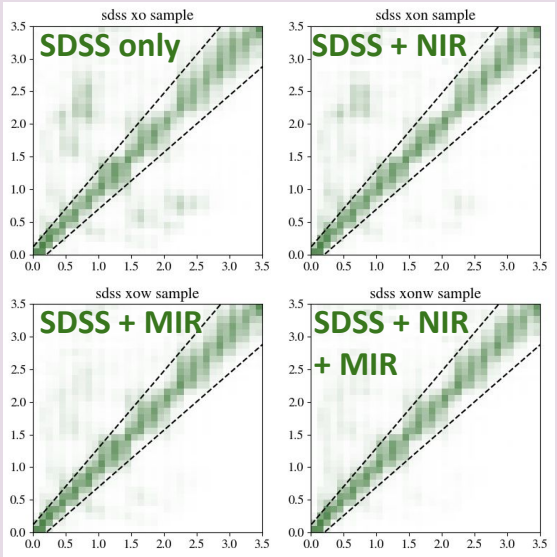


TPZ photo-z versus spec-z



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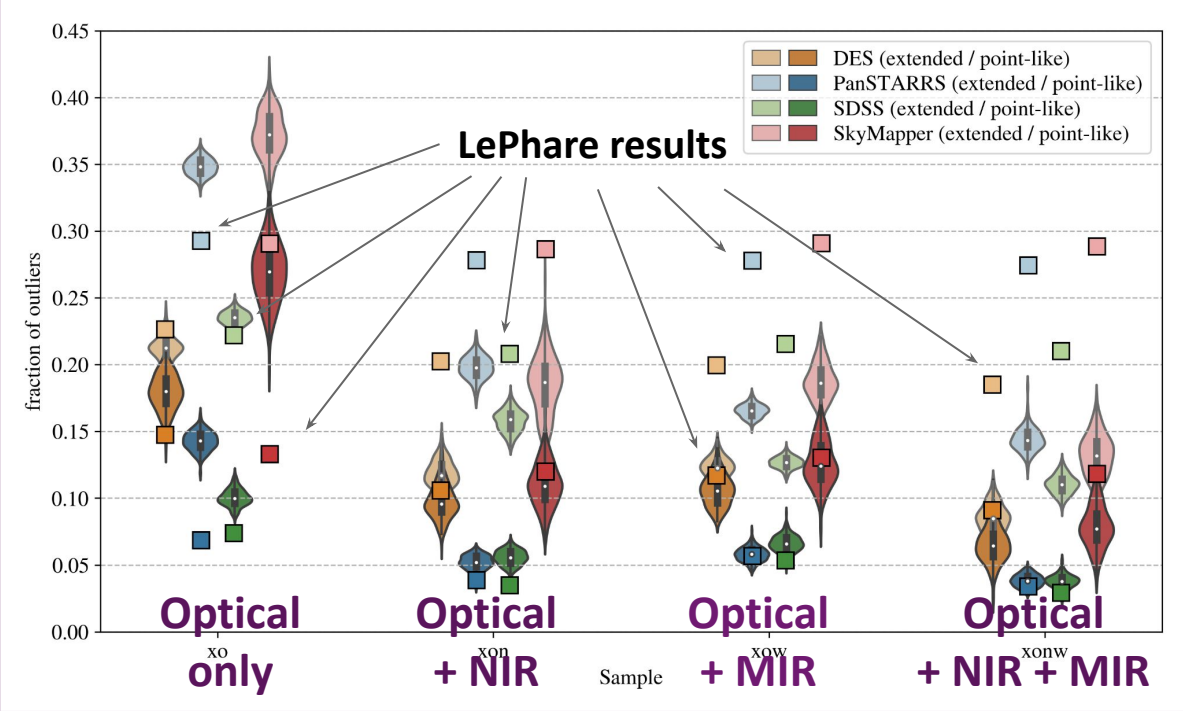
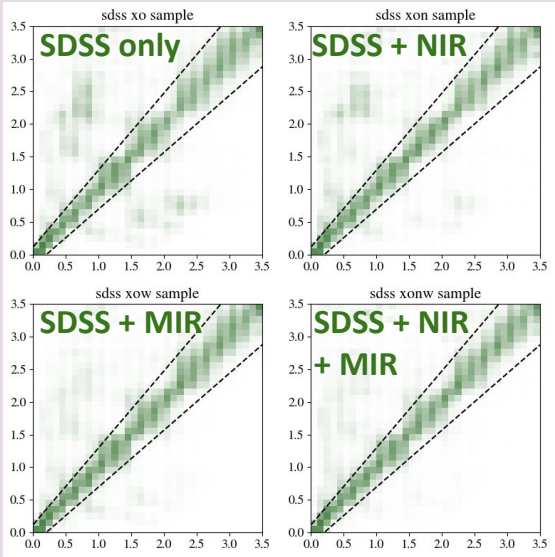
XMM2ATHENA: Photo-z Cross-validation

Results for η using LePhare
(***cross-validation using the training samples***)



TPZ photo-z versus spec-z



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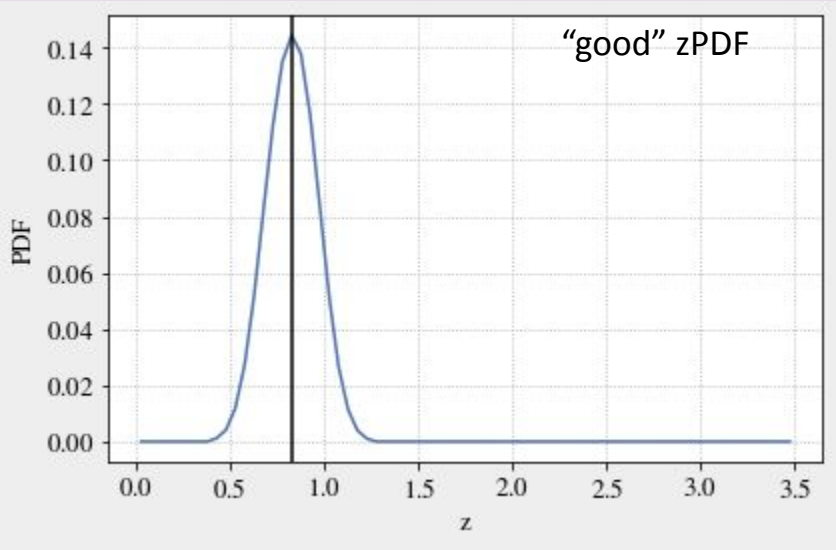
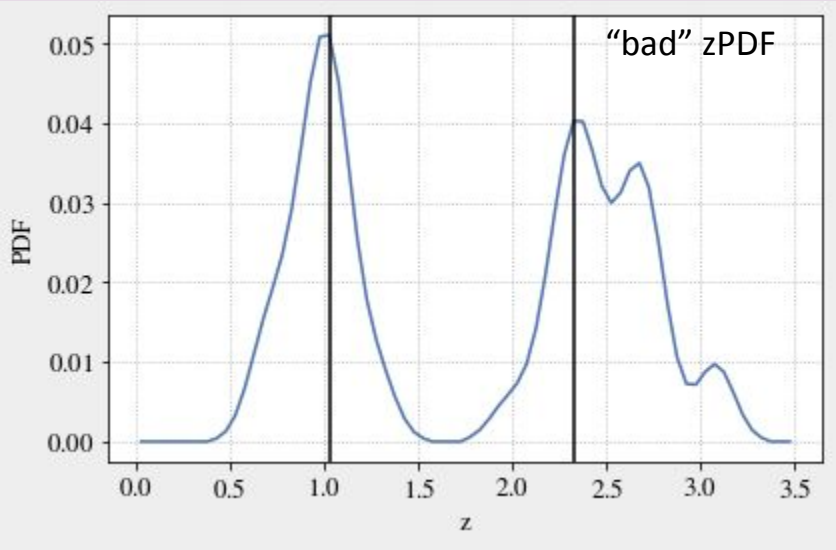
XMM2ATHENA: Photo-z quality flags

Reliability of TPZ and LePhare photo-z estimated through photometry coverage and the shape of the PDF: zConf, relative peak strength (PS) and number of peaks (NP) [as in Ruiz+2018].





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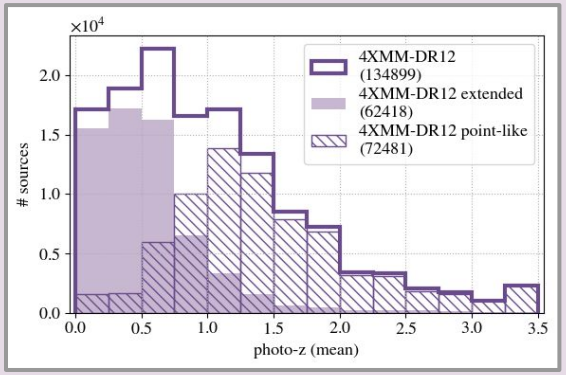
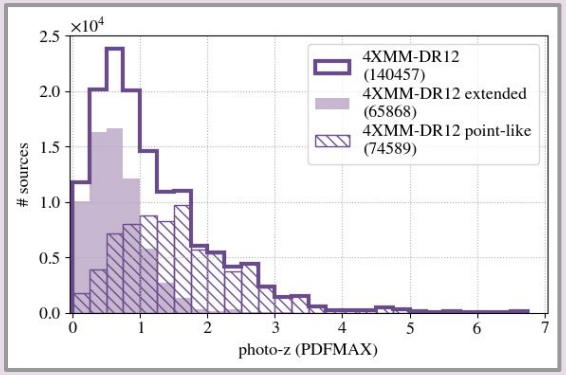
XMM2ATHENA: Photo-z results

4XMM-DR12
~1000 deg^2

TPZ photo-z



LePhare photo-z



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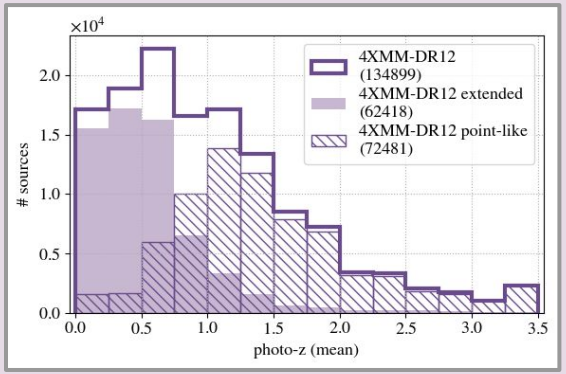
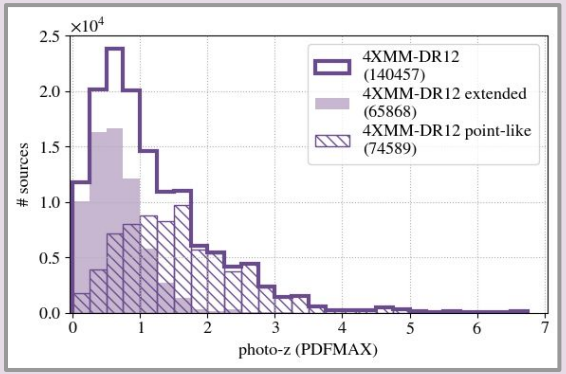
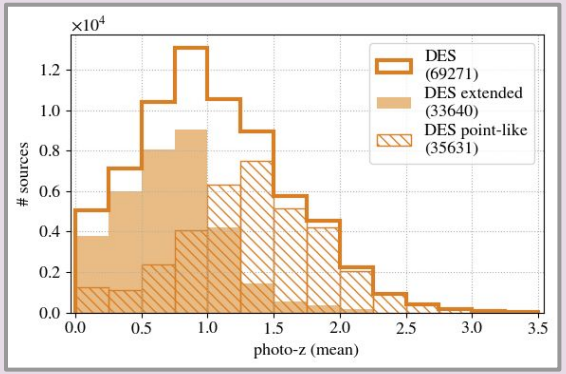
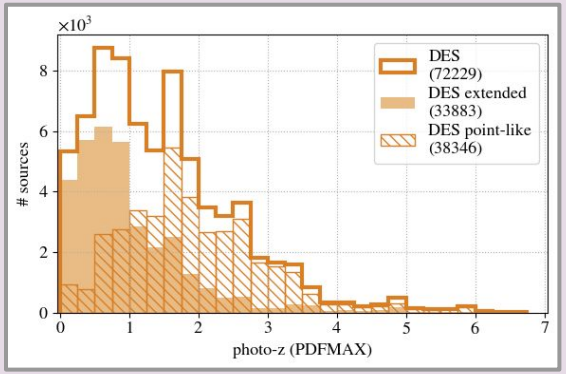




4XMM-DR11 DES-VHS ~200 deg^2





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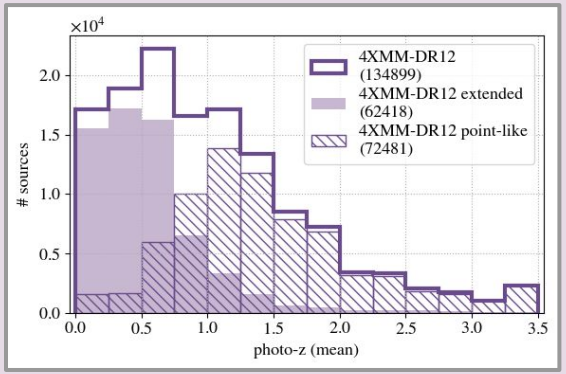
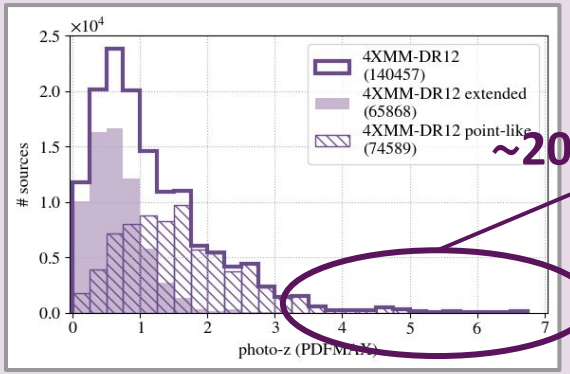
XMM2ATHENA: Photo-z results

TPZ photo-z

LePhare photo-z

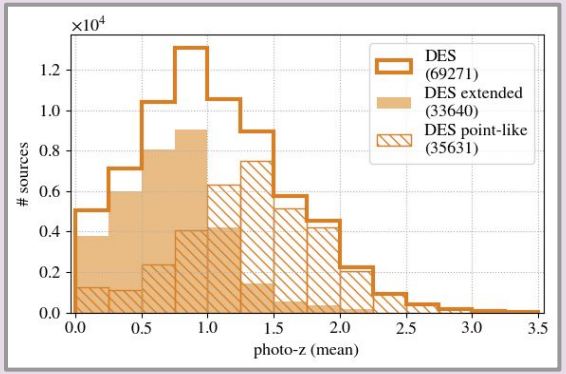
4XMM-DR12
~1000 deg^2

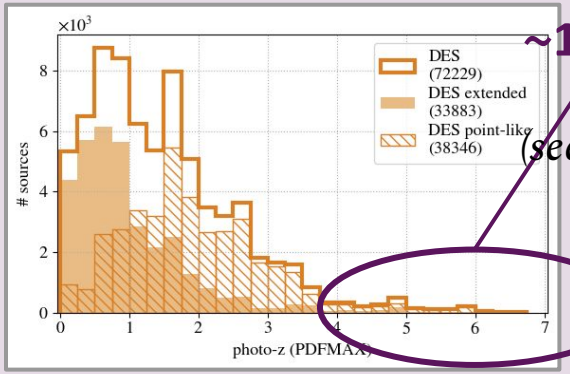




~2000 candidates
z > 3.5

4XMM-DR11
DES-VHS
~200 deg^2





~1000 candidates
z > 3.5

(see E.Pouliasis' talk)

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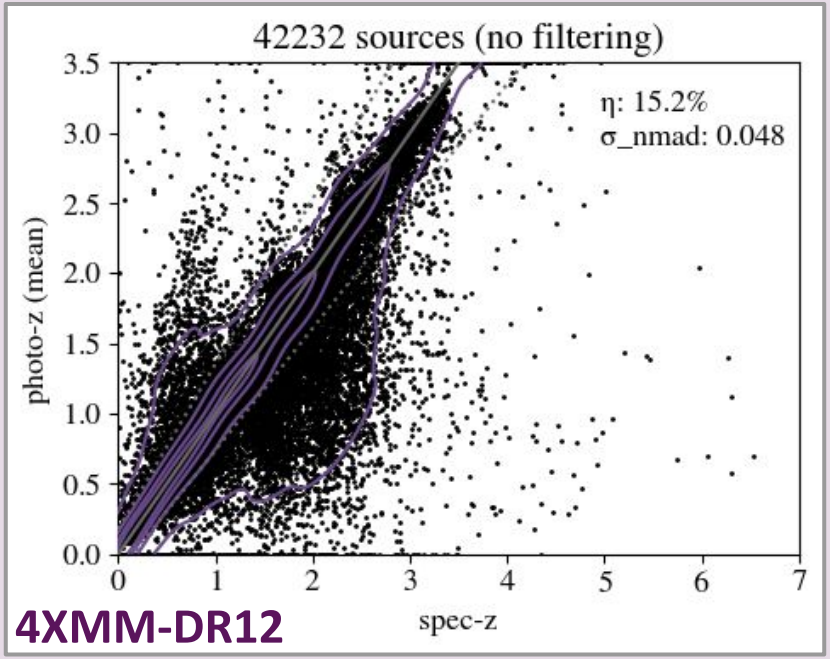
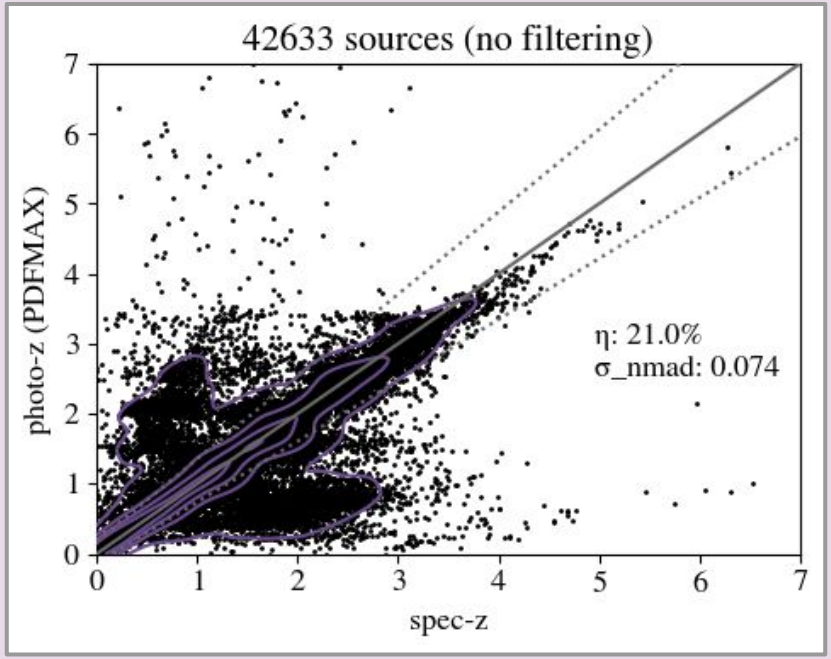
XMM2ATHENA: Sanity check and effect of quality flags

TPZ photo-z



LePhare photo-z



4XMM-DR12

Crossmatch with with MORX spectroscopic sample

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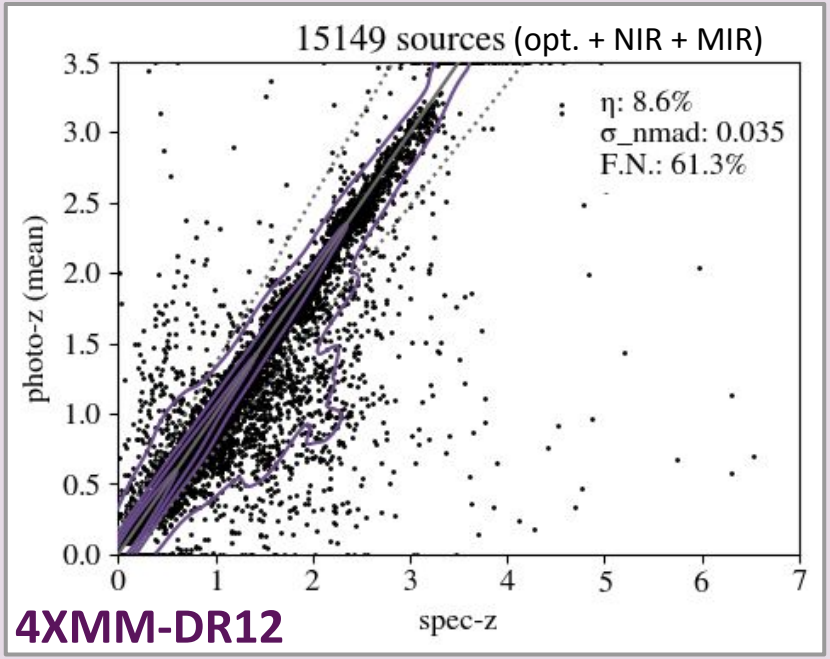

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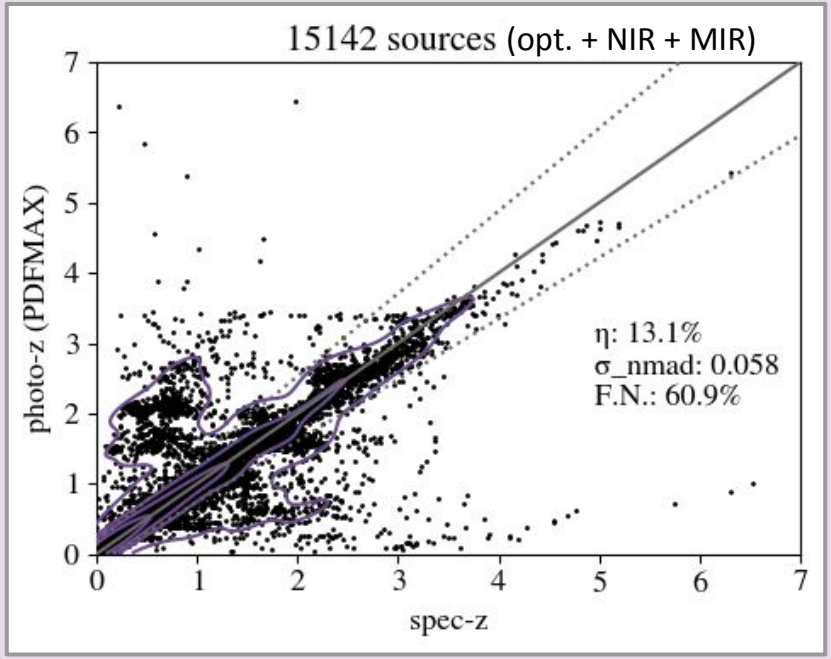

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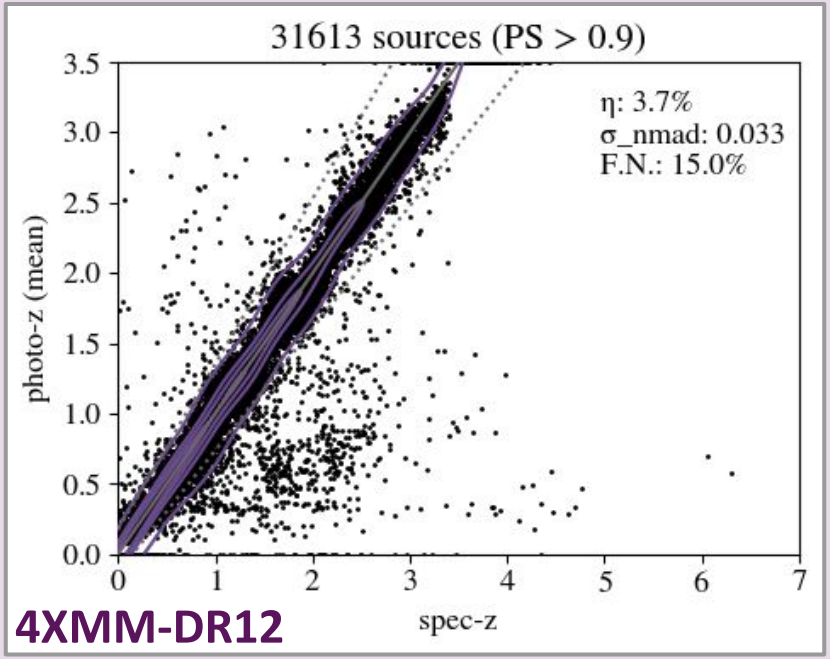

4XMM-DR12

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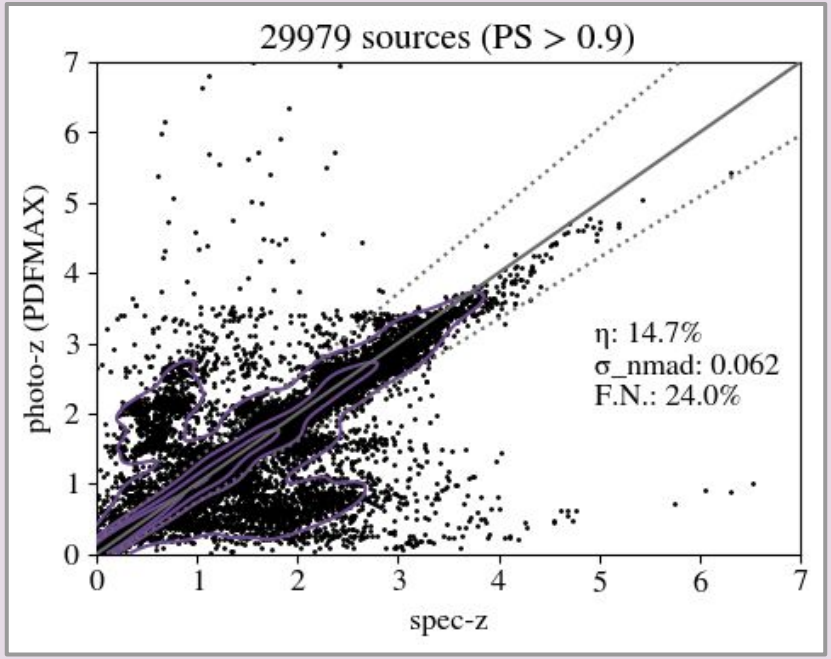

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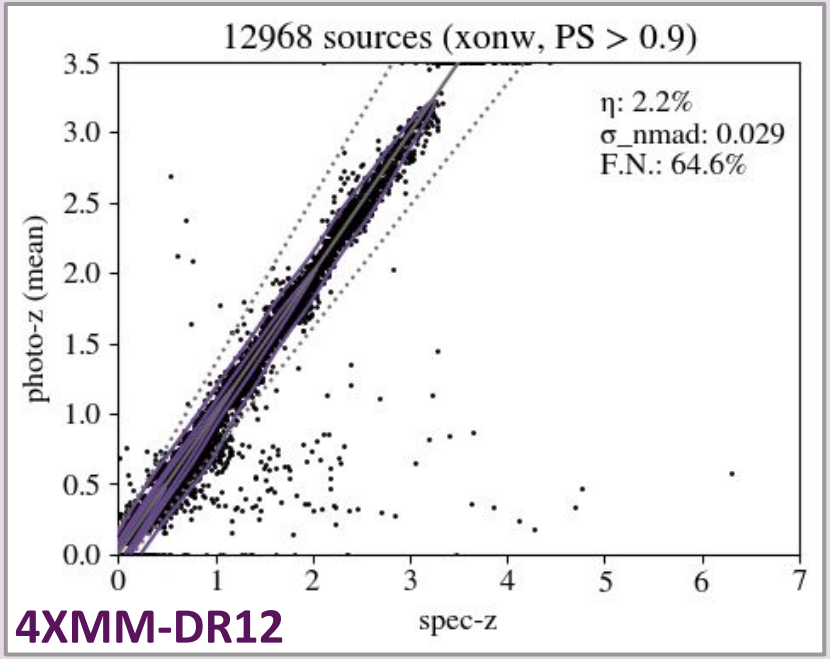

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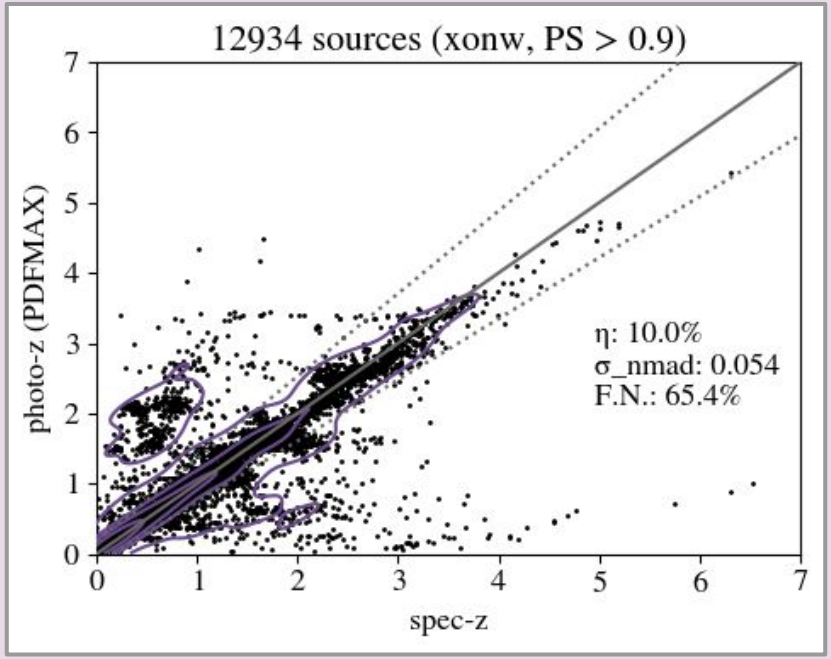

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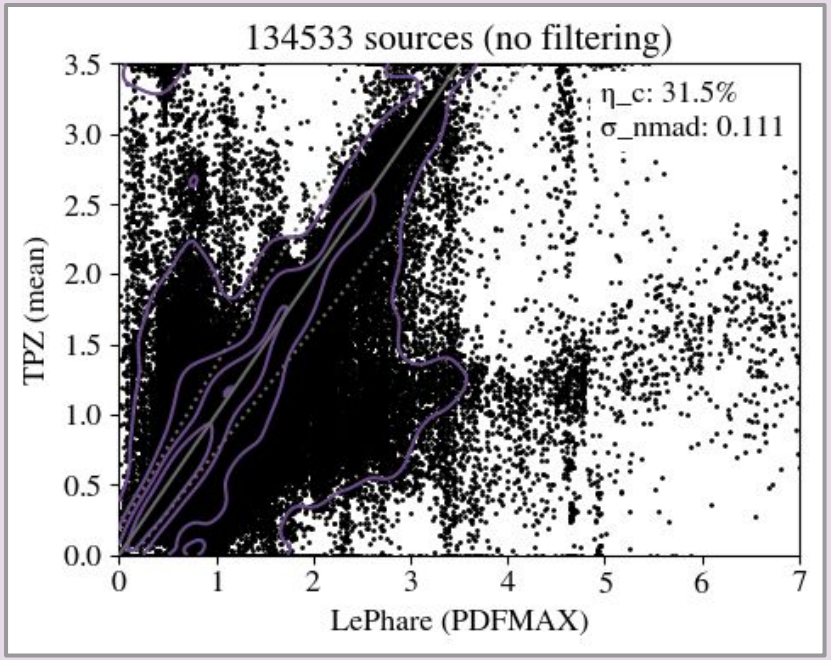
XMM2ATHENA: Comparison between TPZ and LePhare

4XMM-DR12



Consistent results for ~70% of sources

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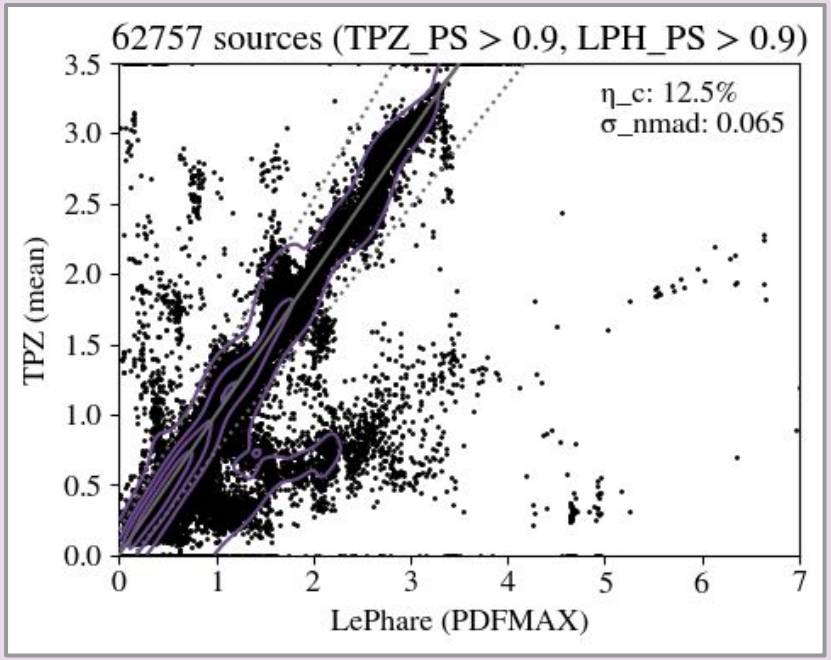

Consistent results for ~88% of sources

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SUMMARY

- **We built a catalogue of photometric redshifts for the 4XMM:**
  - 4XMM-DR12 (full sky, ~1000 sq.deg): ~140,000 sources
    Photo-z for AGN/QSO with SDSS/PanSTARRS/SkyMapper counterparts
  - 4XMM-DR11 (DES-VHS footprint, ~200 sq.deg.): ~72,000 sources
    Photo-z for AGN/QSO with DES counterparts
- **We provide photo-z estimations using two methods:**
  - **TPZ** (machine learning)
  - **LePhare** (template fitting)
- **The catalogue contains quality flags allowing the user to select clean samples with reliable photo-z.**
- **Improvements for the final version:**
  - Catalogue for 4XMM-DR13.
  - Include (at least partially) extragalactic sources within the galactic plane.
  - Improve LePhare photo-z for point-like (AGN dominated) sources.
  - Estimate LePhare photo-z for sources with GAIA, APASS, SUSS counterparts.
  - Better understanding of differences between TPZ and LePhare results.

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