The X-CLASS survey: A catalogue of 1646 X-ray-selected galaxy clusters up to $z \sim 1.5$

E. Koulouridis, N. Clerc, T. Sadibekova + the XCLASS collaboration (2021)
The X-CLASS collaboration

- A 20+ member international team with broad expertise
- Europe: France, Greece, ESA scientists, Germany & UK
- International: Egypt, Uzbekistan, Japan
- Clusters, AGN multi-wavelength science + machine learning, database
- Catalogues fully public and accessible through CDS and database
- MoU regulates internal collaboration work
- Collaboration is project-driven with (currently) best-effort strategy
- Funding to be secured
- Public website in construction...
9333 XMM-Newton observations until 08/2015

2461 observations after a cut at 10 or 20 ks in order to facilitate the computation of the selection function

total area of 269 sq. degrees
1 - Creating the images in soft [0.5-2] keV band and filtering with a wavelet algorithm (Starck & Pierre 1998);
2 - Centroid, extent and count-rate provided by SExtractor;
3 - Maximum likelihood fitting considering PSF and beta-model (Cavaliere & Fusco-Femiano 1978). The sources then are characterized by values of their extent likelihood and extent (best-fit core radius)
Cluster Xclass0219 at $z=0.791$ as confirmed by 11 member galaxies. Left panel: **X-ray image and contours**. Green circles (squares) mark detections of extended (point-like) sources as classified by the XAmin pipeline. Straight lines that cross the image are CCD gaps of the XMM-Newton detector. Right panel: **i-band optical image from PanSTARRS** over-plotted with X-ray contours. **Red circles** mark the member galaxies with available spectroscopic redshift.
Redshift validation

**Confirmed**: if three or more galaxies with concordant spectroscopic redshifts are found within the 500 kpc radius from the centre of the X-ray detection, or alternatively, if the spectrum of the brightest cluster galaxy (BCG) is available.

**Tentative**: if one or two galaxies with concordant spectroscopic redshifts are found within the 500 kpc radius.

**Photometric**: if only photometric redshift information is available in the literature or from our previous dedicated follow-up (Ridl et al. 2017).

**Provisional**: for cases where the available information does not allow us to verify the existence of a galaxy cluster in this position. Further follow-up observations are needed to safely classify these sources. Although these sources are part of the X-CLASS catalogue, they are not included in the on-line database.
SPIDERS:

The sample was compiled based on the correlation of X-ray sources from X-CLASS with the RedMapper optical cluster catalogue, as described in (Sadibekova et al. 2014) and (Clerc et al. 2016).

The (BOSS) spectrograph mounted on the SDSS-2.5m telescope at Apache Point Observatory (Gunn et al. 2006) was used. The catalogue contains **124 validated clusters** (out of the 142 targeted) with SPIDERS follow-up spectroscopy up to a redshift of $z \sim 0.6$. The program led to the collection of **1134 spectra in X-CLASS red sequences**, with a redshift success rate approaching 99% (Clerc et al. 2020).
redshift distribution

The redshift distribution peaks at \( z \approx 0.1 \), while if we remove the pointed observations it peaks at \( z \approx 0.3 \).
Follow-up on-going programs

Optical identification with recent surveys (photometry, zphot, redshifts)

DESI Legacy, PanStarrs, SDSS ...

Complementary spectroscopic observations with MISTRAL@OHP

16 nights in 2021 – 2023; 47 new groups/clusters with redshift, mostly low-z clusters (zMED ~ 0.21)

Update the database with recent other spectroscopic measurements
Follow-up on-going programs

Optical identification with recent surveys (photometry, zphots, redshifts): DESI Legacy, PanStarrs, SDSS ...

Previous multi-λ photometric follow-up with GROND@2.2m – ESO (Ridl et al. 2017). grizJHK photometry, 400+ targets.

~230 clusters already published with $z_{MED} = 0.39$

Still 100+ (distant) clusters remain to analyze

For Southern targets available with DESI, definition of the most probable redshift from the photo-z identifications
Interactive flux measurements

Interactive (manual) mode enabling the user to:

- refine the X-ray cluster centre,
- remove or correct areas incorrectly masked by XAmin (CCD gaps, unresolved blended sources, FOV edge cases),
- re-estimate the background level according to the cluster brightness and extension to get a more precise count-rate measurement,
- optimise the measurements in cases where the source is detected on the missing part of MOS1, and
- set a more accurate and reliable value for the source radii when the growth curve algorithm has failed because of background overestimation (field source contamination, missing part of MOS1, edge effects).

The count rates are computed in six different bands, namely [0.5-2], [2-0], [0.5-0.9], [1.3-2], [2-5] and [5-7] keV, using a full exposure to obtain the highest signal-to-noise ratio.
### Cluster selection criteria

#### Area

| Parameter   | Minimum | Maximum |
|-------------|---------|---------|
| r.a. min    |         |         |
| dec min     |         |         |
| r.a. max    |         |         |
| dec max     |         |         |

**Help**

#### Quality

| Parameter   | Minimum | Maximum |
|-------------|---------|---------|
| xclass min  |         |         |
| redshift min|         |         |
| status min  |         |         |
| xclass max  |         |         |
| redshift max|         |         |
| status max  |         |         |

#### X-ray properties (pipeline outputs)

Results of the extended fit over (MOS1 + MOS2 + PN)

| Parameter     | Minimum | Maximum |
|---------------|---------|---------|
| off radius min|         |         |
| detection ML min|       |         |
| extent ml min |         |         |
| extent min    |         |         |
| counts min    |         |         |
| rate min      |         |         |
| flux min      |         |         |

| Parameter     | Minimum | Maximum |
|---------------|---------|---------|
| off radius max|         |         |
| detection ML max|      |         |
| extent ml max |         |         |
| extent max    |         |         |
| counts max    |         |         |
| rate max      |         |         |
| flux max      |         |         |

**Select** 1559 clusters selected

**Display** the selected subset of clusters.

More information is available in the user's guide.
The new X-CLASS cluster catalogue

Subset of clusters

| xclass | R.A. pipeline | Dec. pipeline | R.A. measured | Dec. measured | NED | obs | redshift | status | total rate | profile |
|--------|---------------|---------------|---------------|---------------|-----|-----|----------|--------|------------|---------|
| 0020   | 193.4380      | 10.1954       | 193.4380      | 10.1851       | ge  | 000134030101 Ts  | 0.654 | confirmed | 0.049 | data       |
| 0023   | 194.2860      | -17.4119      | 194.2930      | -17.4016      | ge  | 001042020101 Ts  | 0.045 | confirmed | 3.738 | data       |
| 0033   | 193.6790      | -29.2227      | 193.6740      | -29.2230      | ge  | 003041010101 Ts  | 0.056 | confirmed | 5.812 | data       |
| 0034   | 193.5950      | -29.0162      | 193.5930      | -29.0131      | ge  | 003014010101 Ts  | 0.053 | confirmed | 4.362 | data       |
| 0035   | 196.2740      | -10.2802      | 196.2740      | -10.2787      | ge  | 003214120101 Ts  | 0.34  | photometric | 0.047 | data       |
| 0036   | 36.3674       | -2.6651       | 36.3677       | -2.6663       | ge  | 003798180101 Ts  | 0.056 | confirmed | 0.167 | data       |
| 0039   | 36.4987       | -2.8272       | 36.4990       | -2.8275       | ge  | 003798180101 Ts  | 0.281 | confirmed | 0.033 | data       |
| 0040   | 35.1871       | -3.4339       | 35.1886       | -3.4339       | ge  | 003798280101 Ts  | 0.327 | confirmed | 0.050 | data       |
| 0042   | 150.1230      | -19.6282      | 150.1220      | -19.6292      | ge  | 004411030101 Ts  | 0.057 | no redshift | 0.052 | data       |
| 0044   | 202.4460      | 11.6835       | 202.4490      | 11.6848       | ge  | 004411080101 Ts  | 0.204 | confirmed | 0.087 | data       |
| 0047   | 172.9830      | -19.9229      | 172.9800      | -19.9271      | ge  | 004423190101 Ts  | 0.307 | confirmed | 3.254 | data       |
| 0048   | 173.0280      | -19.8611      | 173.0280      | -19.8614      | ge  | 004423190101 Ts  | 0.307 | confirmed | 0.154 | data       |
| 0050   | 172.8110      | -19.9336      | 172.8130      | -19.9343      | ge  | 004423190101 Ts  | 0.46  | photometric | 0.023 | data       |
| 0051   | 177.6130      | 1.7500        | 177.6160      | 1.7560        | ge  | 004474020101 Ts  | 0.036 | no redshift | 0.136 | data       |
| 0054   | 145.9370      | 16.7402       | 145.9380      | 16.7381       | ge  | 004694040101 Ts  | 0.180 | confirmed | 0.202 | data       |
| 0056   | 145.8820      | 16.6656       | 145.8860      | 16.6671       | ge  | 004694040101 Ts  | 0.255 | confirmed | 0.202 | data       |
| 0057   | 145.9920      | 16.6871       | 145.9950      | 16.6875       | ge  | 004694040101 Ts  | 0.253 | confirmed | 0.057 | data       |
| 0059   | 31.9565       | 2.1553        | 31.9576       | 2.1567        | ge  | 005214030101 Ts  | 0.40  | no redshift | 0.042 | data       |
| 0062   | 44.1414       | 0.1037        | 44.1417       | 0.1033        | ge  | 005602030101 Ts  | 0.362 | confirmed | 0.778 | data       |
| 0065   | 339.2510      | -15.2730      | 339.2520      | -15.2731      | ge  | 005602160101 Ts  | 0.31  | photometric | 0.316 | data       |
| 0073   | 10.4501       | -9.4575       | 10.4507       | -9.4569       | ge  | 072380200101 Ts  | 0.056 | confirmed | 15.529 | data       |
| 0078   | 10.7223       | -9.5697       | 10.7225       | -9.5701       | ge  | 006514020101 Ts  | 0.41  | photometric | 0.101 | data       |
| 0079   | 10.5238       | -9.6026       | 10.5231       | -9.6029       | ge  | 006514020101 Ts  | 0.055 | tentative | 0.033 | data       |
| 0082   | 39.4926       | -52.3934      | 39.4929       | -52.3937      | ge  | 006719010101 Ts  | 0.136 | confirmed | 0.250 | data       |
| 0084   | 148.4240      | 1.6999        | 148.4240      | 1.6995        | ge  | 007094040101 Ts  | 0.097 | confirmed | 0.796 | data       |
| 0086   | 348.7650      | -58.9351      | 348.7660      | -58.9354      | ge  | 008134030101 Ts  | 0.44  | photometric | 0.034 | data       |
pipeline measurements and products
The new X-CLASS cluster catalogue
Link to NED and search within 3’ radius
The new X-CLASS cluster catalogue

Subset of clusters

| xclass | R.A. pipeline | Dec. pipeline | R.A. measured | Dec. measured | NED | obs     | redshift | status   | total rate | profile |
|--------|---------------|---------------|---------------|---------------|-----|---------|----------|----------|-----------|---------|
| 0020   | 193.4380      | 10.1954       | 193.4380      | 10.1951       | ge  | 0001934301.10ks | 0.054   | confirmed | 0.045     | data    |
| 0023   | 194.2860      | -17.4119      | 194.2900      | -17.4064      | ge  | 0010428001.10ks | 0.047   | confirmed | 3.738     | data    |
| 0033   | 193.6790      | -29.2227      | 193.6740      | -29.2230      | ge  | 0030413001.10ks | 0.056   | confirmed | 5.882     | data    |
| 0034   | 193.5930      | -29.0162      | 193.5930      | -29.0131      | ge  | 0030341001.10ks | 0.053   | confirmed | 4.362     | data    |
| 0035   | 196.2740      | -10.2802      | 196.2740      | -10.2787      | ge  | 0032141001.10ks | 0.34    | photometric | 0.047     | data    |
| 0038   | 36.5674       | -2.6665       | 36.5677       | -2.6663       | ge  | 0037981801.10ks | 0.056   | confirmed | 0.167     | data    |
| 0039   | 36.4987       | -2.8272       | 36.4990       | -2.8275       | ge  | 0037981801.10ks | 0.291   | confirmed | 0.003     | data    |
| 0040   | 35.1871       | -3.4339       | 35.1886       | -3.4339       | ge  | 0037982801.10ks | 0.327   | confirmed | 0.050     | data    |
| 0042   | 150.1230      | -19.6282      | 150.1220      | -19.6292      | ge  | 0041180001.10ks | 0.057   | no redshift | 0.087     | data    |
| 0044   | 202.4460      | 11.6835       | 202.4490      | 11.6848       | ge  | 0041180001.10ks | 0.204   | confirmed | 3.254     | data    |
| 0047   | 172.9830      | -19.9229      | 172.9800      | -19.9271      | ge  | 0042341001.10ks | 0.307   | confirmed | 0.154     | data    |
| 0048   | 173.0280      | -19.8611      | 173.0280      | -19.8614      | ge  | 0042341001.10ks | 0.307   | confirmed | 0.154     | data    |
| 0050   | 172.8110      | -19.9326      | 172.8130      | -19.9343      | ge  | 0042341001.10ks | 0.46    | photometric | 0.025     | data    |
| 0051   | 177.6130      | 1.7580        | 177.6160      | 1.7580        | ge  | 0044740201.10ks | 0.036   | no redshift | 0.136     | data    |
| 0054   | 145.9370      | 16.7402       | 145.9380      | 16.7381       | ge  | 0046940401.10ks | 0.180   | confirmed | 0.202     | data    |
| 0056   | 145.8820      | 16.6656       | 145.8860      | 16.6671       | ge  | 0046940401.10ks | 0.255   | confirmed | 0.057     | data    |
| 0057   | 145.9920      | 16.6871       | 145.9950      | 16.6875       | ge  | 0046940401.10ks | 0.253   | confirmed | 0.057     | data    |
| 0058   | 31.9565       | 2.1553        | 31.9576       | 2.1567        | ge  | 0052143001.20ks | 0.99    | no redshift | 0.942     | data    |
| 0062   | 44.1414       | 0.1037        | 44.1417       | 0.1033        | ge  | 0056020301.10ks | 0.362   | confirmed | 0.778     | data    |
| 0065   | 339.2510      | -15.2730      | 339.2520      | -15.2731      | ge  | 0056021601.10ks | 0.31    | photometric | 0.316     | data    |
| 0075   | 10.4501       | -9.4575       | 10.4507       | -9.4569       | ge  | 0723802001.20ks | 0.056   | confirmed | 15.529     | data    |
| 0078   | 10.7223       | -9.5697       | 10.7225       | -9.5701       | ge  | 0065140201.10ks | 0.41    | photometric | 0.101     | data    |
| 0079   | 10.5238       | -9.6026       | 10.5231       | -9.6029       | ge  | 0065140201.10ks | 0.055   | tentative | 0.003     | data    |
| 0082   | 39.4926       | -52.3934      | 39.4929       | -52.3937      | ge  | 0067190101.10ks | 0.136   | confirmed | 0.259     | data    |
| 0083   | 148.4240      | 1.0999        | 148.4240      | 1.0995        | ge  | 0070904001.10ks | 0.027   | confirmed | 0.796     | data    |
| 0086   | 348.7630      | -58.9351      | 348.7660      | -58.9354      | ge  | 0081343001.10ks | 0.44    | photometric | 0.034     | data    |
## Redshift validation

| Redshift value: 0.007 | error + - |
|----------------------|-----------|
| Velocity dispersion: | km/s      |
| Number of galaxies: 63 | error + - |
| Final status: confirmed |          |
| Last update: 27/11/200000 | Set by: sadikova |

### Galaxies in the Cluster

| Name | Redshift | Error |
|------|----------|-------|
| 341.27892 | -17.41672 | 0.042649 |
| 341.57635 | -17.45758 | 0.042689 |
| 341.46413 | -17.27822 | 0.042876 |
| 341.62379 | -17.26389 | 0.042963 |
| 341.26487 | -17.61389 | 0.048874 |
| 341.6494 | -17.00978 | 0.048241 |
| 341.36897 | -17.54201 | 0.043377 |
| 341.81307 | -17.38156 | 0.043317 |
| 341.24584 | -17.00589 | 0.043857 |
| 341.42471 | -17.32494 | 0.043198 |
| 341.38458 | -17.37802 | 0.045569 |
| 341.2359 | -17.41314 | 0.045426 |
| 341.42510 | -17.26389 | 0.043469 |

### Redshift histogramme within the entire mask (or in a 7'x7' field)

![Redshift histogram](image)
# The new X-CLASS cluster catalogue

## Subset of clusters

| xclass | R.A. pipeline | Dec. pipeline | R.A. measured | Dec. measured | NED   | obs     | redshift | status     | total rate | profile |
|--------|---------------|---------------|---------------|---------------|-------|---------|----------|------------|------------|---------|
| 0020   | 193.4380      | -11.1954      | 193.4380      | 10.1051       | ge    | 000193438010110ks | 0.654     | confirmed  | 0.049      | data     |
| 0023   | 194.2960      | -17.4119      | 194.2960      | -17.4064      | ge    | 000194296010110ks | 0.047     | confirmed  | 3.738      | data     |
| 0031   | 194.6790      | -20.2227      | 194.6790      | -20.2230      | ge    | 000194679010110ks | 0.016     | confirmed  | 5.882      | data     |
| 0034   | 193.9500      | -29.0162      | 193.9500      | -29.0131      | ge    | 000193950010110ks | 0.053     | confirmed  | 4.362      | data     |
| 0035   | 196.2740      | -10.2802      | 196.2740      | -10.2787      | ge    | 000196274010110ks | 0.34      | photometric | 0.047      | data     |
| 0038   | 36.4074       | -2.6651       | 36.4074       | -2.6063       | ge    | 000364074010110ks | 0.056     | confirmed  | 1.07       | data     |
| 0039   | 36.4087       | -2.8272       | 36.4090       | -2.8275       | ge    | 000364087010110ks | 0.081     | confirmed  | 0.033      | data     |
| 0040   | 35.1871       | -3.4339       | 35.1886       | -3.4339       | ge    | 000351871010110ks | 0.327     | confirmed  | 0.050      | data     |
| 0042   | 150.1230      | -19.6282      | 150.1220      | -19.6292      | ge    | 000150123010110ks | 0.075     | no redshift | 0.057      | data     |
| 0044   | 202.4460      | 11.6835       | 202.4490      | 11.6848       | ge    | 000202446010110ks | 0.204     | confirmed  | 0.087      | data     |
| 0047   | 172.9830      | -19.9229      | 172.9800      | -19.9271      | ge    | 000172983010110ks | 0.307     | confirmed  | 3.254      | data     |
| 0048   | 173.0280      | -19.8611      | 173.0280      | -19.8614      | ge    | 000173028010110ks | 0.307     | confirmed  | 0.154      | data     |
| 0050   | 172.8110      | -19.9326      | 172.8130      | -19.9343      | ge    | 000172811010110ks | 0.46      | photometric | 0.025      | data     |
| 0051   | 177.6130      | 1.7560        | 177.6160      | 1.7560        | ge    | 000177613010110ks | 0.036     | no redshift | 0.136      | data     |
| 0054   | 145.9370      | 16.7402       | 145.9380      | 16.7381       | ge    | 000145937010110ks | 0.180     | confirmed  | 0.202      | data     |
| 0056   | 145.8820      | 16.6656       | 145.8860      | 16.6671       | ge    | 000145882010110ks | 0.255     | confirmed  | 0.253      | data     |
| 0057   | 145.9920      | 16.8871       | 145.9950      | 16.8875       | ge    | 000145992010110ks | 0.253     | confirmed  | 0.057      | data     |
| 0059   | 31.9565       | 2.1553        | 31.9576       | 2.1567        | ge    | 000319565010110ks | 0.090     | no redshift | 0.942      | data     |
| 0062   | 44.1414       | 0.1037        | 44.1417       | 0.1033        | ge    | 000441414010110ks | 0.362     | confirmed  | 0.778      | data     |
| 0065   | 339.2510      | -15.2730      | 339.2520      | -15.2731      | ge    | 000339251010110ks | 0.31      | photometric | 0.316      | data     |
| 0075   | 10.4501       | -9.4575       | 10.4507       | -9.4569       | ge    | 000104501010110ks | 0.056     | confirmed  | 15.529     | data     |
| 0078   | 10.7223       | -9.5697       | 10.7225       | -9.5701       | ge    | 000107223010110ks | 0.041     | photometric | 0.101      | data     |
| 0079   | 10.5228       | -9.6026       | 10.5231       | -9.6029       | ge    | 000105228010110ks | 0.055     | tentative   | 0.043      | data     |
| 0082   | 39.4932       | -52.3934      | 39.4929       | -52.3937      | ge    | 000394932010110ks | 0.116     | confirmed  | 0.259      | data     |
| 0083   | 148.4240      | 1.6999        | 148.4240      | 1.6995        | ge    | 000148424010110ks | 0.097     | confirmed  | 0.796      | data     |
| 0086   | 348.7630      | -58.9351      | 348.7660      | -58.9354      | ge    | 000348763010110ks | 0.44      | photometric | 0.034      | data     |
Interactive flux measurements
The X-CLASS Cluster Survey

- The X-CLASS survey: A catalogue of 1646 X-ray-selected galaxy clusters up to $z \sim 1.5$
  Koulouridis et al., 2021, A&A, 652A, 12K

- Multiwavelength classification of X-ray selected galaxy cluster candidates using convolutional neural networks
  Kosiba et al. 2020, MNRAS. 496. 4141K

- Cosmology with XMM galaxy clusters: the X-CLASS/GROND catalogue and photometric redshifts
  Ridl et al., 2017, MNRAS, 468, 662

- SPIDERS: the spectroscopic follow-up of X-ray-selected clusters of galaxies in SDSS-IV
  Clerc et al., 2016, MNRAS, 463, 4490

- The X-CLASS–redMaPPer galaxy cluster comparison
  Sadibekova et al., 2014, A&A, 571, 87

- The cosmological analysis of X-ray cluster surveys – II. Application of the CR–HR method to the XMM archive
  Clerc et al., 2012, MNRAS, 423, 3561

DATABASE: https://xmm-xclass.in2p3.fr  contact: ekoulouridis@noa.gr
What next?

Importance of the redshift measurements to study the physical properties of clusters: X-ray profile and luminosity, temperature, R500, optical properties of groups and clusters.

Specificity of the XCLASS sample: dominated by faint X-ray sources, mostly low redshift groups and poor clusters + high-redshift clusters.

Constraints of the LX – T – M relation, then the mass function at M < 5×10¹³ Msol.

A cosmological analysis is ongoing, specific to « small clusters »!

Multiple projects from the 20 members of the XCLASS collaboration (AGN in clusters, morphology & LSS, galaxy LF, etc.).

The X-CLASS z<0.2 luminosity-temperature relation (Moysan et al. in prep.).
Thank you!