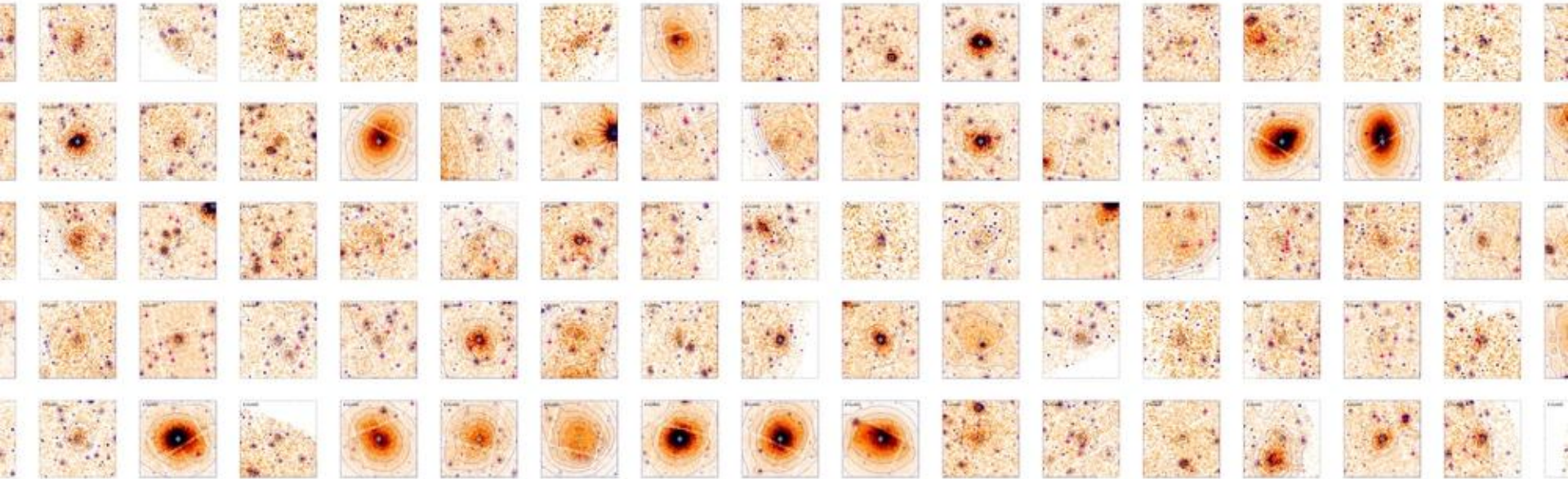


The X-CLASS survey: A catalogue of 1646 X-ray-selected galaxy clusters up to $z \sim 1.5$

E. Koulouridis, N. Clerc, T. Sadibekova + the XCLASS collaboration (2021)



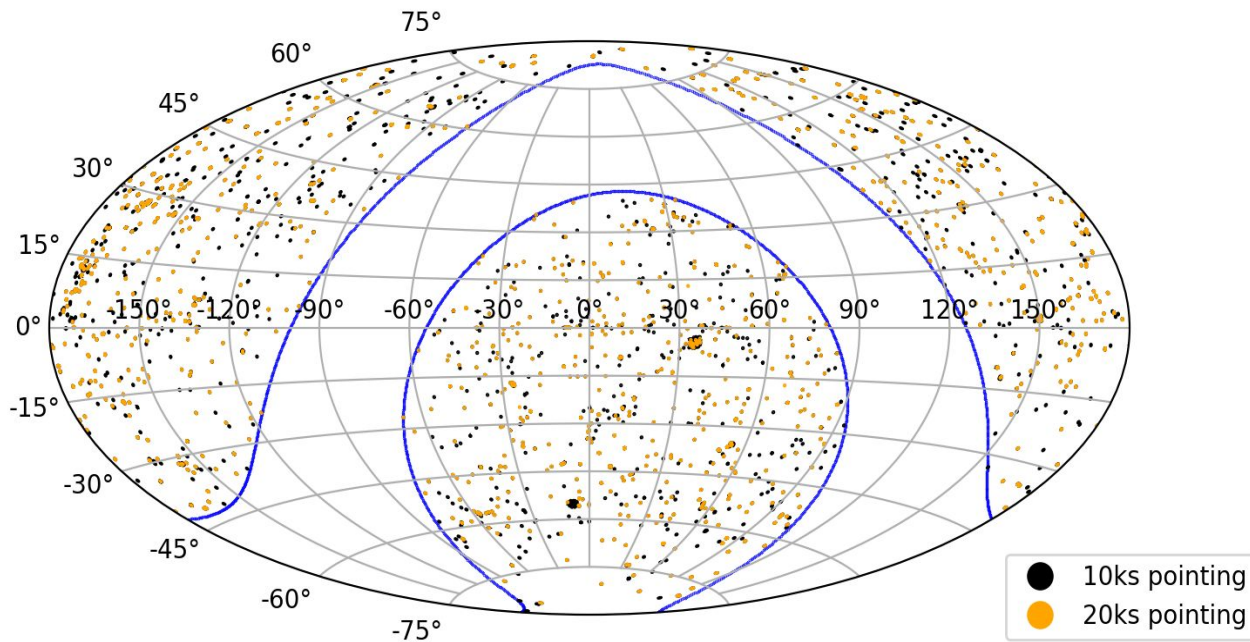
The X-CLASS collaboration

- 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

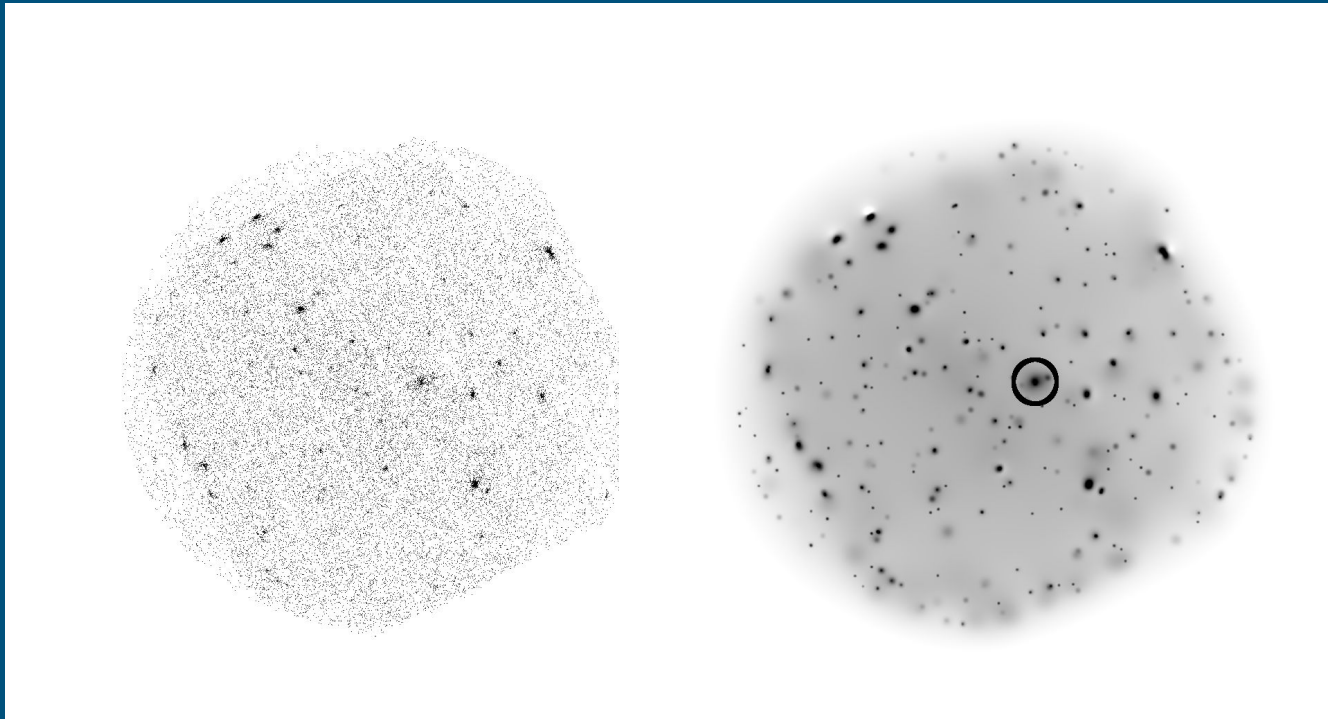
2461 observations
after a cut at 10 or
20 ks in order to
facilitate the
computation of
the selection
function

total area of
269 sq. degrees

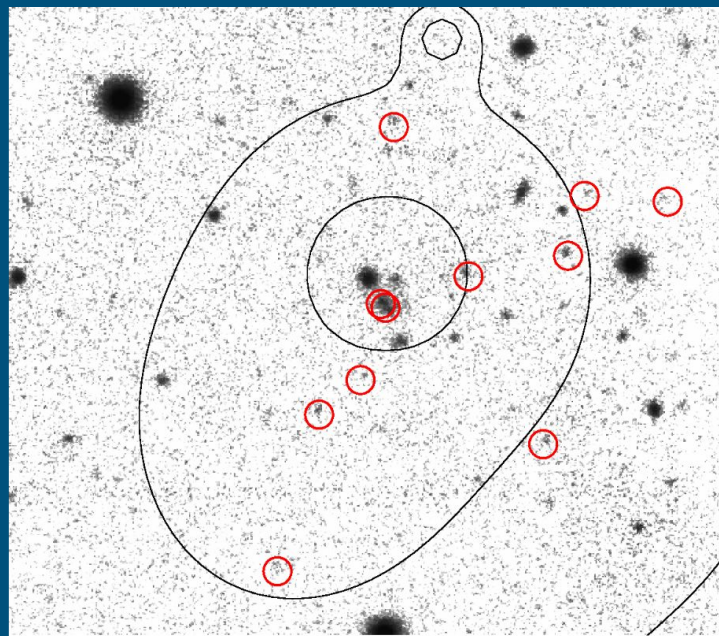
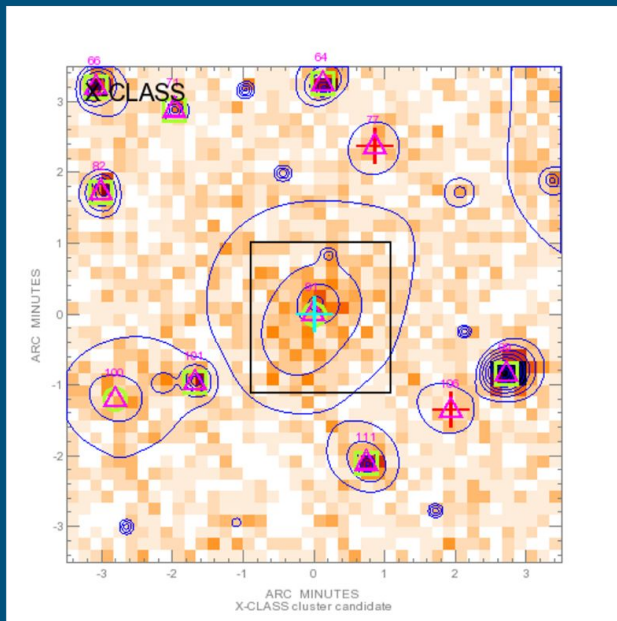


Pipeline source detection - XAmin 3.5

- 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)



Redshift validation



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.

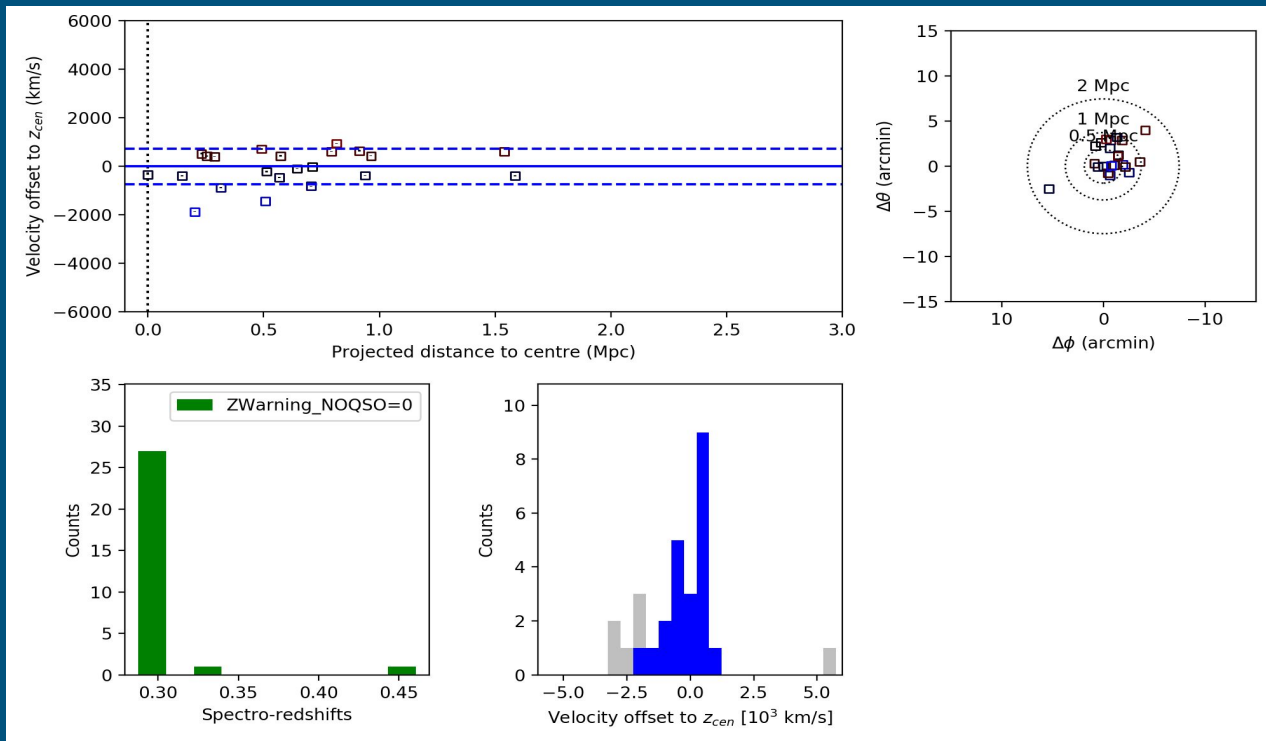
Tentative: if one or two galaxies with concordant spectroscopic redshifts are found within the 500 kpc radius.

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:

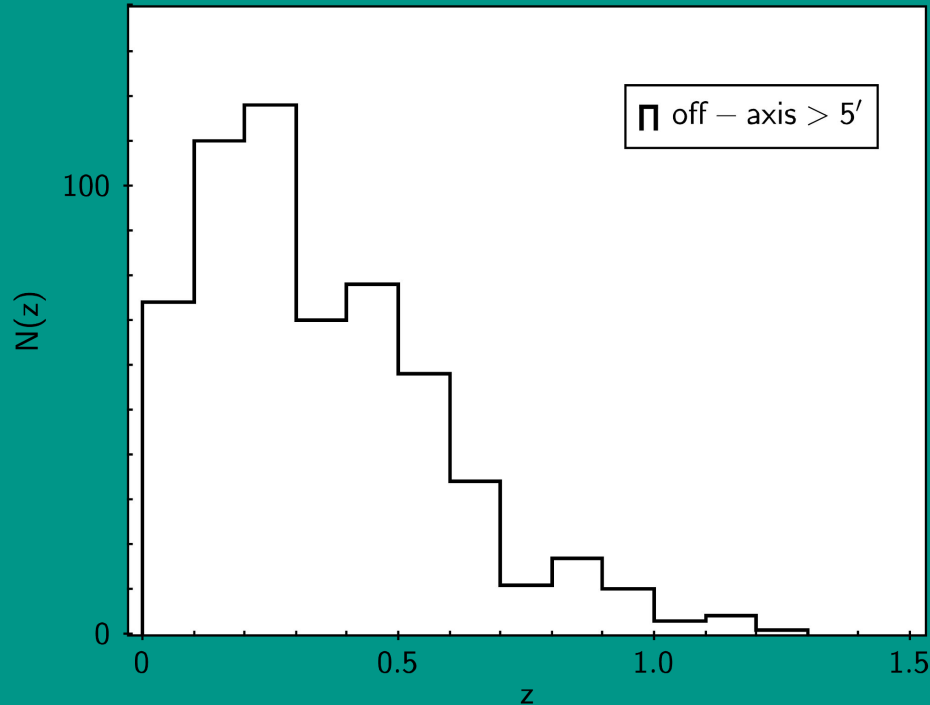
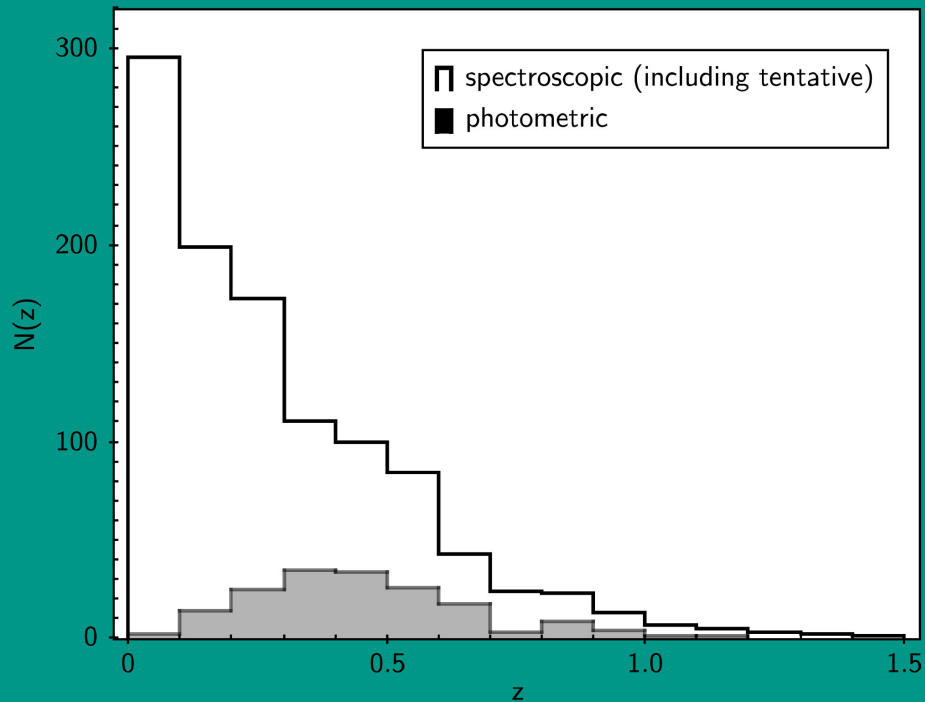
The sample was compiled based on the correlation of X-ray sources from X-CLASS with the RedMapper optical cluster catalogue, as described in (Sadibekova et al. 2014) and (Clerc et al. 2016).

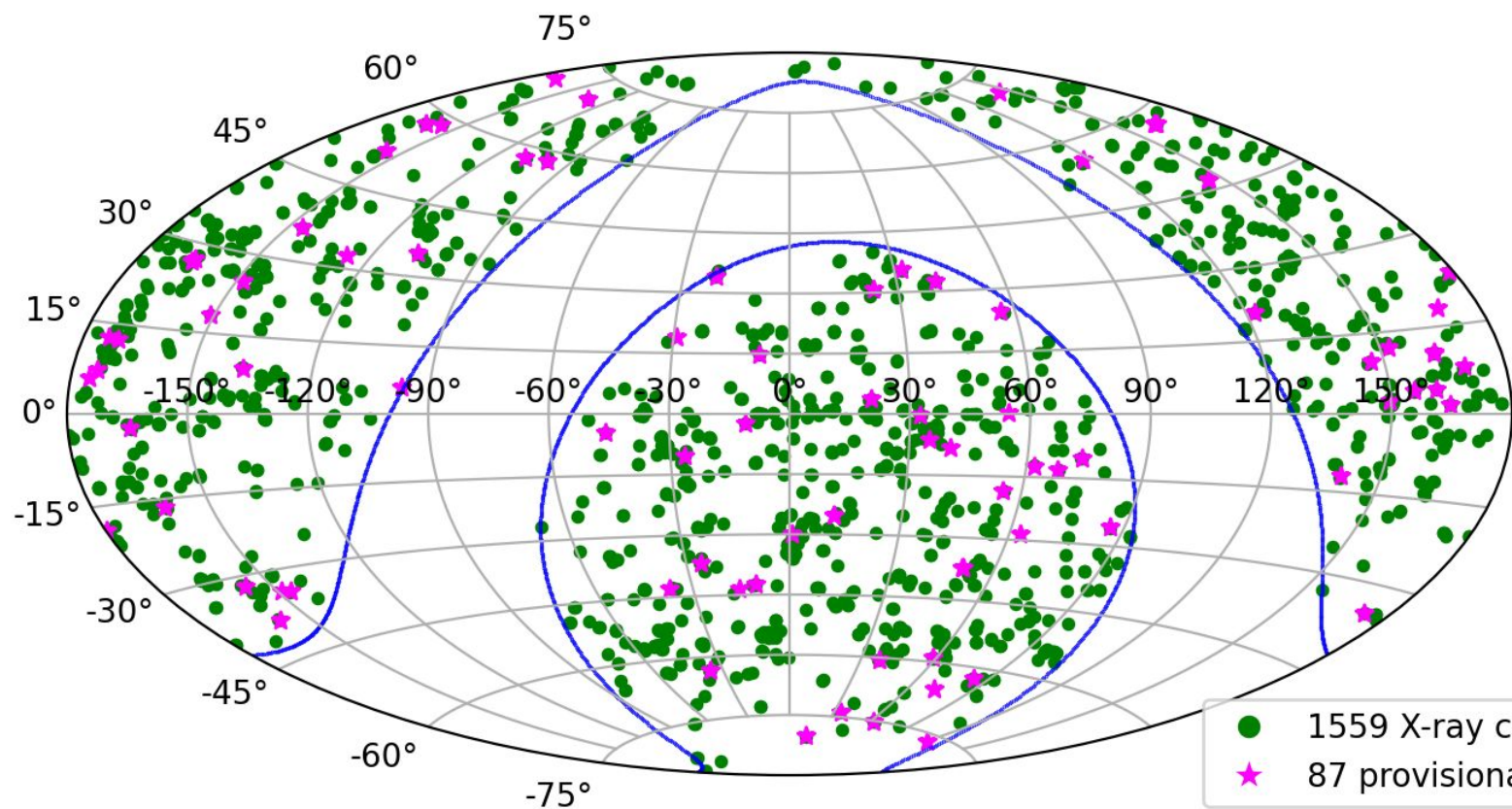


The (BOSS) spectrograph mounted on the SDSS-2.5m telescope at Apache Point Observatory (Gunn et al. 2006) was used. The catalogue contains **124 validated clusters** (out of the 142 targeted) with SPIDERS follow-up spectroscopy up to a redshift of $z \sim 0.6$. The program led to the collection of **1134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

redshift distribution

The redshift distribution peaks at $z \sim 0.1$, while if we remove the pointed observations it peaks at $z \sim 0.3$.





- 1559 X-ray clusters
- ★ 87 provisional sources

Follow-up on-going programs

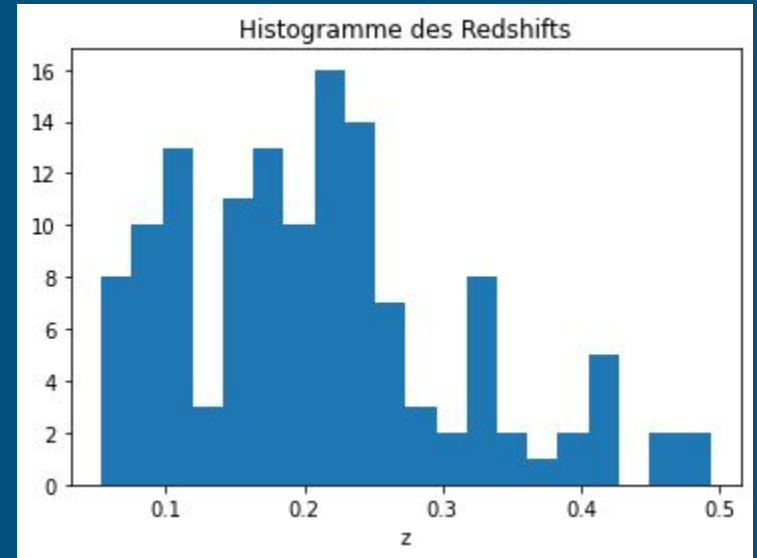
Optical identification with recent surveys (photometry, zphotos, redshifts)

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 ($z_{MED} \sim 0.21$)

Update the database with recent other spectroscopic measurements



Follow-up on-going programs

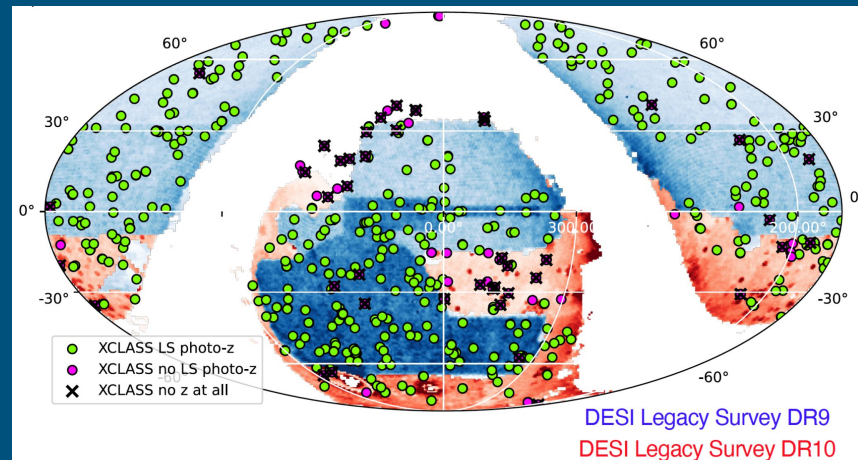
Optical identification with recent surveys (photometry, zphotos, redshifts): DESI Legacy, PanStarrs, SDSS ...

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

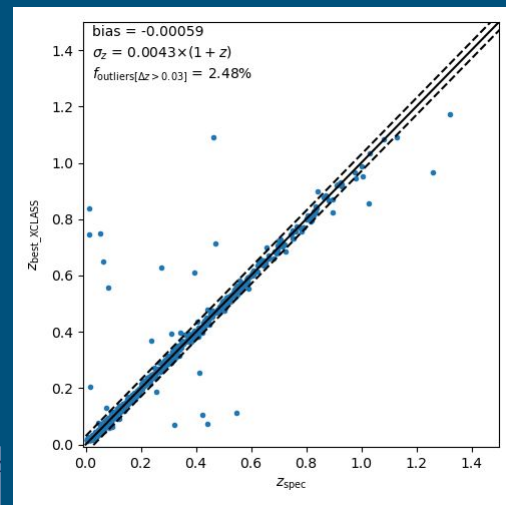
~230 clusters already published with zMED = 0.39

Still 100+ (distant) clusters remain to analyze

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



XCLASS cluster photo-z vs. Spectro-z validation (Sarron et al.)

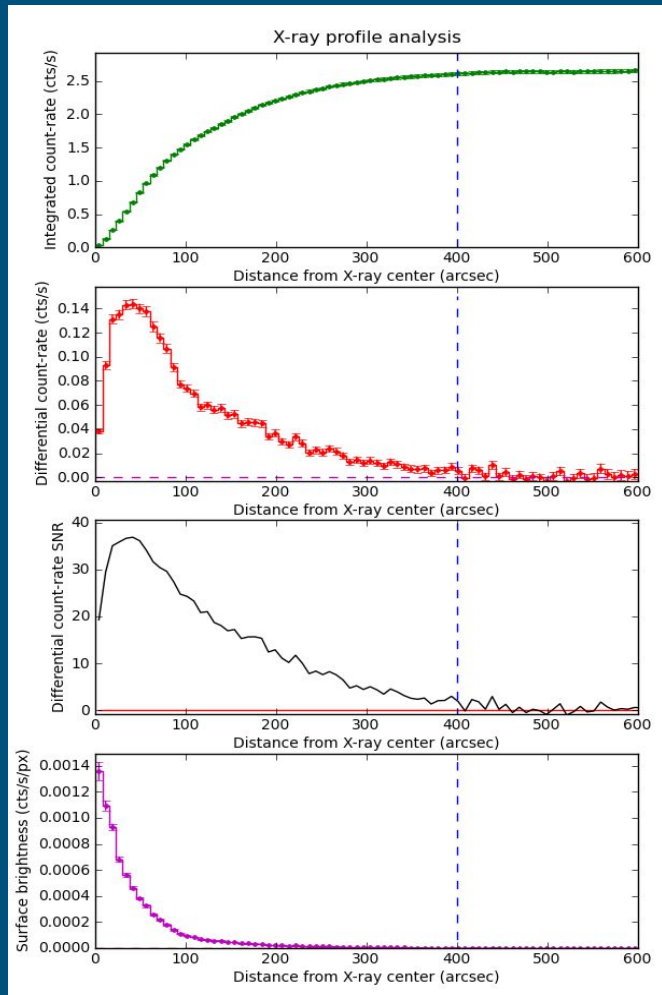


Interactive flux measurements

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

r.a. min r.a. max
dec min dec max

[help](#)

Quality

xclass min xclass max
redshift min redshift max
status min status max

X-ray properties (pipeline outputs)

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

off radius min off radius max
detection ML min detection ML max
extent ml min extent ml max
extent min extent max
counts min counts max
rate min rate max
flux min flux max

Selection

all criteria. [Refresh](#) page.

1559 clusters selected

[Display](#) the selected subset of clusters.

More information is available in the [user's guide](#)



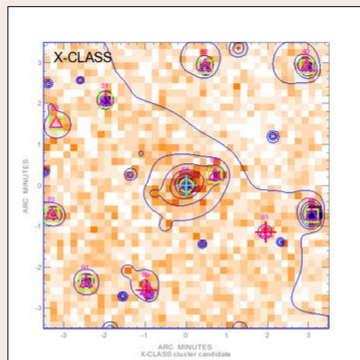
The new X-CLASS cluster catalogue

Subset of clusters

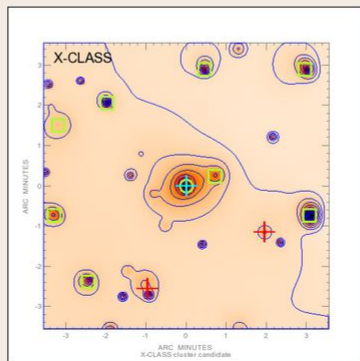
Order by then by

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	go	0001930301_10ks	0.654	confirmed	0.049	data
0023	194.2860	-17.4119	194.2920	-17.4064	go	0010420201_10ks	0.047	confirmed	3.738	data
0033	193.6790	-29.2227	193.6740	-29.2230	go	0030140101_10ks	0.056	confirmed	5.882	data
0034	193.5950	-29.0162	193.5930	-29.0131	go	0030140101_10ks	0.053	confirmed	4.362	data
0035	196.2740	-10.2802	196.2740	-10.2787	go	0032141201_10ks	0.34	photometric	0.047	data
0038	36.5674	-2.6651	36.5677	-2.6663	go	0037981801_10ks	0.056	confirmed	0.167	data
0039	36.4987	-2.8272	36.4990	-2.8275	go	0037981801_10ks	0.281	confirmed	0.033	data
0040	35.1871	-3.4339	35.1886	-3.4339	go	0037982601_10ks	0.327	confirmed	0.050	data
0042	150.1230	-19.6282	150.1220	-19.6292	go	0041180301_10ks		no redshift	0.057	data
0044	202.4460	11.6835	202.4490	11.6848	go	0041180801_10ks	0.204	confirmed	0.087	data
0047	172.9830	-19.9229	172.9800	-19.9271	go	0042341001_10ks	0.307	confirmed	3.254	data
0048	173.0280	-19.8611	173.0280	-19.8614	go	0042341001_10ks	0.307	confirmed	0.154	data
0050	172.8110	-19.9326	172.8130	-19.9343	go	0042341001_10ks	0.46	photometric	0.025	data
0051	177.6130	1.7580	177.6160	1.7580	go	0044740201_10ks		no redshift	0.036	data
0054	145.9370	16.7402	145.9380	16.7381	go	0046940401_10ks	0.180	confirmed	0.136	data
0056	145.8820	16.6656	145.8860	16.6671	go	0046940401_10ks	0.255	confirmed	0.202	data
0057	145.9920	16.6871	145.9950	16.6875	go	0046940401_10ks	0.253	confirmed	0.057	data
0059	31.9565	2.1553	31.9576	2.1567	go	0052140301_20ks	99.90	no redshift	0.042	data
0062	44.1414	0.1037	44.1417	0.1033	go	0056020301_10ks	0.362	confirmed	0.778	data
0065	339.2510	-15.2730	339.2520	-15.2731	go	0056021601_10ks	0.31	photometric	0.316	data
0075	10.4501	-9.4575	10.4507	-9.4569	go	0723802201_20ks	0.056	confirmed	15.529	data
0078	10.7223	-9.5697	10.7225	-9.5701	go	0065140201_10ks	0.41	photometric	0.101	data
0079	10.5228	-9.6026	10.5231	-9.6029	go	0065140201_10ks	0.055	tentative	0.033	data
0082	39.4926	-52.3934	39.4929	-52.3937	go	0067190101_10ks	0.136	confirmed	0.259	data
0083	148.4240	1.6999	148.4240	1.6995	go	0070940401_10ks	0.097	confirmed	0.796	data
0086	348.7650	-58.9351	348.7660	-58.9354	go	0081340301_10ks	0.44	photometric	0.034	data

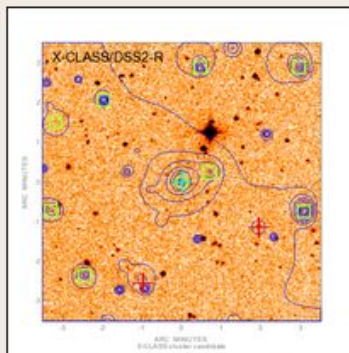
pipeline measurements and products



Raw X-ray image + wavelet contours



Wavelet image + wavelet contours



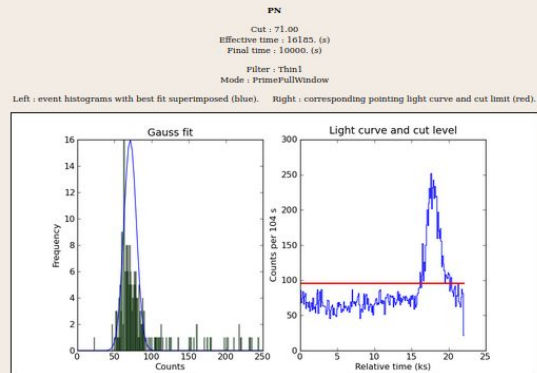
DSS2 band image + wavelet contours

- Green circle : Xumin extended source (C1 or C2)
- Magenta triangle : SExtractor detection
- Red cross : Point-like source having a detection likelihood < 15
- Cyan cross : position of the cluster candidate center
- Green square : Xumin point source

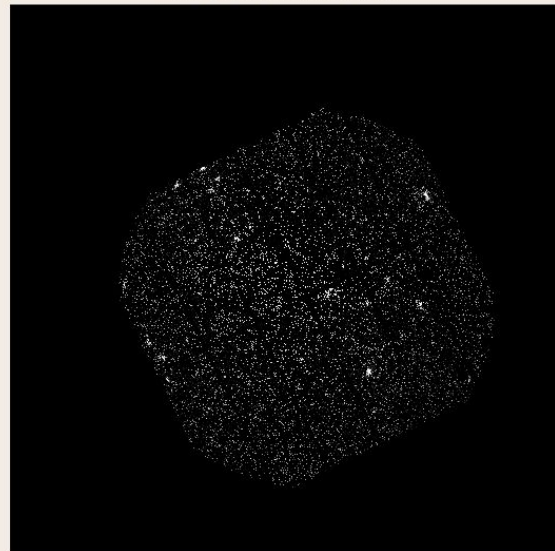
[Zoom optical image \(4'x4'\)](#)

Total (PN + MOS1 + MOS2) Xray Properties -

Off-axis radius:	4.4 arcmin
ML of detection:	360.664
ML of extension:	99.1882
Xumin extension:	13.6669 arcsec
Total counts:	298.931 total (PN + M1 + M2) observed in band B2 (0.5-2 keV) counts
Total rate:	0.049222 total (PN + M1 + M2) observed in band B2 (0.5-2 keV) count rate



Raw image of events in the [0.5-2] keV energy range.



The new X-CLASS cluster catalogue

Subset of clusters

Order by then by

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0033	193.6790	-29.2227	193.6740	-29.2230	go	0030140101_10ks	0.056	confirmed	5.882	data
0034	193.5950	-29.0162	193.5930	-29.0131	go	0030140101_10ks	0.053	confirmed	4.362	data
0035	196.2740	-10.2802	196.2740	-10.2787	go	0032141201_10ks	0.34	photometric	0.047	data
0038	36.5674	-2.6651	36.5677	-2.6663	go	0037981801_10ks	0.056	confirmed	0.167	data
0039	36.4987	-2.8272	36.4990	-2.8275	go	0037981801_10ks	0.281	confirmed	0.033	data
0040	35.1871	-3.4339	35.1886	-3.4339	go	0037982601_10ks	0.327	confirmed	0.050	data
0042	150.1230	-19.6282	150.1220	-19.6292	go	0041180301_10ks		no redshift	0.057	data
0044	202.4460	11.6835	202.4490	11.6848	go	0041180801_10ks	0.204	confirmed	0.087	data
0047	172.9830	-19.9229	172.9800	-19.9271	go	0042341001_10ks	0.307	confirmed	3.254	data
0048	173.0280	-19.8611	173.0280	-19.8614	go	0042341001_10ks	0.307	confirmed	0.154	data
0050	172.8110	-19.9326	172.8130	-19.9343	go	0042341001_10ks	0.46	photometric	0.025	data
0051	177.6130	1.7580	177.6160	1.7580	go	0044740201_10ks		no redshift	0.036	data
0054	145.9370	16.7402	145.9380	16.7381	go	0046940401_10ks	0.180	confirmed	0.136	data
0056	145.8820	16.6656	145.8860	16.6671	go	0046940401_10ks	0.255	confirmed	0.202	data
0057	145.9920	16.6871	145.9950	16.6875	go	0046940401_10ks	0.253	confirmed	0.057	data
0059	31.9565	2.1553	31.9576	2.1567	go	0052140301_20ks	99.90	no redshift	0.042	data
0062	44.1414	0.1037	44.1417	0.1033	go	0056020301_10ks	0.362	confirmed	0.778	data
0065	339.2510	-15.2730	339.2520	-15.2731	go	0056021601_10ks	0.31	photometric	0.316	data
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0079	10.5228	-9.6026	10.5231	-9.6029	go	0065140201_10ks	0.055	tentative	0.033	data
0082	39.4926	-52.3934	39.4929	-52.3937	go	0067190101_10ks	0.136	confirmed	0.259	data
0083	148.4240	1.6999	148.4240	1.6995	go	0070940401_10ks	0.097	confirmed	0.796	data
0086	348.7650	-58.9351	348.7660	-58.9354	go	0081340301_10ks	0.44	photometric	0.034	data

Link to NED and search within 3' radius

xclass 0020



No.	Object Name	RA(deg)	DEC(deg)	Type	Redshift	Redshift Flag	Separation(')
1	WISEA J125345.14+101144.6	193.43795	10.19565	G	0.6544	SPEC	0.01
2	WISEA J125341.52+101010.6	193.42301	10.16980	G	0.2826	SPEC	1.77
3	WISEA J125336.50+101255.8	193.40209	10.21551	G	0.6349	SPEC	2.44

The new X-CLASS cluster catalogue

Subset of clusters

Order by then by

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	go	0001930301_10ks	0.654	confirmed	0.049	data
0023	194.2860	-17.4119	194.2920	-17.4064	go	0010420201_10ks	0.047	confirmed	3.738	data
0033	193.6790	-29.2227	193.6740	-29.2230	go	0030140101_10ks	0.056	confirmed	5.882	data
0034	193.5950	-29.0162	193.5930	-29.0131	go	0030140101_10ks	0.053	confirmed	4.362	data
0035	196.2740	-10.2802	196.2740	-10.2787	go	0032141201_10ks	0.34	photometric	0.047	data
0038	36.5674	-2.6651	36.5677	-2.6663	go	0037981801_10ks	0.056	confirmed	0.167	data
0039	36.4987	-2.8272	36.4990	-2.8275	go	0037981801_10ks	0.281	confirmed	0.033	data
0040	35.1871	-3.4339	35.1886	-3.4339	go	0037982601_10ks	0.327	confirmed	0.050	data
0042	150.1230	-19.6282	150.1220	-19.6292	go	0041180301_10ks		no redshift	0.057	data
0044	202.4460	11.6835	202.4490	11.6848	go	0041180801_10ks	0.204	confirmed	0.087	data
0047	172.9830	-19.9229	172.9800	-19.9271	go	0042341001_10ks	0.307	confirmed	3.254	data
0048	173.0280	-19.8611	173.0280	-19.8614	go	0042341001_10ks	0.307	confirmed	0.154	data
0050	172.8110	-19.9326	172.8130	-19.9343	go	0042341001_10ks	0.46	photometric	0.025	data
0051	177.6130	1.7580	177.6160	1.7580	go	0044740201_10ks		no redshift	0.036	data
0054	145.9370	16.7402	145.9380	16.7381	go	0046940401_10ks	0.180	confirmed	0.136	data
0056	145.8820	16.6656	145.8860	16.6671	go	0046940401_10ks	0.255	confirmed	0.202	data
0057	145.9920	16.6871	145.9950	16.6875	go	0046940401_10ks	0.253	confirmed	0.057	data
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0065	339.2510	-15.2730	339.2520	-15.2731	go	0056021601_10ks	0.31	photometric	0.316	data
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0086	348.7650	-58.9351	348.7660	-58.9354	go	0081340301_10ks	0.44	photometric	0.034	data

Redshift validation

Redshift value : error + -

Velocity dispersion : km/s error + -

Number of galaxies :

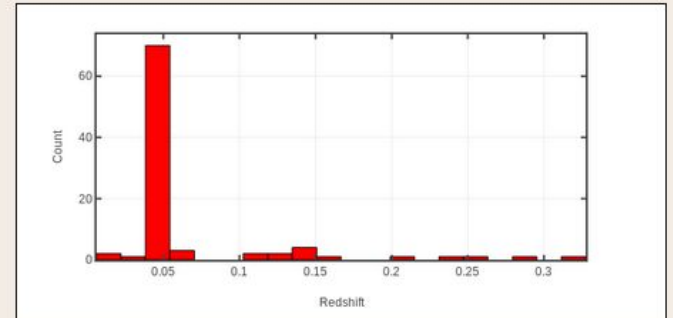
Final status :

Last update : Set by :

Galaxies in the cluster

194.27892	-17.41672	0.041649
194.37625	-17.45736	0.042489
194.34717	-17.27622	0.042876
194.33379	-17.36389	0.043493
194.29487	-17.41739	0.044074
194.2946	-17.46978	0.044214
194.34607	-17.54001	0.044337
194.29167	-17.38156	0.044371
194.24504	-17.49503	0.044587
194.43471	-17.37494	0.045198
194.38458	-17.37022	0.045205
194.3505	-17.41314	0.045415
194.25196	-17.2865	0.045495
194.17117	-17.383	0.045505

Redshift histogramme within the entire mask (or in a 7'x7' field) 11/09/19 00:00



The new X-CLASS cluster catalogue

Subset of clusters

Order by then by

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0040	35.1871	-3.4339	35.1886	-3.4339	go	0037982601_10ks	0.327	confirmed	0.050	data
0042	150.1230	-19.6282	150.1220	-19.6292	go	0041180301_10ks		no redshift	0.057	data
0044	202.4460	11.6835	202.4490	11.6848	go	0041180801_10ks	0.204	confirmed	0.087	data
0047	172.9830	-19.9229	172.9800	-19.9271	go	0042341001_10ks	0.307	confirmed	3.254	data
0048	173.0280	-19.8611	173.0280	-19.8614	go	0042341001_10ks	0.307	confirmed	0.154	data
0050	172.8110	-19.9326	172.8130	-19.9343	go	0042341001_10ks	0.46	photometric	0.025	data
0051	177.6130	1.7580	177.6160	1.7580	go	0044740201_10ks		no redshift	0.036	data
0054	145.9370	16.7402	145.9380	16.7381	go	0046940401_10ks	0.180	confirmed	0.136	data
0056	145.8820	16.6656	145.8860	16.6671	go	0046940401_10ks	0.255	confirmed	0.202	data
0057	145.9920	16.6871	145.9950	16.6875	go	0046940401_10ks	0.253	confirmed	0.057	data
0059	31.9565	2.1553	31.9576	2.1567	go	0052140301_20ks	99.90	no redshift	0.042	data
0062	44.1414	0.1037	44.1417	0.1033	go	0056020301_10ks	0.362	confirmed	0.778	data
0065	339.2510	-15.2730	339.2520	-15.2731	go	0056021601_10ks	0.31	photometric	0.316	data
0075	10.4501	-9.4575	10.4507	-9.4569	go	0723802201_20ks	0.056	confirmed	15.529	data
0078	10.7223	-9.5697	10.7225	-9.5701	go	0065140201_10ks	0.41	photometric	0.101	data
0079	10.5228	-9.6026	10.5231	-9.6029	go	0065140201_10ks	0.055	tentative	0.033	data
0082	39.4926	-52.3934	39.4929	-52.3937	go	0067190101_10ks	0.136	confirmed	0.259	data
0083	148.4240	1.6999	148.4240	1.6995	go	0070940401_10ks	0.097	confirmed	0.796	data
0086	348.7650	-58.9351	348.7660	-58.9354	go	0081340301_10ks	0.44	photometric	0.034	data

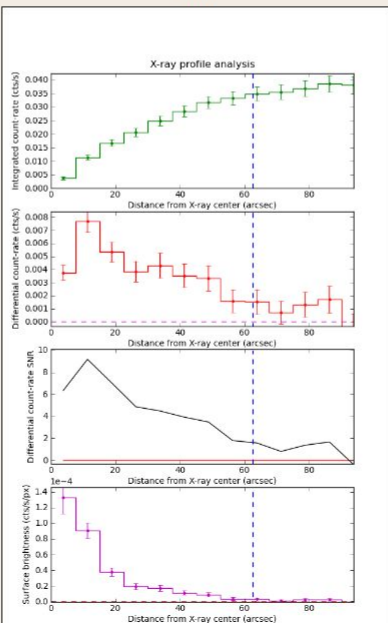
xclass 0020

CR1	b2 [0.5-2] keV	0.0344	error ±	0.0025
CR2	b3 [2-10] keV	-0.0006	error ±	0.0022
CR3	b21 [0.5-0.9] keV	0.0160	error ±	0.0018
CR4	b24 [1.3-2] keV	0.0099	error ±	0.0013
CR5	b31 [2-5] keV	0.0028	error ±	0.0014
CR6	b33 [5-7] keV	0.0002	error ±	0.0010

Unit : c/s

R fit	62.5 arcsec
N_{H}	$1.4 \cdot 10^{20} \text{ cm}^{-2}$

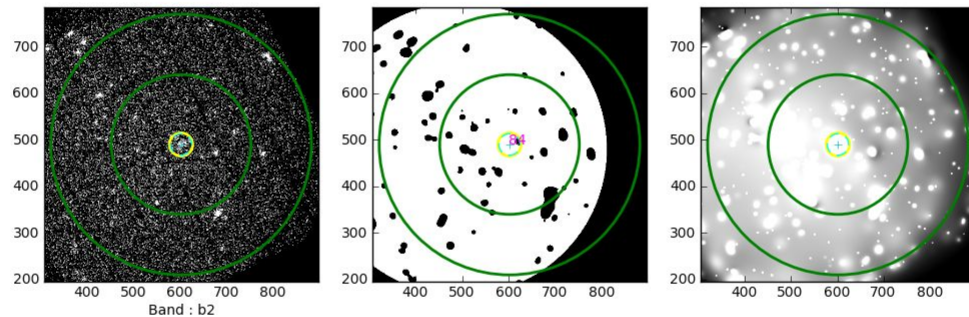
Profile



Interactive flux measurements

Region

FluxMes images :
Pointing 0001930301 - Exposure full - Source 84 - Detector(s) m1m2pn



Left: Photon image **Middle:** Masked sources on the filtered image **Right:** Filtered image

- Dash cyan circle: limit of the automatic integration (not used)
- Yellow circle: limit of the interactive integration
- Green circles: background region

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

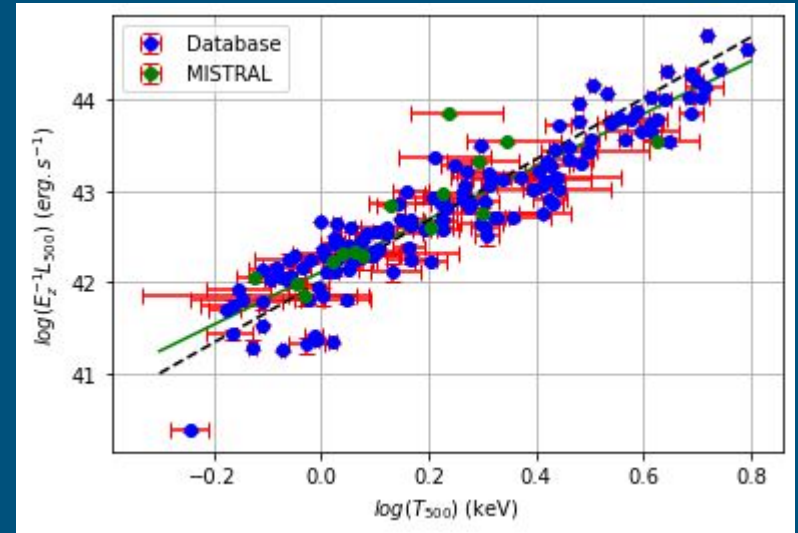
What next ?

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 $M < 5 \times 10^{13} M_{\text{sol}}$

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



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



Thank you!