Reanalysis of the RASS with a source detection algorithm optimised for extended surface brightness distributions

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für
Astronomie

eROSITA

German eROSITA Consortium meeting

Reanalysis of the RASS with a source detection algorithm optimised for extended surface brightness distributions

· **Motivation** · Simulation.
· Simulation.
· Detection.
· Classification

· Observation.
· Candidates.
· Identification

Motivation

- **Tension** between primary CMB and cluster counts (Planck collaboration 2014)
- **Questions**: are cluster samples detected incomplete?
- **This work**: with the RASS data, search for very extended X-ray clusters that might be missed in previous works (e.g. MCXC, Piffaretti+11)
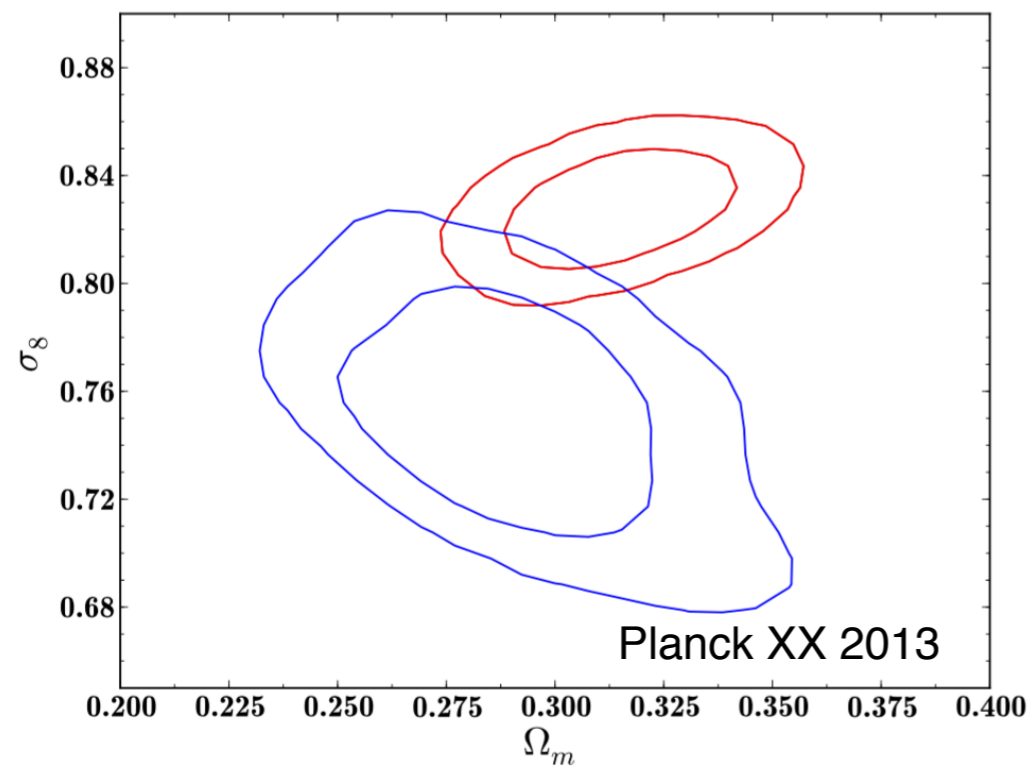

Fig. 11. 2D Ω_m–σ_8 likelihood contours for the analysis with *Planck* CMB only (red); *Planck* SZ + BAO + BBN (blue) with $(1 - b)$ in $[0.7, 1]$.
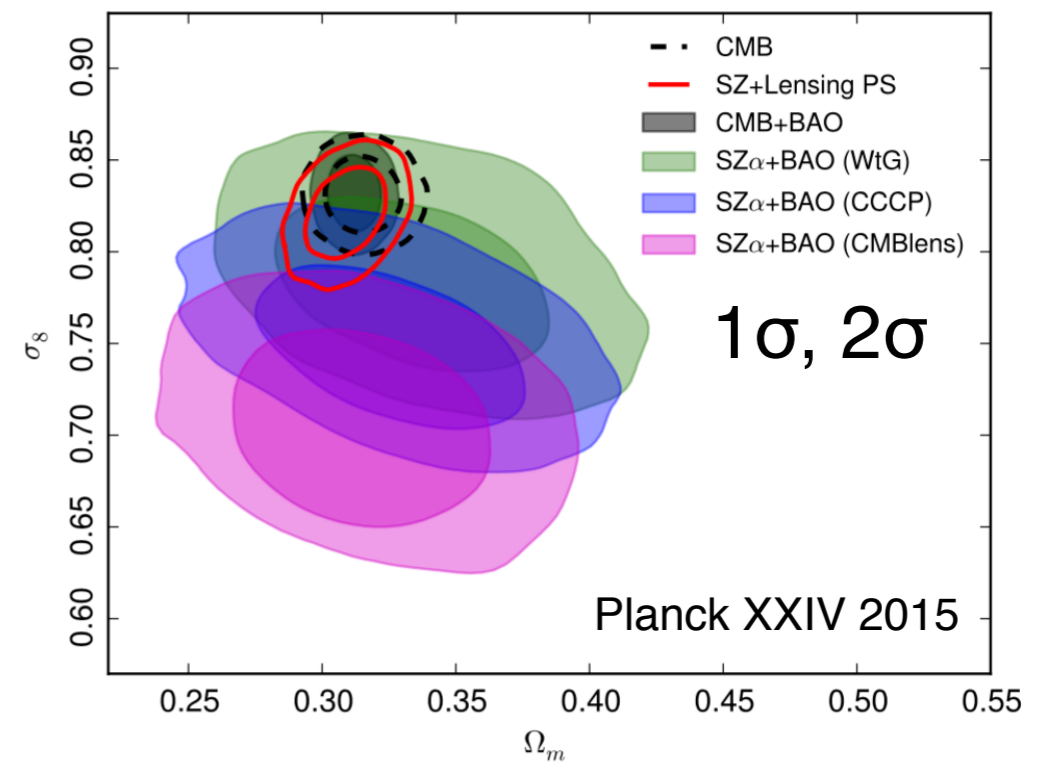
Fig. 7: Comparison of constraints from the CMB to those from the cluster counts in the (Ω_m, σ_8)-plane.

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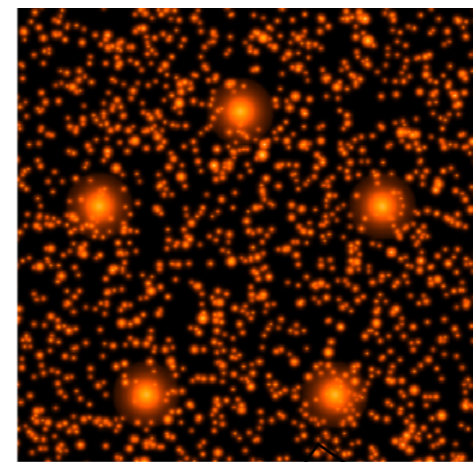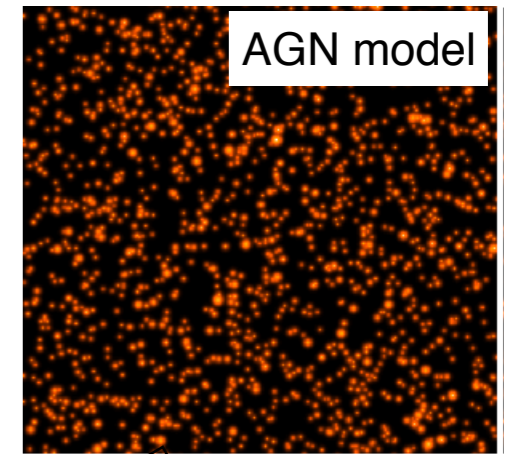 - Identification

Setup for Simulation

1. **AGNs:** brightness distribution from Moretti et al. 2003, and distributed over the simulation.

2. **Clusters:** spherically symmetric β model of the surface brightness of galaxy cluster (Cavaliere & Fusco-Femiano 1976).

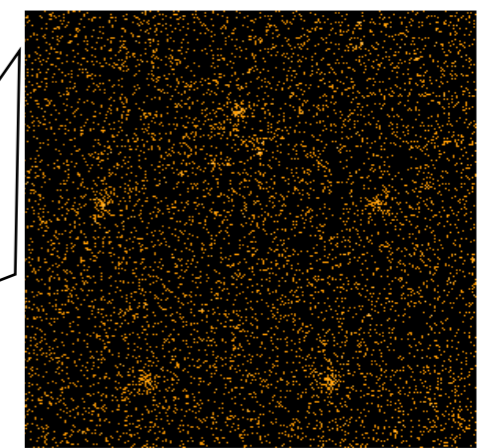$$S_X(r) \propto \left[1 + \left(\frac{r}{r_c} \right)^2 \right]^{-3\beta + 1/2}$$

3. Controlled cluster characteristics:

β	0.4	0.55	0.66	0.7					
r_c (pixel)	2	3	4	5	6	7	8	16	32
flux$_{cluster}$ (10^{-11} erg s^{-1} cm^{-2})	0.1		0.3		0.5		1.0		5.0

AGN model

+cluster model

+bgd+poisson noise +ROSAT response

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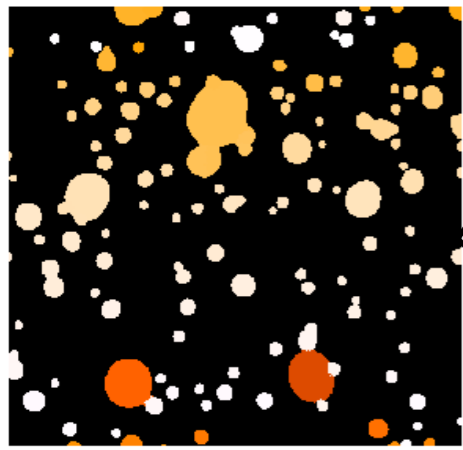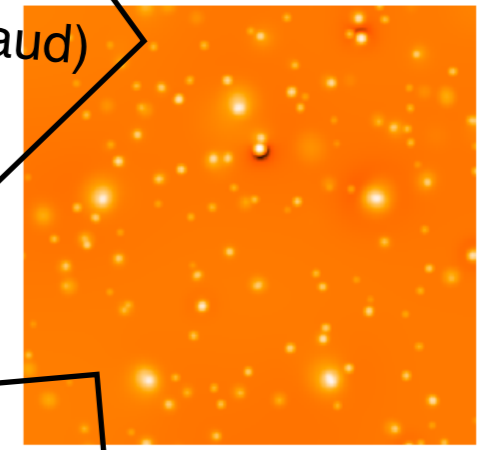
Detection
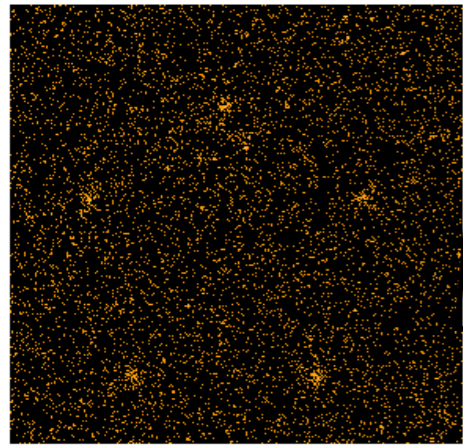
1. **Wavelet:** filter images with a multi-resolution wavelet method to produce reconstructed images (erwavelet, from Florian Pacaud)

2. **Source extractor** (SExtractor, Bertin & Arnouts 1996)

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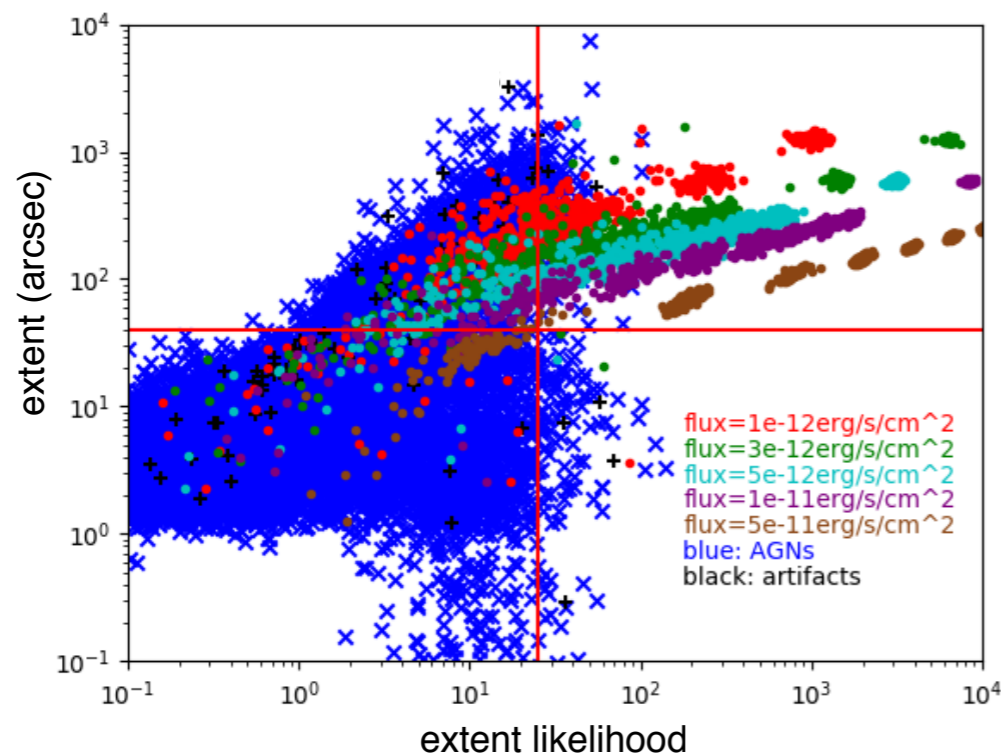 - Identification

Classification

Maximum likelihood fitting (From Mariam E. Ramos-Ceja):

1. point-like and extended source modelling; 2. important parameters: extent likelihood and extent

minimum extent likelihood	minimum extent	purity	completeness	purity +completeness
25	35	0.9650	0.8357	1.8007
25	45	0.9661	0.8355	1.8015
25	*40*	*0.9655*	*0.8355*	*1.8010*
30	40	0.9822	0.8147	1.7968
20	40	0.9400	0.8653	1.8053

balance between sample completeness and purity

extent-likelihood > 25
extent > 40

flux=1e-12erg/s/cm^2
flux=3e-12erg/s/cm^2
flux=5e-12erg/s/cm^2
flux=1e-11erg/s/cm^2
flux=5e-11erg/s/cm^2
blue: AGNs
black: artifacts

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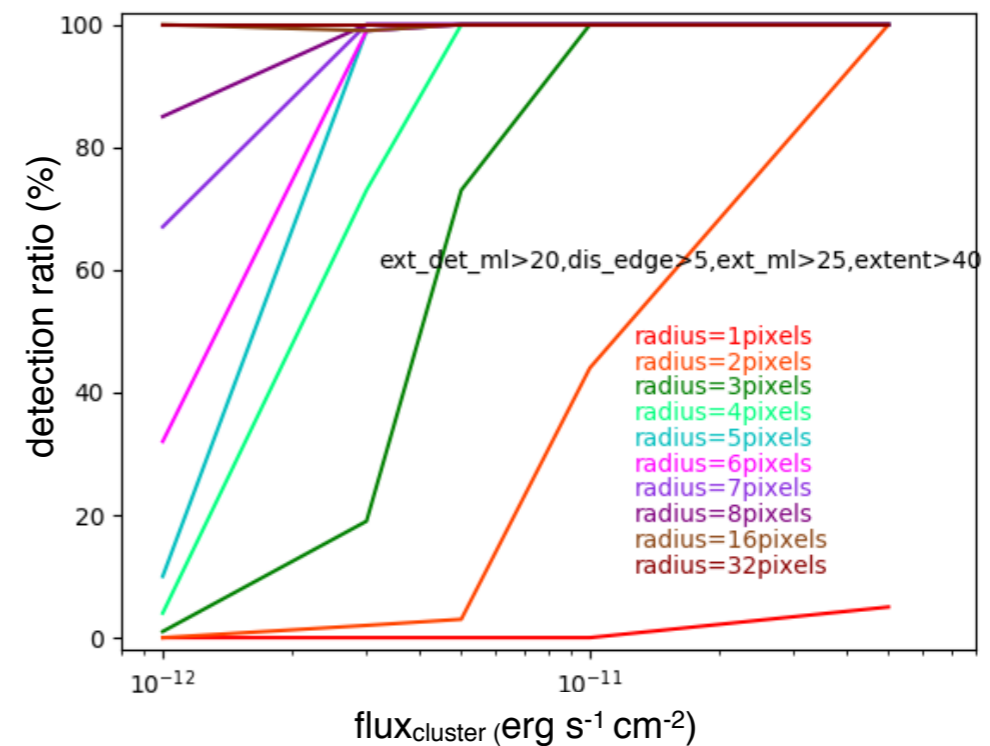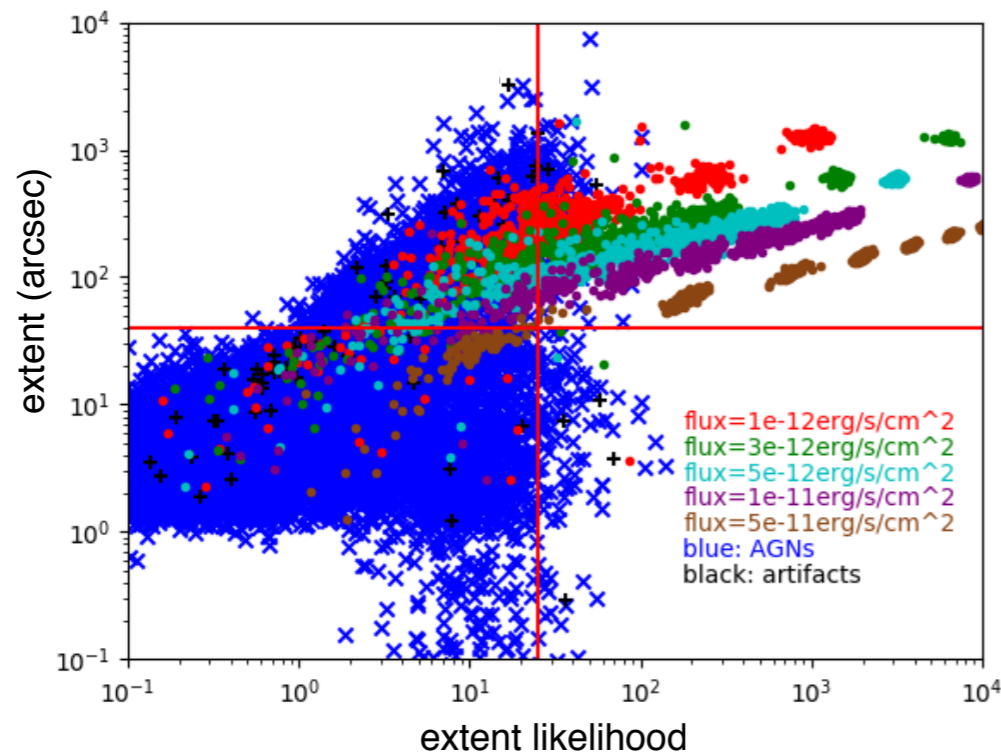 - Identification

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flux=1e-11erg/s/cm^2
flux=5e-11erg/s/cm^2
blue: AGNs
black: artifacts

ext_det_ml>20,dis_edge>5,ext_ml>25,extent>40

radius=1pixels
radius=2pixels
radius=3pixels
radius=4pixels
radius=5pixels
radius=6pixels
radius=7pixels
radius=8pixels
radius=16pixels
radius=32pixels

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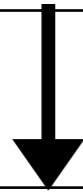 - **Candidates**.
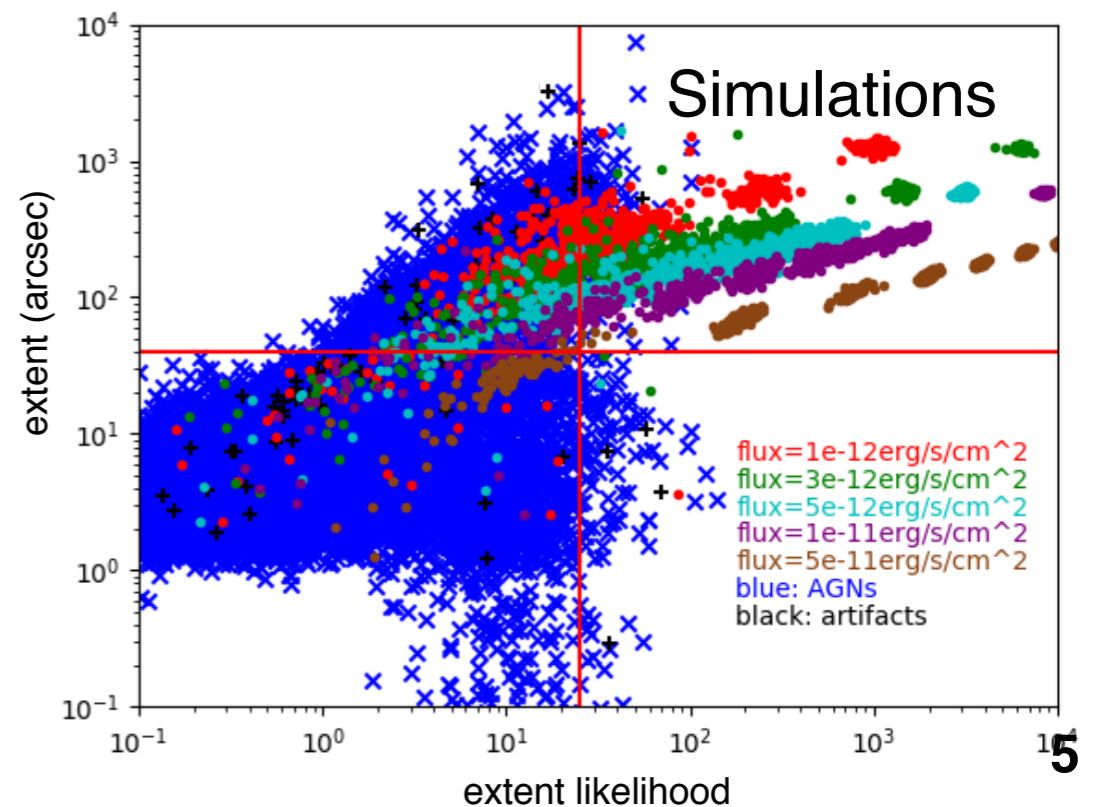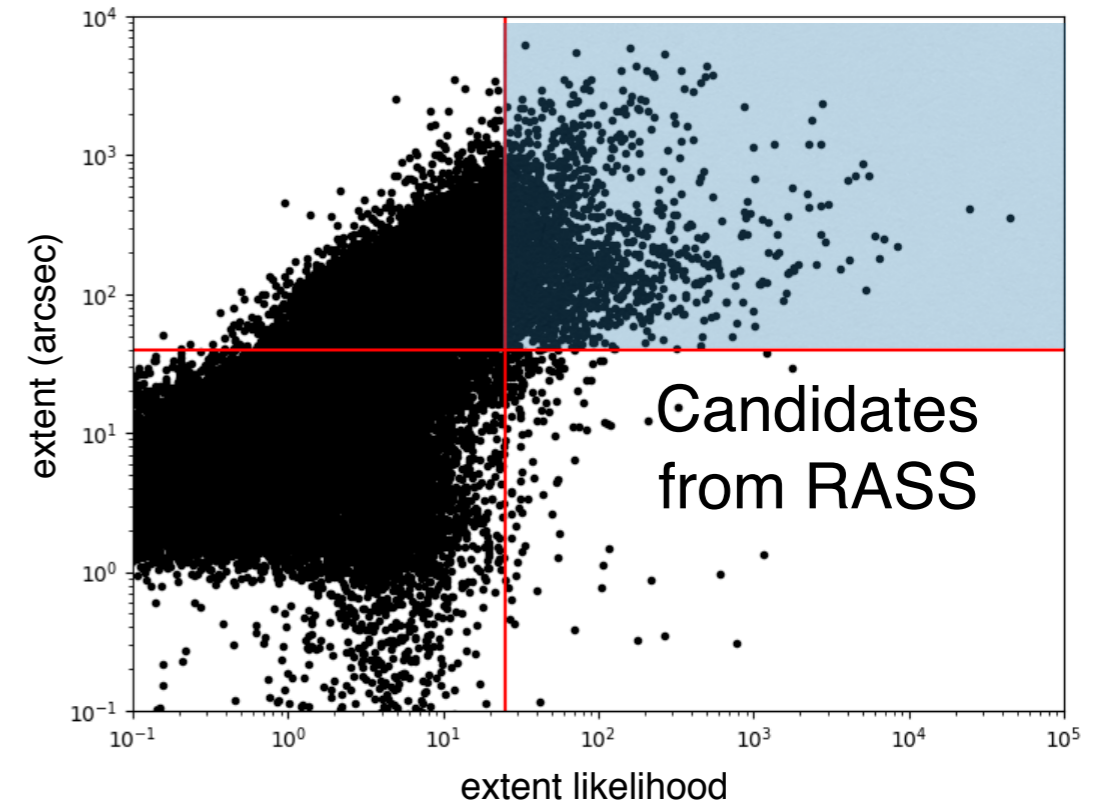 - Identification

Candidates

all-sky detection
(out of the galactic plane, LMC, SMC, Virgo regions):
1084 detections

remove repeated detections:
1059 detections

difference of exposure time < 20%,
and exposure time > 100 s:
999 candidates

Candidates from RASS

Simulations

flux=1e-12erg/s/cm^2
flux=3e-12erg/s/cm^2
flux=5e-12erg/s/cm^2
flux=1e-11erg/s/cm^2
flux=5e-11erg/s/cm^2
blue: AGNs
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Reanalysis of the RASS with a source detection algorithm
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- Motivation
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  - Simulation.
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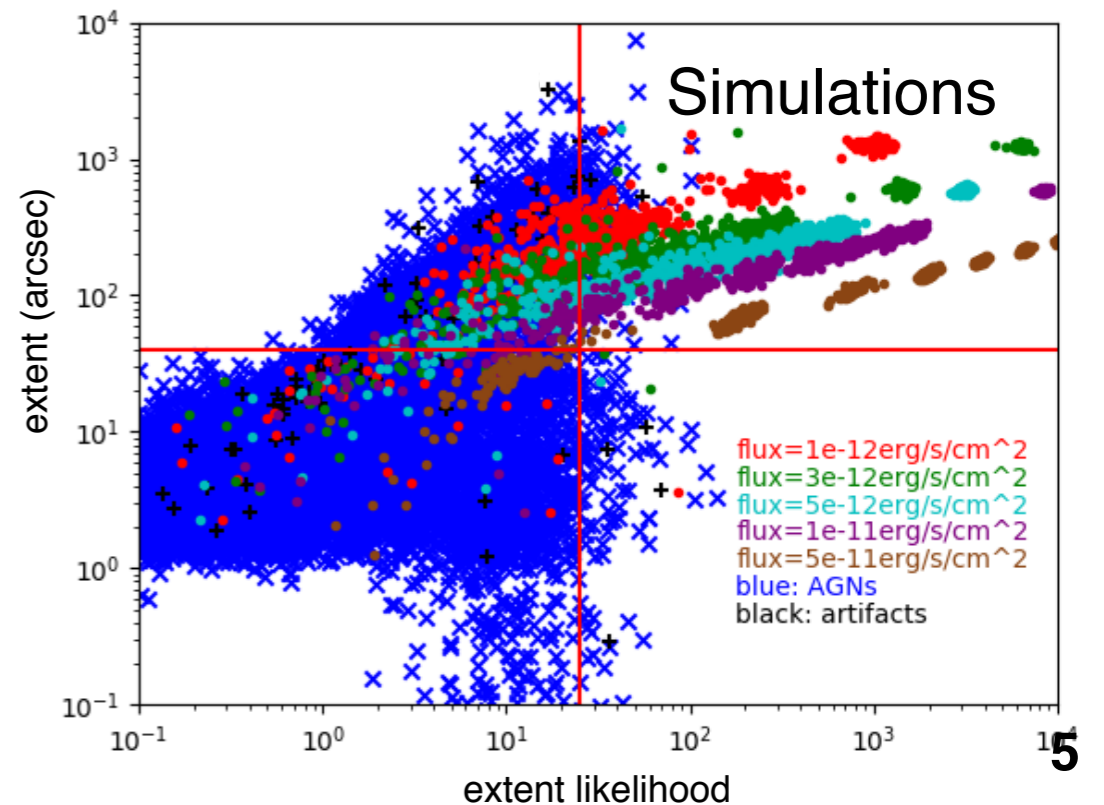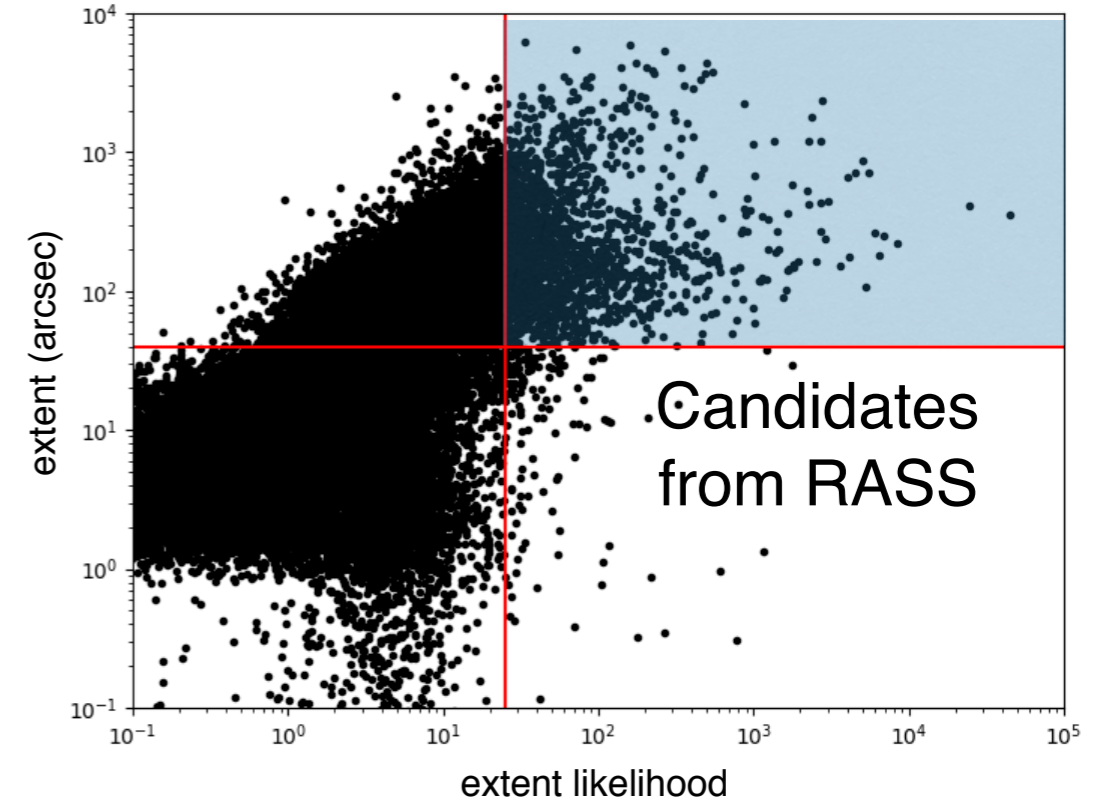 - **Candidates**.
  - Identification

Candidates

all-sky detection
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1084 detections
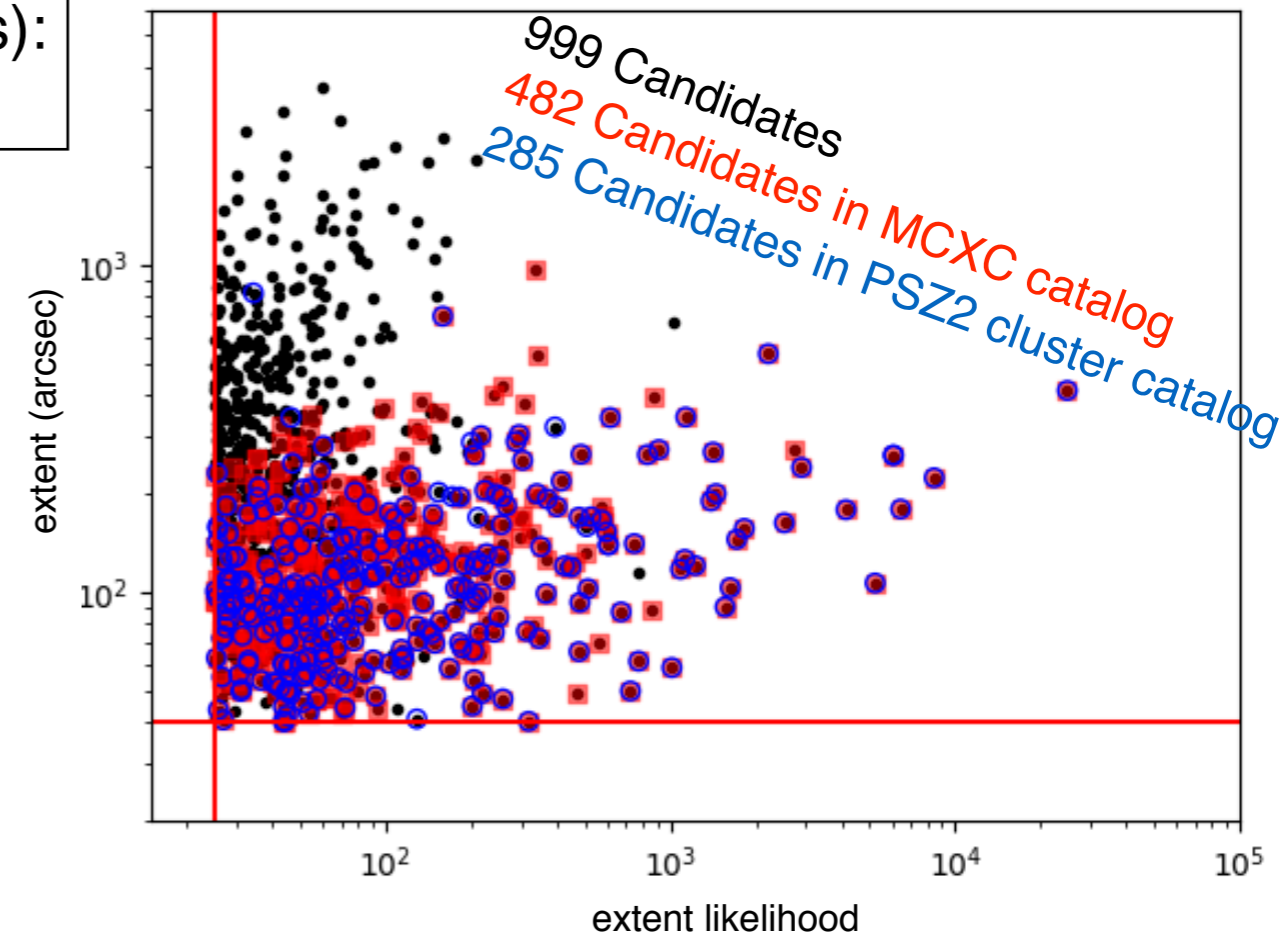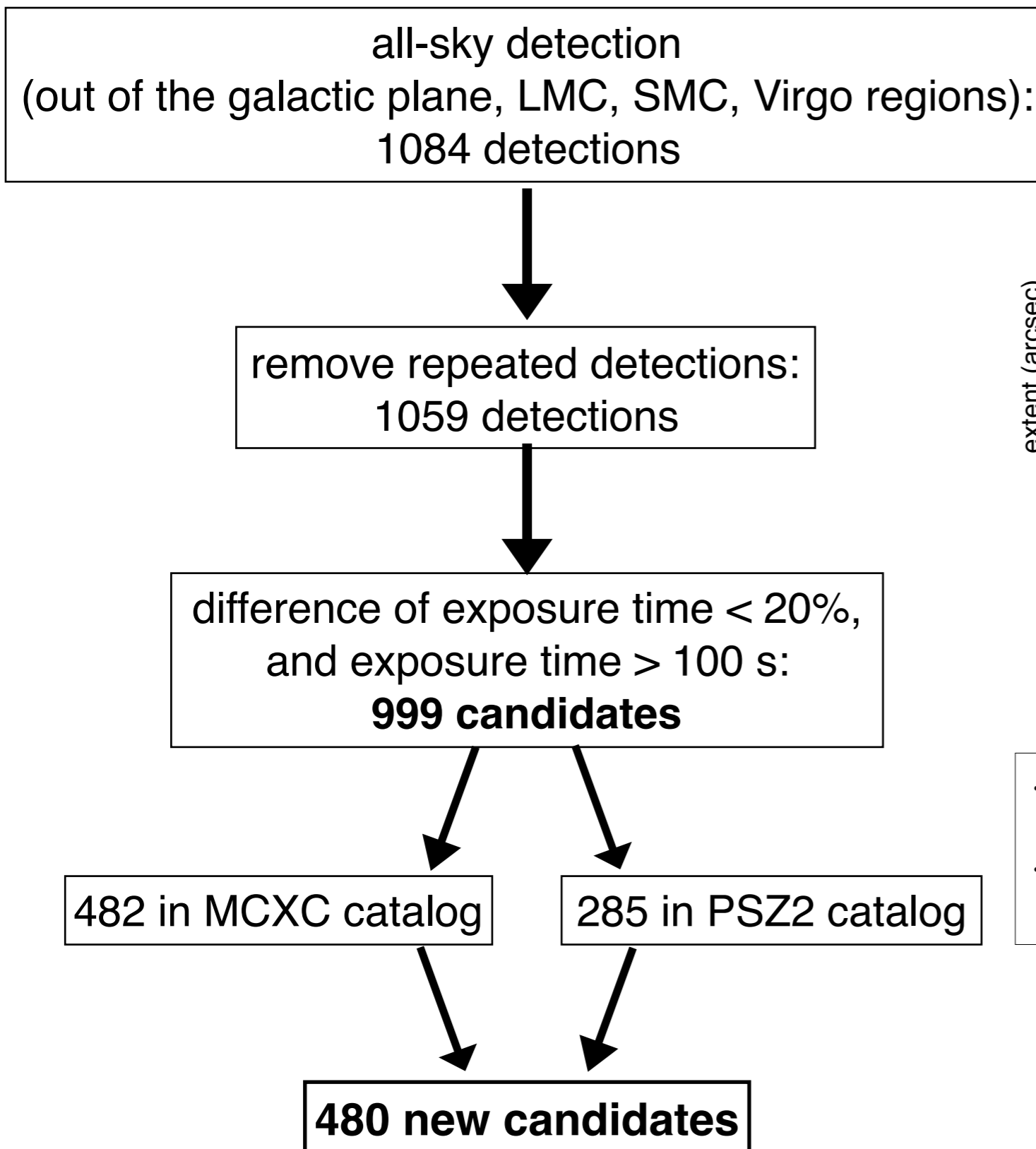
remove repeated detections:
1059 detections

difference of exposure time < 20%,
and exposure time > 100 s:
999 candidates

Q: how to evaluate candidates?

Candidates
from RASS

Simulations

flux=1e-12erg/s/cm^2
flux=3e-12erg/s/cm^2
flux=5e-12erg/s/cm^2
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Reanalysis of the RASS with a source detection algorithm
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· Motivation   · Simulation.   · Observation.
              · Simulation.   · **Candidates**.
              · Detection.   · Identification
              · Classification

Candidates

all-sky detection
(out of the galactic plane, LMC, SMC, Virgo regions):
1084 detections

remove repeated detections:
1059 detections

difference of exposure time < 20%,
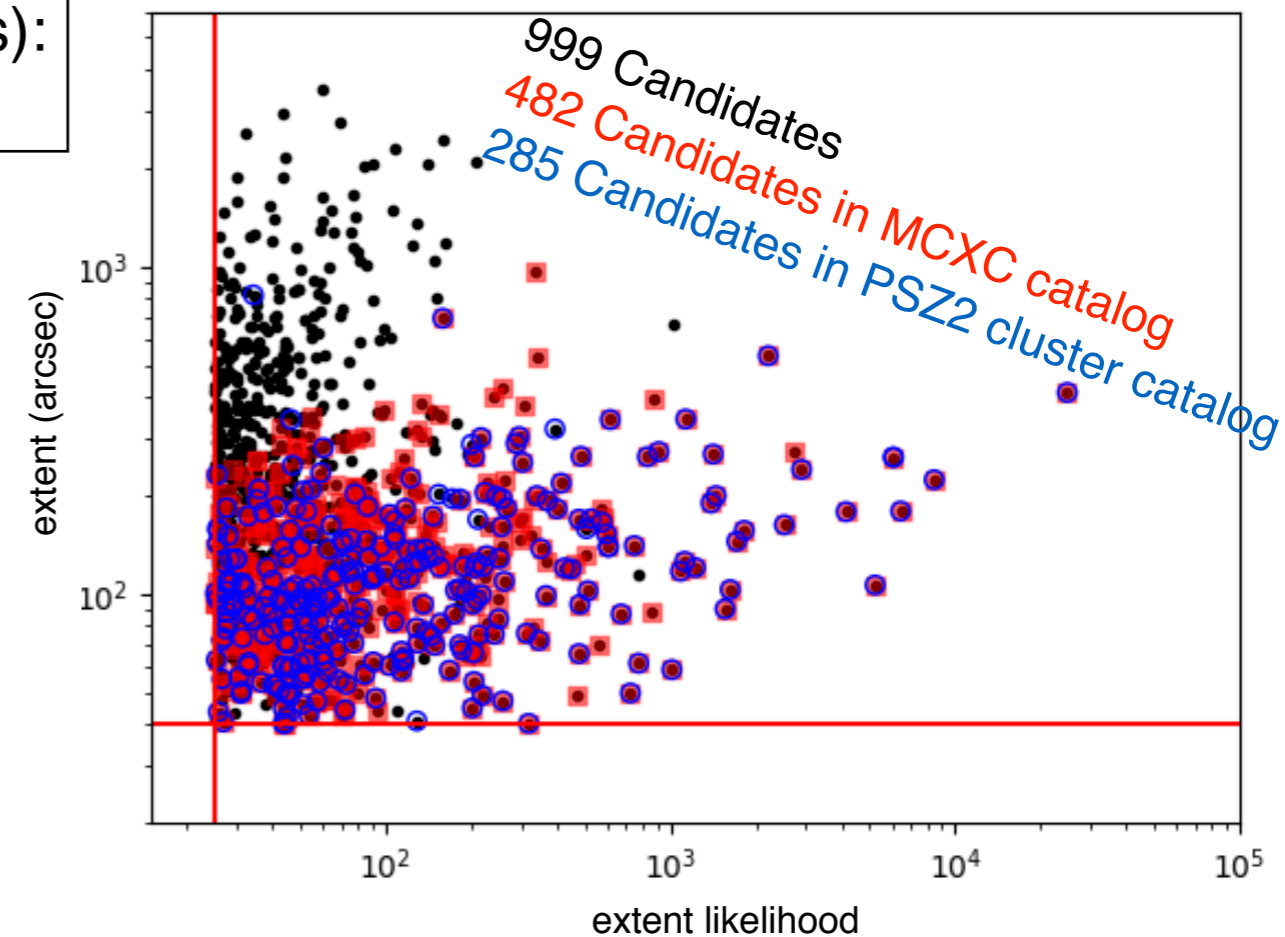and exposure time > 100 s:
999 candidates

482 in MCXC catalog

285 in PSZ2 catalog

480 new candidates

999 Candidates
482 Candidates in MCXC catalog
285 Candidates in PSZ2 cluster catalog

extent (arcsec)

extent likelihood

· MCXC catalog: a Meta-Catalogue of X-ray detected Clusters of
  galaxies, includes 1743 clusters (Piffaretti et al. 2011)
· PSZ2 catalog: the second Planck catalogue of Sunyaev-Zeldovich
  sources, includes 1653 clusters (Planck Collaboration et al. 2016)

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Candidates

all-sky detection
(out of the galactic plane, LMC, SMC, Virgo regions):
1084 detections

⬇

remove repeated detections:
1059 detections

⬇

difference of exposure time < 20%,
and exposure time > 100 s:
999 candidates

482 in MCXC catalog   285 in PSZ2 catalog
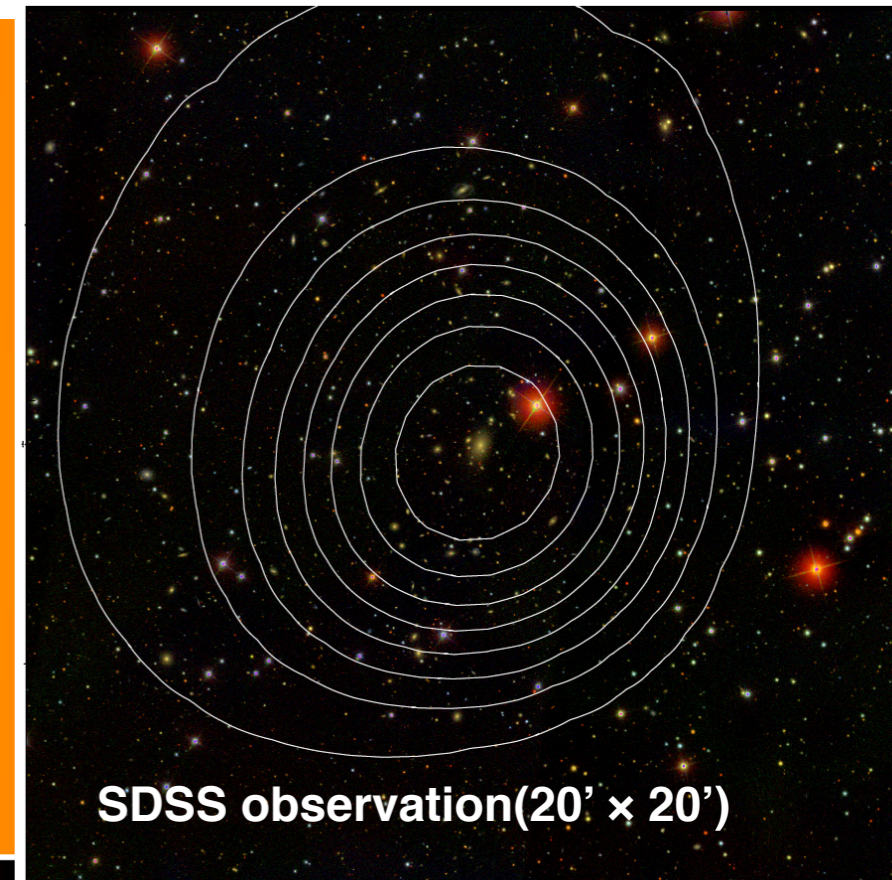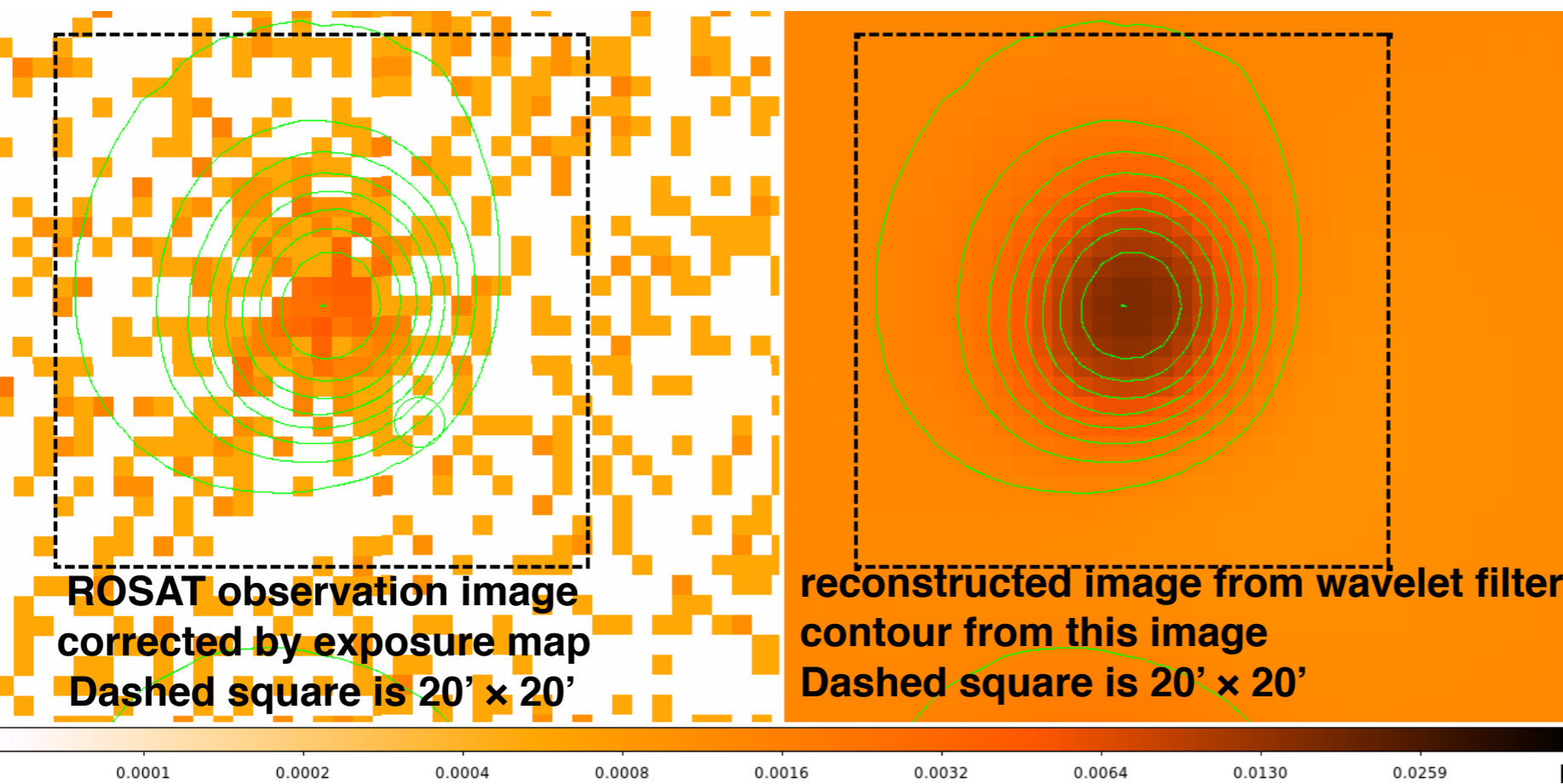
480 new candidates

Q1: are they real galaxy clusters?

Q2: if real, why are they not detected before?   5

999 Candidates
482 Candidates in MCXC catalog
285 Candidates in PSZ2 cluster catalog

extent (arcsec) vs extent likelihood

· MCXC catalog: a Meta-Catalogue of X-ray detected Clusters of galaxies, includes 1743 clusters (Piffaretti et al. 2011)
· PSZ2 catalog: the second Planck catalogue of Sunyaev-Zeldovich sources, includes 1653 clusters (Planck Collaboration et al. 2016)

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New Candidates: Examples

Q1: are they real galaxy clusters?

ROSAT observation image corrected by exposure map
Dashed square is 20' × 20'

reconstructed image from wavelet filter
contour from this image
Dashed square is 20' × 20'

SDSS observation(20' × 20')

Example 1:
count rate = 0.16 counts/s, flux = 1.8×10^{-12} erg s^{-1} cm^{-2}, extent = 55.67, extent likelihood = 71.23

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New Candidates: Examples

Q1: are they real g

ROSAT observation in
corrected by exposure
Dashed square is 20'

0.0001   0.0002   0.0004

Example 1:
count rate = 0.

ion(20' × 20')

d = 71.23

Reanalysis of the RASS with a source detection algorithm optimised for extended surface brightness distributions

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New Candidates: Examples

Q1: are they real galaxy clusters?

ROAST observation image corrected by exposure map
Dashed square is 20' × 20'

reconstructed image from wavelet filter contour from this image
Dashed square is 20' × 20'

SDSS observation(20' × 20')

| 0.000023 | 0.000032 | 0.000050 | 0.000084 | 0.000154 | 0.000293 | 0.000569 | 0.001125 | 0.002226 |

Example 2:
count rate = 0.26 counts/s, flux = 2.9×10^{-12} erg s^{-1} cm^{-2}, extent = 91.75, extent likelihood = 60.31

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New Candidates: Examples

Q1: are they re...

**ROSAT observation...
corrected by expos...
Dashed square is 2...**

0.000023   0.000032

Example 2:
count rate =

...vation(20' × 20')

...ood = 60.31

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Preliminary flux distribution of new candidates

Q2: if real, why are they not detected before?

flux limit of REFLEX
3×10^{-12} erg s^{-1} cm^{-2} in 0.1-2.4keV

55 candidates
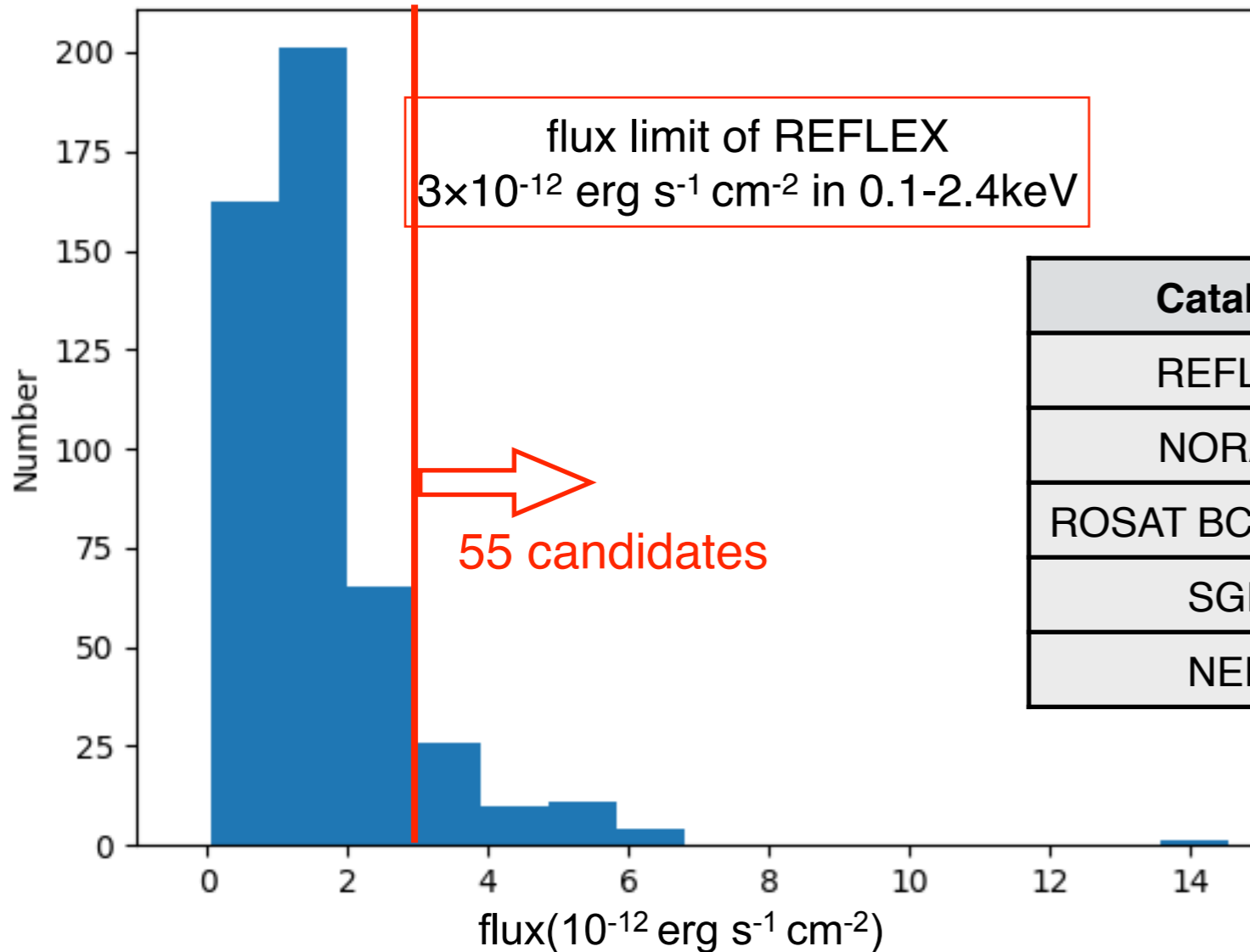
Catalog	Flux limit(erg s^{-1} cm^{-2})	Energy band(keV)
REFLEX	3×10^{-12}	0.1–2.4
NORAS	0.06 cts/s	0.1–2.4
ROSAT BCS+eBCS	2.8×10^{-12}	0.1–2.4
SGP	1.5×10^{-12}	0.1–2.4
NEP	2×10^{-14}	0.5–2.0

Summary

1. We use an optimised source detection and classification algorithm to search for very extended galaxy clusters within the RASS data.

2. The algorithm include wavelet filtering, source extraction, maximum likelihood fitting and visual inspection in optical wavelengths.

3. We expect that this work will increase the number of X-ray galaxy clusters and provide a better understanding on the possible incompleteness of X-ray selected cluster samples.
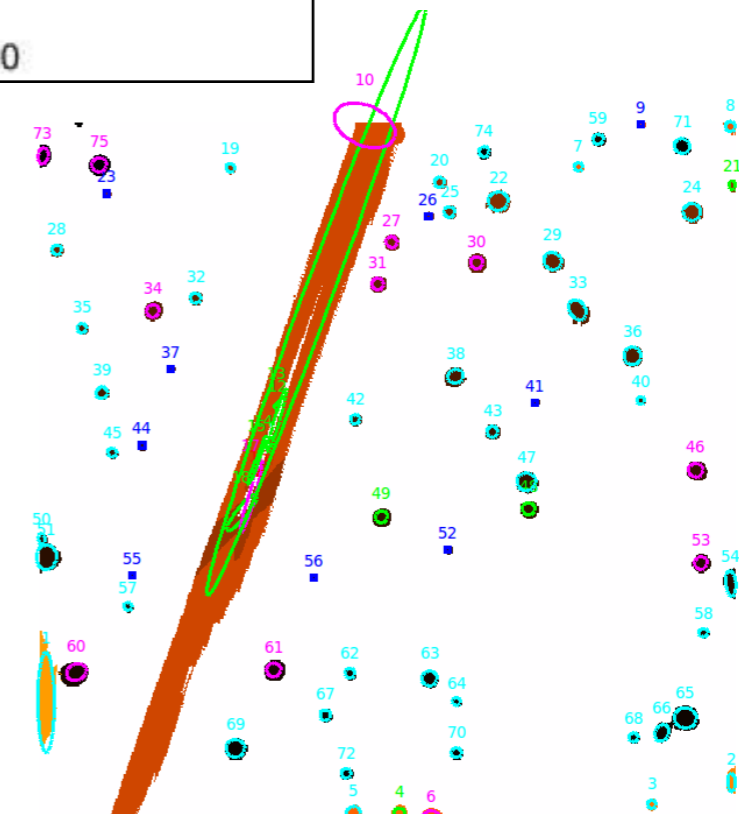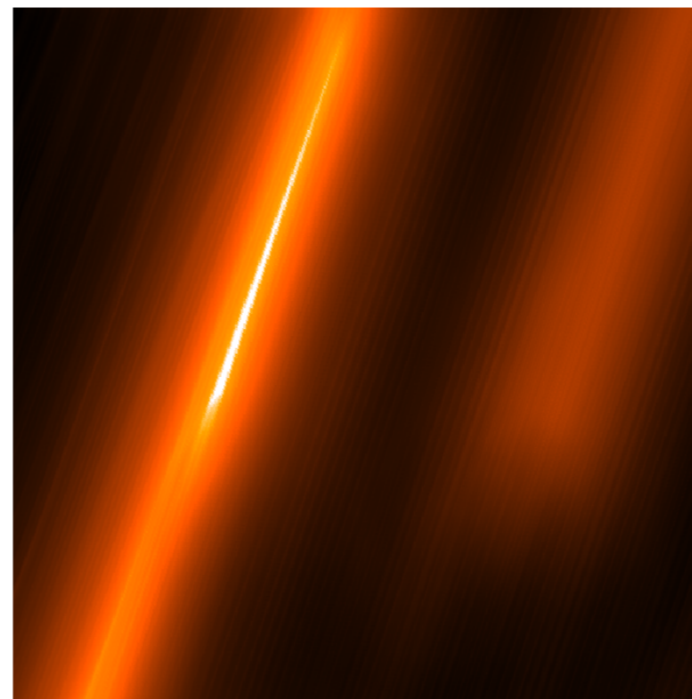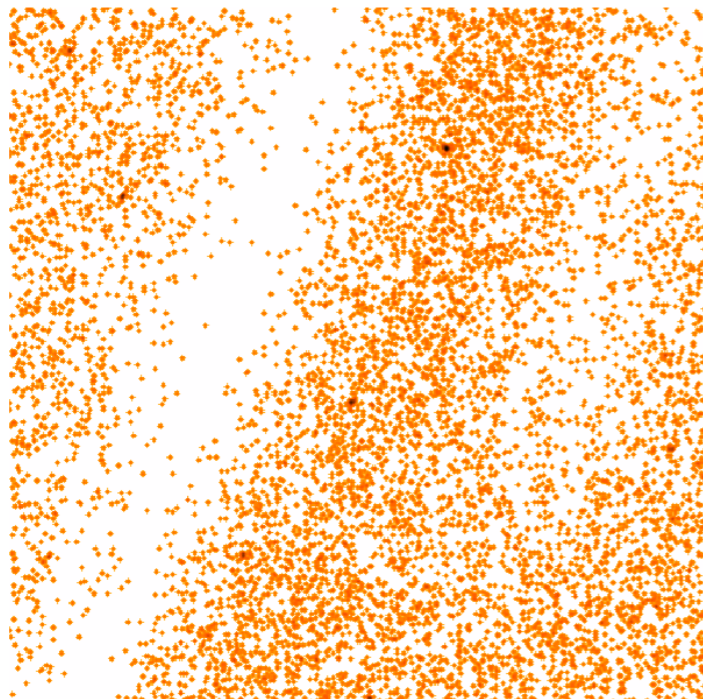
Thank you for your attention!

Questions or comments are welcome!

Backup slides
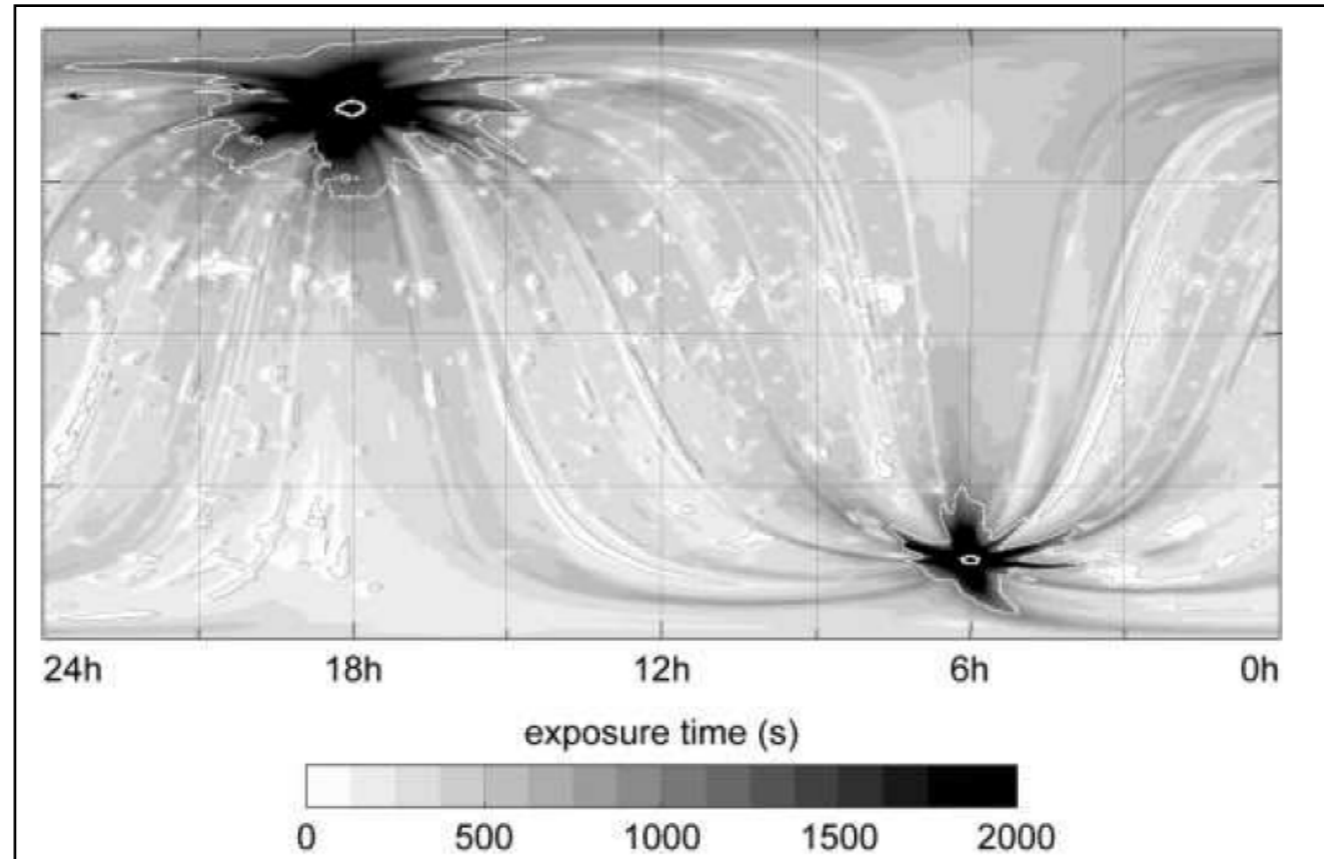
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Exposure time problem

one tile: 6.4deg × 6.4deg

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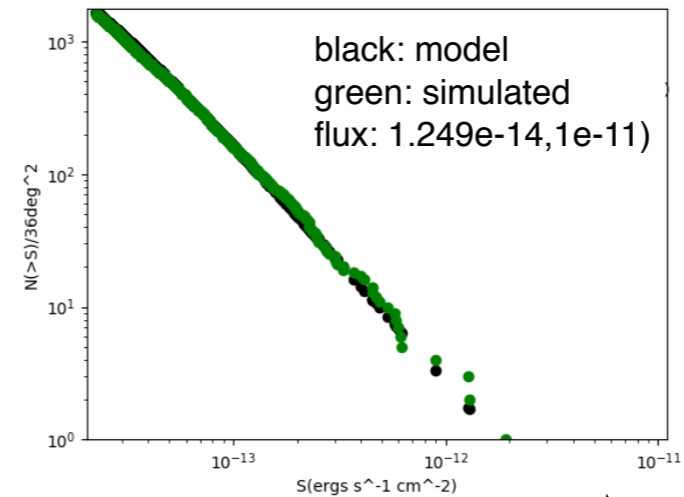
Setup for Simulation

1. **AGNs:** brightness distribution from Moretti et al. 2003, and distributed over the simulation.

$$N(> S) = N_{S(H)} \left[\frac{(2 \times 10^{-15})^{\alpha_{1,s(H)}}}{S^{\alpha_{1,S(H)}} + S_{0,S}^{\alpha_{1,S(H)} - \alpha_{2,S(H)}} S^{\alpha_{2,S(H)}}} \right] \text{cgs}$$
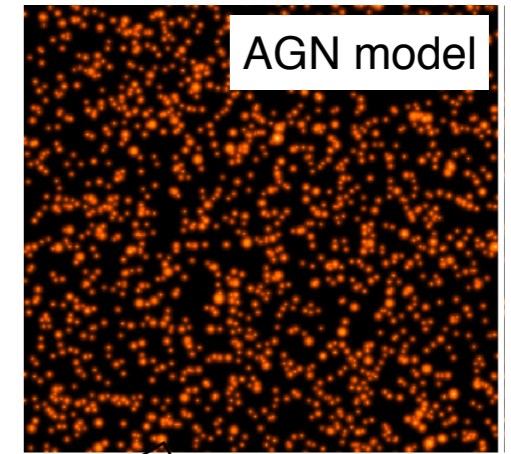
2. **Clusters:** spherically symmetric β model of the surface brightness of galaxy cluster (Cavaliere & Fusco-Femiano 1976).

$$S_X(r) \propto \left[1 + \left(\frac{r}{r_c} \right)^2 \right]^{-3\beta + 1/2}$$

3. Other instrumental and background parameters:
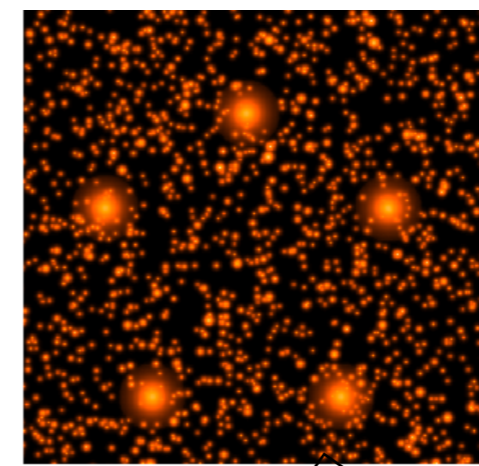   - Exposure time: 450 s
   - N_H: 5.945×10^{20} cm^{-2}
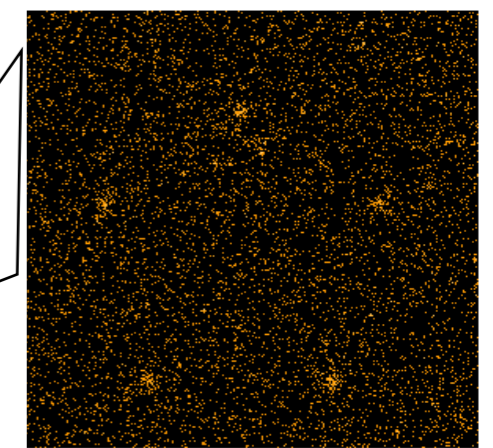   - Background: 0.08 photon counts/pixel
   - Poisson noise

4. Controlled cluster characteristics:

β	0.4	0.55	0.66	0.7					
r_c (pixel)	2	3	4	5	6	7	8	16	32
flux$_{cluster}$ (10^{-11} erg s^{-1} cm^{-2})	0.1		0.3		0.5		1.0		5.0

black: model
green: simulated
flux: 1.249e-14,1e-11)

N(>S)/36deg^2
S(ergs s^-1 cm^-2)

AGN model

+cluster model

+bgd+poisson noise
+ROSAT response

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One simulation example
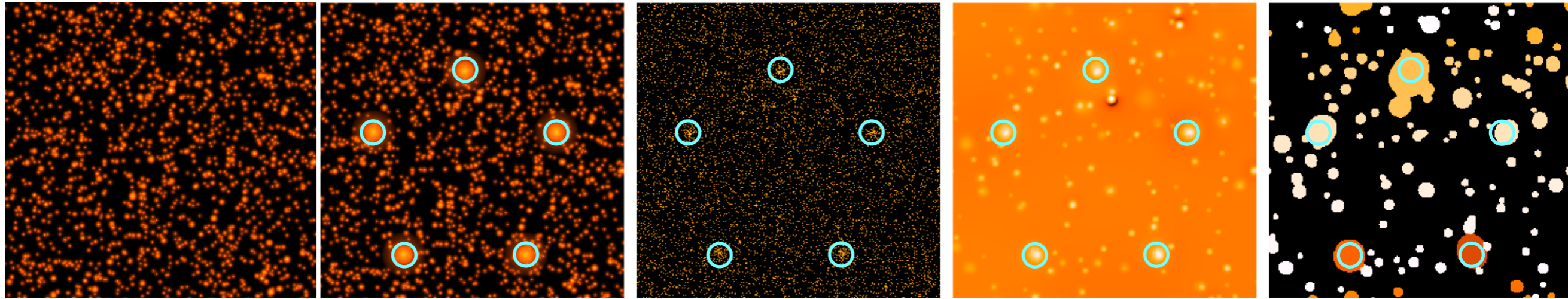
AGNs

AGNs
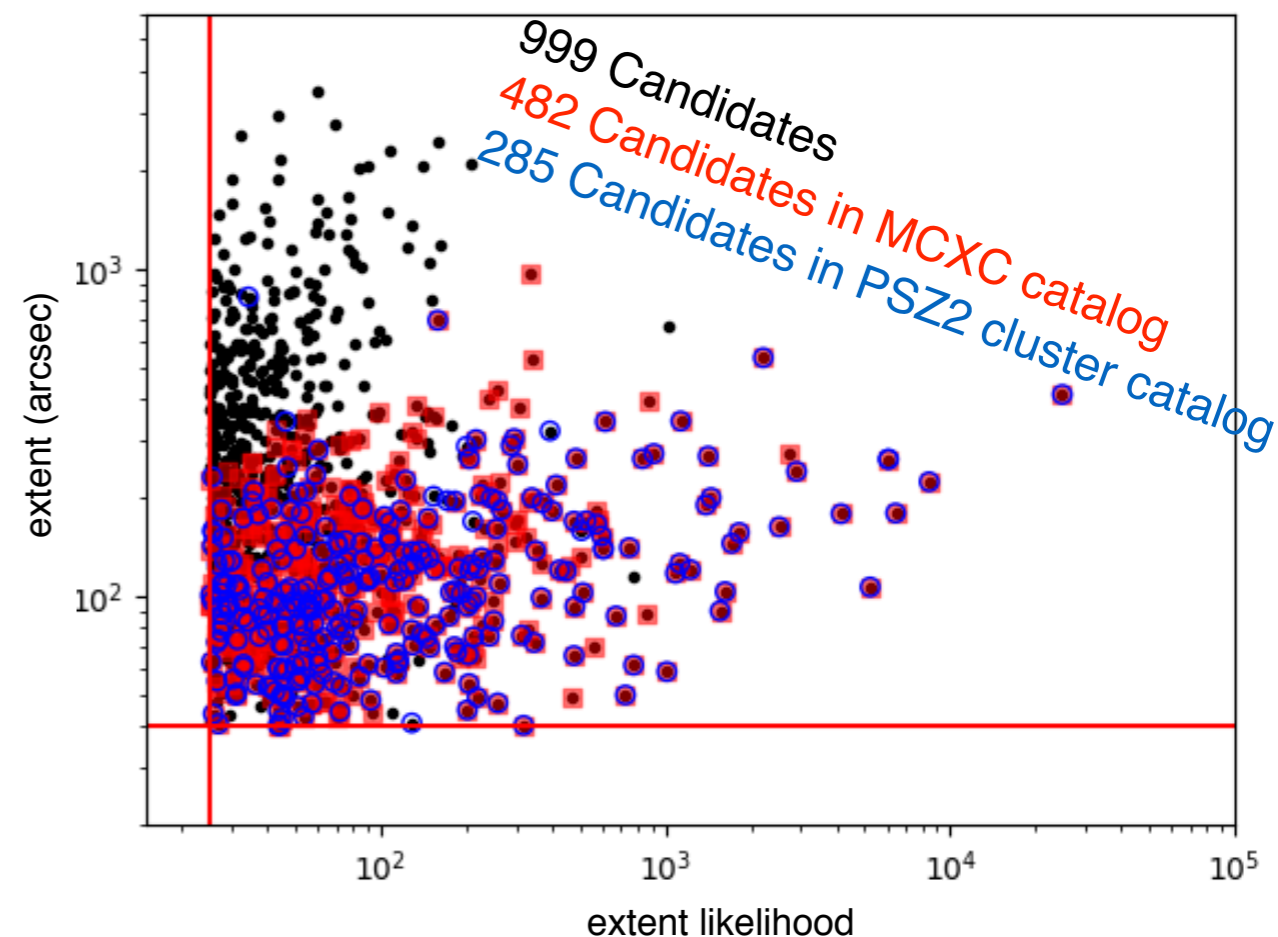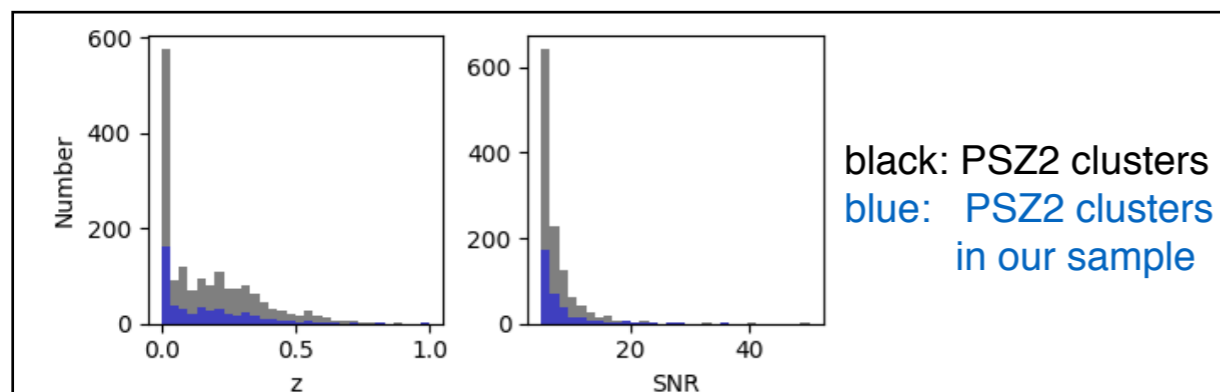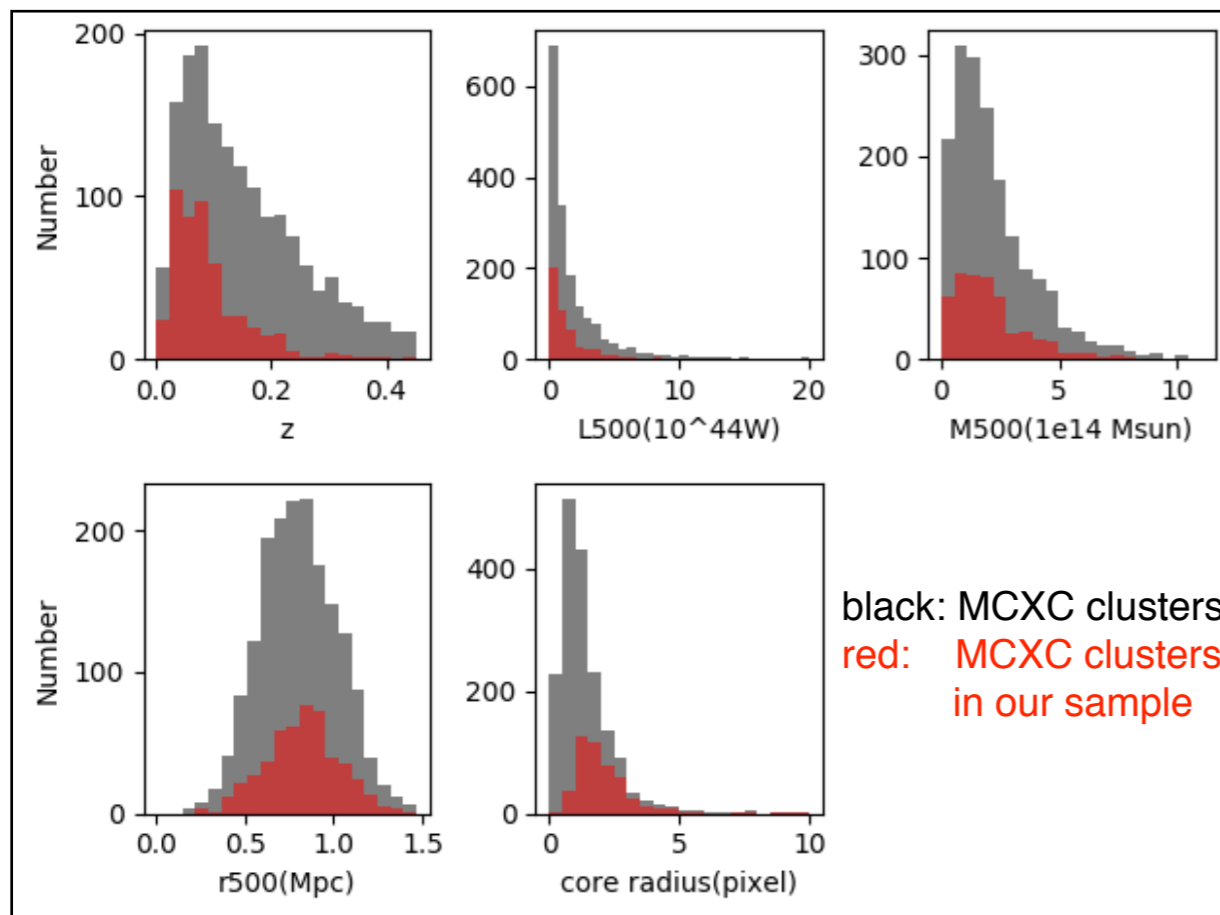+clusters

AGN+clusters
+bgd+poisson noise
+ROSAT response

filtered image after
erwavelet

detection of
SExtractor

r_c = 5 pixel (3.75'), flux$_{cluster}$ = 5×10^{-12} erg s^{-1} cm^{-2}

cyan circles (radius = 3.5 r_c)

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Candidates in MCXC and PSZ2 catalogs:

black: MCXC clusters
red: MCXC clusters
        in our sample

black: PSZ2 clusters
blue: PSZ2 clusters
        in our sample

999 Candidates
482 Candidates in MCXC catalog
285 Candidates in PSZ2 cluster catalog

- MCXC catalog: a Meta-Catalogue of X-ray detected Clusters of galaxies, includes 1743 clusters (Piffaretti et al. 2011)
- PSZ2 catalog: the second Planck catalogue of Sunyaev-Zeldovich sources, includes 1653 clusters (Planck Collaboration et al. 2016)