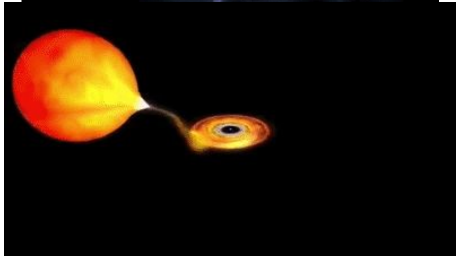
Not-so-supermassive BHs: where and why to find them!

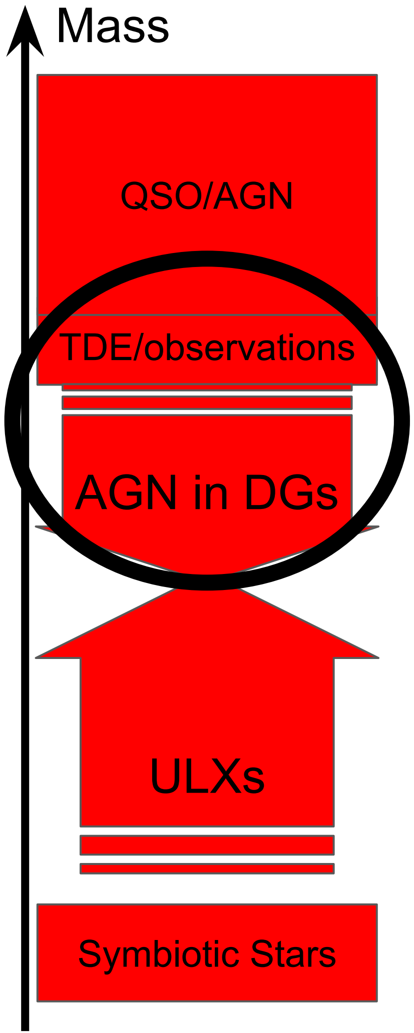
Andrea Sacchi (CfA/SAO)

Collaborators:
Akos Bogdan (CfA)
Urmila Chadayammuri (MPIA)
Angelo Ricarte (CfA)
Steven Dillmann (Stanford)
Kevin Paggeot (CfA)
Peter Kosec (CfA)
Rafael Martinez-Galarza (CfA)

X-raying accreting sources

← Today's talk →





X-raying accreting sources

Mass

X-raying accreting sources

Mass

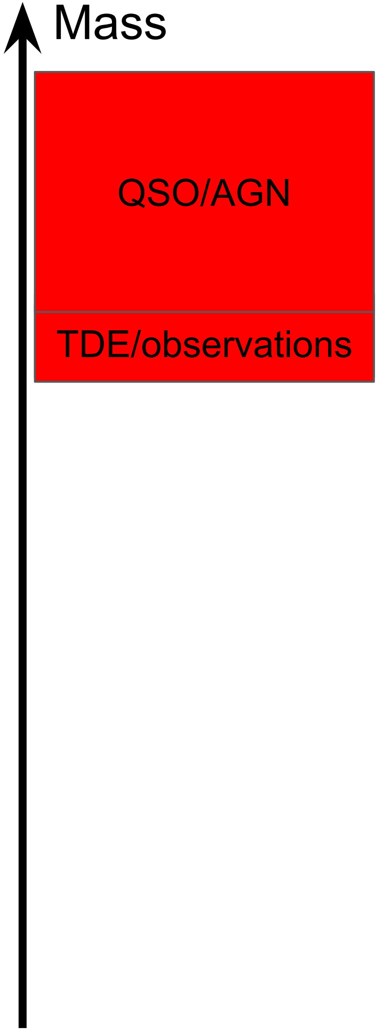
TDE/simulations

X-raying accreting sources

Mass

TDE/observations

X-raying accreting sources



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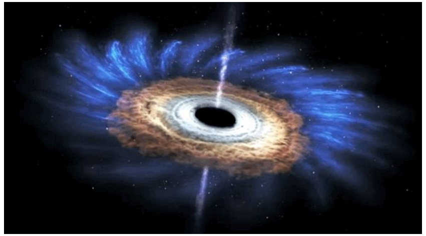

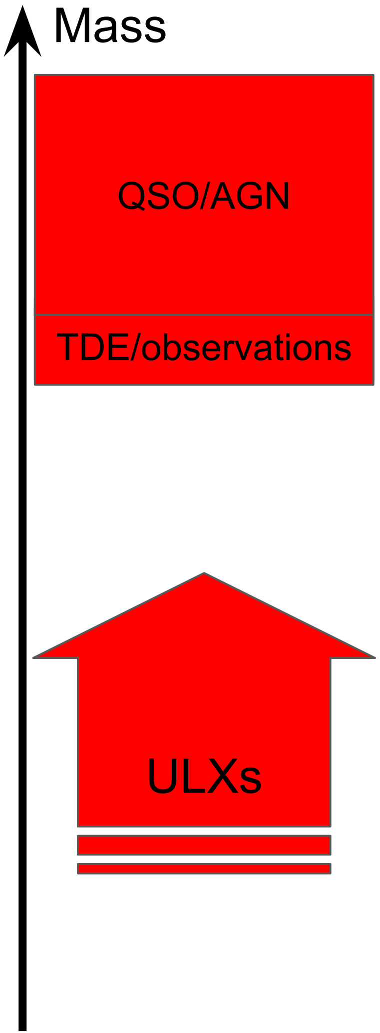

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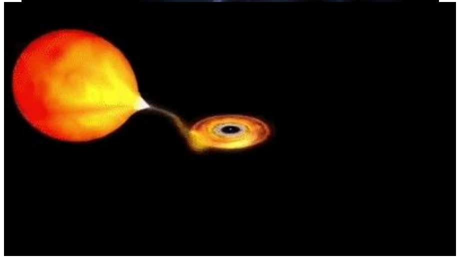

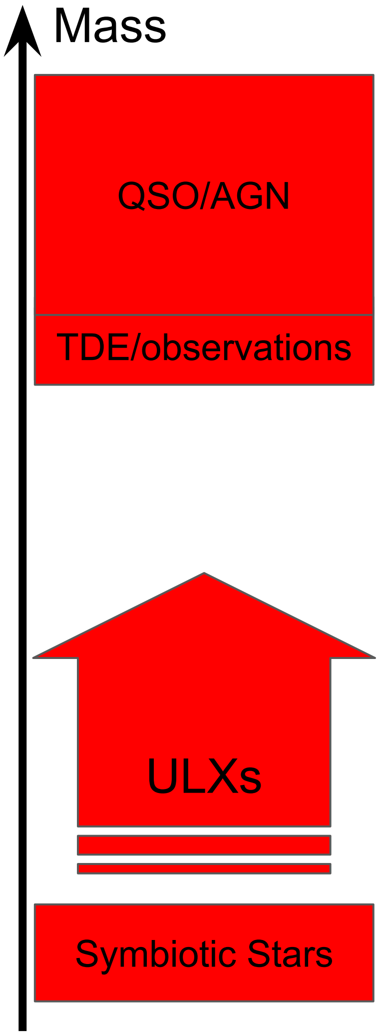

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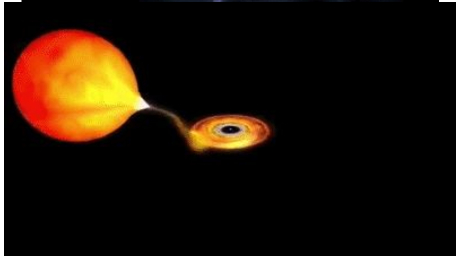
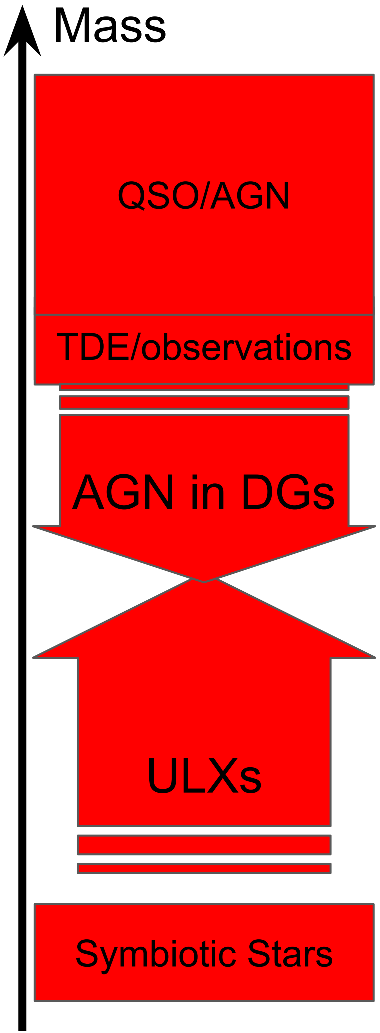
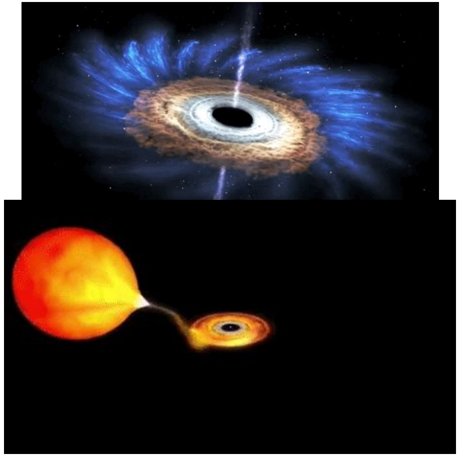
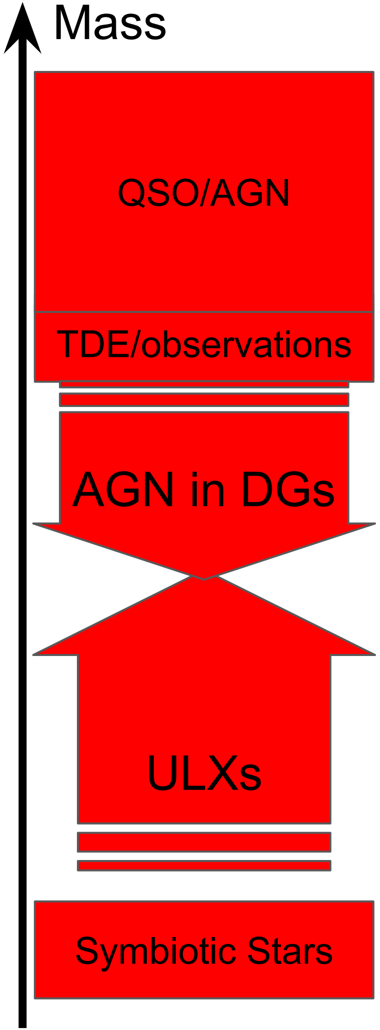




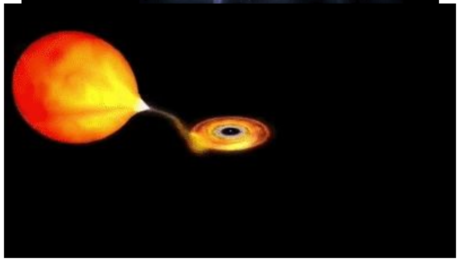
X-raying accreting sources

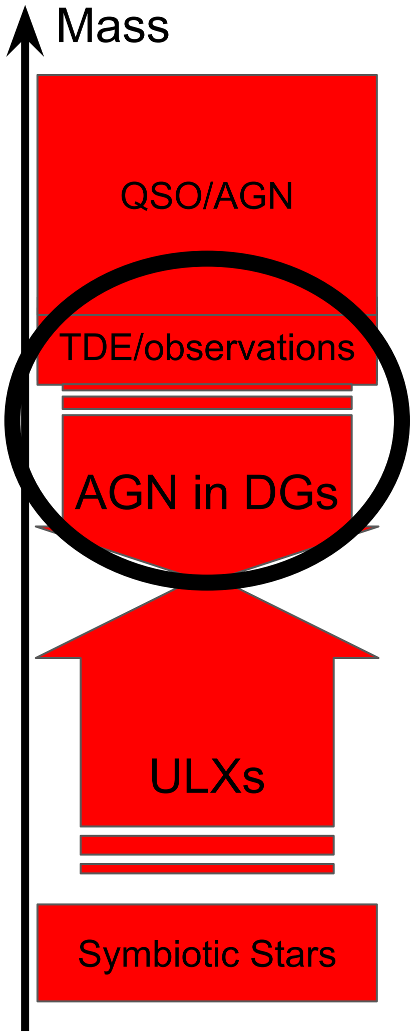




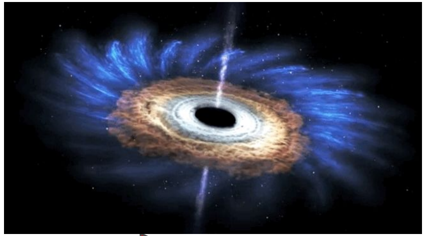
X-raying accreting sources

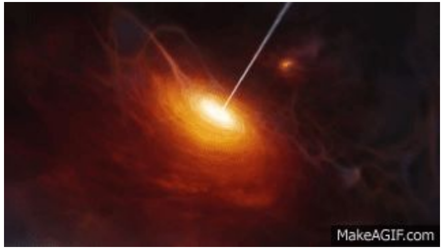
Today's talk

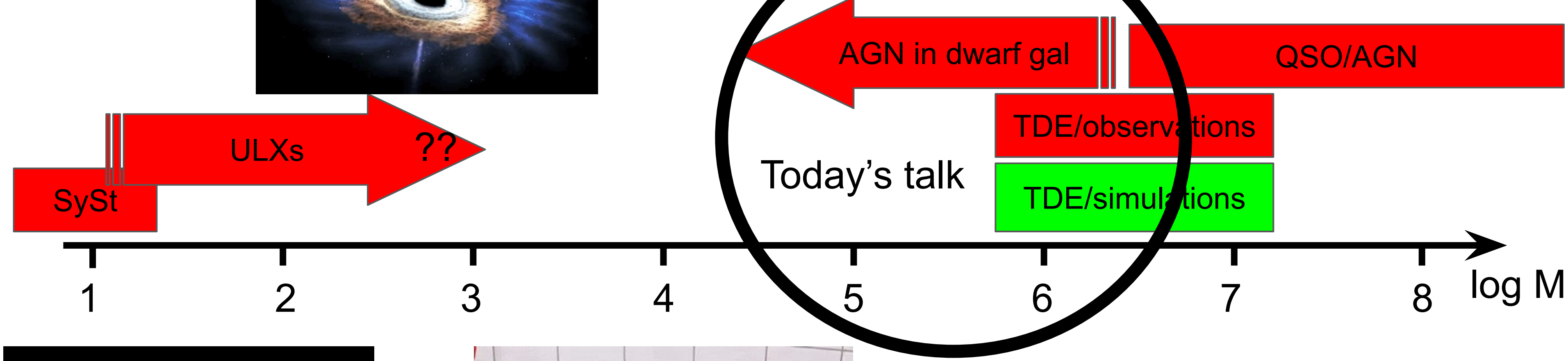


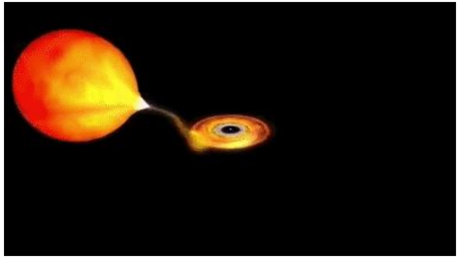


Accretion across all mass scales



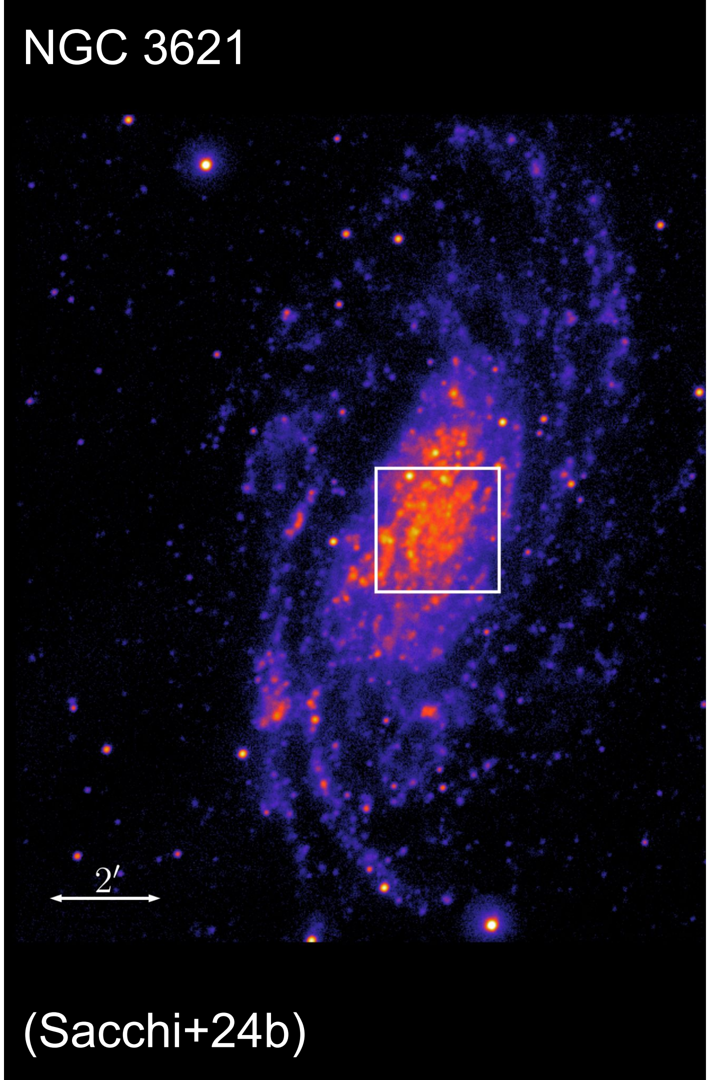






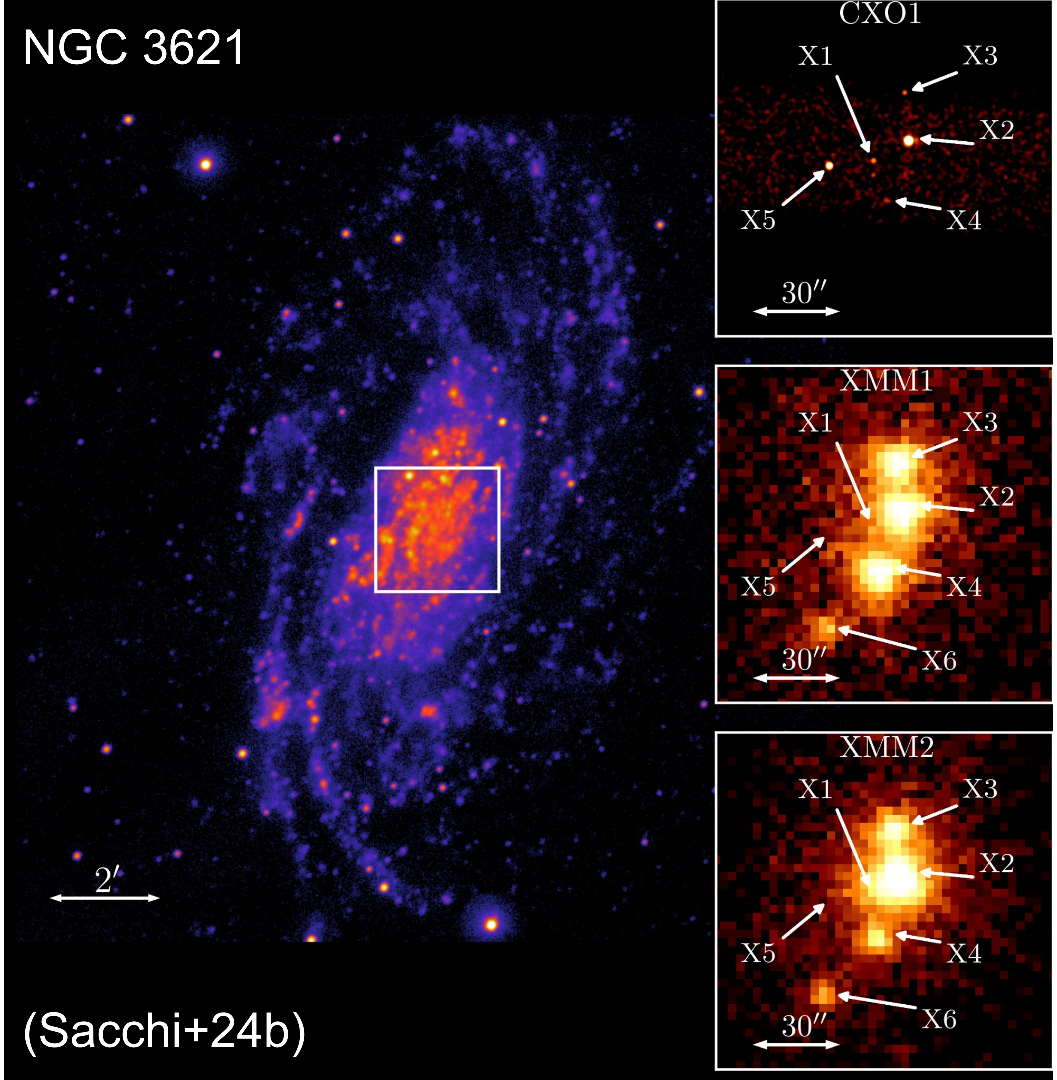
Why X-ray?

Optical →



Why X-ray?

Optical



X-ray

AGN in dwarf galaxies: The eROSITA revolution

Andrea Sacchi (CfA/SAO)

Collaborators:
Akos Bogdan (CfA)
Urmila Chadayammuri (MPIA)
Angelo Ricarte (CfA)

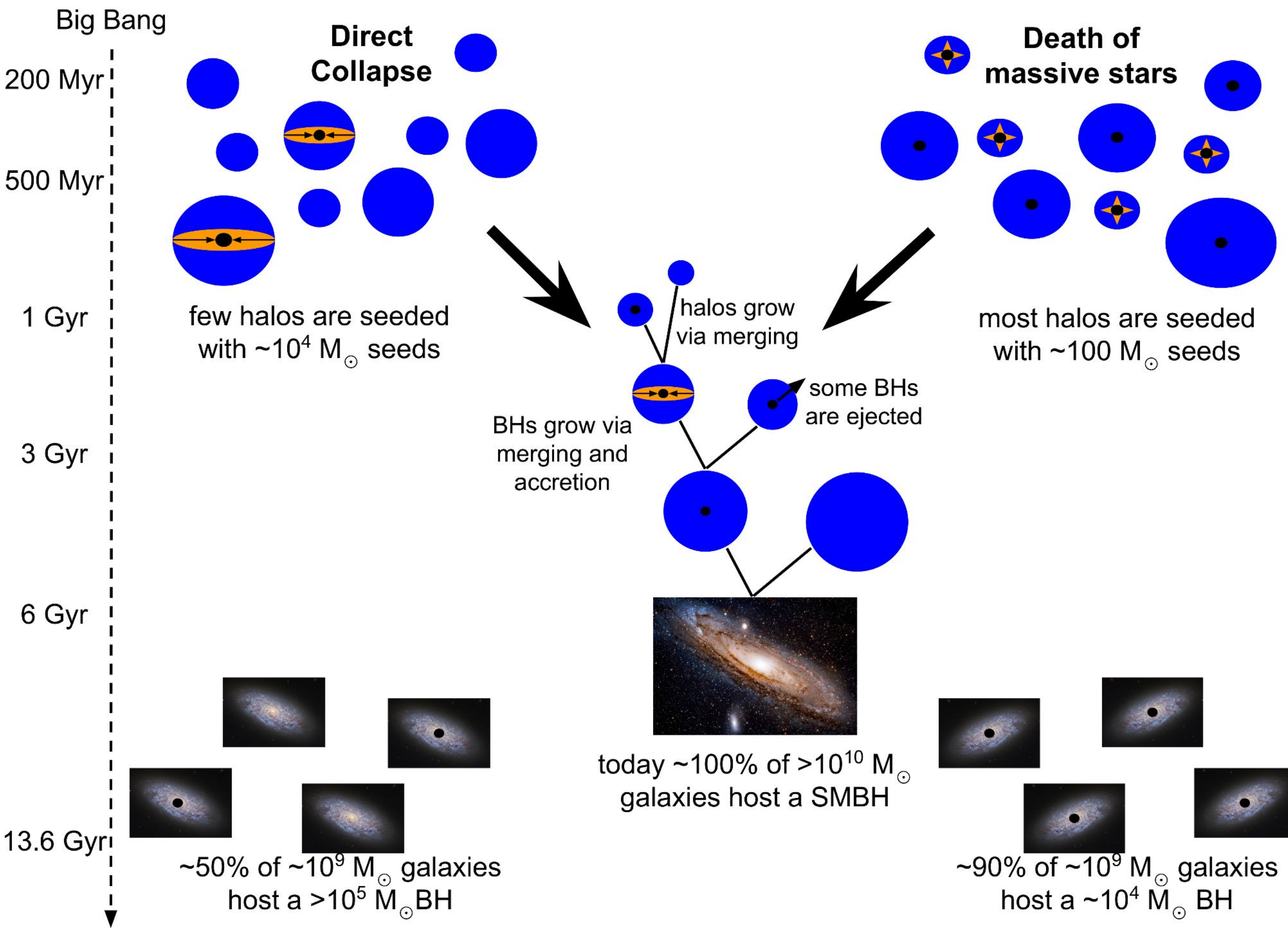
Motivation

Adapted from Greene12

Seeding mechanisms

Growth history

Accretion physics



Similar efforts

- Bykov+24 (AGN in dwarf galaxies, Eastern half of the sky)
- Hoyer+24 (MBHs in NSCs)
- Kyritsis+24 (SFR-driven X-ray emission from non-active galaxies)

Building the sample

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eRASS1 (Merloni+24)
Fx (in different bands), position
~930’000 sources

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Fx (in different bands), position
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+

Hecate catalogue (Kovlakas+21)
M_{gal}, SFR, z
5’775 dwarf galaxies
(1e6 $M_{\odot}$<M_{gal}<3e9 $M_{\odot}$)

Building the sample

eRASS1 (Merloni+24)
Fx (in different bands), position
~930’000 sources

+

Hecate catalogue (Kovlakas+21)
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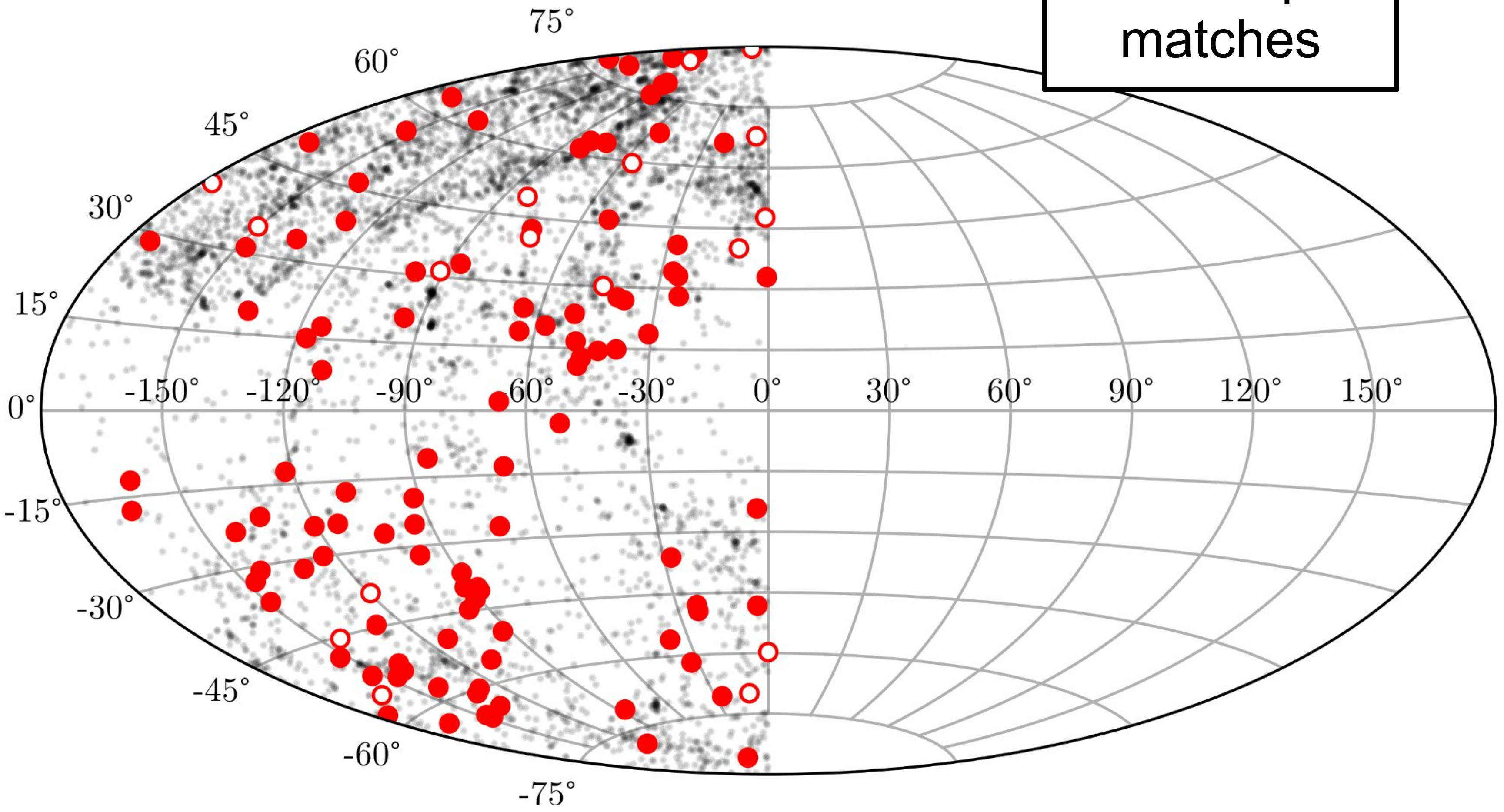
5’775 dwarf galaxies
(1e6 $M_\odot < M_{gal} <$ 3e9 $M_\odot$)

↓

120 unique matches

Building the sample

120 unique matches



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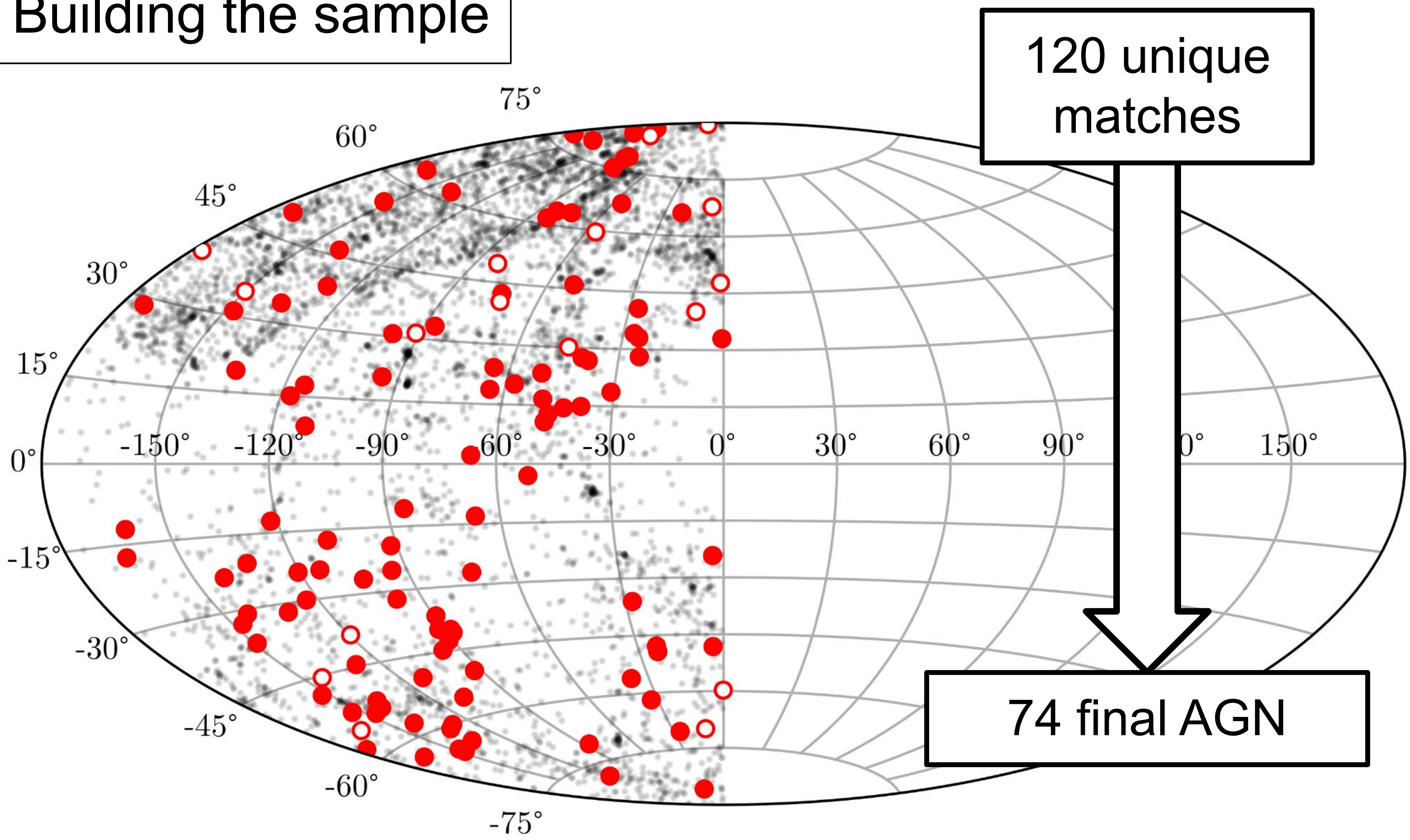
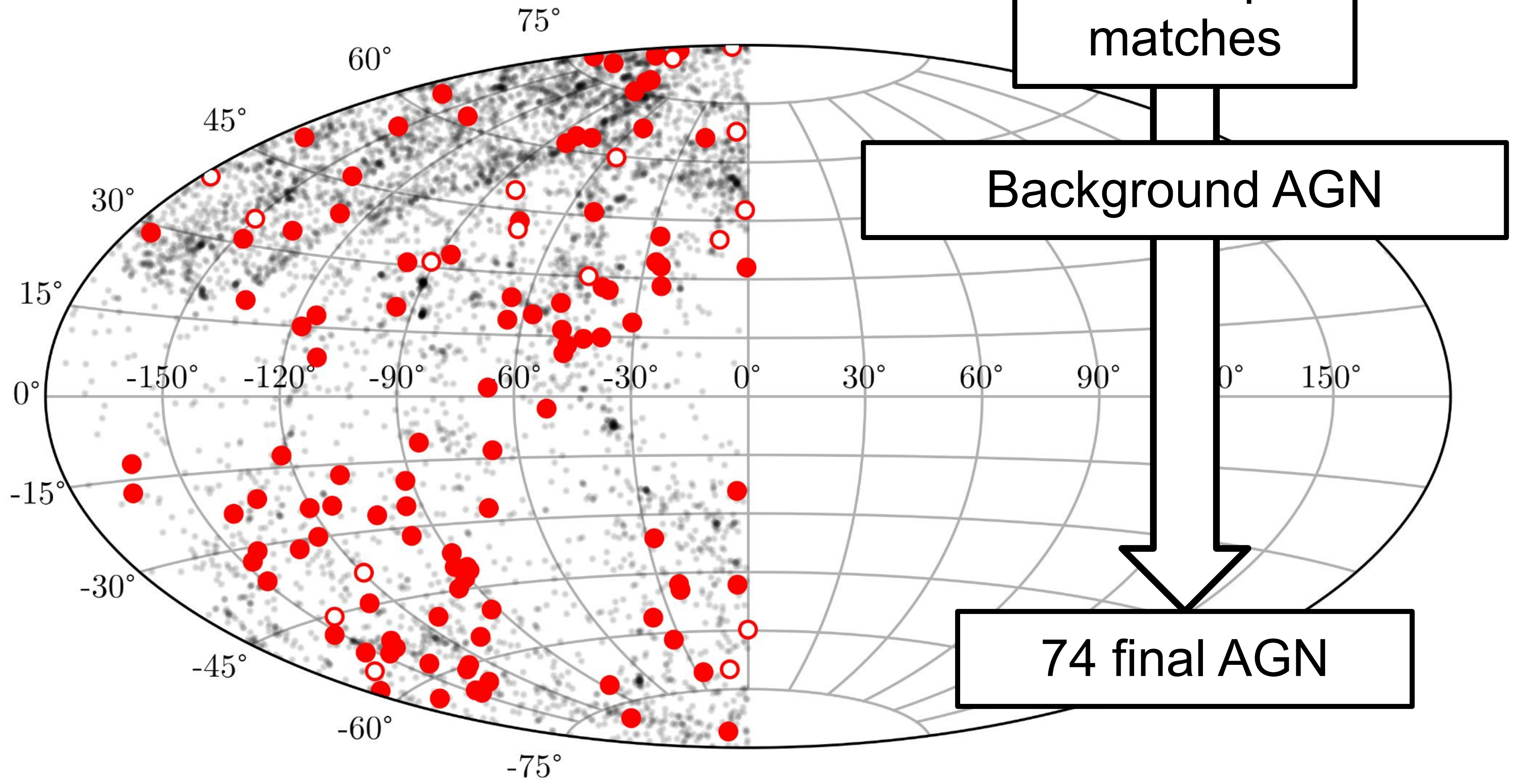


Building the sample



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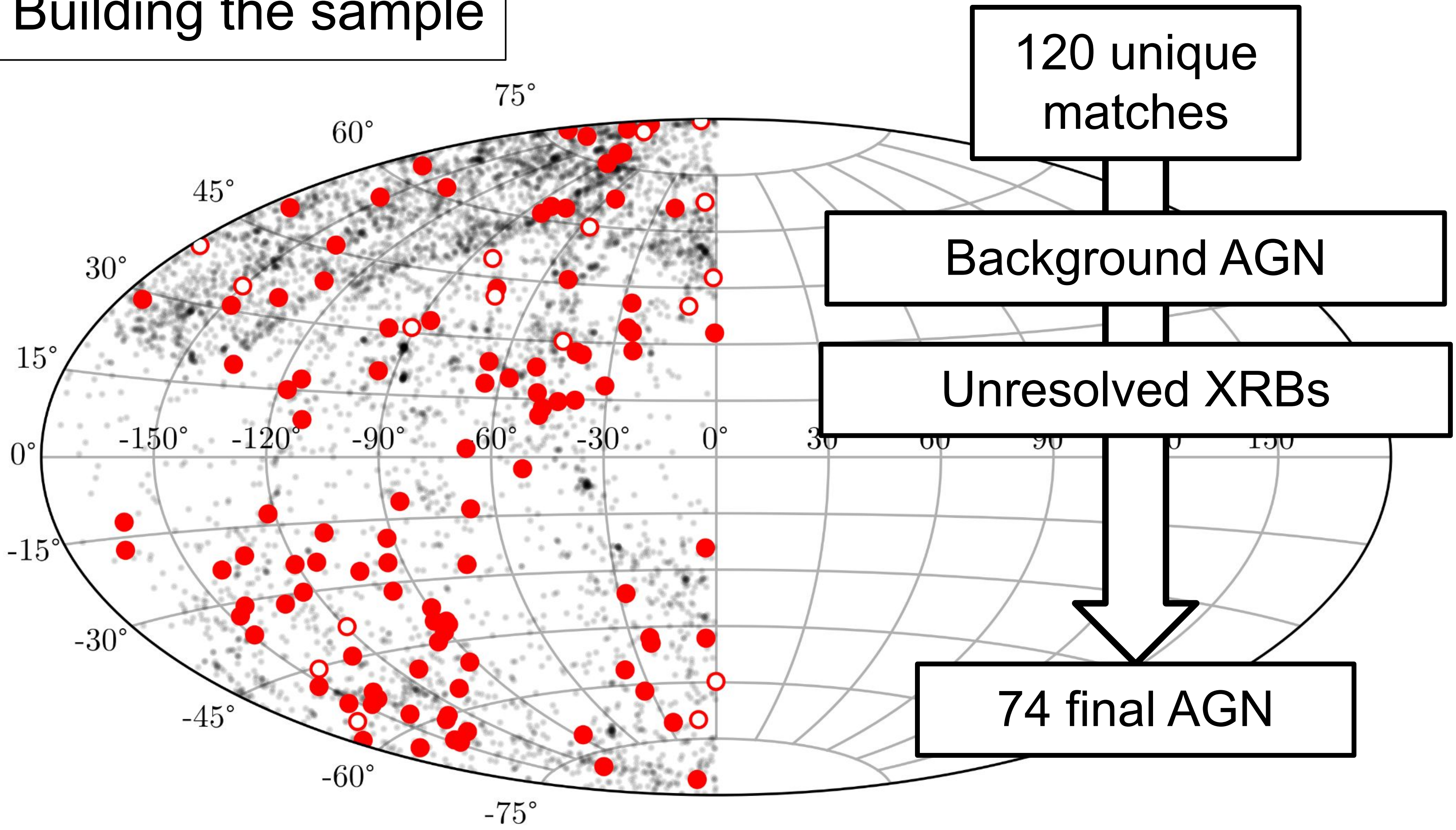

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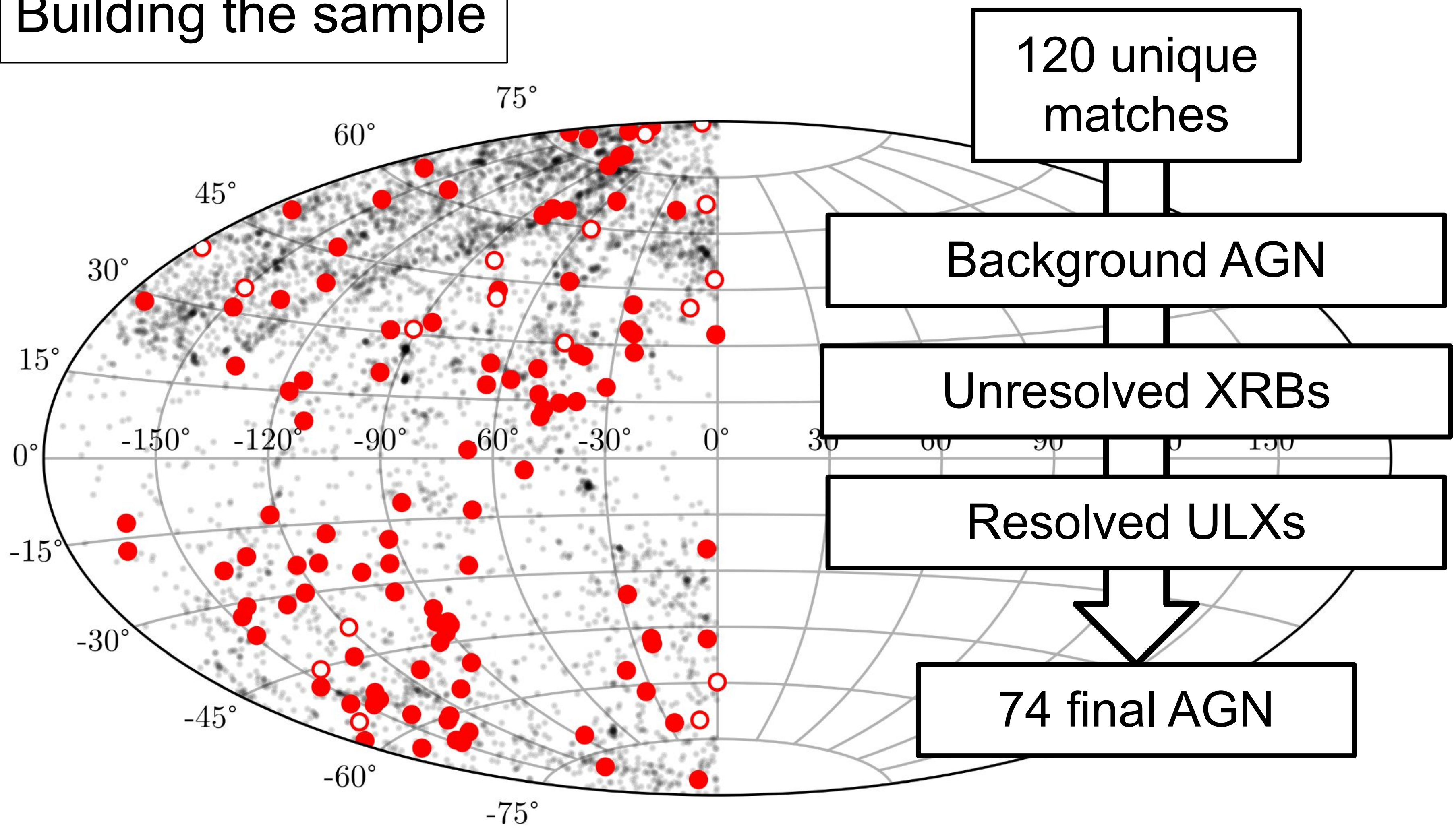
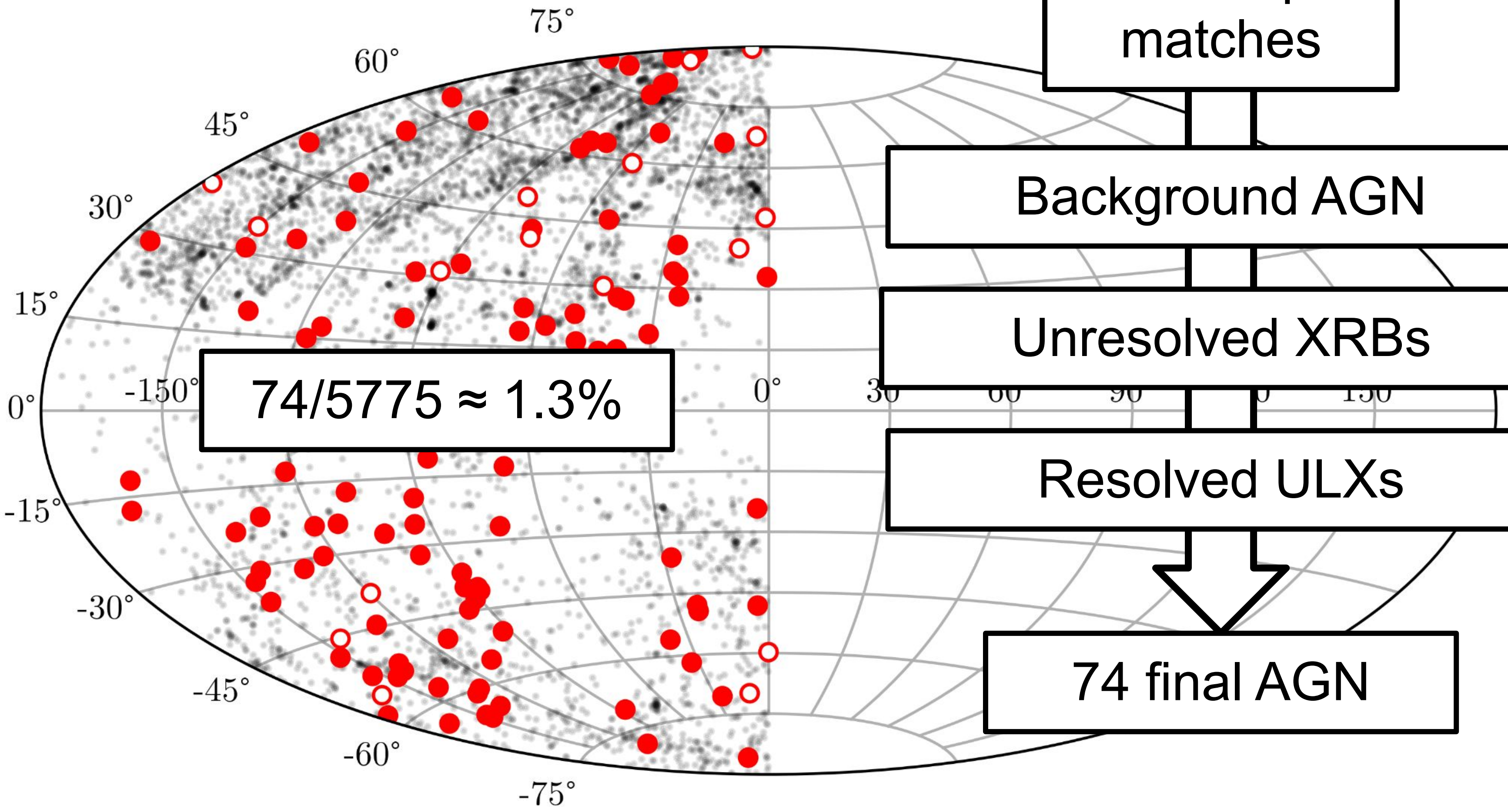


Building the sample



74/5775 ≈ 1.3%

120 unique matches

Background AGN

Unresolved XRBs

Resolved ULXs

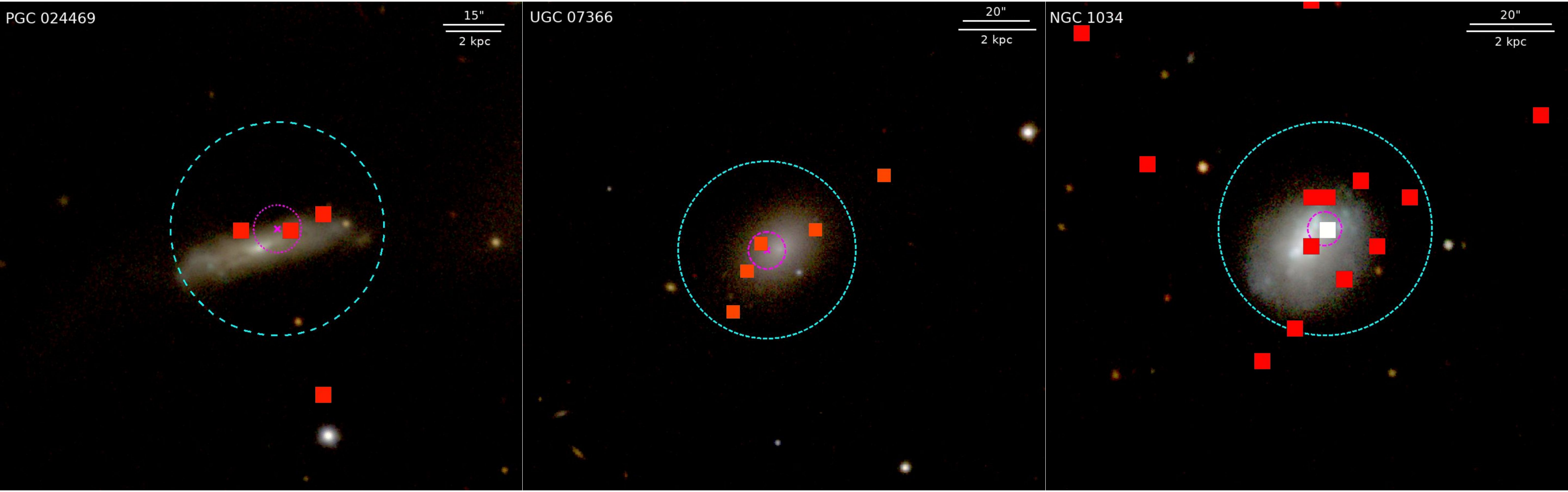
74 final AGN

Sample properties

74 AGN-dwarf galaxy pairs

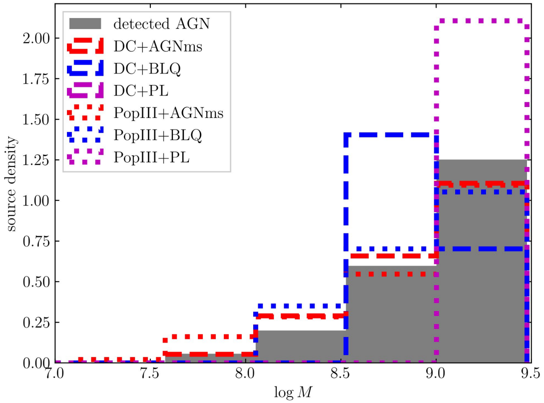
Sample properties

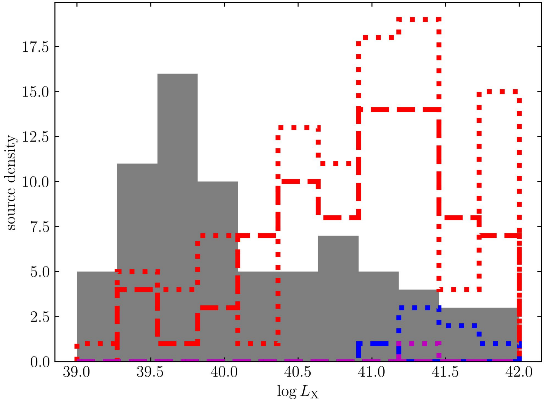
74 AGN-dwarf galaxy pairs

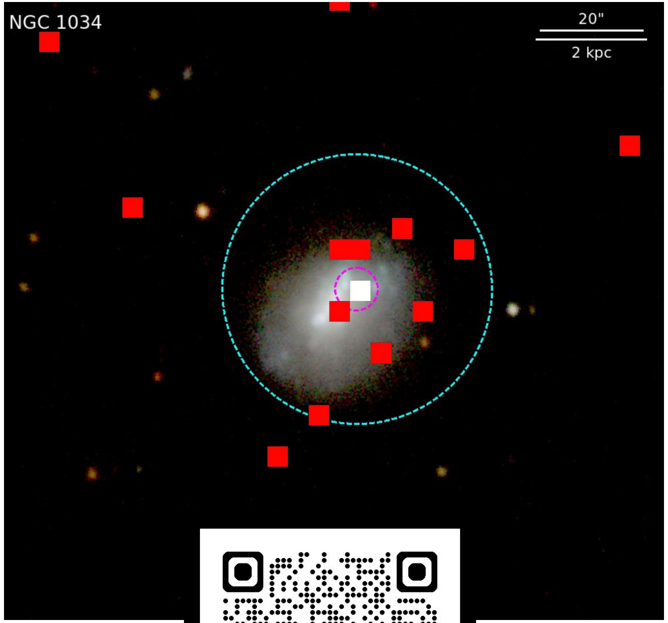


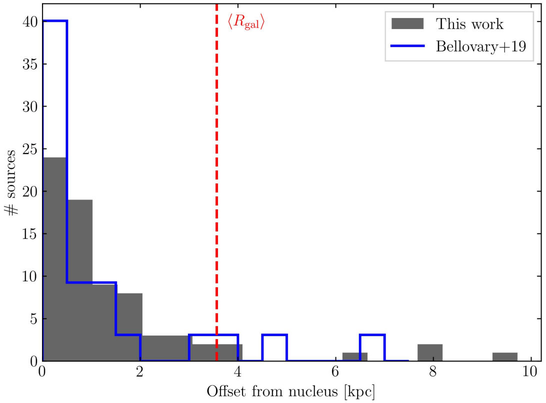
AGN in Dwarf Galaxies: the eRASS1 Revolution

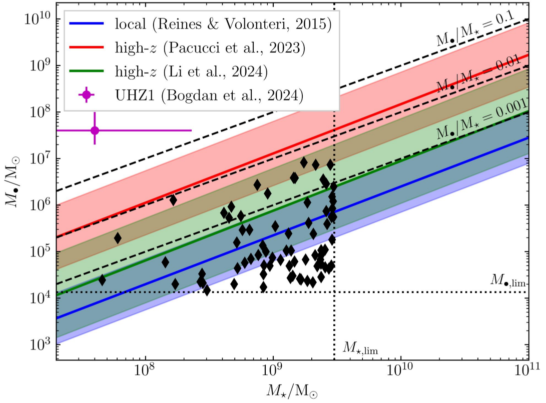
Andrea Sacchi (CfA/SAO)







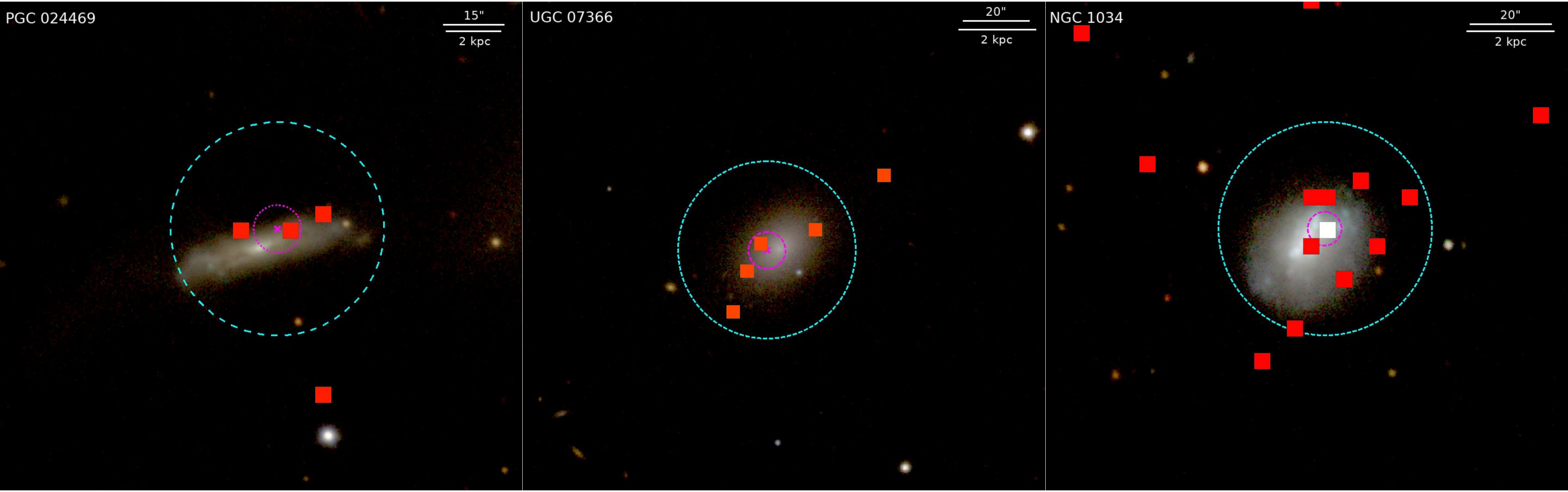




andrea.sacchi(at)cfa.harvard.edu

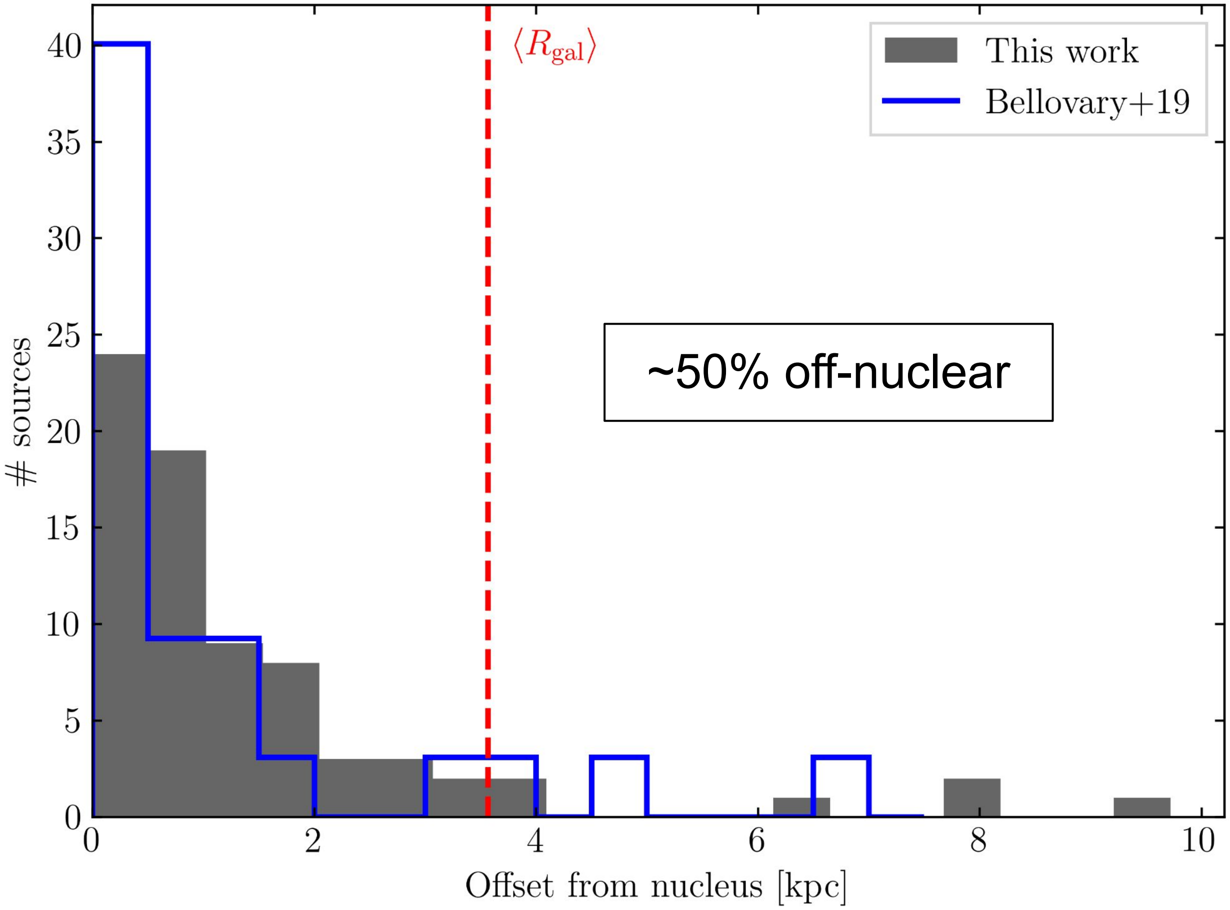
Sample properties

74 AGN-dwarf galaxy pairs

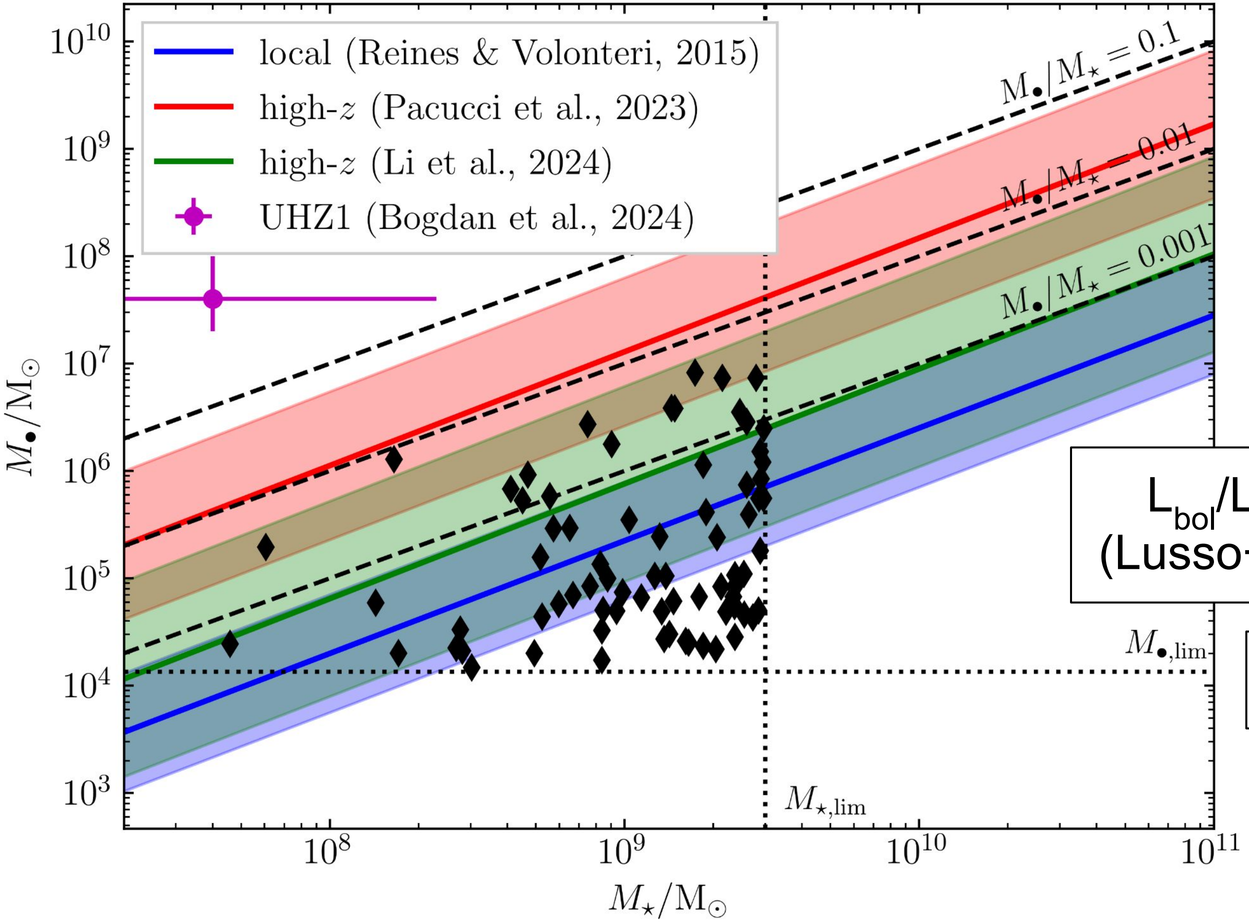


SDSS-gri images + eROSITA counts +
eROSITA position error (magenta) and PSF (cyan)

Sample properties: off-nuclear AGN



Sample properties: M_{BH}–M_{gal} relation



$L_{bol}/L_{2\text{-}10\ keV}$ = 16.7
(Lusso+12, Duras+20)

λ_{Edd}=1%

Comparison with mock-samples

Semi-analytical models (Ricarte+18a/b, Chadayammuri+23)

Comparison with mock-samples

Semi-analytical models (Ricarte+18a/b, Chadayammuri+23)

Seeding

Growth

Comparison with mock-samples

Semi-analytical models (Ricarte+18a/b, Chadayammuri+23)

Seeding

Growth

rare “heavy” seeds
(DC)

abundant “light” seeds
(PopIII)

Comparison with mock-samples

Semi-analytical models (Ricarte+18a/b, Chadayammuri+23)

Seeding	Growth: major mergers	Growth: "steady" mode
rare "heavy" seeds (DC)		
abundant "light" seeds (PopIII)		

Comparison with mock-samples

Semi-analytical models (Ricarte+18a/b, Chadayammuri+23)

Seeding	Growth		
	major mergers		"steady" mode
	$\lambda_{Edd}=1 \longrightarrow M\text{–}\sigma$	(PL)	$f(\lambda_{Edd})\sim PL$
rare "heavy" seeds (DC)			
abundant "light" seeds (PopIII)			

Comparison with mock-samples

Semi-analytical models (Ricarte+18a/b, Chadayammuri+23)

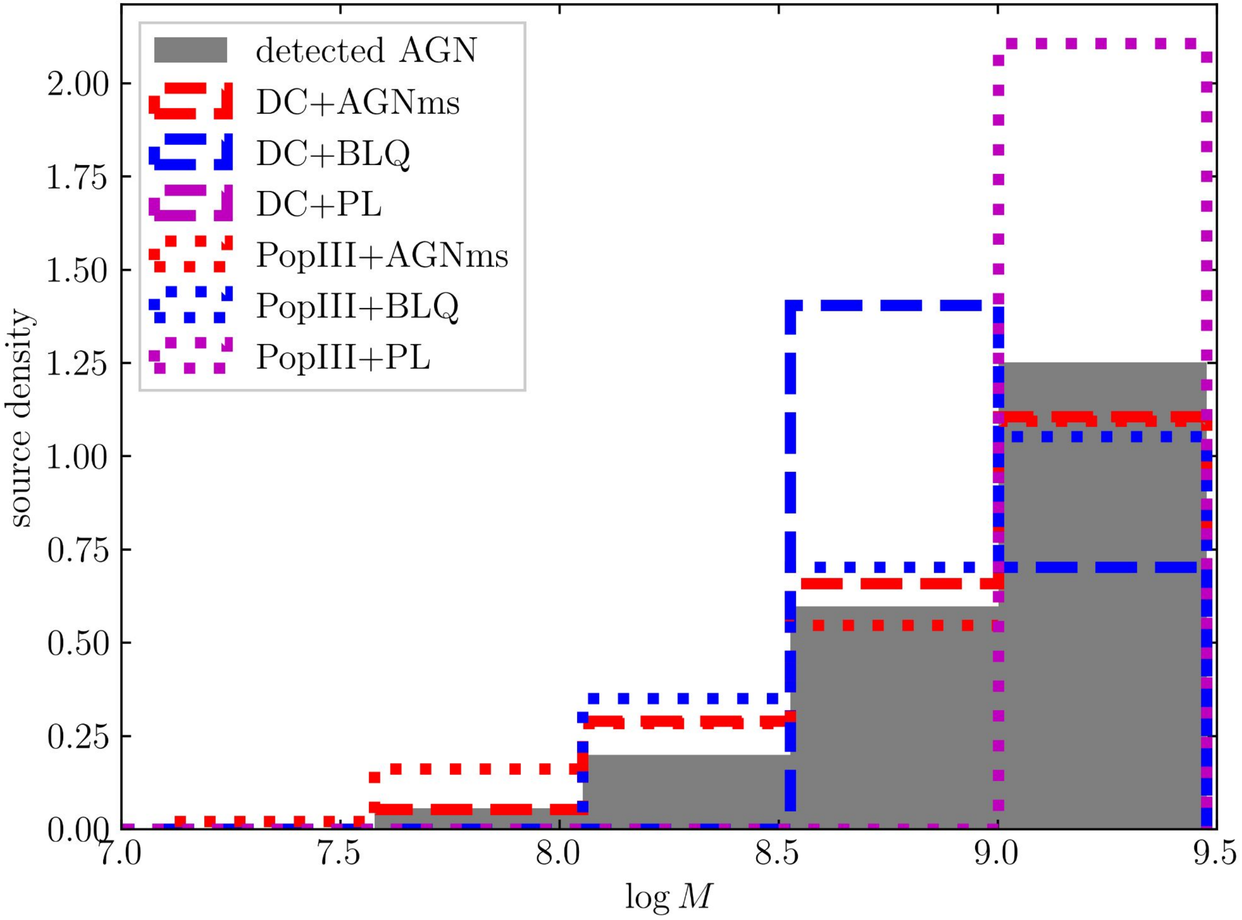
Seeding	Growth		
	major mergers		"steady" mode
rare "heavy" seeds (DC)	$\lambda_{Edd}=1 \longrightarrow$ M–σ	(PL)	$f(\lambda_{Edd})$~PL
abundant "light" seeds (PopIII)	$\lambda_{Edd}=1 \longrightarrow$ M–σ	(AGNms)	λ_{Edd}=1‰ SFR

Comparison with mock-samples

Semi-analytical models (Ricarte+18a/b, Chadayammuri+23)

Seeding	major mergers	Growth	"steady" mode
rare "heavy" seeds (DC)	$\lambda_{Edd}=1 \longrightarrow M–\sigma$	(PL)	$f(\lambda_{Edd})$~PL
	$\lambda_{Edd}=1 \longrightarrow M–\sigma$	(AGNms)	λ_{Edd}=1‰ SFR
abundant "light" seeds (PopIII)	$f(\lambda_{Edd})$~BLQ	(BLQ)	$\lambda_{Edd}=0$

Comparison with mock-samples



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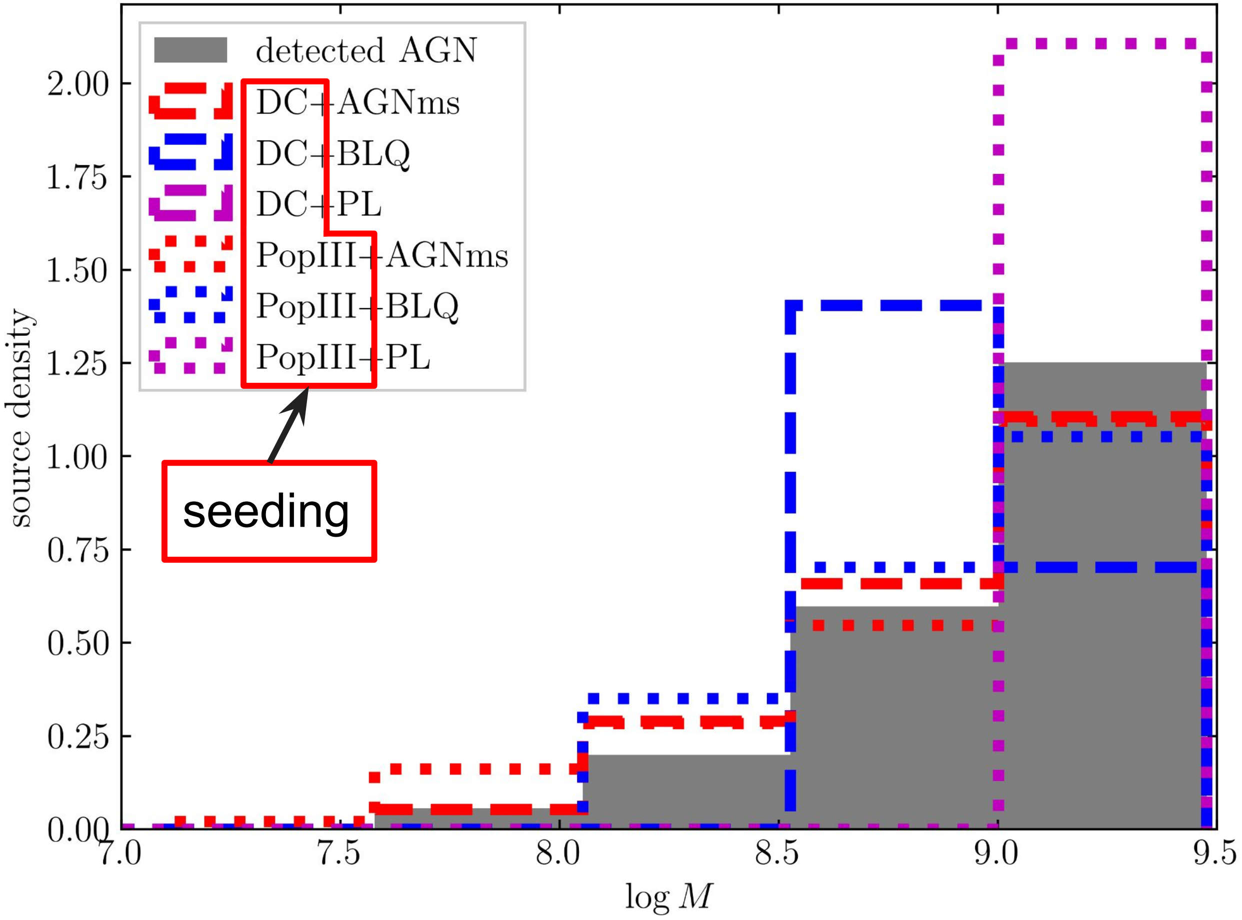

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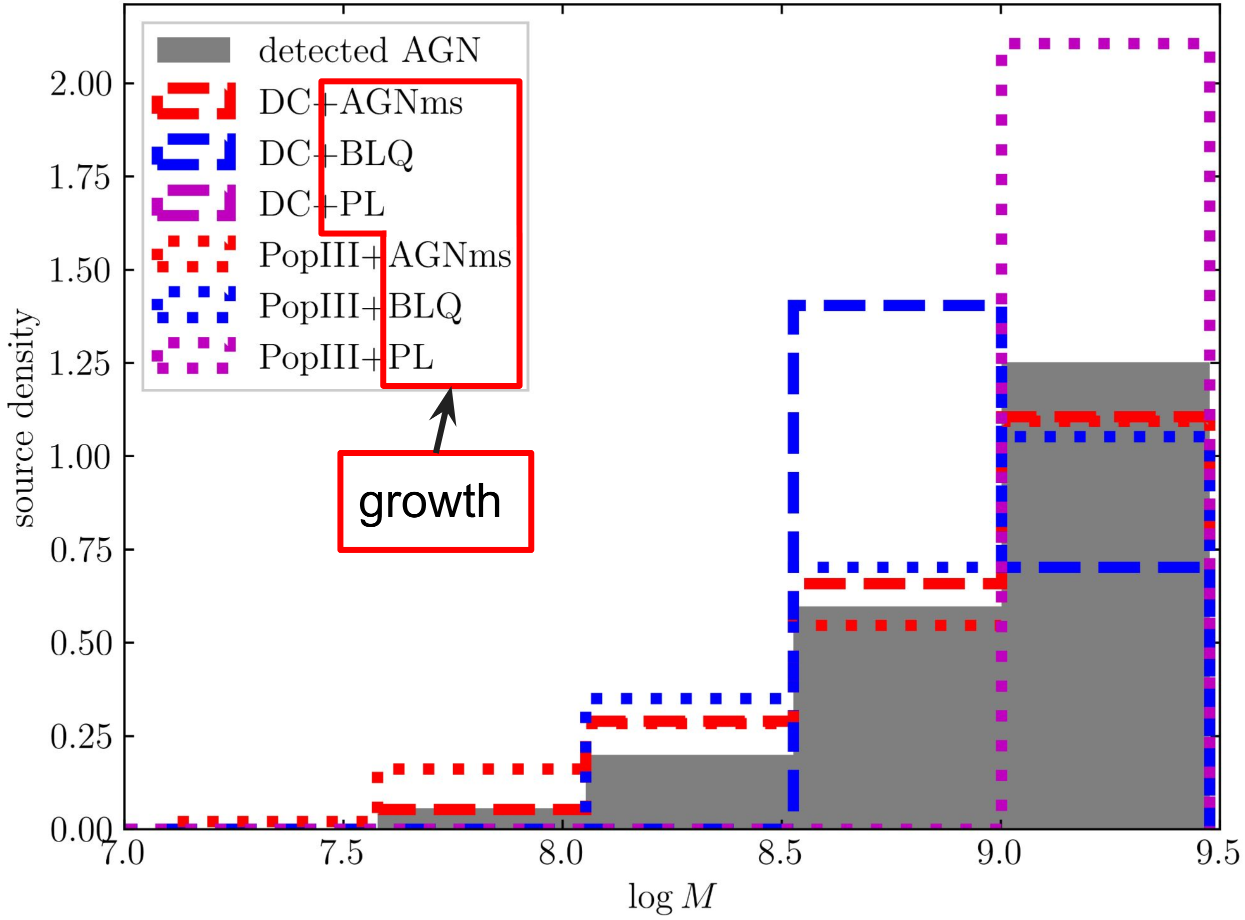

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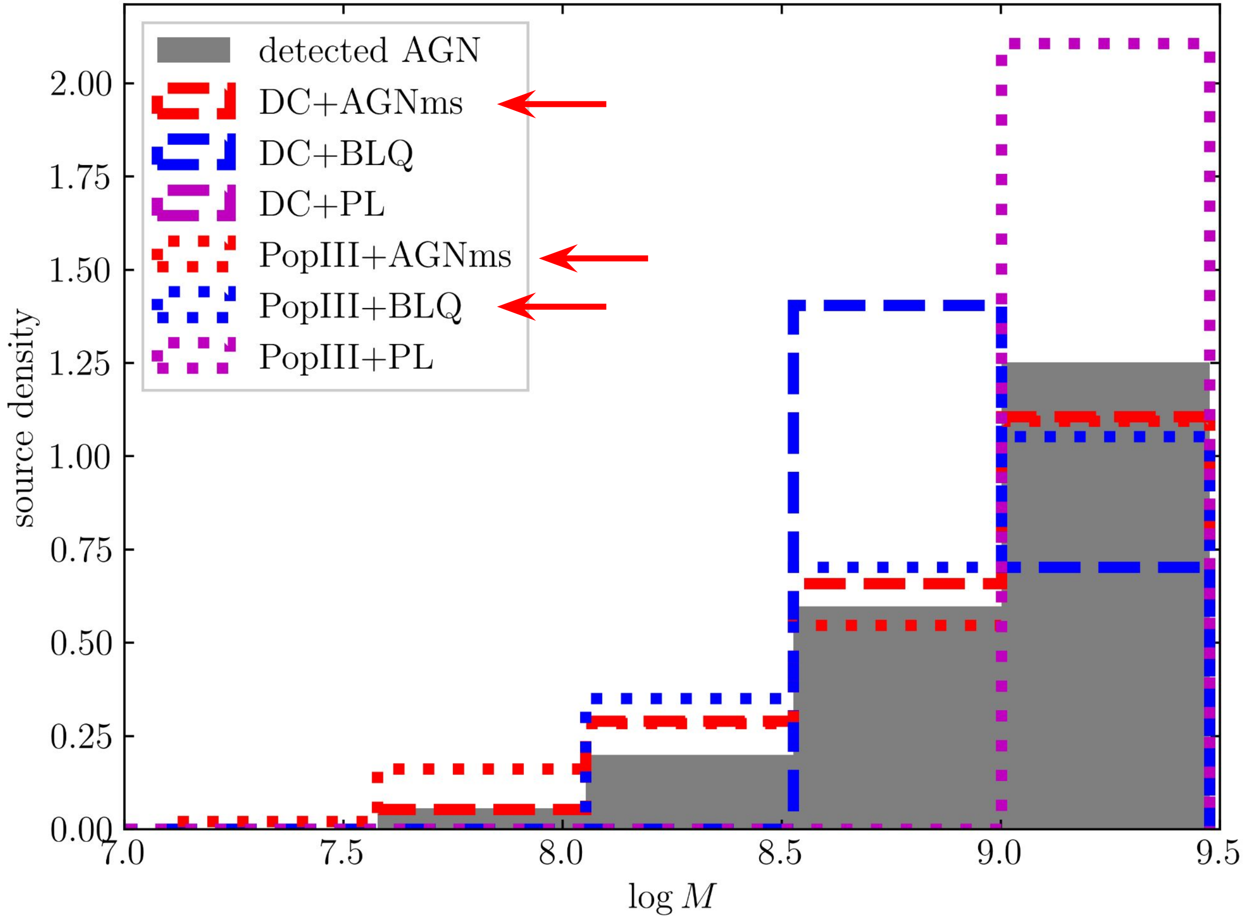

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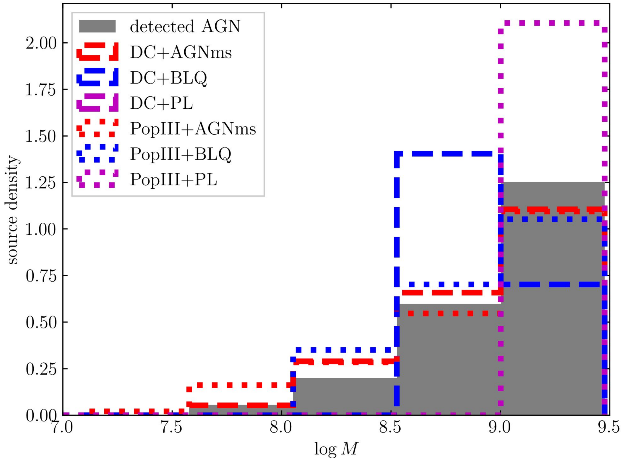

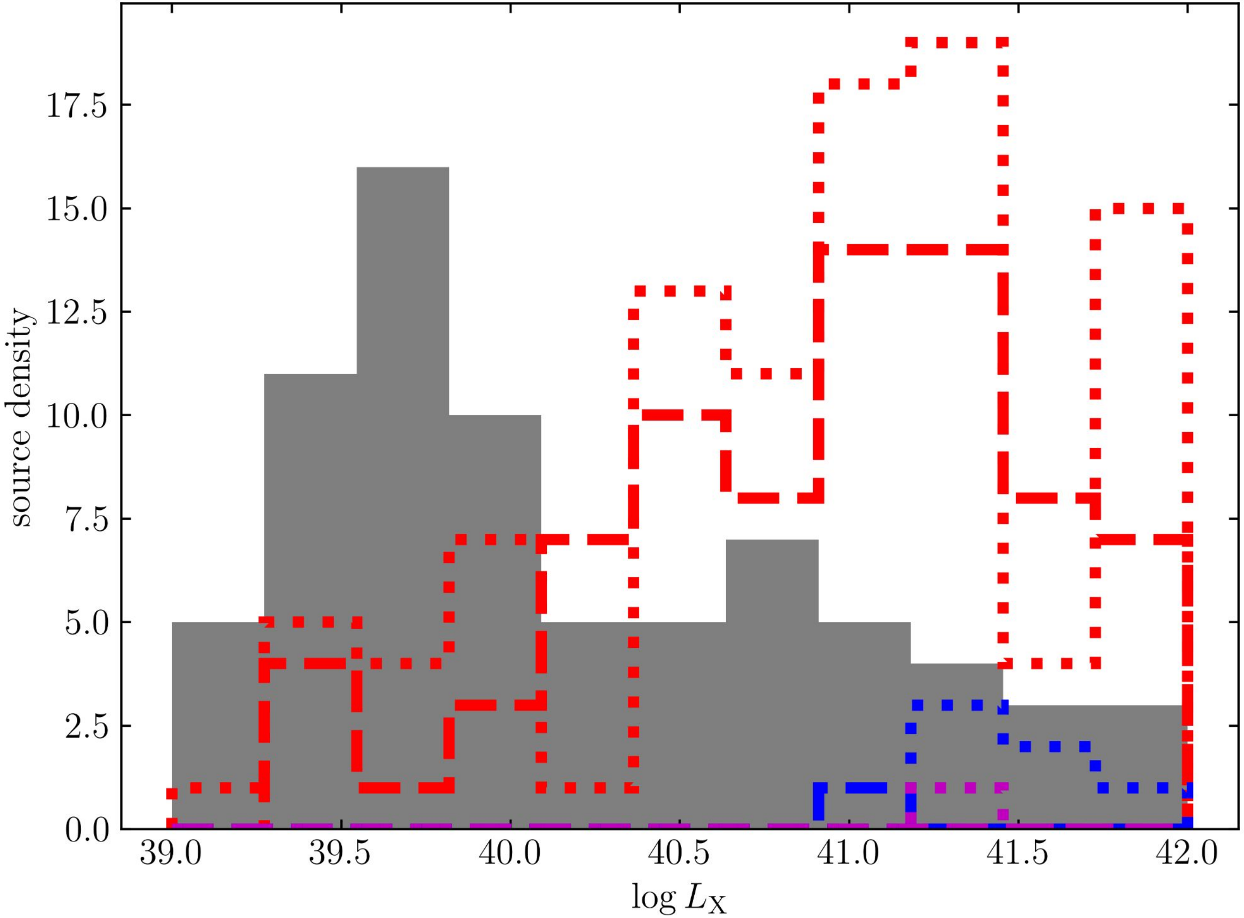

Conclusions pt.1

- 74 X-ray-bright AGN in dwarf galaxies
- Comparison with theoretical predictions
  - Offset and M_{BH}–M_{gal} relation
- Key observables to inform models
  - seeding and growth mechanisms

Sacchi+2024c →

Conclusions

- 74 AGN in dwarf galaxies (eRASS1 + HECATE)
- In line with theoretical expectations on off-nuclear AGN
- Too shallow to discriminate between seeding mechanisms
- Sensitive to the “steady” mode of accretion
    - prompts for more modelling efforts

Sacchi+2024c ⟶

Hyperluminous supersoft X-ray sources in the Chandra Catalog

Andrea Sacchi (CfA/SAO)

Collaborators:

Kevin Paggeot (CfA)
Steven Dillmann (Stanford)
Peter Kosec (CfA)
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What is an HSSs?!

- Hyperluminous ($L_x > 1e41$ erg/s)
- Supersoft ($\Gamma > 3$)
- X-ray sources!
- (p/r)TDEs, QPEs, CLAGN, ANTs

What is an HSSs?!

- Hyperluminous ($L_x > 1e41$ erg/s)
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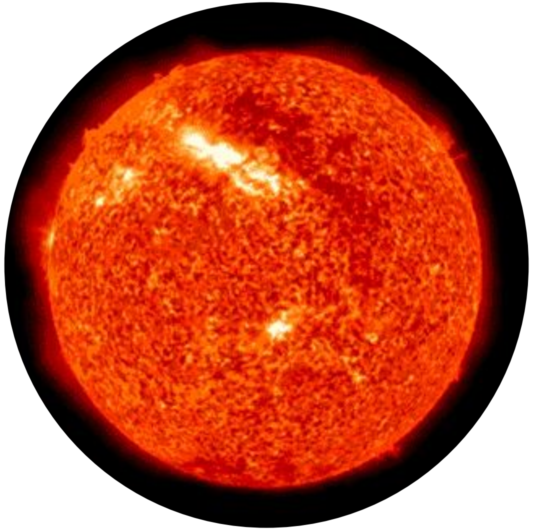
What is a TDE?



What is a TDE?

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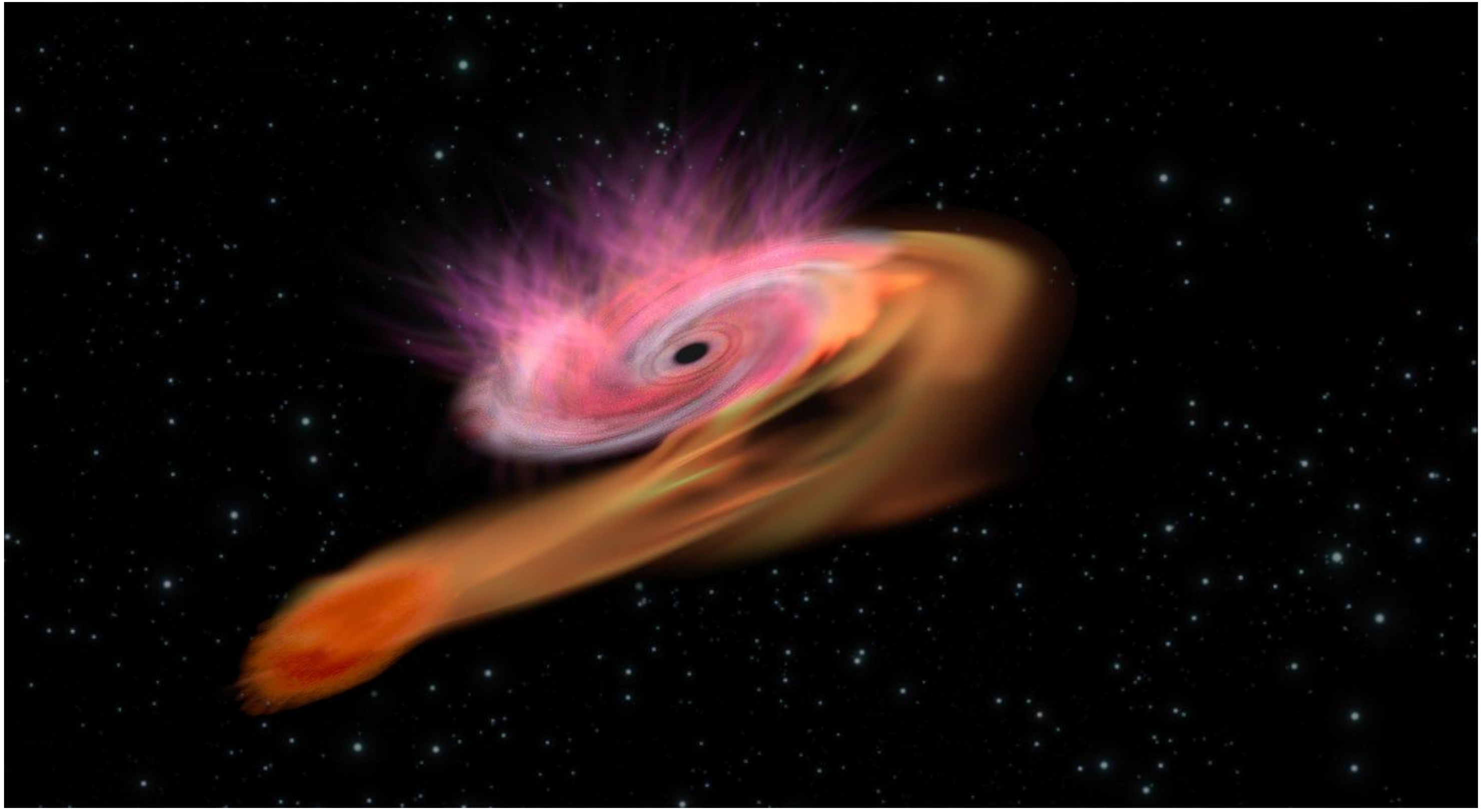
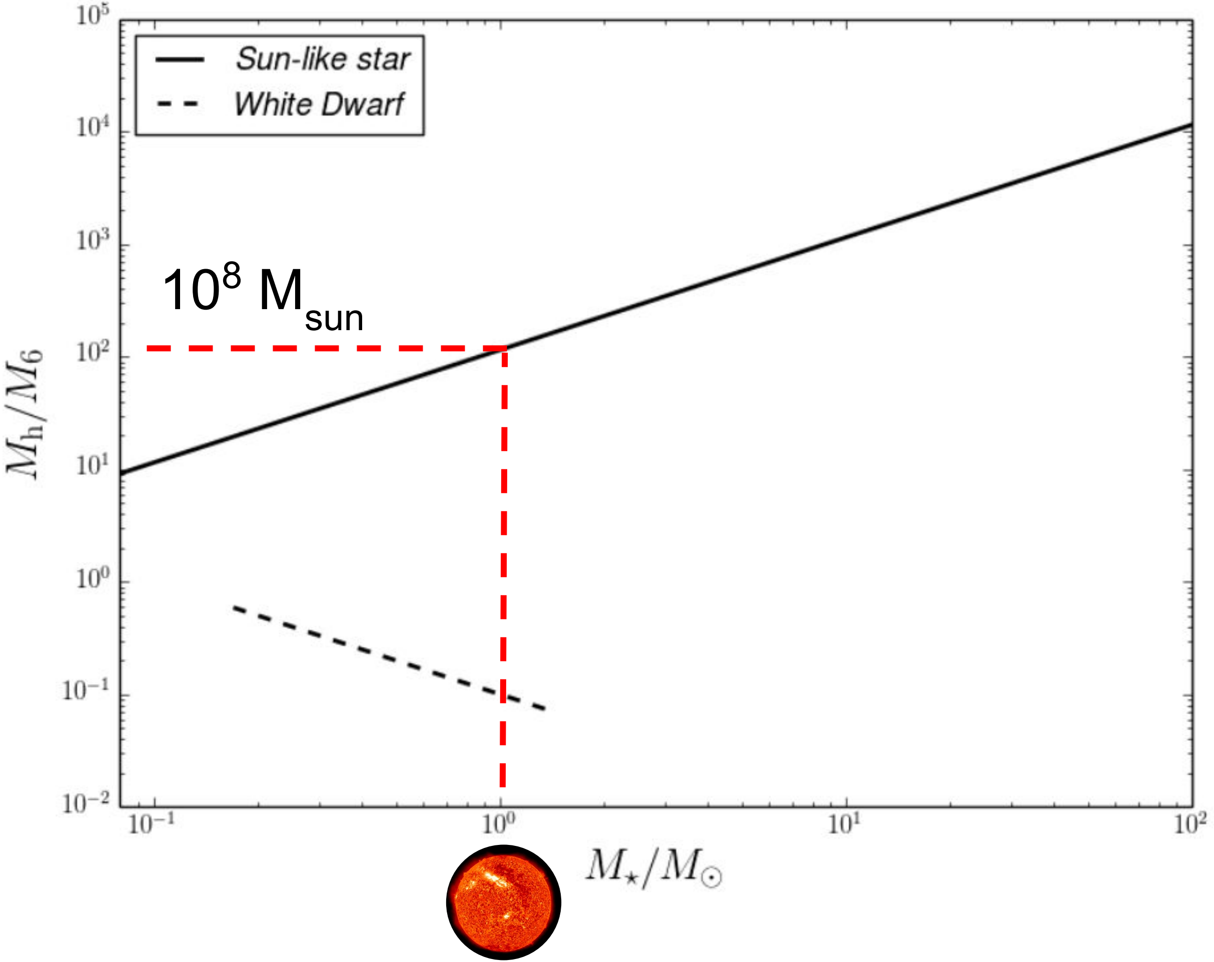


What is a TDE?

$R_t \propto M_{bh}^{1/3}$

$R_s \propto M_{bh}$



Why an archival search?

- HSSs are rare
- Catalogues are large (4XMM+CSC ~ 1.5M individual sources)
- Distinct spectral features

Results based on 4XMM

- ~ 800’000 4XMMDR9
- 60 candidate sources
- 15 known HSSs
- 9 new HSSs
- 3 candidates + 1 TDEs (Sacchi+2023)

HSSs in the Chandra archive

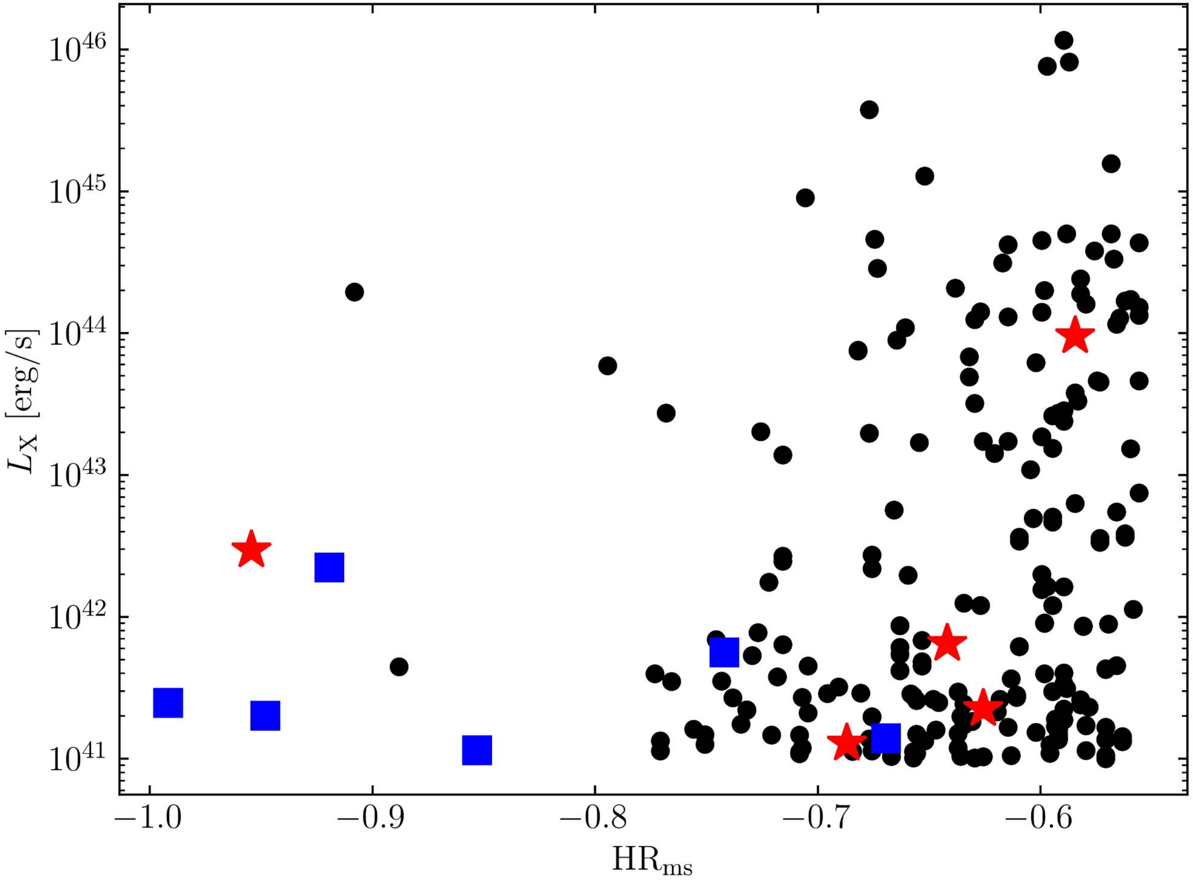
- ~ 1.3M (detections) in CSC2.1
- S/N + HR (mid-soft band) + Flux
- Crossmatch with SIMBAD: redshift + classification
- Let’s filter!

Filtering algorithm

- Supersoft: HR<-0.55 (Γ>3)
- Hyperluminous: L_X>1e41 erg/s
- “Good quality”: S/N>7 (soft band)

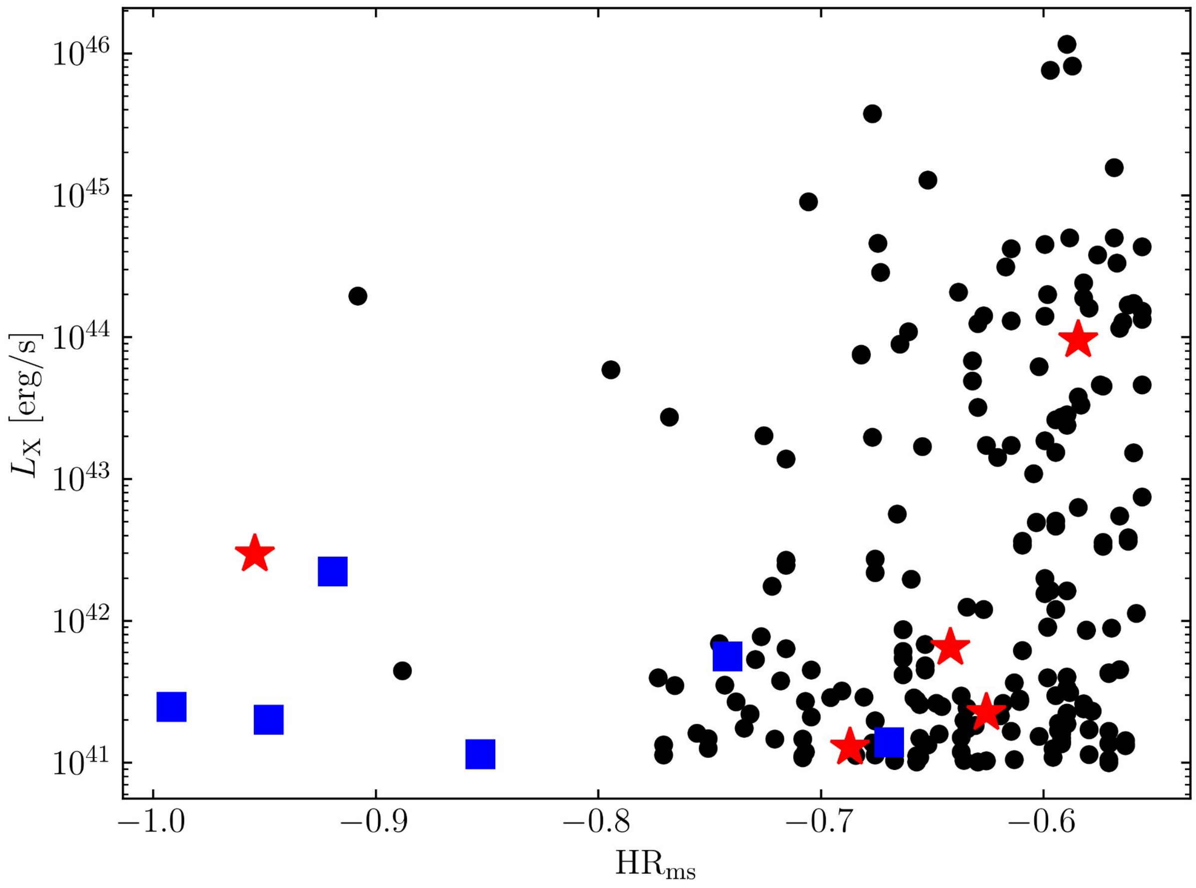
Filtering some more

- 125 sources (222 obs)



Filtering some more

- 125 sources (222 obs)
- 114 excluded



Filtering some more

- 125 sources (222 obs)
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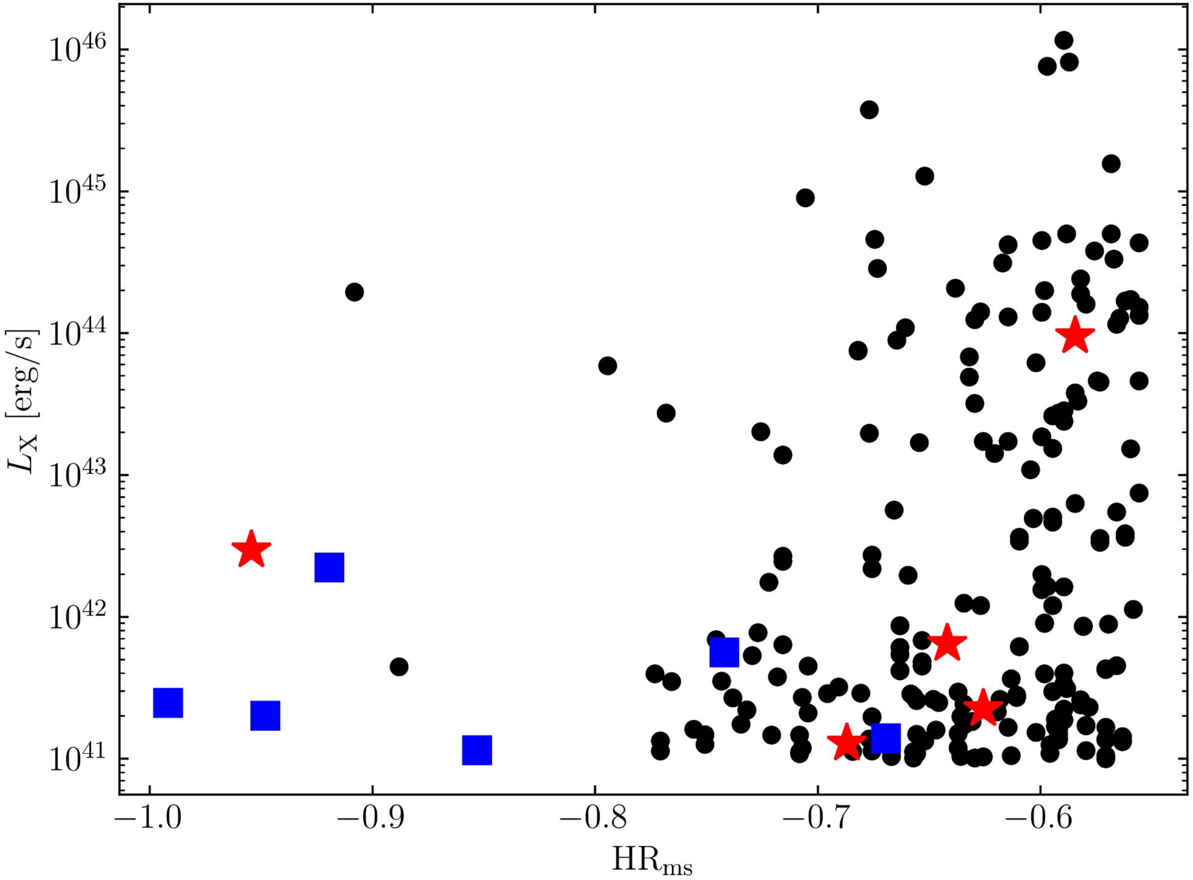
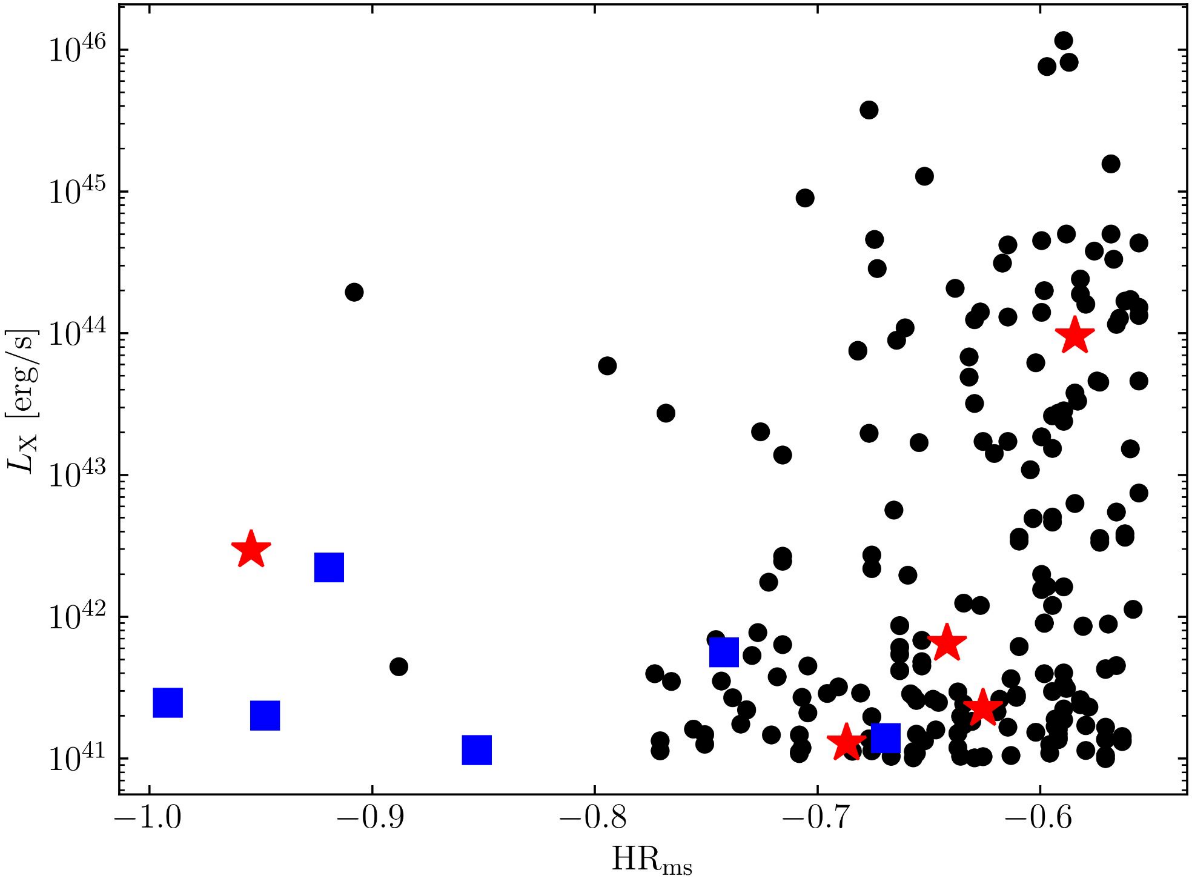
- 6 known HSSs (■)



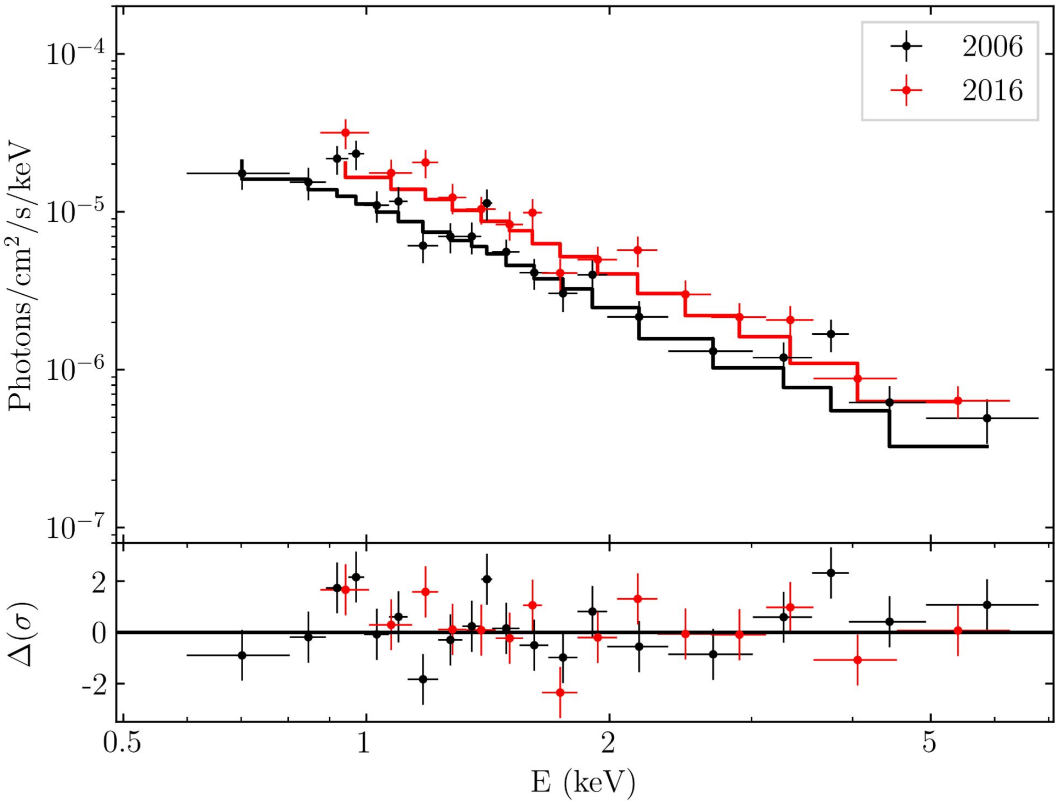
Filtering some more

- 125 sources (222 obs)
- 114 excluded
- 6 known HSSs (■)
- 5 final candidates (★)



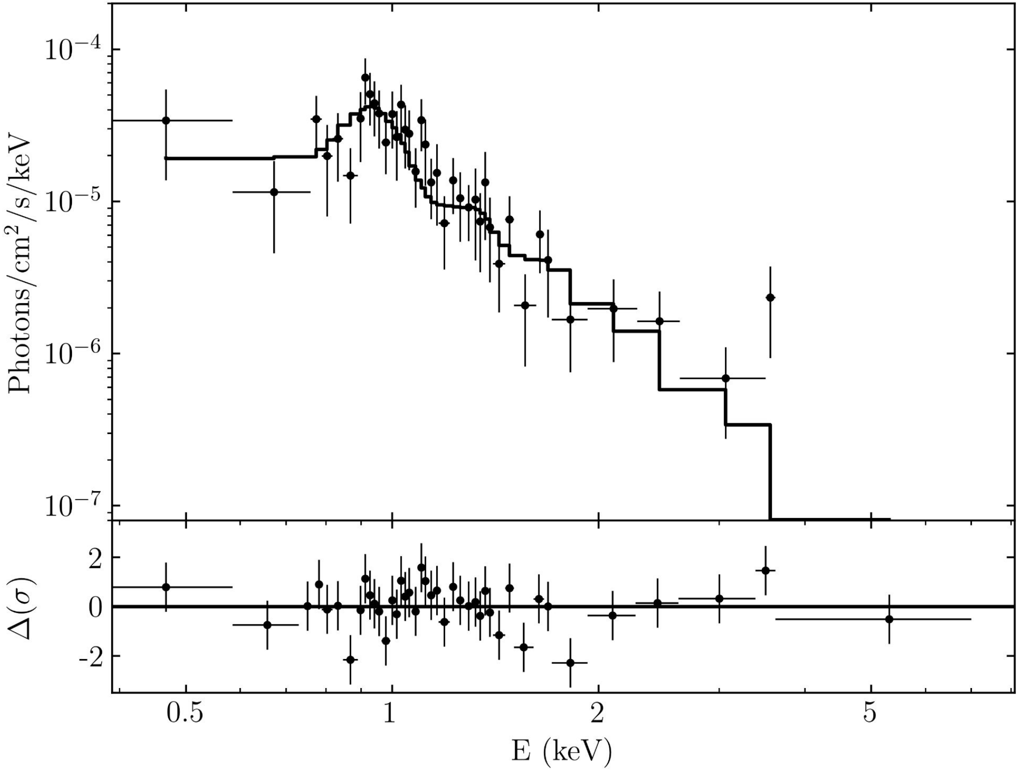
5 final candidates

- 1 AGN
  - $\Gamma \sim 2$
  - $L_X \sim 5e43$ erg/s
  - Little variability



5 final candidates

- 1 AGN
  - Γ~2
  - L_X~5e43 erg/s
  - Little variability
- 3 XBONG
  - Apec profile
  - L_X~1e41 erg/s
  - Stable emission

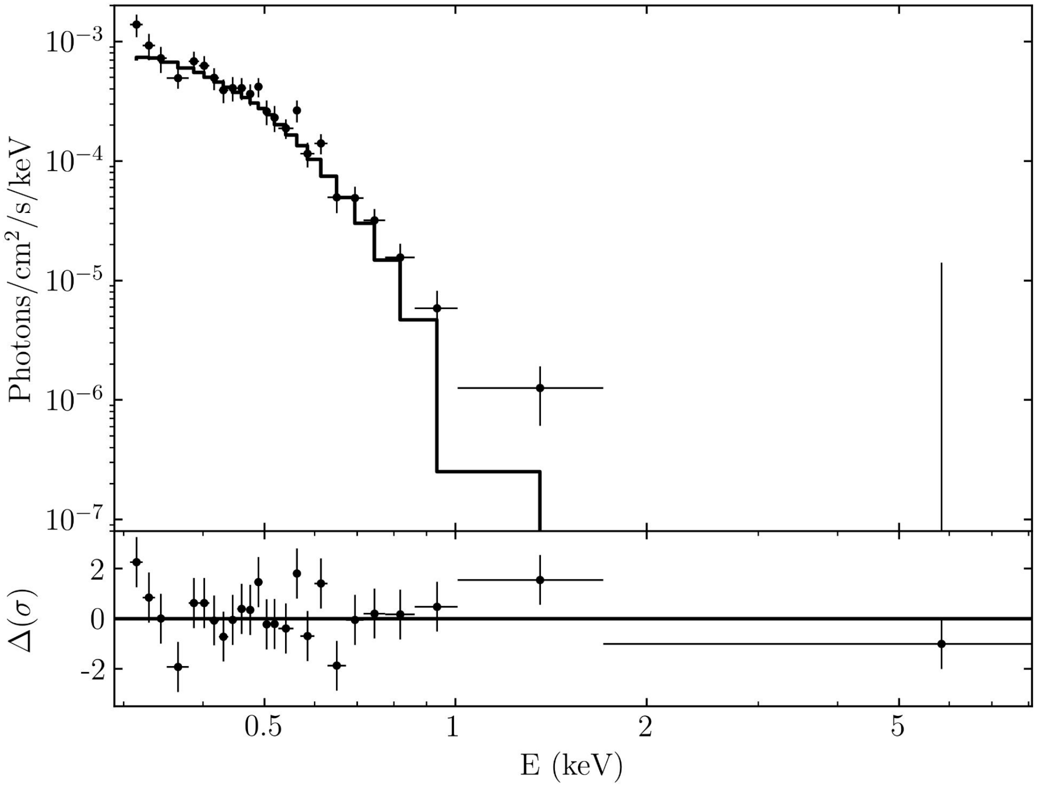


5 final candidates

- 1 TDE: J1035+57
  - L_X~2e42 erg/s
  - z ~ 0.1
  - kT ~ 90 eV
  - Strong variability:

    Detection in 2002

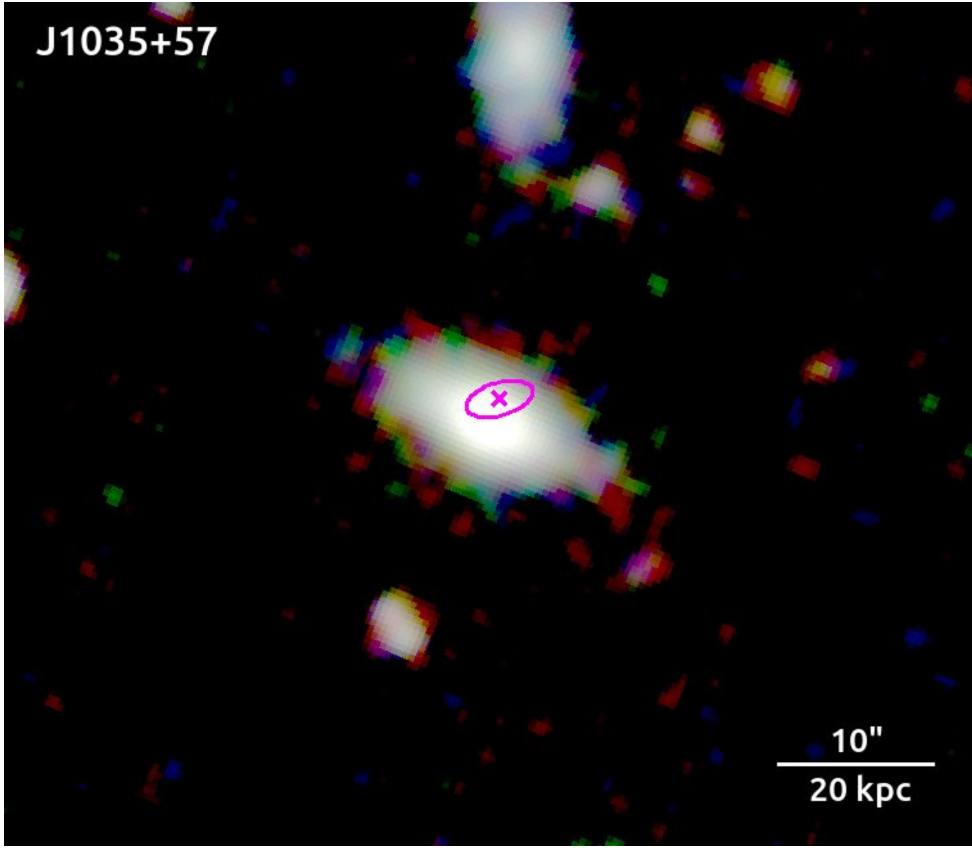
    UL(2001)~1.5e41 erg/s



5 final candidates

- 1 TDE candidate: J1035+57
  - M_{BH}=1e8-1e9 Msun

    - M_{gal}–M_{bh} outlier
    - TDE+IMBH



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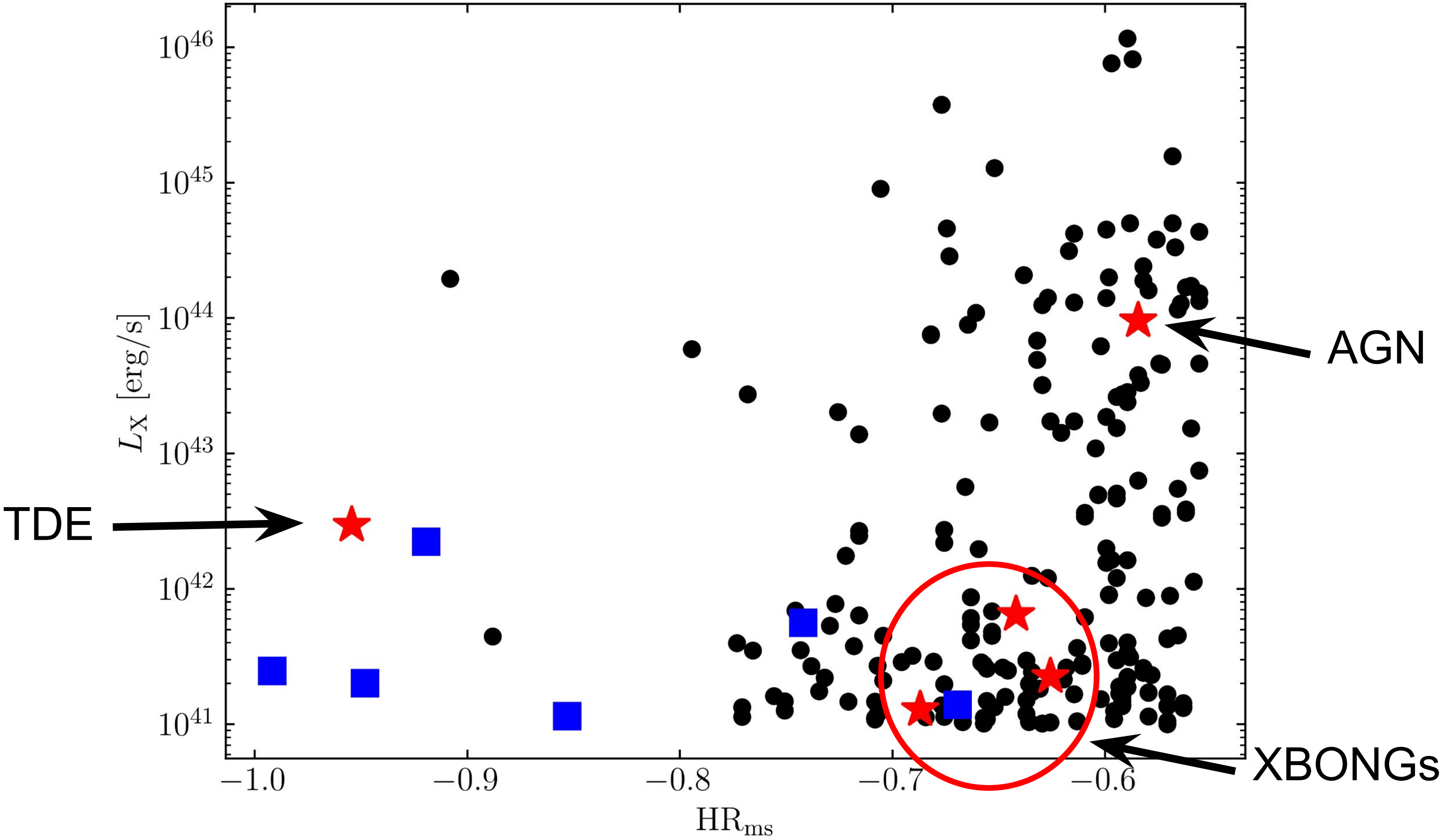
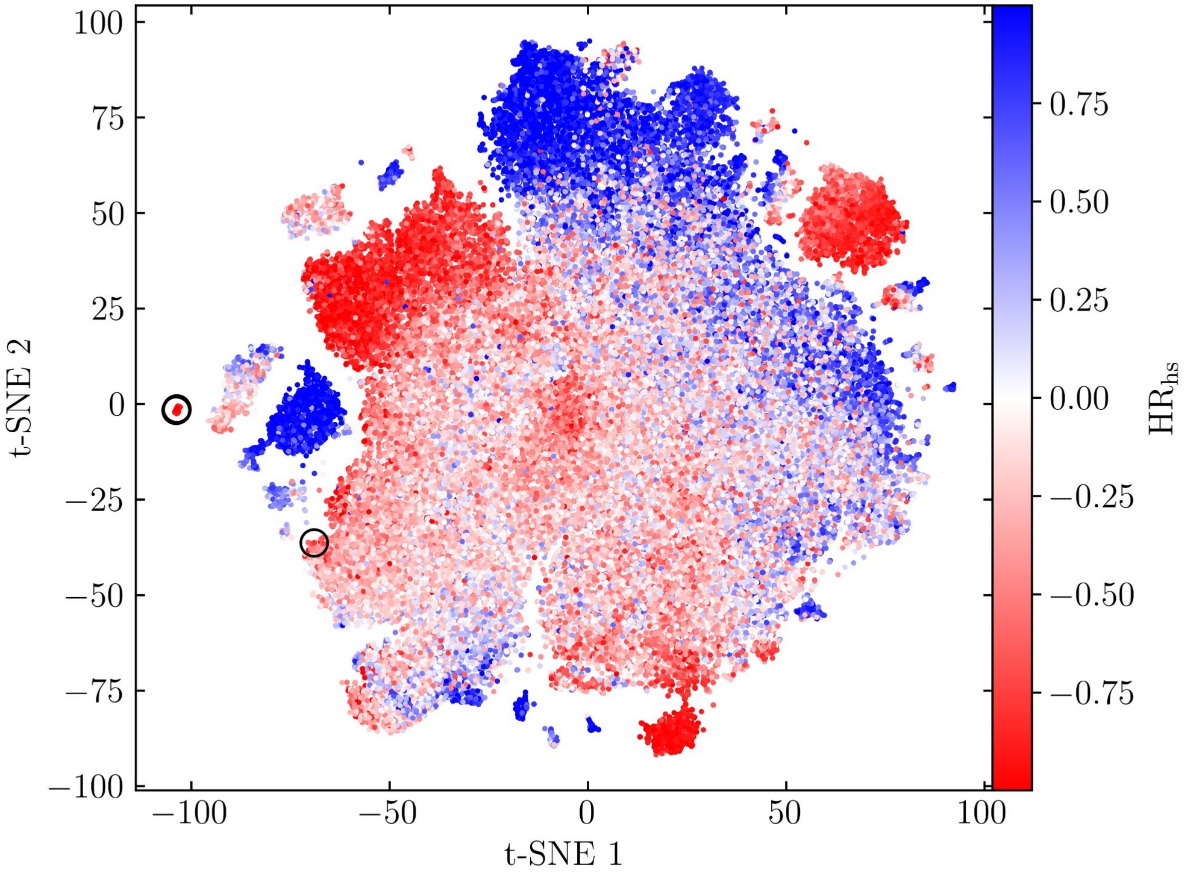
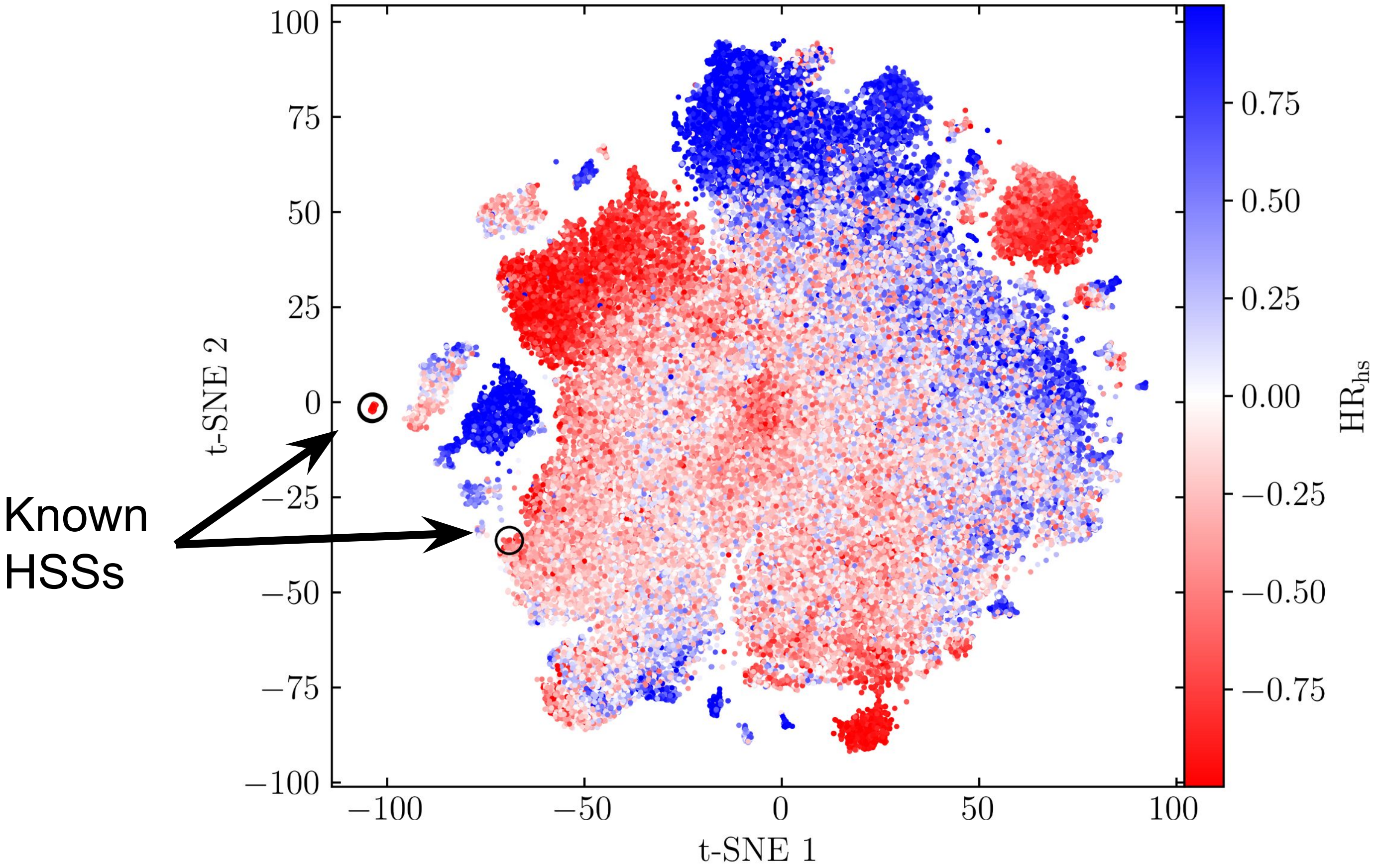


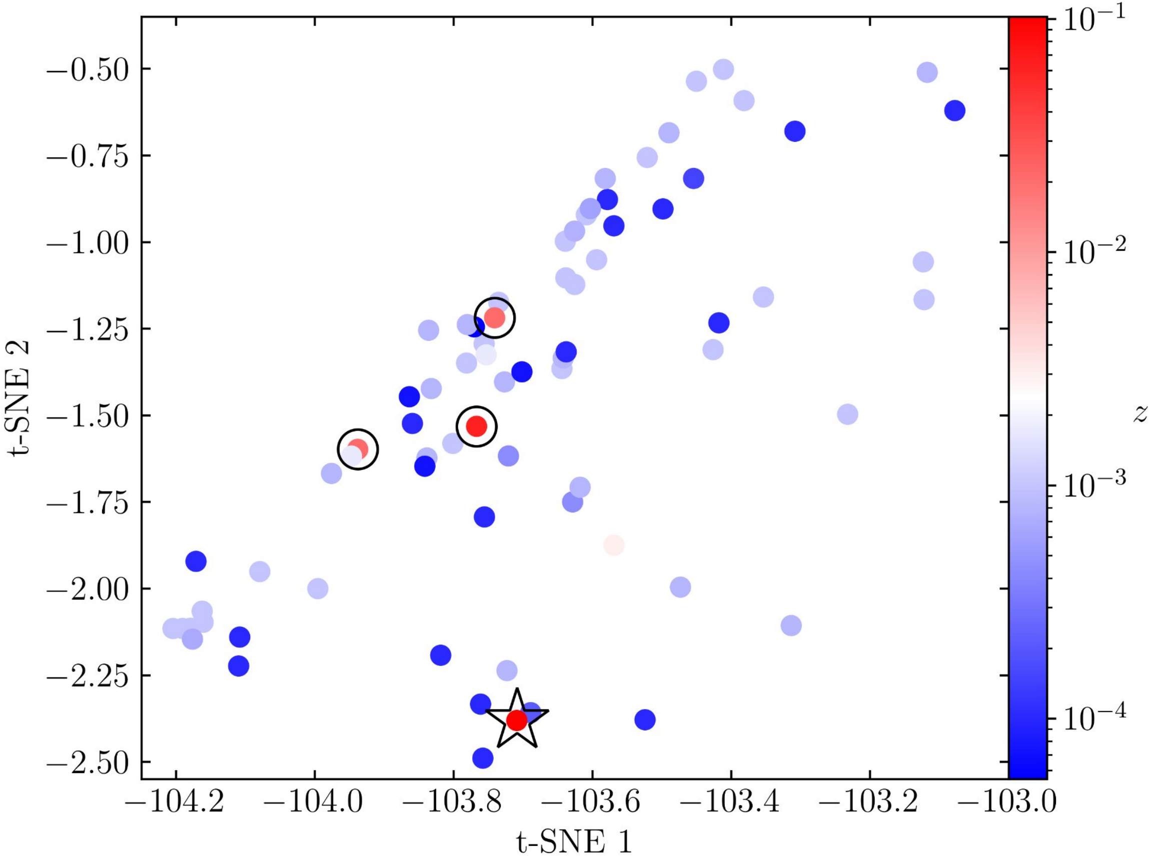
Can we play smarter?



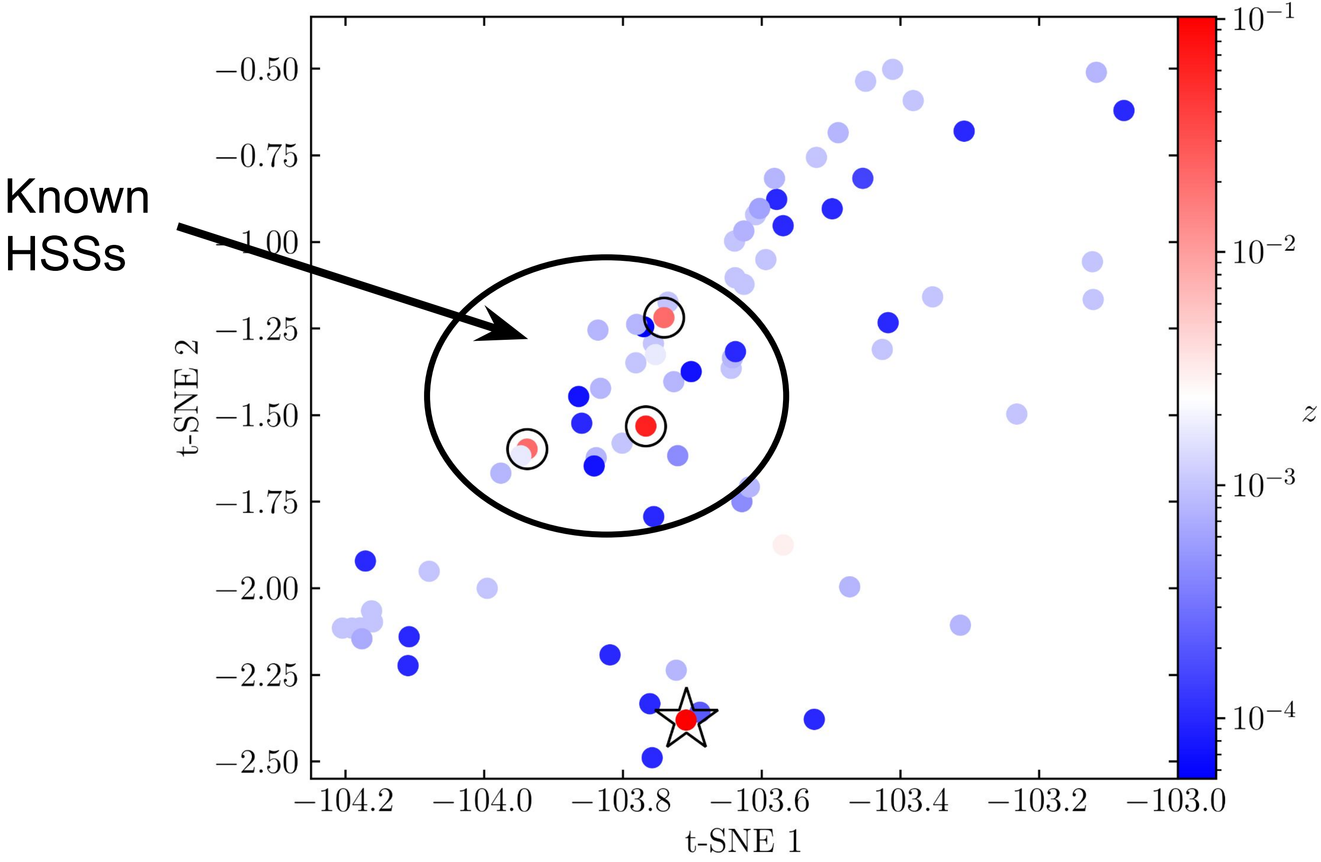
Can we play smarter?



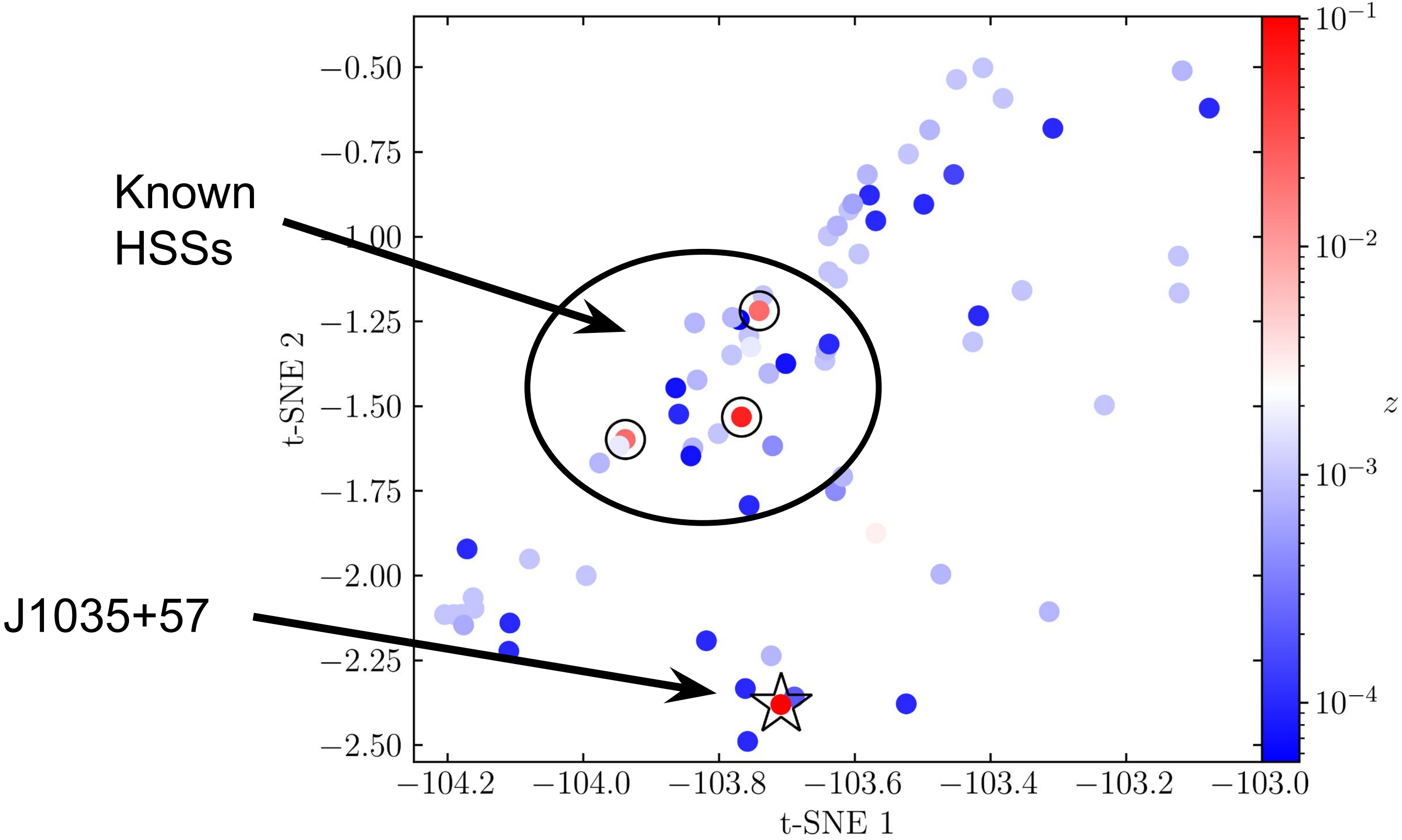
Can we play smarter?



Can we play smarter?



Can we play smarter?



Conclusions pt.2

- Archival searches are cool (and free)!
- 1 new TDE (on an IMBH?) found in the CSC
- ML method can help exploiting the full potential of available catalogues

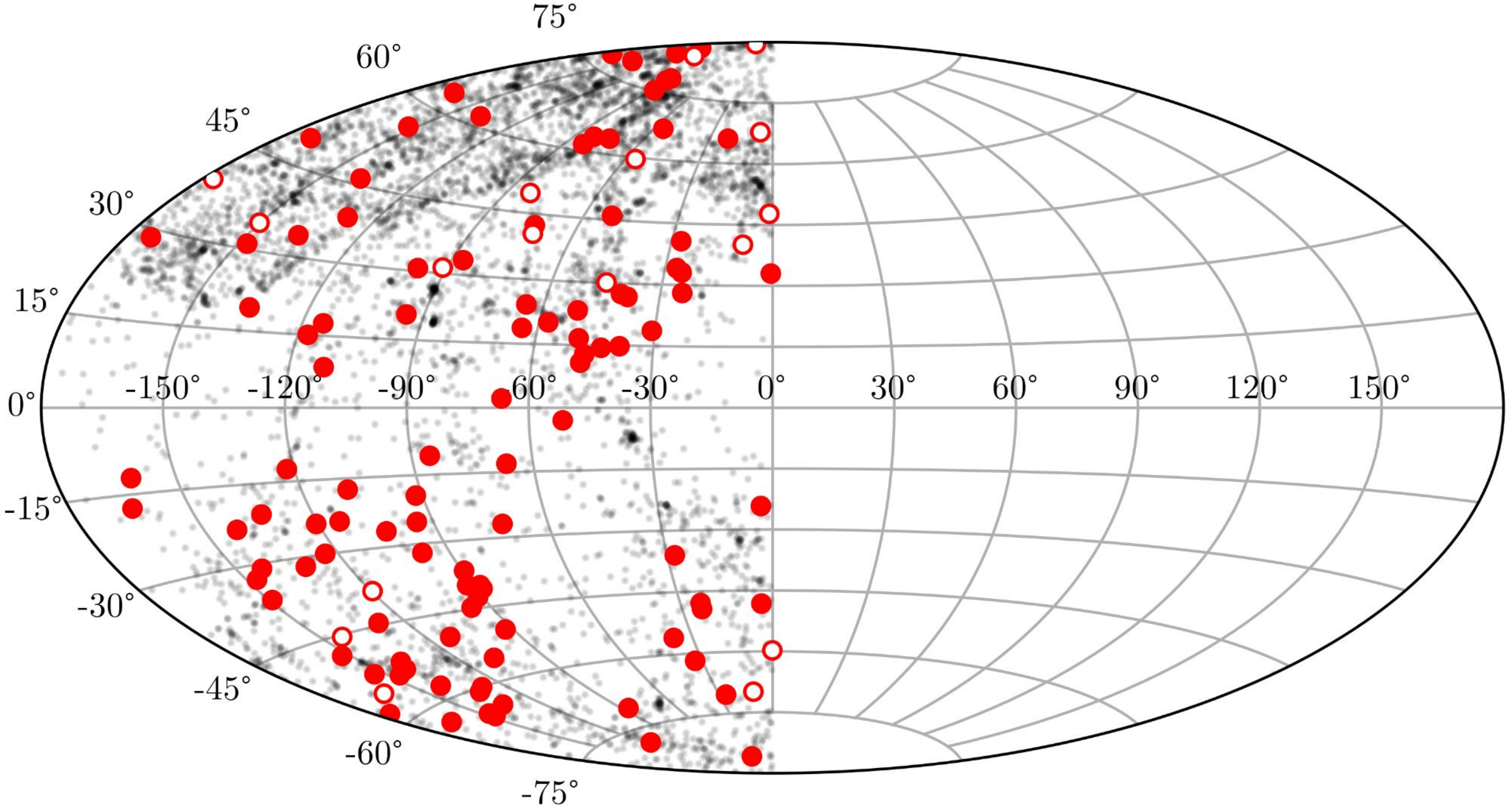
Sacchi+2025b →

Conclusions for real

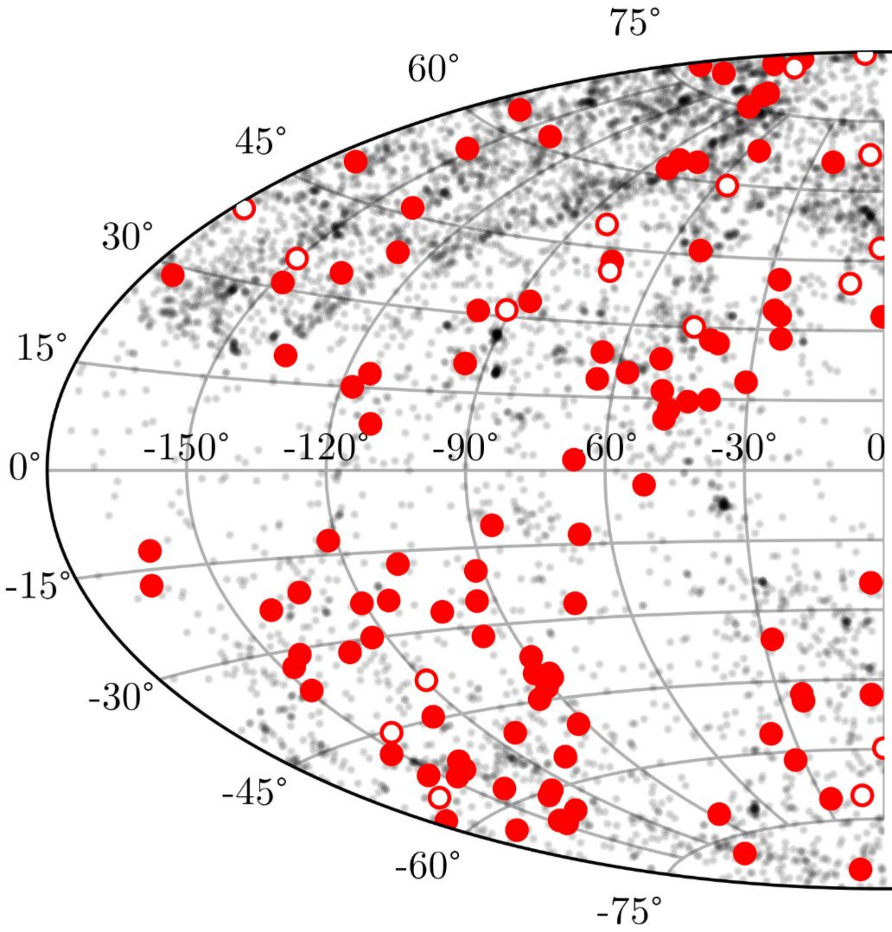
- IMBHs are key to learn how BHs are formed and grow
- The X-ray band is particularly suited to find (accreting) IMBHs
- Archival searches can still bring forth hidden gems
- Especially if powered by a clever usage of ML tools

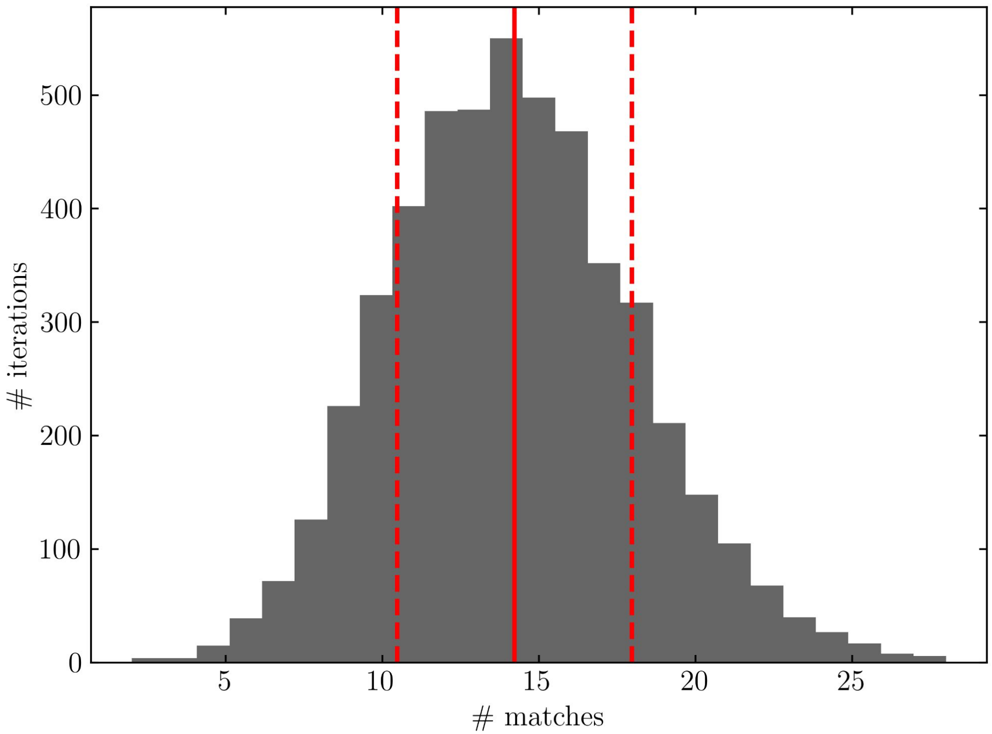
Backup slides

Background AGN



Background AGN





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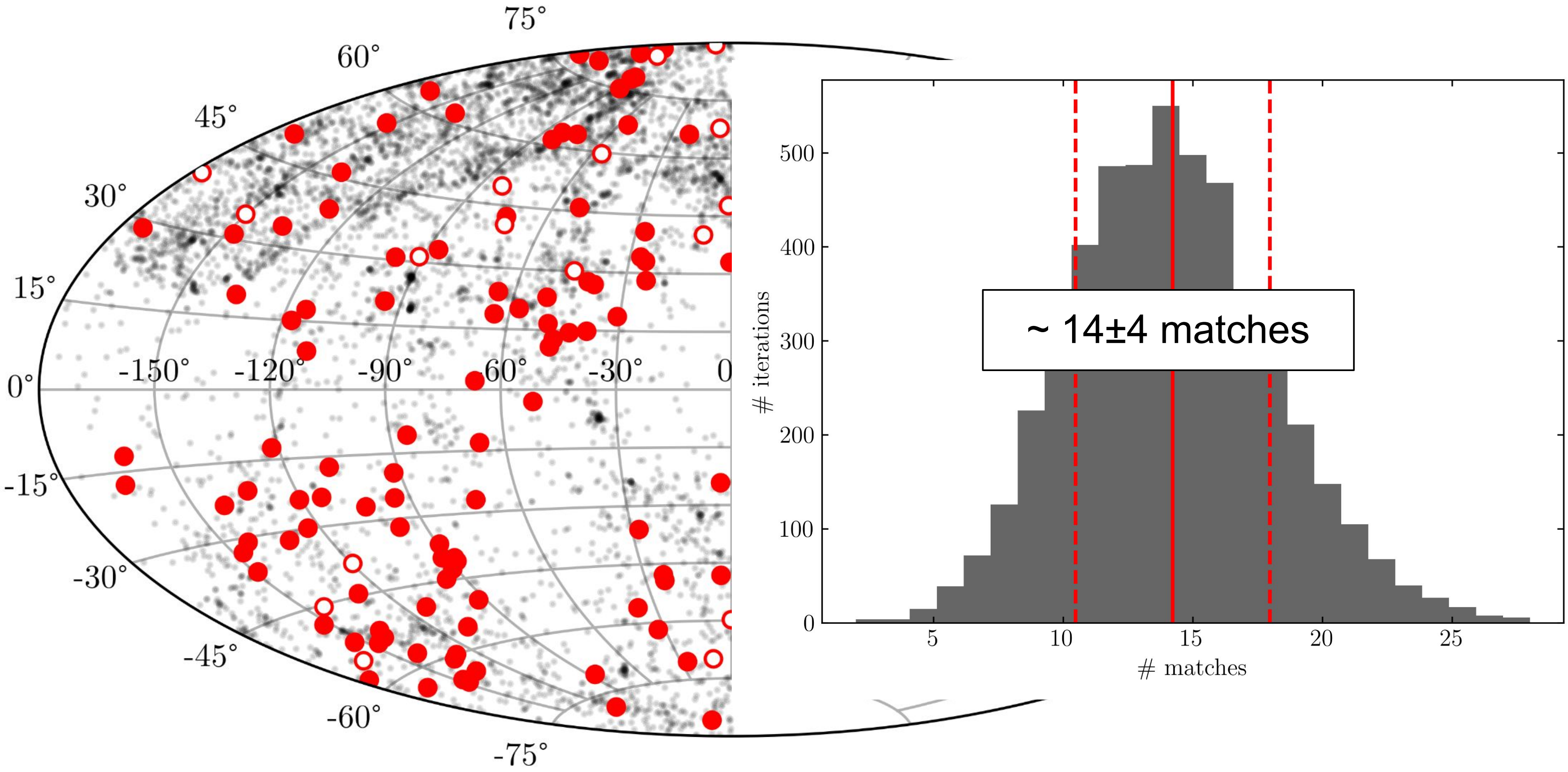

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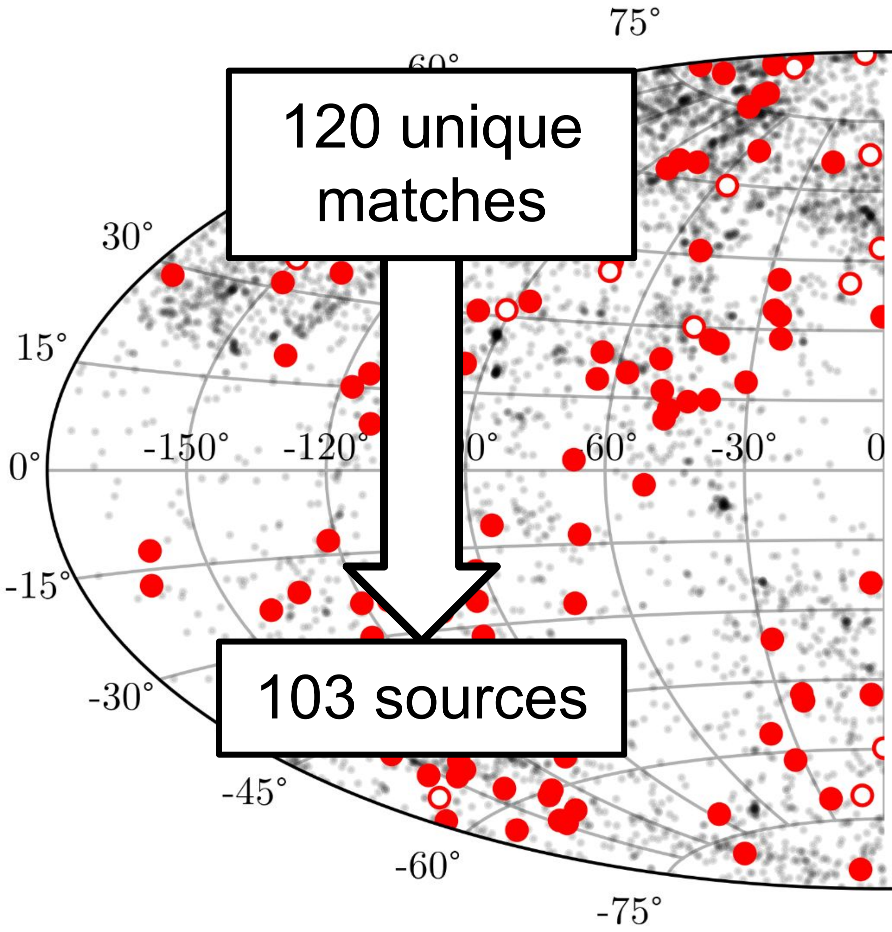

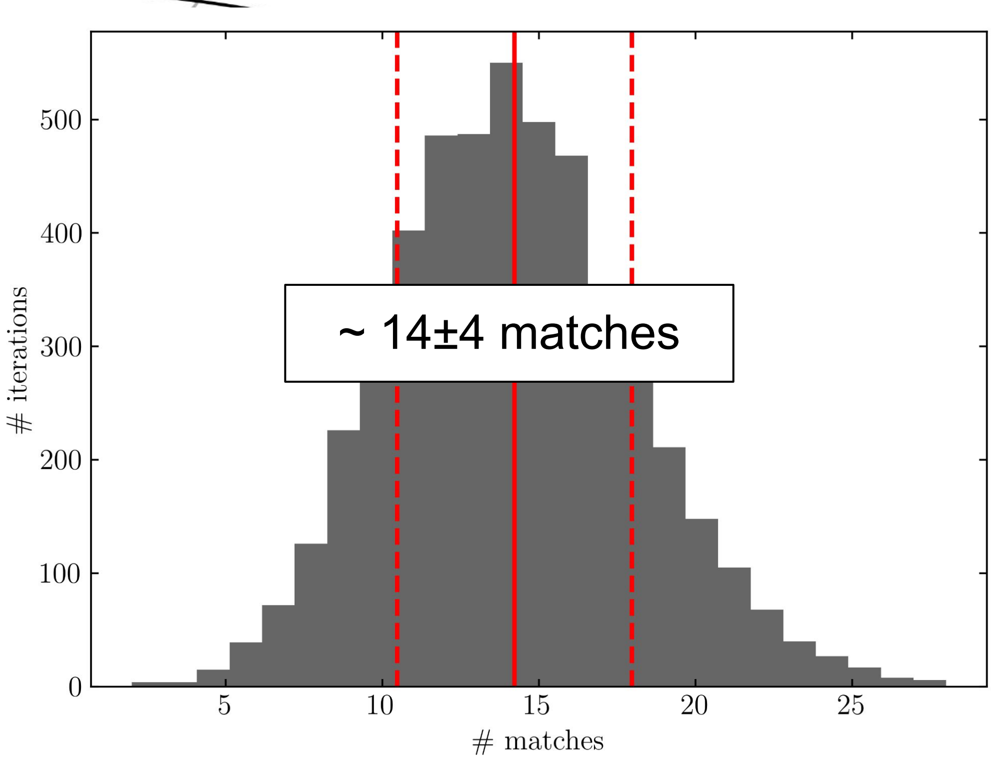

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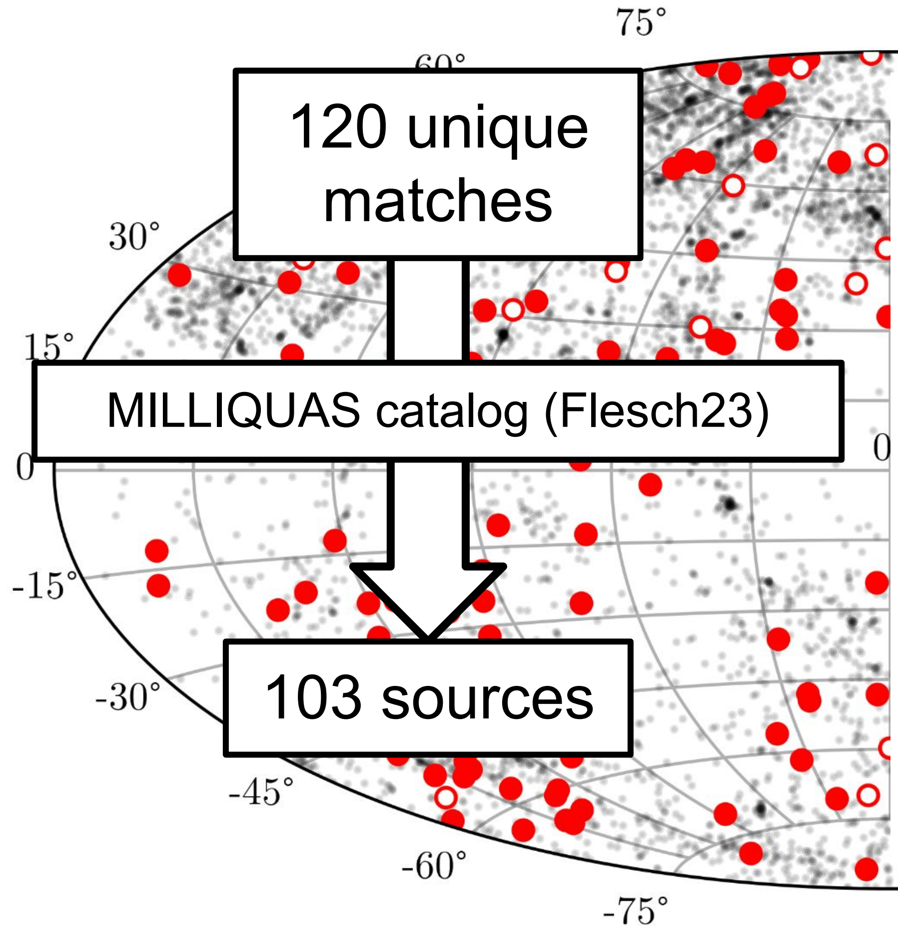
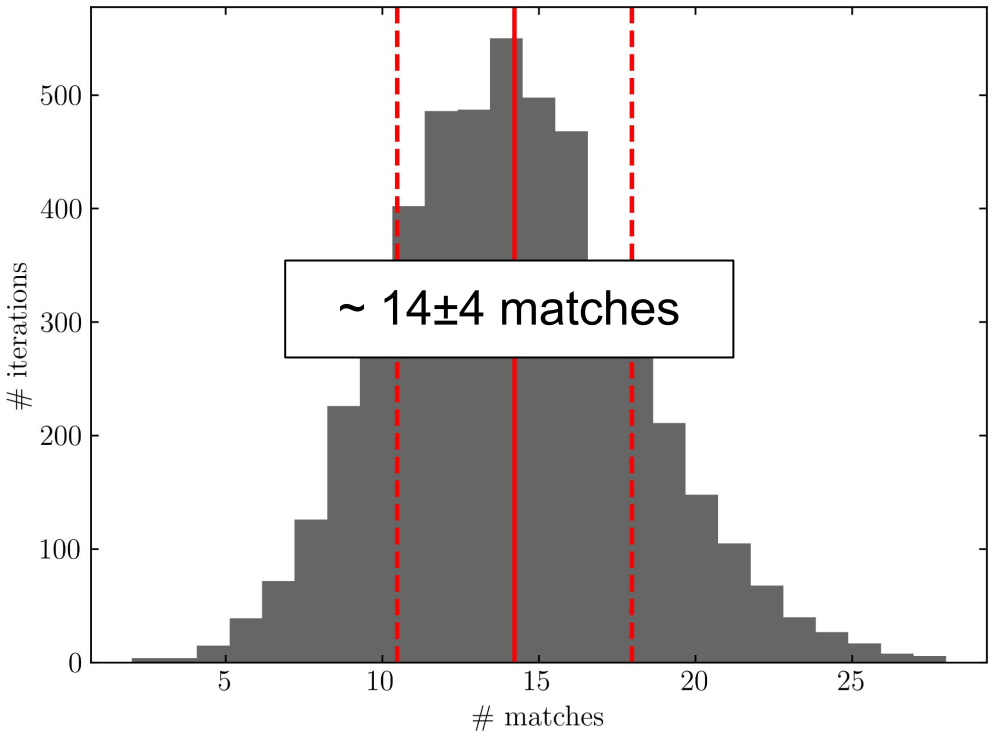


120 unique matches

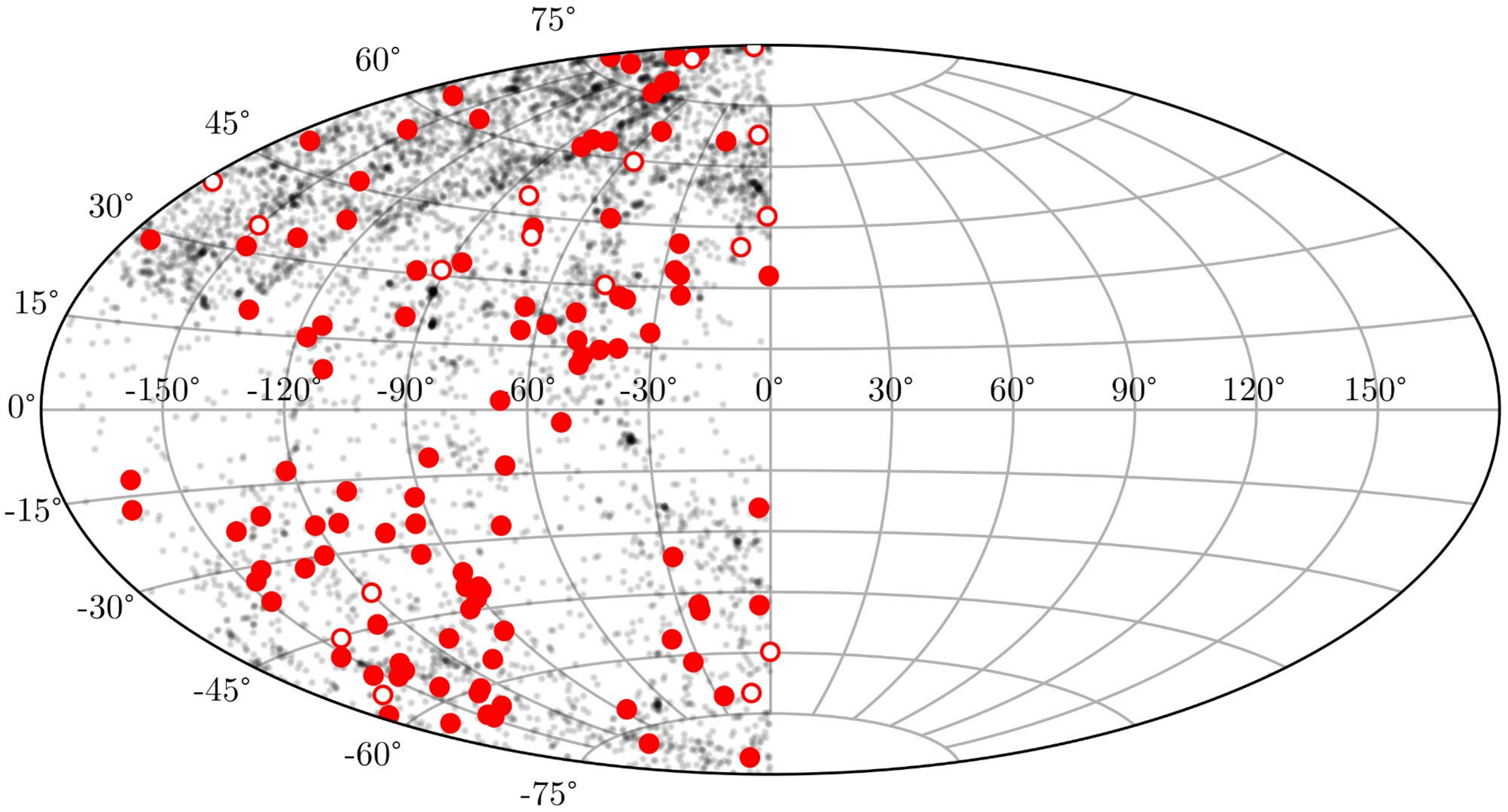
MILLIQUAS catalog (Flesch23)

103 sources

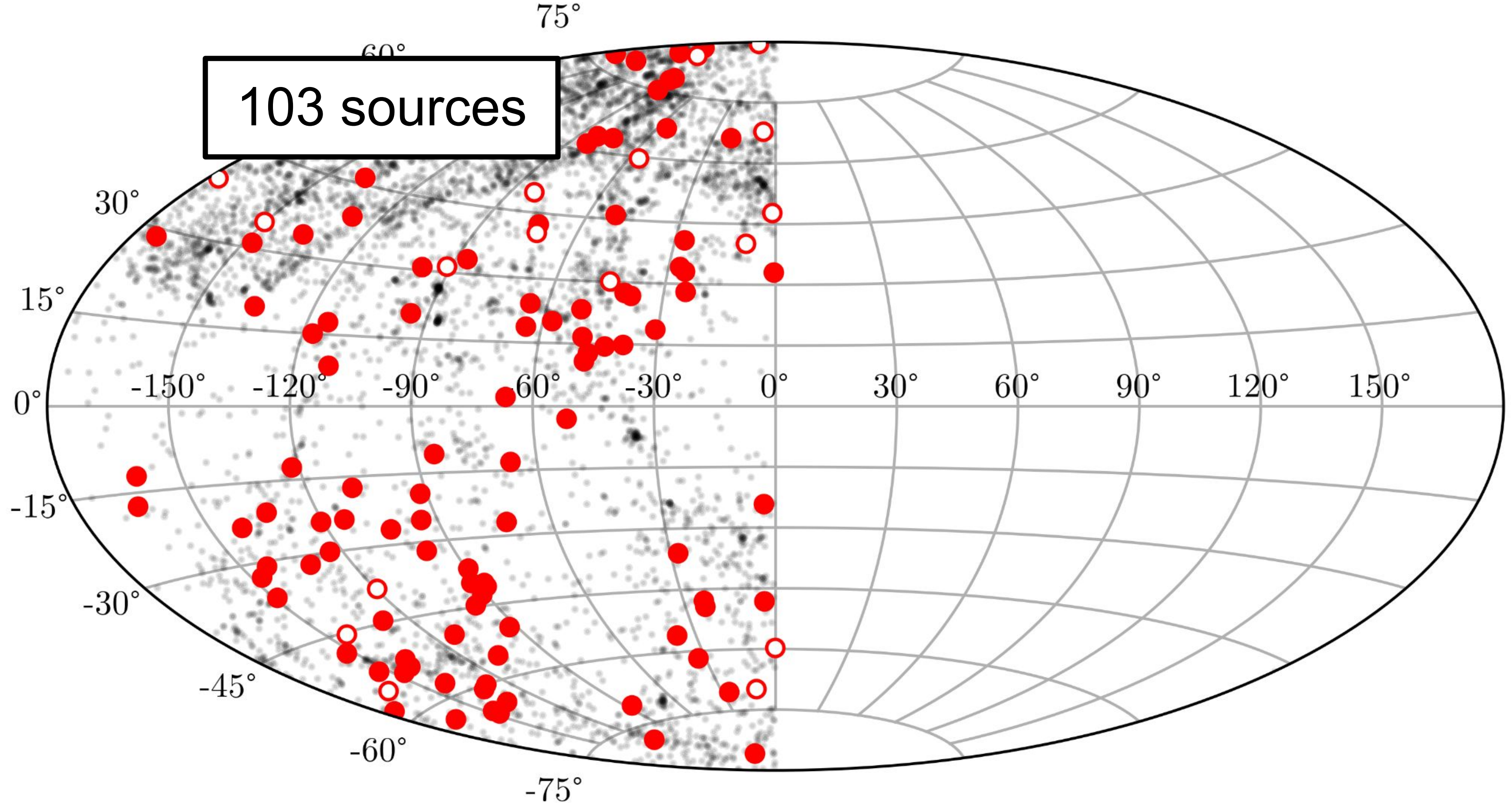


~ 14±4 matches

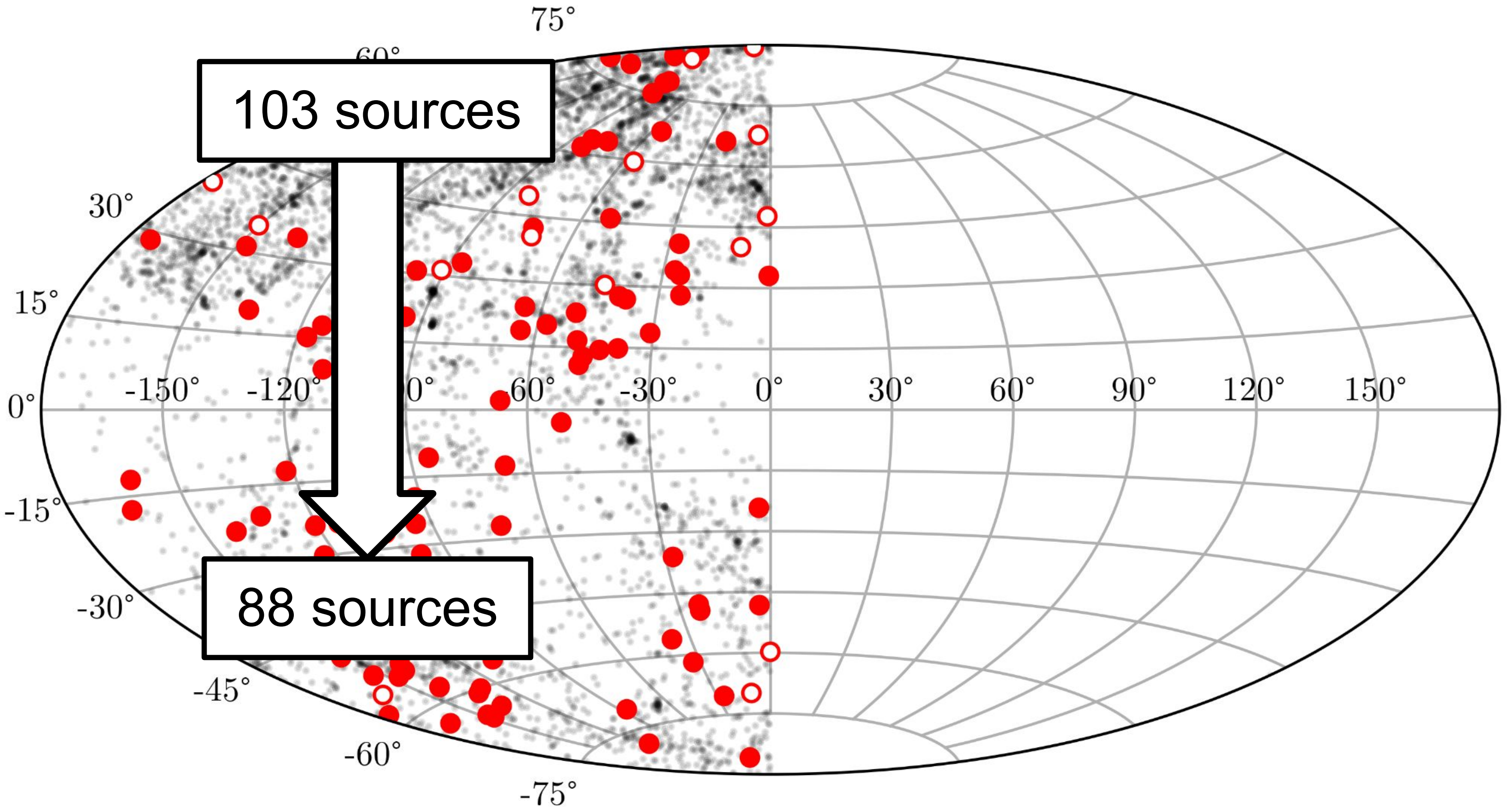
Unresolved XRBs



Unresolved XRBs



Unresolved XRBs



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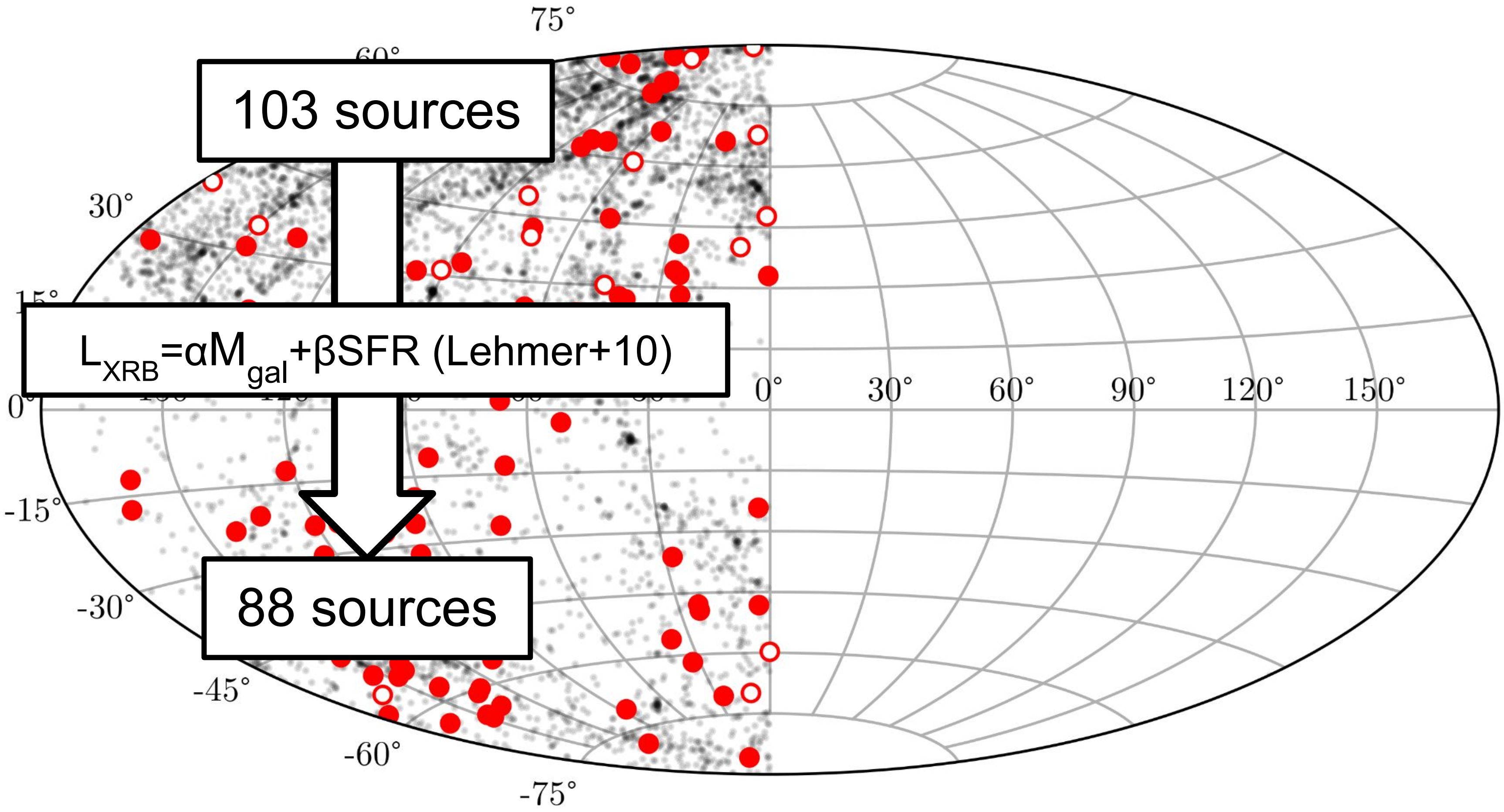

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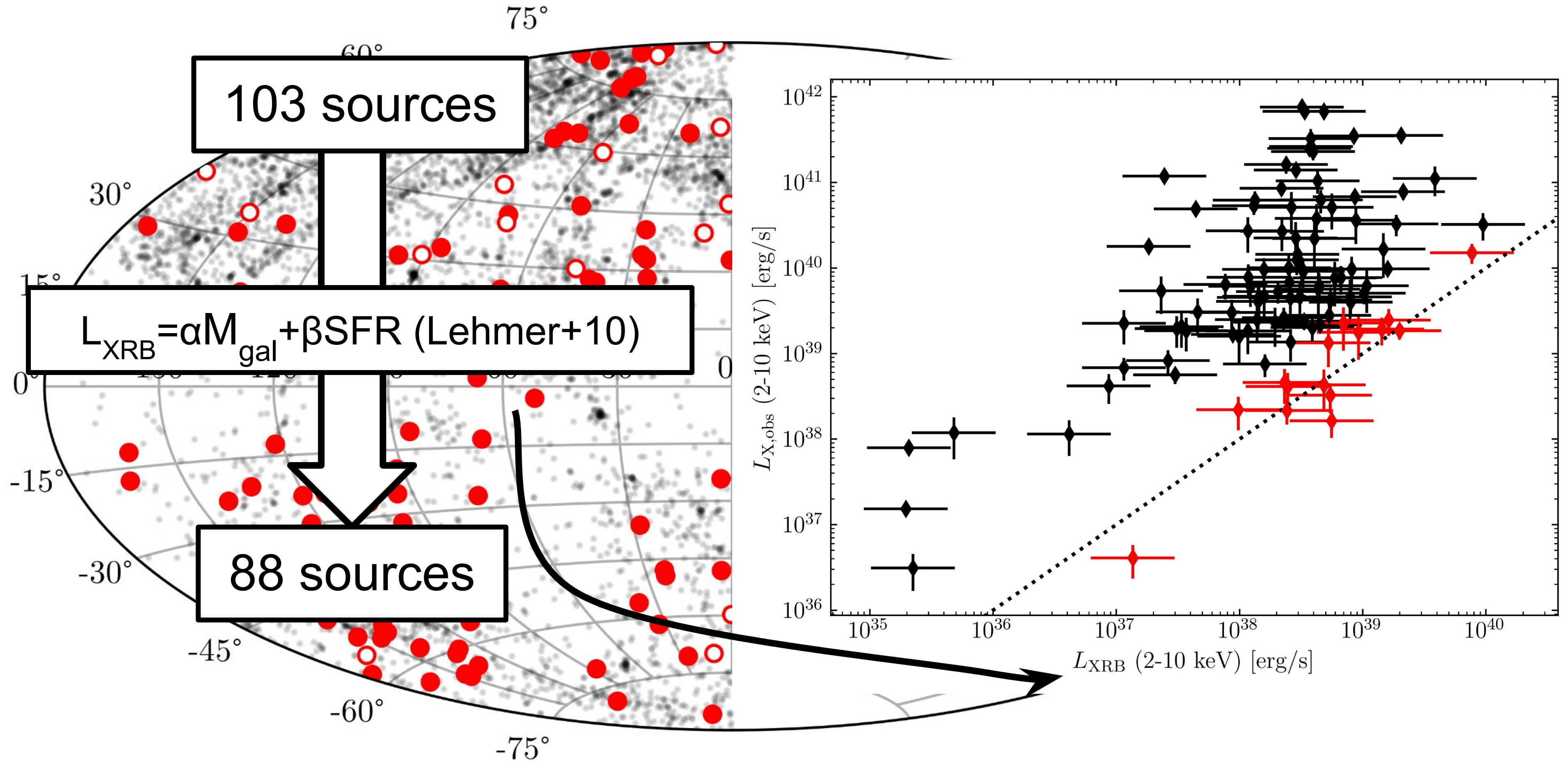
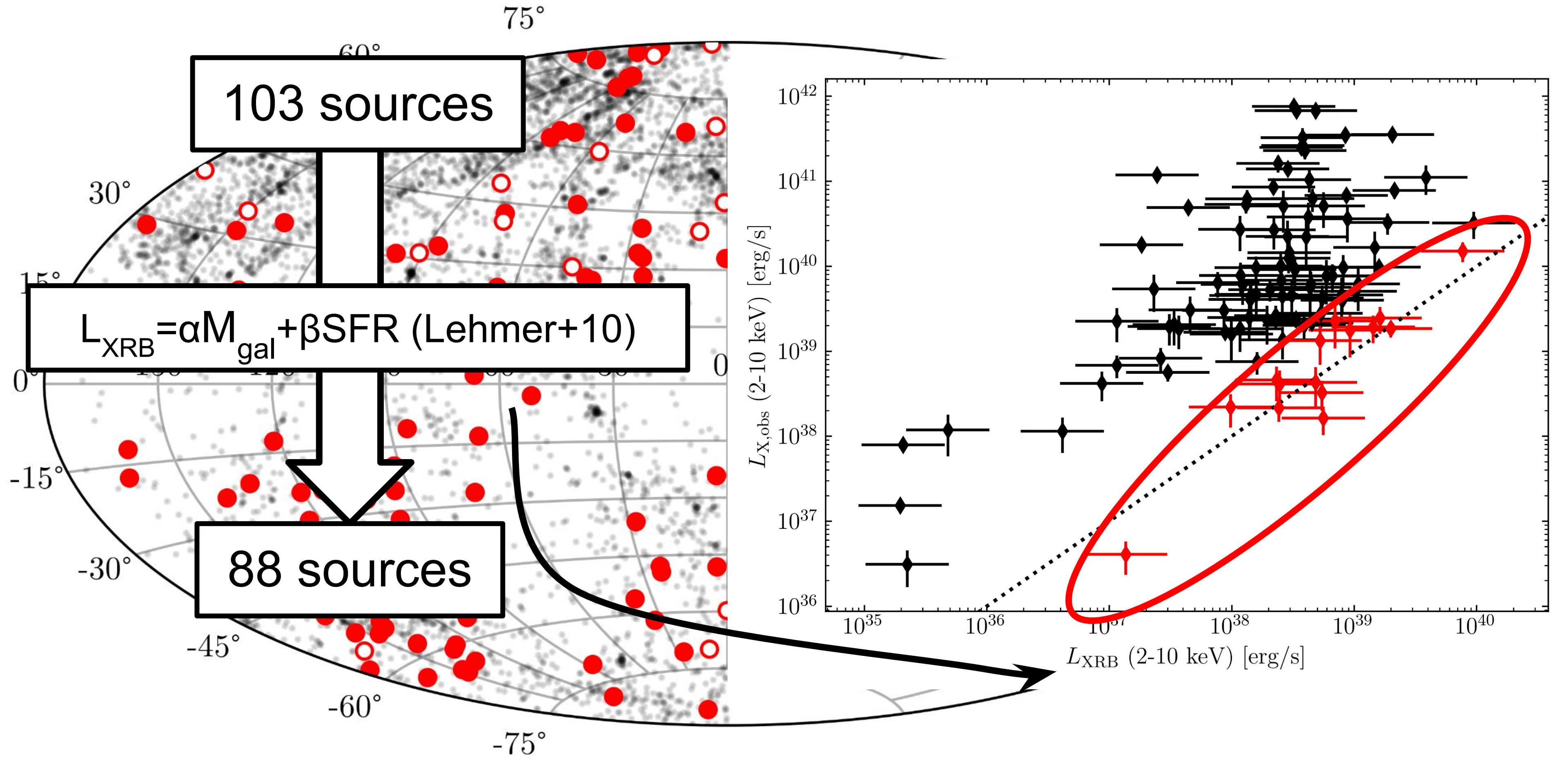
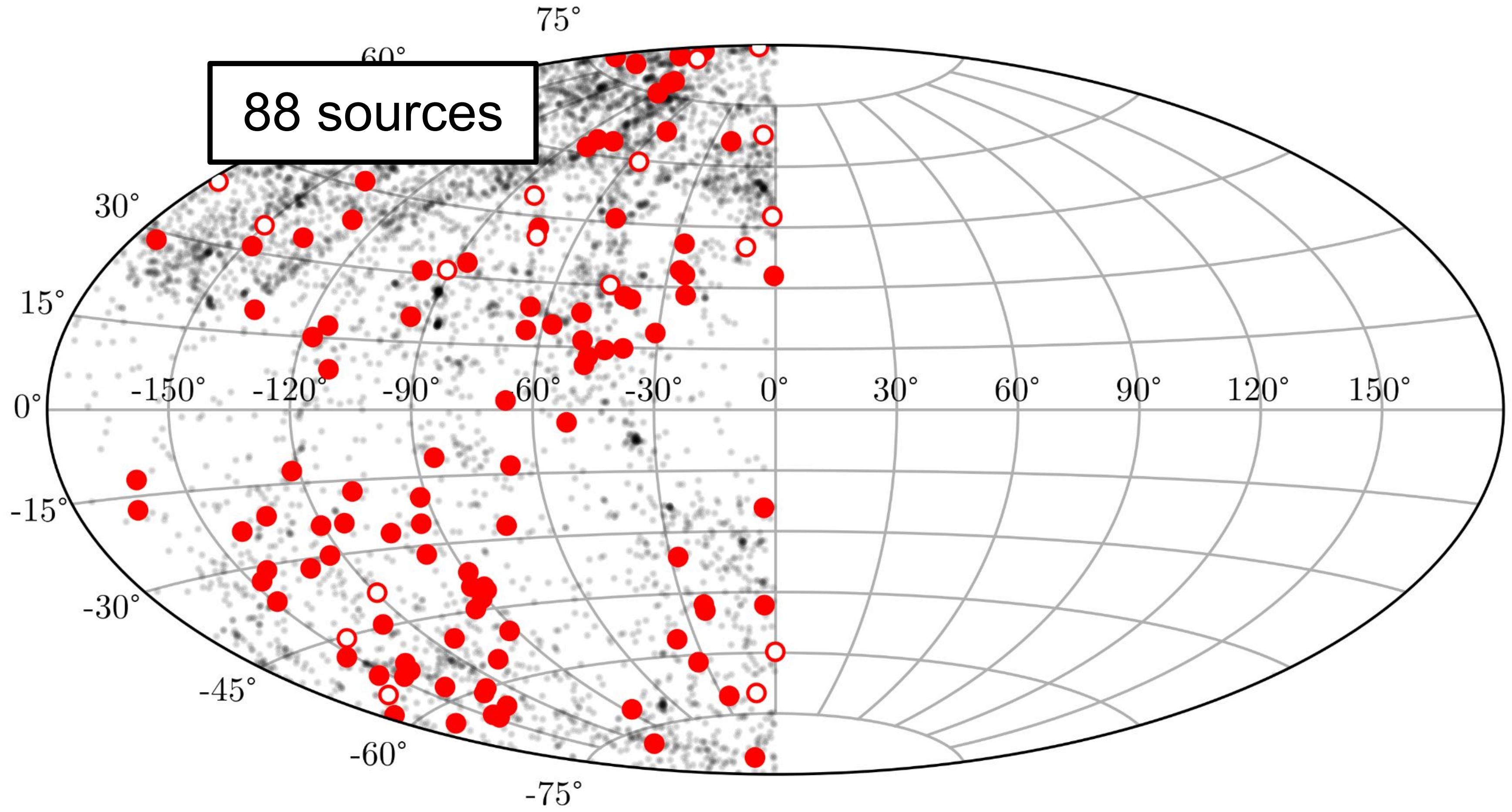


Unresolved XRBs

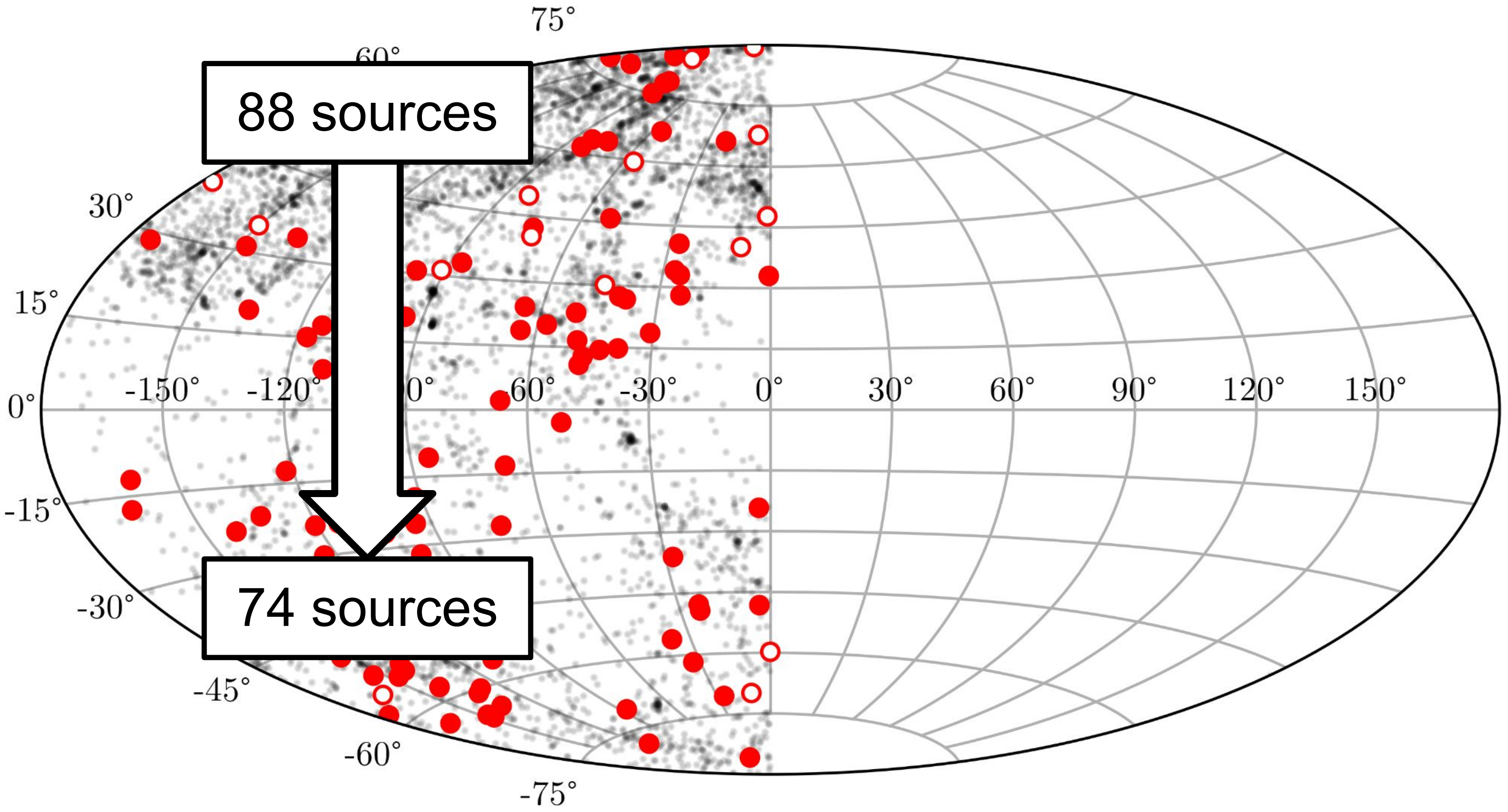


Resolved ULXs

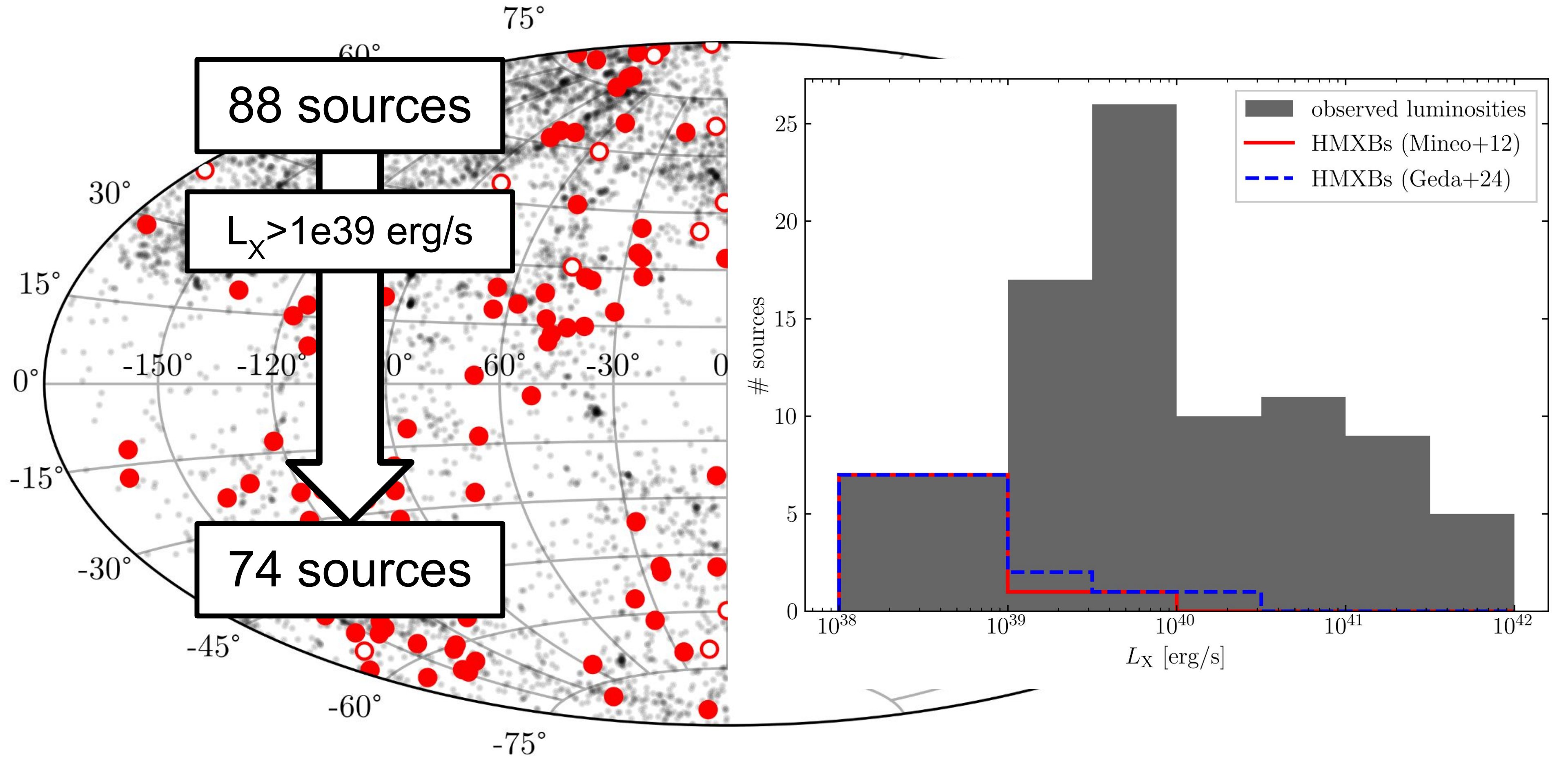
88 sources



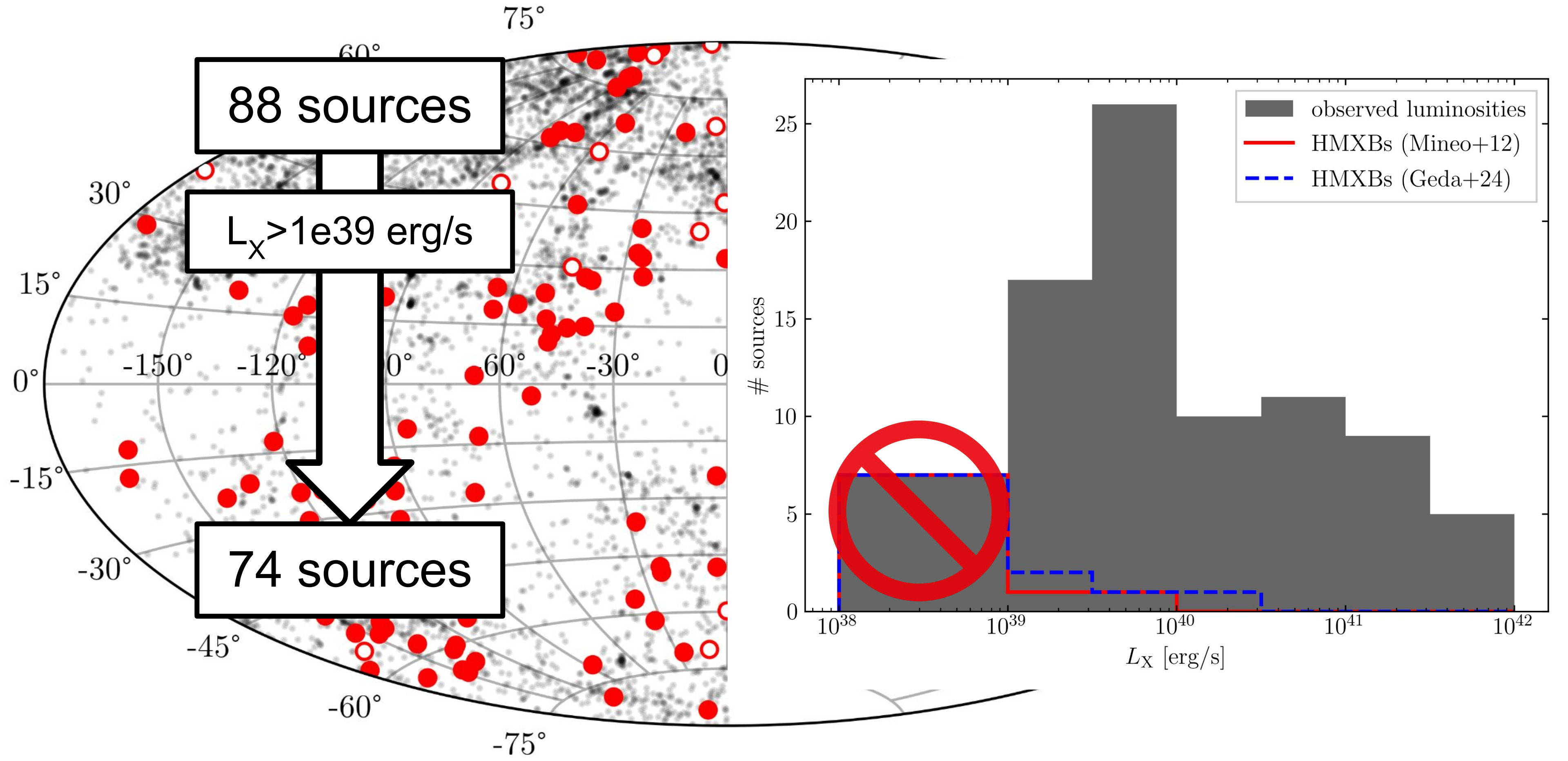
Resolved ULXs



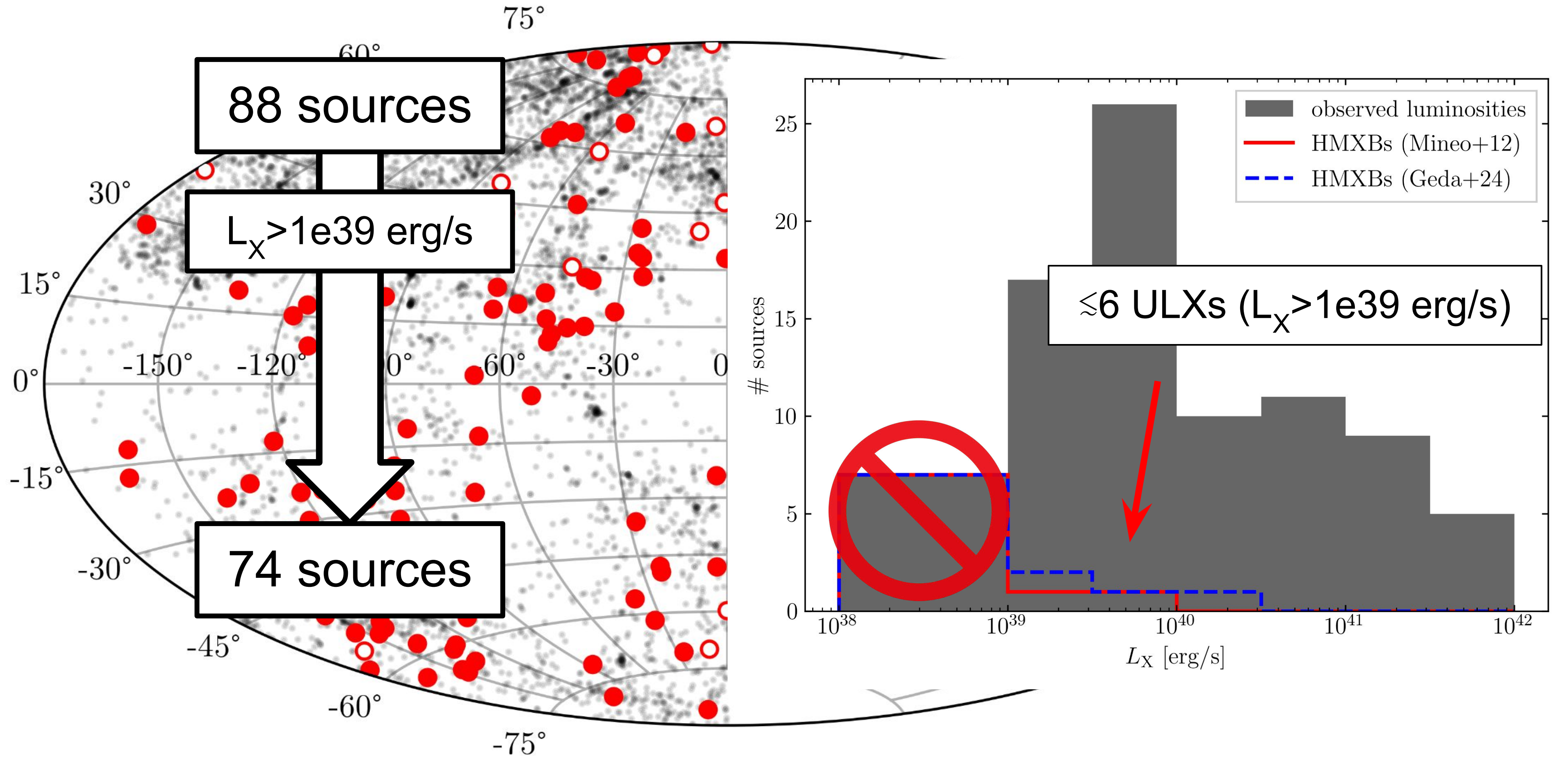
Resolved ULXs



Resolved ULXs



Resolved ULXs



Resolved ULXs