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ComPACT: ACT+Planck galaxy cluster catalogue

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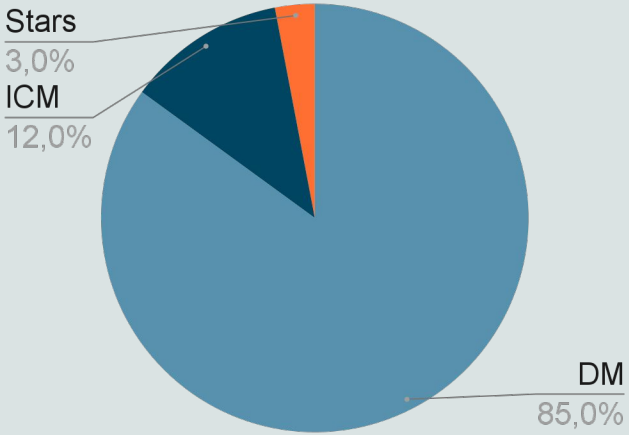
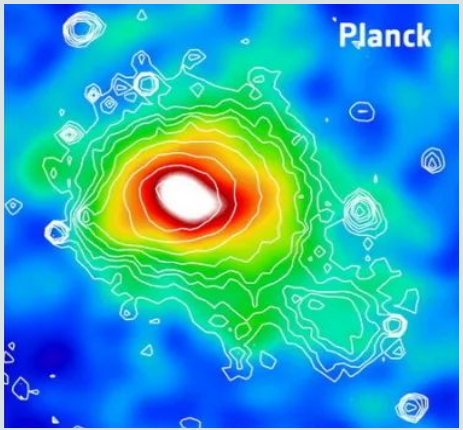
Galaxy clusters are the most massive gravitationally bound objects





The Coma cluster in the microwave range (Credit: Planck)

Catalogue of galaxy clusters in SZ

Main sky surveys in the microwave range:

- The Atacama Cosmology Telescope (ACT) ~18000 deg2
- Planck full sky
- The South Pole Telescope (SPT) ~2500 deg2

Hilton et al.

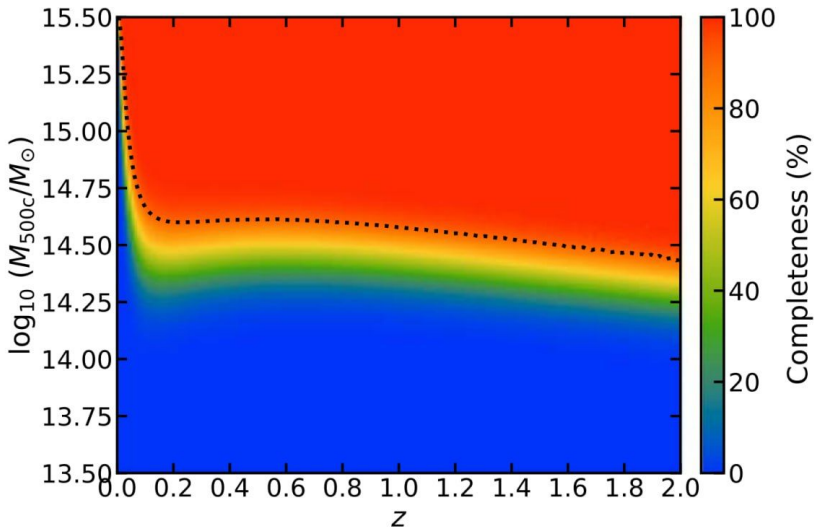
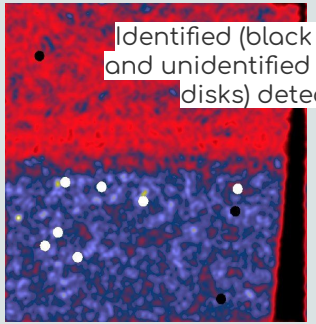


Figure 7. Completeness for $S/N_{2.4} > 5$ as a function of redshift, in terms of M_{500c}^{UPP}, over the full 13,211 deg^2 survey footprint. The Tinker et al. (2008) halo mass function and Arnaud et al. (2010) scaling relation are assumed (see Section 2.4). The dashed black contour marks the 90% completeness limit.

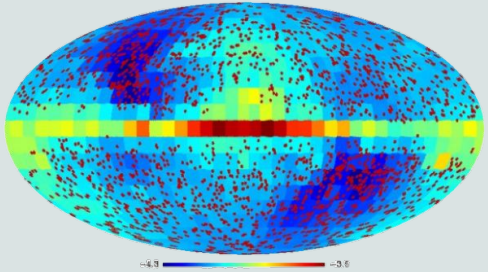
Different approaches to detect new galaxy clusters

Combining microwave data collected on different telescopes



PSZSPT (Mellin+ 2021)

Total: 419 clusters
New with respect to PSZ and SPT: 54



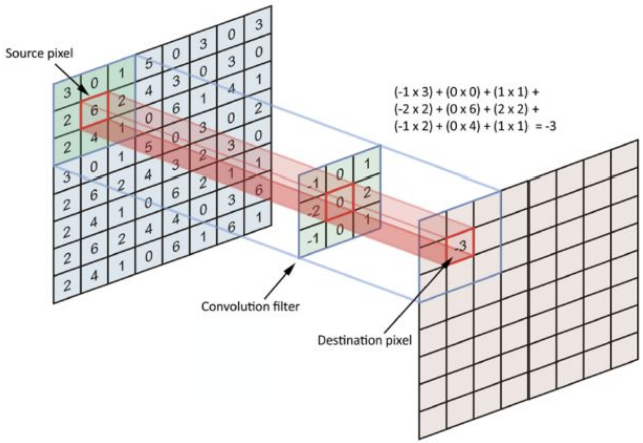
ComPRASS - combining microwave and X-ray data collected at the telescopes: Planck and RASS (Tarrío+ 2019)

Total: 2323 clusters
New with respect to PSZ and SPT: 514

Multi-Component Matched Filter cluster confirmation algorithm (MCMF)

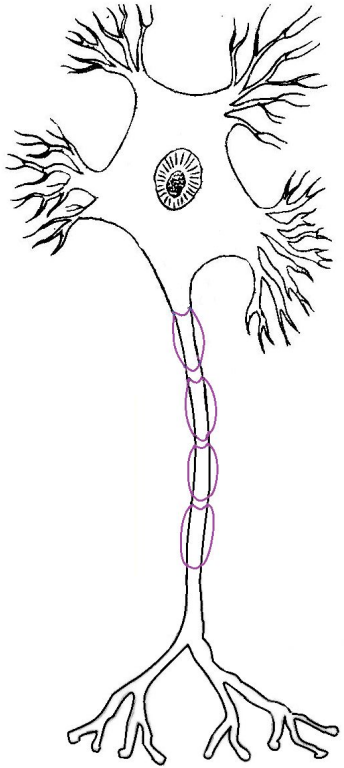
	New
SPT-SZ MCMF (Klein+ 2023)	324
PSZ MCMF (Hernández-Lang+ 2023)	589

Neural networks are efficient for pattern recognition



Analogy with object recognition by the human brain

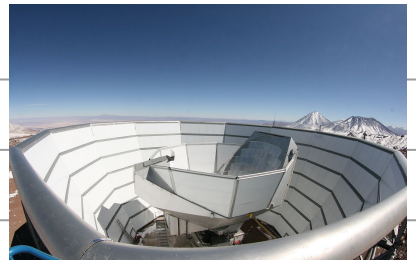
For pattern recognition, we use convolutional layers, which are then transformed into fully connected (linear) layers for classification.

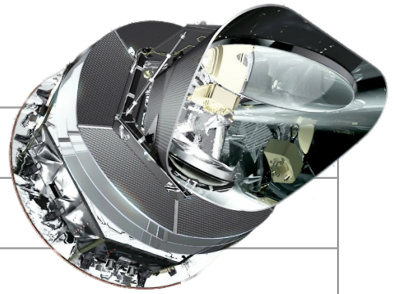


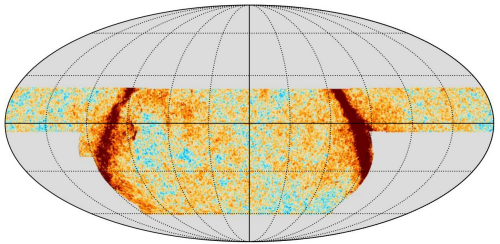
Purposes of this work:

- Create a data-driven method to search for clusters in ACT + Planck data
- Create a catalogue of clusters sampled in the millimetre range and investigate its properties

	ACT	Planck
Years of exploitation	2008 - 2022	2009 - 2013
Place	Atacama desert	L2
Resolution	0.5 arcmin	1.8 arcmin
Noise	Noise pollution from water vapour	Spatially uncorrelated
Area coverage	~18000 deg2	all sky
Frequences	98, 150, 224 GHz	100, 143, 217 GHz + 353, 545, 857 GHz
References	Aiola+ 2020	Planck Collaboration (2014, 2016)

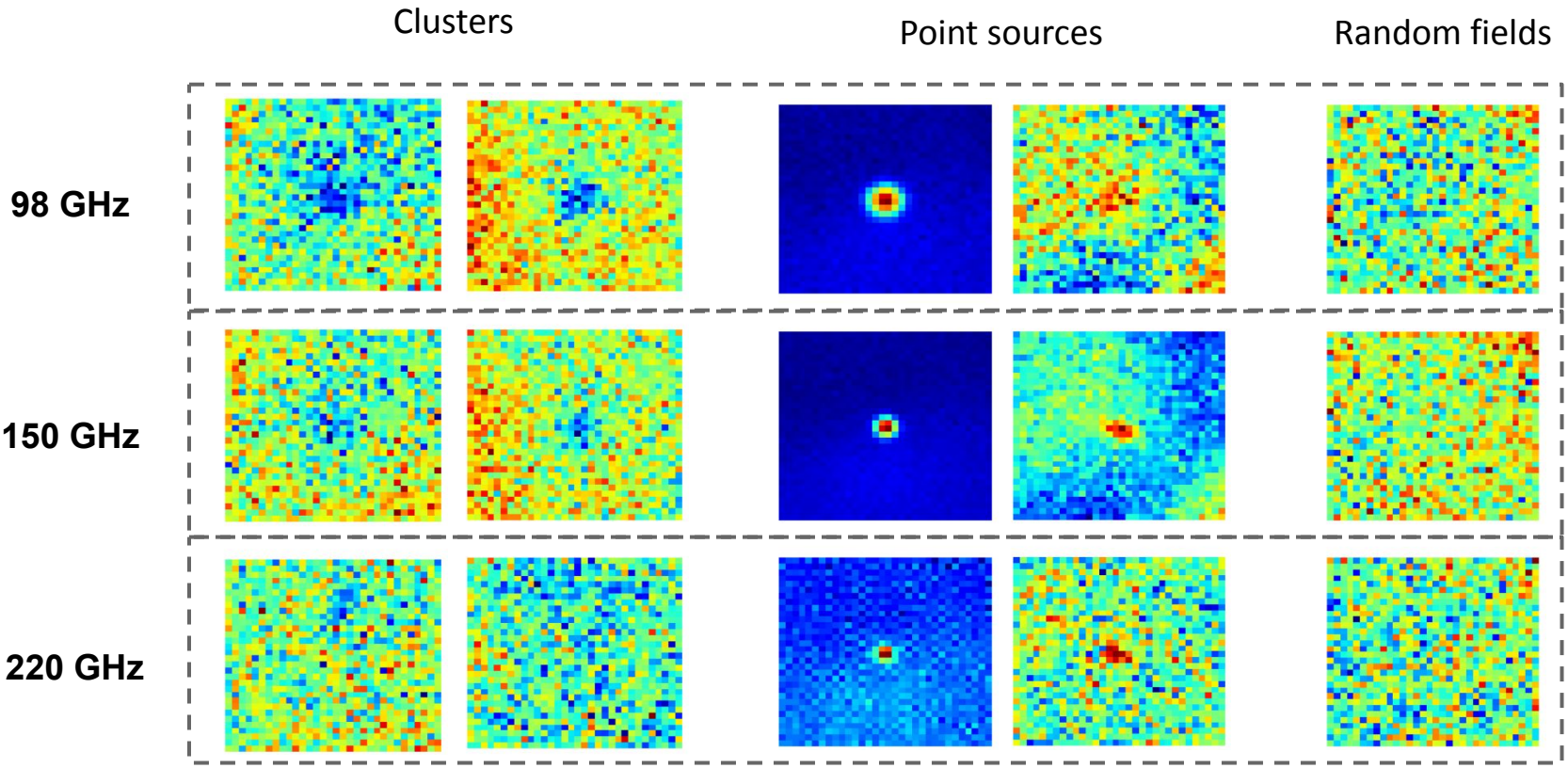






Combined ACT+Planck maps: Naess+ 2020

Data

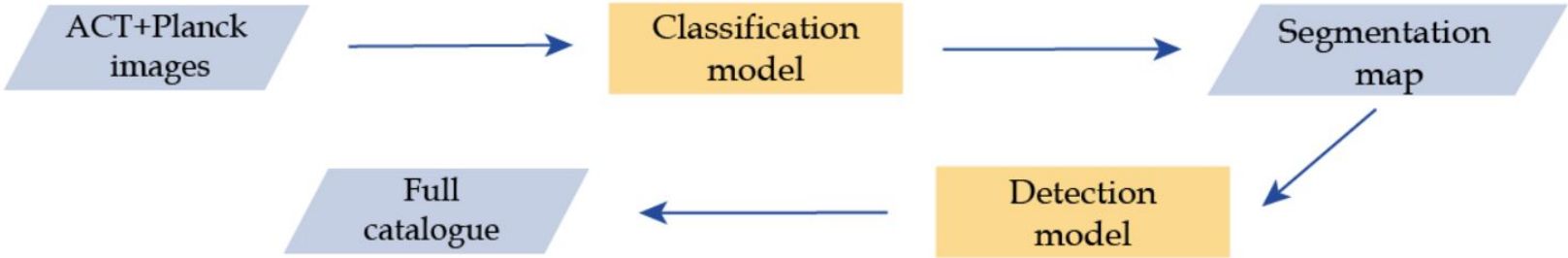


ACT DR5 clusters (Hilton+ 2020)

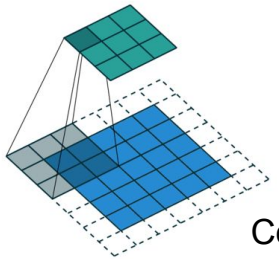
Two-season ACTPol Extragalactic Point Sources (Datta+ 2018)

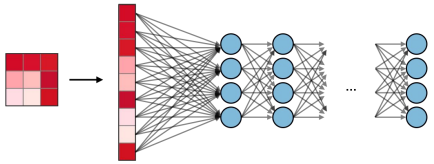
Dusty Star-forming Galaxies and AGN in the Equatorial Survey (Gralla+2020)

Scheme of creating catalogue



In a given direction (RA, DEC), we cut a 16'x16' region from the maps and feed the neural network input



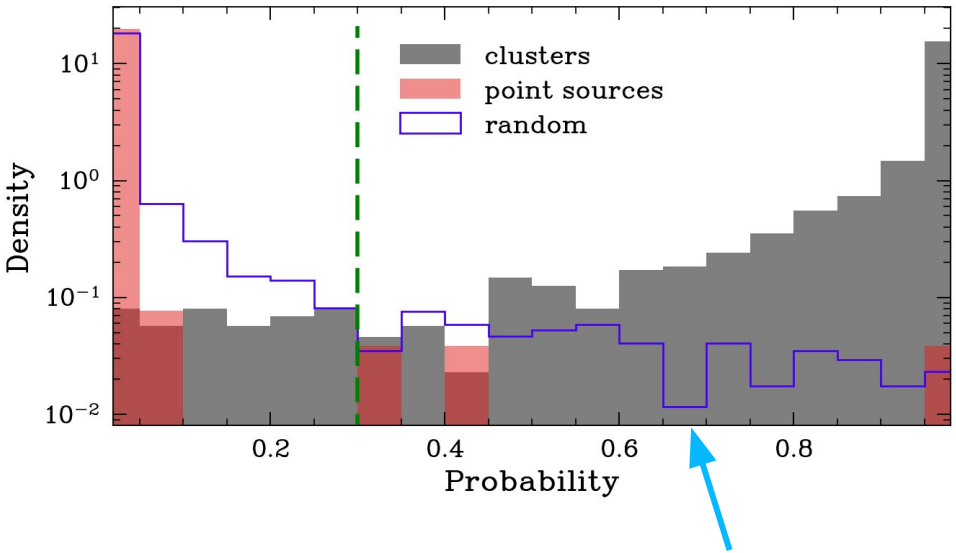


Connected and multi connected layers

Is there a cluster in the centre of the field?

Probability p

Behaviour of samples with known class as a function of probability



3 % of random fields and 0.06 % of AGN are located in the region with p > 0.3

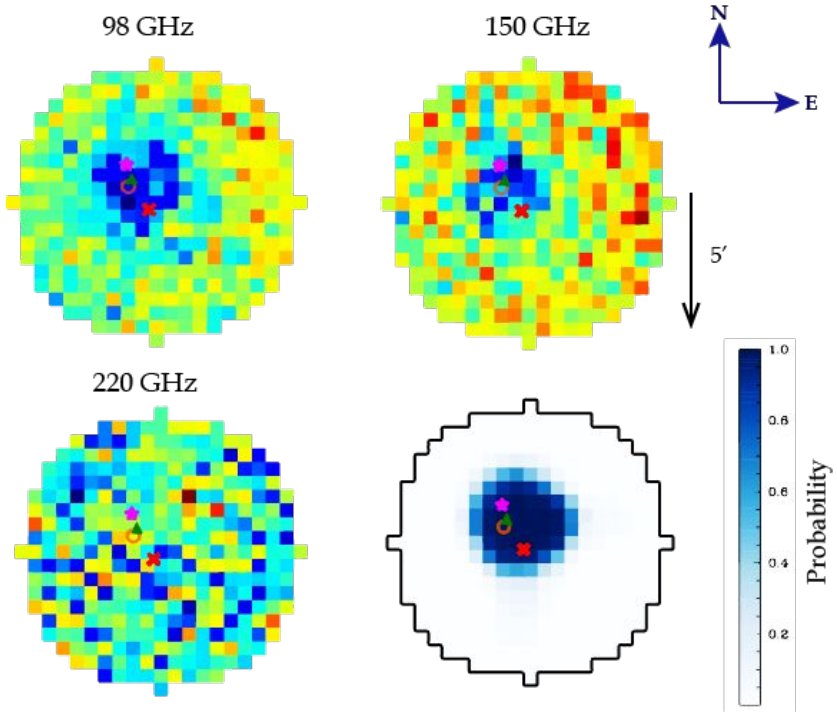
- The model finds the ACT DR5 catalogue clusters well
- If there is an AGN within 2' of the cluster, the model predictions will not change

- (SZcat) SZ_G098.31-41.19
- PSZ2
- ACT DR5
- pixel with max probability

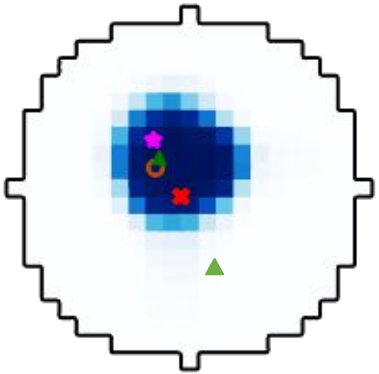
An example of how the model sees the cluster

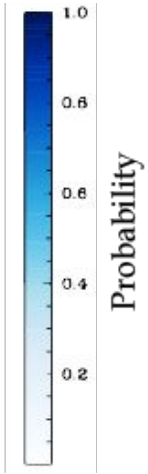
Applying the model pixel by pixel in a circle for 5 minutes

The model highlights the area of cluster and suppresses noise



Segmentation map

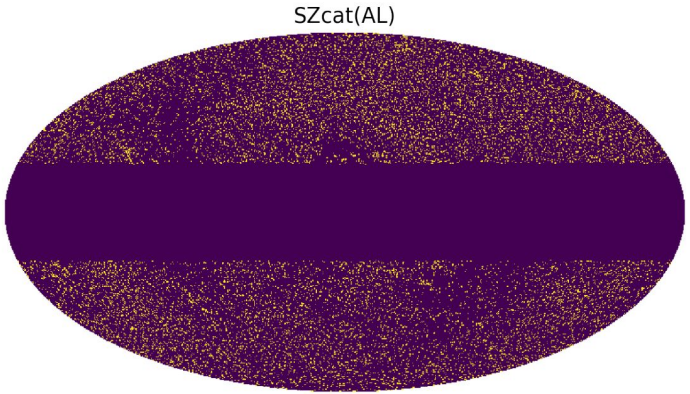




By choosing min threshold (p = 0.3), we get a group of pixels

Max probability, [pmax]

Area, [S]



SZcat - applying deep learning to Planck microwave data (Burenin+2018, Meshcheryakov+2022)

SZcat

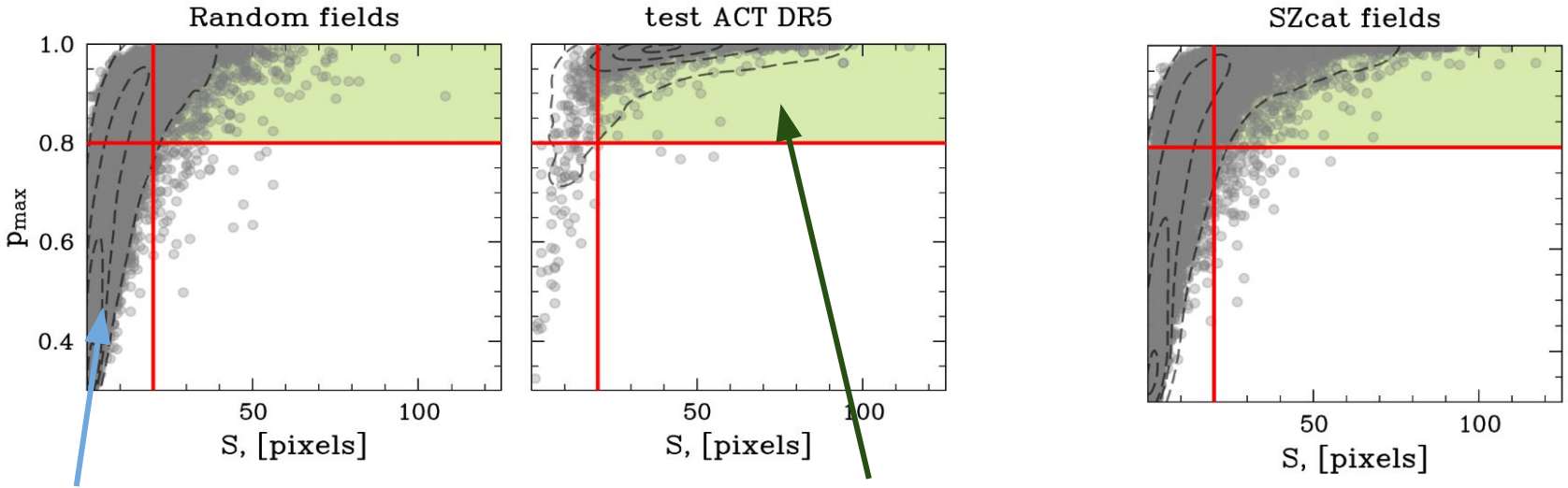
Extended catalogue of Planck sources obtained with the U-net deep learning model trained on HFI channels (100, 143, 217, 353, 545, 857 GHz)

Precision ~ 21 %

In the ACT field lies 14,850

https://github.com/astromining/planck_szcat

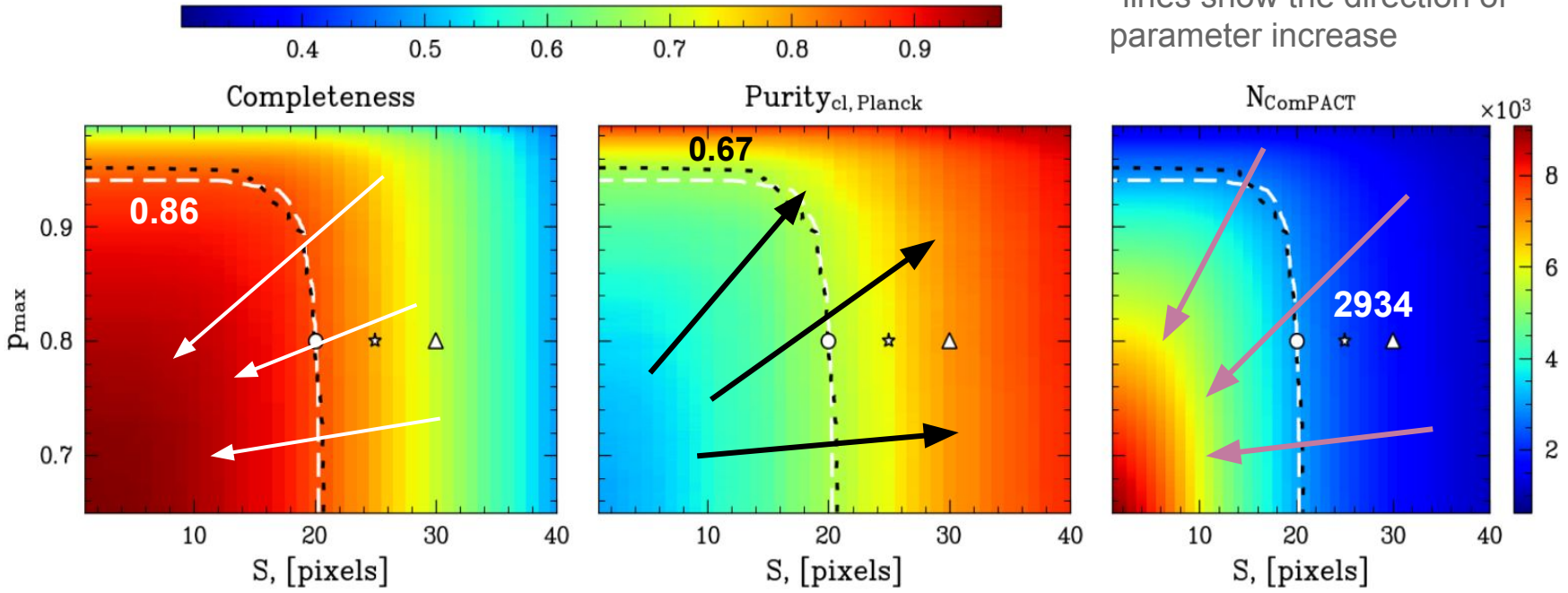
Classification model → Segmentation map → Detection model



Random fields
are concentrated into the region of small areas and probabilities

Clusters
are extended objects and have a high probability

*lines show the direction of parameter increase



Optimise completeness regarding to ACT DR5 and PSZ2z

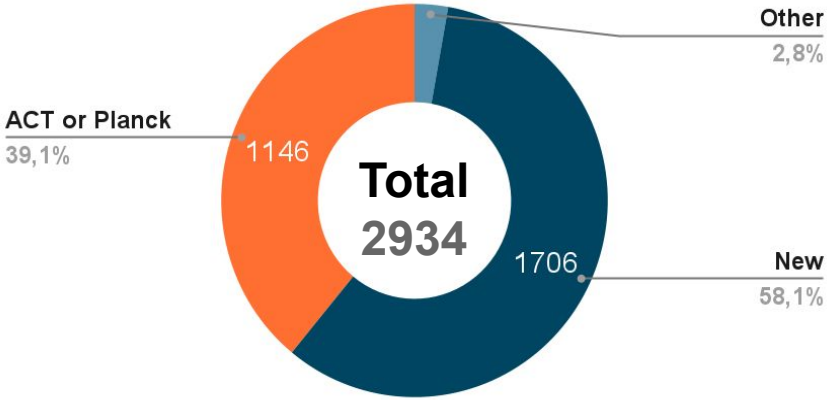
$$C = N^{\star}_{cl}/N_{cl}$$

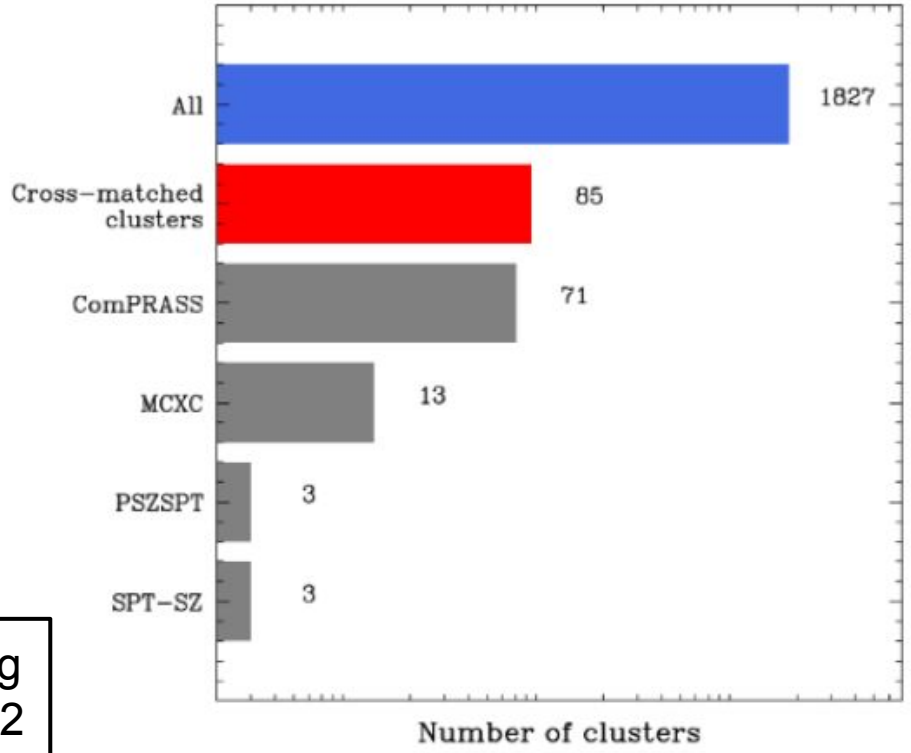
Optimise % of Planck clusters in the catalogue

$$PP = \frac{N_{cat} - N_{random}}{N_{cat}}$$

Changing the number of objects in the catalogue depending on the selected parameters

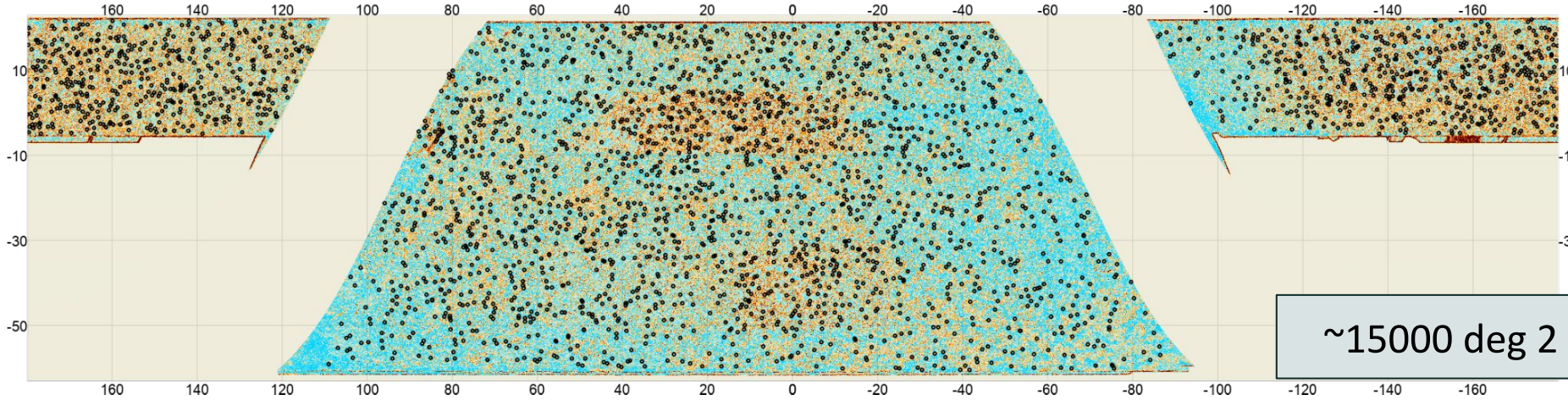
ComPACT



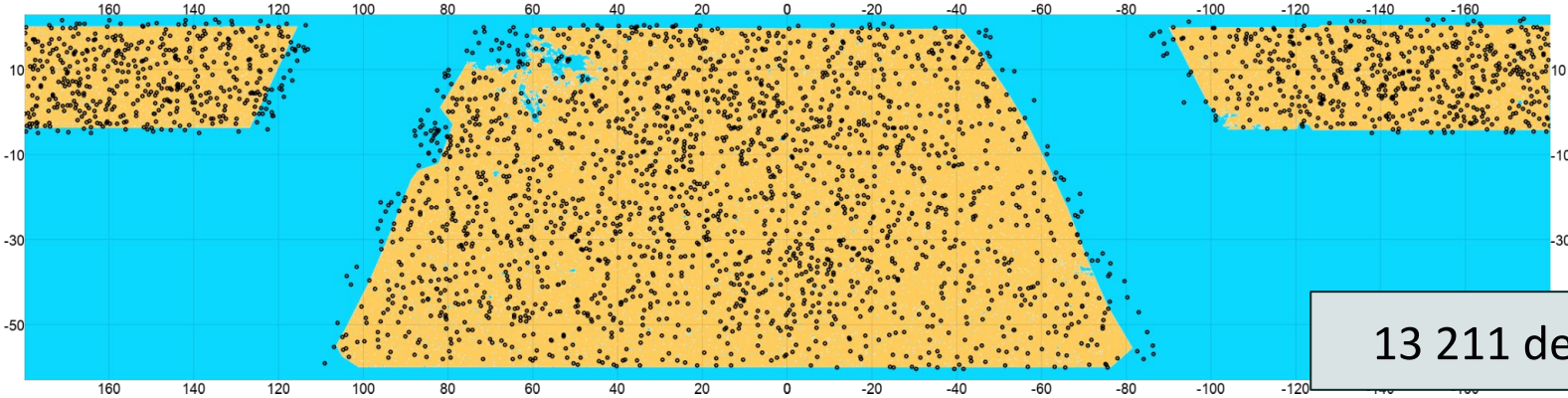


1788 new regarding ACT DR5 and PSZ2

Sky coverage



~15000 deg 2

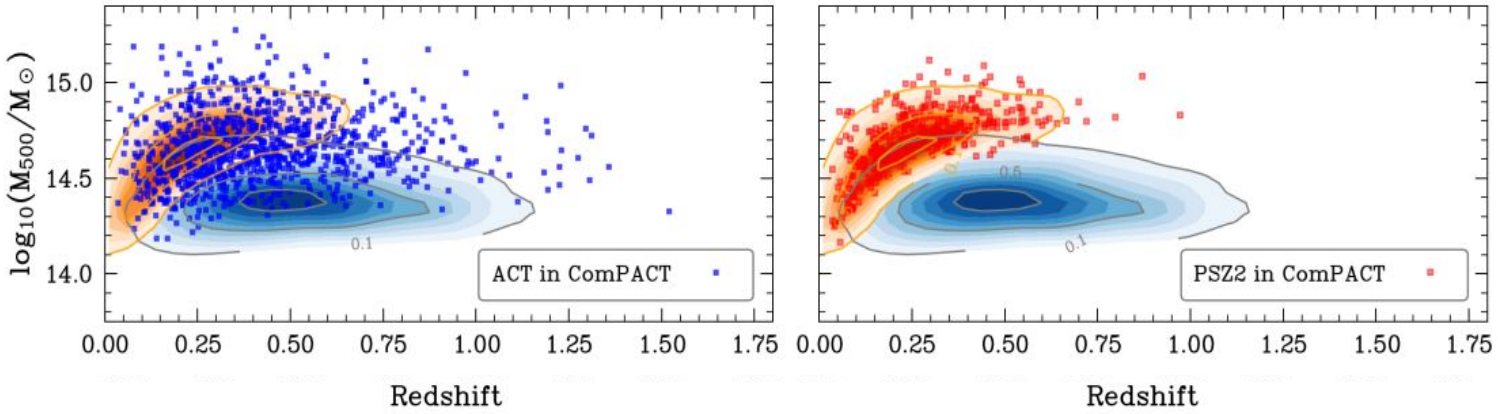


13 211 deg 2

ComPACT: Purity and Completeness

	Priority 3 (S > 20)	Priority 1 (S > 30)
Percentage of Planck clusters	0.68	0.8
Min purity from SZcat purity	0.74	0.84
Completeness	0.86	0.7
	More complete sample	Cleaner sample

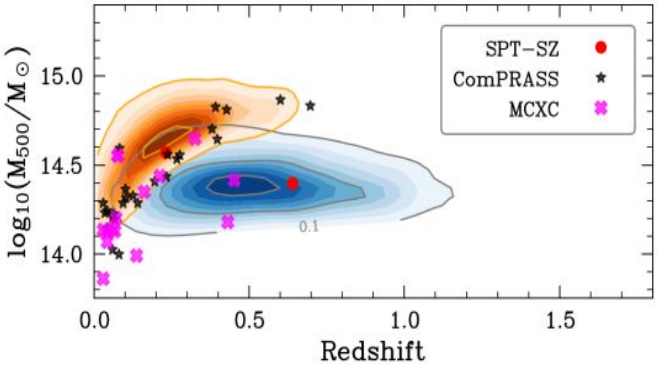
ComPACT on Mass-redshift



Blue contour = ACT DR5
Orange contour = PSZ2z

- Finding Planck clusters outside the underlying distribution
- The M-z plane characterises the selection function

ComPACT objects not from ACT and Planck



Conclusions

- We developed a deep learning method to search galaxy clusters in ACT+Planck maps for the first time
- The resulting first neural network catalogue contains 2962 SZ-objects with cluster purity conservatively estimated as ≳74–84 % and is publicly available
- Our deep learning algorithm detects previously unknown galaxy clusters, i.e. it is capable of detecting SZ sources below the detection threshold adopted in the published galaxy cluster catalogues (such as ACT DR5 and PSZ2)

https://github.com/astromining/ComPACT
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