Deep Learning Detection of Galaxy Clusters with YOLOv10: From SDSS to Rubin/LSST

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Introduction

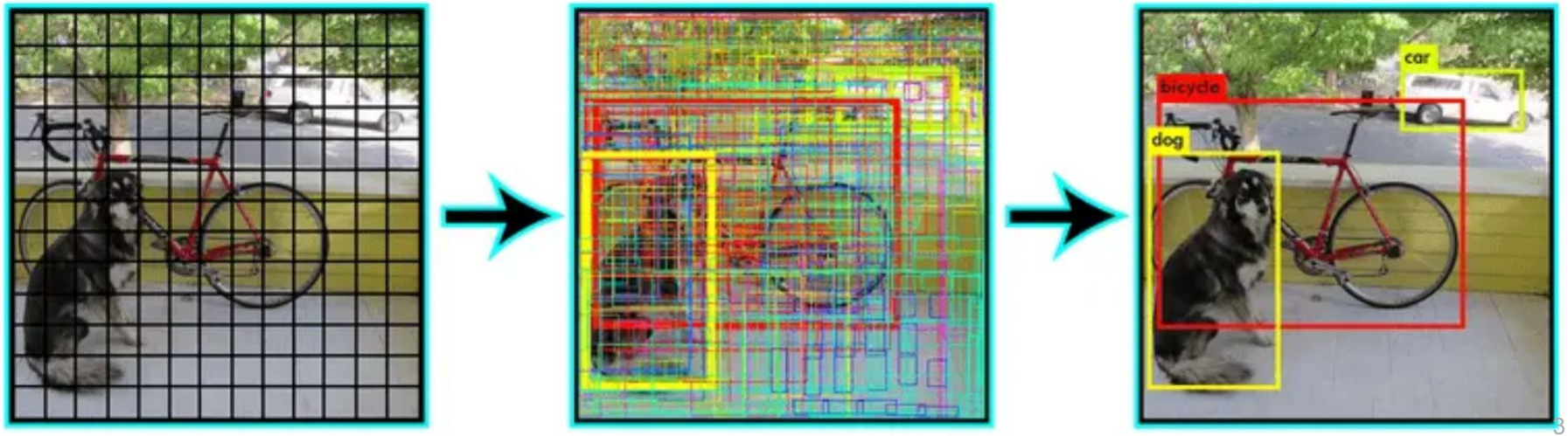
- Galaxy Clusters Detections
  => Largest gravitationally bound system
  => Key cosmological probes (matter density, structure evolution, etc…)
  => Excellent tracers of LSS
  => Offer insights to the inner workings of galaxies

- Traditional Methods
  → Typically rely on galaxy catalogs (e.g. colors, photometric redshifts)
  → These approaches are subject to biases and systematic uncertainties

- Deep Machine Learning Methods

What is YOLO ?

- YOLO, YOLOv3 (Redmon 2015; Redmon & Fahradi 2018)
- Convolutional Neural-Network (CNN)
- Modified to detect galaxy clusters in color images -> YOLO-CL (Grishin, Mei, Ilic 2023)
- One-shot detection (single forward pass for bounding box and classification)



YOLO-CL datasets

Grishin, Mei, Ilic 2023, see also Grishin et al. 2025

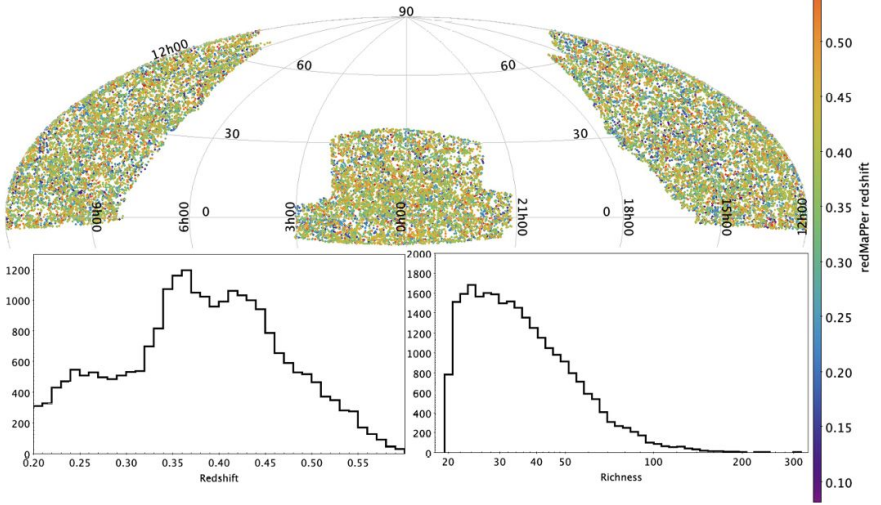
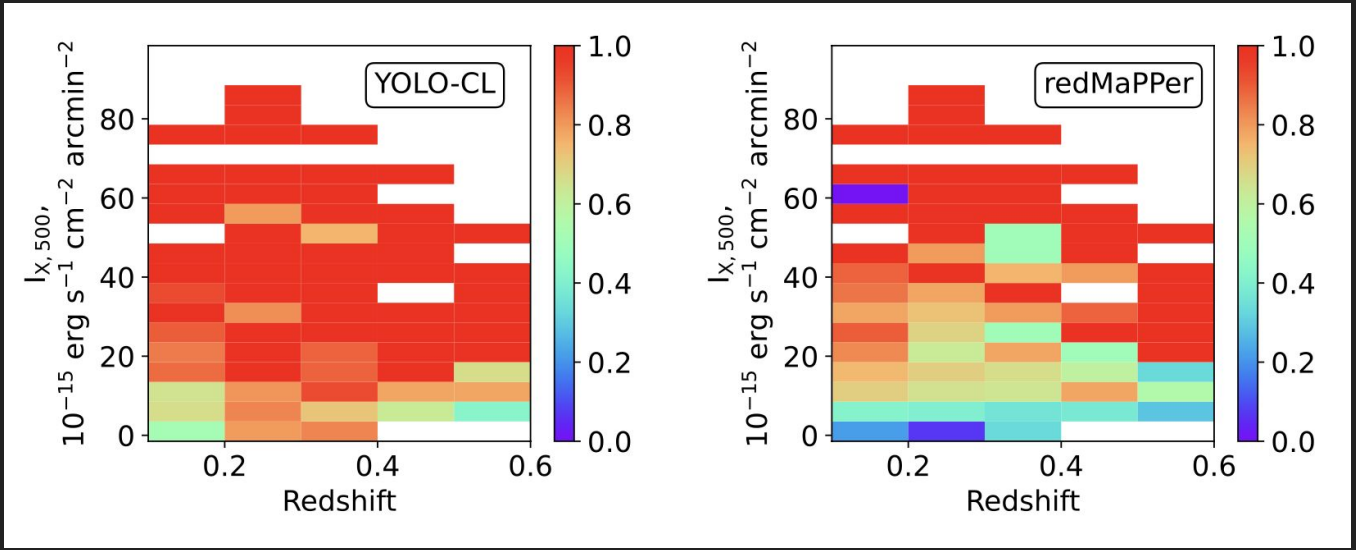


Fig. 1. The redMaPPer sample of 24,406 clusters used to train and validate our network. Top: Sky map of the positions of the redMaPPer clusters in celestial coordinates, where color indicates the photometric redshift of the cluster as estimated by the redMaPPer algorithm. Bottom: the training and validation redMaPPer sample redshift (left) and richness (right) distribution.

Trained on the redMapper cluster catalog (26,111 redMaPPer clusters) and applied to galaxy clusters detected in the X-ray emission from the MCXC2021 catalog (Meta-Catalog of X-ray detected Clusters of galaxies).

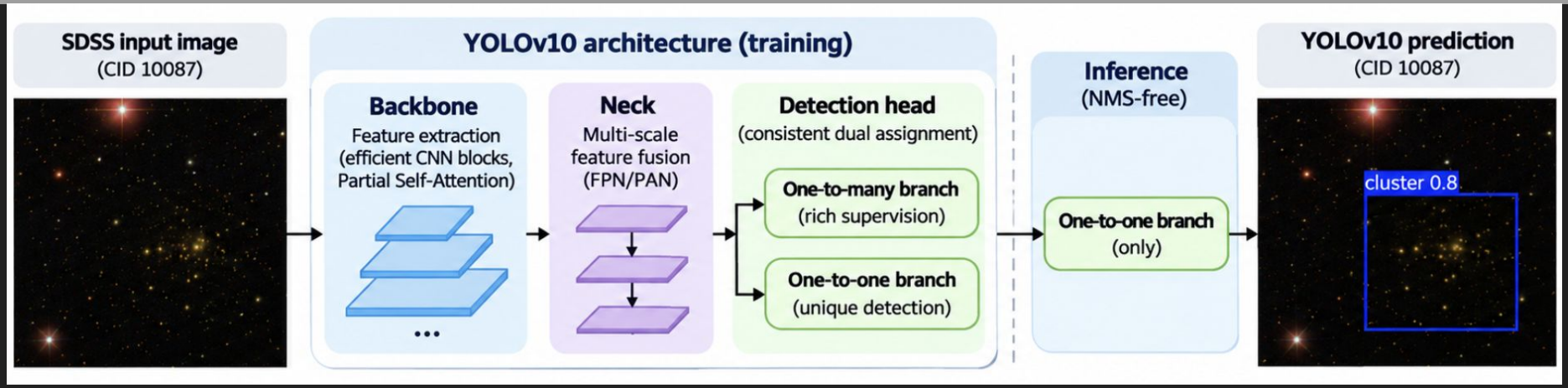
Performance YOLO-CL applied to the Sloan Digital Sky Survey (SDSS)

Grishin, Mei, Ilic 2023, see also Grishin et al. 2025



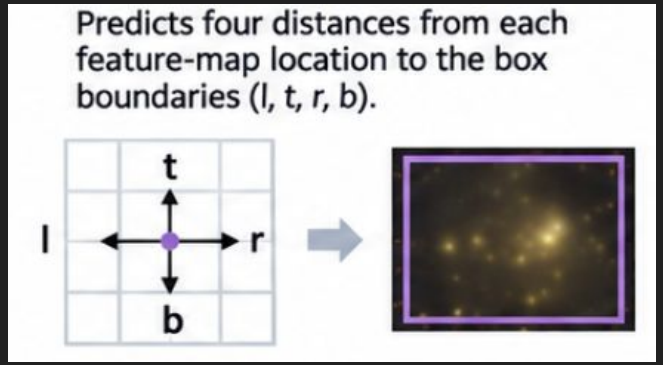
When applied to individual cluster, it reaches lower in X-ray surface brightness and produces ~95% complete and pure cluster catalogs but when extended to large-scale surveys we obtain only ~60% completeness and purity

YOLO-v10 Architecture



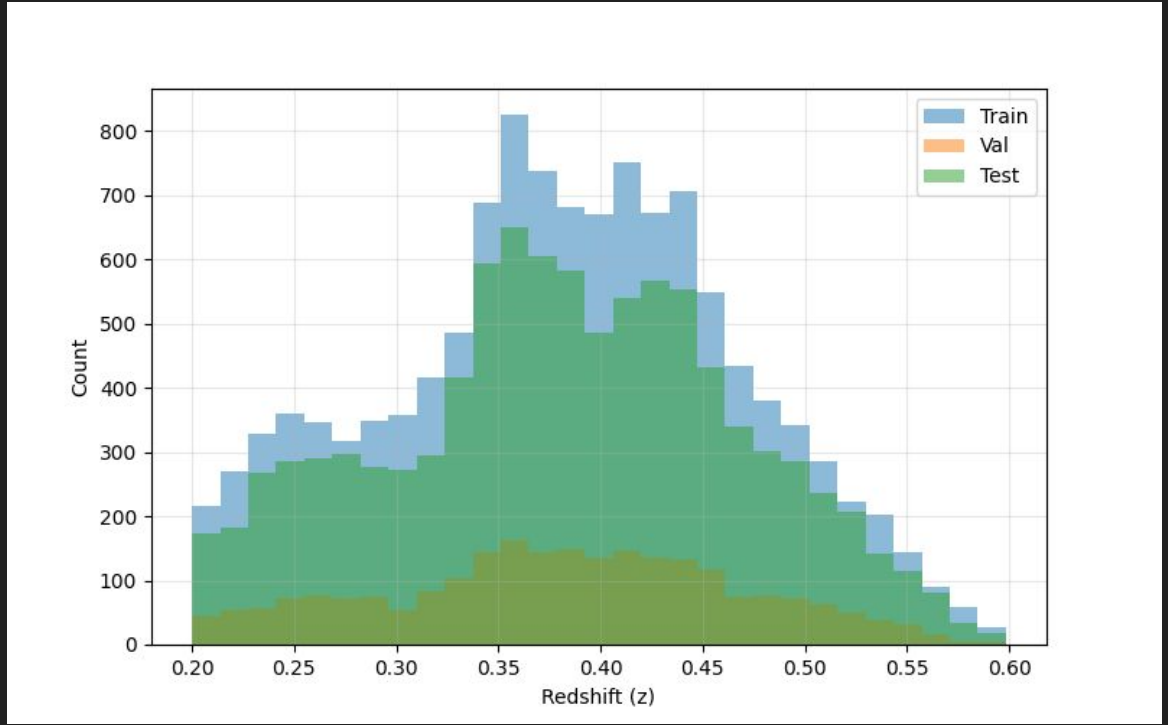
Key Innovations :

- Modernized model design
- Anchor-free detection
- Consistent dual assignment



YOLOv10 - Application to the SDSS

- SDSS: 26,111 redMaPPer clusters
- After applying filtering and data augmentation => total of 35 957 images (9764 are blanks ~27% -> help distinguish between clusters and background)
- Dataset split :
  - Train (~60)
  - Val (~10%)
  - Test (~30%)



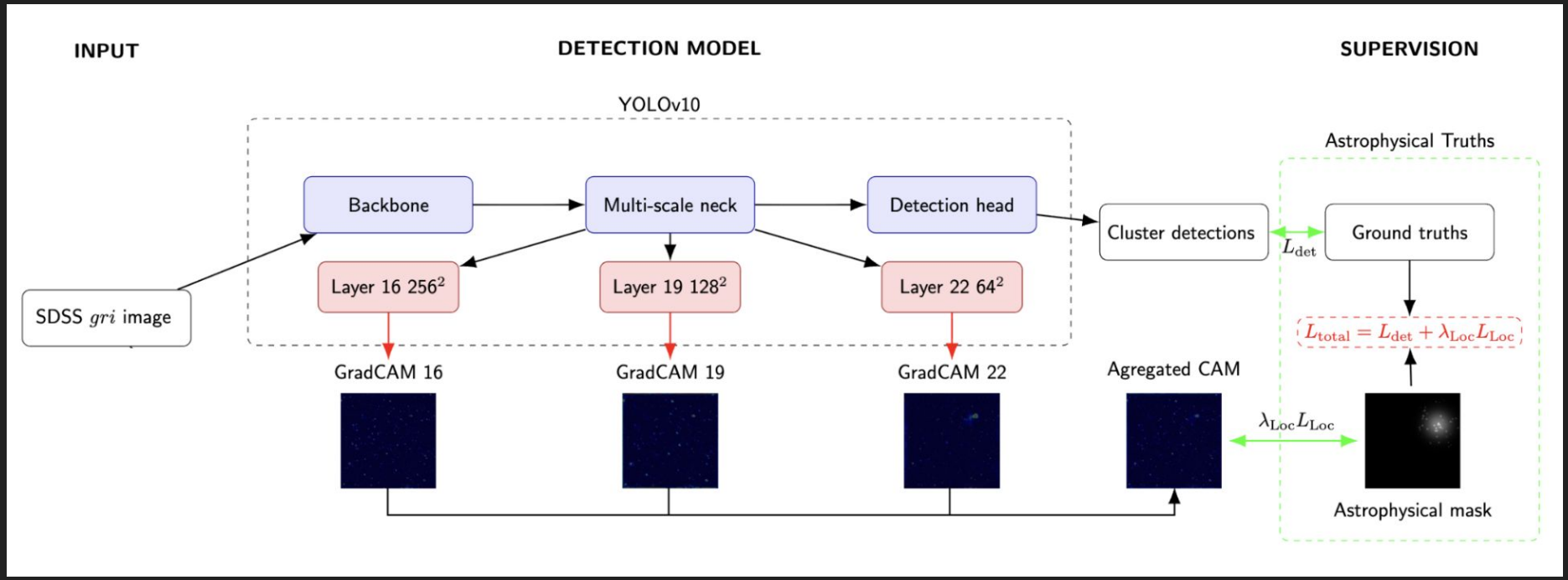
Tran et al. in preparation

Visual examples



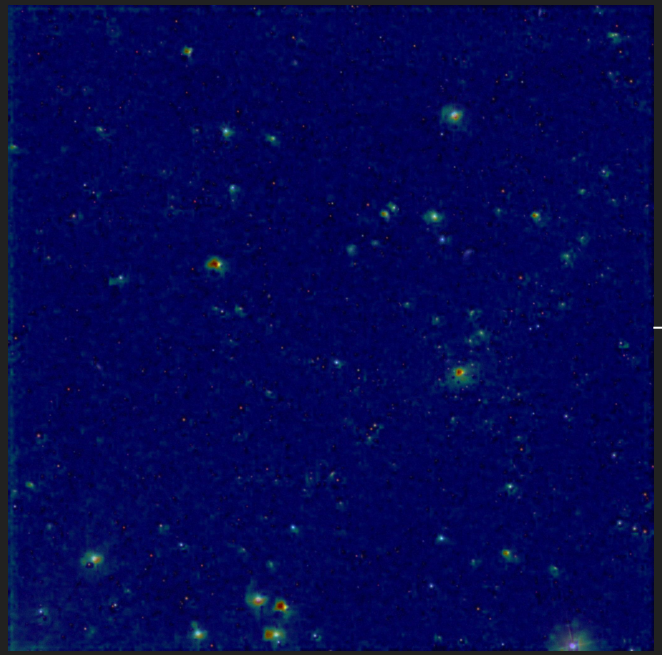


YOLO-CL10x : Explainability



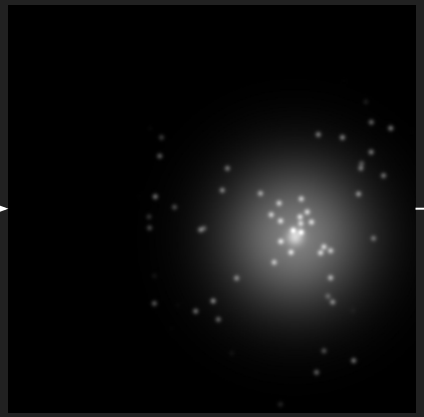
Tran et al. in preparation

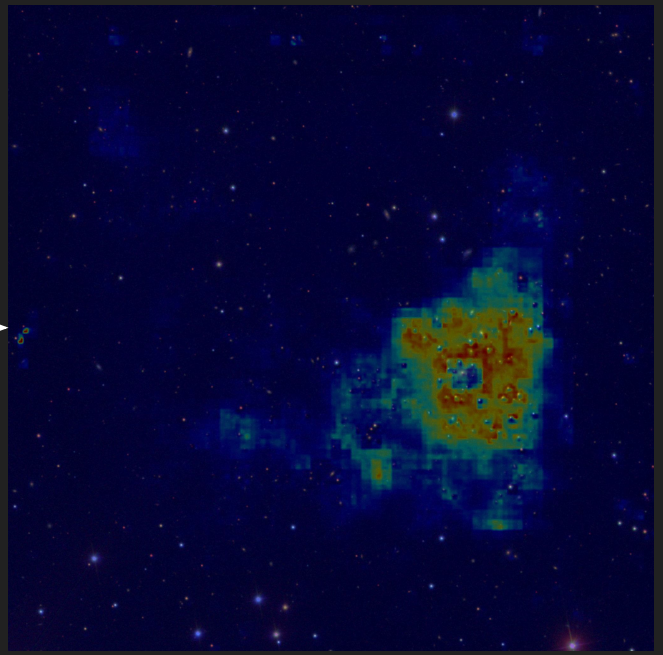
Mask training



Before CAM

Mask

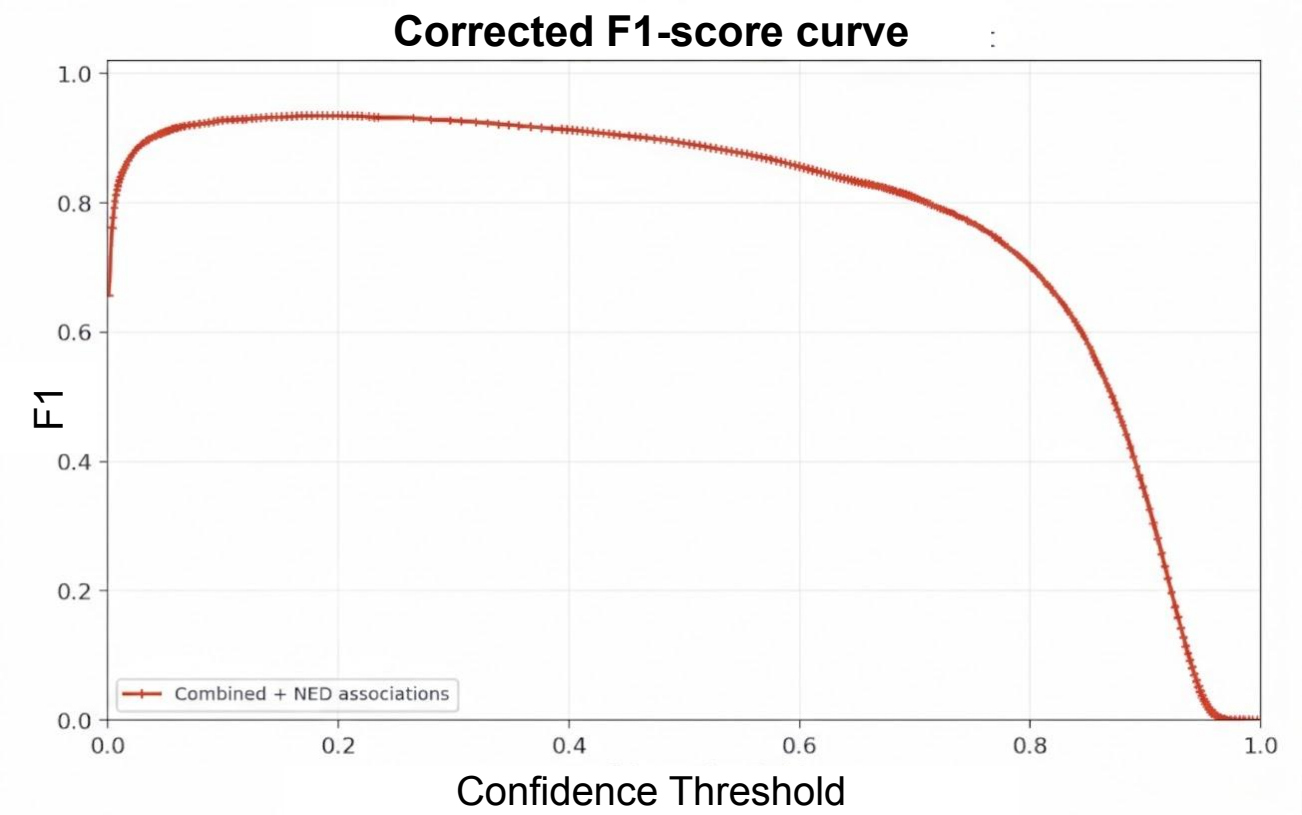




After CAM

Performance (SDSS)

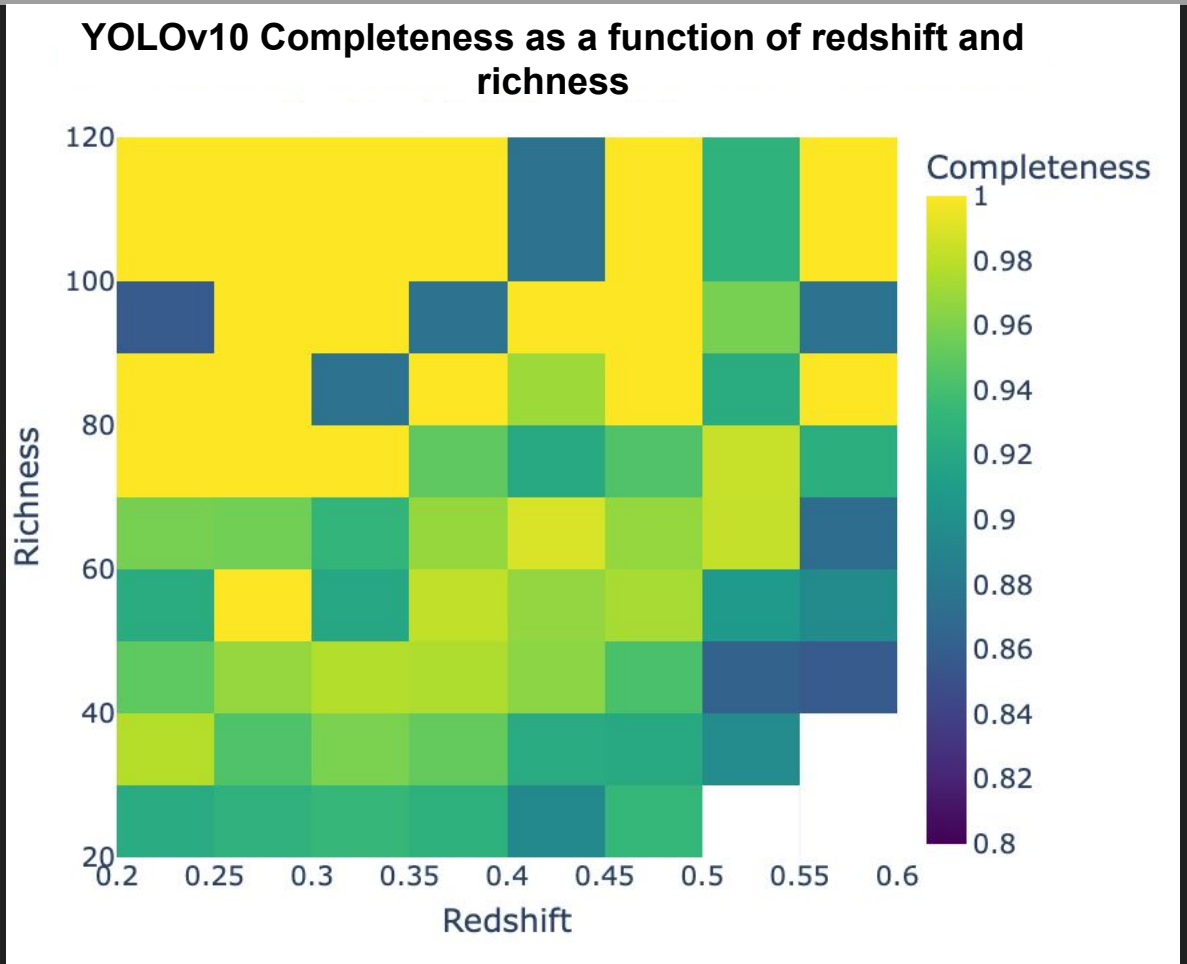
YOLOv10 Completeness and Purity on SDSS: 93% (relaxed AP = 97%)



=> promising balance but requires careful post-processing to obtain

Tran et al. in preparation

Performance (SDSS)



Tran et al. in preparation

Summary

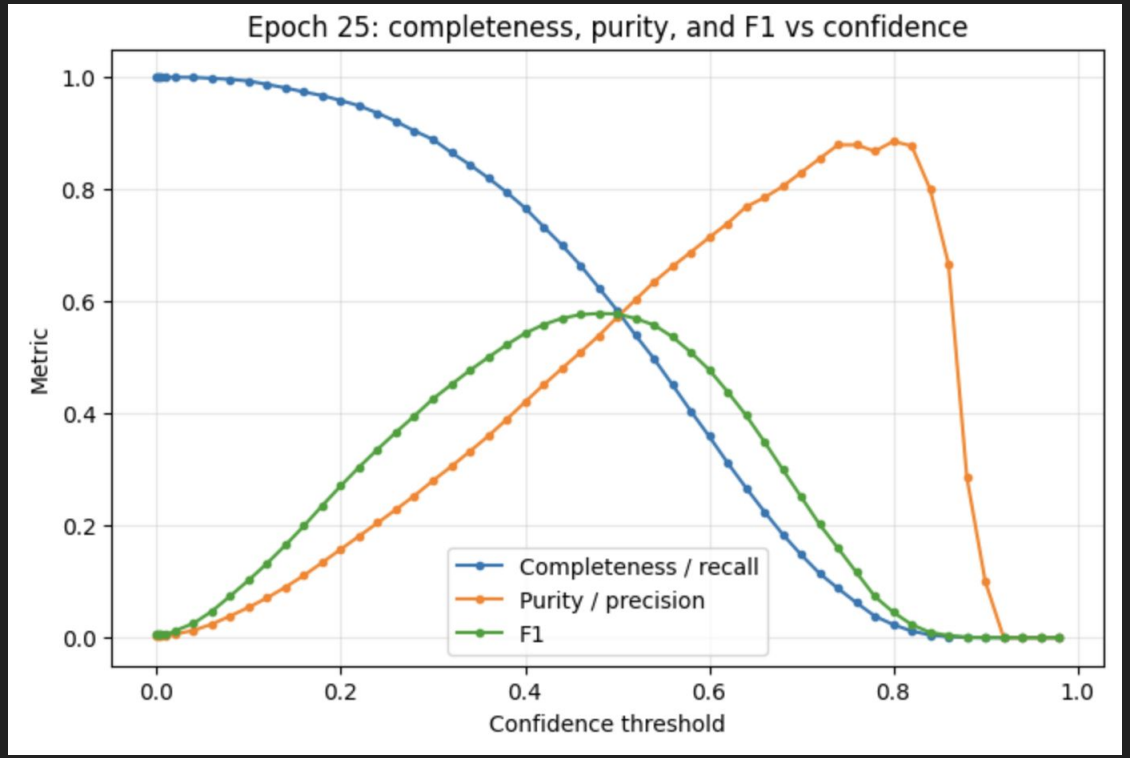
- YOLOv10 provides a modern CNN-based framework for detecting galaxy clusters directly from SDSS images.
- It achieves promising detection performance, while careful evaluation is necessary to understand false positives, missed clusters and selection effects.
- Explainability and extension to LSST-like “*survey mode*” imaging are important next steps for large-scale surveys such as LSST

Questions ?
Thank You !

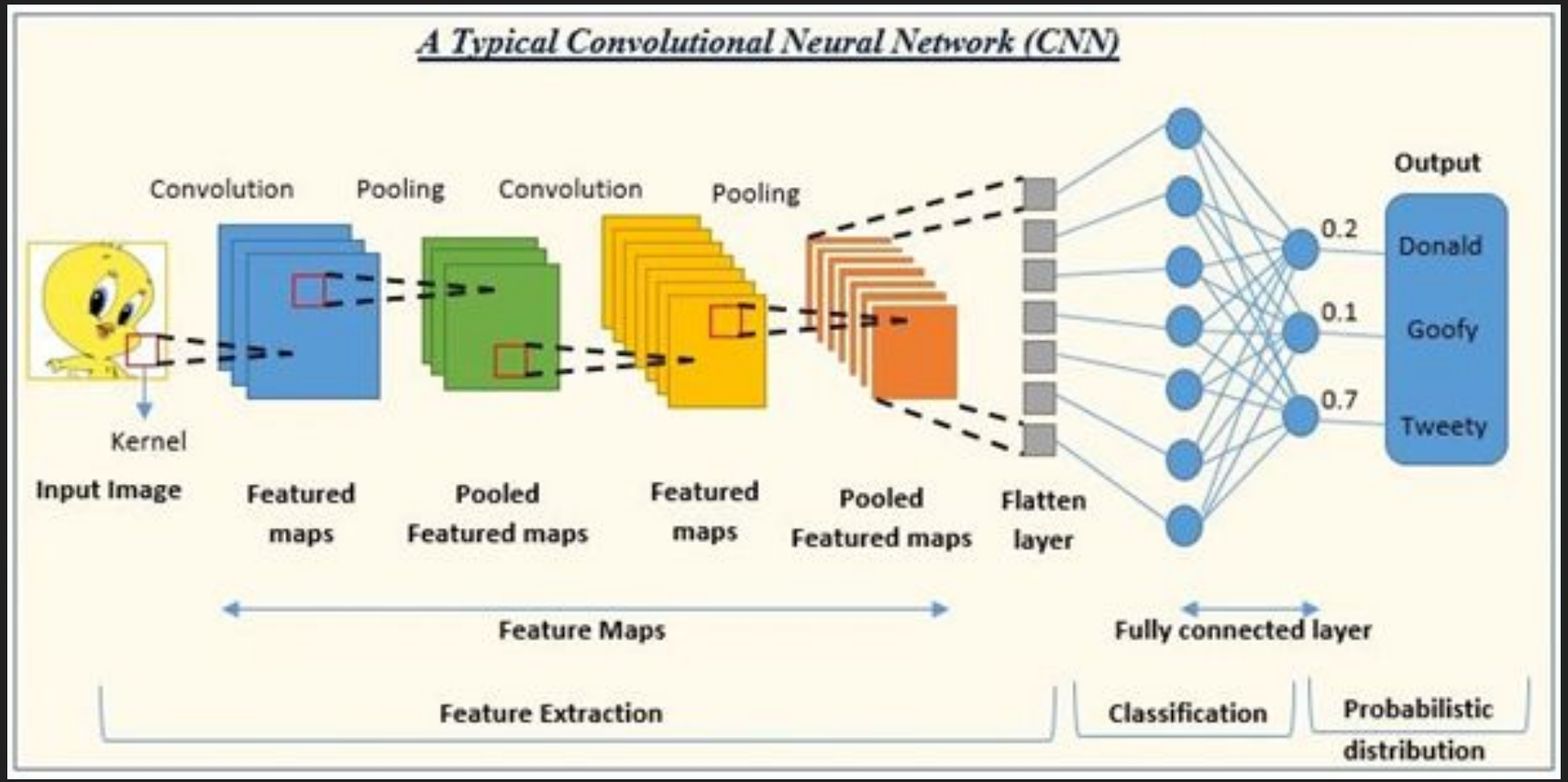
Extra slides

Performance

- YOLO-CL Completeness and Purity on SDSS: 57% (AP@50 = 59%)



CNN

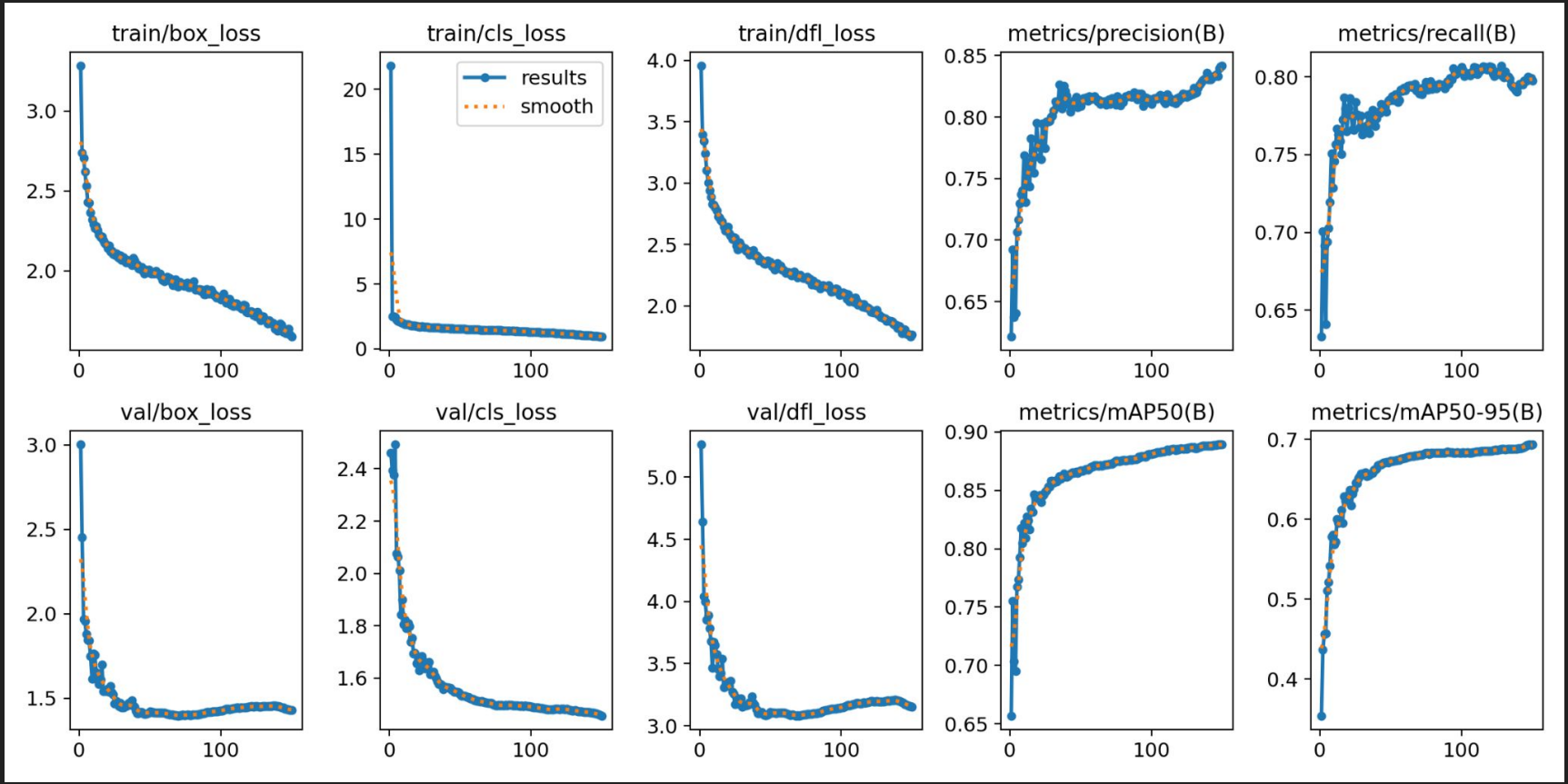

A Typical Convolutional Neural Network (CNN)
Convolution
Pooling
Convolution
Pooling
Output
0.2
0.1
0.7
Donald
Goofy
Tweety
Kernel
Input Image
Featured maps
Pooled Featured maps
Featured maps
Pooled Featured maps
Flatten layer
Feature Maps
Fully connected layer
Feature Extraction
Classification
Probabilistic distribution

Current status & Future steps and challenges

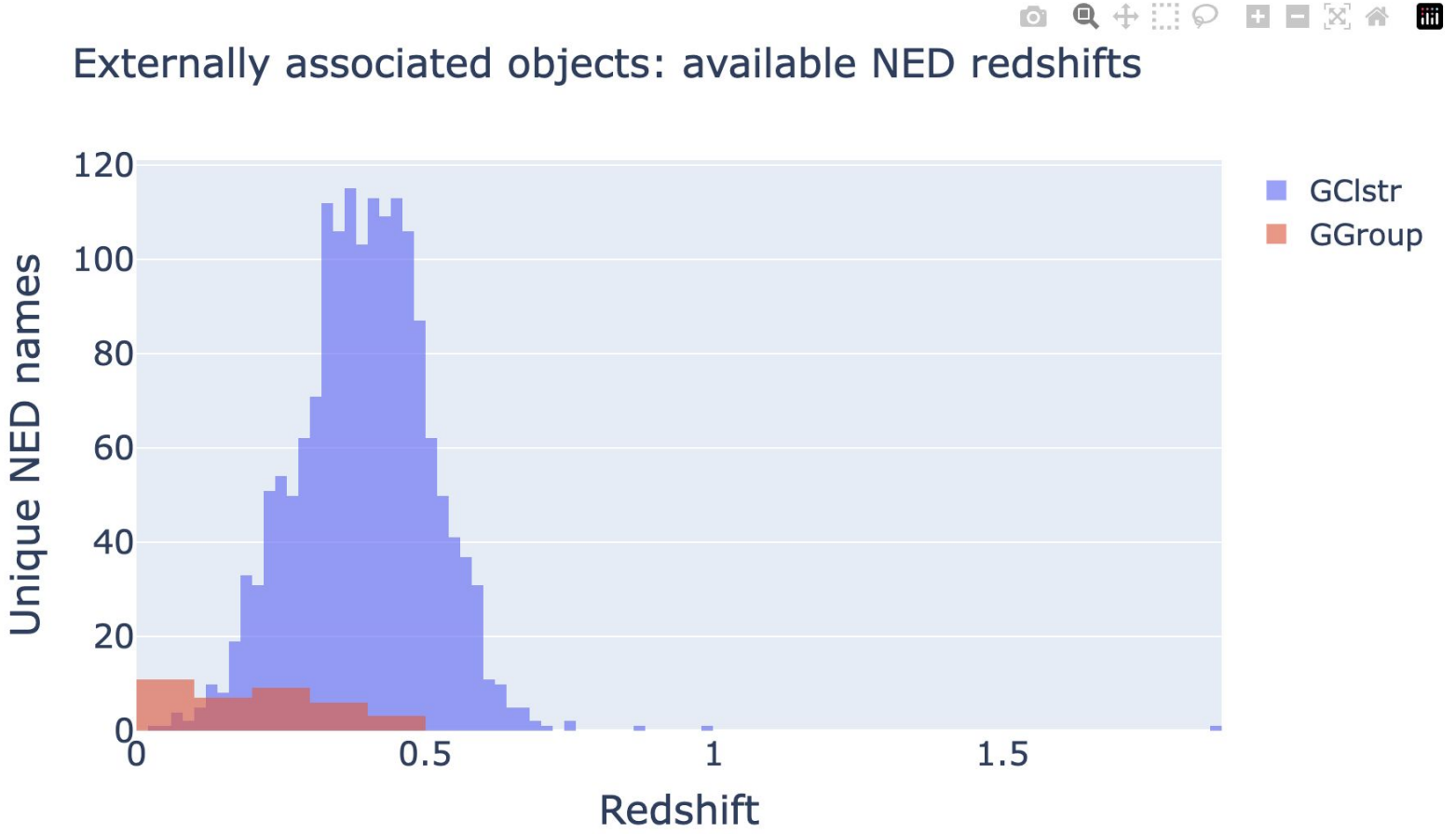
- My goal is to optimize YOLO-CL10X for “Survey mode” in order to apply the model to LSST and combined LSST and EUCLID images => how robust is it beyond the training distribution ?

- I will also improve the network to include more information on the cluster such as redshifts, members and mass.

Training and Validation



NED: 1756 excluded predictions; 1745 unique NED names. Multiple candidates and aliases can represent the same physical system.



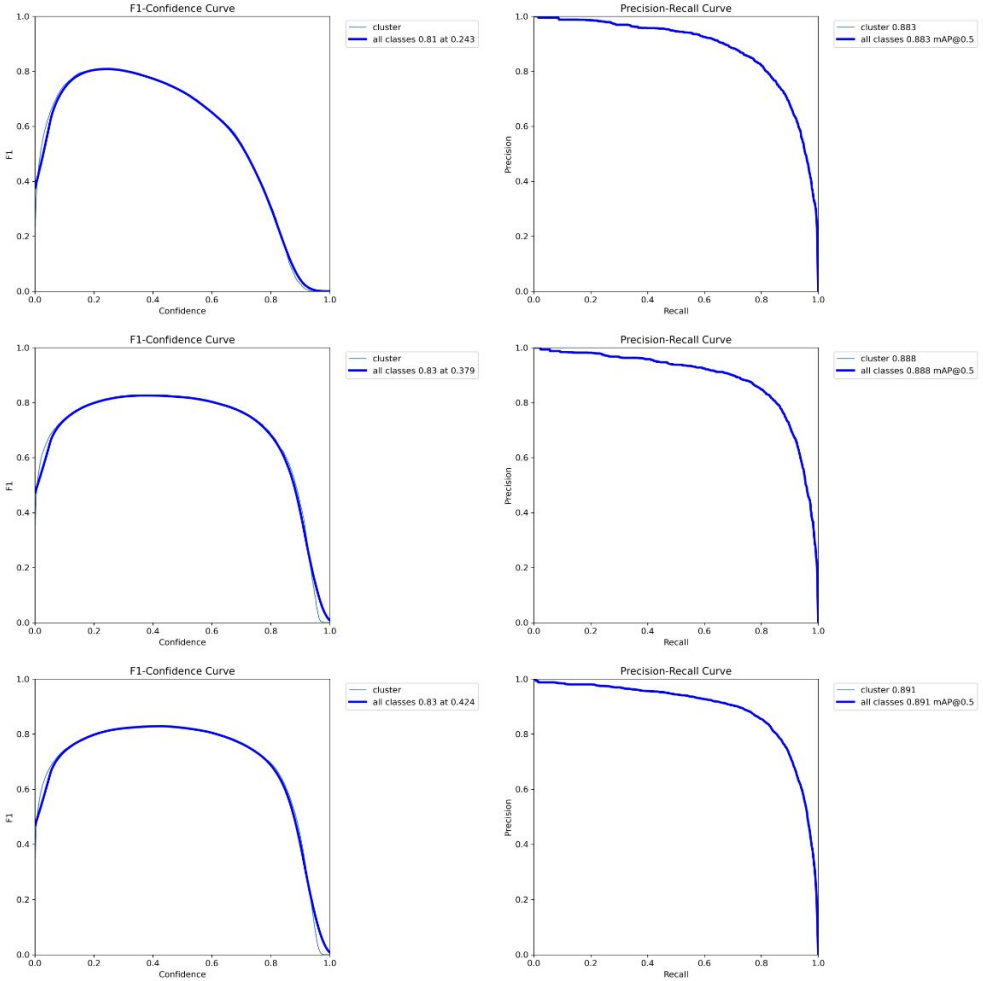


Fig. 4: *Left*: F1-score vs Detection Threshold validation and test curves outputted by YOLOv10's Ultralytics framework. The baseline is the top plot while the ESCPLAIN-applied finetune is in the middle and finally the test-split validation is on the bottom row; *Right*: The corresponding Precision-Recall validation and test curves with their respective mAP50.

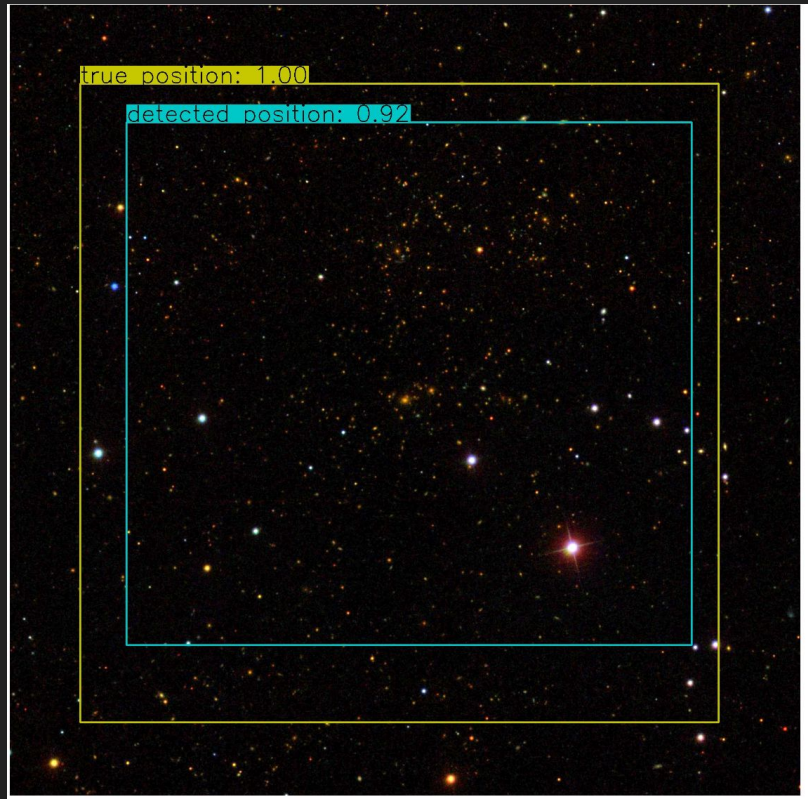


Fig. 2. SDSS image cutout of a redMaPPer cluster in our sample. The yellow box corresponds to the minimal rectangle encompassing all redMaPPer cluster members, which is the box used to train YOLO-CL. In cyan, the box detected by our network YOLO-CL, with the associated confidence level in the top left corner. The image size is 13.5 x 13.5 arcmin^2, and the pixel size is 0.396 arcsec.

Grishin, Mei, Ilic 2023, see also Grishin et al. 2025