

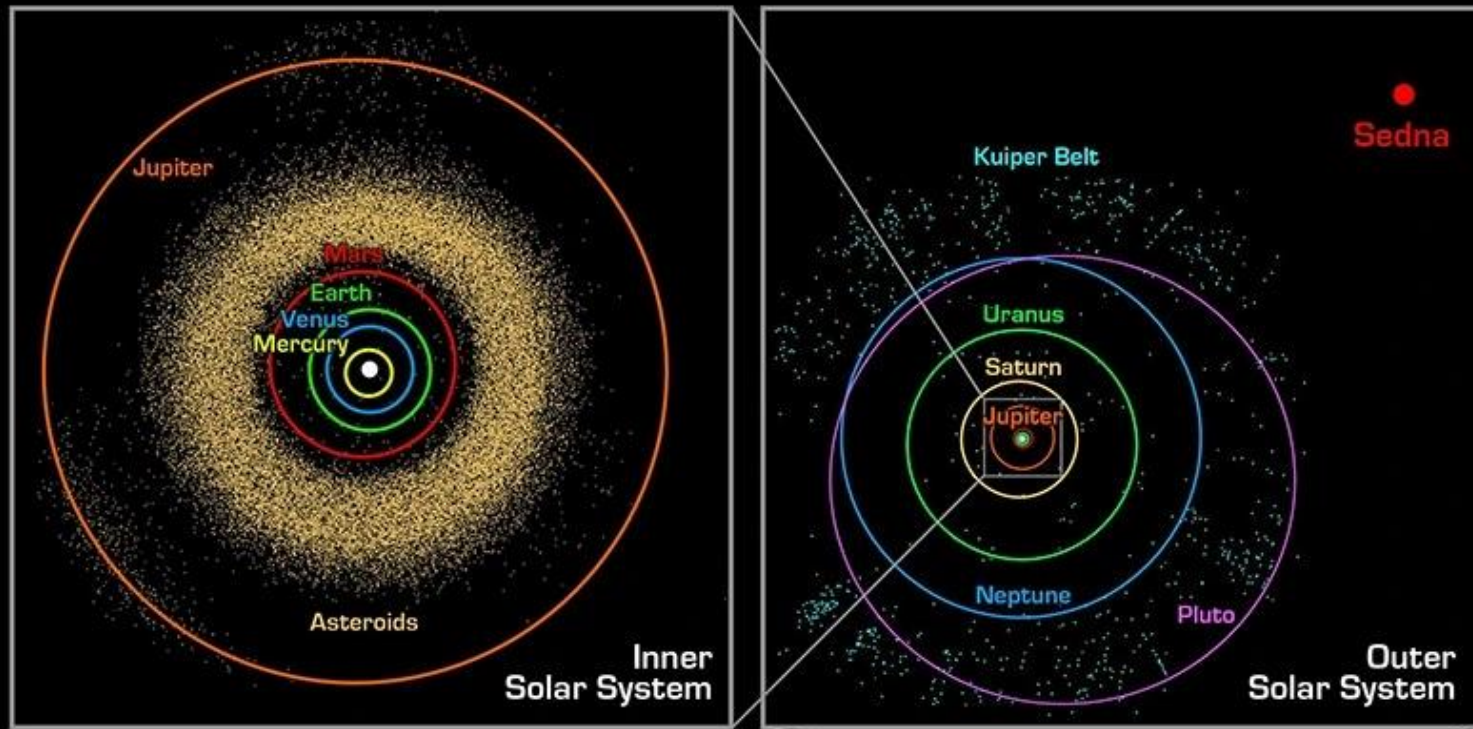
Deep Learning For Asteroid Detection

LOOKING FOR ASTEROIDS IN THE MOA
SURVEYS' MICROLENSING DATA

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University of Auckland, NZ



Minor Planets

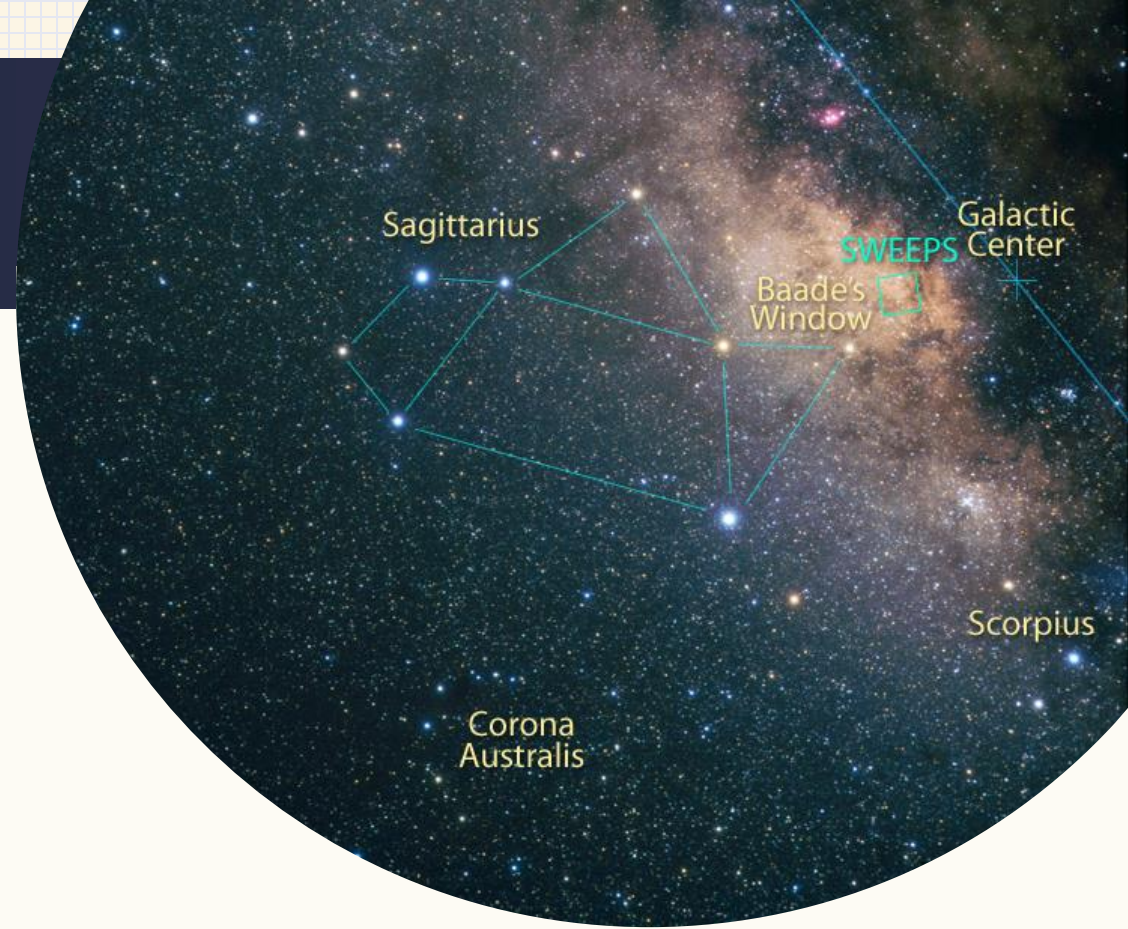


- Asteroids: near-Earth, main belt, trojans, centaurs, trans-Neptunian objects
- Remnants of early solar system
 - Formation
 - Composition
- Distributed throughout the solar system

MOA: Microlensing Observations in Astrophysics



University of Canterbury's Mt John observatory, Tekapo.



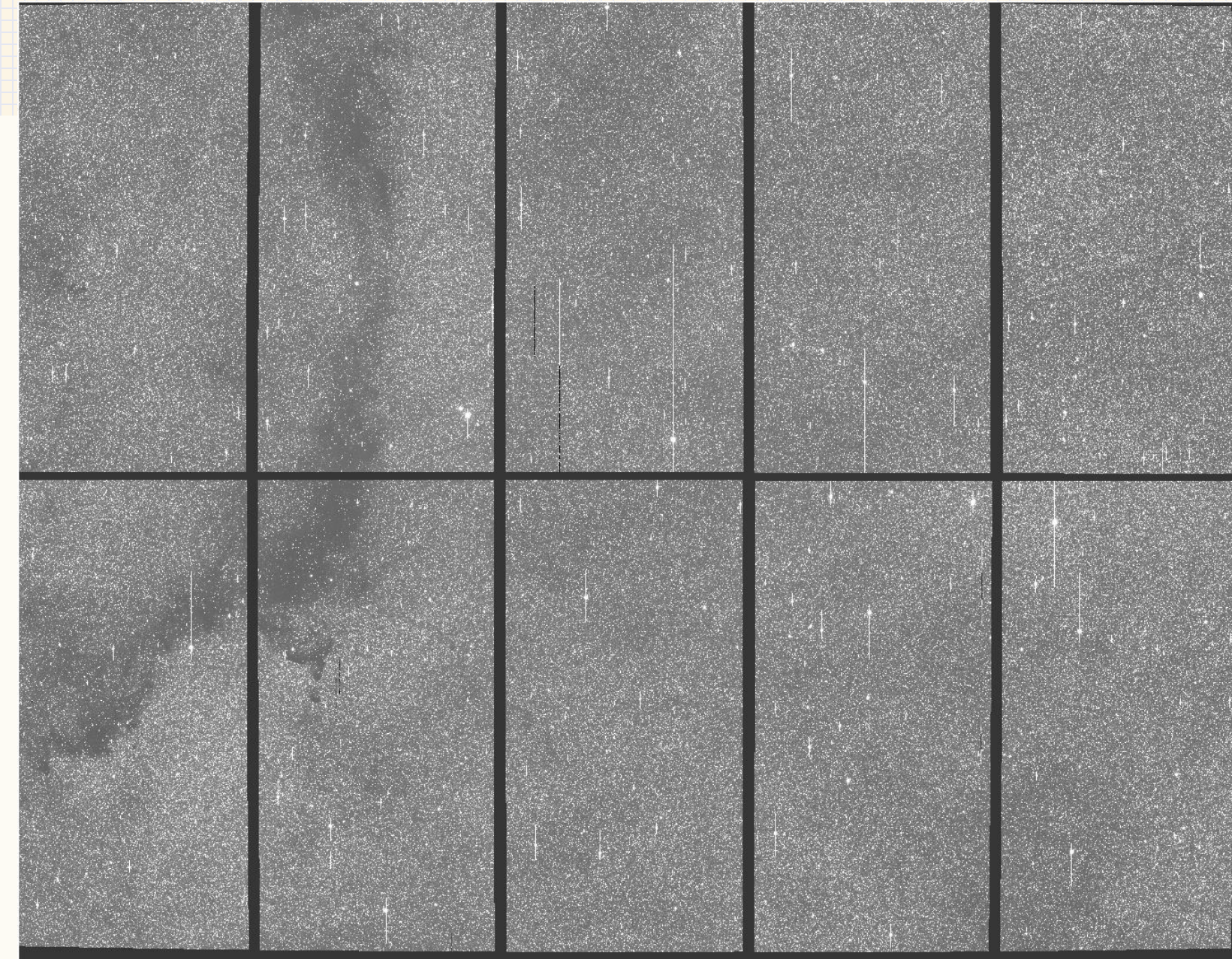
- 1.8m MOA-II telescope
- 2.2^2 degrees field of view
- Scans of the Galactic Bulge several times each night.

MOA-II

- 10 CCDs: 3cm by 6cm
- Each has 2048 by 4096 pixels.
- Entire area is 8k by 10k

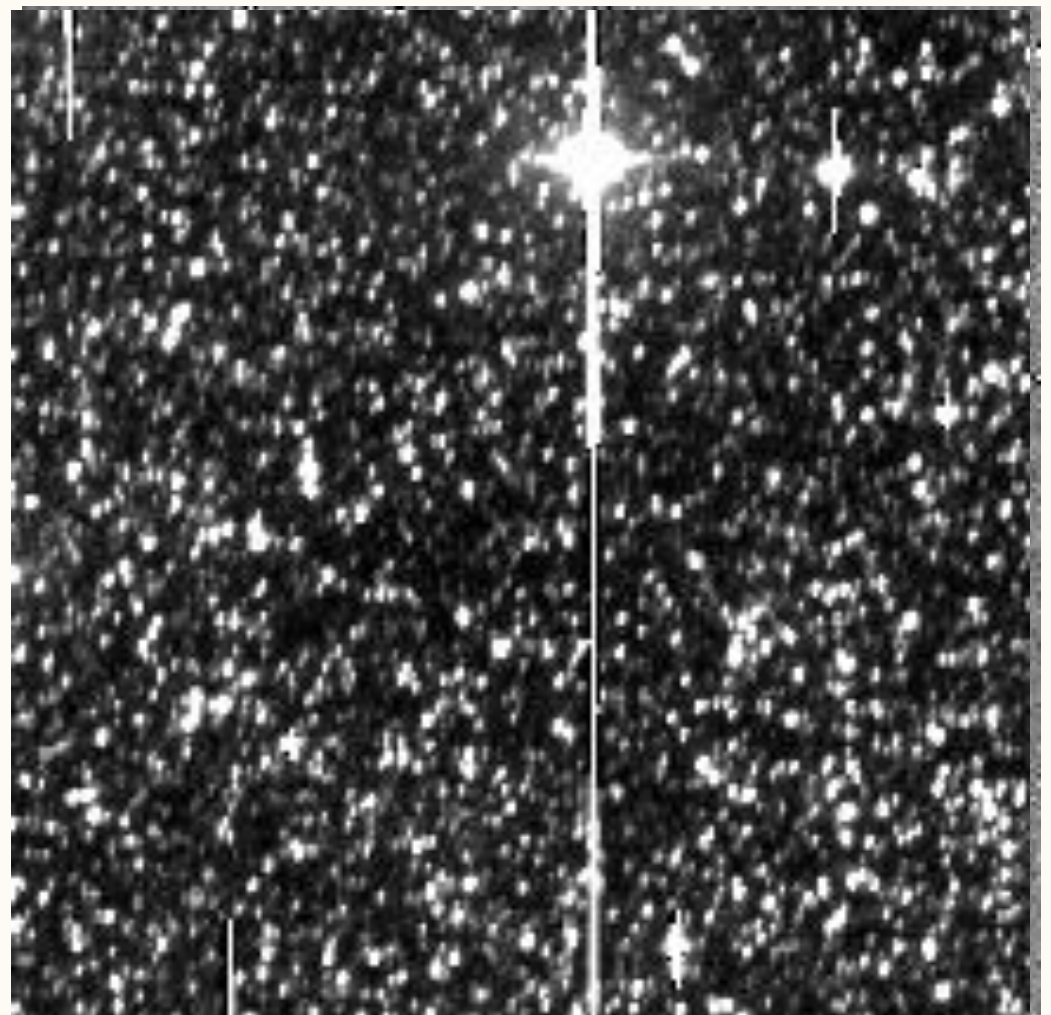
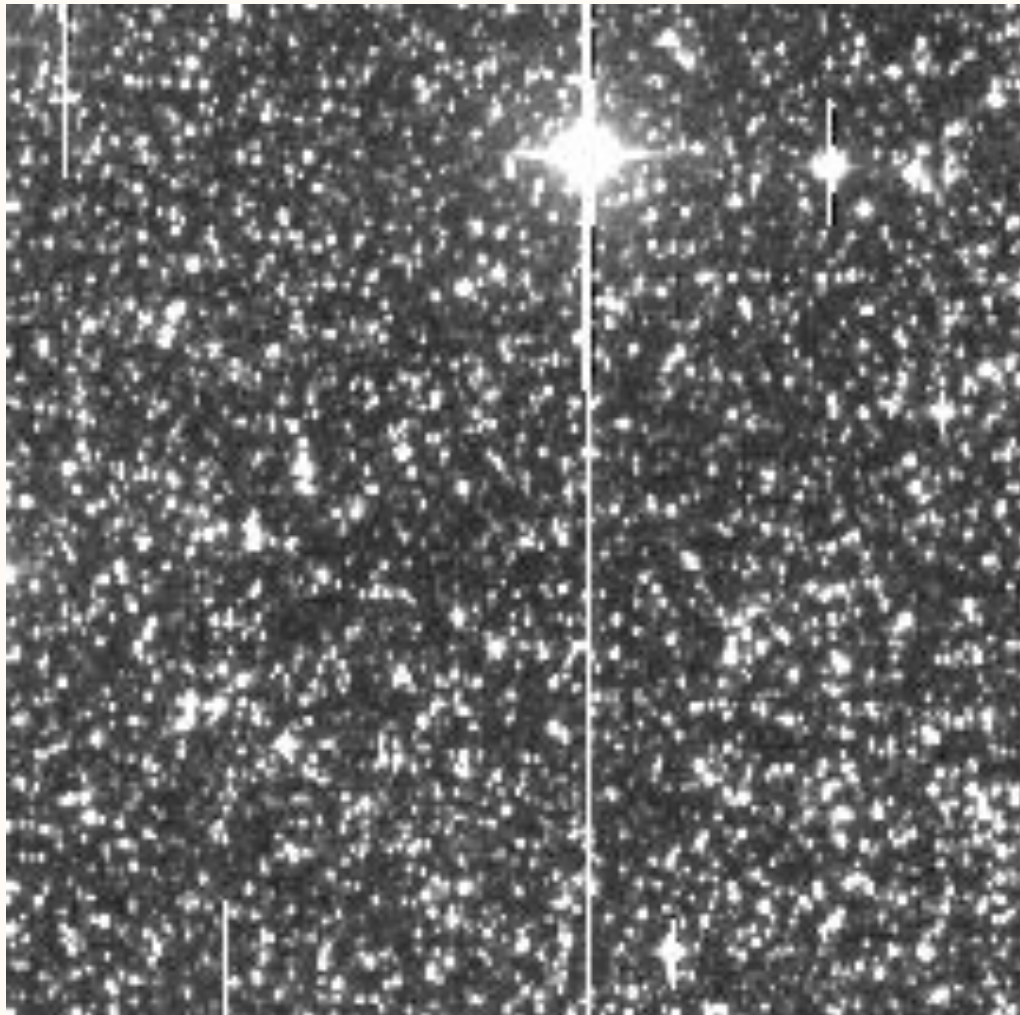


MOACam3



Mosaic of Galactic Bulge Field 1

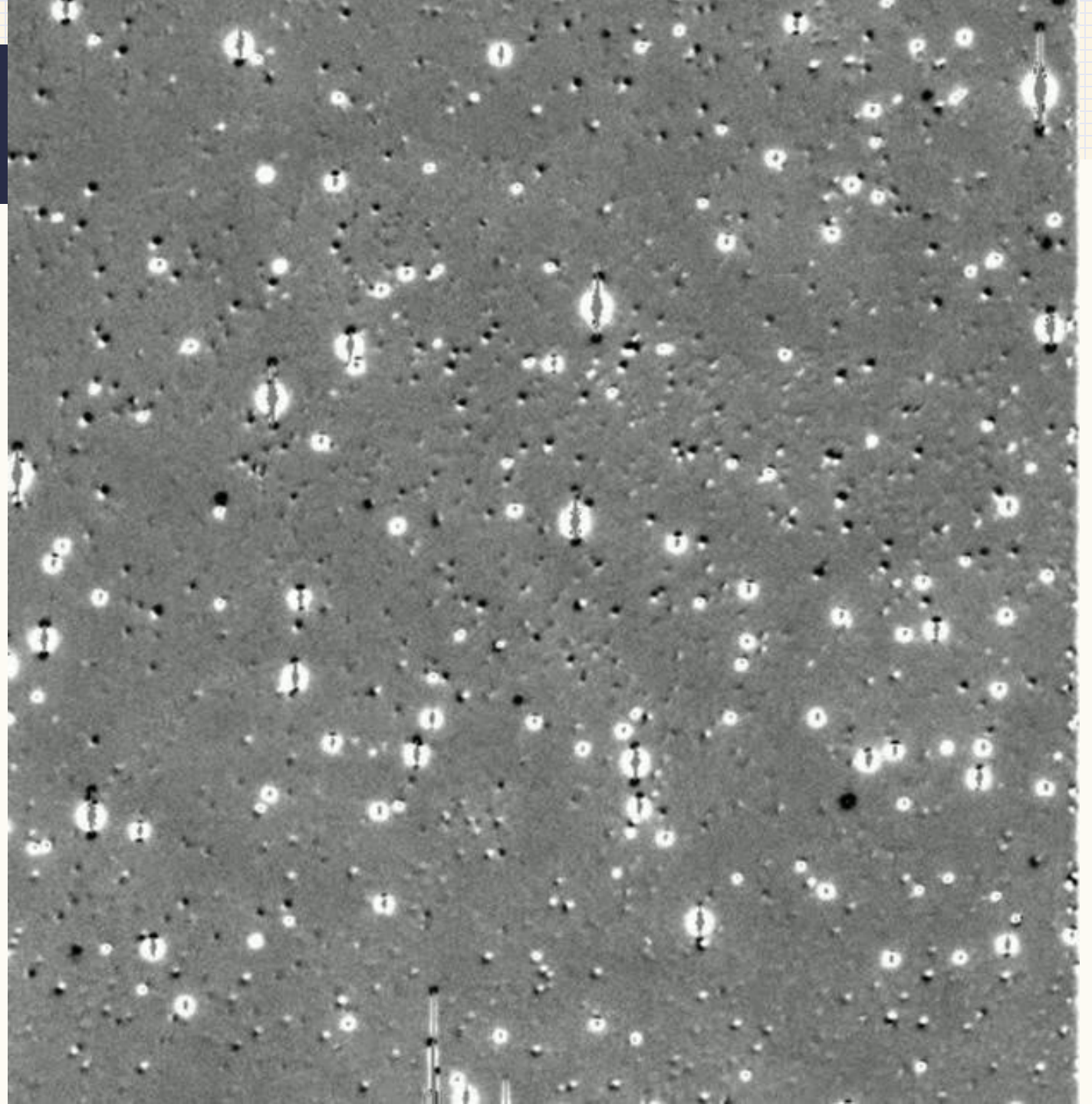
Difference Imaging Analysis



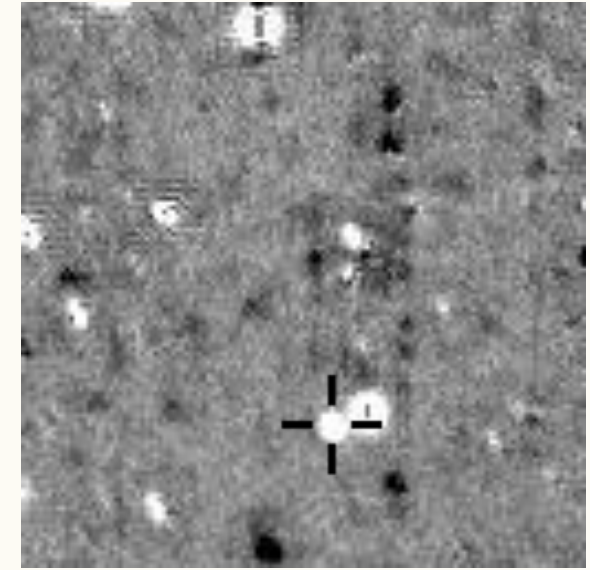
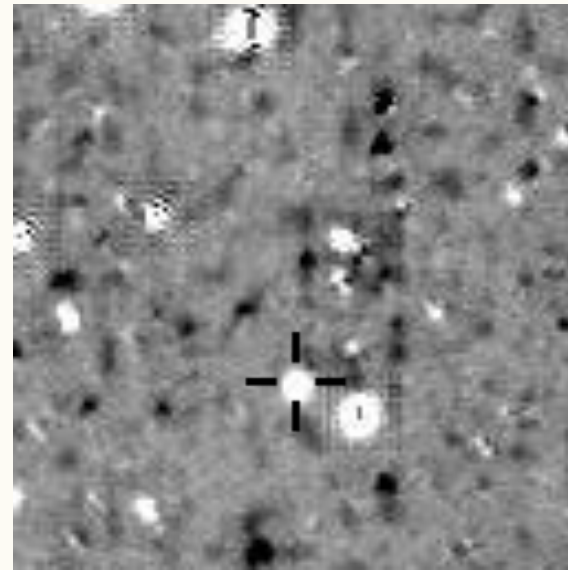
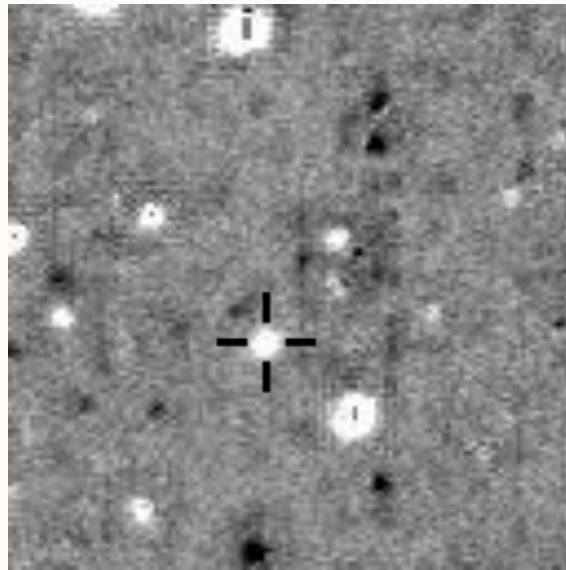
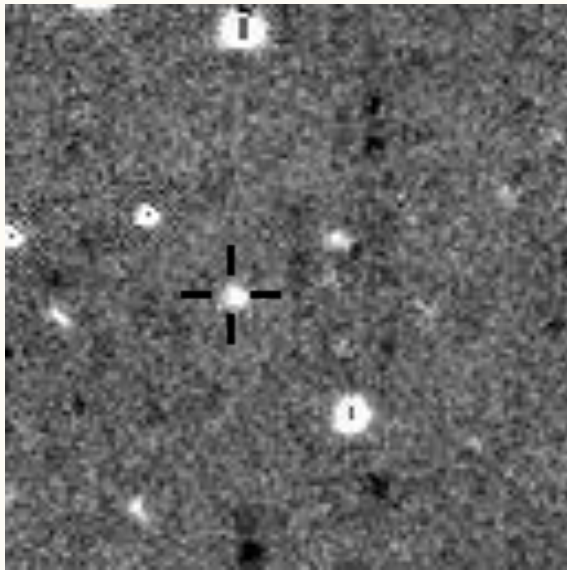
Bond, I. A., Abe, F., Dodd, R. J., Hearnshaw, J. B., Honda, M., Jugaku, J., ... Yock, P. C. M. (2001). Real-time difference imaging analysis of MOA Galactic bulge observations during 2000. *Monthly Notices of the Royal Astronomical Society*, 327(3), 868–880.

Asteroids in MOA

- Composite of all observations on May 15th 2008
- 51 observations
- Cadence of 10-12 minutes
- 5 asteroid with visible magnitude between 19.5 and 20.4



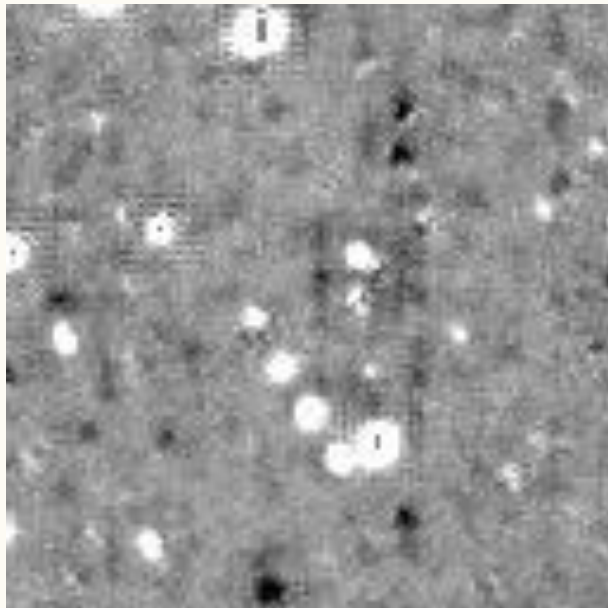
Asteroids in MOA



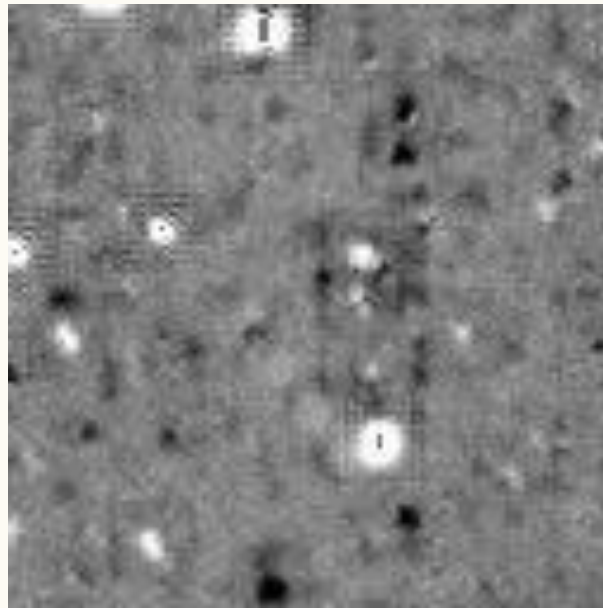
The main-belt asteroid (78153) 2002 NX24 on 23-June-2006 as seen in the MOA-II data

Asteroids in MOA: Image Stacks

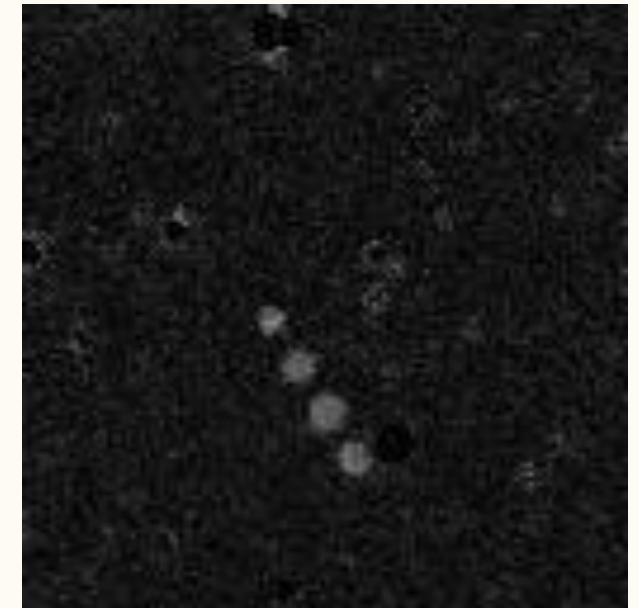
Brightest pixel stack



Median pixel stack



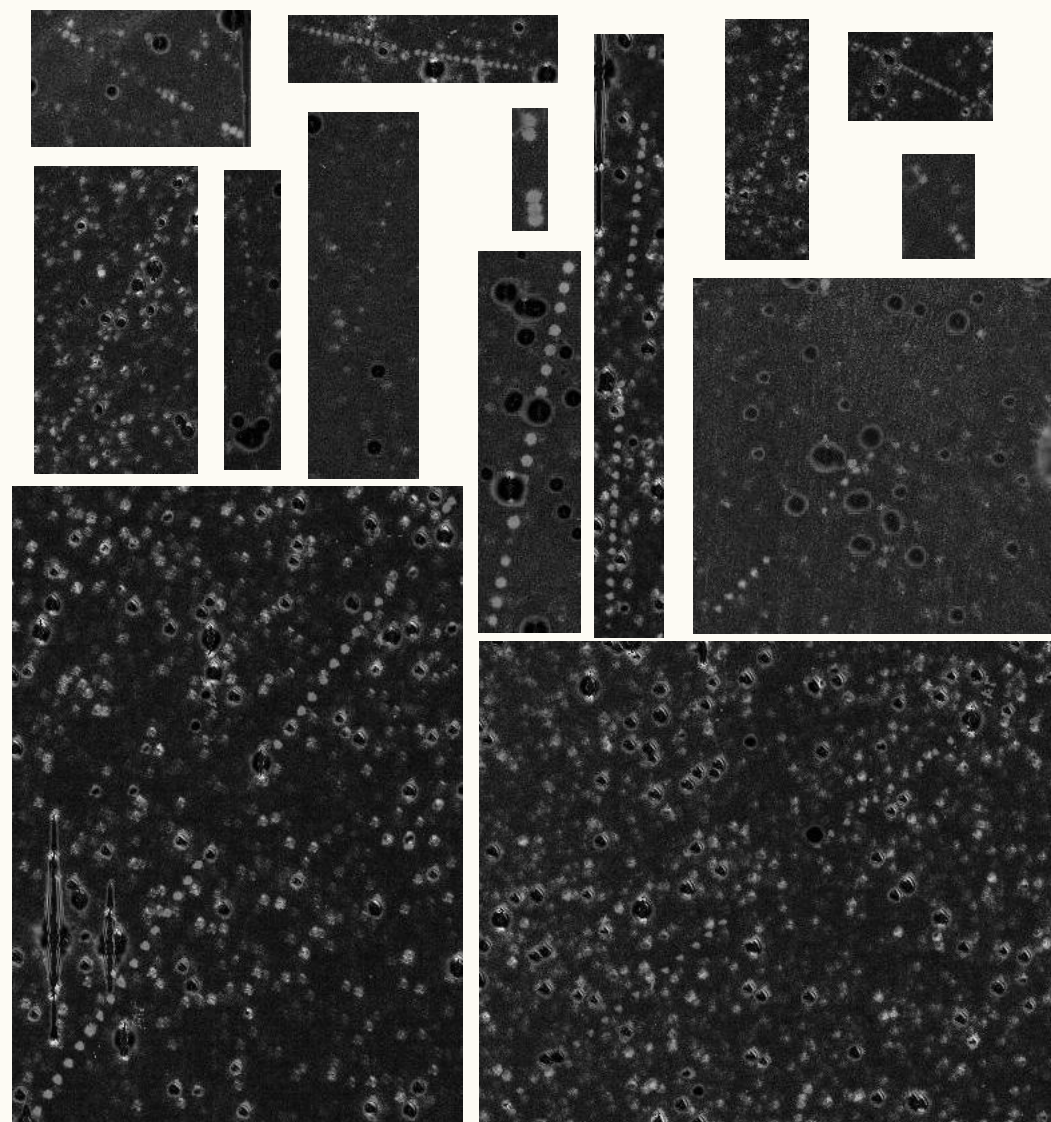
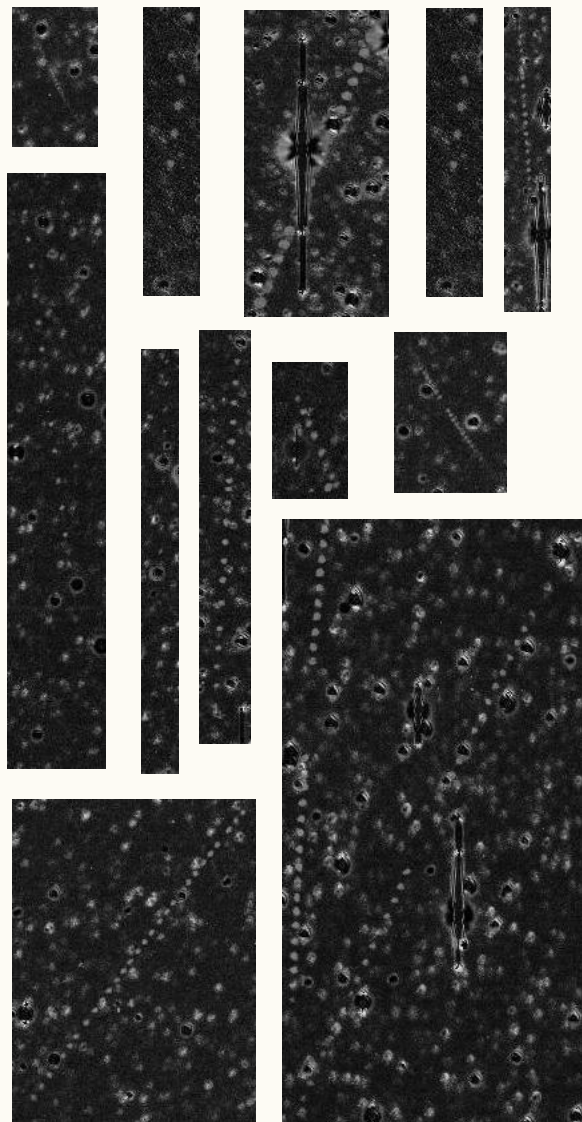
Subtracted stack
(Brightest – Median)



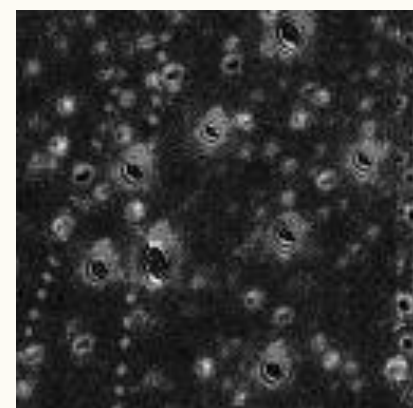
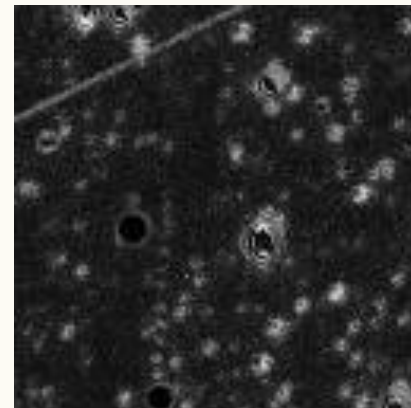
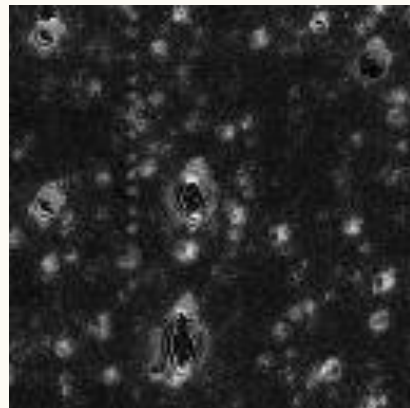
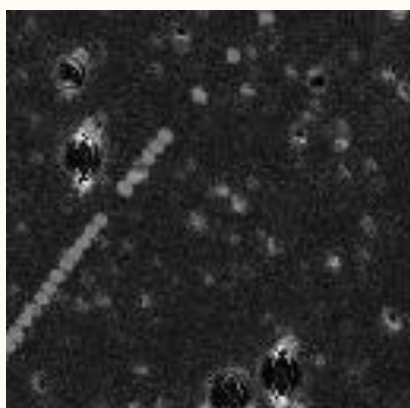
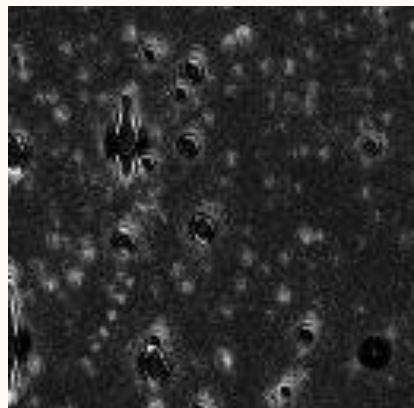
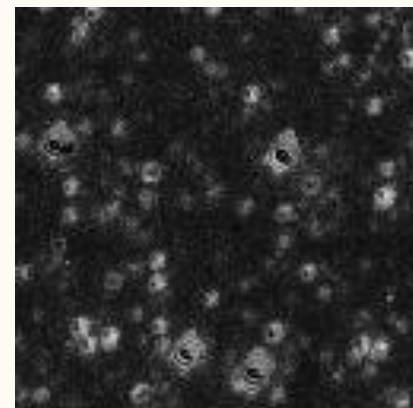
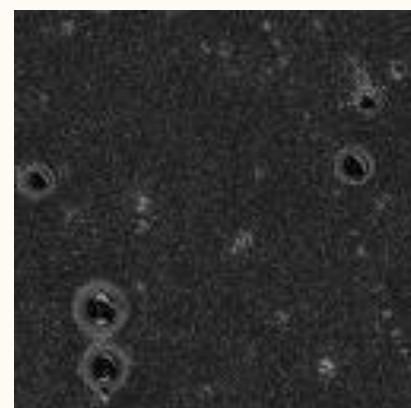
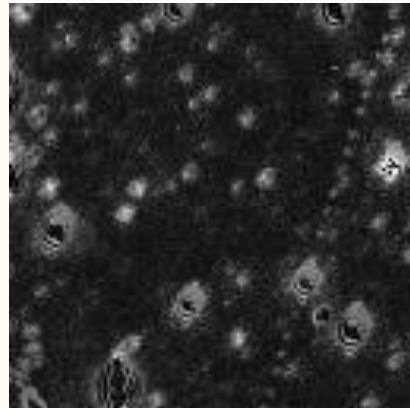
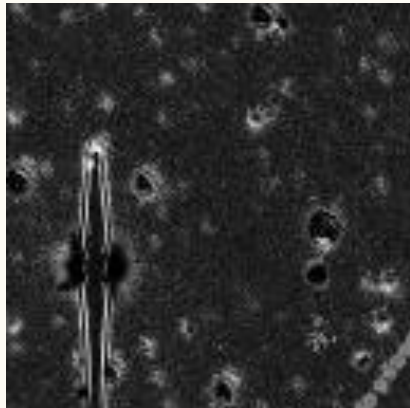
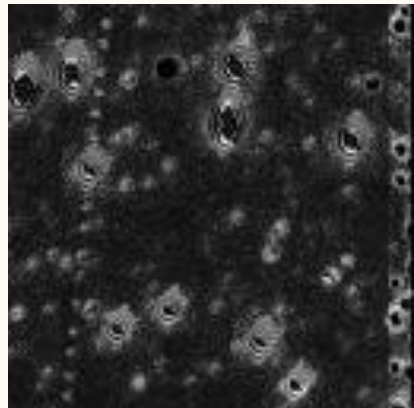
Partial tracklet of the main-belt asteroid (78153) 2002 NX24 on 23-June-2006 as seen in the MOA-II data

Creating the Dataset: Tracklets

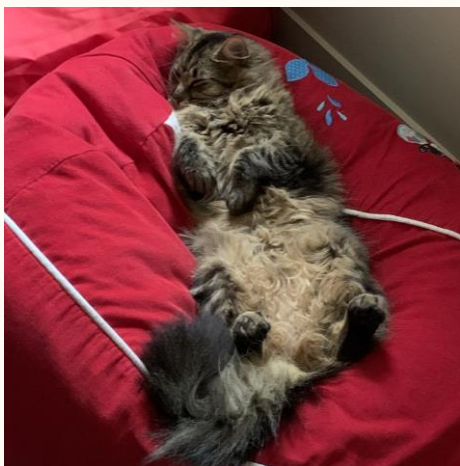
- 14 years of exposures from GB5 - chip 5: 50K observations
- Create subtracted stack
- List of all known asteroids
- Scan images to find the ones where a tracklet is visible
- 2073 tracklets found with visible magnitude 20.5 or lower



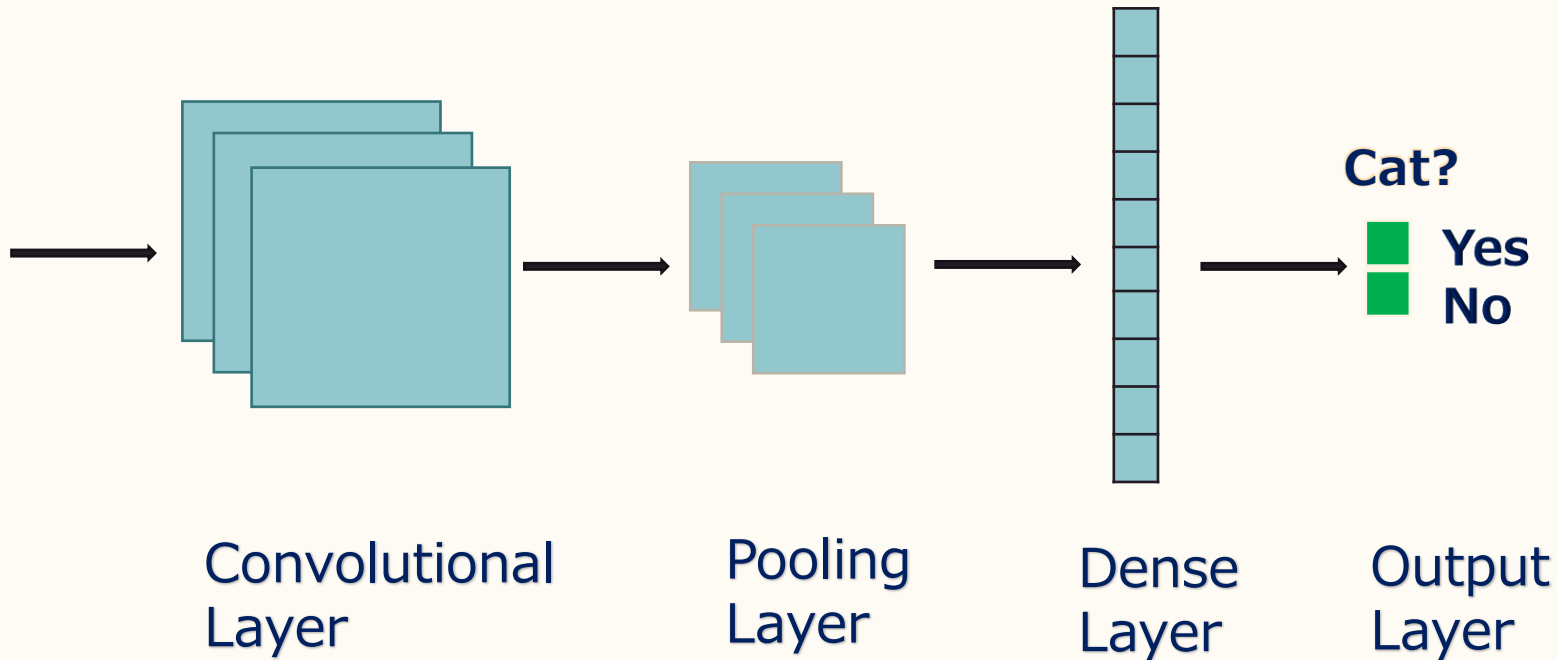
Creating the Dataset: Tracklets in Uniform Images



Convolutional Neural Network (CNN)



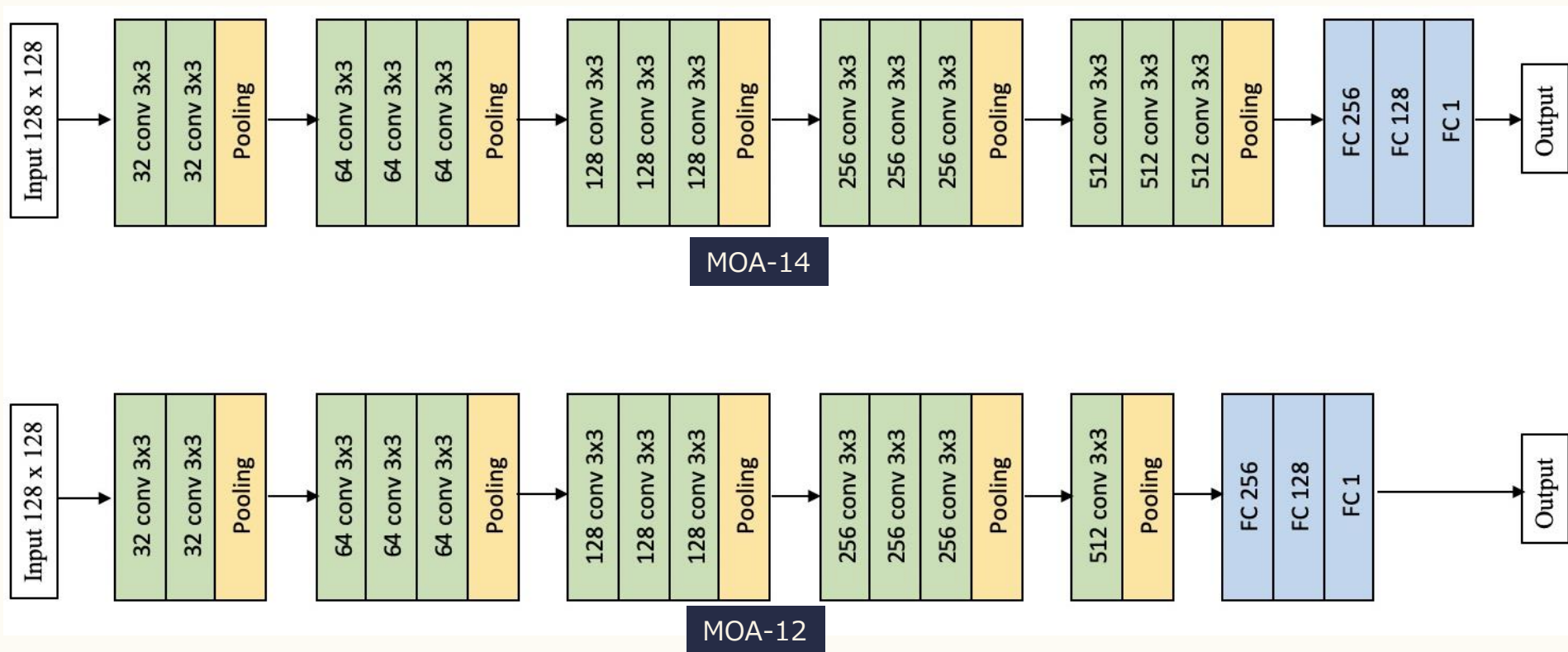
Input Layer



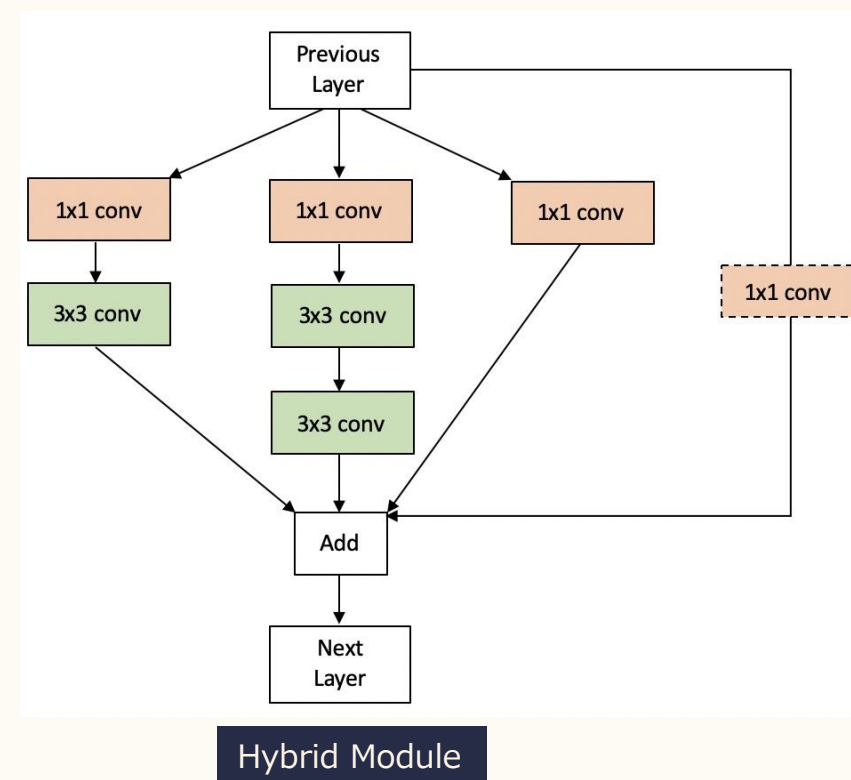
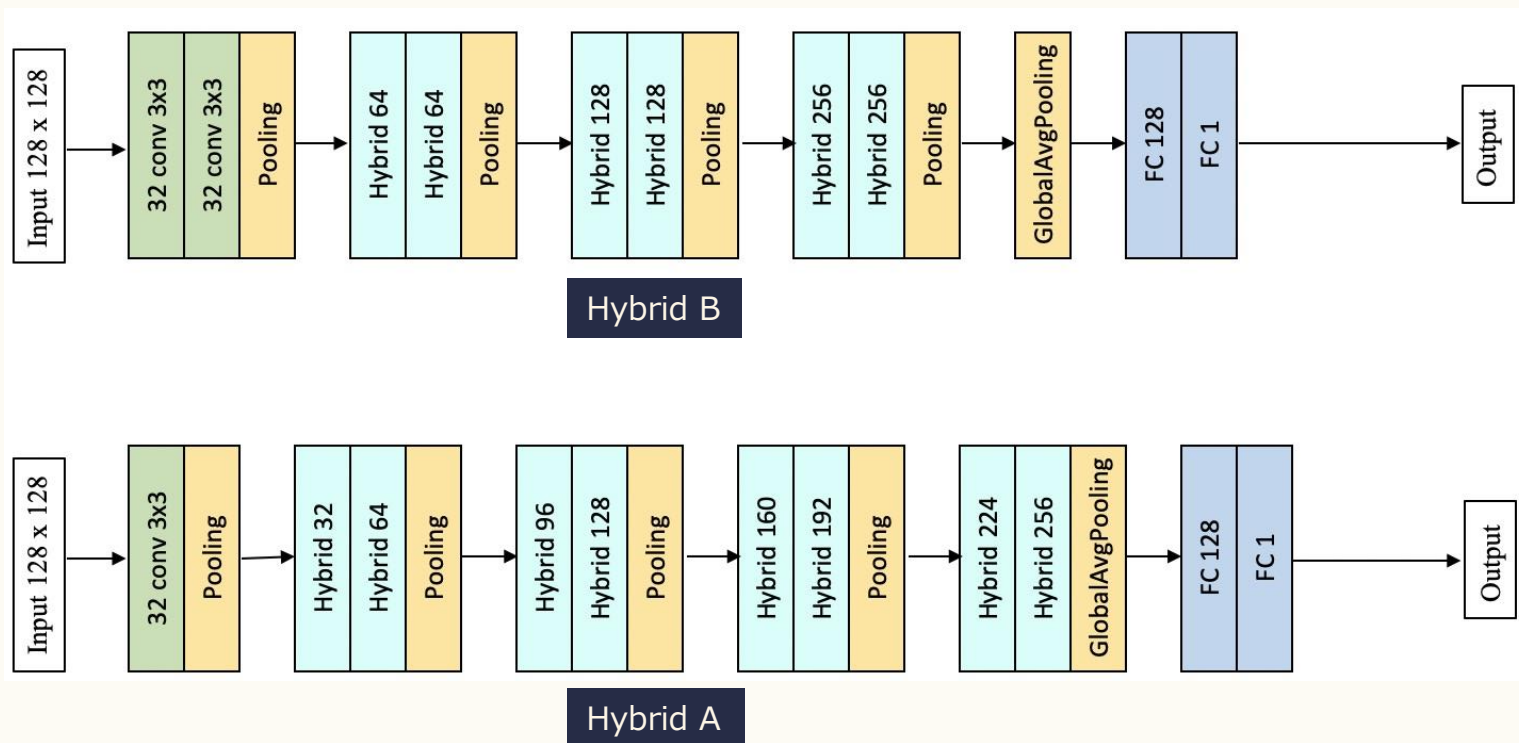
- Input is an image
- Everything between the input and output is the hidden layer
 - Magic of mathematics
- Purpose is to accurately predict output from the input
 - Minimize the loss

Classification Architectures: Winners

- VGG-like
- Fewer parameters
- MOA-15 with one additional “32 conv 3x3” block



Classification Architectures: Winners



Classification Architectures: Dataset

- 4072 images with tracklets
- 19,682 images without tracklets
- Data in training and validation sets is augmented
 - 8 augments per tracklet images
 - Random 35% of augments for the no tracklet images
- No overlap between the 3 sets
- Further test set: tracklets from other fields and chips
 - 300 tracklet images
 - 2000 no tracklet images

	Train	Validation	Test
Yes	3322	415	335
No	15,595	2039	2048

(a)

	Train	Validation	Test
Yes	29,898	3735	335
No	59,261	7748	2048

(b)

Classification Architectures: Evaluation GB5-R5 Test Set

	Recall	Precision	FN/FP
MOA-12	89.85%	86.49%	34/47
MOA-14	90.15%	83.20%	33/61
MOA-15	90.15%	90.15%	33/33
Hybrid A	90.15%	80.11%	33/75
Hybrid B	89.55%	80.00%	35/75

Classification Architectures: Evaluation GB-All Test Set

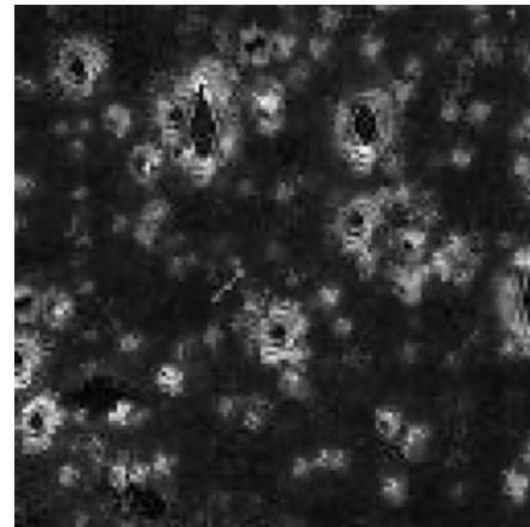
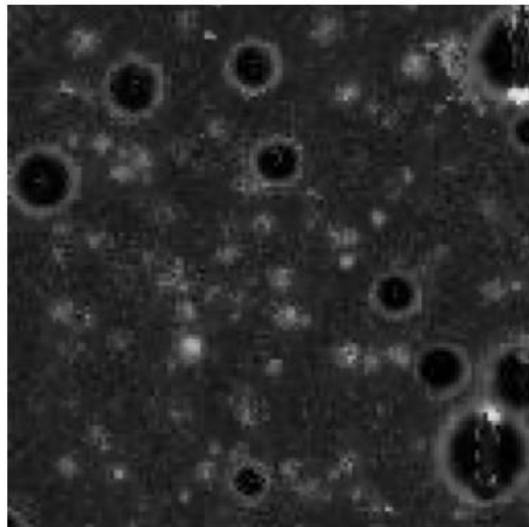
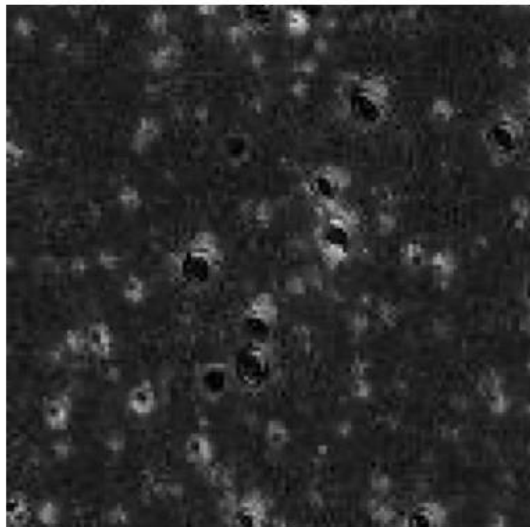
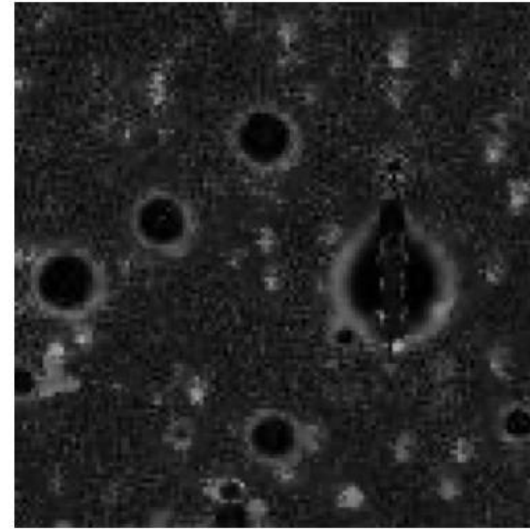
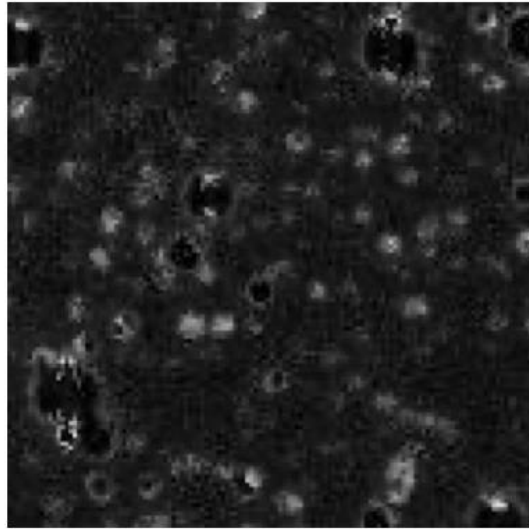
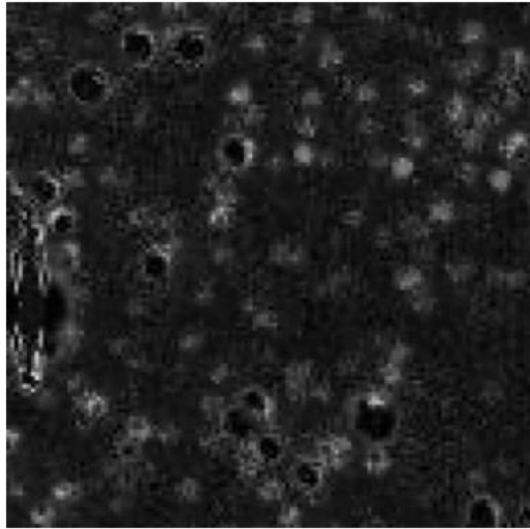
	Recall	Precision	FN/FP
MOA-12	94.00%	79.89%	18/71
MOA-14	94.33%	74.28%	17/98
MOA-15	94.00%	80.11%	18/70
Hybrid A	94.67%	72.63%	16/107
Hybrid B	94.67%	76.96%	16/85

Classification Architectures: Ensemble

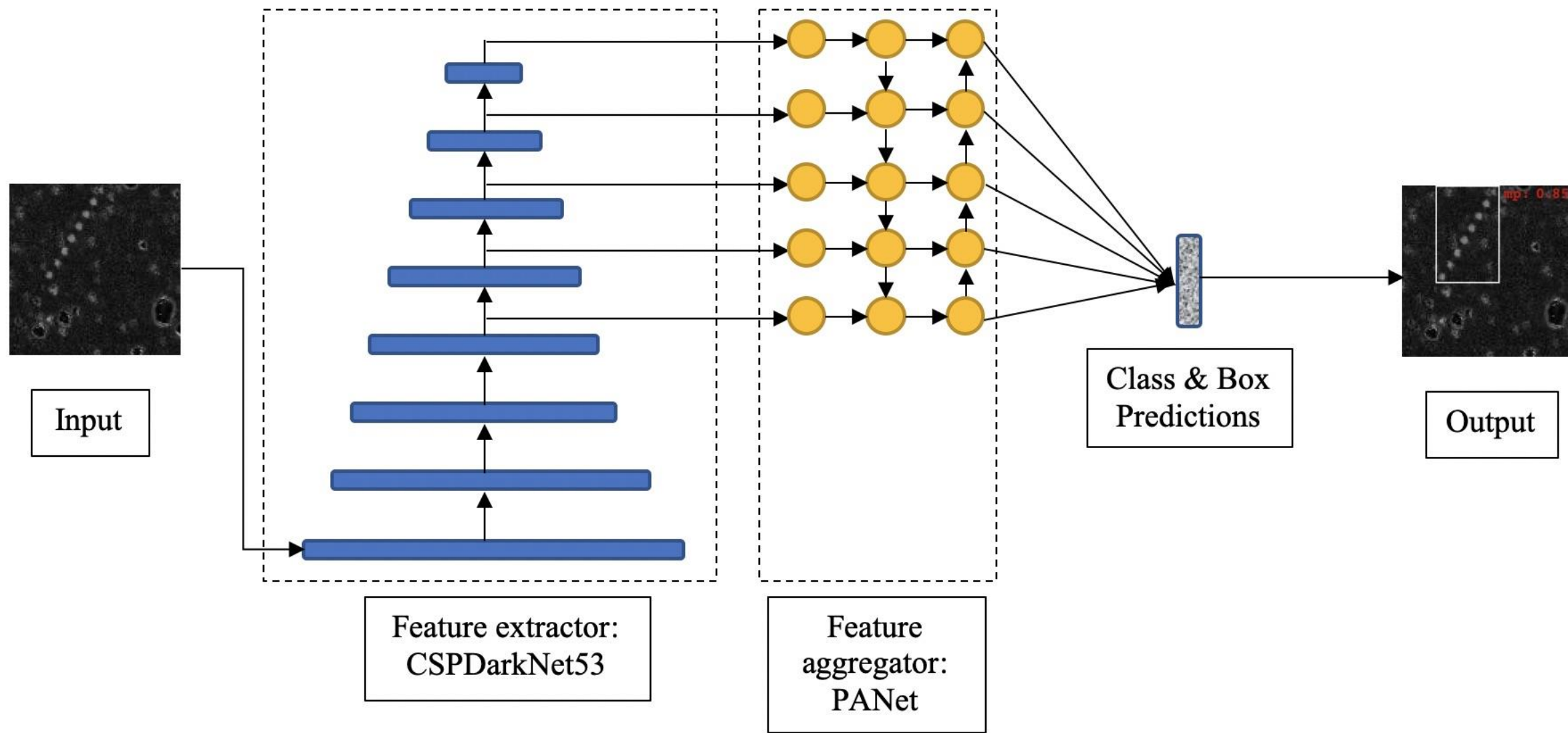
	Recall	Precision	FN/FP
Ensemble-Max-GB5-R5	94.33%	63.71%	19/180
Ensemble-Avg-GB5-R5	91.34%	86.69%	29/47
Ensemble-Max-GB-All	97.67%	50.78%	7/284
Ensemble-Avg-GB-All	96.33%	86.27%	11/46

Object Detection: Impetus

To quickly spot obscured and hard-to-find tracklets

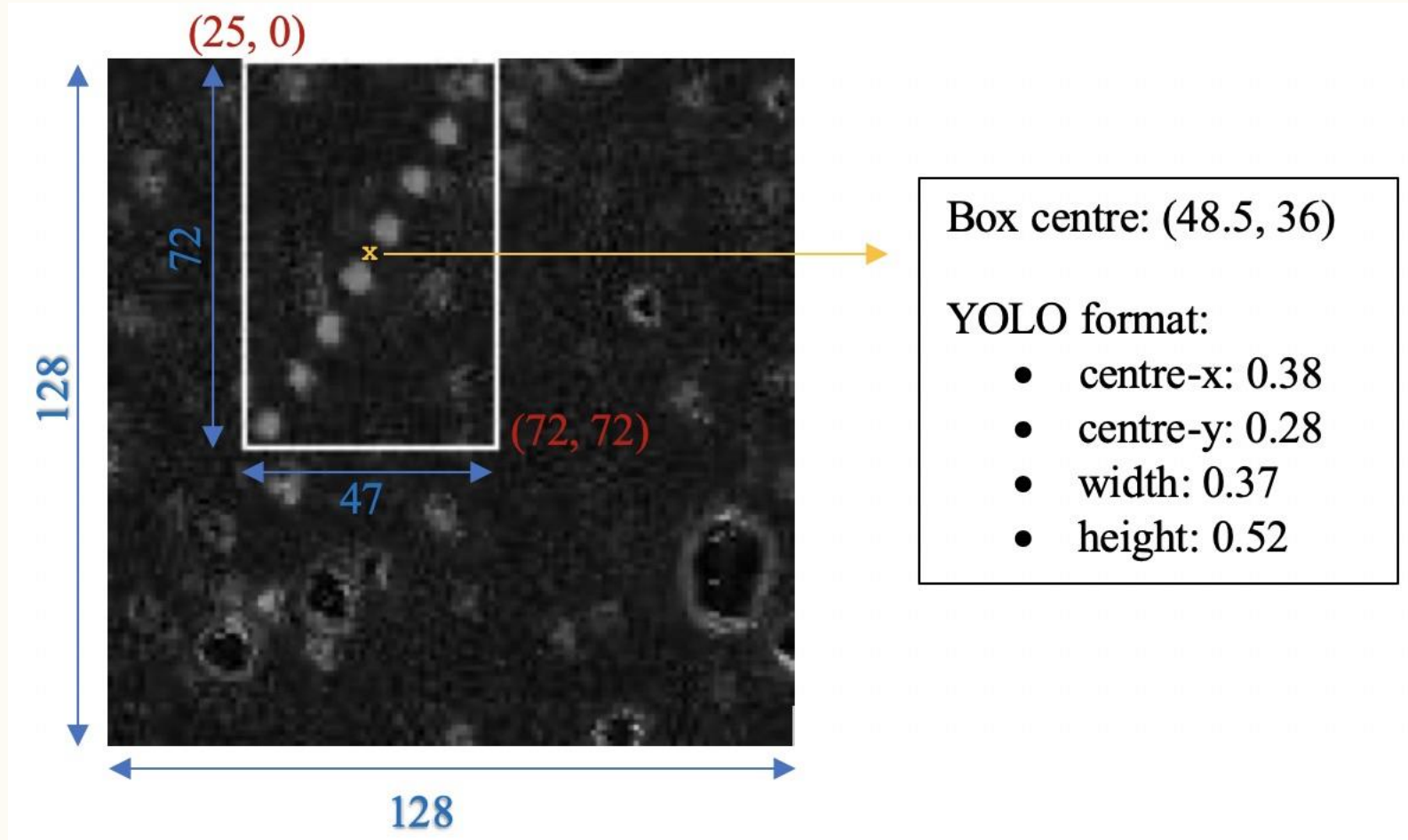


Object Detection: YOLOv4

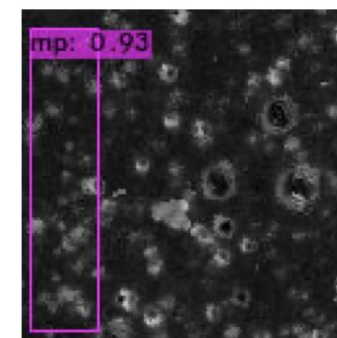
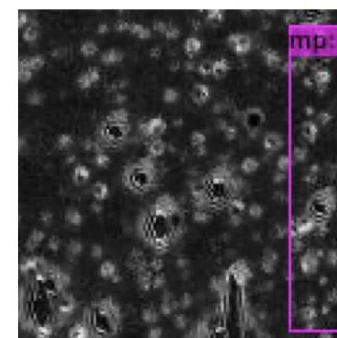
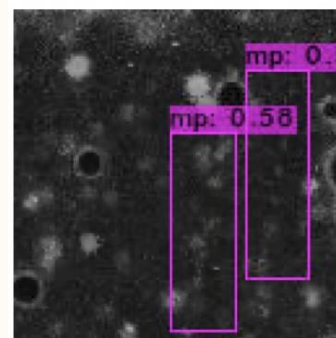
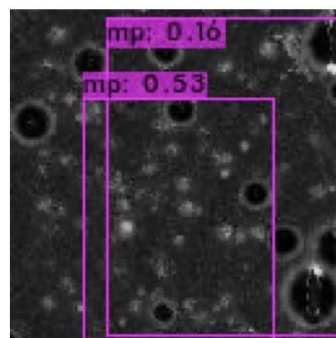
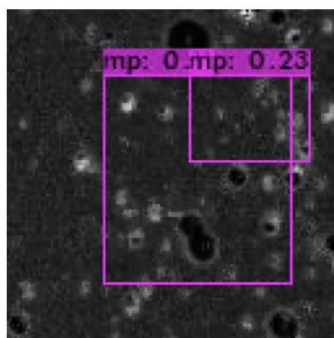
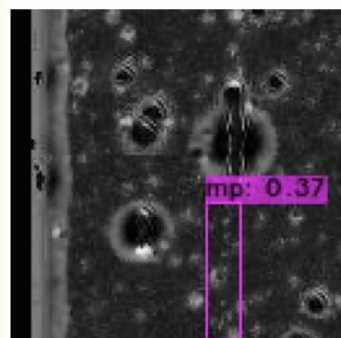
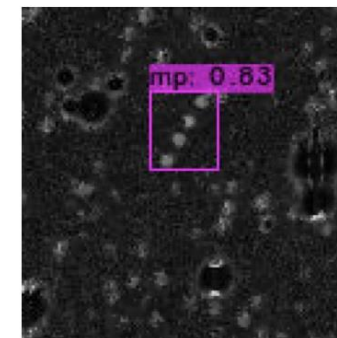
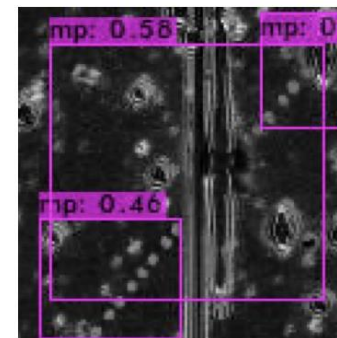
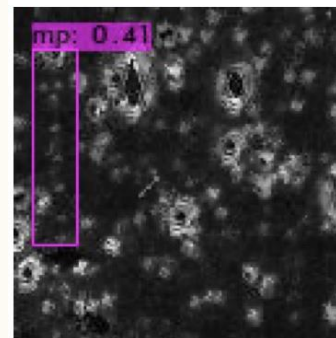
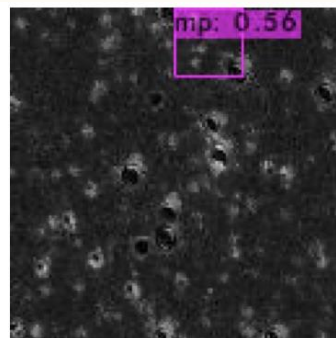
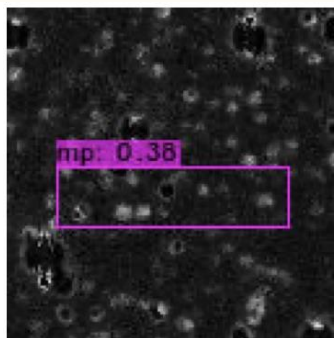
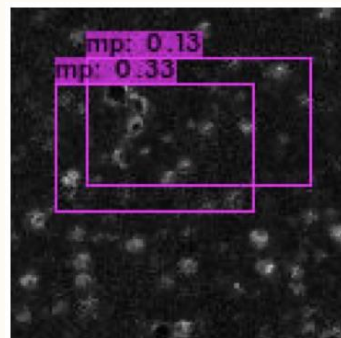


YOLO: Dataset

- Line clipping results for initial box coordinates
- YOLO format expects positional data with respect to the image dimensions
- 4153 tracklet images
 - 3737 training set
 - 416 test set



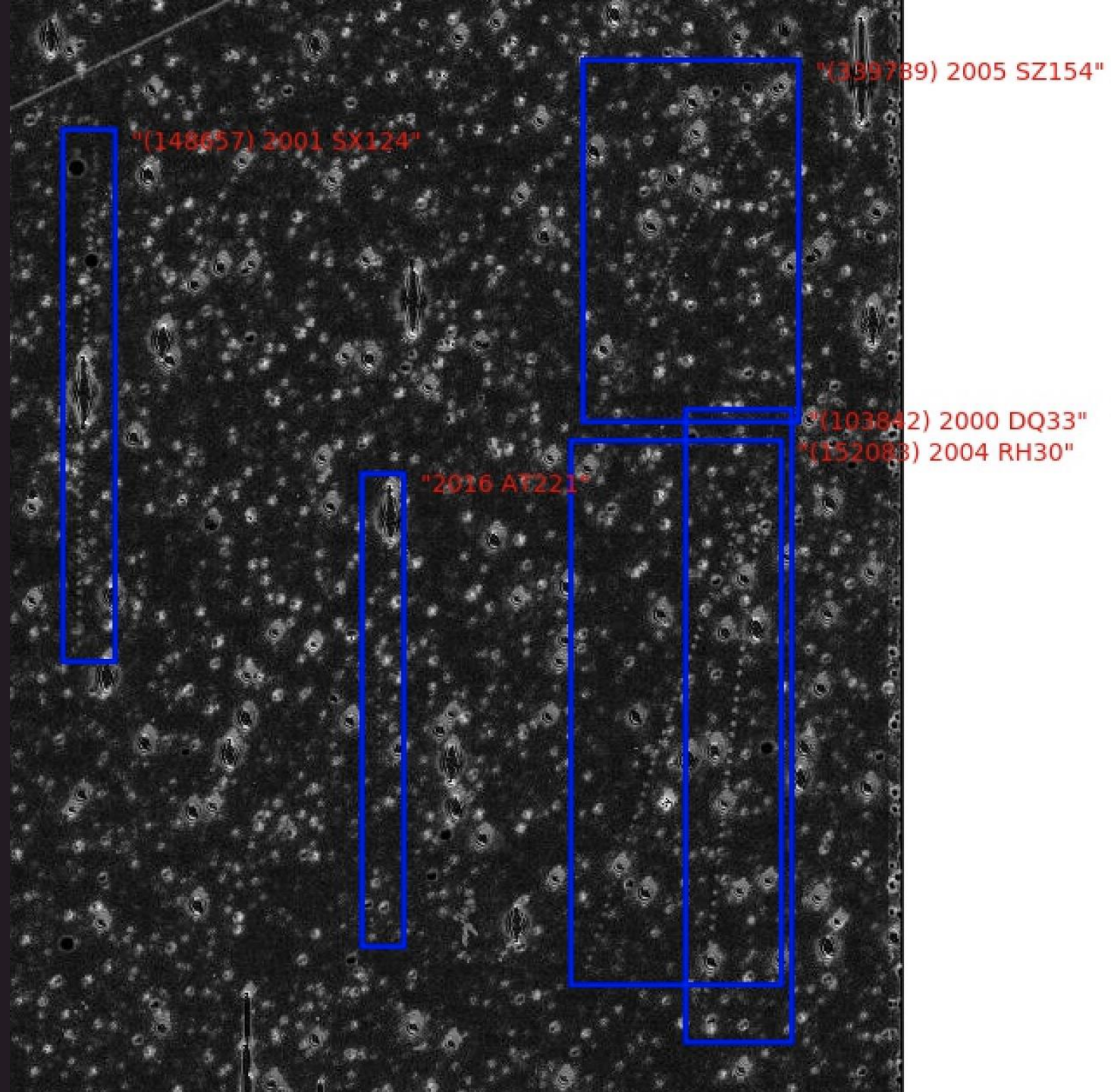
YOLO: Results- mAP of 90.95%



Summary and New Beginnings

- Methodology to extract known asteroids from survey data and use these to construct labelled datasets for supervised deep learning
- Possible to train deep learning models with a small amount of real data that generalizes well to categorize unseen data
- Both networks will be used for finding tracklets in the 500K GB5-R5 images with no known asteroid tracklets
- Integrate with software like HelioLinC to determine if candidate detections are solar bound objects
- Apply techniques and networks used with MOA to other surveys
 - CLASSY: Classical and Large: A Solar SYstem Survey
 - TNO survey with CFHT

Thank you!



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