Machine Learning assisted NEO Discovery and Polarimetric Characterization with Astronomical Surveys

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We are a group of over two dozen astronomers, computer scientists, data scientists and digital Big Data research platform experts at 11 universities and research institutes in South Africa and Europe. We study Near-Earth Objects (NEOs) for Planetary Defence and scientific purposes.

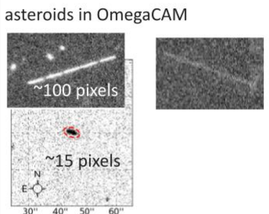
We present our research and development programme for algorithms and digital data analysis platforms for machine learning-assisted NEO discovery and polarimetric characterisation in astronomical surveys. Typically this is serendipitous because these surveys are designed for galactic and extragalactic science.

The morphological appearance of NEOs in astronomical images ranges from a point spread function of just a few pixels in extent to an elongated linear feature spanning hundreds of pixels. Here we focus on detection and classification of elongated linear features based solely on astronomical images. We aim for a pure and complete detection and classification to as low as possible signal-to-noise for both the smallest and the largest linear extents. In addition we want to develop the pipeline for the detection and classification as a generic software component that is generically configurable for surveys and can be interfaced or embedded in the associated astronomical data handling systems. So we want to make the approach applicable to survey images that vary in terms of image spatial resolution, image quality and depth.

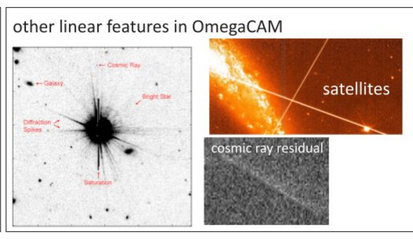
NEO Discovery

- OmegaCAM surveys archive: order 750 NEOs at signal-to-noise > 3 (Saifollahi+2023)
- Euclid Wide survey: order 15000 detectable NEOs (Carry 2018)

asteroids in OmegaCAM



other linear features in OmegaCAM



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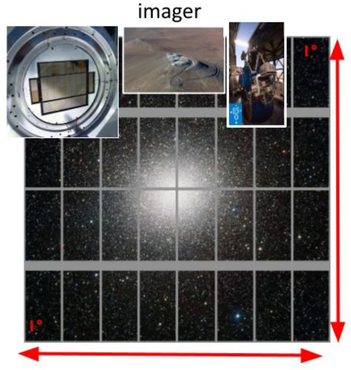
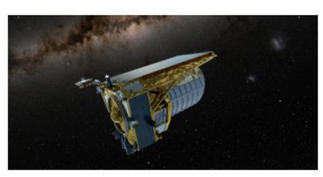
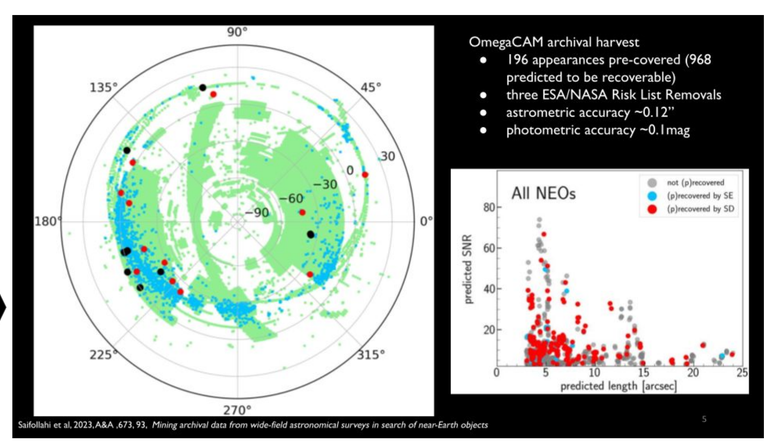
OmegaCAM, 265Mpix panoramic imager



Euclid satellite

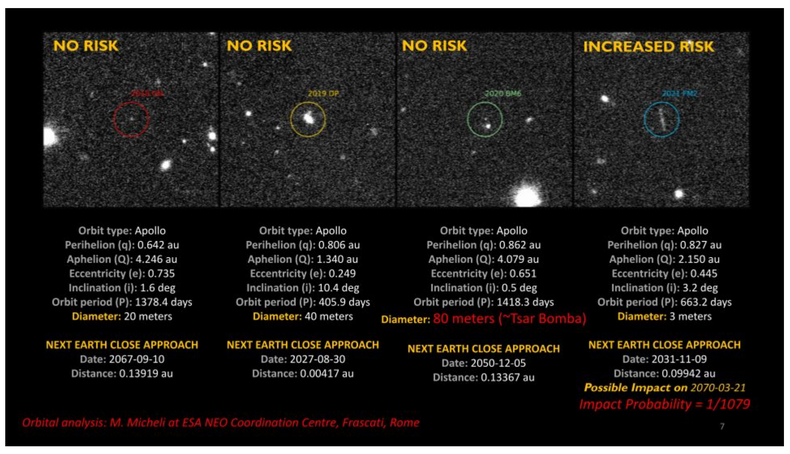




OmegaCAM archival harvest

- 196 appearances pre-covered (968 predicted to be recoverable)
- three ESA/NASA Risk List Removals
- astrometric accuracy ~0.12"
- photometric accuracy ~0.1mag

Saifollahi et al. 2023, A&A ,673, 93, *Mining archival data from wide-field astronomical surveys in search of near-Earth objects*



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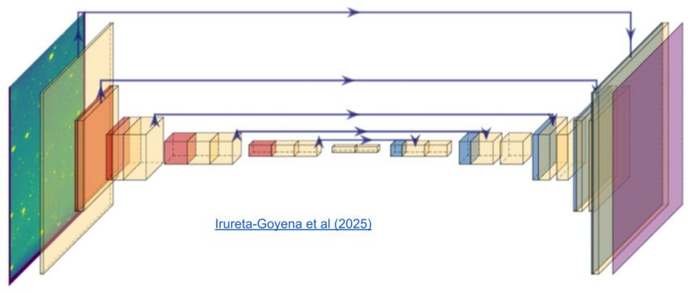
U-NET (TernausNet) machine learning architecture for OmegaCAM archival data



Irureta-Goyena et al (2025)

Yellow blocks: (transpose) convolutions, Red and blue: max-pooling and unpooling. Arrows from encoder to decoder: skip connections. Thickness blocks proportional to number channels after transformation. Height blocks: relative map size after transformation.

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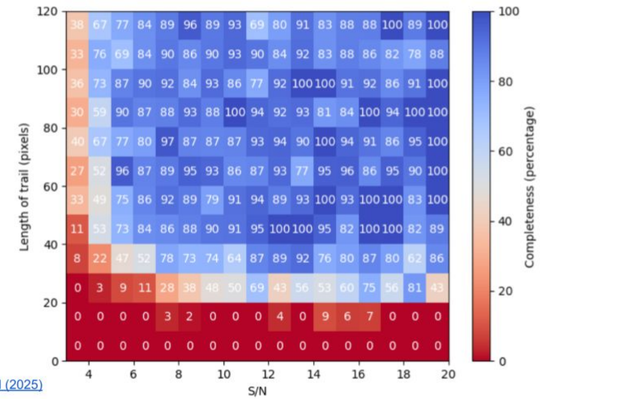
Asteroid streak detection with U-NET TernausNet straight from OmegaCAM images (synthetic streaks)



Irureta-Goyena et al (2025)

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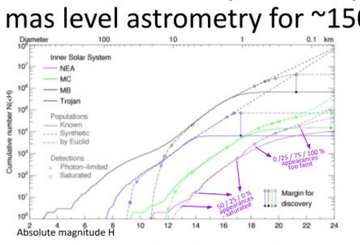
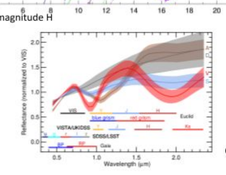
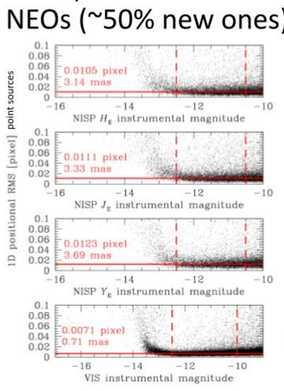
Euclid Wide Survey Planetary Defence predicted harvest: mas level astrometry for ~15000 NEOs (~50% new ones)





Carry 2018



Librato+2024

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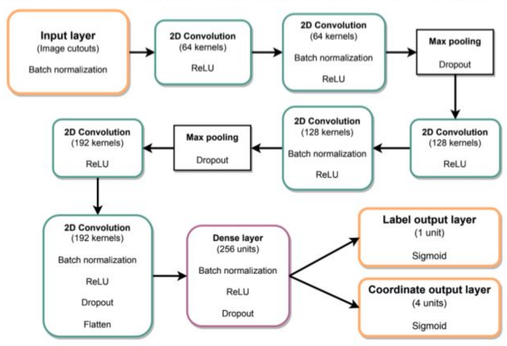
Architecture of the Convolution Neural Network for asteroid streak detection. Contains 2 043 975 trainable parameters.



Pöntinen+2023

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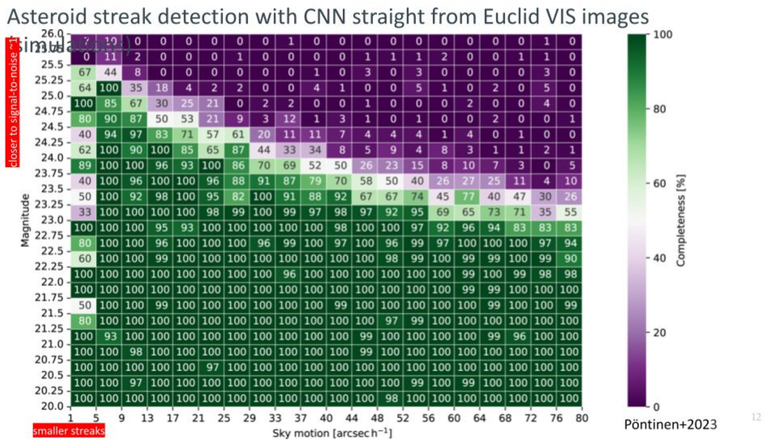
Asteroid streak detection with CNN straight from Euclid VIS images



Pöntinen+2023

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Generalizing from asteroid streaks: linear morphologies in astronomical surveys

Large area astronomical imaging surveys contain appearances of many types of linear, streak-like features. These include NEOs and other solar system objects, CCD charge bleeding, diffraction spikes, cosmic ray impacts, meteor fireballs, very elongated galaxies and (increasingly) human-made satellites (see visual examples in panel 3). Automatic detection and classification of these classes with high completeness and precision can immensely speed up the usage of these surveys not only for Planetary Defence and Space Situational Awareness, but also for solar system research. Additionally, this detection and classification is already valuable during the phases of survey data processing and quality assessment.

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PhD research project Max Chong

As a next step forward we have embarked on a PhD research project at the interface of computer science and astronomy at Stellenbosch University and the University of Groningen.

The plan is to develop a multi-class object detector and classifier pipeline for linear features suited for OmegaCAM, Euclid and other ground- and space-based astronomical surveys. We have started on OmegaCAM. For the asteroid streaks this project takes inspiration from Irureta-Goyena et al (2025) and Pöntinen et al (2023) and evaluate the usage of Vision Transformers. It shall generalize from asteroids to detecting and classifying satellites in OmegaCAM images we take inspiration from Stoppa et al (2024) and Paillassa et al (2020). The next steps after this are to generalize to more classes of linear features and to generalize to the Euclid and other surveys such as LSST surveys.

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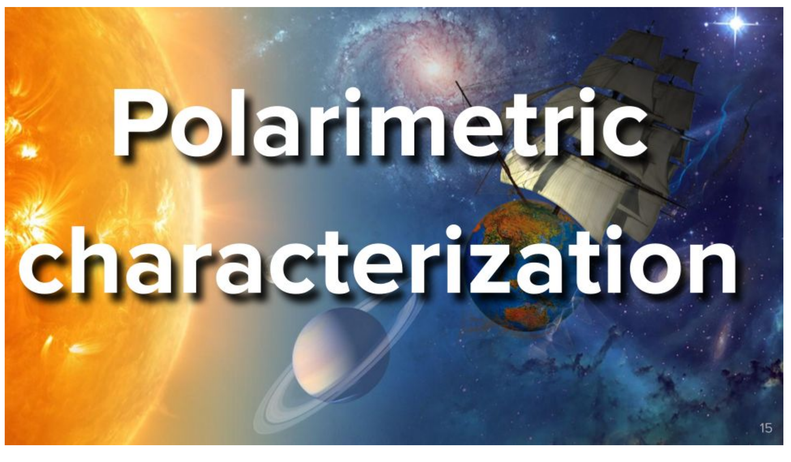

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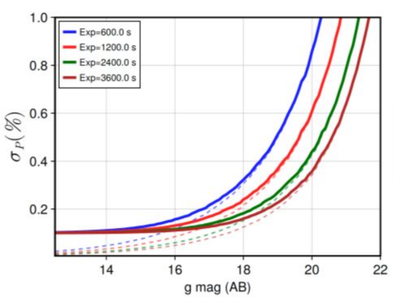
VSTPOL: OmegaCAM, 265Mpix *polarimetric* panoramic imager, commissioning 1st half 2026

Preliminary estimated performance for zero-polarization input



Castignani et al 2025, in prep

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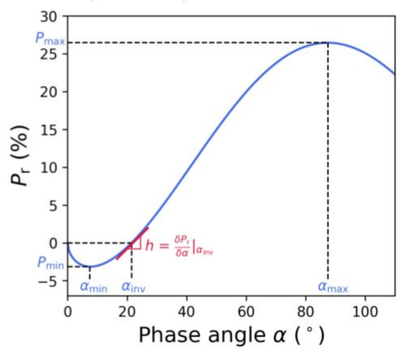
Example of polarisation parameter dependence on phase for NEOs



Castignani et al 2025, in prep
Bagnulo et al 2024

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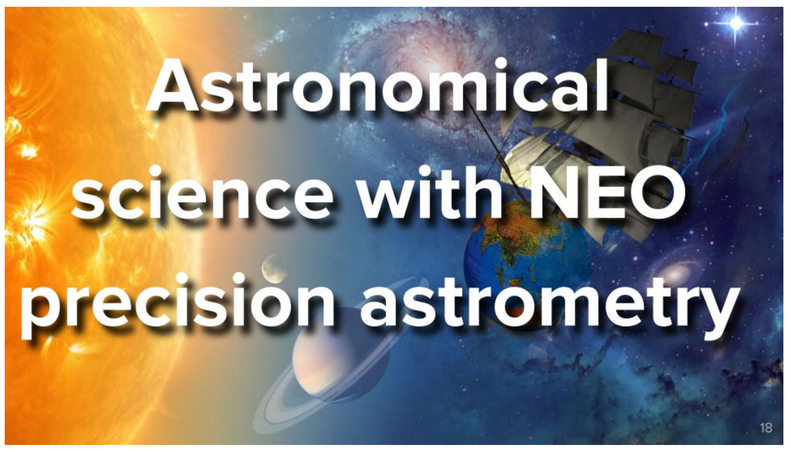

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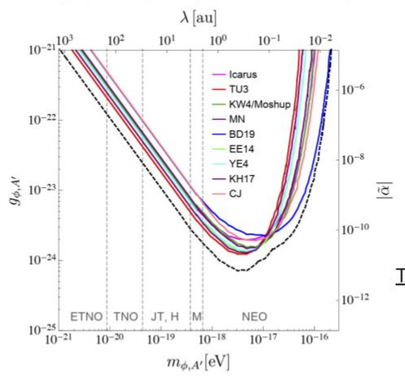
Constraining ultralight dark matter and deviations from General Relativity and/or Standard Model through (Euclid?) NEO precision astrometry



Tsai et al 2023

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