Optical-Based Space Surveillance & Tracking: Leveraging UNSW Observatory for Research and Education

Dr Yang Yang
Space Engineering Lecturer
School of Mechanical and Manufacturing Engineering
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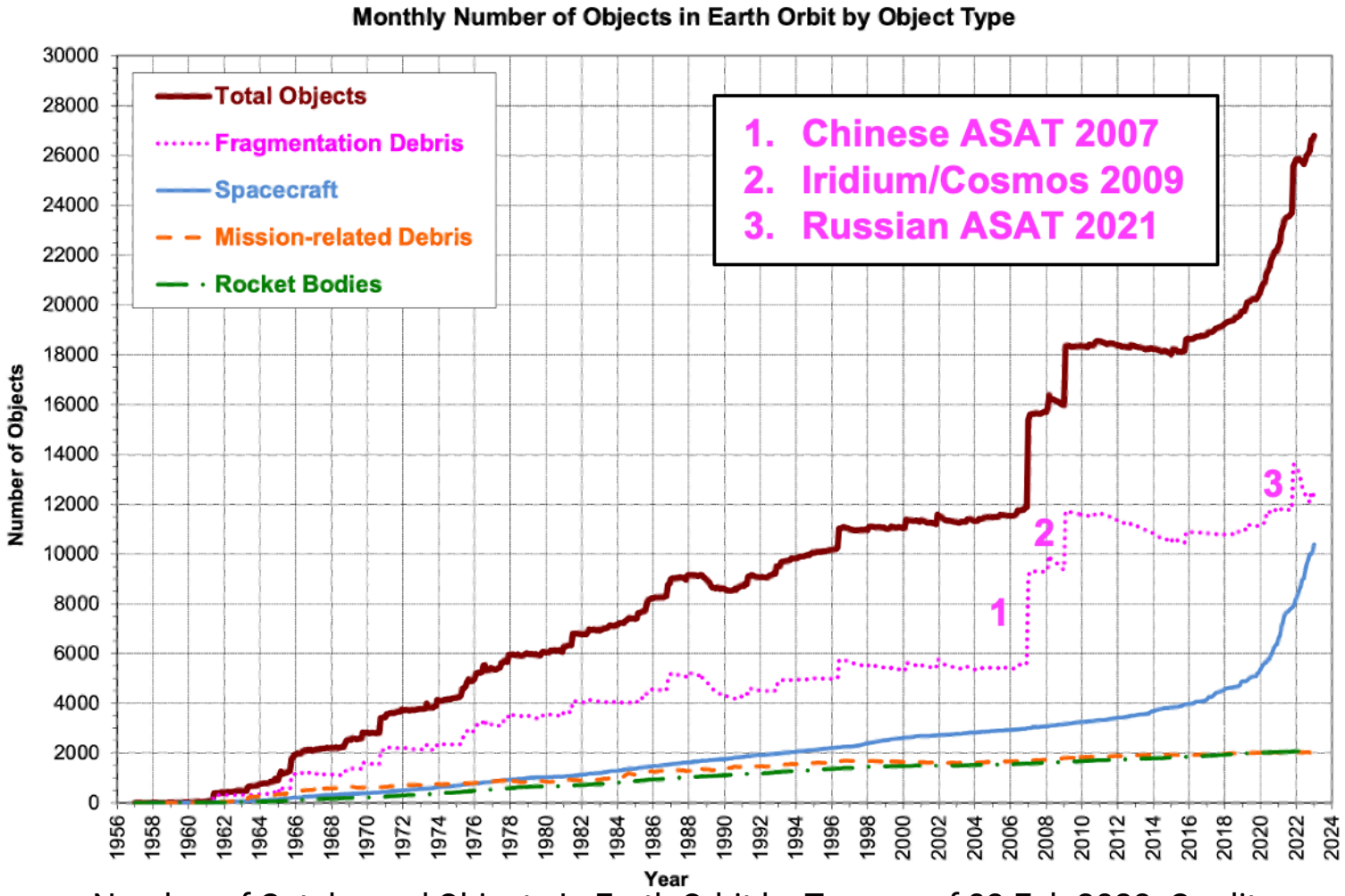
Space Environment

- ~9,000 operational satellites*
- >365,000 debris >10 cm
- ~1,000,000 debris 1~10 cm
- 130 million particles <1 mm
- Number of spacecraft, objects and debris rising significantly

Kessler Syndrome: collisions create more debris leading to a runaway chain reaction of collisions and more debris. [Donald Kessler, 1978]

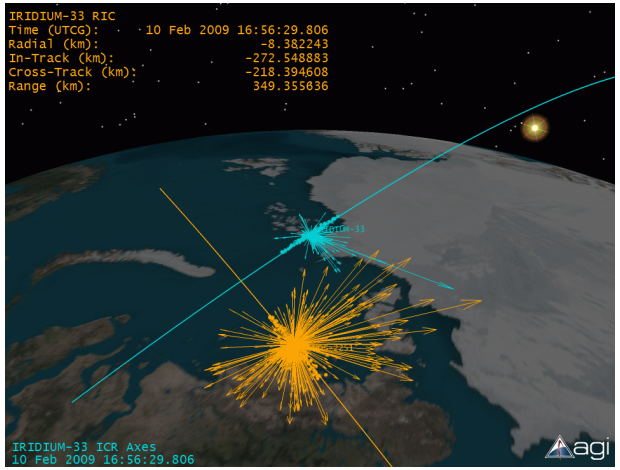


Number of Catalogued Objects In Earth Orbit by Type as of 03 Feb 2023. Credit: NASA Orbital Debris Programme Office

* ESA Space Environment Statistics, https://sdup.esoc.esa.int/discosweb/statistics/

Hazards of Space Debris

Satellite Collision in Orbit



Iridium 33/Cosmos 2251 Collision on 10 February, 2009, Credit: CelesTrak

Risk to Human Spaceflight

ISS Performing Numerous Active Manoeuvres to Avoid Collision

International Space Station
@Space_Station

Shortly after 9 p.m. EDT, @NASA instructed crews aboard the space station to shelter in their respective spacecraft as a standard precautionary measure after it was informed of a satellite break-up at an altitude near the station's earlier Wednesday. Mission Control continued to monitor the path of the debris, and after about an hour, the crew was cleared to exit their spacecraft and the station resumed normal operations.

Unexpected Landing on Earth

Australian Space Agency
@AusSpaceAgency

We are currently making enquiries related to this object located on a beach near Jurien Bay in Western Australia.

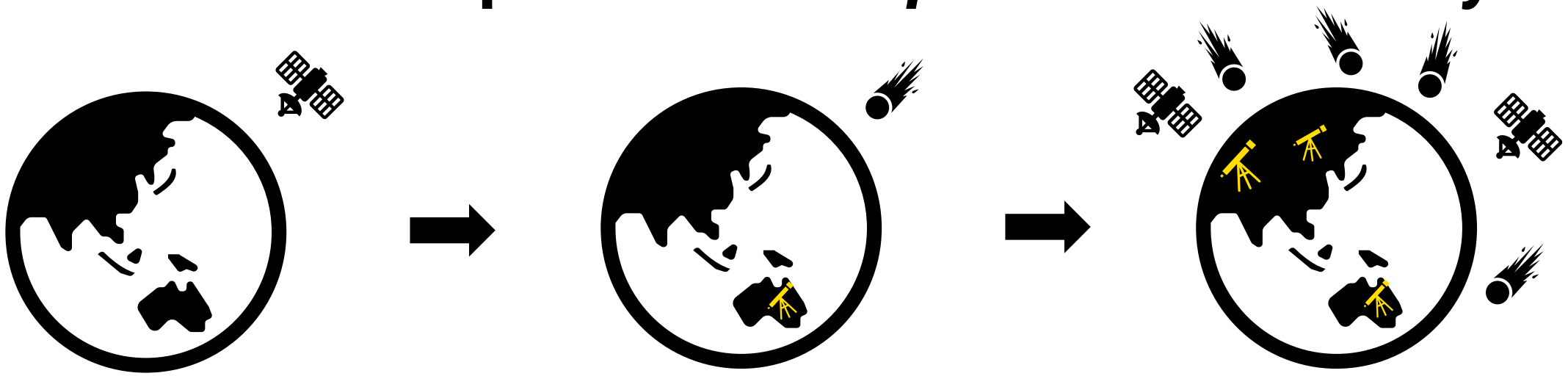
The object could be from a foreign space launch vehicle and we are liaising with global counterparts who may be able to provide more information.

[More in comments]

Indian Rocket's 3rd Stage Landed on WA Beach, Australia (Found in mid-July 2023)

How can we reduce the impact of space debris to promote the long-term sustainability of outer space activities?

Research Roadmap - *Towards Space Sustainability*



Spacecraft Navigation
Single Satellite Single Sensor

Reliable Orbit Determination
Single Space Object Single Sensor

Space Surveillance & Tracking
Multiple Space Objects Multiple Sensors

Spacecraft navigation: Estimating the three-dimensional position and velocity of a spacecraft (relative to a frame of reference).
Orbit determination (OD): the same function as spacecraft navigation, extended to all space objects including space debris.
Space surveillance & tracking (SS&T): a network of sensors

- capable of surveying and tracking multiple space objects,
- providing data, information and services on space objects to support[#]
  - Collision avoidance decision-making
  - Active space junk removal

Estimation/filtering framework

- Astrodynamics modelling
- Measurement processing

[#]EU space programme (2021–2027)

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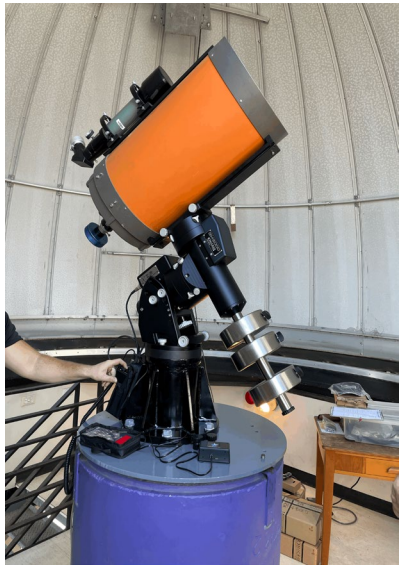
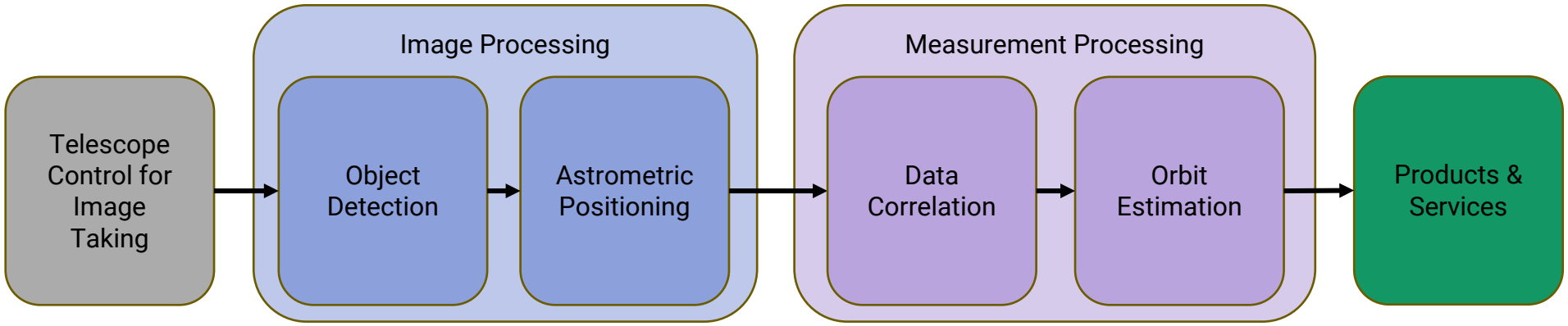
UNSW Space Surveillance & Tracking Node

UNSW Observatory

Systems	Component	Specifications
Mount	Mount	10 Microns GM2000II - Combi
	GPS Device	MGBOX V2 GPS USB Weather Station
Telescope	Telescope	14-inch Schmidt-Cassegrain
	Aperture	35cm
	Focal Length	3910mm
	Focal Ratio	f11
Sensor	Camera	ZWO ASI533MM [MONO]
	Field of View	0.17 deg x 0.17 deg



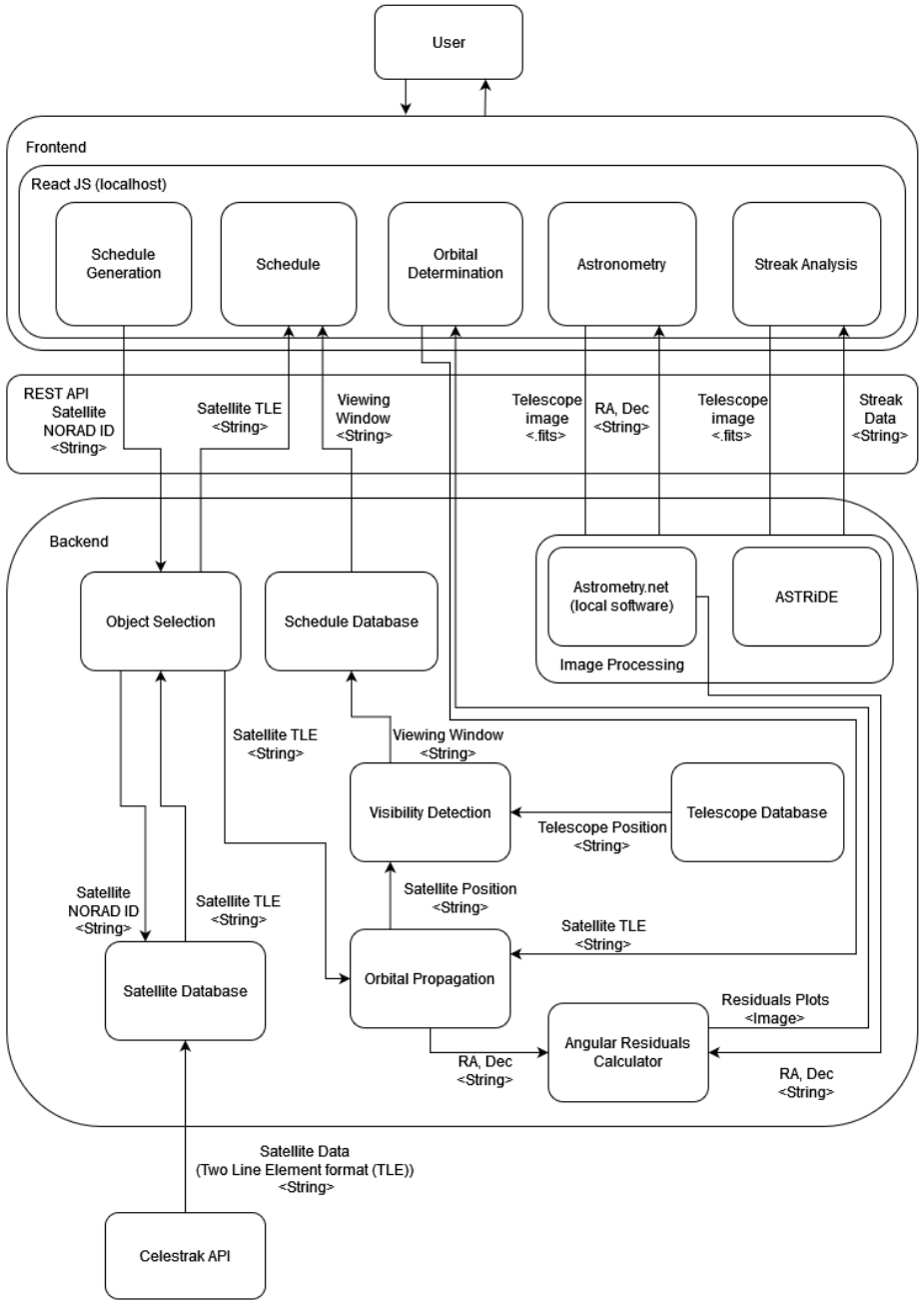
UNSW C14 Telescope

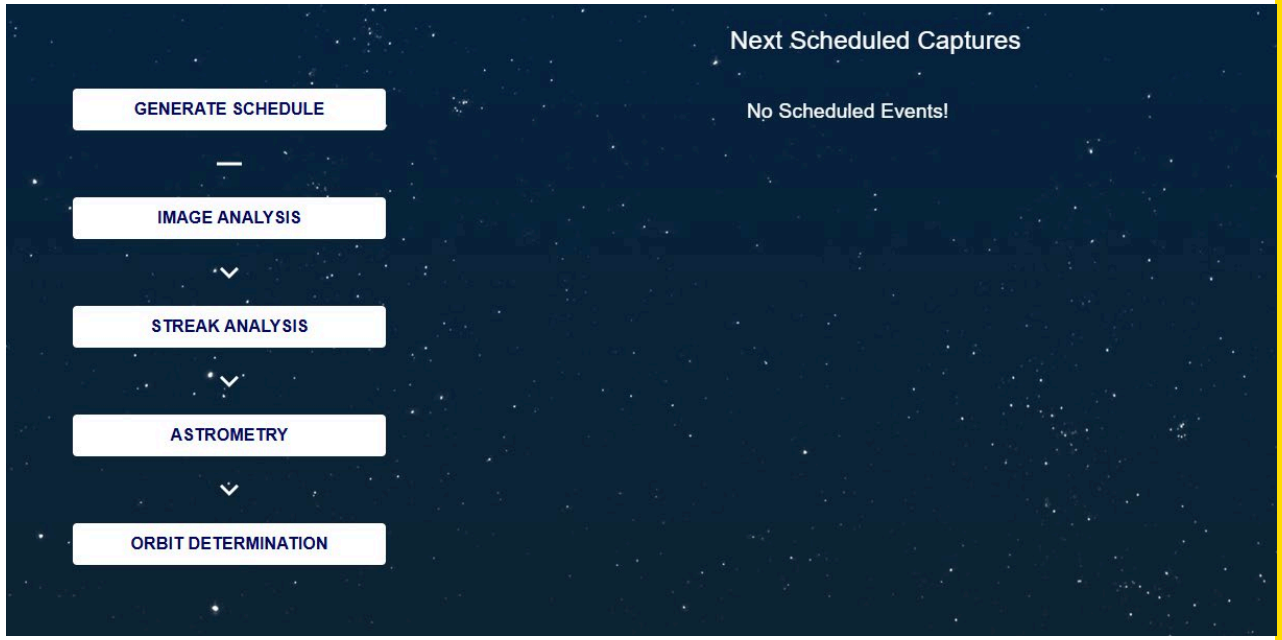


Optical Tracking Pipeline

Collaborators: **Prof Michael Ashley** (UNSW Physics) and **A/Prof Lee Spitler** (Macquarie Uni)

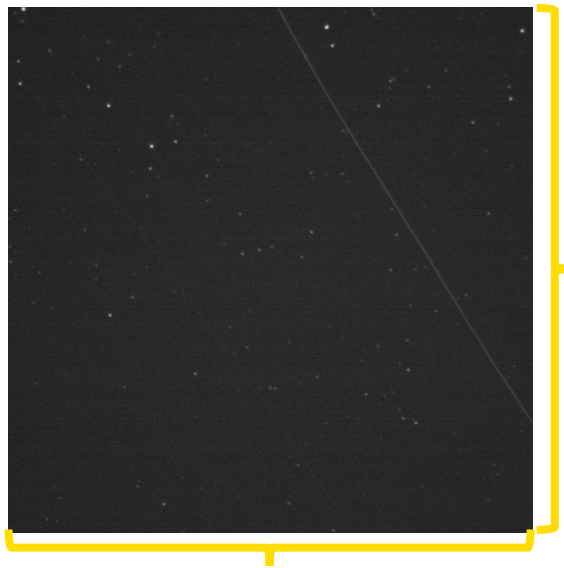
CSE UG Capstone Project: Optical Tracking Pipeline UI Design





Screenshot of the pipeline/home screen
Credit: Backend Merchants Team

Honours Project 1: Multiple Satellite Tracking Control System



UNSW C14 Telescope Image

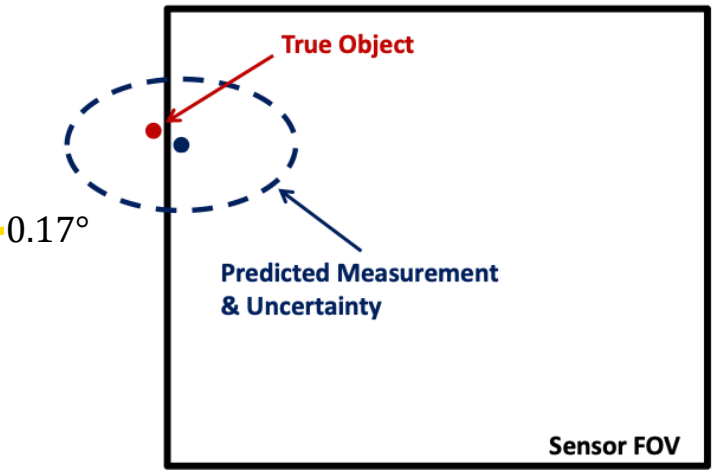
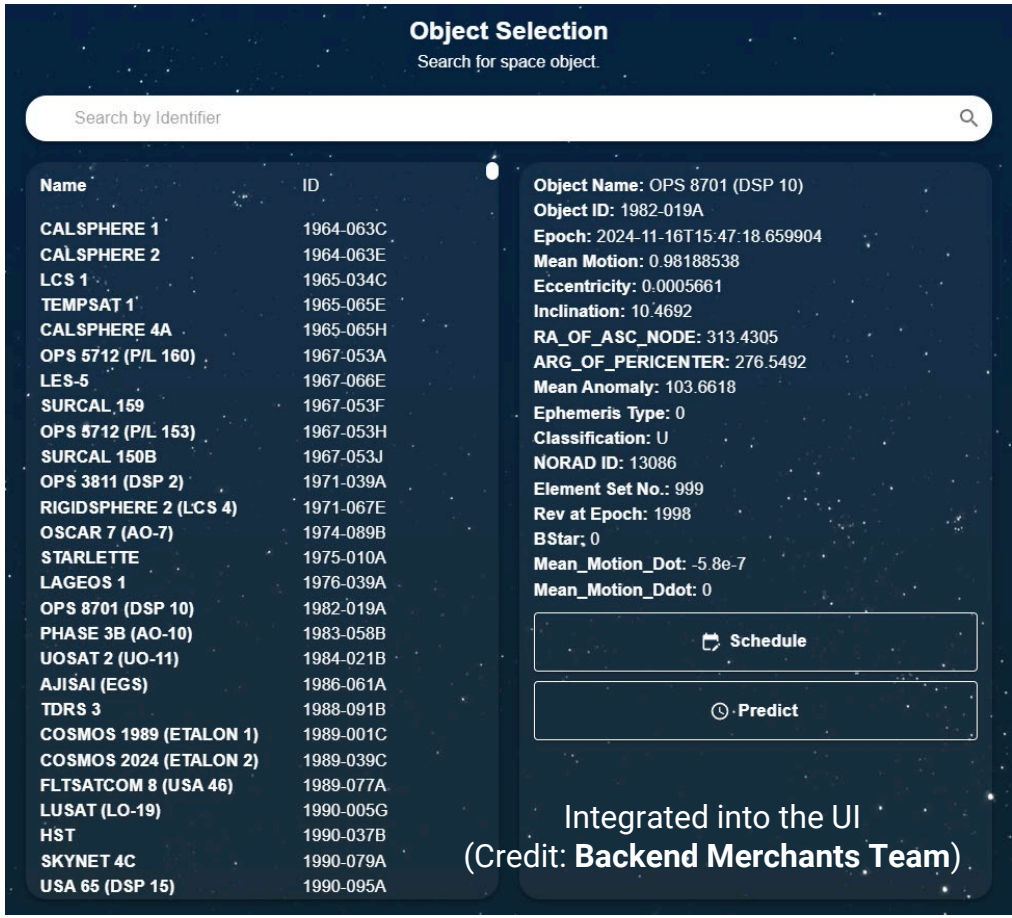


Illustration of Sensor Field of View
(Credit: Steve Gehly)



Integrated into the UI
(Credit: **Backend Merchants Team**)

UG student: Julia Joharis, on-going project

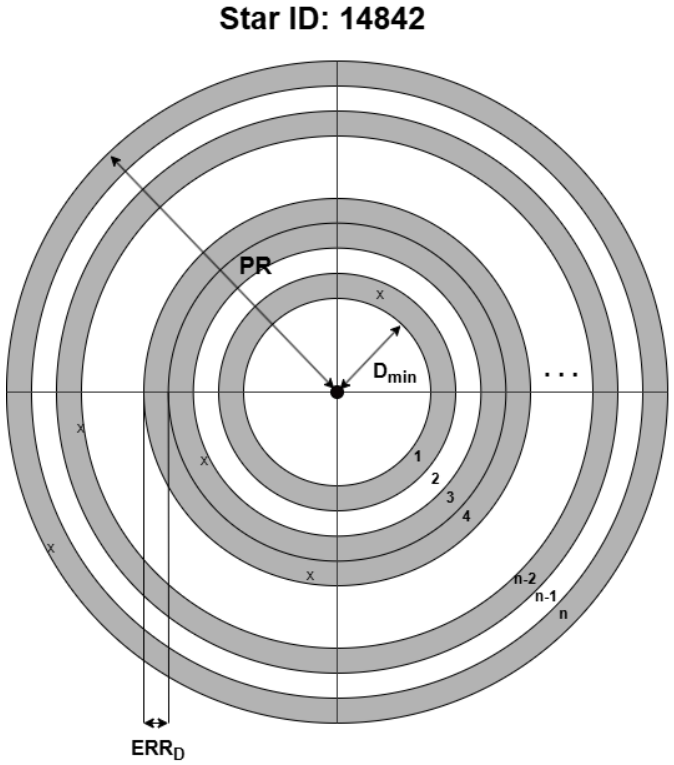
- Leverages an in-house **high-fidelity orbit propagator** for visibility analysis and object selection
- Uses Starlink satellite ephemeris as a case study
- To do: 10 Microns GM2000II mount control

User story: how can the visibility window and sky position of a given space object be calculated to enable accurate telescope pointing?

Honours Project 2: Star Identification

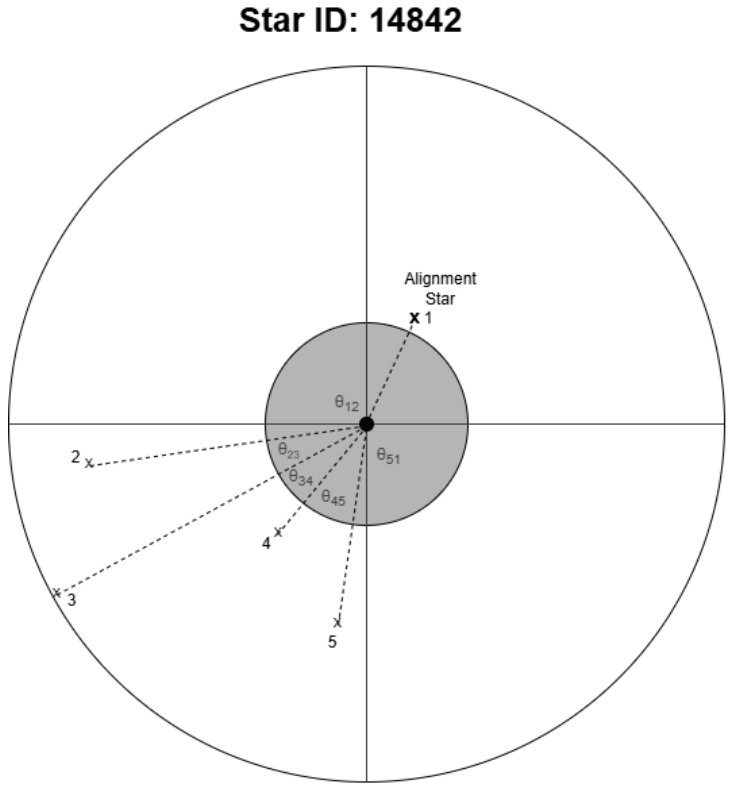
UG student: Joshua Kim, completed project

- Radial and dynamic cyclical star identification algorithm
- A final **identification rate of 92%** for real-world satellite tracking images



14842 Radial Pattern								
Ring	1	2	3	4	...	n-2	n-1	n
Bit	1	0	1	1	...	1	0	1

Example of a **radial pattern** being generated

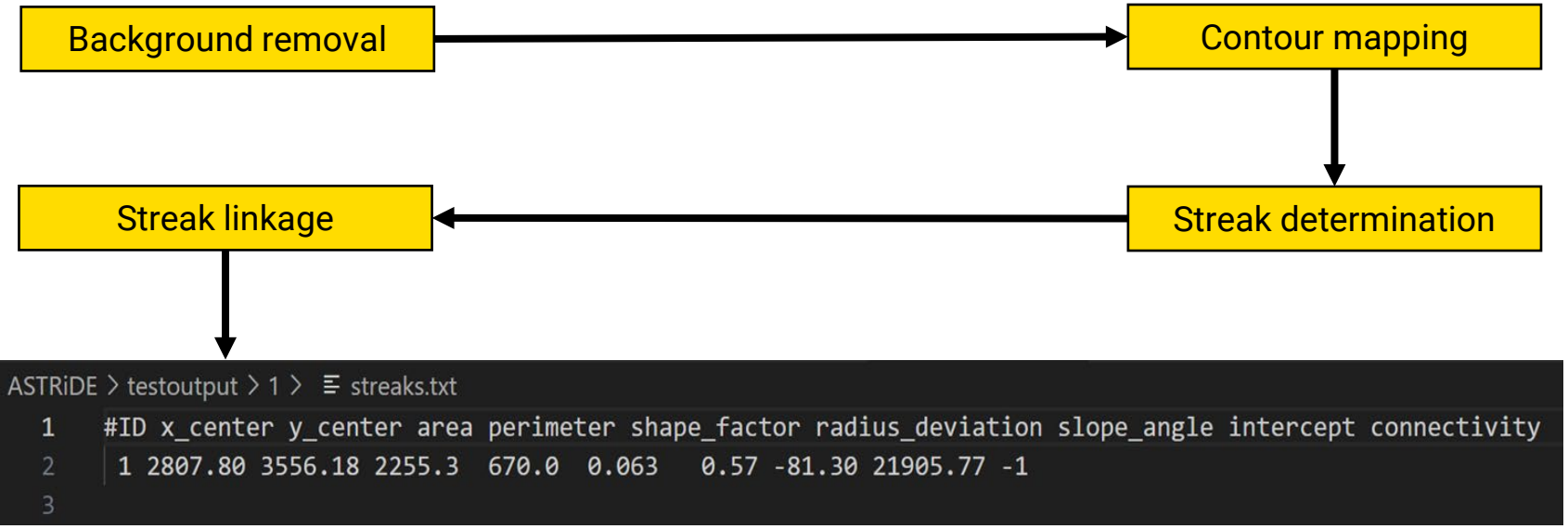


Example of a **cyclical pattern** based on successive stars

Honours Project 3: Streak Detection

UG student: Aisha Kozak, completed project

- Based on the existing **ASTRiDE** (Automated Streak Detection for Astronomical Images)
- Two new features: **discontinuous streaks** merge and **boarder streaks** handling
- **Precision improved by 18.8%** and **recall by 2.9%** for the given ~60 images



ASTRiDE working flowchart

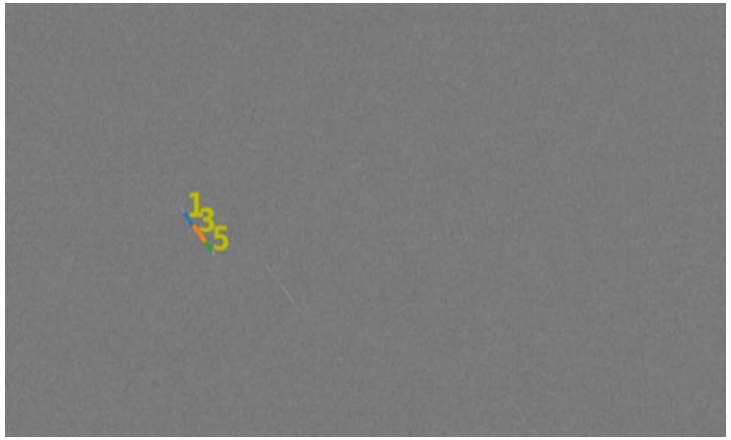
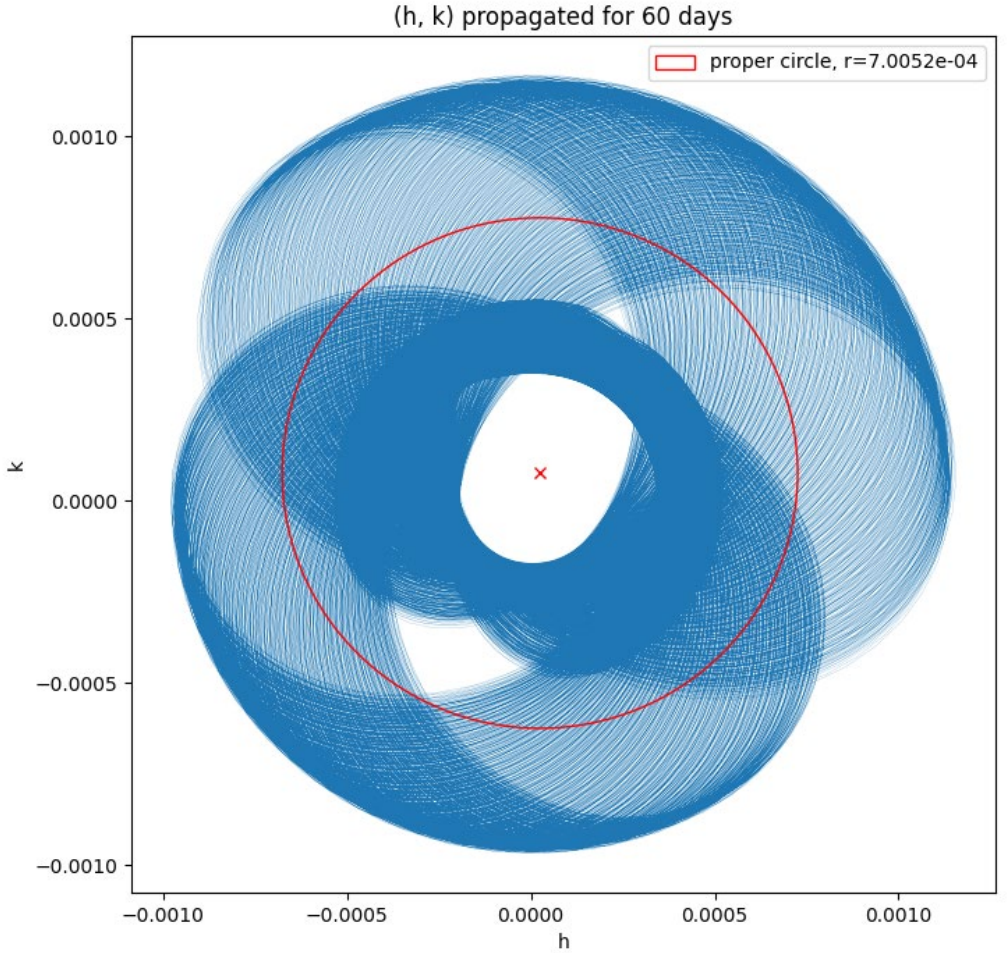


Illustration of discontinuous streaks

Honours Project 4: Supervised Clustering of Break-up Fragments

Modified equinoctial elements:

$$p = a(1 - e^2)$$
$$f = \tan\left(\frac{i}{2}\right)\cos(\Omega)$$
$$g = \tan\left(\frac{i}{2}\right)\sin(\Omega)$$
$$h = e \cdot \sin(\omega + \Omega)$$
$$\mathrm{k} = e \cdot \cos(\omega + \Omega)$$
$$L = \omega + \Omega + \theta$$



Proper element extraction by circle fitting

UG student: Michael Ling, on-going project

- Leverage the in-house **high-fidelity orbit propagator** rather than the TLE/SGP4
- Circle fitting for **proper elements extraction**
- Use a **breakup model** to generate synthetic orbit
- To do: Density Based Spatial Clustering for Applications with Noise **(DBSCAN) for clustering**

Concluding Remarks

- **UNSW Observatory**: A premier platform for research and education.
- **Research Focus**: Advancing technologies to manage small field-of-view challenges in visibility prediction and image processing.
- **Education Endeavours**: Offering robust topics for engineering students across various disciplines.
- **Future Goal**: Establishing an automated space tracking facility.

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Any questions?

Dr Yang Yang
Email: yang.yang16@unsw.edu.au