

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

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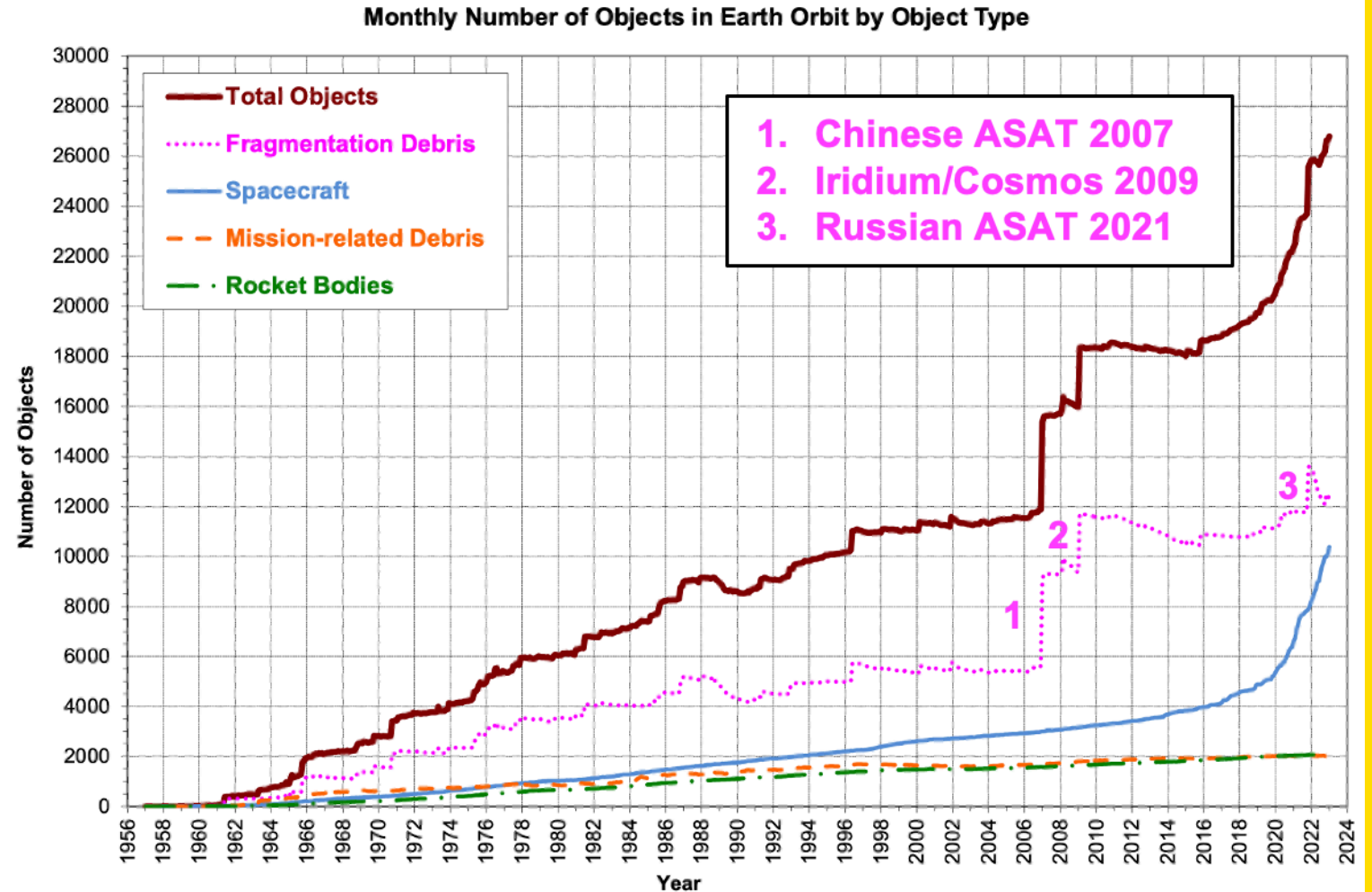
4 December 2024

# 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]

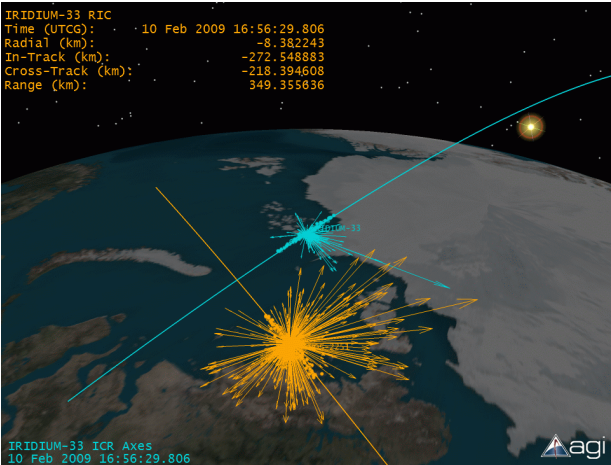


Number of Catalogued Objects In Earth Orbit by Type as of 03 Feb 2023. Credit: NASA Orbital Debris Programme Office

\* 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 3<sup>rd</sup> Stage Landed  
on WA Beach, Australia (Found in  
mid-July 2023)



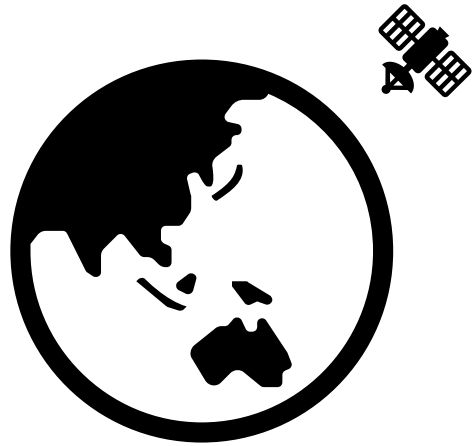


How can we reduce the impact of space debris to promote the long-term sustainability of outer space activities?

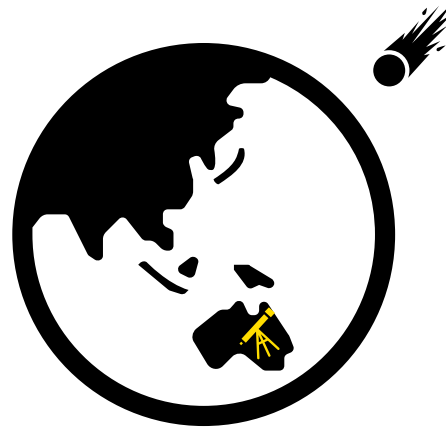




# Research Roadmap - *Towards Space Sustainability*



Spacecraft Navigation  
Single Satellite Single Sensor



Reliable Orbit Determination  
Single Space Object Single Sensor



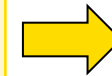
Space Surveillance & Tracking  
Multiple Space Objects Multiple Sensors

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)

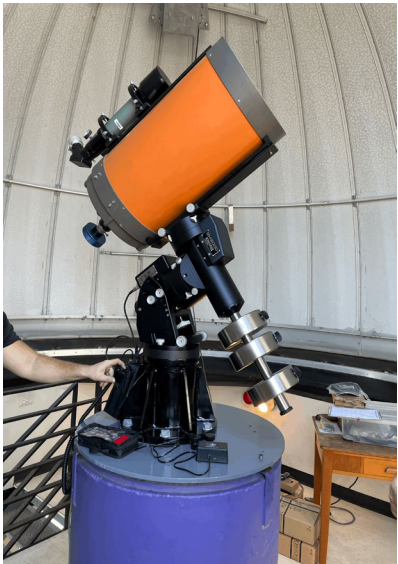


# UNSW Space Surveillance & Tracking Node

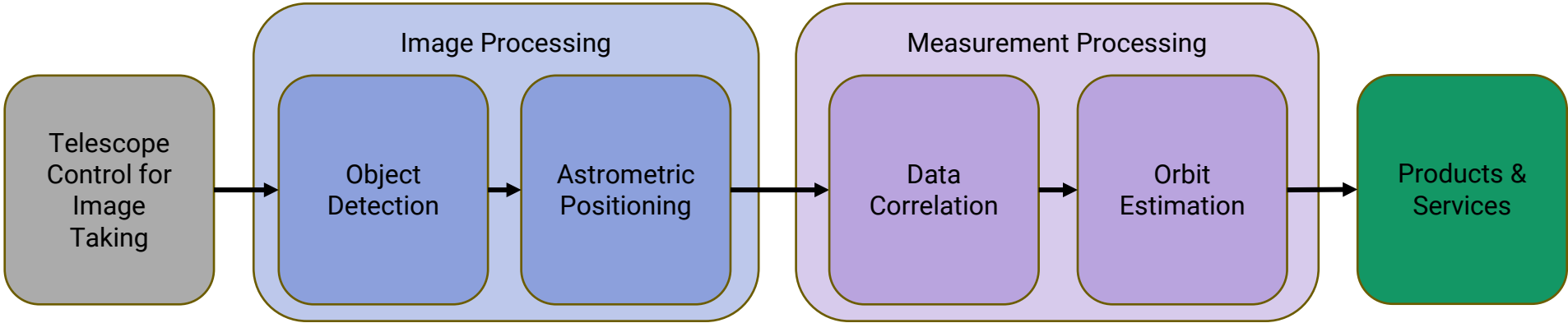


UNSW Observatory

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



UNSW C14 Telescope

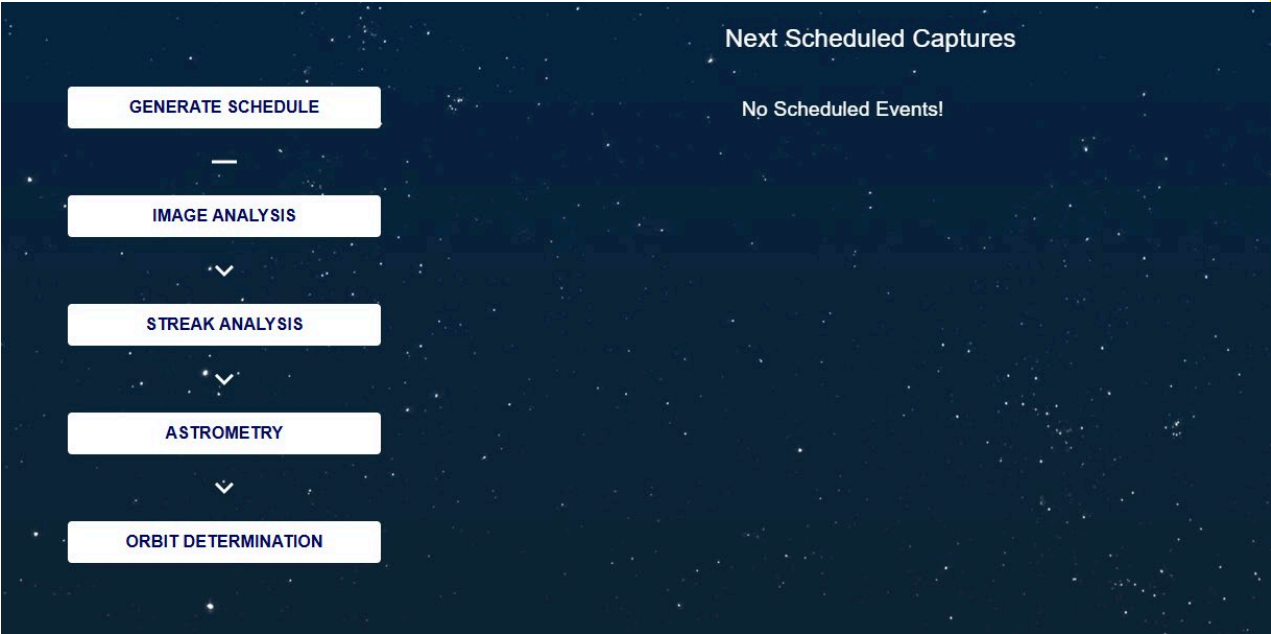
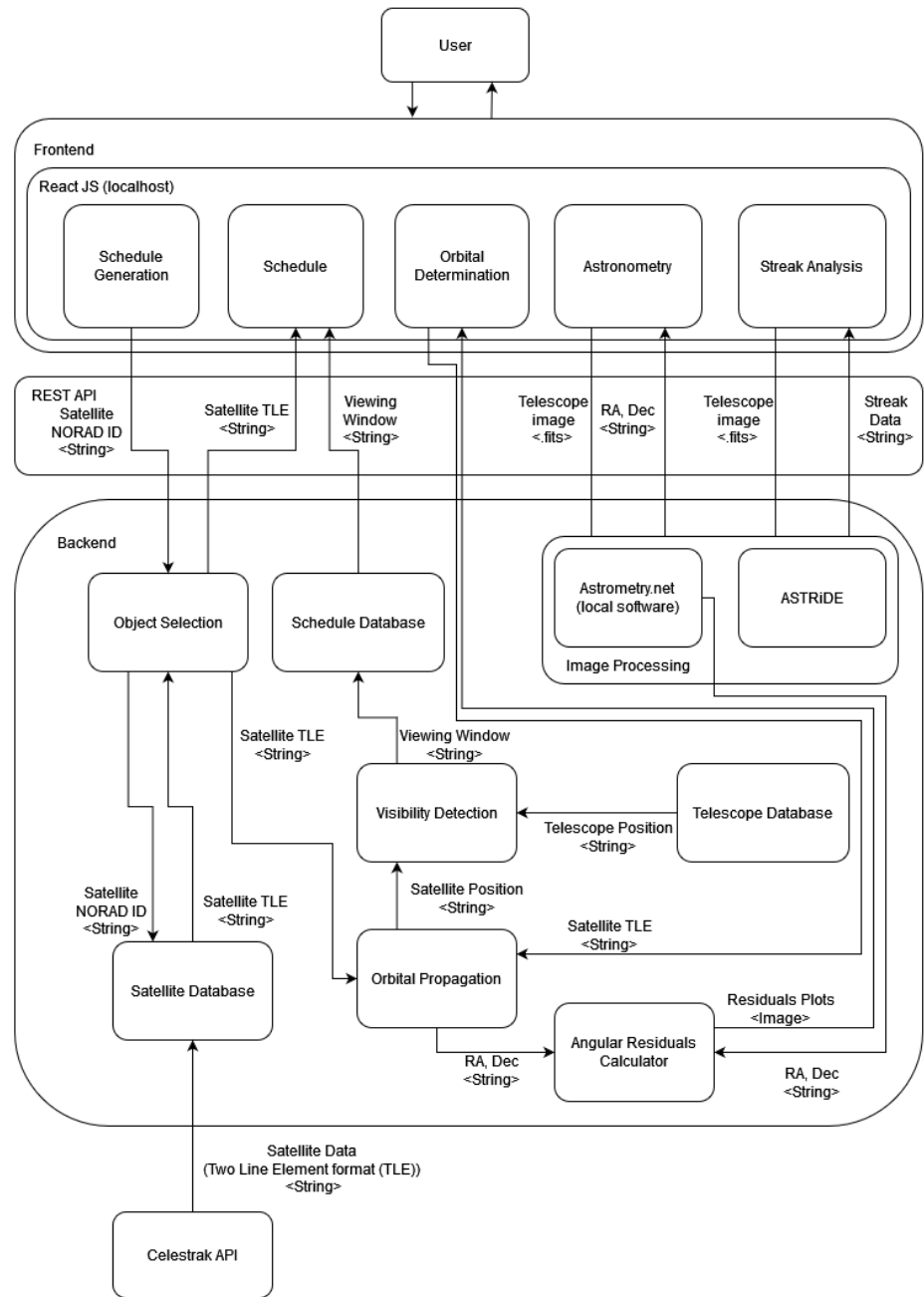


Optical Tracking Pipeline

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

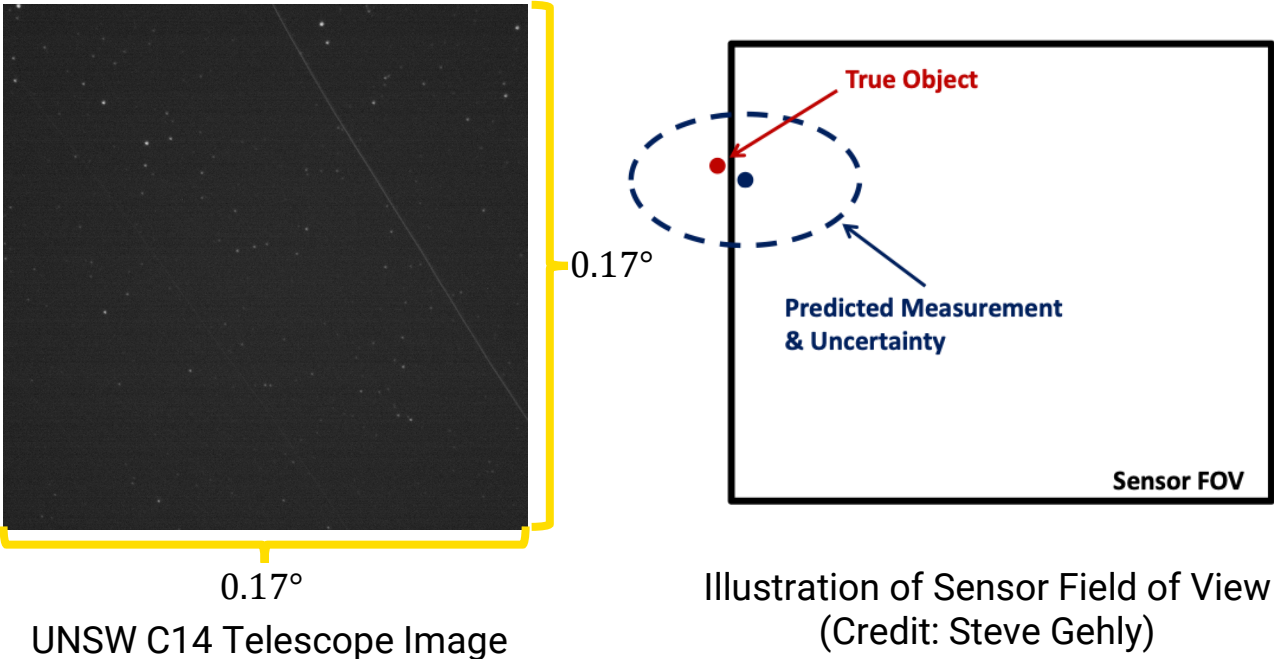


# CSE UG Capstone Project: Optical Tracking Pipeline UI Design



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

# Honours Project 1: Multiple Satellite Tracking Control System



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

### Object Selection

Search for space object.

Search by Identifier

Name	ID
CALSPHERE 1	1964-063C
CALSPHERE 2	1964-063E
LCS 1	1965-034C
TEMPSAT 1	1965-065E
CALSPHERE 4A	1965-065H
OPS 5712 (P/L 160)	1967-053A
LES-5	1967-066E
SURCAL 159	1967-053F
OPS 5712 (P/L 153)	1967-053H
SURCAL 150B	1967-053J
OPS 3811 (DSP 2)	1971-039A
RIGIDSPHERE 2 (LCS 4)	1971-067E
OSCAR 7 (AO-7)	1974-089B
STARLETTE	1975-010A
LAGEOS 1	1976-039A
OPS 8701 (DSP 10)	1982-019A
PHASE 3B (AO-10)	1983-058B
UOSAT 2 (UO-11)	1984-021B
AJISAI (EGS)	1986-061A
TDRS 3	1988-091B
COSMOS 1989 (ETALON 1)	1989-001C
COSMOS 2024 (ETALON 2)	1989-039C
FLTSATCOM 8 (USA 46)	1989-077A
LUSAT (LO-19)	1990-005G
HST	1990-037B
SKYNET 4C	1990-079A
USA 65 (DSP 15)	1990-095A

Object Name: OPS 8701 (DSP 10)

Object ID: 1982-019A

Epoch: 2024-11-16T15:47:18.659904

Mean Motion: 0.98188538

Eccentricity: 0.0005661

Inclination: 10.4692

RA\_OF\_ASC\_NODE: 313.4305

ARG\_OF\_PERICENTER: 276.5492

Mean Anomaly: 103.6618

Ephemeris Type: 0

Classification: U

NORAD ID: 13086

Element Set No.: 999

Rev at Epoch: 1998

BStar: 0

Mean\_Motion\_Dot: -5.8e-7

Mean\_Motion\_Ddot: 0

[Schedule](#)

[Predict](#)

Integrated into the UI  
(Credit: Backend Merchants Team)

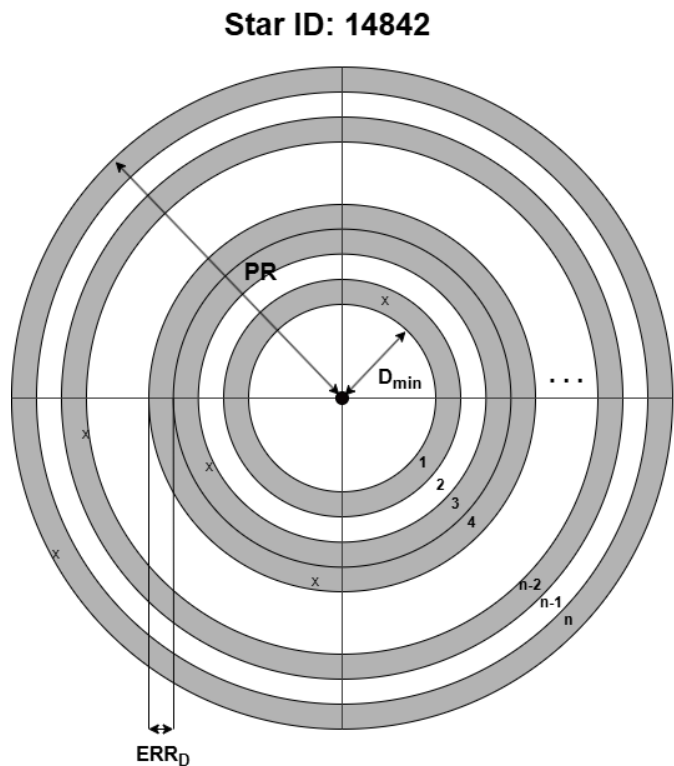
User story: how can the visibility window and sky position of a given space object be calculated to enable accurate telescope pointing?



# Honours Project 2: Star Identification

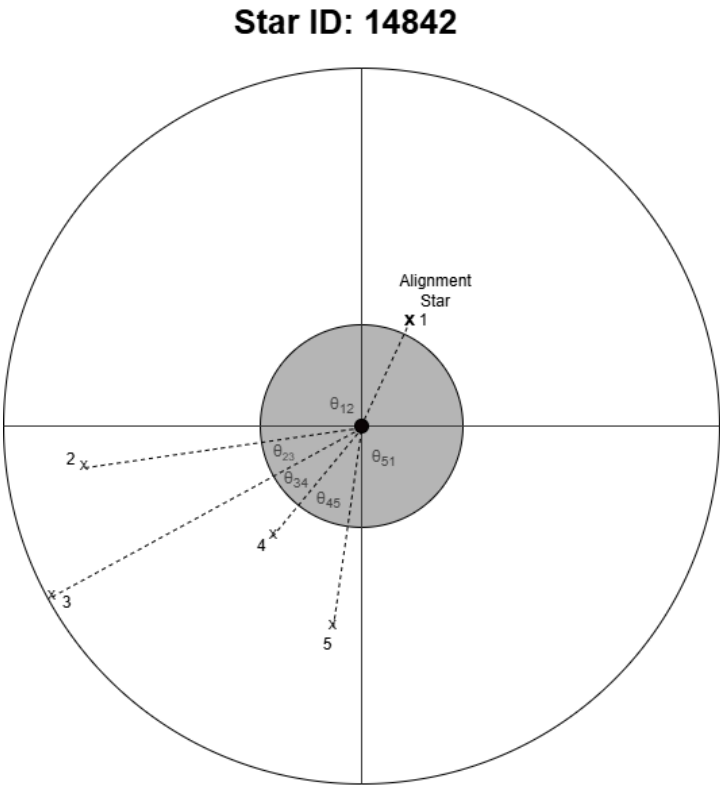
UG student: Joshua Kim, completed project

- 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



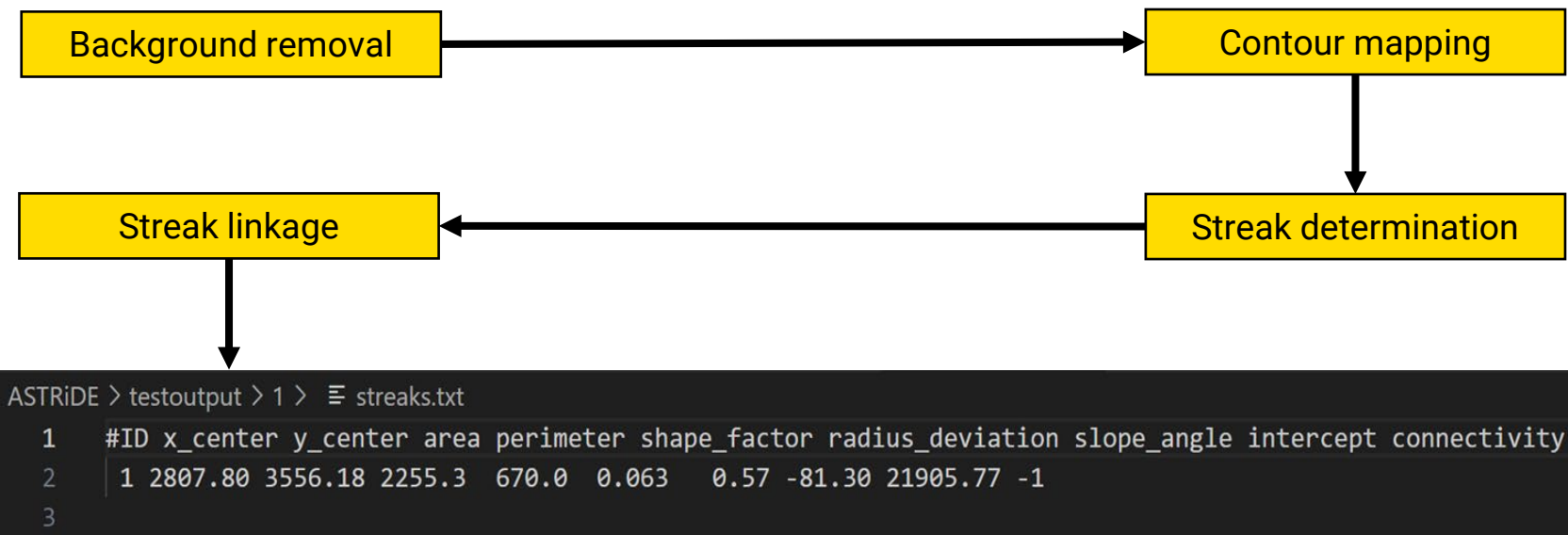
Example of a **cyclical pattern** based on successive stars



# 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

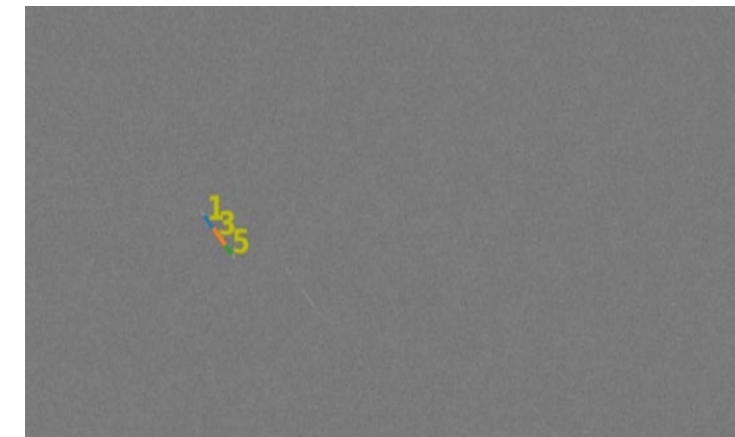


Illustration of discontinuous streaks

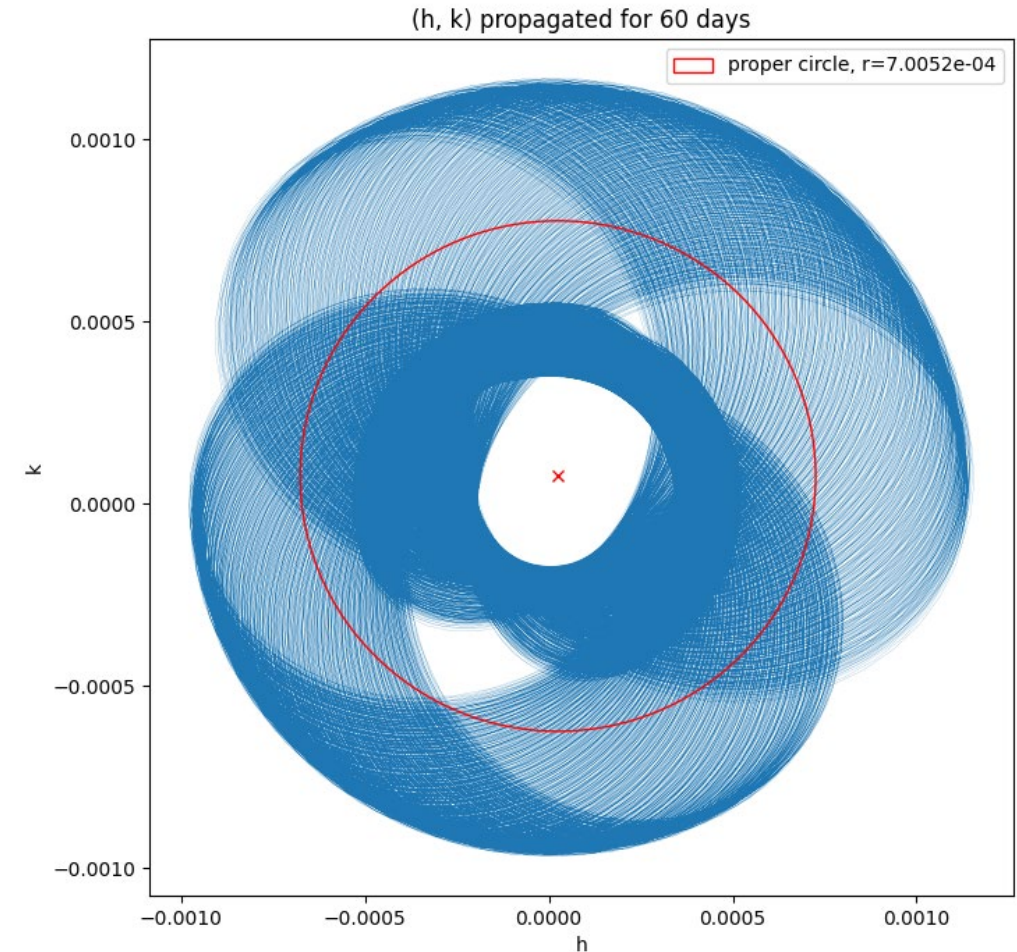
# Honours Project 4: Supervised Clustering of Break-up Fragments

Modified equinoctial elements:

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

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.

# Any questions?

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