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軌跡を用いた軌道上物体検出手法の提案と適用結果

Orbital object detection algorithm using streaks

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軌道上物体の光学観測において，見かけ上比較的高速で移動する対象を高感度で検出できる手法を提案する．本手法は画像中を高速移動する物体の軌跡内の信号を積算することで検出感度を向上させている．本手法の有効性を確かめるために，オーストラリア・リモート観測所（ARO）での観測データを用いて解析を行った．暗い物体の検出結果より，軌跡を構成するピクセル一つ一つの平均信号強度が背景雑音よりも小さい場合であっても検出可能であることが確かめられた．本発表では比較的暗い物体についての解析結果を報告する．

This study proposes a new image processing algorithm to detect objects using their apparent streaks. A faint streak can be improved its noise-to-signal ratio with the root square of its pixel length by compression. We apply this algorithm to datasets observed at Australia remote observatory in order to confirm validity. As a result, we confirmed that the algorithm can detect object appeared with streaks fainter than background noise.

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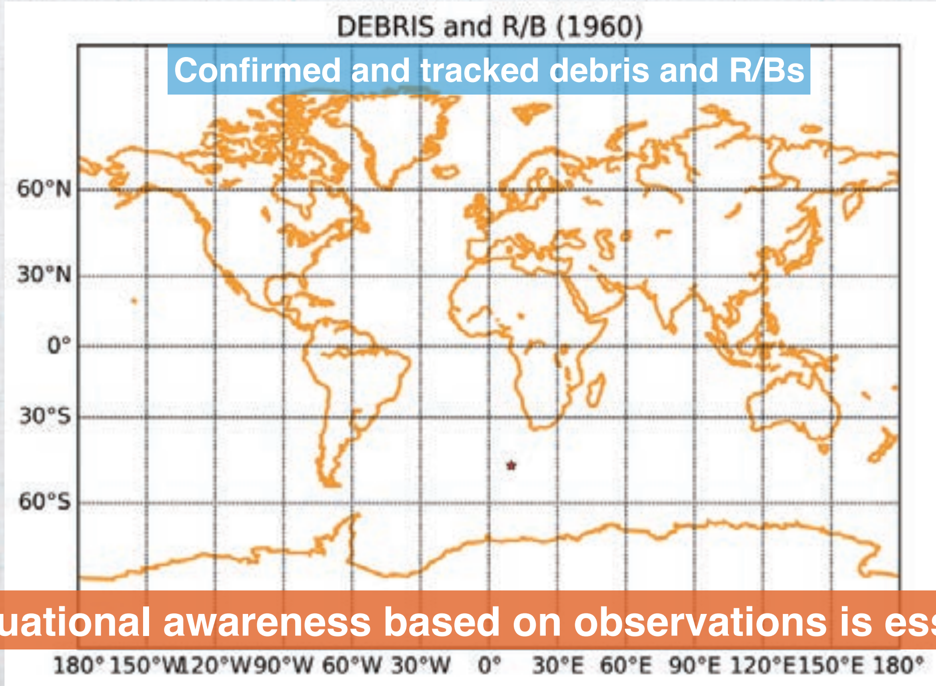
Space debris workshop (Chofu, 2014/Dec./17-19)

Abstract

- We developed a new image processing algorithm.
- We can detect an object appeared as streaks with a signal intensity weaker than 1.0 σ_{bkg}.
- We find objects that are not detected by a conventional method.

Evolution of the orbital environment



A situational awareness based on observations is essential.

Introduction

- JAXA has conducted survey observations for geosynchronous orbit (GSO) objects.
- The survey may misses objects appeared as faint streaks.

Introduction

- We developed a new image processing algorithm.
- The algorithm focuses on apparently moving objects.
- The algorithm improves a signal-to-background-noise ratio (SNR).

Object detection flow

1. Image preprocessing (noise reduction, flat correction and star elimination)
2. Image morphing (Skewing processing)
3. Image compression (Summing signals along vertical axis)
4. Steak position determination (Moving average)
5. Object search (correlation between streaks)

Object detection flow

1. Image preprocessing (noise reduction, flat correction and star elimination)

Streak detection in an each image

2. Image morphing (Skewing processing)
3. Image compression (Summing signals along vertical axis)
4. Steak position determination (Moving average)
5. Object search (correlation between streaks)

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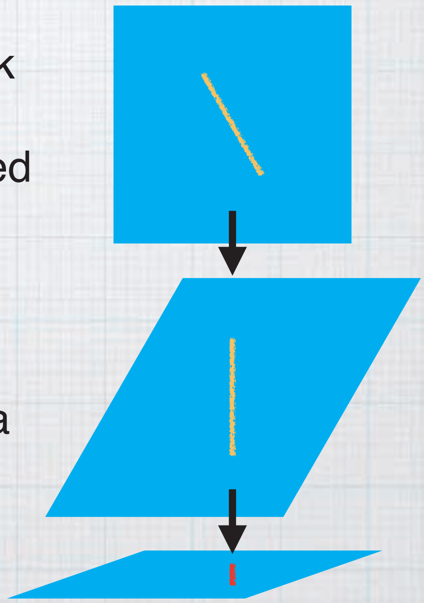
SNR improvement

A. Morphing an image to align a streak along the vertical axis.
(This sequence is repeatedly applied with various skewing angles to search unknown streaks.)

B. Compressing the image along the vertical axis. Compression means a local summing calculation.



SNR improvement
$\propto \sqrt{n_{pix}}$

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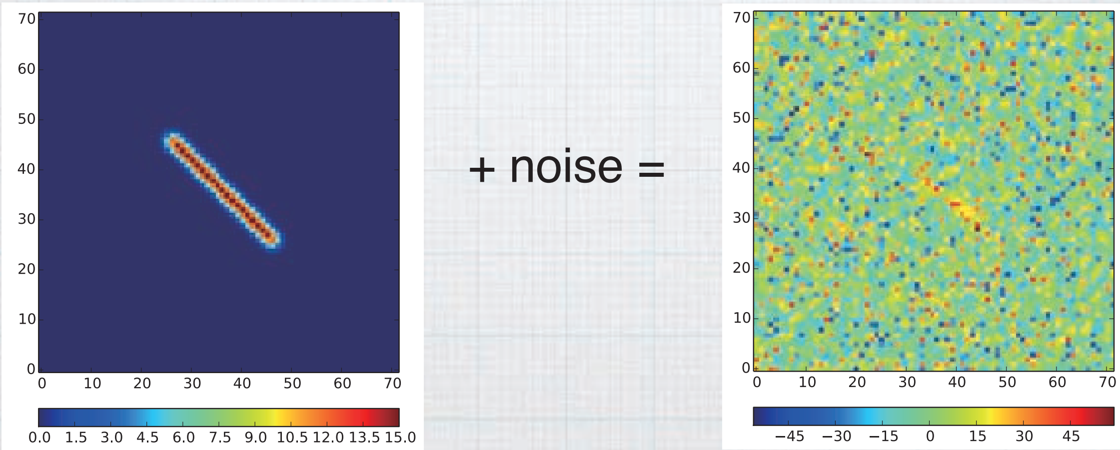
Exemplification using a theoretical streak



Signal intensity of 1.0 σ_{bkg}

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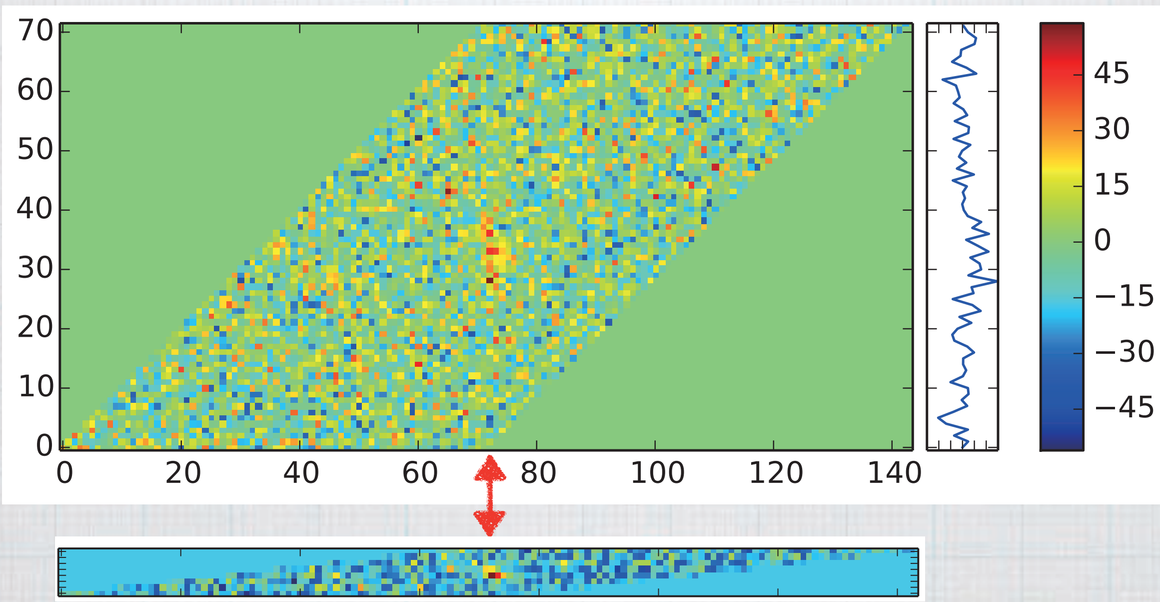
Exemplification of the skewing and the compression sequences



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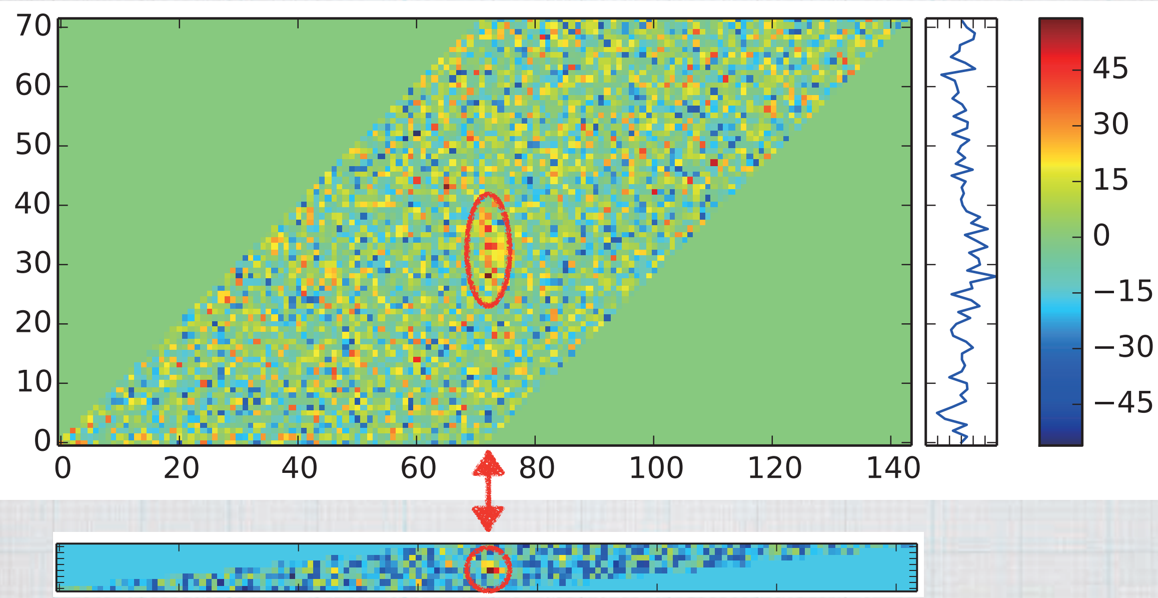
Exemplification of the skewing and the compression sequences



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Object detection flow

1. Image preprocessing (noise reduction, flat correction and star elimination)
2. Image morphing (Skewing processing)
3. Image compression (Summing signals along vertical axis)
4. Steak position determination (Moving average)
5. Object search (correlation between streaks)

Streak position determination
↓
Object search using time-series images
(False alarm rejection)

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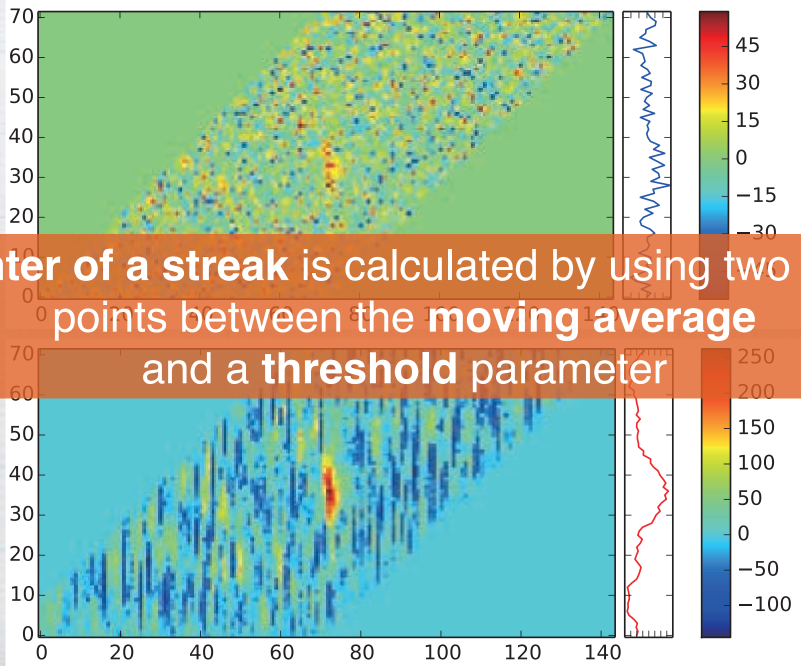
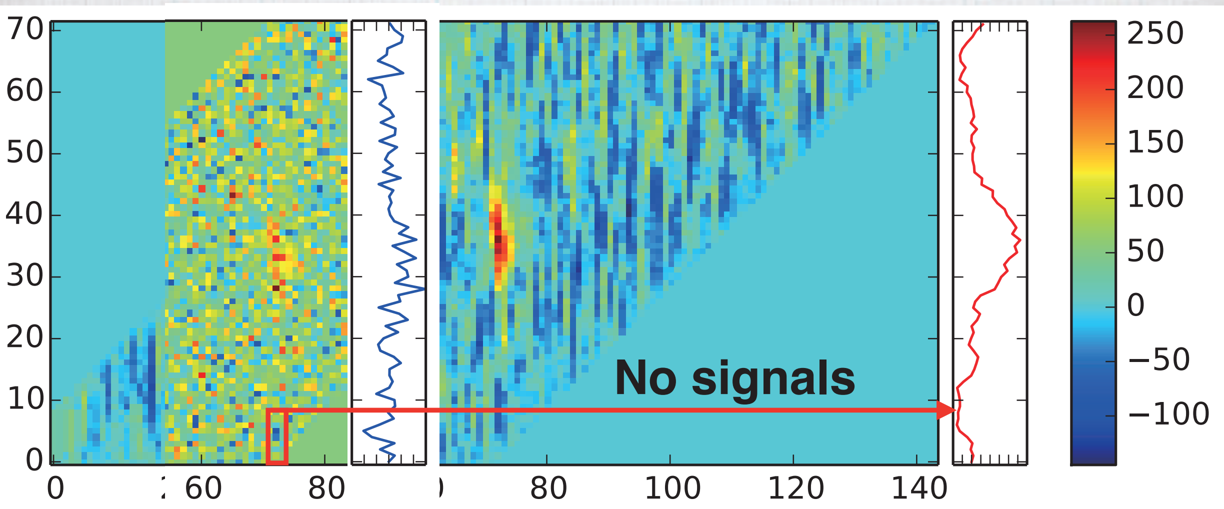
Streak position determination



The **center of a streak** is calculated by using two crossing points between the **moving average** and a **threshold** parameter

Streak position determination



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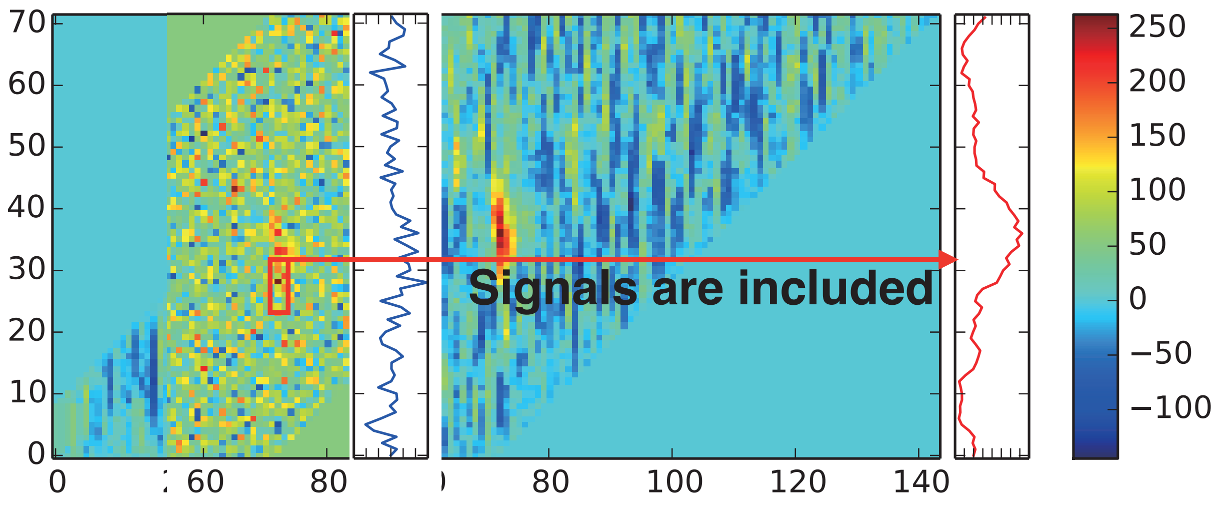
Streak position determination



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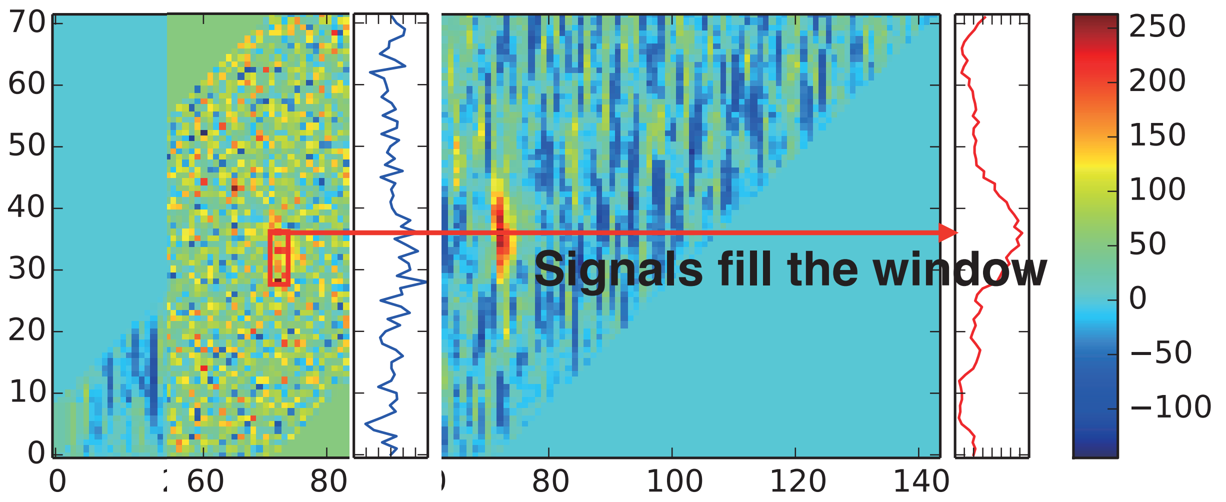
Streak position determination



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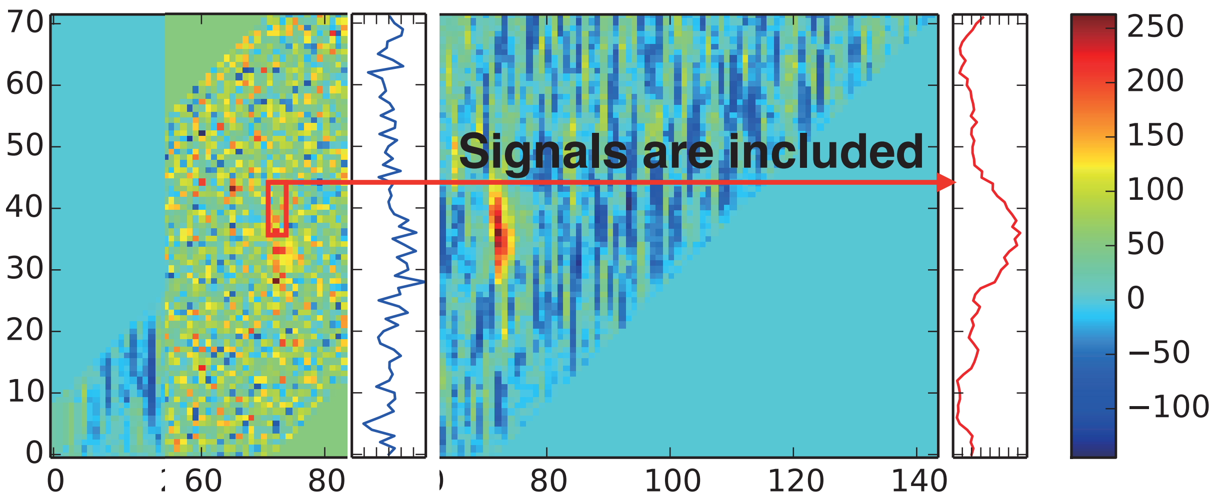
Streak position determination



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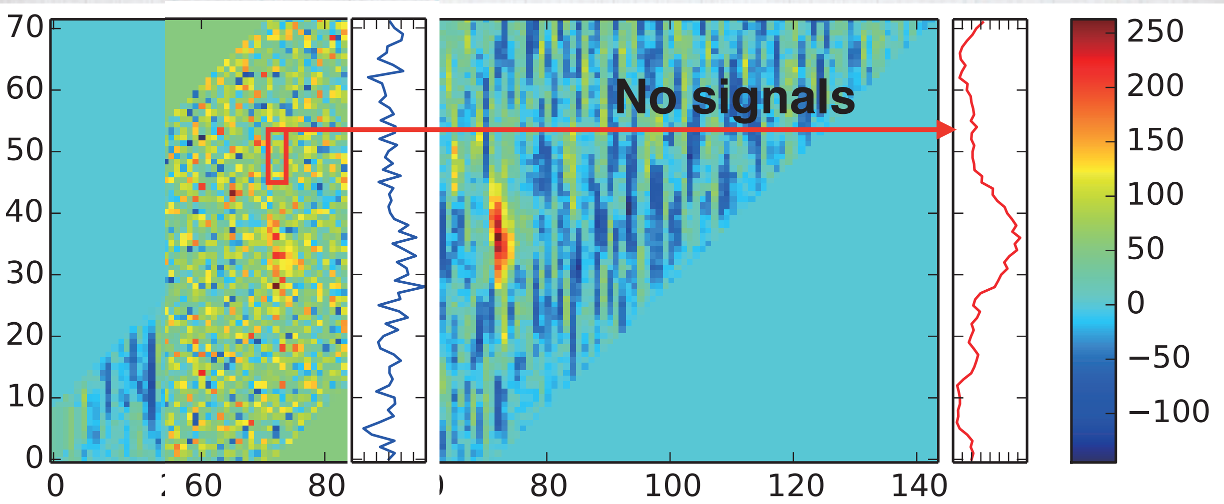
Streak position determination



An ascending and a descending **crossing points**, and a **window width** yield the **center of a streak**.

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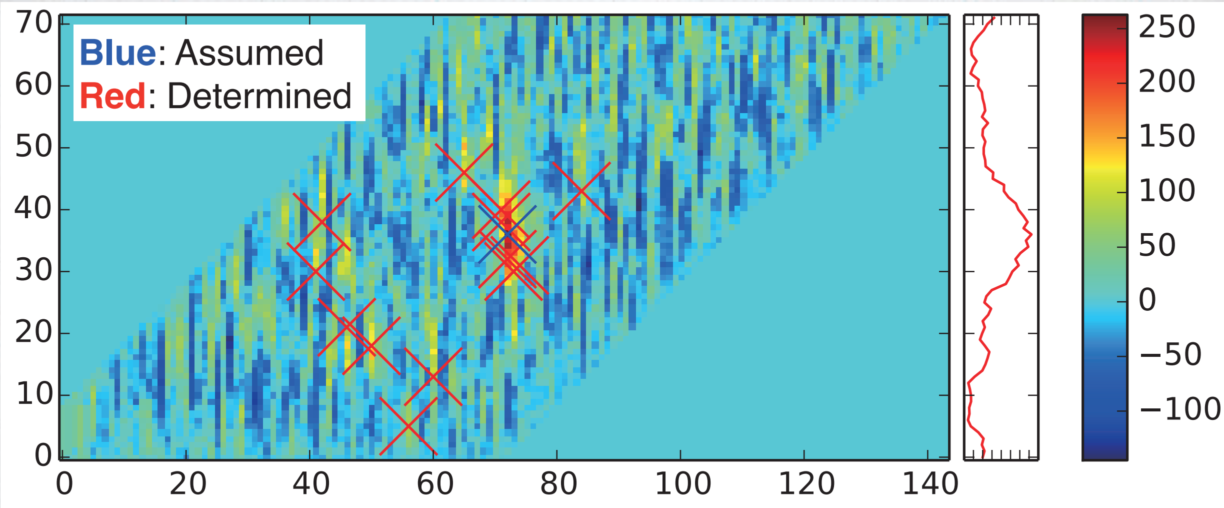
Exemplification of the determination sequence



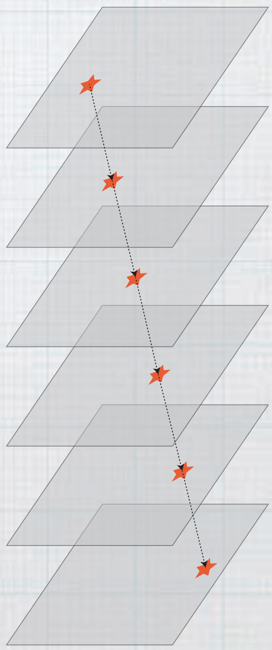
There are false detections caused by noise.

→A lot of false detections from an image

→**False alarm rejection using images**

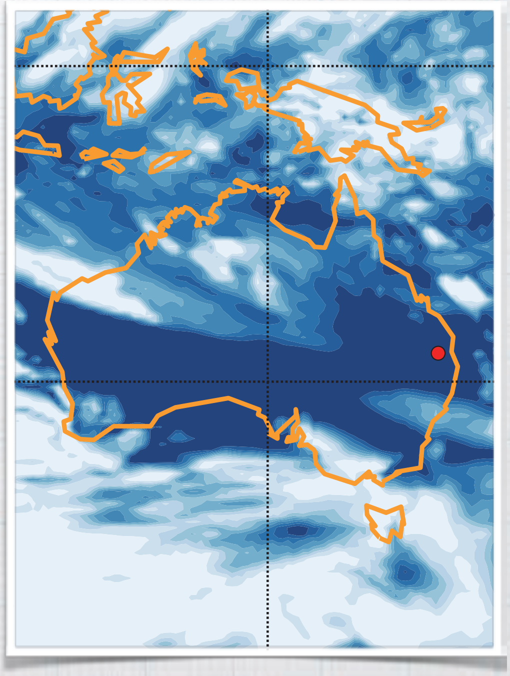
Object search

- Correlating determined centers' positions
- Likelihood assessment
  - A number of correlated centers
  - Uniformity and linearity



Empirical confirmation

- Australia Remote Observatory (ARO)
- GSO surveys
- Target: Mid-Earth Orbit (MEO) objects (e.g., navigation sat.)
- 18-cm aperture
  Apparent vel.: approx. 5 pixel/s
- 25-cm aperture
  Apparent vel.: approx. 7 pixel/s



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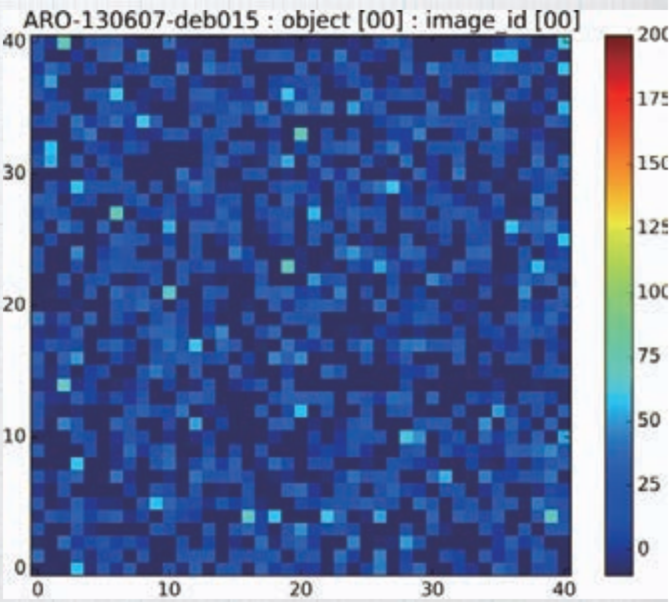
The darkest result

- Skewing angles
  : 1.6 degrees step,
  21 loops (±16 degrees)
- Compression widths
  :(18-cm aperture)
  9,18 pixels
- Contributed image IDs
  7 8 9 10 11 12 13 14 15 16 17



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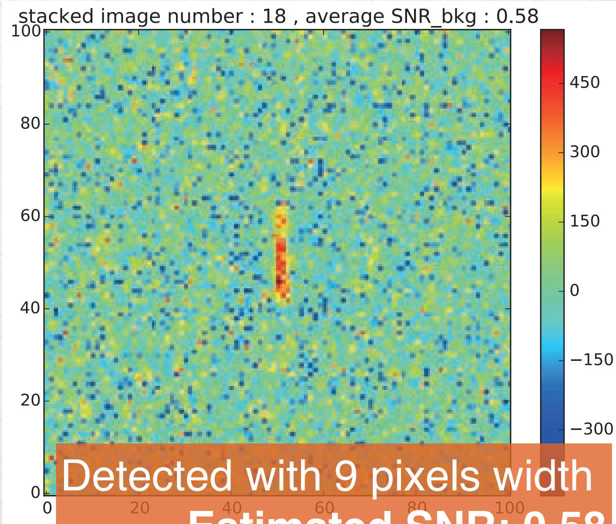
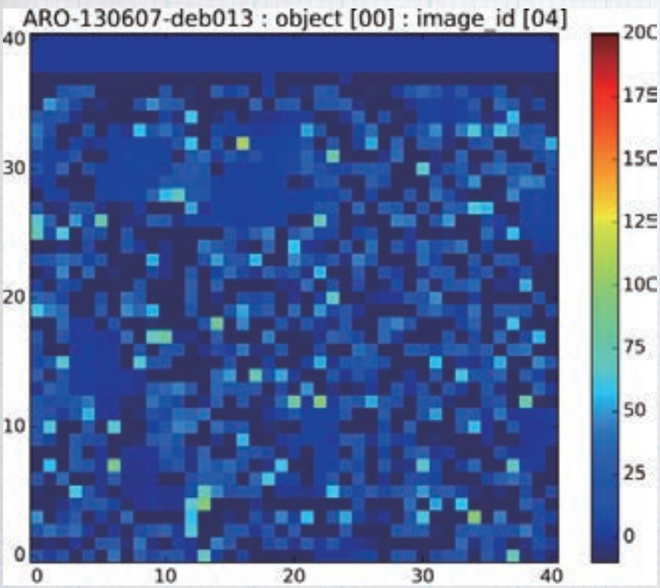
The darkest result

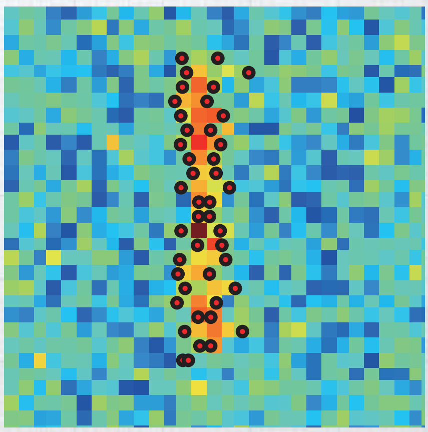
- COSMOS 2456 (Russian navigation sat.)
- Integrating all 18 frames focusing around the center of streaks.
- It confirms detection and estimates the SNR.



Detected with 9 pixels width
Estimated SNR: 0.58
(Threshold parameter 2.0)
(Detection limit 0.67)

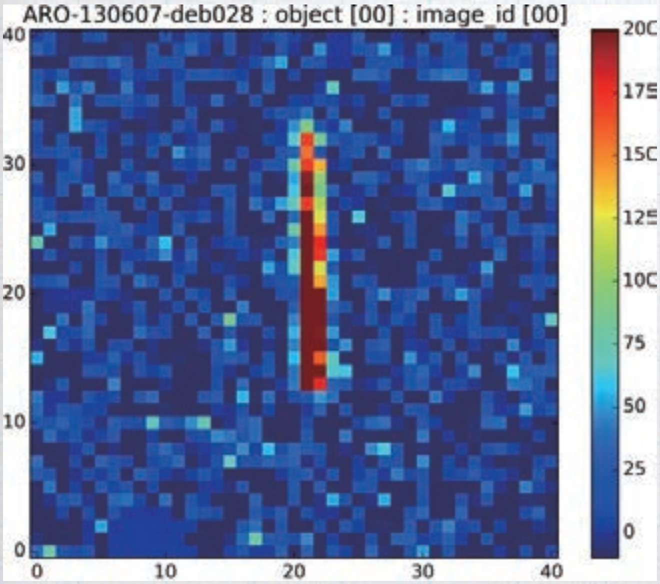
Other results: fainter than 2.0 σ_{bkg} (18-cm aperture)

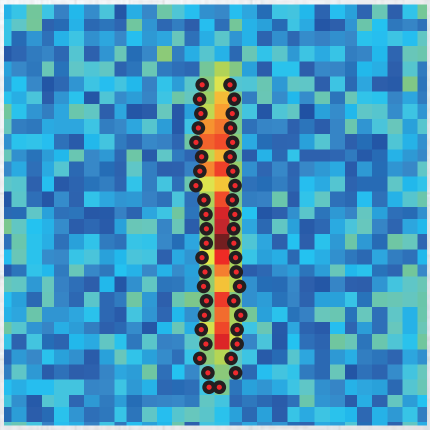




COSMOS 2456
SNR: 0.79

Other results: fainter than 2.0 σ_{bkg} (18-cm aperture)





COSMOS 1650
SNR: 1.27

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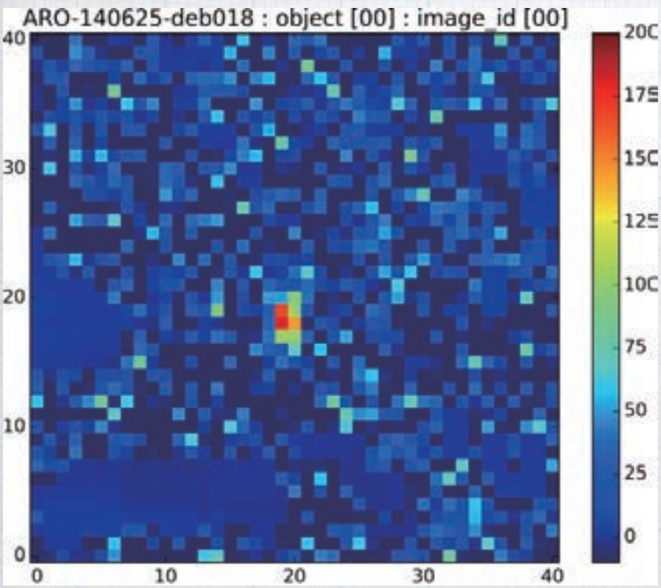
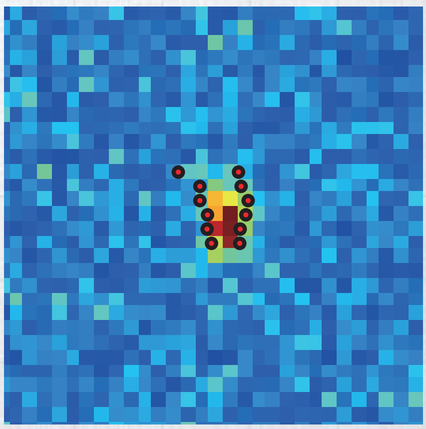
Other results: fainter than 2.0 σ_{bkg} (25-cm aperture)





Fengyun 2A AKM
SNR: 1.74

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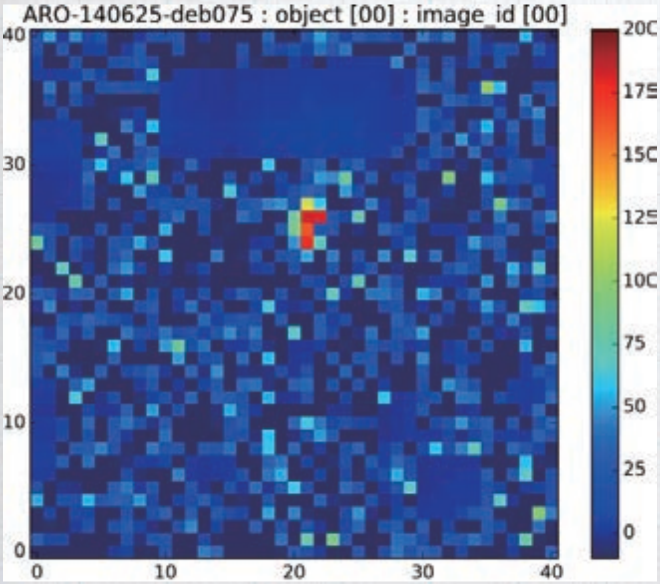
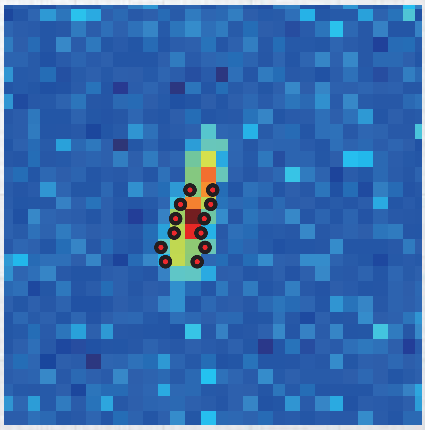
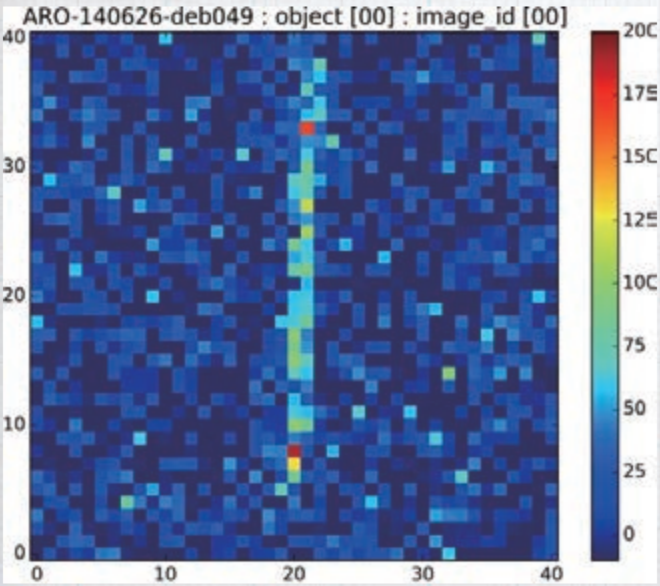
Other results: fainter than 2.0 σ_{bkg} (25-cm aperture)

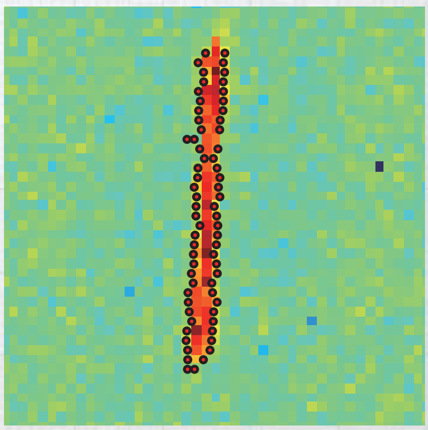




GALAXY 7
SNR: 1.91

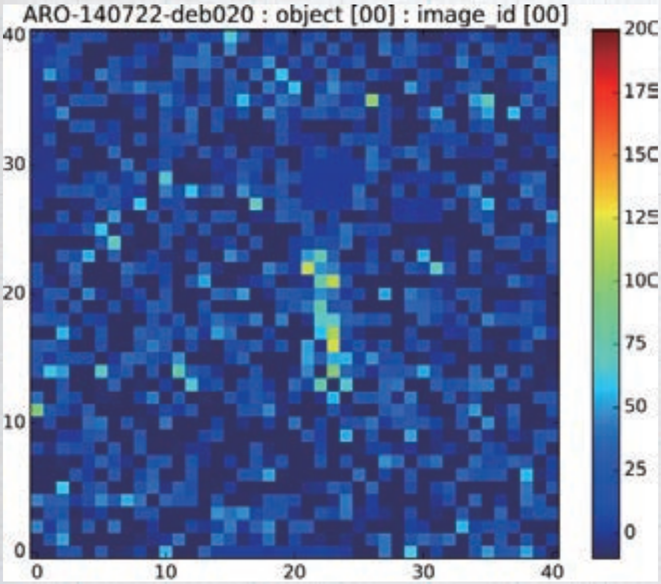
Other results: fainter than 2.0 σ_{bkg} (25-cm aperture)

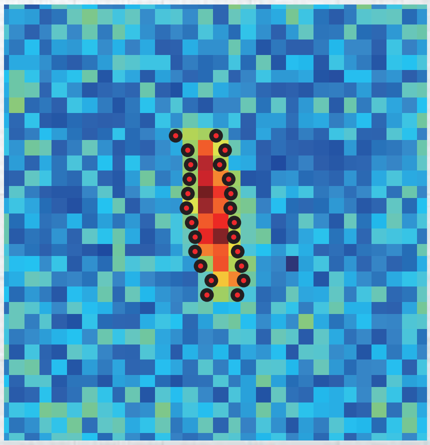




NAVSTAR 10
SNR: 1.95

Other results: fainter than 2.0 σ_{bkg} (25-cm aperture)





Uncorrelated
SNR: 1.48

Summary

- We developed a new image processing algorithm to detect faint objects using streaks.
- We can detect objects even their streaks are weaker than background noise.
- The effectiveness of the algorithm is empirically confirmed.
- NOTE: The algorithm is potentially contributive to other faint objects in low Earth orbit, or unknown near Earth objects.

Backup slides

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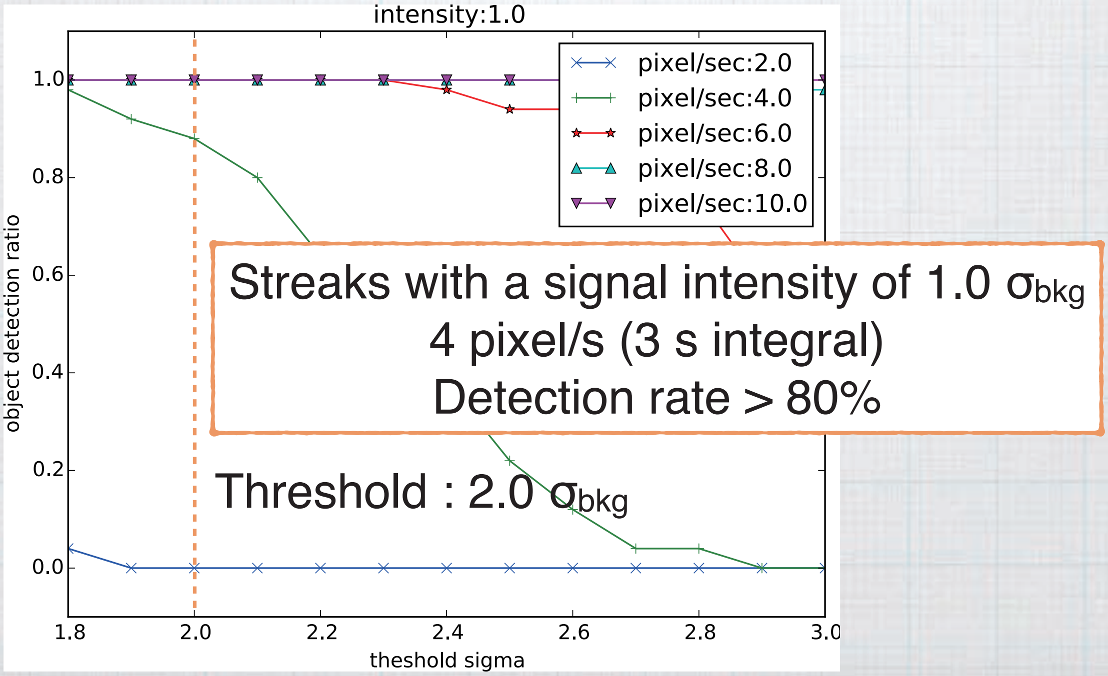
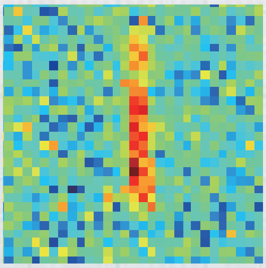
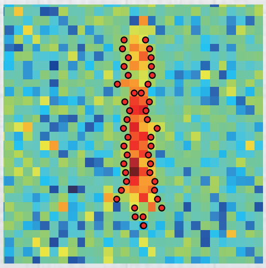
Detection rate as a function of the threshold



Estimation of a per-pixel-SNR

1. Integrating streaks in time-series images
2. Calculating the length of the integrated streak by using an estimated motion function
3. Estimating the width of the integrated streak by 1-D Gaussian fitting
4. Comparing the sum of the signals of the streak to background noise





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Calculation speed enhancement

- Optimization of the algorithm
- Parallel computing using a graphics processing unit (GPU)

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