Detection of Small Sized GEO Debris Using FPGA Based Stacking Method

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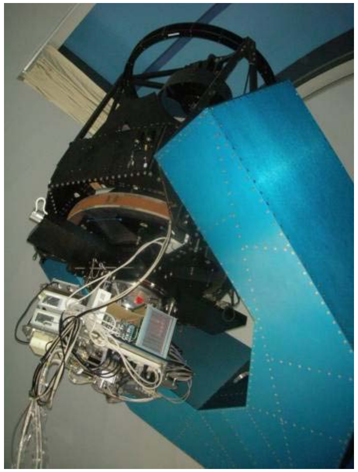
Abstract

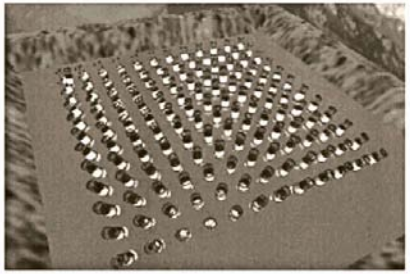
In order to detect faint moving objects such as space debris, asteroids and comet, a FPGA based analysis method has been developed. The original stacking method, which uses multiple images to improve signal-to-noise ratio and runs as a software on PC, has a disadvantage of taking enormous time to analyze. A new algorithm and its installation into a FPGA board solved the problem by reducing analysis time about one thousandth. A collaborative observation between Japan and Taiwan was conducted to search for undiscovered debris fragments generated from a breakup event of US Titan IIIC Transtage. A lot of fragments that may be related to the breakup were discovered by analyzing with the method which verifies the effectiveness of the method.

Objective

Our goal is to establish cost-effective observation system for small sized GEO/LEO objects.



- Large telescope requires large CCD camera
- Large telescope requires large building
- Large telescope requires much money to maintain and run.



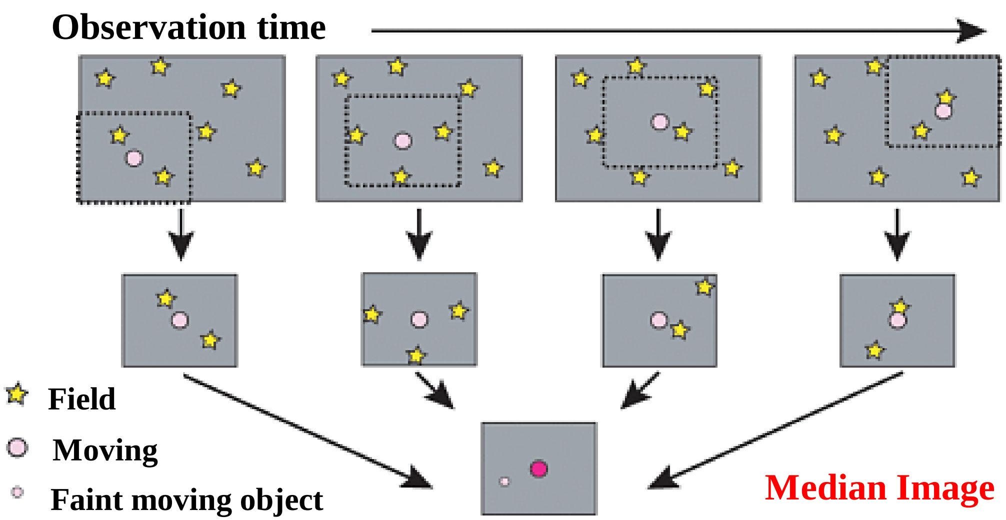
<u>Small telescope and sophisticated image processing is able to overcome.</u>

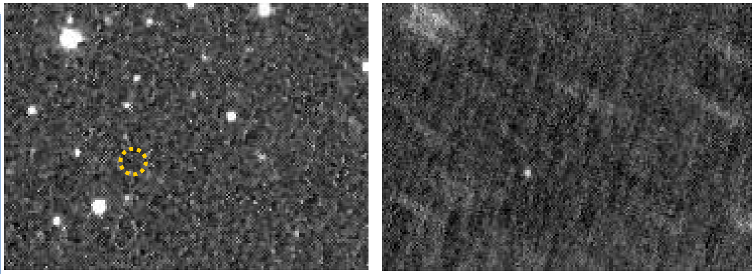
- Simple system is easy to build, maintain and run.
- Many systems will be used to cover large sky area or/and to distribute all the globe.

Stacking method

The stacking method uses multiple CCD images to detect very faint objects that are undetectable on a single CCD image.

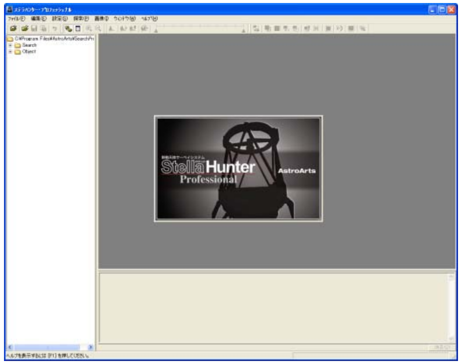
Concept of the stacking method





An asteroid detect with the stacking method. One CCD image (left) and the stacked image (right).

Sub-images are cropped from many CCD images to follow the presumed movement of moving objects. Faint objects are detectable by making the median image of these sub-images.

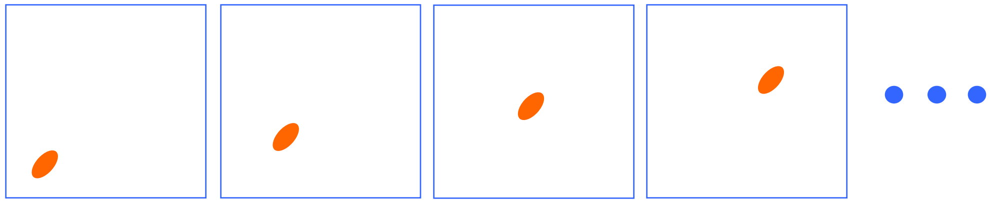


Stellar Hunter Professional: Commercial software for discovering asteroids and comets.

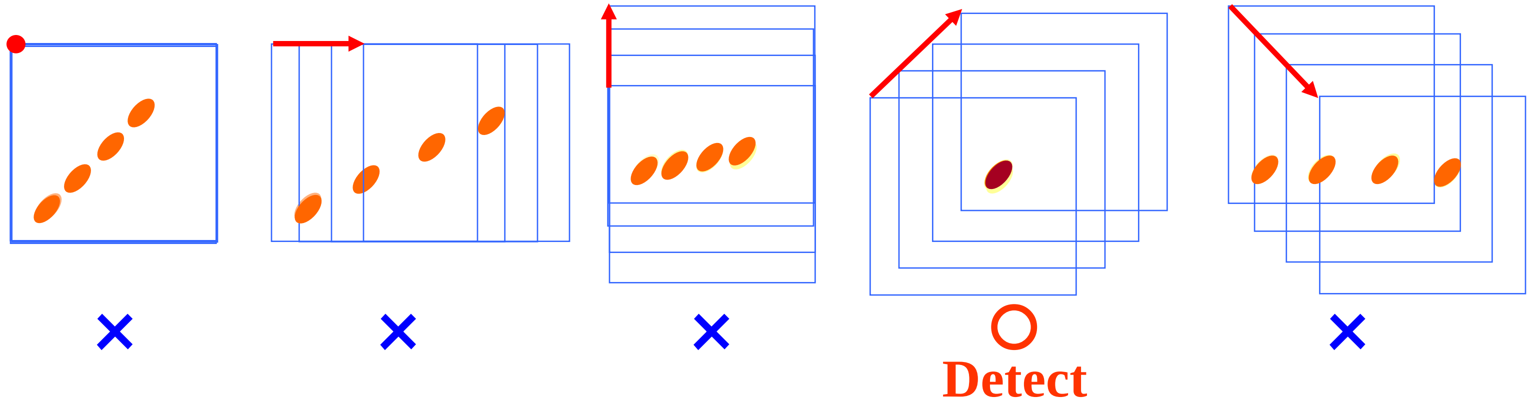
Many asteroids were discovered by the method.

Stacking method

The only weak point of the method is taking time to analyze the data in case of detecting unseen object whose movement is not known, because various movements of the object have to be presumed.



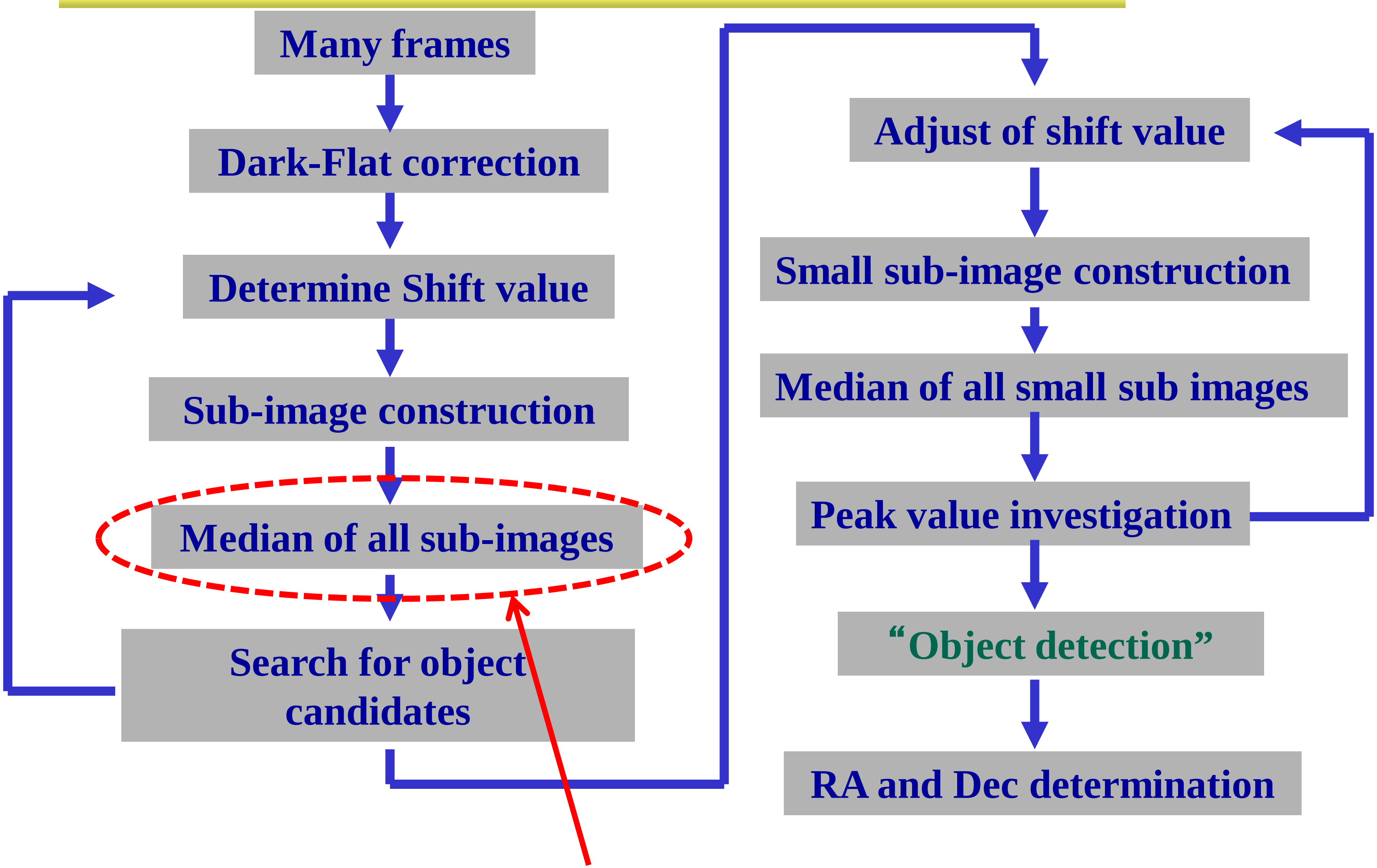
Many CCD image are taken with telescope-fixed mode.



Images are stacked in many ways, as various shift values are presumed. Once a object is detected, its movement is also determined.

Analysis time for 65536 processes of 32 1024×1024-pixel frames which are intended to detect objects moving within 256×256 pixels is about 280 hours using 1 normal PC.

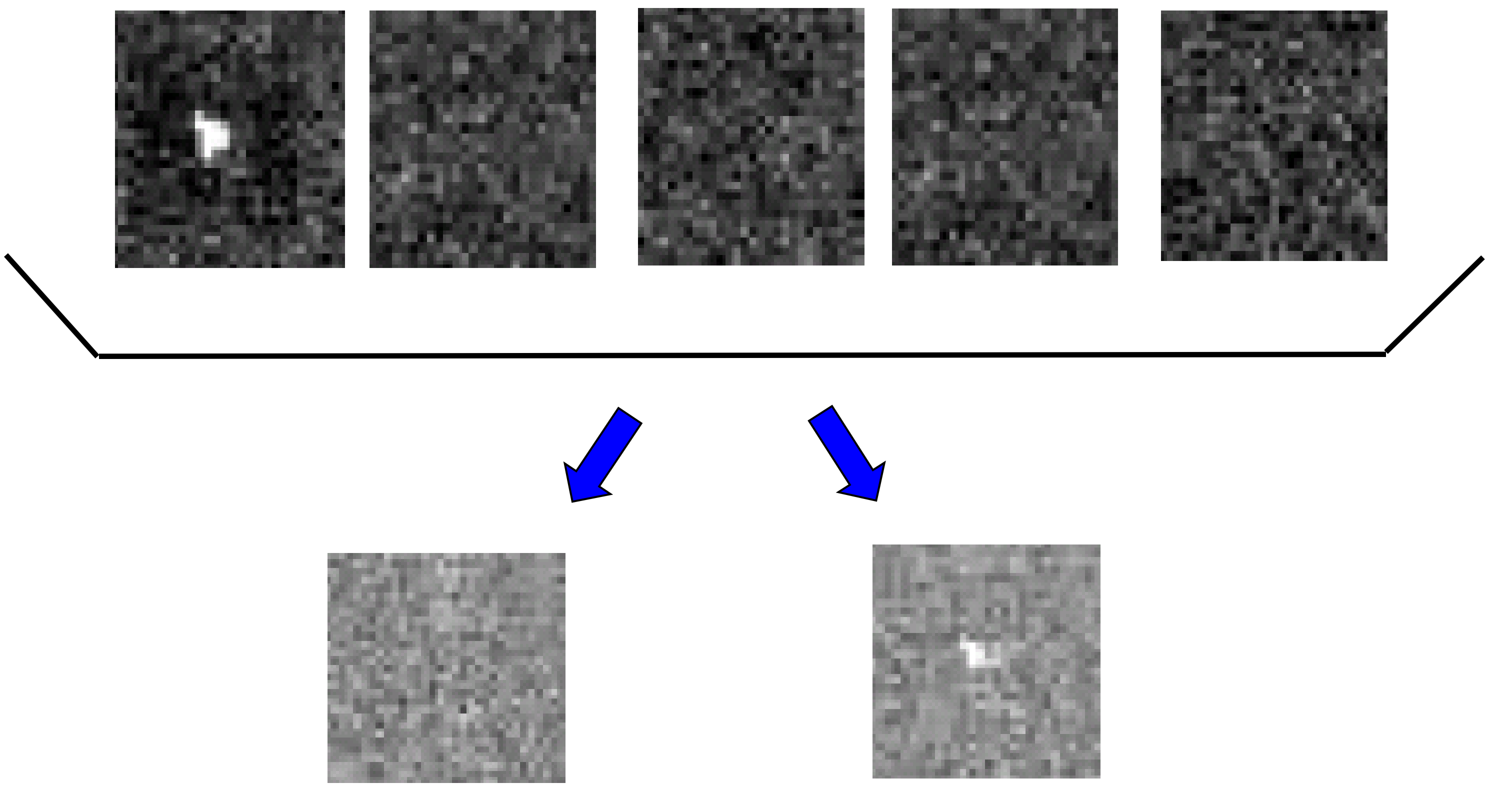
Data analysis process：Stacking method



Calculating median is the most time-consuming part

Data analysis process：Stacking method

Difference between median and average



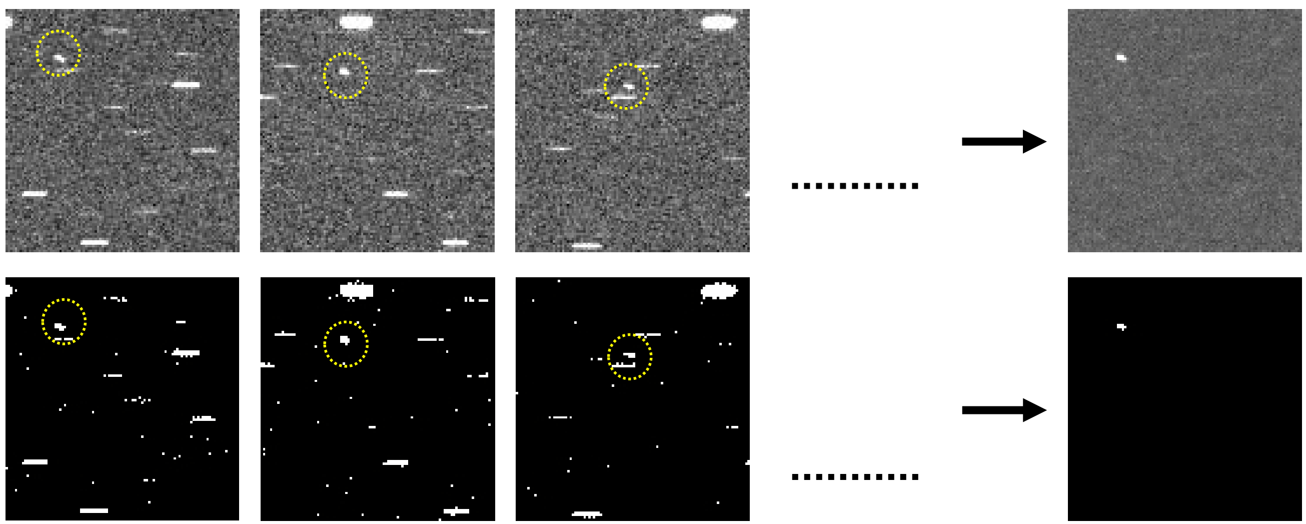
Median **Average**

Development of the new algorithm

Calculating median is complicated and time-consuming process as compared with calculating average.

Simple calculation process like average that contains the advantage of median is required.

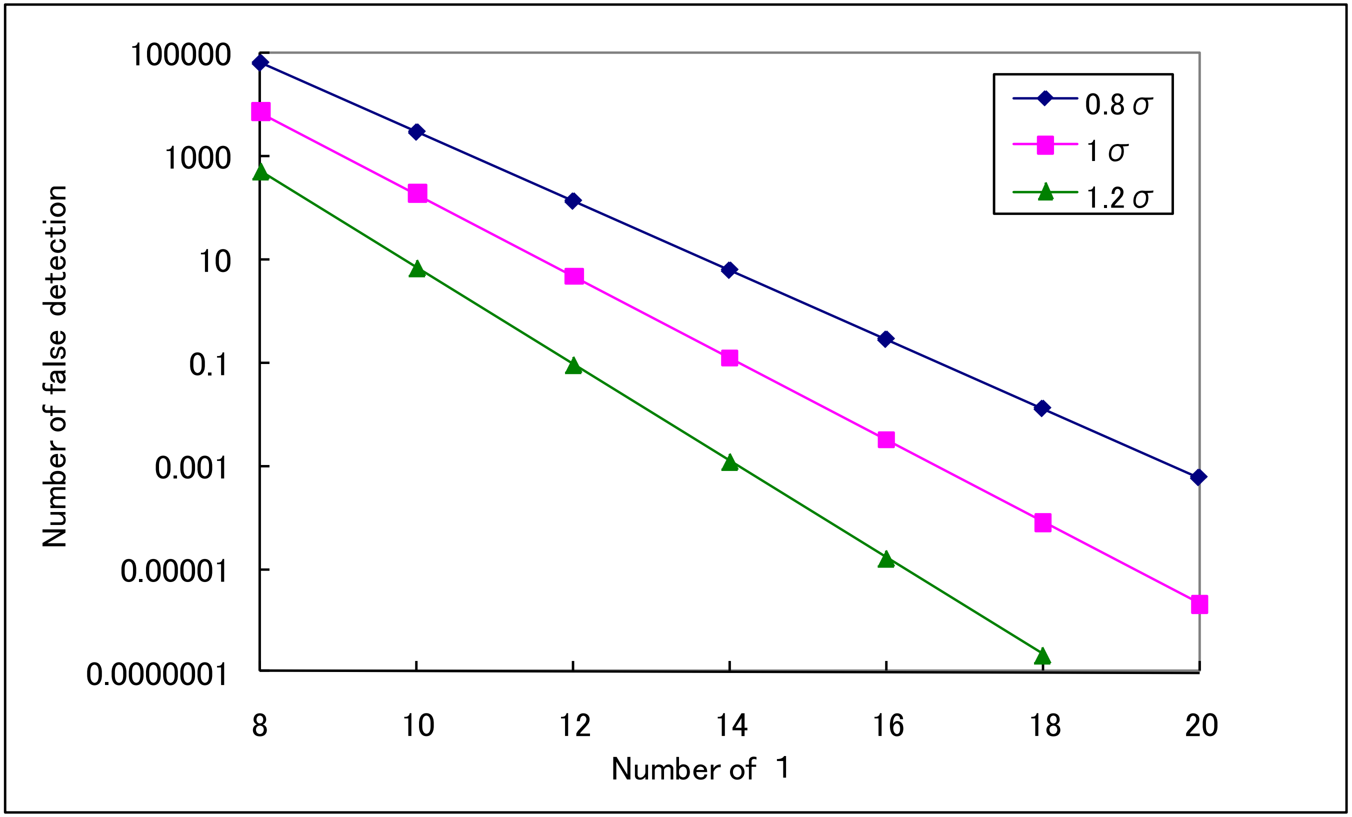
Binarization solves the problem!!



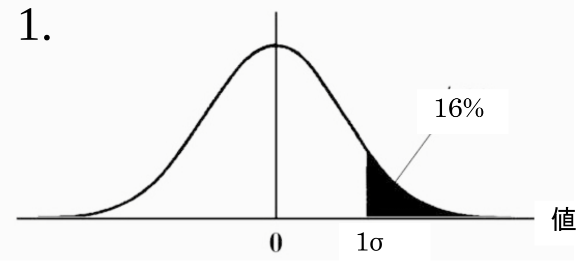
Deference between the original algorithm of the stacking method (upper) and the new algorithm using binarized images.

Analysis time is reduced to one 60th.

Development of the new algorithm



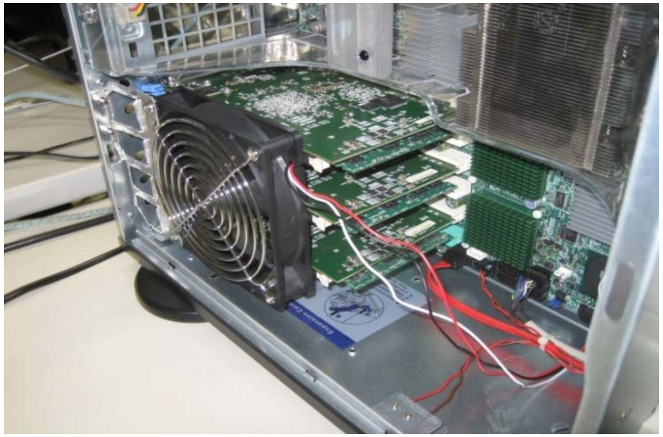
Number of false detection vs. number of 1.



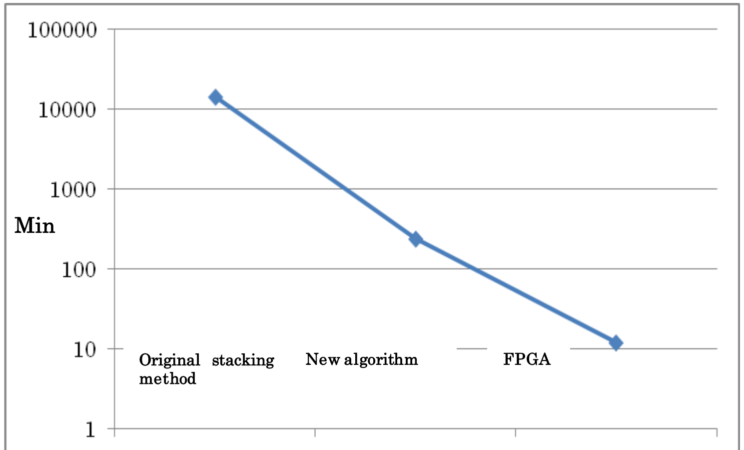
Development of the new algorithm

The new algorithm is installed to the FPGA board for further speed-up.

FPGA board H101-PCIXM manufactured by Nallatech.



FPGA board system manufactured by iDAQs.



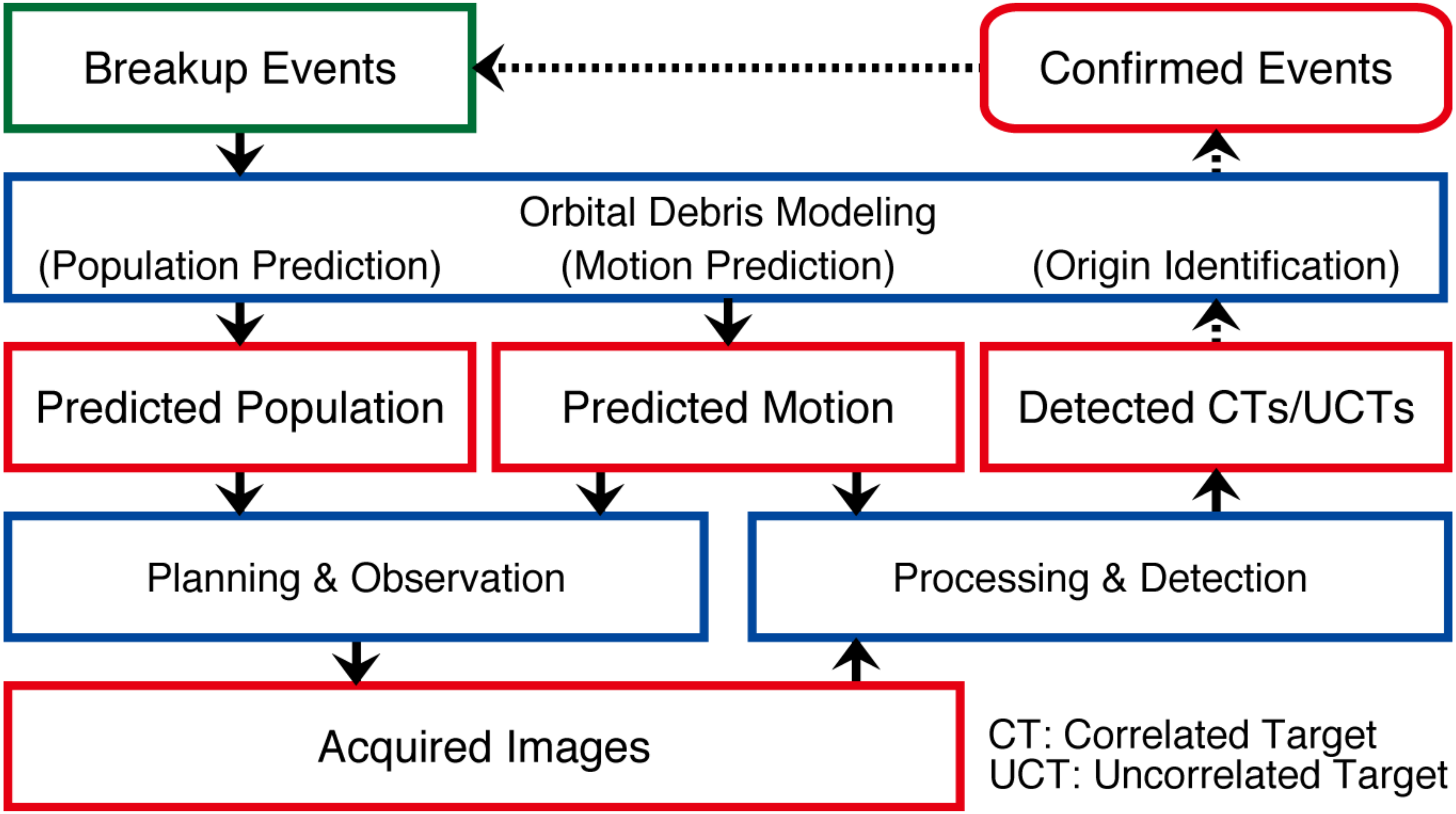
Change of analysis time

Analysis time is reduced one 20th more. (Total is one 1200th.)

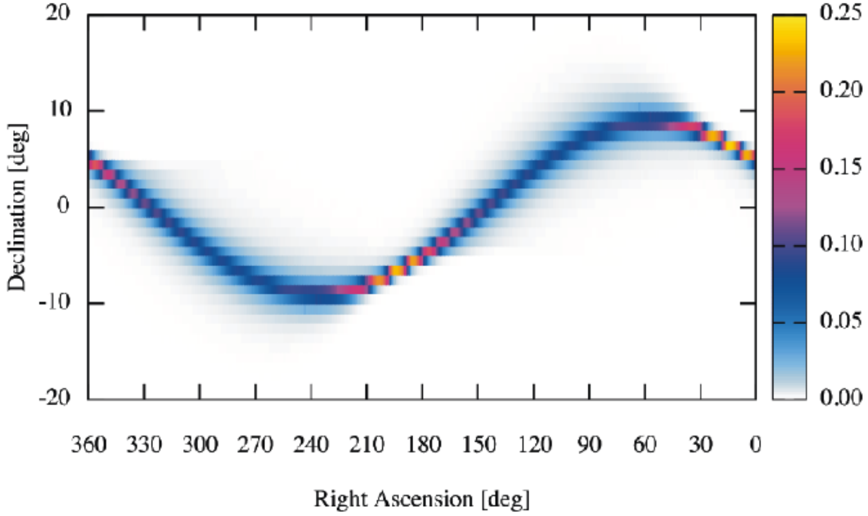
280 hours → 14 minutes

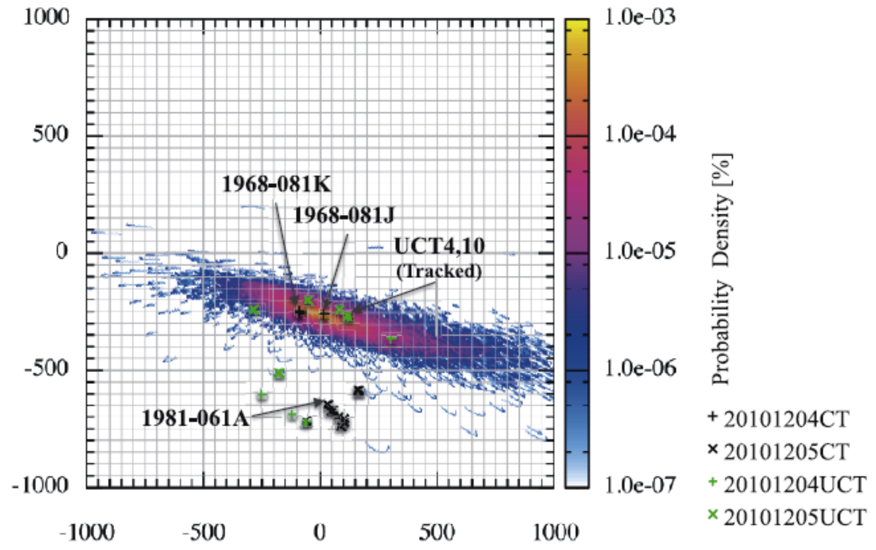
Observation of Titan3C fragments based on Modeling

Orbital Debris Modeling developed at Kyushu University can predict where and when is the most effective for the fragments to be observed.



Example of Prediction and Observation Results



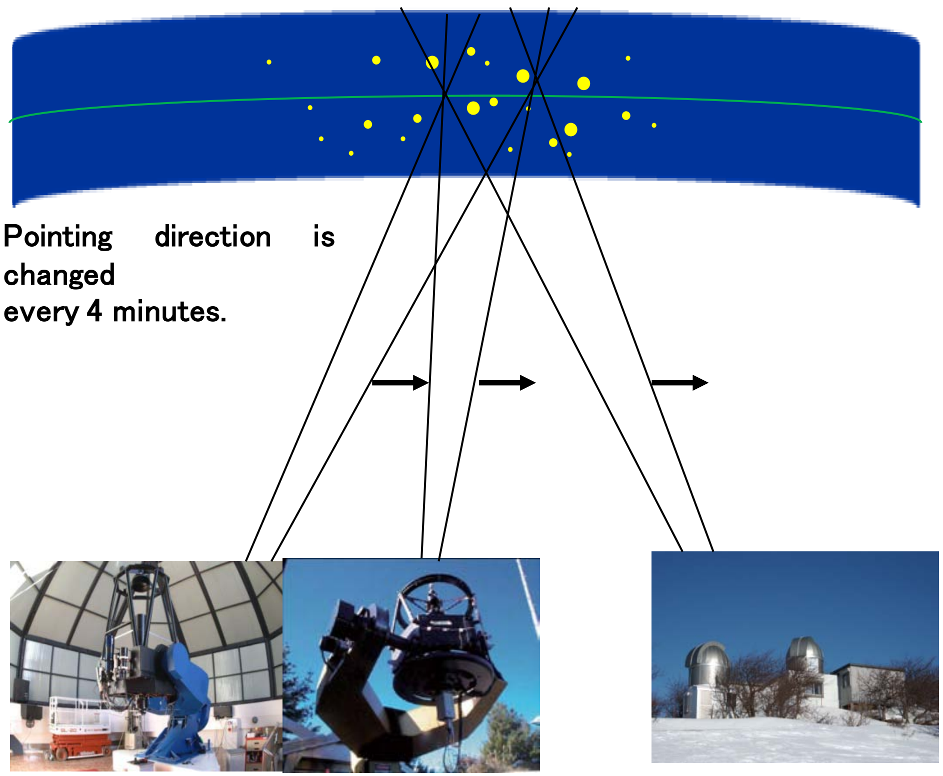


Population prediction
(Titan 3C fragments)

Motion prediction
(Titan 3C fragments compered with observation data)

Observation

Observation was carried out on Oct 20, 21 and 22 using 2 telescopes in Taiwan and one telescope in Japan



Lulin 1m telescope | TAOS telescope | JAXA telescope

LOT	TAOS	Nyukasa
D: 1m	D: 0.5m	D: 0.35m
FOV: 0.2×0.4°	FOV: 1.3×1.3°	FOV: 1.3×1.3°

1st field
1−second exposure ×1
4−seconds expousre×32

↓

2nd field
1−second exposure ×1
4−seconds expousre×32

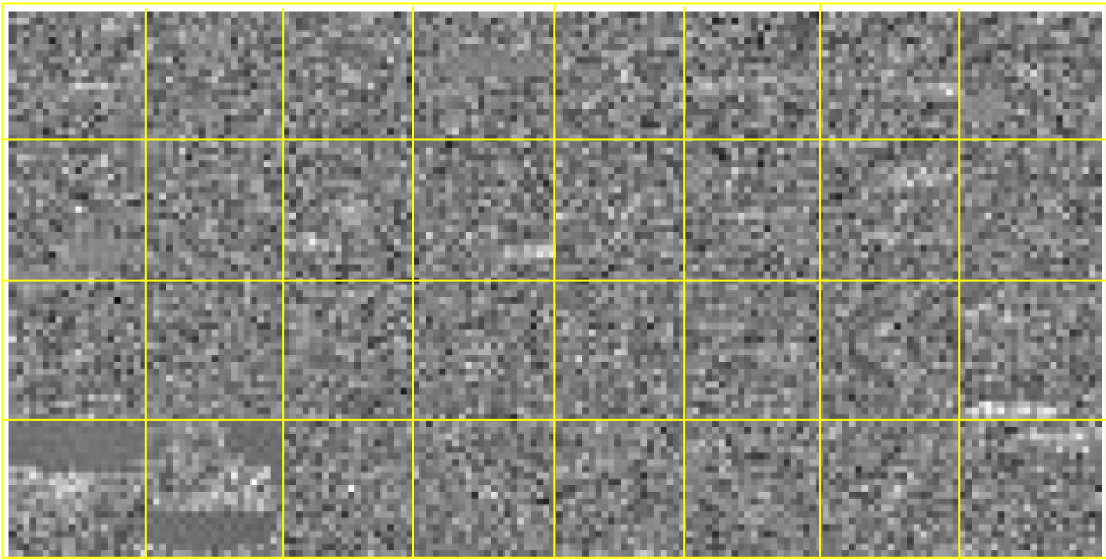
↓

3rd field
1−second exposure ×1
4−seconds expousre×32

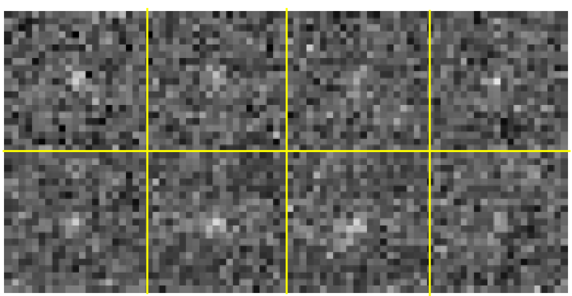
⋮

Observation sequence

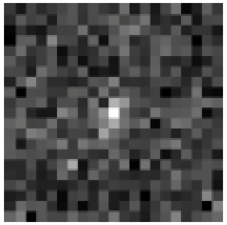
Results



No stack



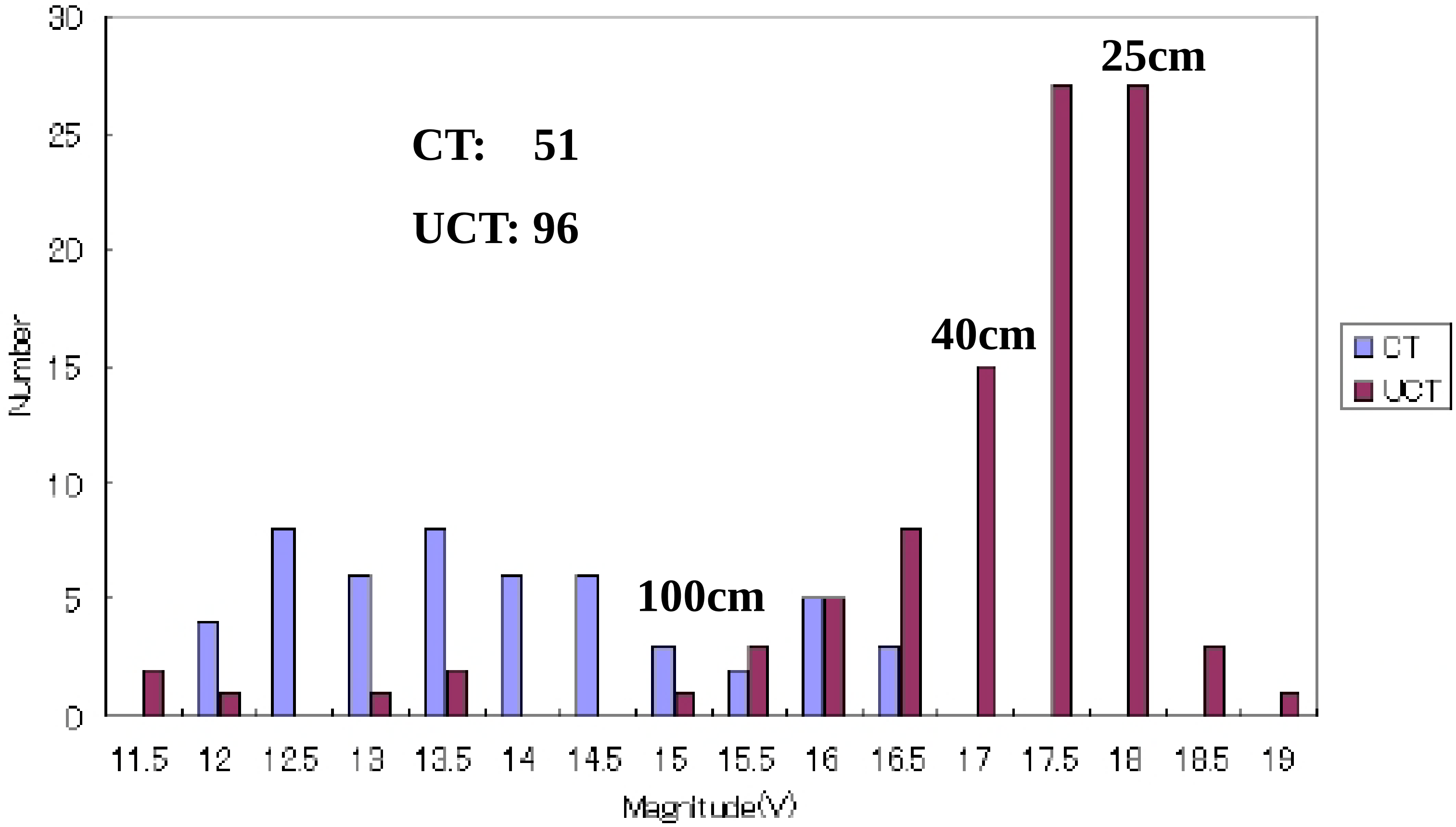
8-frame stack



32-frame stack

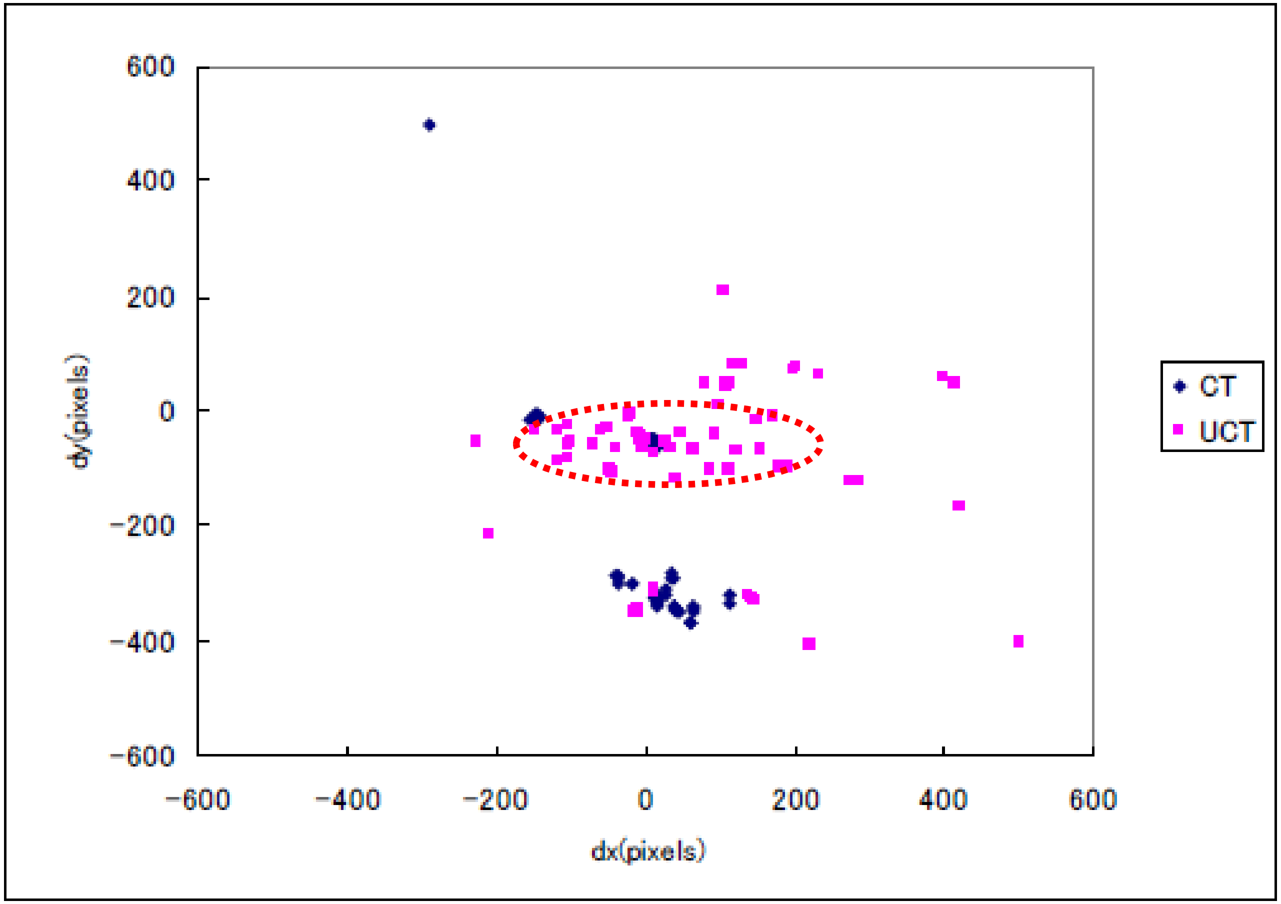
Detected object of 17.7 magnitude

Results



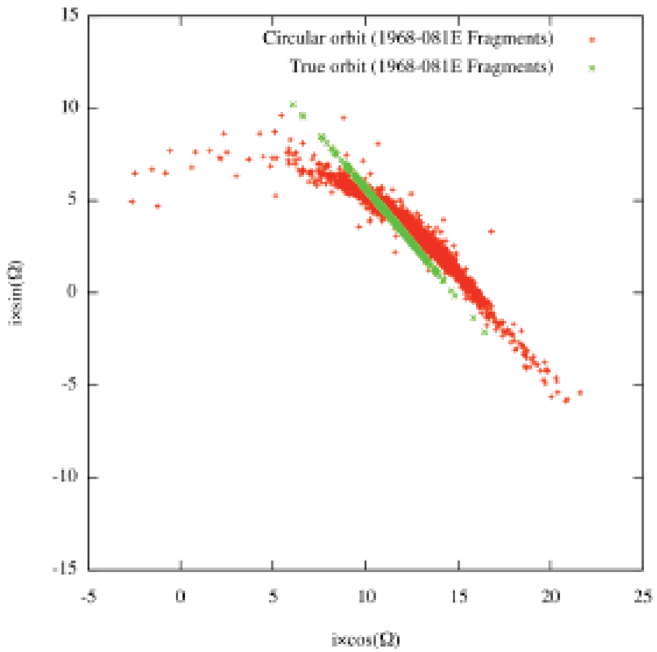
Magnitude distribution of detected objects

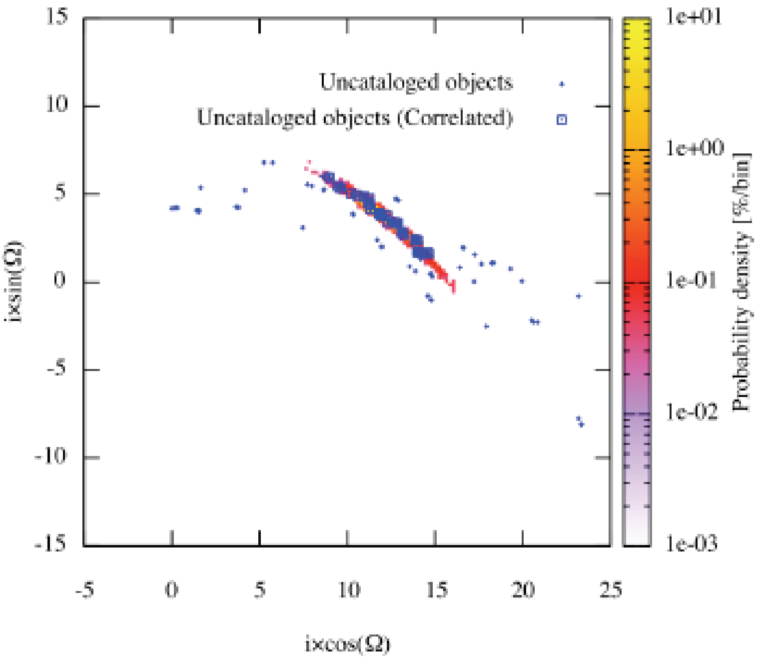
Results



Motion distribution of detected objects

Origin Identification





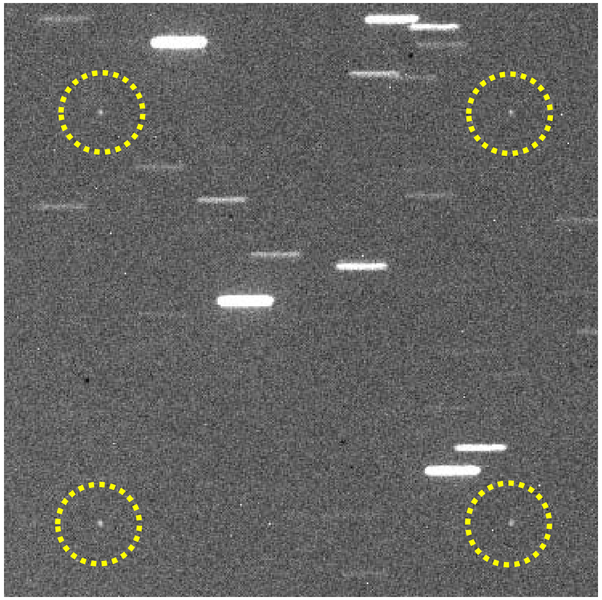
True orbit at the breakup → **Propagation** → **True orbit at present**

↓

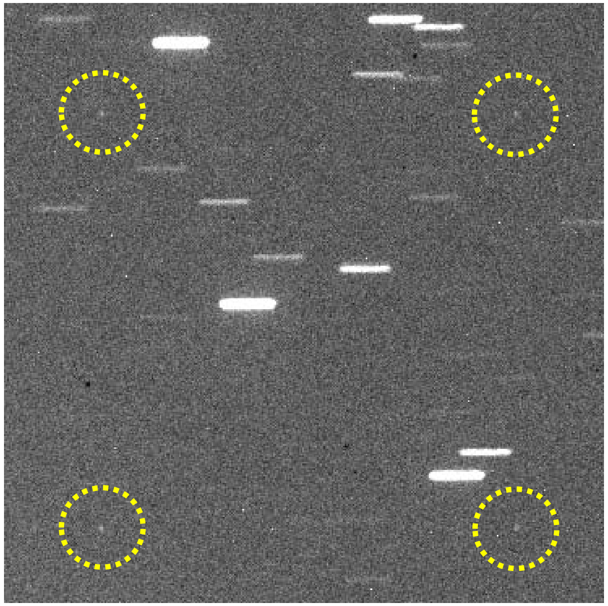
Circular orbit at present → **Inverse-propagation** → **Circular orbit at the breakup**

Detection Efficiency

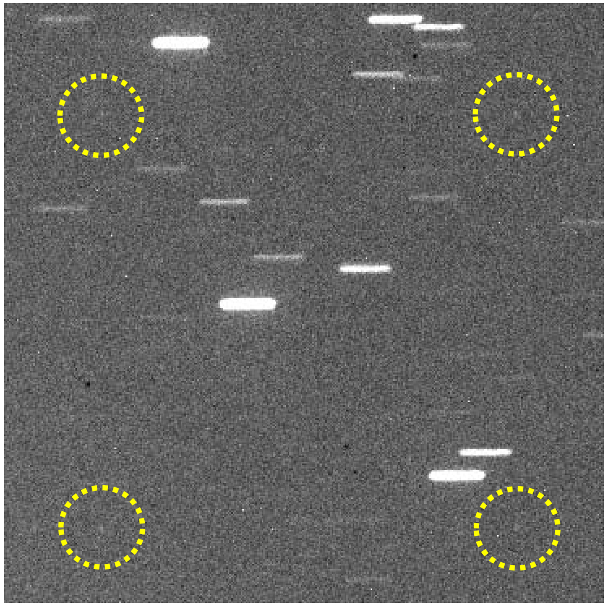
Detection Efficiency was calculated by embedding artificial objects of various brightness on real frames and reanalyzing them using the same FPGA system.



16.5-magnitude

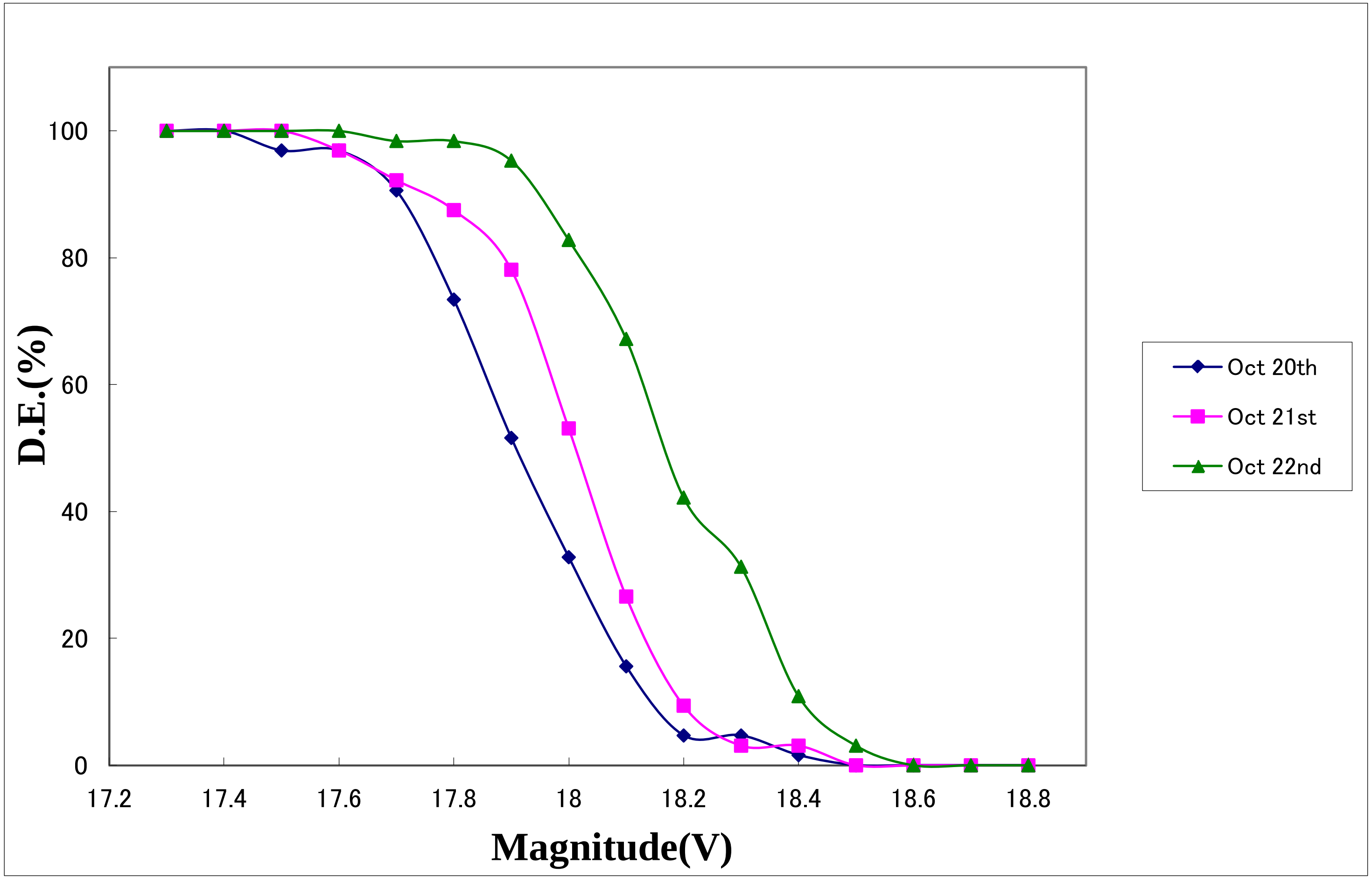


17.0-magnitude

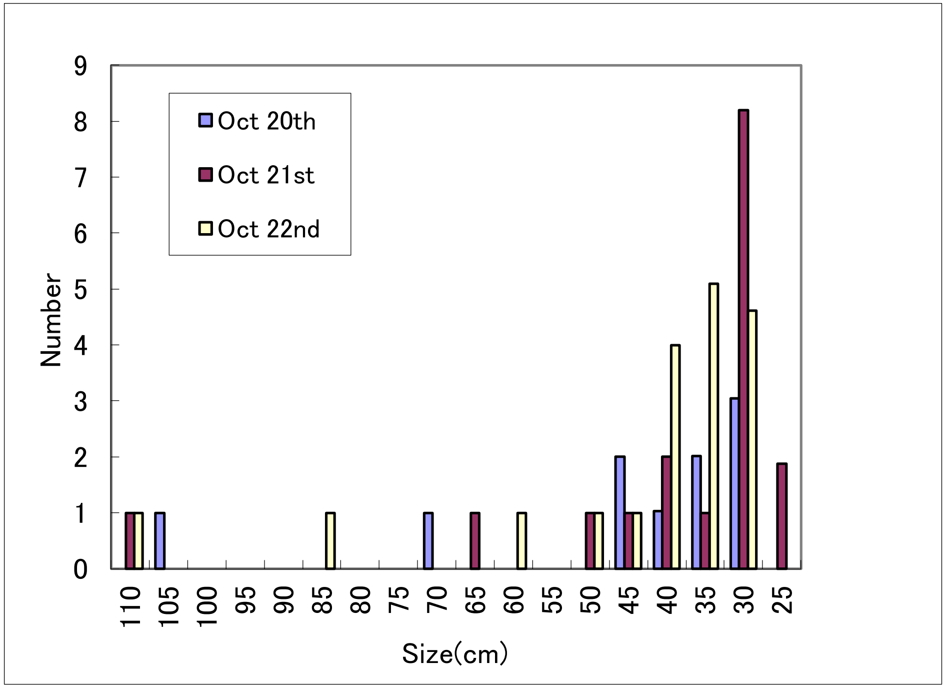


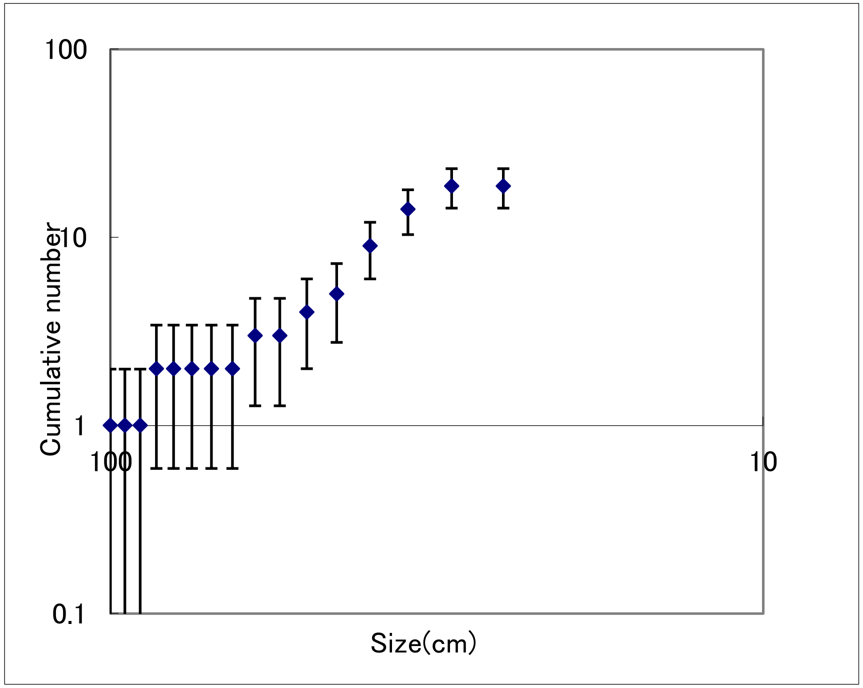
17.5-magnitude

Detection Efficiency



Size Distribution





Summary

In order to detect faint moving objects such as space debris, asteroids and comet, a FPGA based analysis method has been developed. The original stacking method, which uses multiple images to improve signal-to-noise ratio and runs as a software on PC, has a disadvantage of taking enormous time to analyze. A new algorithm and its installation into a FPGA board solved the problem by reducing analysis time about one thousandth. A collaborative observation between Japan and Taiwan was conducted to search for undiscovered debris fragments generated from a breakup event of US Titan IIIC Transtage. A lot of fragments that may be related to the breakup were discovered by analyzing with the method which verifies the effectiveness of the method.