F2

GEO デブリの画像処理及び光度変動

Image-processing and light curve of orbital objects around GEO

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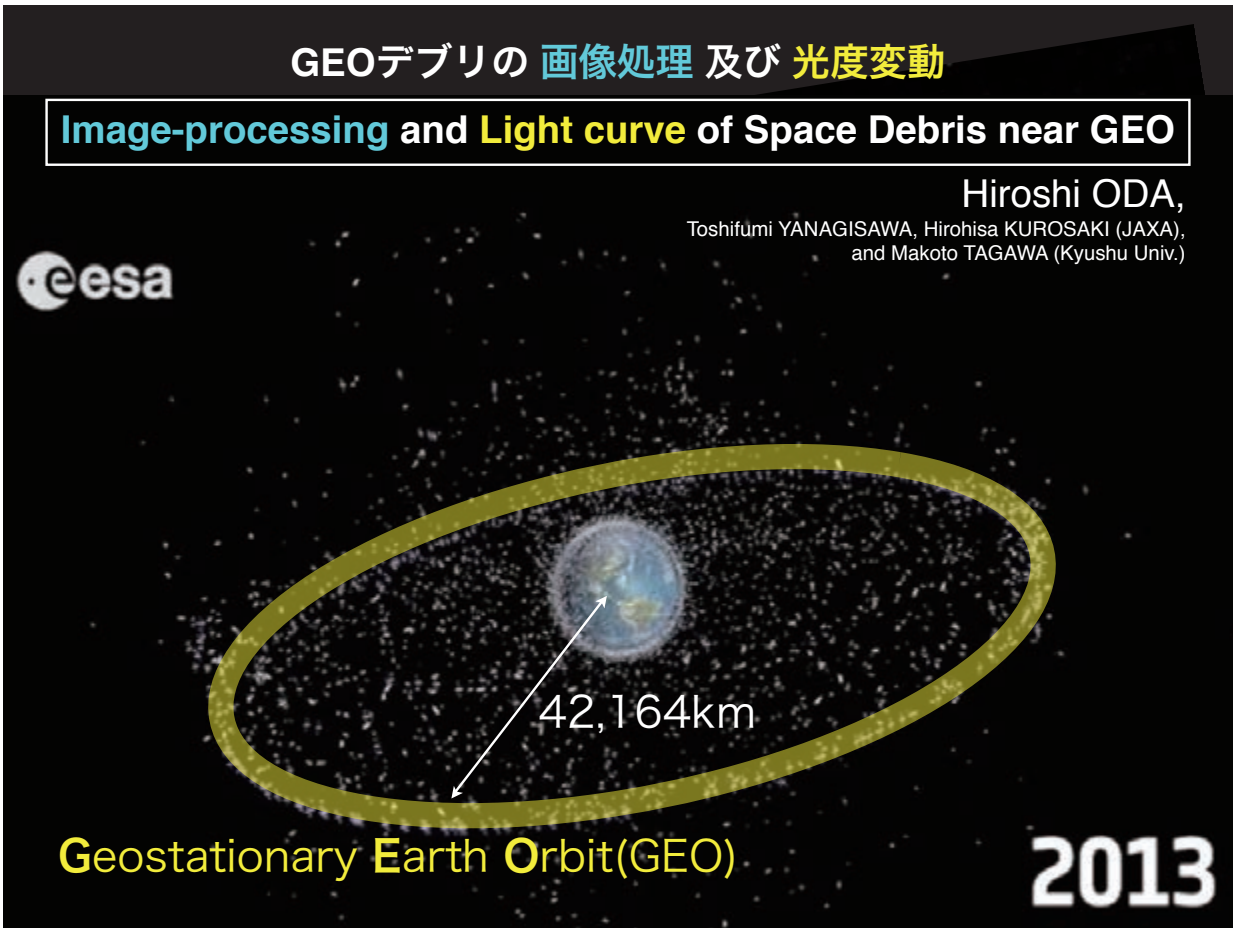
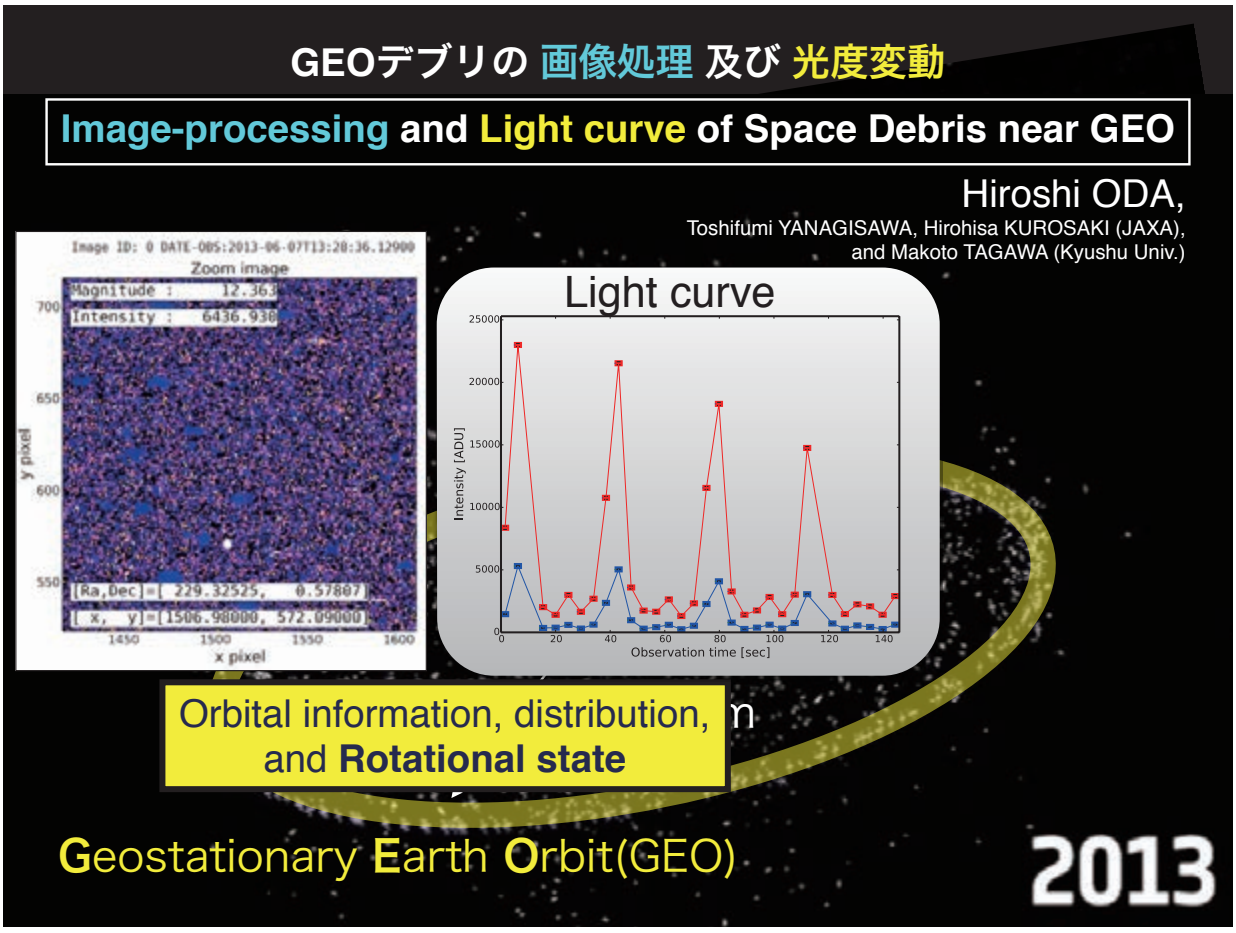
Makoto TAGAWA (Kyushu Univ.)

スペースデブリ光学観測の画像処理、検出手法、および検出物体の光度変動の解析結果について報告する。 観測は地平座標固定モード(静止軌道物体は画像内で静止)で行い、一領域につき露光時間 3 秒で 32 枚撮像したものを 1 データセットとした。これらの画像に対して直線運動検出法を適用することで移動物体を検出し、検出された移動物体に対し測光を行い光度変動を調べた。その結果、検出物体が回転している可能性を示唆する光度変動を示すものが多数確認された。本講演ではこれらの解析結果について報告する。また、スペースデブリの回転を誘起させる機構についても議論する。

We report on image-processing, detection and light curve of space debris around the geosynchronous Earth orbit (GEO). In GEO survey observation, we employ the horizontal coordinate system, and set the exposure time to be 3 seconds. A dataset of an observation region consists of 32 successive light frames. We detect moving objects by applying the uniform linear motion detection method to the dataset, and perform photometry on the images to investigate the light curve. As a result, we found that a lot of the detected objects show the time variation in the light curve which provides information on the rotational state of the detected object. We also discuss the cause of the rotation of orbital objects.





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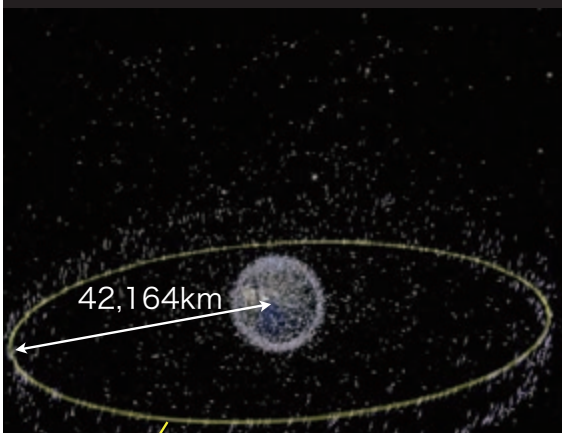


Geosynchronous **E**arth **O**rbit (GEO)

Orbital information, distribution, and **Rotational state**

Observation Site

Nyukasa Observatory

Dome 1
35cm telescope + CCD
FOV: 1.4° x 1.4°
GEO survey

Dome 2
25cm + CCD:
18cm + CCD:
LEO survey
NEO survey

Introducing and testing
2 CMOS Cameras

35° 40' 42" N
139° 33' 24" E
Alt. of 55m

35° 54' 16" N
138° 10' 08" E
Alt. of 1870m

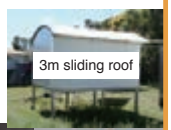
27° 26' S
151° 43' E
Alt. of 406m

Chofu Observatory

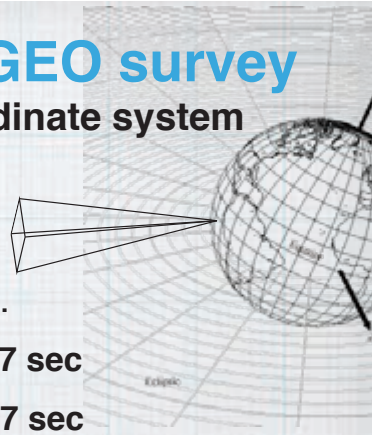
Tri-Axial Mount
35cm + CCD
FOV: 7.6′ x 6.1′
LEO tracking

Australia Remote Obs.

18cm (→ 25cm) + CCD
FOV: 3.17° x 3.17°
GEO survey
NEO survey



Observation and Dataset for GEO survey



* We employ **the horizontal (topocentric) coordinate system**
  - Stars move horizontally
  - Perfect GEO objects are stationary.
* Time interval: **3 sec exposure + Readout time**.
  - ARO: 3 sec exposure + 1.7 sec readout ~ **4.7 sec**
  - Nyukasa: 3 sec exposure + 2.7 sec readout ~ **5.7 sec**
* Duration: (4.7 or 5.7 sec) x 32 images **~150 sec**

Note: The dataset is optimised for detection efficiency but light curves

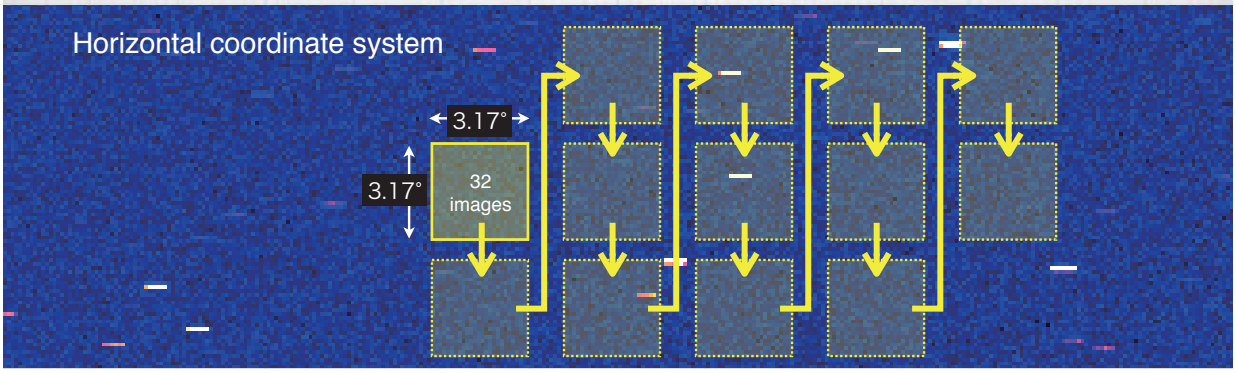
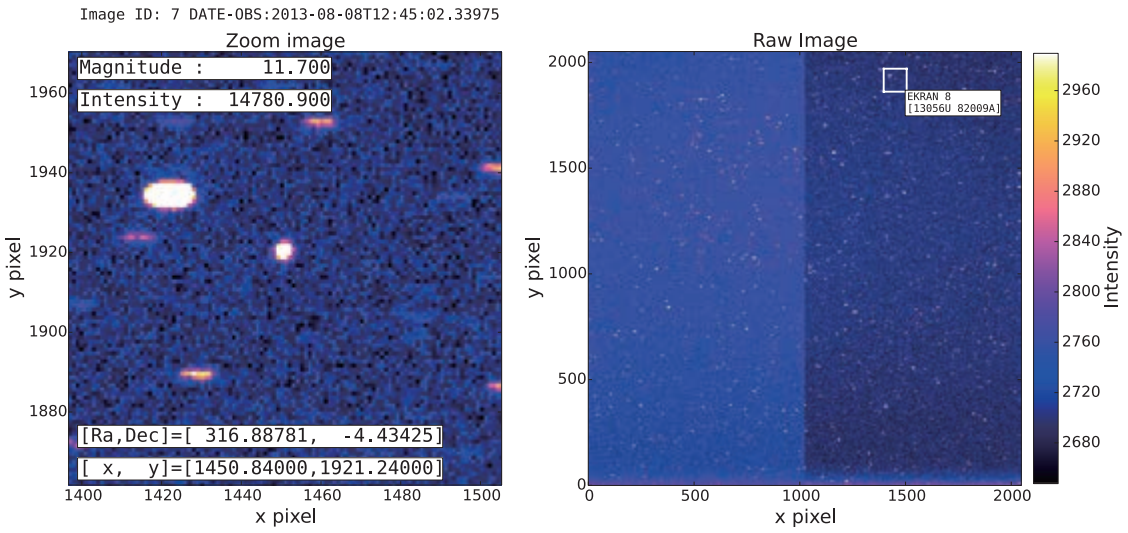


Image-processing

* Raw image
* Dark-Bias subtraction, Flat correction, BKG subtraction
* Diurnal motion object (star trail) masking



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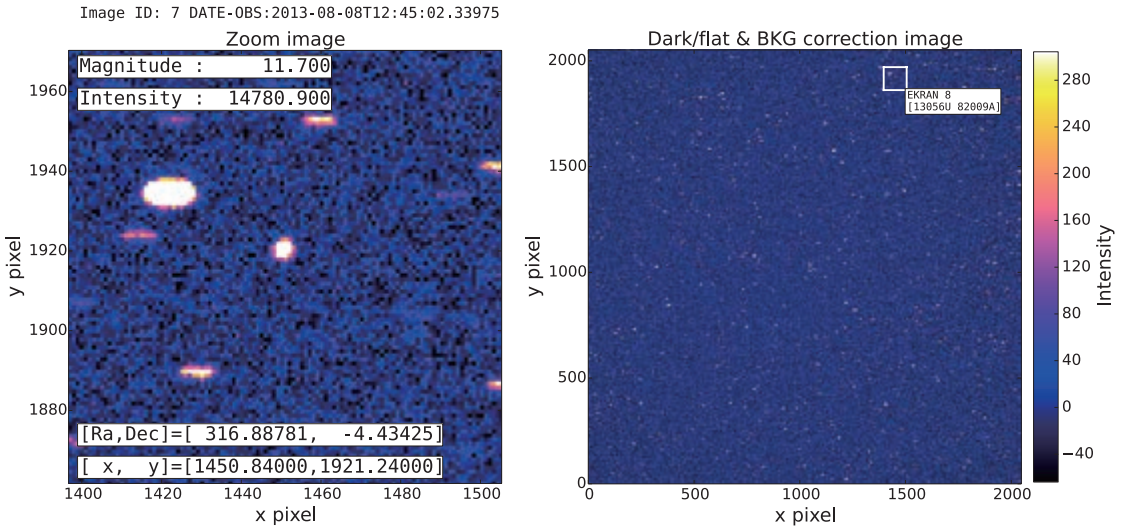

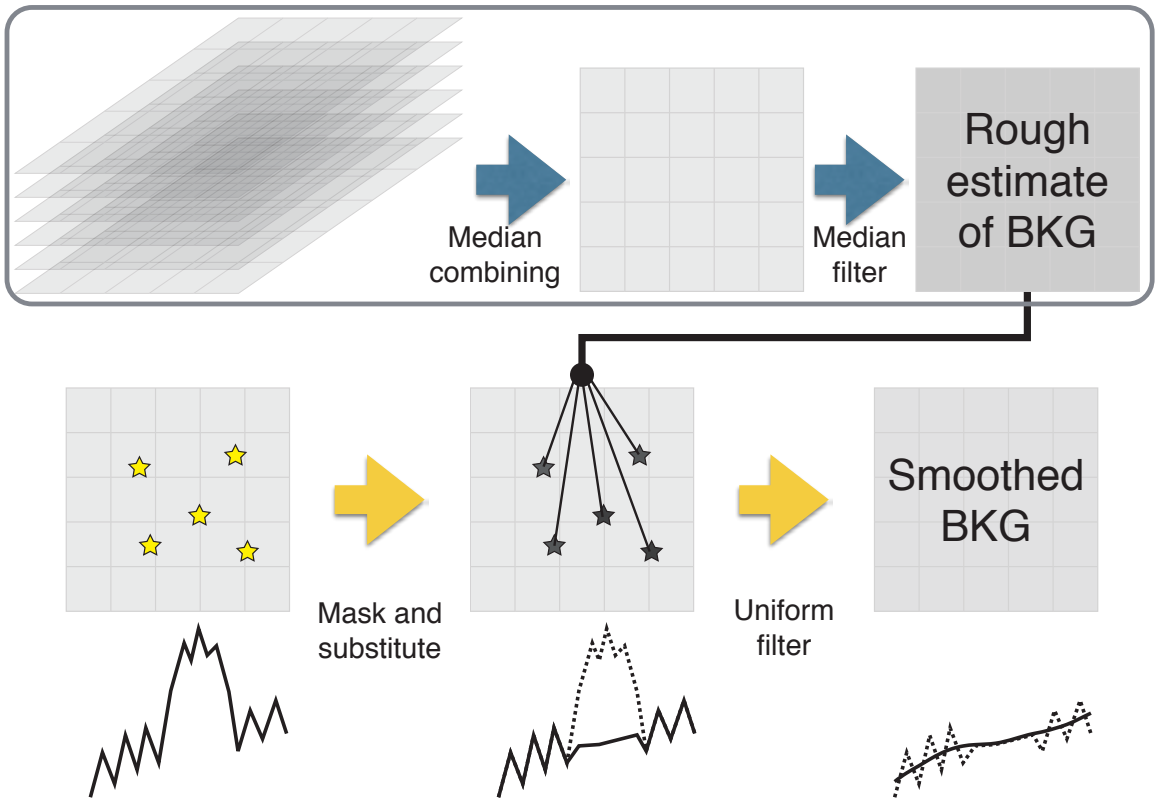

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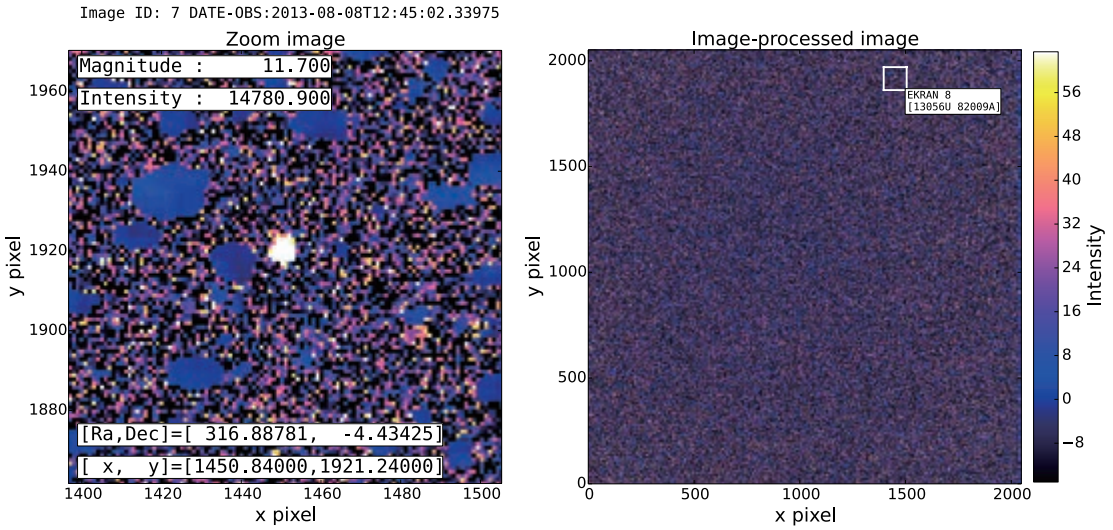
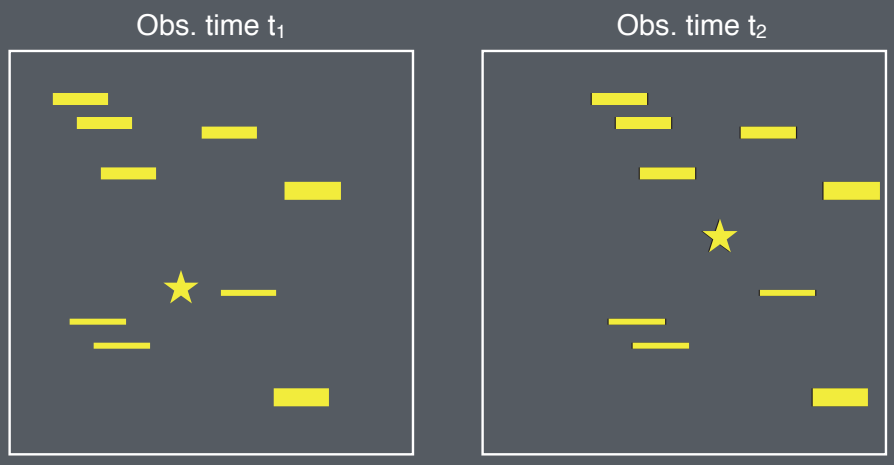


Diurnal motion object (star trail) masking

For the convenience in detection of orbital objects, we want to mask star trail…



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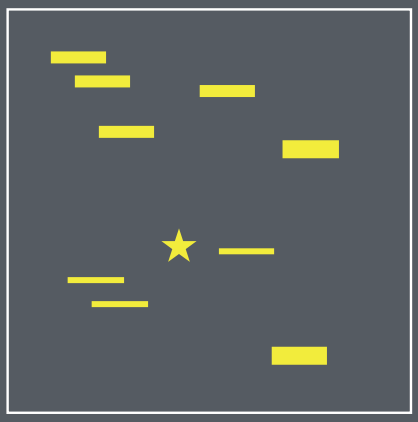
Obs. time t_1



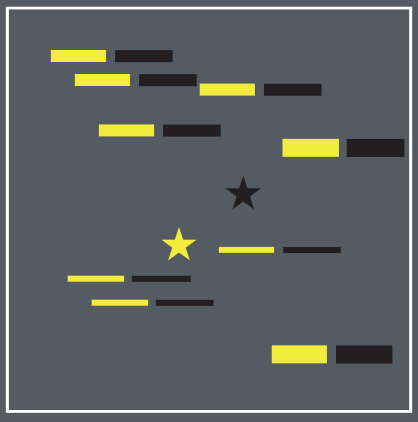
Obs. time t_2

Mask bright pixels

Diurnal motion object (star trail) masking

For the convenience in detection of orbital objects, we want to mask star trail…

Obs. time t_1



Overlay masked image

Obs. time t_2

Mask bright pixels

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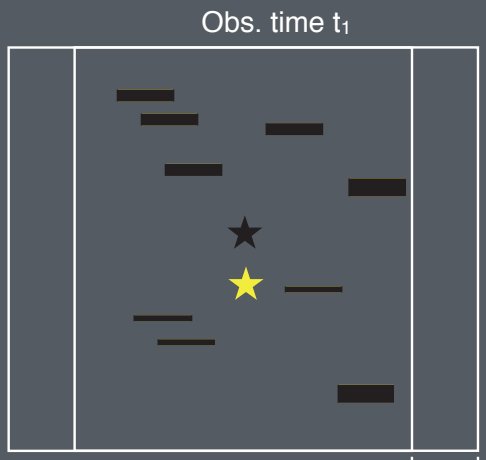
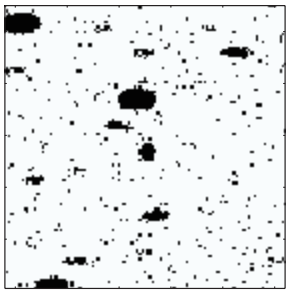
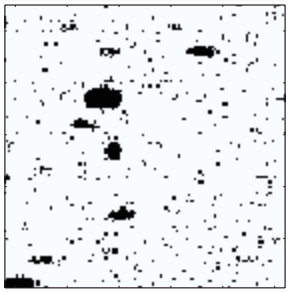


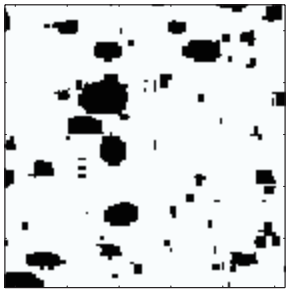
Mask bright pixels



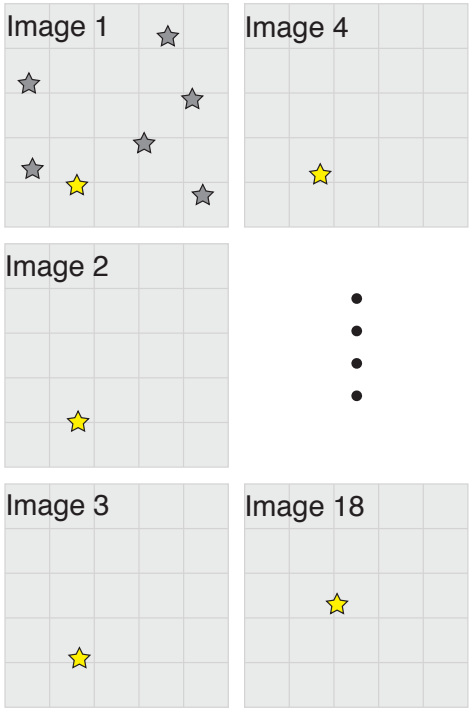
Shift by the travel distance due to the diurnal motion



Shift by the travel distance due to the diurnal motion



Detection algorithm: Uniform linear motion detection



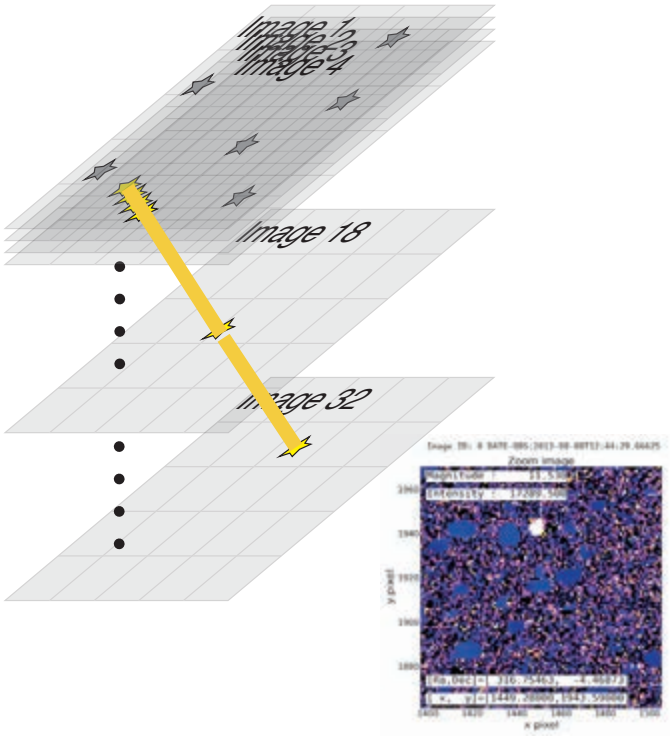
limited by the computational resources

▸ **Step1**
Select 500 candidates based on
- shape (blurred by atmospheric turb.)
- Intensity (brightest 500)

At this step,
noise, cosmic rays, etc… are included.

▸ **Step2**
Search objects showing the uniform linear motion
- 9 out of first 18 light frames

Detection algorithm: Uniform linear motion detection



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▸ **Step2**
Search objects showing the uniform linear motion
- 9 out of first 18 light frames

▸ **Step3 (for lightcurve)**
extrapolate the detected path to the **32th image** and follow-up search

Photometry

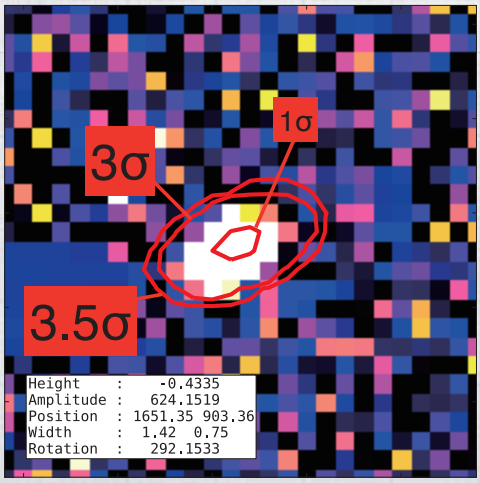
☑ Moving objects leave trailed image (**not circle and ellipse**)

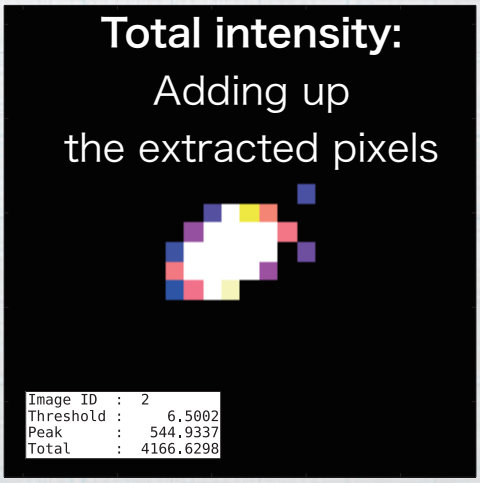
Extract pixels adequate for photometry using the 2D-Gaussian fit

*Step 1: Crop region surrounded by **3.5σ**

➡ apparently inadequate pixels are excluded.

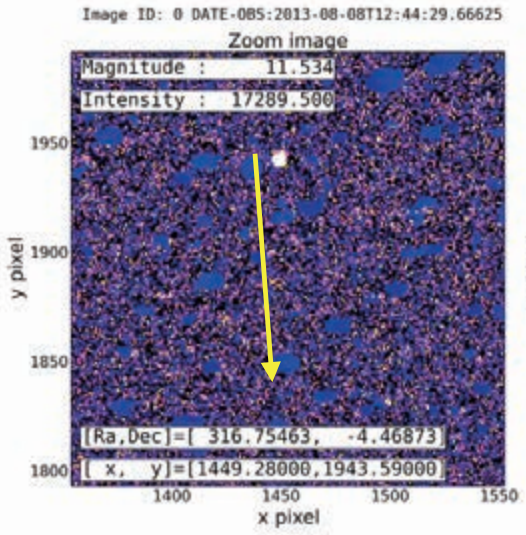
*Step 2: Extract pixels whose value greater than the value at **3σ**

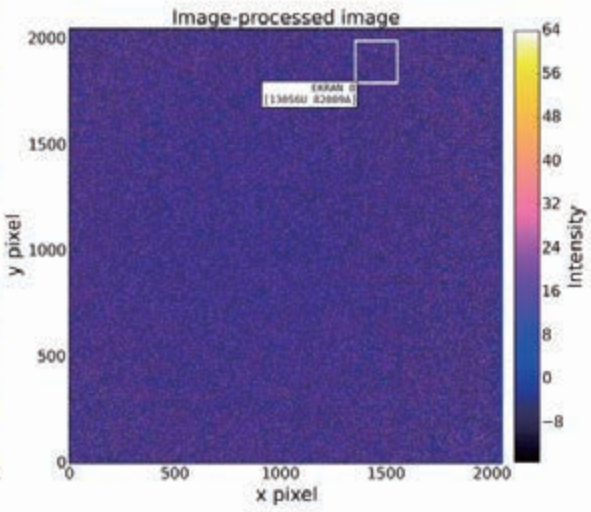




Example of a bright object

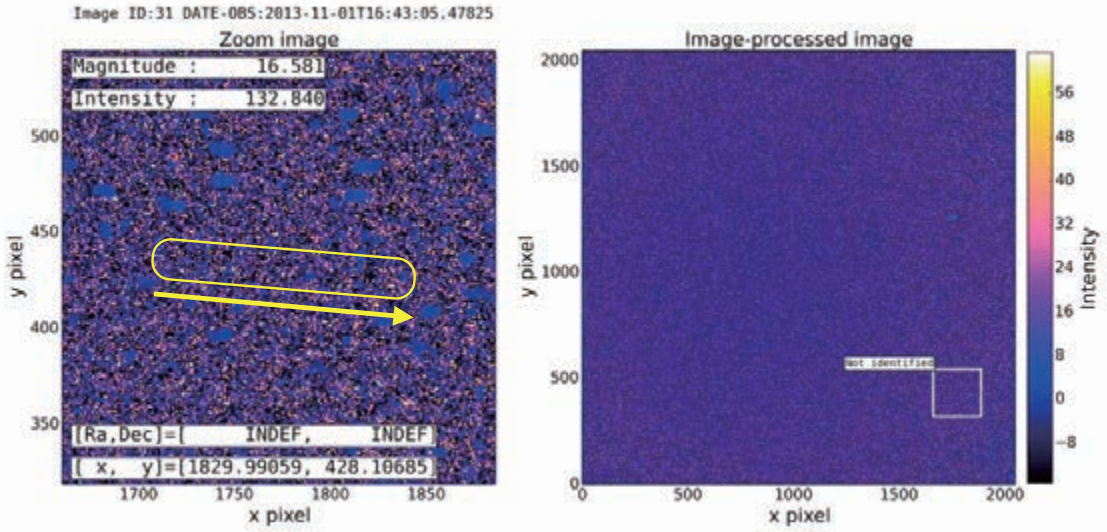
2013/08/08, region 027, object 0:
Mean mag. 11.79





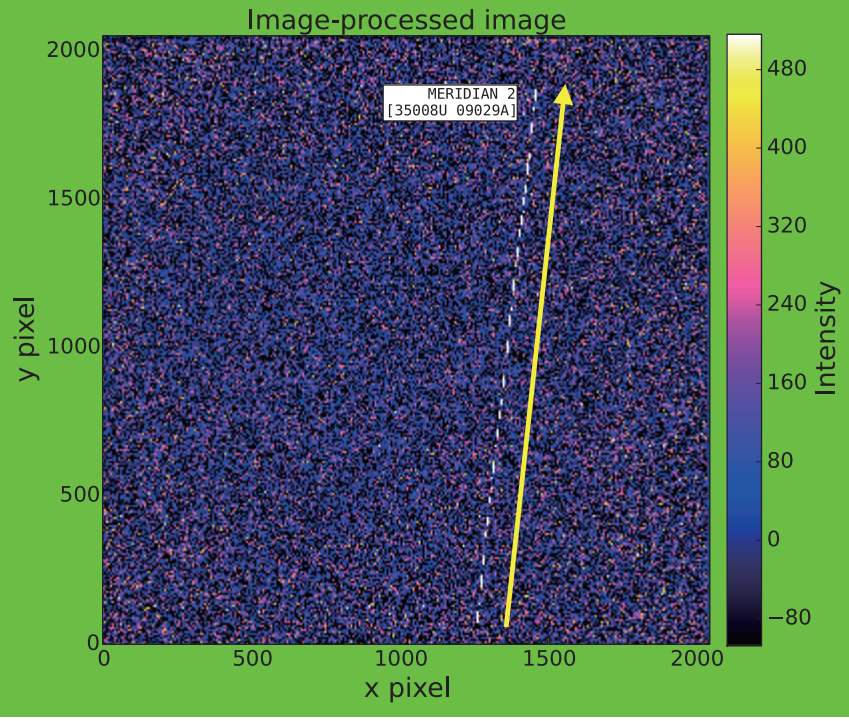
Example of a faint object

2013/11/01, region 049, object 0:
Mean mag. 15.11

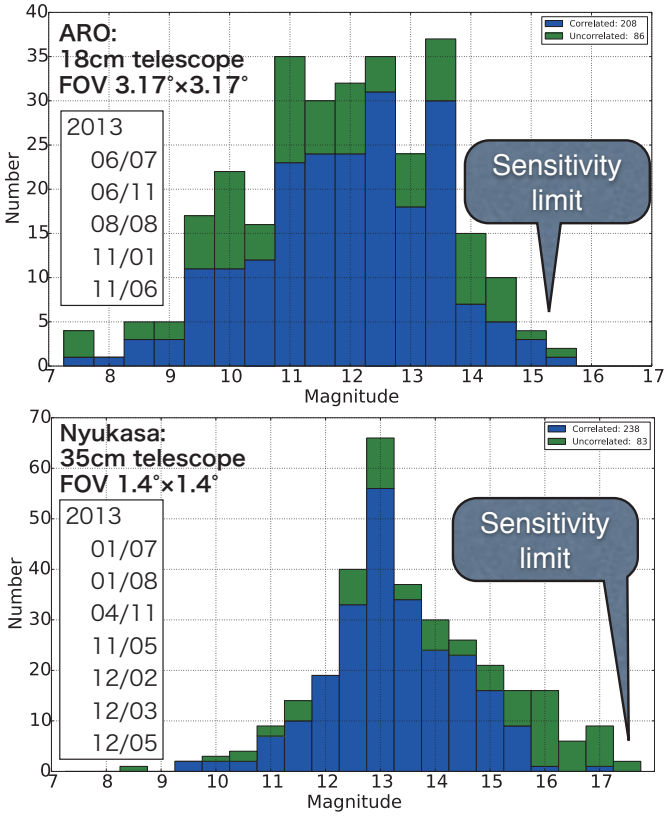


Example of a fast (and bright) object

2013/11/01, region 058, object 0:
Velocity = 21.85 pix/sec(~ 0.034 deg/sec)



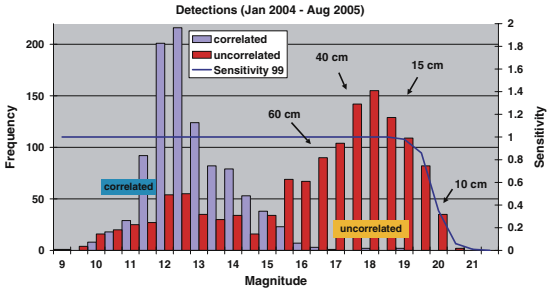
Magnitude-Number distribution



Peak at ~12-13 Mag.

- reflects the size distribution in the catalog.

ESA's 1-m telescope

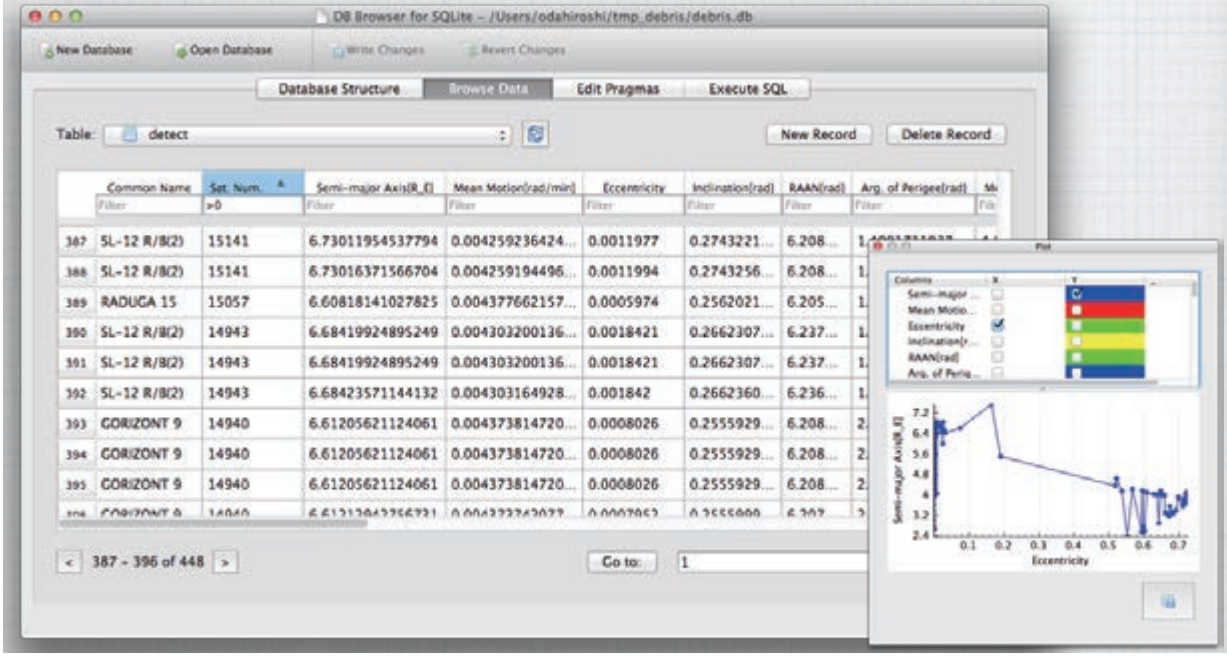


Schildknecht et al. 2004

Note: A lot of detected object shows a time variation in the light curve.
The "mean" mag. could not represent the proper size.

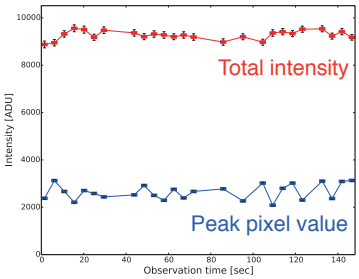
Database Management

* **Database Language: SQLite**
  - Python standard library (Our codes are written in Python)
* **Database Structure**
  - Correlated objects: Orbital elements in TLE catalog + Astrometry + Photometry
  - Uncorrelated objects: Astrometry([RA, Dec], etc…) + Photometry(Mag., etc…)

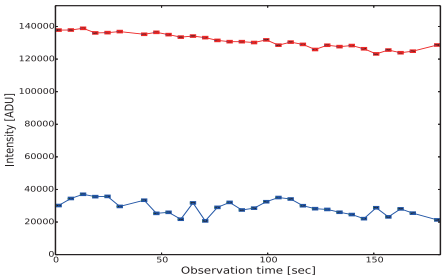


Light curve: Stable Example

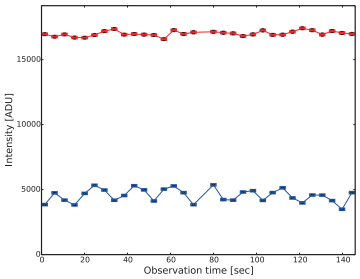
2013/06/11@ARO



2013/11/05@Nyukasa



2013/11/06@ARO

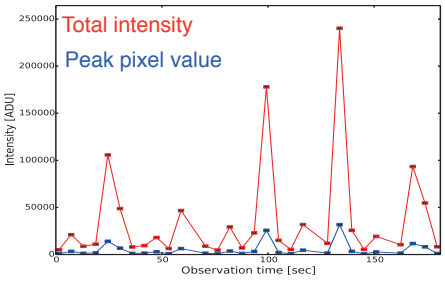


Correlated: JCSAT 5 [25067] - communication satellite

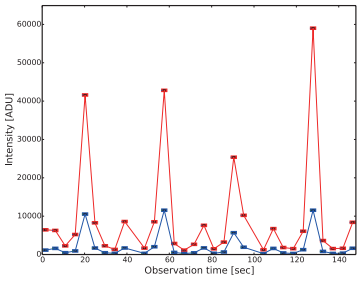
Date	Semi-major Axis[R	Eccentricity	Inclination [rad]	RAAN [rad]	Argument of Perigee[rad]	Mean Mag.
06/11	6.61	0.00046	0.0484	1.214	0.17	11.74
11/05	6.61	0.00053	0.0537	1.191	2.74	11.11
11/06	6.61	0.00053	0.0537	1.191	2.75	10.96

Light curve: Periodic Oscillation (Spike-like) Example

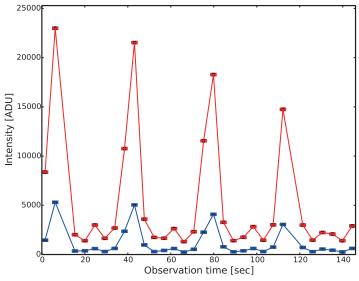
2013/01/07@Nyukasa



2013/06/07@ARO



2013/11/06@ARO



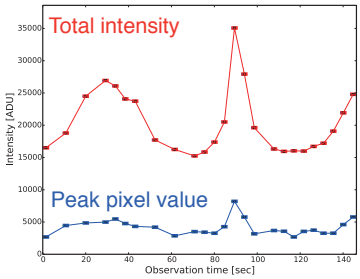
Period of about 40 seconds?
Constant period?

Correlated: SATCOM K2 [16276] - communication satellite, de-orbited in 2002

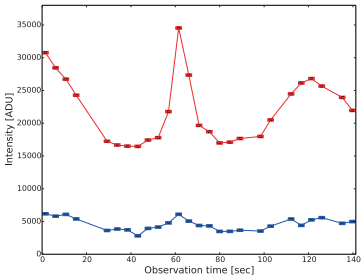
Date	Semi-major Axis[R	Eccentricity	Inclination [rad]	RAAN [rad]	Argument of Perigee[rad]	Mean Mag.
01/07	6.64	0.0008	0.224	0.678	2.00	11.77
06/07	6.64	0.0009	0.229	0.647	2.51	12.71
11/06	6.64	0.0012	0.232	0.615	2.62	12.76

Light curve: (Moderately) Long Periodic Oscillation Example

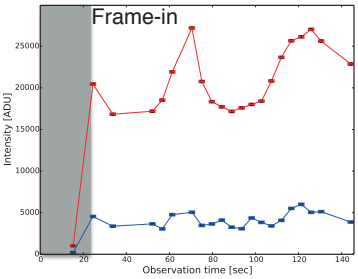
2013/11/01@ARO



2013/11/06@ARO



2013/11/06@ARO



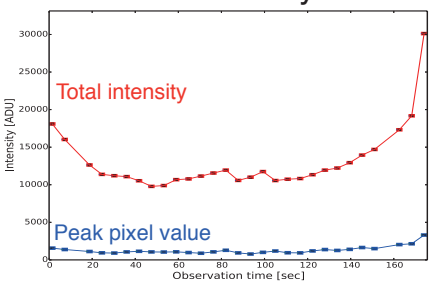
Period of about 120 seconds?
2 characteristic faces?

Correlated: EXPRESS 1 [23319] - communication satellite, launched in 1994

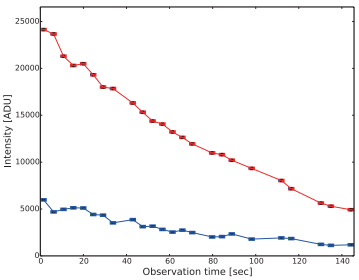
Date	Semi-major Axis[R	Eccentricity	Inclination [rad]	RAAN [rad]	Argument of Perigee[rad]	Mean Mag.
11/01	6.63	0.00074	0.1994	0.757	1.948	10.86
11/06	6.63	0.00073	0.1996	0.756	1.951	10.70
11/06	6.63	0.00073	0.1996	0.756	1.951	10.91

Light curve: (Likely) Long Periodic Oscillation Example

2013/04/11@Nyukasa

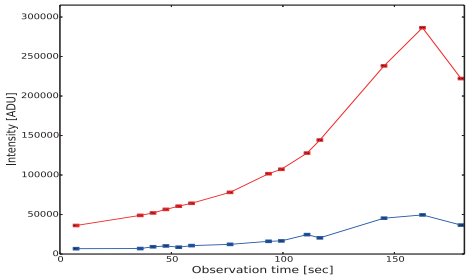


2013/11/01@ARO

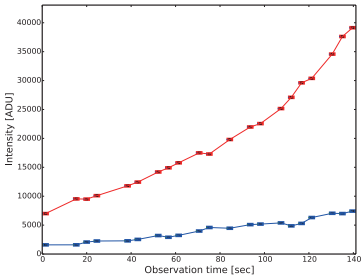


Period of about 200~300 seconds?
Longer observing time is required!

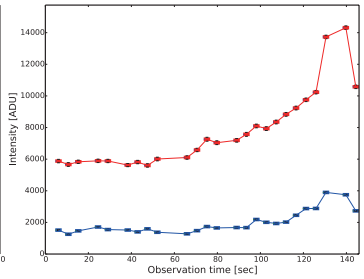
2013/11/05@Nyukasa



2013/11/06@ARO



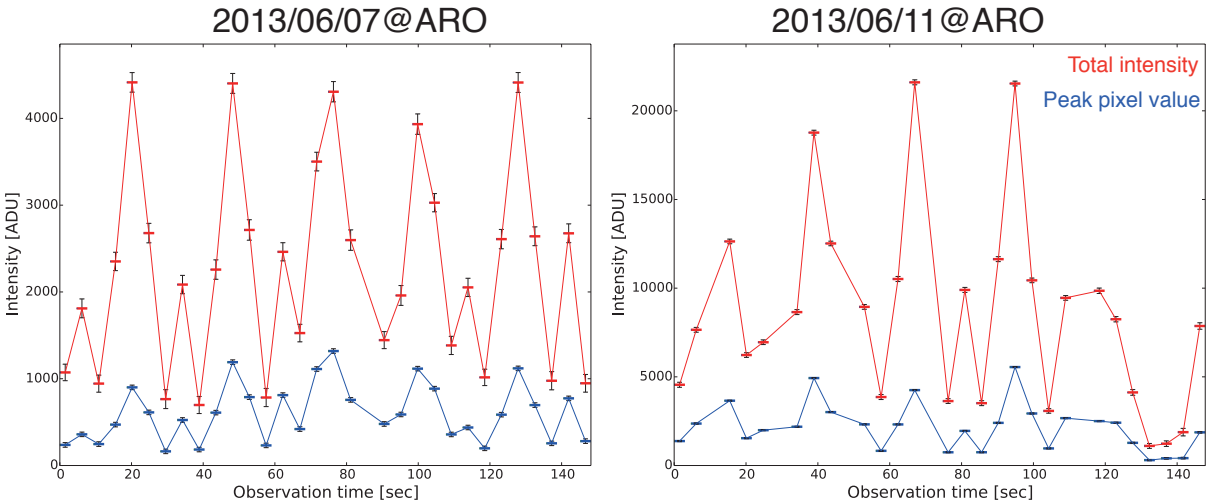
2013/11/06@ARO



Correlated: RADUGA 1-7 [28194] - communication satellite, launched in 2004

Date	Semi-major Axis[R	Eccentricity	Inclination [rad]	RAAN [rad]	Argument of Perigee[rad]	Mean Mag.
04/11	6.606	0.0002635	0.1230	1.1023	0.1784	13.12
11/01	6.610	0.0004036	0.1301	1.0568	1.3865	11.71
11/05	6.610	0.0003984	0.1302	1.0561	1.4027	11.00
11/06	6.610	0.0003984	0.1302	1.0561	1.4027	11.32
11/06	6.610	0.0003984	0.1302	1.0561	1.4027	11.77

Light curve: Rapid Oscillation Example



Period of about less than 5~10 seconds?

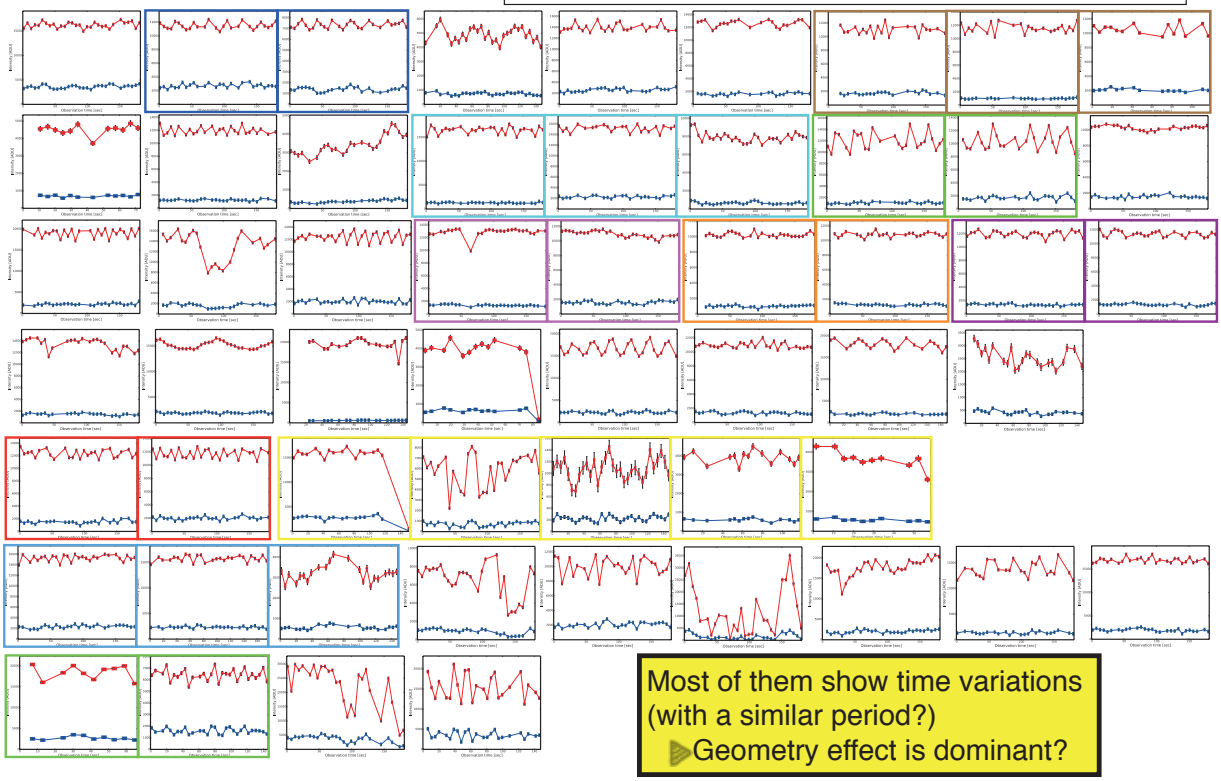
Shorter observation time interval is required!

Correlated: ARABSAT 3A [25638] - communication satellite, launched in 1999

Date	Semi-major Axis[R	Eccentricity	Inclination [rad]	RAAN [rad]	Argument of Perigee[rad]	Mean Mag.
06/07	6.615	0.000467	0.0707	1.1451	5.421	11.74
06/11	6.615	0.000478	0.0708	1.1446	5.406	12.11

Light curve: SL-12 R/B(2) series

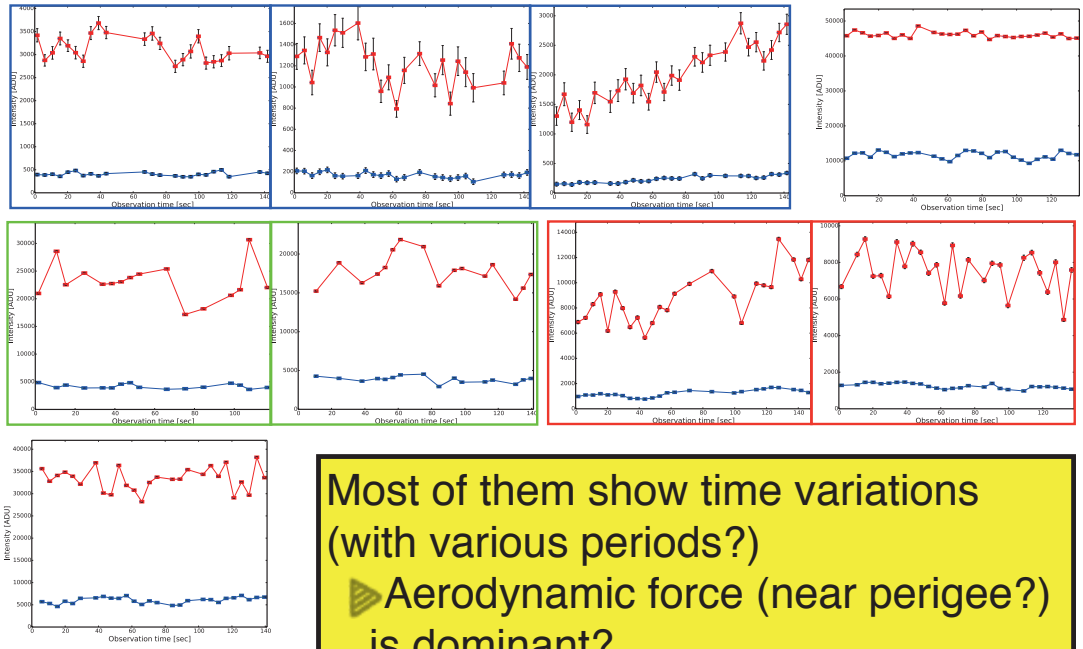
$a \sim 6.5\text{-}6.7\ [R_E],\ e \sim 0.0043\text{-}0.0045$



Most of them show time variations (with a similar period?)
▶Geometry effect is dominant?

Light curve: ARIANE 5 R/B series

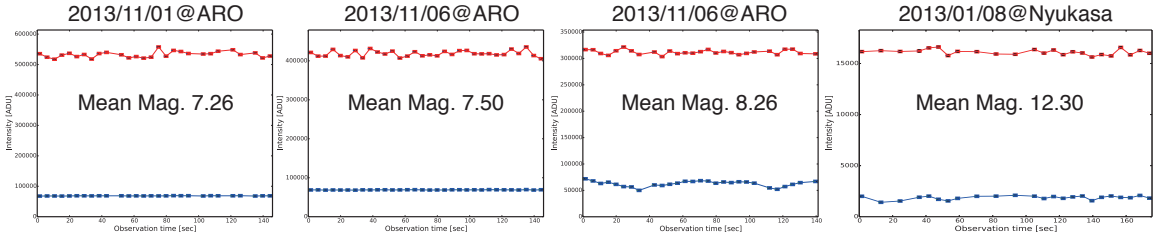
$a \sim 3.5\text{-}3.8\ [R_E],\ e \sim 0.71\text{-}0.72$



Most of them show time variations (with various periods?)
- Aerodynamic force (near perigee?) is dominant?

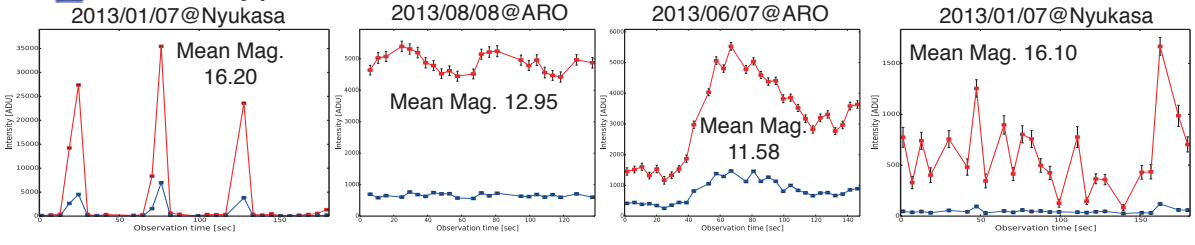
Light curve: Uncorrelated Objects

☑ Stable and bright



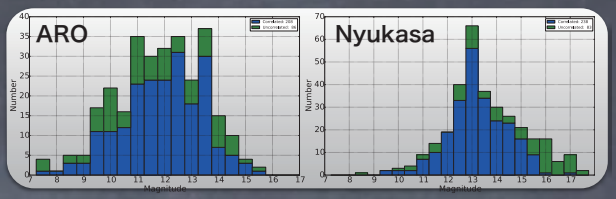
possibly operated, but just not listed in the catalog for some reasons?

☑ Various type of time variation

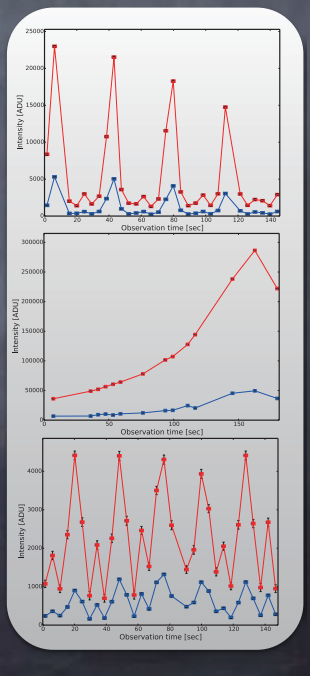


rotating debris?

Summary



- **GEO survey observation**
  - 18cm telescope + CCD @ ARO
  - 35cm telescope + CCD @ Nyukasa
  - 32 images in a region (optimised for detection efficiency)
- **Image-processing, detection algorithm**
  - Dark/Flat, BKG subtraction, diurnal motion (star trail) masking
  - Uniform linear motion detection
  - Photometry (for motion blurred objects)
- **Detection result**
  - ARO: 208 correlated + 86 uncorrelated in 5 night data
  - Nyukasa: 238 + 83 in 7 night data
- Database management (using SQLite)
- **Light curve**
  - A lot of detected objects show a time variation
    - Longer observing time is required for long periodic oscillation.
    - Shorter time interval is required for short periodic oscillation.
  - Optimised observation and detailed analysis is on going.



Future works

- We replaced 18cm telescope with 25cm telescope in June 2014
  - Sensitivity limit must be improved (by a magnitude of 1?)
- **Improve detection algorithm: Stacking method**
  - Stack images shifted along to the **“all possible predicted”** moving direction.
    - Detection limit is expected to be improved by a magnitude of 2 empirically.
  - However, huge computational resources are required…
  - We plan to accelerate it by making use of GPU(e.g., NVIDIA Tesla K20).