F2

軌道上光学デブリ観測ミッションの検討

Feasibility study for Space-Based optical observation mission of space Debris

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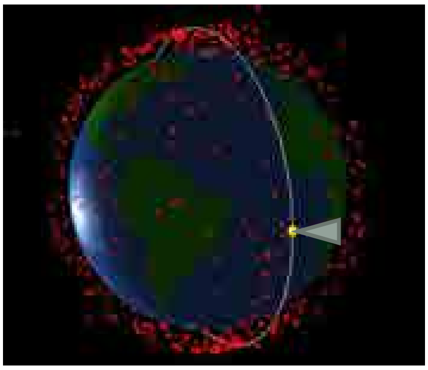
軌道上光学センサによる静止軌道デブリ観測は、既に実現され多くの成果をあげている。但し、デブリの密集している高度 800km 周辺の低軌道に関しては、観測の検討が報告されているものの実現に至ってはいない。
軌道上光学観測は、デブリに対して 0° に近い位相角(デブリへのセンサー視線方向と、太陽入射方向との角度)が取れる、大気の影響（例えば気象状況（雲と降水）、エアロゾルやローカルな光害）がない、長時間・広範囲のデブリ観測が可能である等、地上観測にはない利点がある。重要なのはこれらの利点を最大限に生かしたシステムをどのように構築するかである。
今回、軌道上観測の効率に影響を及ぼす要因としての衛星軌道、CCD のピクセル数、視野角、視野方向、バックグランドノイズ、センサシステムなどを検討した。
本報告では、新機軸を目指したこれらのミッション検討結果について報告する。

FEASIBILITY STUDY FOR SPACE-BASED OPTICAL OBSERVATION MISSION OF SPACE DEBRIS



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Outline

- **Objectives**
- Merit-demerit of space-based observation
- Observation method
- Debris Characteristics
  - radiation properties, Aungular velocity
- Environmental factors
  - Stray light, background light
- Study of sensor
- Data processing
  - Debris detection
  - Orbit determination
  - Catalog efficiency analyses
- Conclusion

Objectives

- Decide the orbit of the objects which seems to collide with the satellite exactly.
- When a crush accident happened, we survey an overall expanse.
- We create the catalogue of the objects (more than 1cm) in orbit of 600-800km that a lot of Japanese satellites are operated.
- The goal detects the 5% (TDB) of the whole in 1 year.

⇩

Build structure of the cooperation with the ground observation.

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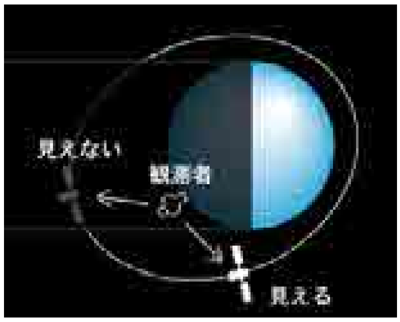
Merit of space-based observation(1/2)



- 24h/7h availability: No limitation e.g. by
  - Wheather (clouds, rain, aerosols, absorption)
  - Day/night cycle
  - Moon light, Light pollution
- Not a geographical limit
  - Location is an issue for the ground observation
- Flexibility of the operation
  - Most suitable observation strategy exists for various debris orbit.
  - Tracking of the time that is longer than ground observation is possible, and a cover range is wide.
- Fast detection of debris and high re detection to enable "Quasi-tracking"
  - To create a catalogue of unknown space debris.
  - To quick response to crushing accident, collision avoidance, etc..
  - Faster than ground-based observations high potential can detect.

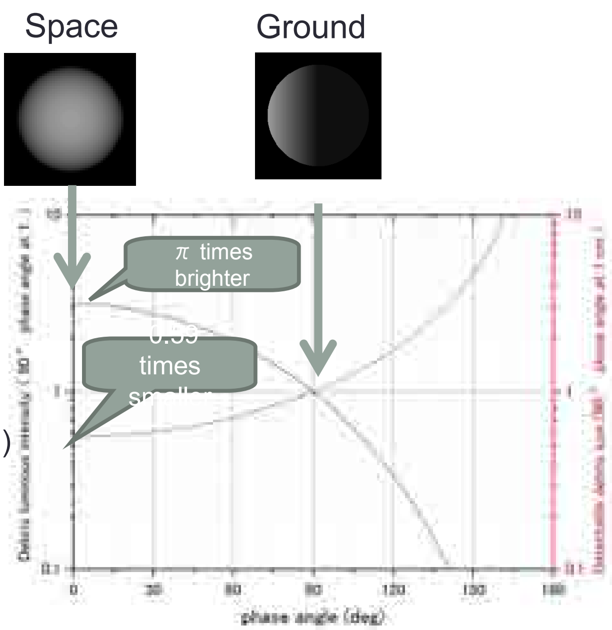
Merit-demerit of space-based observation(1/2)

Efficient debris detection and measurement accuracy

・Background noise reduction (no atmosphere)
→ increased sensitivity, detection of smaller objects possible

・Diffraction-limited optics (atmosphere degrade resolution)→ improvement of sensitivity and spatial resolution

・Debris brightness (brighter than on Earth if often)
-> Smaller pahse angle and short distance to the debris



The phase angle of 0°, can be observed π times brighter than the phase angle of 90°.
0.59 times as small debris can be seen.

Demerit　of space-based observation

- Limits of the satellite mission life
- High costs (general recognition)
- Technical challenges, for example:
  - In a short period of time to determine the orbital debris.
  - Exact observation（time, satellite's altitude, pointing accuracy and stability）are required.
  - Need for a limited time, for near real-time downlink

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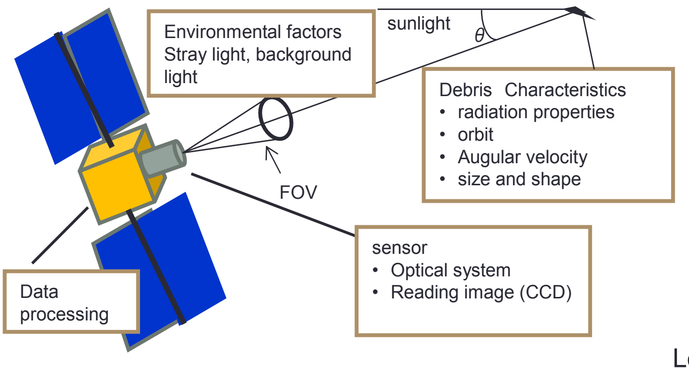
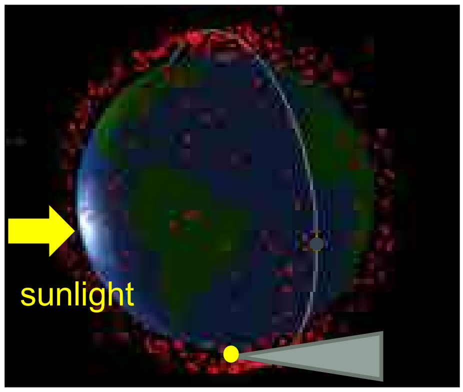
Observation method

The phase angle can be optimized, if the objects appear in the field of view of the sensor like full moons (phase angle = 0°), e.g. using sun-synchronous orbits in the vicinity of the day-night terminator and the line of sight directed anti-solar. Moreover, a satellite's orbit is 600 km altitude. (800 to 1000 km with high debris density is avoided.)





Low orbit debris observation satellite (draft) (STK)

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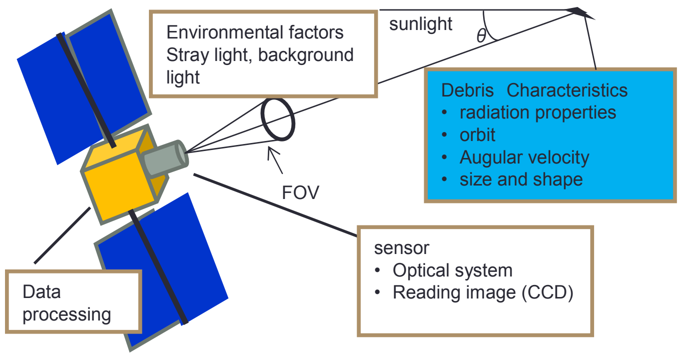

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Debris Characteristics

- Debris apparent luminosity
- Condition: 1 AU solar luminosity is -26.74 magnitude
  phase angle: 0 °
  Albedo: 0.1
  Debris size: Lambertian balls 1 cm in diameter
- Luminous intensity in 1000 km away from debris will 17.7 mag. level.
- Distance to the debris
- Angular velocity
  - Widely distributed to 0.02 degrees / second to 3 degrees / sec.
  - The median is 0.4 degrees / sec
  - If you are trying to shoot the image so as not to catch debris tail longer than 1 ", a fast-moving object angular velocity of 0.4 degrees / s, we must be shorter exposure time 0.7msec.

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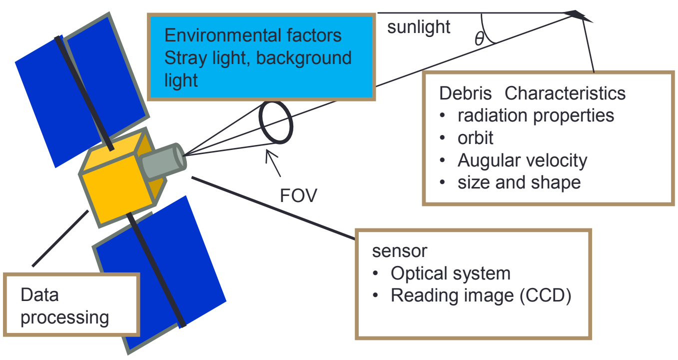
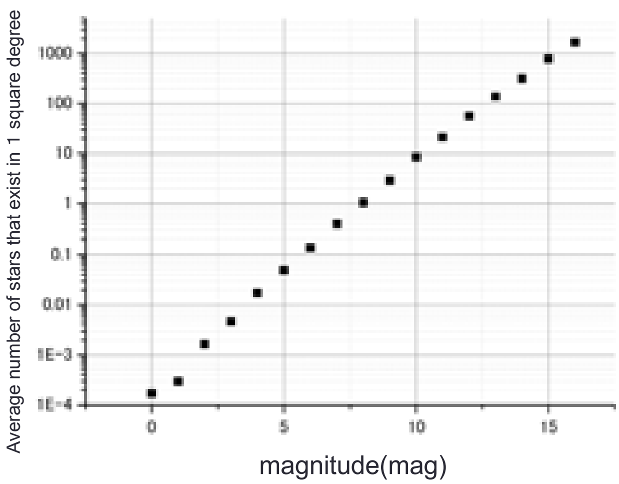


Background Noise

Scattered radiation from discrete sources (atmospheric reflections, zodiacal light, milky way, bright stars) and any stray light are background noise.

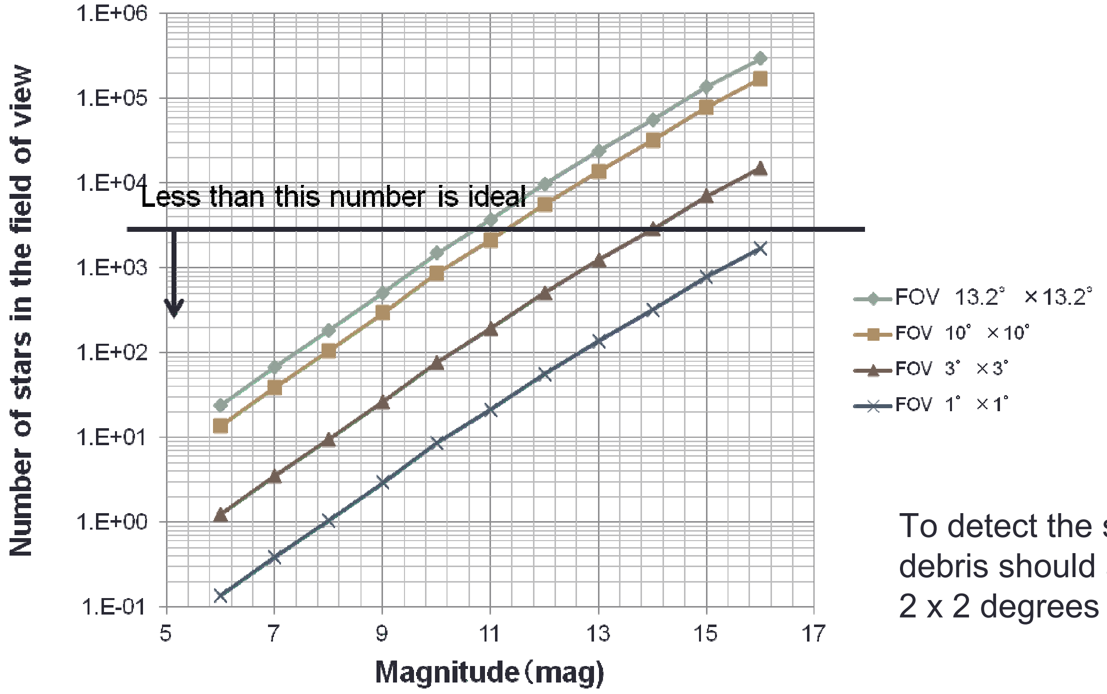
Number of stars within the field of view

- Estimate the number of stars into 1 square degree field of view.
- Values below the containing region of the milky way stars are concentrated.
- And according to chronological scientific tables, leaving about 20 degrees from the milky way, star will be approximately 1/2.



magnitude	Average number of stars in 1 square degree
9	2.9
10	8.5
11	21.2
12	56.0
13	136.6
14	317.1
15	780.5
16	1683

Number of stars within the field of view and viewing angles



To detect the small debris should about 2 x 2 degrees FOV.

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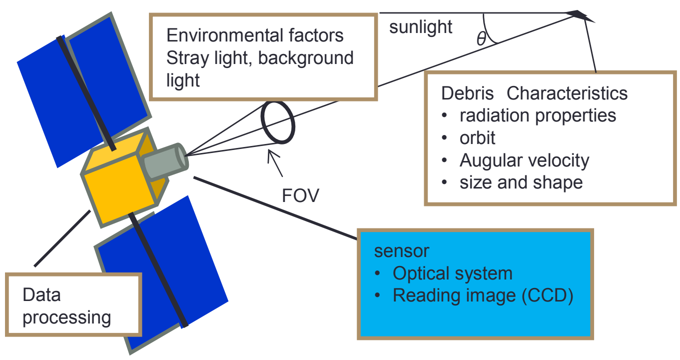

Optical sennsor review

-Debris detection ability is determined by what? -

	Item	Relationship between detection of debris diameter and each item				
		proportion	Proportion to the 1/2 power	Inverse proportion	Inverse proportion to the power of 1/2	a remarks column
Smaller is better	Range	○				
Smaller is better	Debris verosity		○			
Smaller is better	SN		○			
Smaller is better	Focal length		○			（Fn small things 1.2 is ideal）
Bigger is better	Aperture			○		
Bigger is better	debris object albedo				○	
Bigger is better	Exposure times of 1 pixel				○	
Bigger is better	Optical properties				○	
Bigger is better	Pixel size				○	（However, spatial resolution is worse）

Diameter of the light receiving optical system, as large as possible.
Proportional to 1/2 of the focal length of the light receiving optical system, the diameter of the debris which can be observed, increases in inverse proportion to the power of 1/2 of the pixel size of the detector. This is a derived from the integral time. Therefore, the focal length of the receiving optical system is as small as possible, the pixel size of the detector is as large as possible.
Optical system aperture size to as large as possible , and f-number （F = focal length / aperture）to as small as possible.

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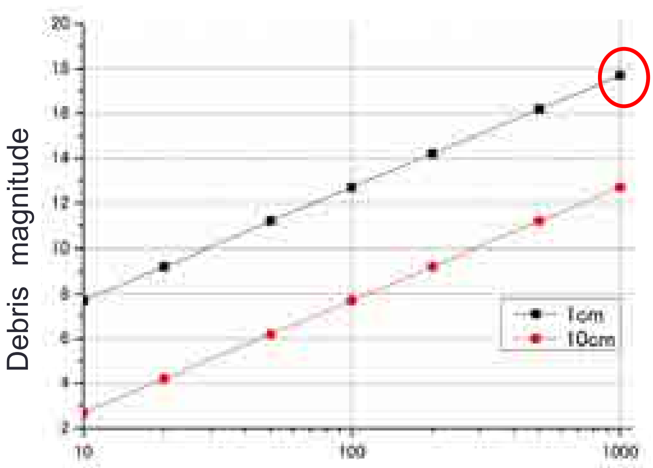
Relation to magnitude of debris by size and distance

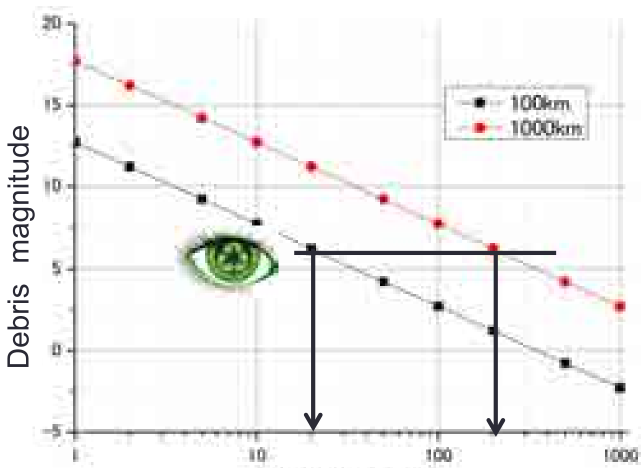
-Lambertian ball, albedo=0.1 and phase angle=0° -



Distance from debris(km)

Relationship between magnitude and distance from the debris

Black:1cm、Red:10cm



Debris diameter(cm)

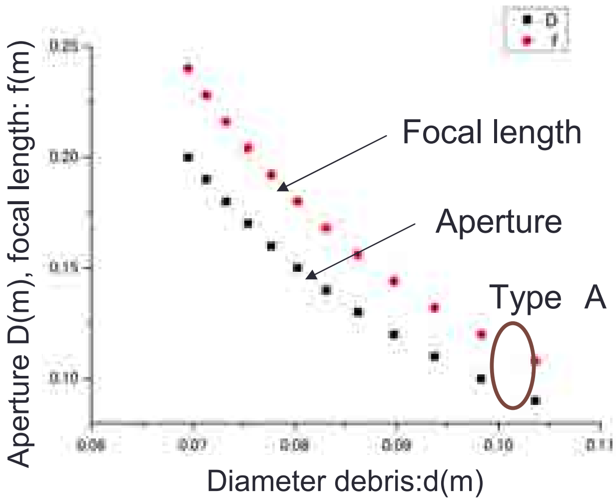
Relationship between debris diameter and magnitude

Black：100km、Red:1000km

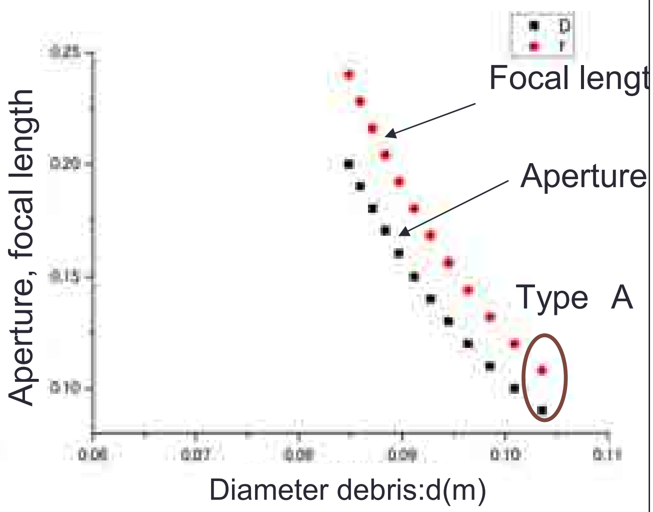
※ Nak is 0.85

Relationship between debris size and focal length detection, diameter

- F number is fixed to 1.2： Type A Camera(Next page)-



Unchanging image degradation rate



Consider the focal image degradation rate

Camera specification (draft)

Lambertian ball , Range 1000km, albeo 0.1
phase angle=0 ° , Debris velocity 0.4° /sec,
4×4Binning

Item	Lens		Reflector	
	Type A	Type B	Type C	Type D
Detector	24μm×24μm 2048×2048 CCD	←	←	←
Focal length (f) (mm)	106.5	100	183.4	600
F number (Fn)	1.2	1.4	1.2	3
Full-width（FOV)	13.3° ×13.3°	14.2° ×14.2°	7.7° ×7.7°	2.3×2.3°
Effective aperture (D)(mm)	88.7	71.4	152.0	200
Wavelength range（⊿λ）	0.2μm（450~650nm, standard wavelength :550nm）	←	0.3μm（400~700nm,standard wavelength:550nm）	←
Optical properties	0.215	0.222	0.3	0.188
S/N（dB）	5（goal 2）	←	←	←
read noise	10e- （goal 5e-）	←	←	←
Detect size (cm) ( ) in stacking method	10.4（6.6)	12.3(7.8)	5.5(3.4)	9.6(6.08)
Priority	2	4	1	3

Comparison of image sensor

	CCD	EMCCD	CMOS	I. I.＋CCD（CMOSD)
Number of pixels	△	◎	◎	same CCD or CMOS
Structure（Simplicity）	△	◎	◎	as above
Power consumption	×	◎	◎	as above
Image quality	◎	△	△	as above
Quantum efficiency	◎	△	△	as above
Electronic shutter	◎	△	△	as above
Blooming	×	◎	◎	as above
Linearity	◎	×	◎	×
Life	―	―	―	Vulnerable to bright light
Reading speed（rt）	＞0.1sec	＞0.1sec	0.03～0.01sec	10ns～ms
Low-noise（ high SN)	◎	◎	◎	Photon counting
Evaluation results	◎（rt＞0.1sec）	×	◎（rt<0.1）	◎（Protection against bright ligh）

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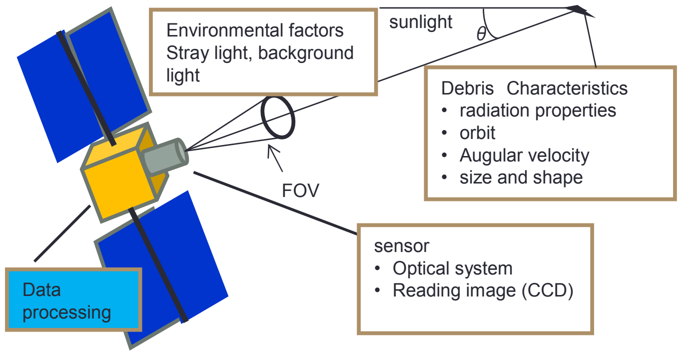


Data processing

- **Method for observation of space debris**

（1）observation, fixed in inertial space

（2）observation, tracking and space debris

- **Observation data processing in inertial space-fixed view**

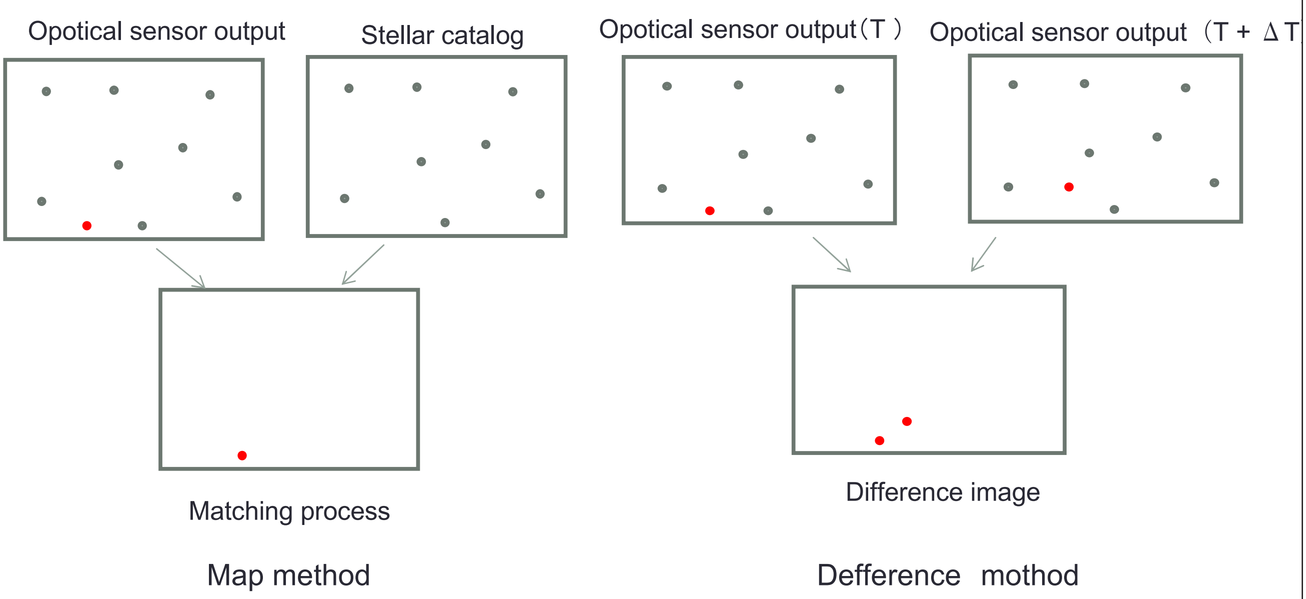
Need to catch the debris moves through the stars in a fixed field of view relative to.

Following two as possible and how.

（1）to detect debris, compared to stellar catalog(map method)

（2）Motion detection, frames before and after diff as debris (defference　mothod)

Data processing



Trade-offs of mapping method and difference method

Not work well either way darker than the marginal magnitude of optical sensor debris detection.

So many stellar, map method is unavailable in this case.

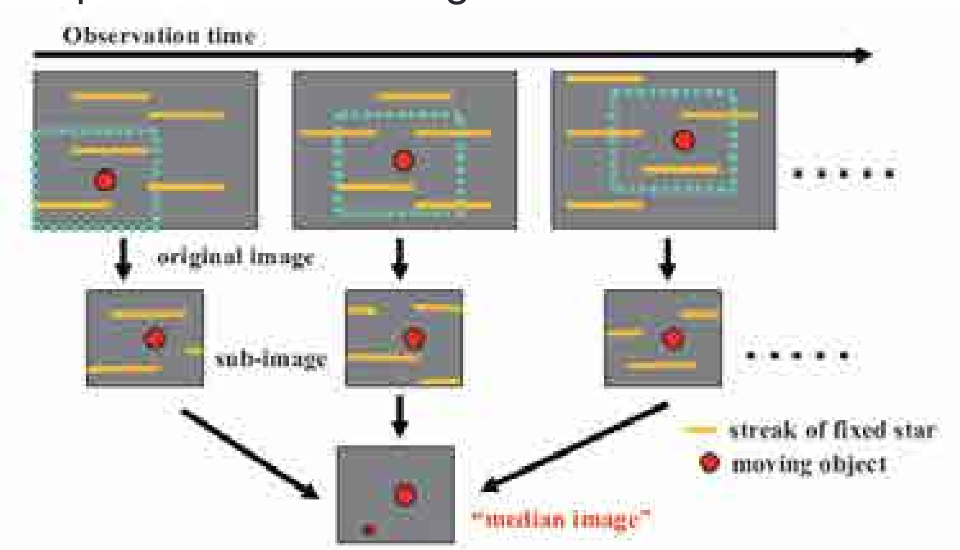
Adopt a finite-difference method.

In addition, do not acquire only debris, and the degree that can decide a field of view direction is necessary for the fixed stellar data.

If is type A; I think and should be set threshold 4 magnitude level (TBD) from the number of stars in the field of view.

Stacking method

- The stacking method, using multiple CCD images to detect very faint objects that are undetectable on a single CCD image. Can to recognize dark object about 6 times with 30 pieces of CCD image.



Data processing

Onboard processing

- Pre-treatment: background noise processing, image enhancement & shaping, Centroid processing
- Improved detection sensitivity: Stacking method

Ground processing

- Catalog object identification and labeling
- Selection analysis of debris
- Orbit determination

Orbit determination

- Determine the debris orbit in the conditions that can be observed several times the same debris within three days.
- After orbit determination, update the orbit data once a few days on the ground system　(cataloged).

- Subject of future investigation
  - Ability of ground-based observations after the orbit decision. If the orbit is identified, tracking how much large debris until systems is possible?
  - Required number of ground-based observations.

Catalog efficiency analyses

Simulation conditions

Satellite: sun-synchronous orbits in the vicinity of in the day-night trminator and the line of sight directed anti-solar. 600 km altitude.

Objects: 600 to 800 km altitude, eccentricity 0.002 choosing 967 objects

Period: 01/15/2013 ~ 01/25/2013

Optical sensor : 15.8 ° × 15.8 ° FOV

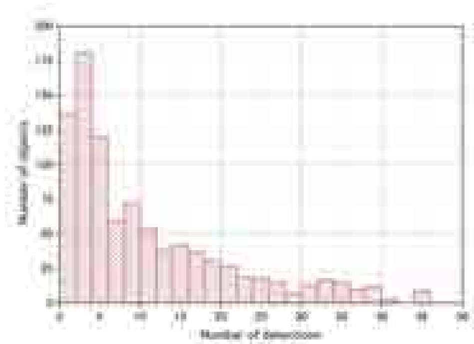
Exposure time 1sec

To count up newly detected objects in the CCD.

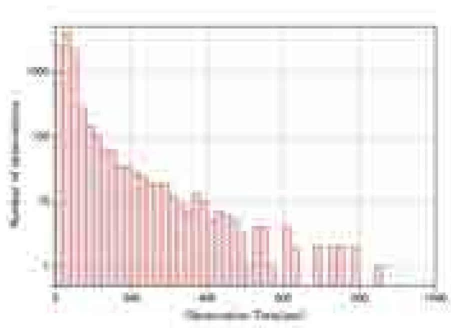
Result(1/2)

Detection objects in the number of in different times

Detection time	Number of objects	Percentage
1day	585	60.5%
2days	792	81.9%
3days	855	88.4%
4days	883	91.3%
10days	937	96.9%

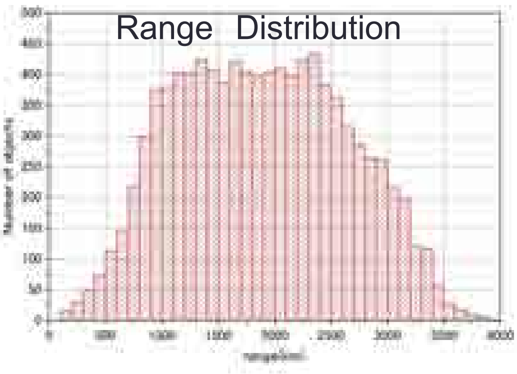


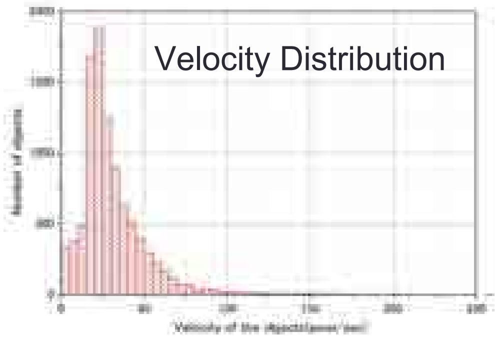
Number of detections of three days from 2013/01/15. 315 (32.6%)individual objects can be observed continuously for 3 days.

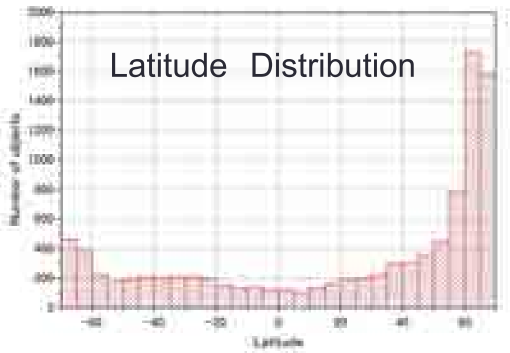


Observation time of object(3 days)

Result(2/2)







Conclusion

- Presented a feasibility study on space based optical observation mission.
- Space observations have many advantages.
- In the future, we consider error factor (satellite altitude, a sensor field of vision direction, the satellite time) for orbit determination and realization of satellite.