F8

低軌道デブリ地上光学観測システムの検討

Investigation of ground-based optical observation system for LEO objects

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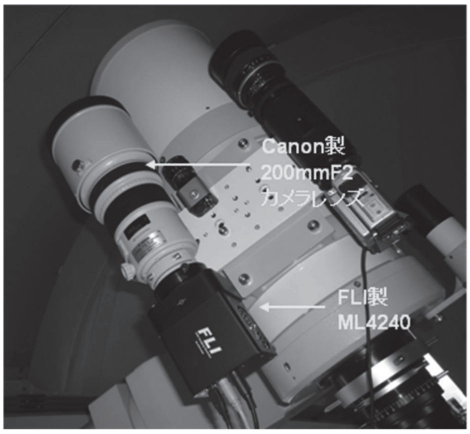
低軌道は多くの地球観測衛星等が投入される重要な軌道である。近年、デブリや衛星同士の衝突、破砕事故などで低軌道の環境は悪化の一途をたどっている。人類の宇宙活動を継続するために、このような状況に早急に対処する必要がある。現在、低軌道デブリはレーダーによって主に観測されている。一方、光学観測装置による低軌道デブリの観測可能性が議論され始めている。光学観測装置による低軌道デブリの観測は日照や天候による影響をうけるという弱点をもつが費用が抑えられるという利点がある。市販の安価なCCDカメラやPCを多数利用した光学観測システムを世界中に展開することにより、現在のレーダー観測網を上回る能力を引き出すことができるかもしれない。

今回は低軌道デブリを対象とした40台の光学観測装置を持つ2つの観測サイトでの精密軌道決定の有効性の検討を行った。STK を用いたシュミレーションにより、多くの観測データの中から、経度の離れた2局、4台の観測装置の観測データにおける同一物体の対応付けが可能であることがわかった。このことはこのような観測システムを用いることにより、多数の未カタログデブリの精密な軌道決定ができるということを示している。

The low earth orbit is very important as many earth observation satellites are entered. Recently, this orbit is deteriorated by numerous pieces of space debris which is caused by collisions of satellite, breakups and so on. In order to maintain human activities in space, we have to cope with the space debris problem as soon as possible. Currently radar equipments are primary methods to observe LEO debris. Optical observation has an advantage of low cost, although it is effected by lighting condition of the sun and weather. The optical observation system consisted of large number of cost-effective CCDs and high-speed PCs at various sites in the world may overcome the current radar observation network.

We have examined the possibilities of precise orbit determination using two observation sites containing 40 sets of optical equipments. Simulations using STK have shown that identical objects were recognized from the data of 4 individual equipments installed on 2 separate sites using the lots of circular orbital elements calculated from many observation data. This enables us to determine orbits of many un-cataloged LEO objects precisely.



低軌道デブリ光学観測装置
Optical observation equipment for LEO debris

5th Space Debris Workshop

Investigation of ground-based optical observation system for LEO objects

Japan Aerospace Exploration Agency(JAXA)
Aerospace Research and Development Directorate
Innovative Technology Research Center

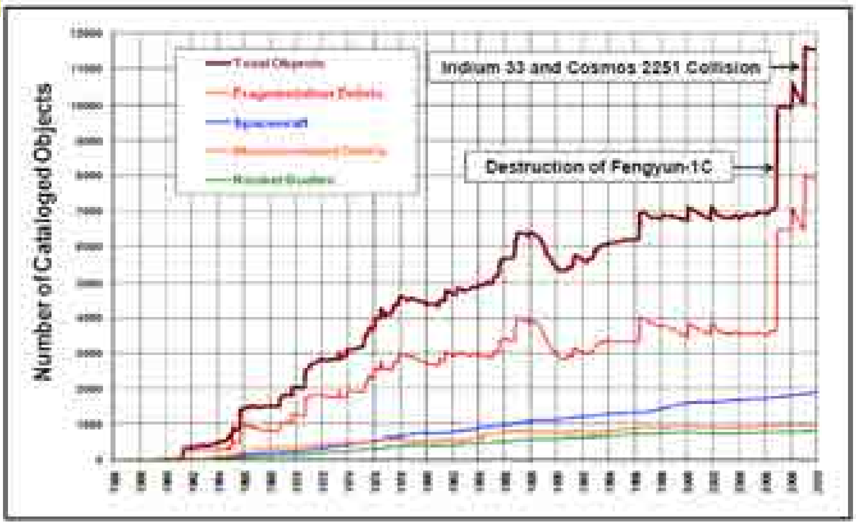
T.Yanagisawa and H.Kurosaki

Abstract

The low earth orbit is very important as many earth observation satellites are entered. Recently, this orbit is deteriorated by numerous pieces of space debris which is caused by collisions of satellite, breakups and so on. In order to maintain human activities in space, we have to cope with the space debris problem as soon as possible. Currently radar equipments are primary methods to observe LEO debris. Optical observation has an advantage of low cost, although it is effected by lighting condition of the sun and weather. The optical observation system consisted of large number of cost-effective CCDs and high-speed PCs at various sites in the world may overcome the current radar observation network.

We have examined the possibilities of precise orbit determination using two observation sites containing 40 sets of optical equipments. Simulations using STK have shown that identical objects were recognized from the data of 4 individual equipments installed on 2 separate sites using the lots of circular orbital elements calculated from many observation data. This enables us to determine orbits of many un-cataloged LEO objects precisely.

Background



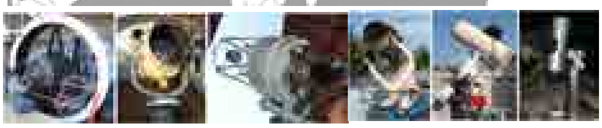
LEO environment (around 800-1000km altitude where lots of Japanese satellites reside) is being deteriorated rapidly by the ASAT, the collision caused by Iridium 33 and Cosmos 2251, and so on.

Error of conjunction assessments become large because of inaccuracy of TLE. Japanese satellites in LEO fully rely on the alert information of JSpOC of U.S. However we don't know how accurate it is.

Japan needs to have own methods to evaluate the environment of LEO.

Background

Phased array of Kamisaibara Spaceguard Center



Russian ISON network using a lot of optical telescopes

Observation methods of LEO debris

①Radar observation

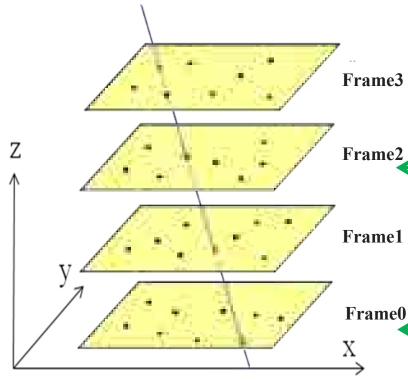
24-hour observation. SSN of U.S. Japan also has a radar observation facility owned by JSF(Japan Space Forum) in Kamisaibara. Its detection ability is 1m at 600km altitude which is not enough for small sized LEO debris. A disadvantage of radar observation system is a huge expenditure for its construction and maintenance.

②Optical observation

A few hours observation because of lighting condition of the Sun. Effected by weather conditions. ISON network of Russia. Basic research is being carried out by Innovative technology research center of JAXA. Very cost effective system.

Investigated the usefulness of the large array of optical sensors for LEO debris observation

Observation equipments and data analysis software



Concept of the line-identifying technique

Many frames

↓

Candidates are searched using a threshold and a shape parameter

↓

Candidates which create straight line are detected as moving object

Observation equipments:

・Canon EF200mmFL IS USM

・FLI 2K2K back-illuminated CCD camera ML4240

FOV : 7.65×7.65°

Exposure interval : 1.5 sec

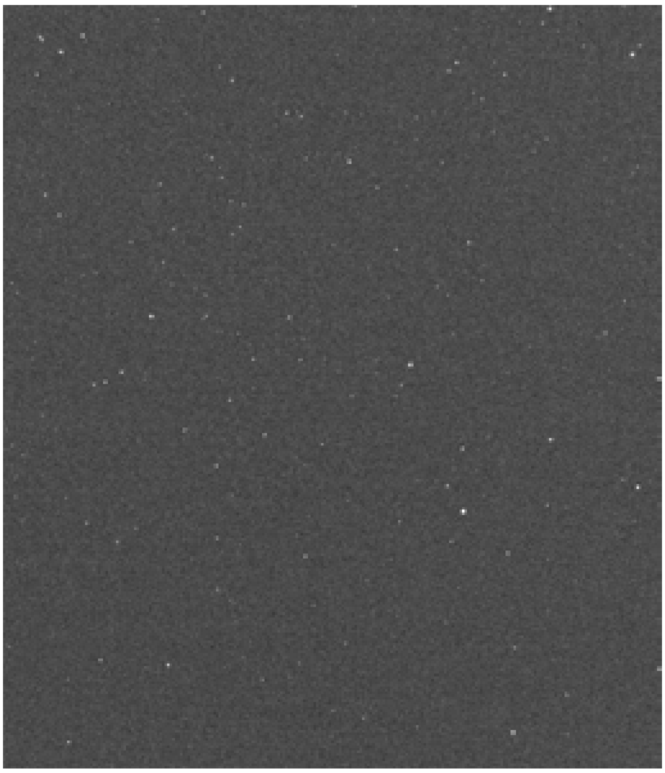
Data analysis software:

The line-identifying technique developed for GEO debris detection.

It can detect moving objects with constant velocity.

The equipments and the software enable us to detect LEO objects of 60cm at 1000km altitude.

Observation

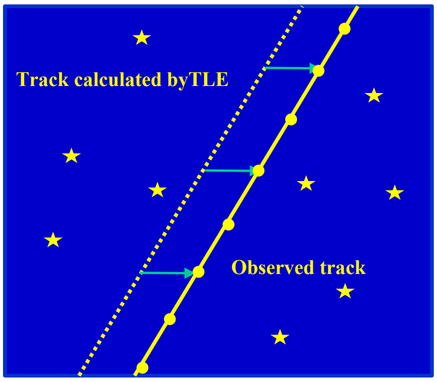


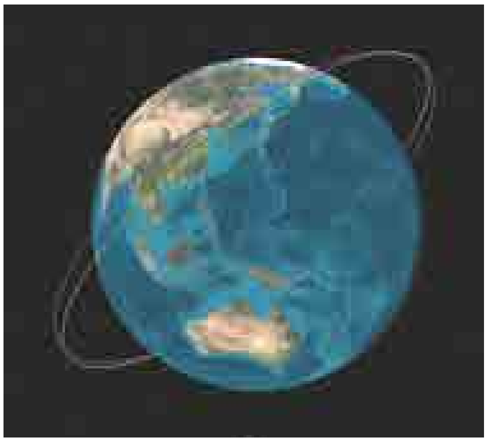
Sequential images of 17525 (MOMO-1)

Exposure time:　50msec

Interval:　1.5 sec

Possibility of orbit improvement

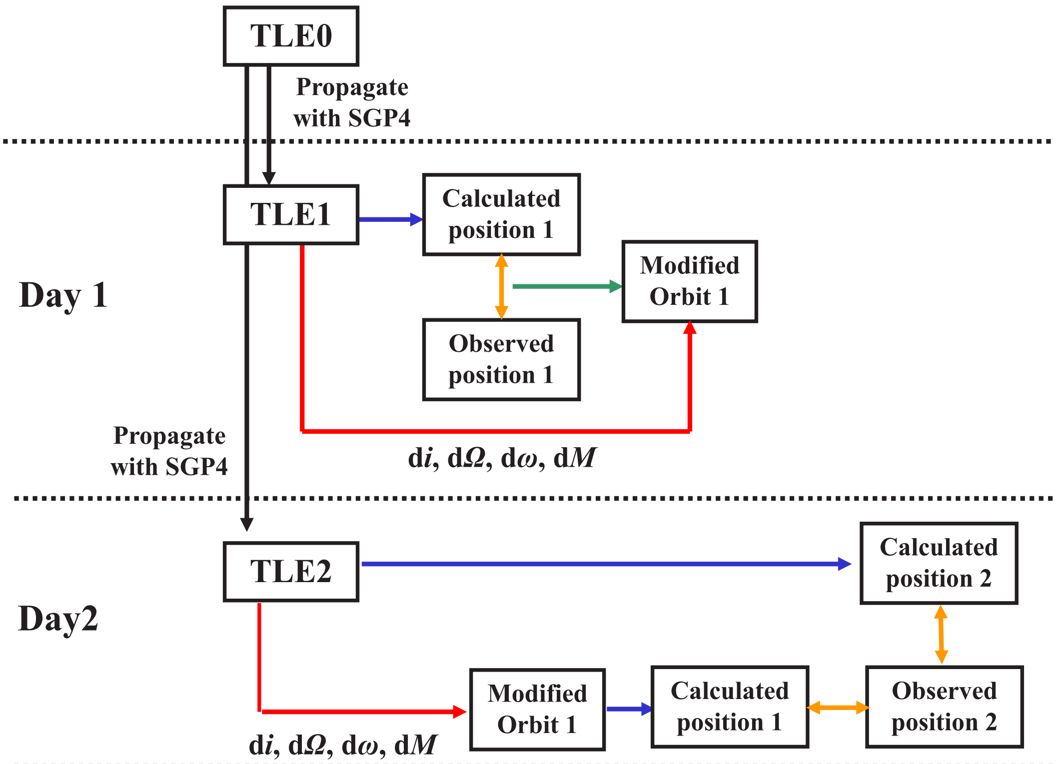




4 elements of TLE are improved to fit the observed track using the least square method.

Positions in the next day are calculated with improved orbit and evaluated the improvements by comparing calculated positions with observed ones.

Orbit improvement and its evaluation



Analysis result 1（O-C(TLE)）

date	time(UT)	Observed RA,Dec		Calculated RA,Dec		O-C in RA,Dec	
2011-09-07	17.86012	86.0493	39.0816	86.0322	39.1818	79.580	-360.892
2011-09-07	17.86056	85.5900	38.6503	85.5795	38.7440	89.275	-337.166
2011-09-07	17.86106	85.0919	38.1484	85.0692	38.2408	104.008	-332.604
2011-09-07	17.86150	84.6509	37.7052	84.6239	37.7932	123.072	-316.736
2011-09-07	17.86194	84.2094	37.2540	84.1820	37.3411	123.940	-313.691
2011-09-07	17.86237	83.7774	36.8000	83.7536	36.8951	107.273	-339.651
2011-09-07	17.86281	83.3423	36.3432	83.3186	36.4345	106.127	-328.854
2011-09-07	17.86325	82.9143	35.8833	82.8871	35.9697	121.109	-311.191
2011-09-07	17.86369	82.4903	35.4121	82.4590	35.5000	138.224	-319.364
2011-09-07	17.86413	82.0631	34.9382	82.0345	35.0278	125.788	-322.724
2011-09-07	17.86457	81.6465	34.4673	81.6134	34.5509	144.646	-301.074
2011-09-07	17.86506	81.1718	33.9217	81.1488	34.0153	100.880	-336.825
2011-09-07	17.86551	80.7501	33.4331	80.7254	33.5193	141.000	-310.236
2011-09-07	17.86598	80.3186	32.9075	80.2874	32.9971	133.978	-322.726
2011-09-07	17.86642	79.9170	32.4170	79.8809	32.5047	154.201	-312.769
2011-09-07	17.86686	79.5160	31.9230	79.4778	32.0088	162.316	-308.803
2011-09-07	17.88650	64.7388	8.2280	64.6998	8.3057	142.617	-279.827
2011-09-07	17.88694	64.4740	7.7076	64.4322	7.7836	151.812	-273.688
2011-09-07	17.88741	64.1865	7.1529	64.1493	7.2283	135.172	-271.273
2011-09-07	17.88785	63.9251	6.6314	63.8858	6.7106	138.859	-285.135
2011-09-07	17.88829	63.6647	6.1138	63.6267	6.1952	137.688	-293.163
2011-09-07	17.88873	63.4078	5.6065	63.3689	5.6822	140.025	-272.598
2011-09-07	17.88917	63.1536	5.0954	63.1134	5.1716	145.442	-274.469
2011-09-07	17.88961	62.9013	4.5926	62.8601	4.6636	148.741	-255.472
2011-09-07	17.89005	62.6508	4.0883	62.6091	4.1581	150.457	-251.199
2011-09-07	17.89049	62.4033	3.5802	62.3603	3.6552	155.009	-269.983
2011-09-07	17.89092	62.1563	3.0843	62.1193	3.1664	133.350	-295.444
2011-09-07	17.89136	61.9124	2.5899	61.8748	2.6689	135.368	-284.404
2011-09-07	17.89185	61.6437	2.0416	61.6051	2.1182	139.048	-275.836
2011-09-07	17.89229	61.4064	1.5550	61.3651	1.6288	148.680	-258.876

stddev in RA = 133.458
stddev in Dec = 301.052

1.645km on orbit
0.727km on orbit

JAXA

Analysis result 2（O-C(improved)）

date	time(UT)	Observed RA,Dec		Calculated RA,Dec		O-C in RA,Dec	
2011-09-07	17.86012	86.0493	39.0816	86.0545	39.0900	-29.508	-58.065
2011-09-07	17.86056	85.5900	38.6503	85.6023	38.6597	-15.857	-33.996
2011-09-07	17.86106	85.0919	38.1484	85.0926	38.1562	-3.138	-28.175
2011-09-07	17.86150	84.6509	37.7052	84.6478	37.7083	14.383	-11.238
2011-09-07	17.86194	84.2094	37.2540	84.2064	37.2560	13.626	-7.158
2011-09-07	17.86237	83.7774	36.8000	83.7784	36.8097	-4.478	-32.144
2011-09-07	17.86281	83.3423	36.3432	83.3439	36.3489	-7.056	-20.307
2011-09-07	17.86325	82.9143	35.8833	82.9128	35.8938	6.530	-1.808
2011-09-07	17.86369	82.4903	35.4121	82.4858	35.4146	22.381	-9.094
2011-09-07	17.86413	82.0631	34.9382	82.0611	34.9414	8.604	-11.618
2011-09-07	17.86457	81.6465	34.4673	81.6405	34.4643	26.215	10.888
2011-09-07	17.86506	81.1718	33.9217	81.1761	33.9284	-10.764	-24.172
2011-09-07	17.86551	80.7501	33.4331	80.7534	33.4322	20.115	3.244
2011-09-07	17.86598	80.3186	32.9075	80.3158	32.9099	11.944	-8.536
2011-09-07	17.86642	79.9170	32.4170	79.9097	32.4172	31.199	2.040
2011-09-07	17.86686	79.5160	31.9230	79.5070	31.9212	38.238	6.580
2011-09-07	17.88650	64.7388	8.2280	64.7393	8.2244	-1.887	13.192
2011-09-07	17.88694	64.4740	7.7076	64.4720	7.7026	7.160	17.846
2011-09-07	17.88741	64.1865	7.1529	64.1882	7.1477	-9.718	18.711
2011-09-07	17.88785	63.9251	6.6314	63.9268	6.6305	-6.253	3.378
2011-09-07	17.88829	63.6647	6.1138	63.6668	6.1155	-7.640	-5.155
2011-09-07	17.88873	63.4078	5.6065	63.4091	5.6029	-4.729	12.887
2011-09-07	17.88917	63.1536	5.0954	63.1537	5.0920	-0.332	3.478
2011-09-07	17.88961	62.9013	4.5926	62.9005	4.5951	2.749	28.905
2011-09-07	17.89005	62.6508	4.0883	62.6496	4.0801	4.246	29.656
2011-09-07	17.89049	62.4033	3.5802	62.4009	3.5776	8.580	3.212
2011-09-07	17.89092	62.1563	3.0843	62.1600	3.0993	-13.290	-17.828
2011-09-07	17.89136	61.9124	2.5899	61.9156	2.5922	-11.480	-8.421
2011-09-07	17.89185	61.6437	2.0416	61.6459	2.0421	-8.057	-1.687
2011-09-07	17.89229	61.4064	1.5550	61.4060	1.5511	1.311	14.113

stddev in RA = 14.317
stddev in Dec = 19.596

0.082km on orbit
0.107km on orbit

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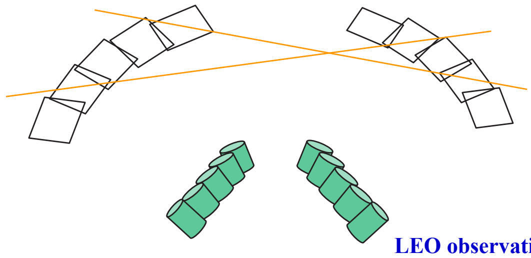
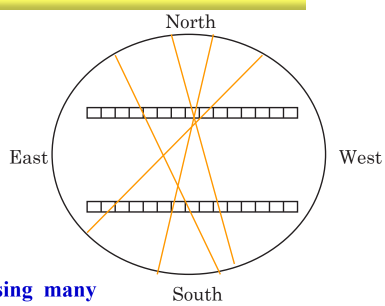
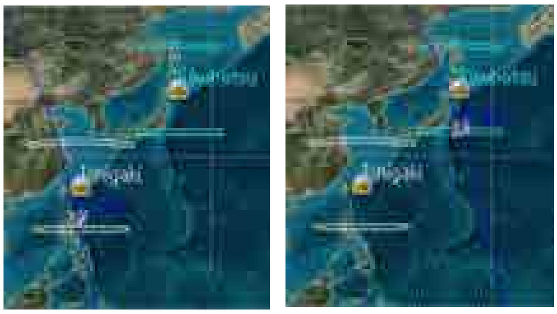
Large array of optical sensors for LEO debris observation





LEO observation system using many optical sensors

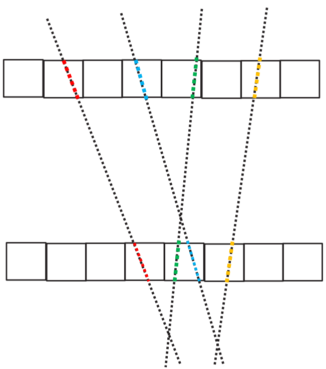


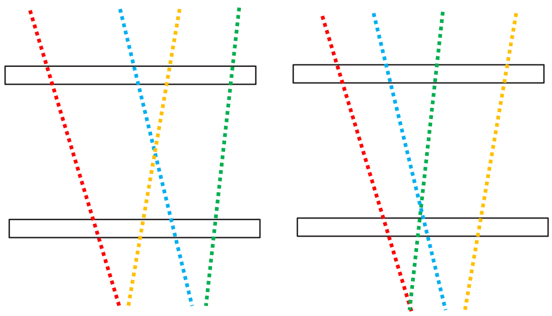
Detections of identical object at 2 sites

●Many optical observation units are installed to cover large area since each unit has narrow FOV. In order to get long arc for accurate orbit determination, 2 narrow rectangular regions which separate about 80-degree are observed using 40 observation units.

●Observation of 2 consecutive passes enable us to do accurate orbit determination. For this reason, 2 longitudinally separated sites are considered.

Observational simulation





Accurate orbit determination

Identification of same objects in 2 sets at each site

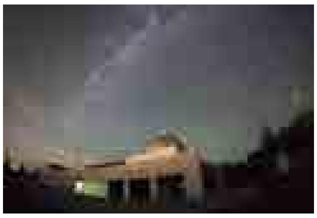
Identification of same objects at 2 sites

One object is observed 2 times at each site (4 times in total). Identifications of same objects from many observed positions are needed.

Observational simulation

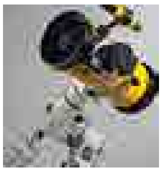
Observation sites:

Ishigakijima Observatory (Okinawa)



Rikubetsu Observatory (Hokkaido)

Observation equipments:

[ + ] ×40

20 units are pointed to Az 0-degree and El 50-degree, other 20 units Az 180-degree and El 50-degree. Each set is located to observe east-west-elongated rectangular region.

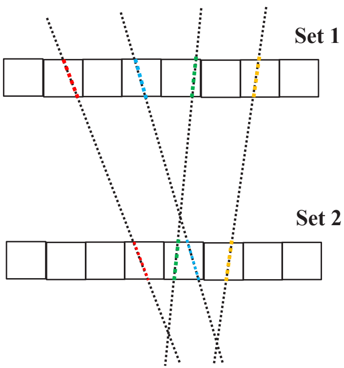
Observation date and time: Apr/11/2012 8:40-11:40(UT) Rikubetsu

Apr/11/2012 10:20-13:29(UT) Ishigaki

Targets: 14574 TLEs of Apr/11/2012 distributed at Space Track web site.

Observed coordinates(RA and Dec) of each object at each site are calculated every second interval using STK(Satellite Tool Kit) software.

Observational simulation



Identification at each site

872 and 636 objects were detected at the set 1 and 2 of Ishigaki, respectively. 473 objects were detected at both sets.

916 and 934 objects were detected at the set 1 and 2 of Rikubetsu, respectively. 458 objects were detected at both sets.

Identification conditions

①Difference of observation times: Less than 700-sec

②Change rate of circular radiuses: Less than 0.1-degree

③Difference of inclinations: Less than 1.0-degree

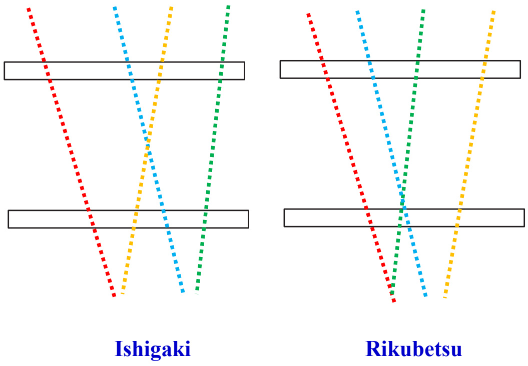
④Difference of RAANs: Less than 1.0-degree

⑤Difference of direction cosines at the middle of observation time of 2 set: Less than 5.0-degree

⬇

465 objects out of 473 ones at Ishigaki (98.3%) and 454 objects out of 458 ones at Rikubetsu (99.1%) are identified.

Observational simulation



Out of Ishigaki's 463 and Rikubetsu's 454 identified objects, 154 objects were observed at both sites.

Identification condition

① Difference of observation times: 5600−7700-sec

② Change rate of circular radiuses: Less than 0.05

③ Difference of inclinations: Less than 1.5-degree

④ Difference of RAANs: Less than 1.0-degree: Less than 1.0-degree

⑤Difference of direction cosines at the middle of observation time of either of the two sits: Less than 90-degree

↓

143 objects out of 154 ones (92.9%) are identified

Same object identifications out of many observation data taken at 2 sets of observation units at 2 sites are possible. Which means objects coordinates separating about 80-degree of 2 passes are available. Therefore, accurate orbital determinations will be carried out.

Future Plan

- Improvement of equipments①: Camera lens → Small telescope
- Improvement of equipments②: Development of fast detection devices (CMOS sensor and so on)
- Improvement of analysis method: Line-identifying method → Stacking method

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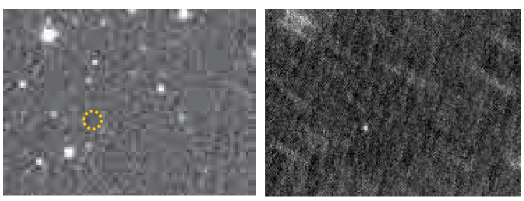
Objective: Detection of 10cm objects at 1000km altitude

- Orbit determination experiment using the data taken at Rikubetsu and Ishigaki
- Cooperation with space based optical observation system for LEO debris



A detected object using the stacking method. Before-analysis (left) and after-analysis (right).

Space based optical observation system

Summary

It is possible to establish a large array system of optical sensors for LEO debris observation which is able to carry out accurate orbit determination of many LEO objects with relatively low cost.

In the future, we would like to improve observation equipments and analysis methods to detect 10cm objects at 1000km altitude. We also will carry out actual orbit determinations using the data taken at 2 separated observation site and evaluate its accuracy.