DEBRIS RESEARCH ACTIVITIES IN JAPAN

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ABSTRACT

Space debris research activities in Japan is to be presented in the categories of 1) Observation, 2) Modeling, 3) Protection and 4) Mitigation, in accordance with those applied in the IADC (Inter Agency Space Debris Coordination Committee).
Optical telescope and the radar dedicated to the observation of the space debris have been developed and set in the western part of Japan and applied to the international space debris observation campaign coordinated by the IADC.
Japan has made an important role in publishing the Protection Manual and the leading role in that of the Space Debris Mitigation Guideline, in IADC.
In this presentation, the activities in four categories above mentioned are to be reported in more detail.

1. OBSERVATION OF SPACE DEBRIS

1.1. Optical Observation

Japan Spaceguard Association (JSGA) has developed the telescope applied to the observation of space debris since 1990's supported by the Science and Technology Agency (STA), presently the Ministry of Education, Culture, Sports, Science and Technology, and has operated it under the contracted with National Space Development Agency of Japan (NASDA), presently Japan Aerospace Exploration Agency (JAXA). The observatory named Bisei Spaceguard Center (BSGC) has started its test observations since Feb. 2000 to find an effective detection sequence of space debris and made an extensive observation during the IADC campaign in Jan. 2003 (Isobe and Tajima, 2003). Since its 1m telescope has a wide field of 2.5deg. × 3.0deg., motion of geosynchronous satellites and space debris can be detected in the field in an each sequence of observations extending over 10 minutes. This makes the first order of orbital element determination of detected objects possible. In the past, BSGC has performed mainly the Az-El fixed observation and the satellite tracking observation. In the campaign, BSGC has performed the R.A-Decl. fixed observation.
Tab. 1 and Fig. 1 shows an observation plan and the traces of the GEO object, respectively. Tab. 2 shows a set of values with the number of those detected in an hour.
Fig. 2 shows some example of the observation results get in a period of 1 hour and half. The ordinate and the abscissa indicates the right ascension of ascending node and the observation time, respectively. Round marks are the positions of detected objects observed and the solid lines are the predicted traces of catalogued objects that passed in the field of the telescope, shown as the dashed line.

Table 1. Observation plan

Time period	2003/1/21 – 1/31
Observation direction	Right Ascension: near by 90 degrees Declination: 0 deg.
Angles of Telescope	3deg. (1m telescope), 2deg. (50cm telescope)
Exposure time	10sec.

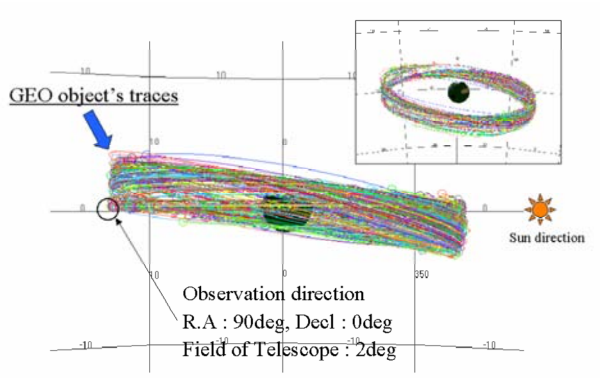

Figure 1. Observation direction and GEO object's trace

Table 2. Result of observation

Date	Observation time (UTC)							Data Num.	Used Telescope
	10:00	11:00	12:00	13:00	14:00	15:00	16:00		
21-Jan-03	25	41	36	26	10			138	1m
22-Jan-03 ~27-Jan-03	<< Other observation / bad weather >>								
28-Jan-03					11			11	0.5m
29-Jan-03						1	2	3	0.5m
30-Jan-03	6	14	3		15			38	0.5m
31-Jan-03	6	8						14	0.5m

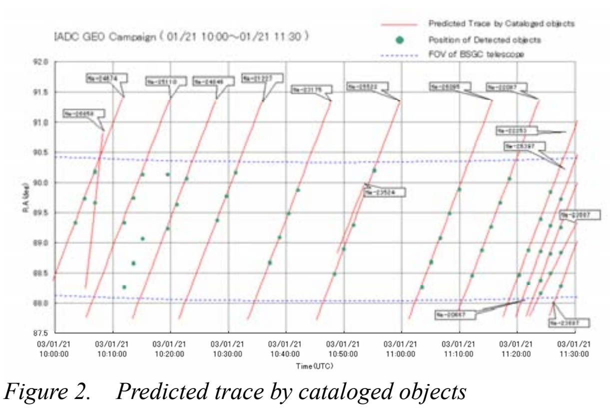

Figure 2. Predicted trace by cataloged objects

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Almost all round marks are considered to be the catalogued objects, since they are on the solid line. Others, not on the solid lines, are considered to be the unknown ones.

Some catalogued objects were not shown on the Fig. 2, because of the bad seeing and/or darkness of the objects, it seems. BSGC has not been able to detect the objects in the case where there seems to be some errors in the orbit information of NASA satellite catalogue, due to the maneuver of the objects and others. After the observations, the simple estimation of the orbits of the 44 detected objects was carried-out.

In this observation strategy, it was concluded that the strategy applied could get data of many objects in a short time and dark and/or high inclination ones could not be detected due to the short exposure time. The measure to solve these problems remain as the future study.

In order to develop the detection technology, Institute of Space Technology and Aeronautics (ISTA), JAXA, has also engaged, since 1999, in the observation of space debris, using the conventional telescope: 0.35m Schmidt Casegrain telescope has been applied to the observation of the debris in LEO and 0.35m Newtonian one to that in GEO (Nakajima et al., 2004).

For small LEO debris observation, the line detection method was proposed. Fig. 3 shows the results of the observation. By accumulating the pixel data along the direction of small debris path, it is expected to be able to detect 30 to 40 times darker LEO debris than those detected by the conventional method.

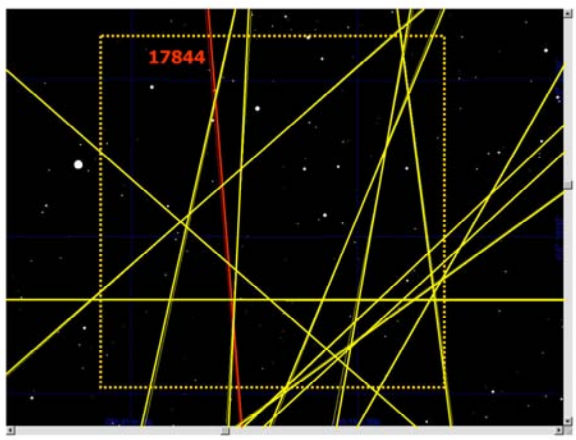

Figure 3. Trajectories of LEO small debris passed through a FOV of 0.6×0.6 deg. during 30 minutes. The red line is a catalogued number (SSC17844).

For the GEO debris detection, the orbit determination of them, the development of the automatic debris detection software and the high speed read-out CCD camera cooling system by the refrigerator, has been developed by ISTA. Fig. 4 shows 1k × 1k and 2k × 2k CCD cameras and Fig. 5 shows the 4k × 4k one. The total read/write time of the CCD tip is about 4 sec.. A refrigerating cooling system in place of the liquid nitrogen cooler is under development, though the Perche cooling system has been applied to that presently, since it is easy to handle. The temperature is expected to be controlled around -100°C by applying the new refrigerating cooling system, and, then, the exposure time to observe the GEO debris should be 5-10 sec.. An evaluation of the system using the present cooling system is planned.

Figure 4. One Tip CCD Cameras (1K×1K and 2K×2K)

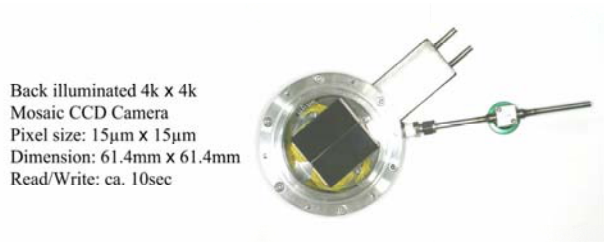

Figure 5. 4K×4K Mosaic CCD Camera

Stacking method has been applied to the development of the automatic debris detection software. By applying this method together with the commercial moving object detection software (Stella Hunter Professional ^{TM}, Astro Arts Inc.) to moving objects as asteroids and comets, 40 new asteroids were detected in the 0.35m telescope image data. The darkest object was about 21 magnitude.

Tri-axial ellipsoid model of one LEO debris, its rotational axis direction in the celestial sphere, the compositional parameter and its rotational period were successfully determined by using only light curve data measured by the optical telescope (Yanagisawa et al., 2004). Fig. 6 shows the light curve data of COSMOS 2082R/B, used for the present analysis. Following assumptions were applied to the present analysis.

1. The shape of the target is tri-axis ellipsoid.
2. It is rotating around the shortest axis.
3. The rotational axis is fixed in the celestial sphere.

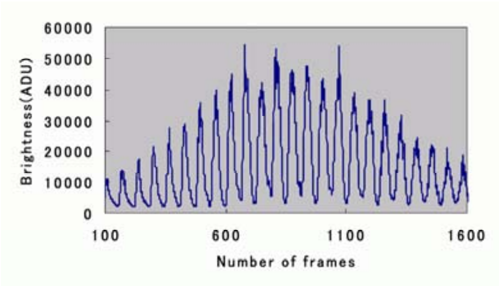

Figure 6. The light curve data of cosmos2082R/B

Fig. 7 and Fig. 8 shows the relative position of the rotational debris and the observer, and the corresponding light curve to be observed, respectively. Though some more detailed study and evaluation of the present results are necessary, the present method is considered to have a wide applicability to determine the motion of the space debris to be retrieved by the space activities.

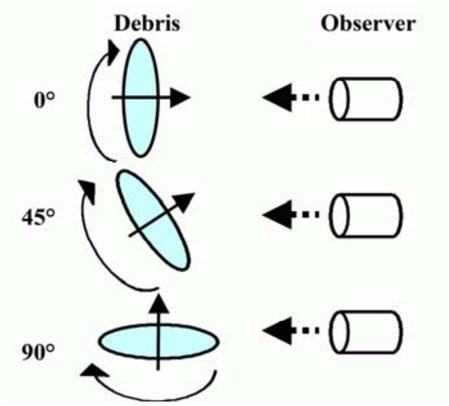

Figure 7. Various geometries of debris and observer

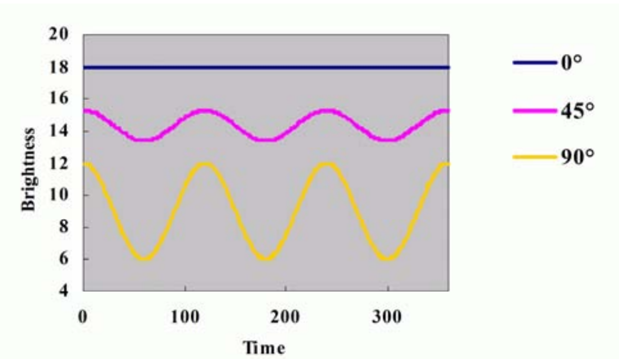

Figure 8. Corresponding light curve of the various geometries in Fig. 7

Study on the applicability of the high resolution camera to scan solar arrays to detect the signs of impacts of space debris, has started in Kyushu University (Kurakazu and Hanada, 2004, Hirayama et al., 2002, 2003, 2004, Kawamura et al., 2004).

1.2 Radar

JAXA has developed phased array radar with JSGA for the observation of space debris, which is set at the Kamisaiba Spaceguard Center (KSGC) and started its operation from Apr. 2004. Though it has rather low sensitivity and can detect 1m objects at a distance of 700km, it has a capability to detect up to 10 objects in a 40deg. × 60deg. field, by using a beam scanning system. Fig. 9 shows its dome structure and the radar antenna.

Figure 9. KSGC (Kamisaibara Spaceguard Center)

2. MODELING OF SPACE DEBRIS ENVIRONMENT

2.1 Orbital Debris Evolutionary Model

GEODEEM, an orbital debris evolutionary model for the geosynchronous regime, has been updated to provide a better and more accurate description and understanding of GEO debris environment, by Kyushu University (Hanada and Yasaka, 2004). The advantage of the present version over the previous one include

1) Objects are categorized according to their longitude stability, not by their period and inclination. (Tab. 3)
2) NASA standard break-up model 2000 revision has been adopted.
3) Collision probability is estimated based on an error sphere, not based on a finite element method.
4) An orbit propagator is introduced to account for the orbital evolution of break-up fragments.

Table 3. Object categories and their definition

Categories	Description	Longitude	GEO crossing?
1	Operational spacecraft	Constant	Yes
2	Abandoned spacecraft	Librating	Yes
3	Disposed spacecraft	Drifting	No
4	Rocket bodies	Drifting	No
5	Fragments crossing GEO	Drifting	Yes
6	Fragments staying above/under GEO	Drifting	No

The comparison study has been carried out under the following baseline projection scenario.

1) A 100-year projection in 1-year increments
2) An 8-year traffic cycle of the years 1994 to 2001 is cycled throughout the projection period.

3) No mitigation measure taken
4) The mean of 30 Monte Carlo iterations representing the resulting environment
5) The standard deviation of 30 Monte Carlo iterations representing the error of the model results

The other projection scenario, (post-mission disposal projection) makes use of the baseline features described above, but with some mitigation methods.

Each spacecraft is assumed to have a mission lifetime of 10 years. If the end-of-life is reached after the 10th year in the projection period, the spacecraft is moved to the drift orbit above GEO. All rocket upper stages are left in their original orbits. The traffic cycle was referred to (Harnández and Jehn, 2002). The traffic of the years 1994 through 2001 cycles was applied for 100 years beginning in the year 2002.

In Tab. 4, which shows mean quantities after 100 years with standard deviation in parentheses, no differences between the two scenarios is obtained excepting for collision activities, Fig. 10 shows the differences between two scenarios for the population growth of objects crossing GEO ring. The present results are requested to be compared to other approach in near future.

Table 4. Mean quantities after 100 years (standard deviation in parentheses)

Projection	Objects>10cm	Explosions	Collisions
Baseline projection	7918.90 (933.00)	S/C: 3.67 (2.15) R/B: 12.53 (4.06)	0.27 (0.72) 30MC runs: 8
PMD projection	7912.03 (934.65)	S/C: 3.67 (2.15) R/B: 12.53 (4.06)	0.03 (0.45) 30MC runs: 1

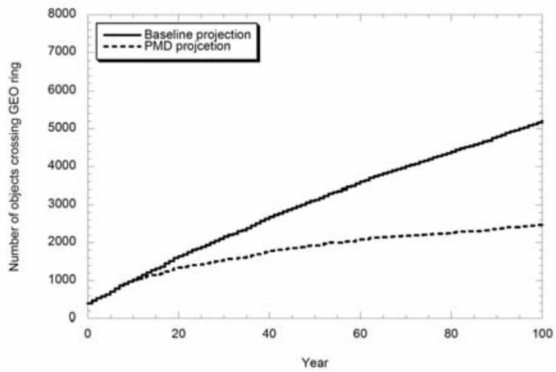

Figure 10. Population growth of objects crossing GEO ring

2.2 Low-velocity Collision Model

NASA standard break-up model has been supposed to be applied to the low velocity collisions with some simple modifications. Fragment area-to-mass distribution measured in the low-velocity impact tests did not match with those produced by the NASA hypervelocity collision model, however. To investigate this disagreement, another series of impact tests have been carried out at an impact velocity range less than 1,500m/s (Hanada, 2000, 2004, Hata et al., 2003, 2004). A target specimen was a thin aluminum honeycomb sandwich shell with CFRP face sheets, used for satellite structure and/or rigid antenna reflector. The projectile was a 5/16 inches aluminum solid ball. From these test, it was shown that a theoretical lower boundary can exist on fragment area-to-mass distribution at a smaller characteristic length range and that the fragment area-to-mass distribution produced by the NASA hypervelocity collision model appear mostly lower than the theoretical lower boundary. (Fig. 11)

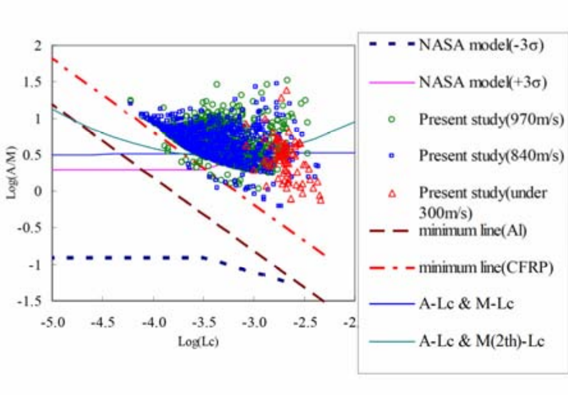

Figure 11. Area-to-mass distribution

3. PROTECTION OF SPACE DEBRIS

3.1 Hypervelocity Impact Test Facility

ISTA has developed the hypervelocity impact test facility where the averaged impact velocity of 10 k/s is established (Kibe et al., 2003a). The velocity of 10k/s is essential to study the protection problems of space debris in LEO. In place of the conventional Gas Gun, ISTA has developed the Conical Shaped Charge System which can launch a projectile of one gram mass or larger at the averaged impact velocity of 10k/s. Fig. 12 and Tab. 5 show the overview of the test facility and the results of the tests, respectively.

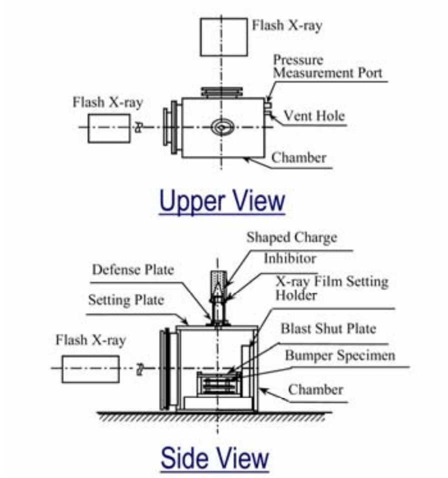

Figure 12. Test set-up for vacuum condition

Table 5. Summary of Debris Bumper Tests

Test Case	Vacuum	Target	Jet Mass [g]	Jet Velocity [km/sec]
1	Atmosphere	Steel Plate 2	1.91	10.49
2	0.1atm	Steel Plate 2	2.05	10.96
3	0.1atm	Bumper	1.95	-
4	0.1atm	Steel Plate 2	2.23	10.87
5	0.1atm	Bumper	1.80	-

In parallel with the impact test, some method to estimate the impact mass to the target has been proposed and evaluated. The brightness of the flash X-ray image depends strictly on the total areal mass density along the projection path of the X-ray.
In order to determine the correlation between the brightness of each pixel in the flash X-ray image and the areal mass density, a reference scale of an aluminum wedge is put in each flash X-ray photo frame. The areal mass density of each pixel in the projectile image can be determined by comparing its brightness with the corresponding part of the reference scale image in the same flash X-ray photo. The total mass is calculated as a sum of the areal density at each pixel. Tab. 6 shows the results of the tests carried-out using the dummy projectiles.

Table 6. Summary of Dummy Projectile Test

Dummy Projectile	Estimated Mass* [g]	Theoretical Mass [g]	Error [%]
A1	1.99	2.18	-8.9
A2	2.10	2.18	-3.7
A3	2.22	2.18	1.6
B1	2.09	2.14	-2.3
B2	2.32	2.14	8.2
B3	2.46	2.14	15.0
C1	1.86	1.78	4.5
C2	1.79	1.78	0.3
C3	1.77	1.78	-0.8
D1	1.28	1.07	19.6
D2	1.11	1.07	3.7
D3	1.01	1.07	-5.6

* Average Values at two times Tests
(Distances between projectile and X-ray film are 120mm and 250mm.)

To establish the higher impact velocity, counter impact system has been proposed and basic tests have been carried out by Kyushu Institute of Technology (KIT) (Akahoshi et al., 2005). They applied the technology of Electrothermal-Chemical (ETC) gun to the 1^{st} stage of the Two-Stage Light Gas Gun (TSLGG), which is to be set on the both side of the measurement section of the counter impact system. They measured the delay time of ETC-based TSLGG as well as the time variation of current, discharge voltage and pressure. Fig 13 shows the configuration of the proposed system.

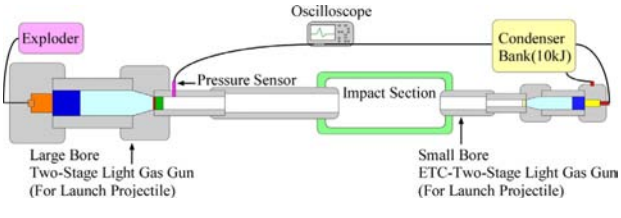

Figure 13. Configuration of the Counter Impact System

3.2 Hypervelocity Impact Test

In order to evaluate the applicability of the metallic mesh to the bumper of the manned spacecraft, hypervelocity impact tests were carried out at KIT by using the TSLGG (Higashide et al., 2005). Analysis of the image data showed the stainless mesh could reduce the velocity of the projectile up to 35%.
KIT also executed the hypervelocity impact test to characterize the physical properties of fragments from low-velocity catastrophic impact on a micro satellite (Nakashima et al., 2005).

3.3 Protection Manual

JAXA has cooperated with other members of IADC to publish the Protection Manual applied to the design of some space systems, especially of the manned one.

4. MITIGATION OF SPACE DEBRIS

4.1 Mitigation Practice

Though MDS-1 spacecraft, which orbit is 35,686km × 383km, had originally been planned to ascent its perigee to avoid the interference with the manned orbit after its mission lifetime, the lifetime reduction was considered to be more effective in the view point of the long term prevention of orbital environment and, then, the perigee was descended to about 200km in Aug., 2003. Then the corresponding orbital lifetime became less than 10 years, which is in compliance with the Mitigation Guideline of IADC.

4.2 Active Removal System for Post-Mission Space Systems

JAXA has proposed and studied the Active Removal System for Post-Mission Space Systems (Kibe et al., 2003b). Some simulation analysis shows the total collision risk would be reduced about 30%, when at most 100 debris would be removed from the crowded orbit at the 800-900km altitude to the 650km one where the orbital lifetime is estimated to be about 25 years.
It has been proposed two concepts to remove the spacecraft, both of which apply the Electro-Dynamic Tether (EDT) System. Fig. 14 and Fig. 15 shows the system with expendable EDT and that with reusable one, respectively. To catch the spacecraft, the estimation of the motion of the spacecraft to be removed is essential and some measure would be necessary to reduce its angular momentum. JAXA has carried out some simulation to estimate the motion of target spacecraft and has proposed some measure to reduce its angular momentum and evaluated its effectiveness.

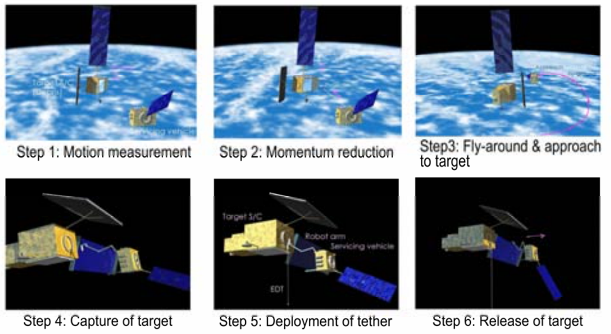

Figure 14. Operation sequence of the active debris removal system (Expendable)

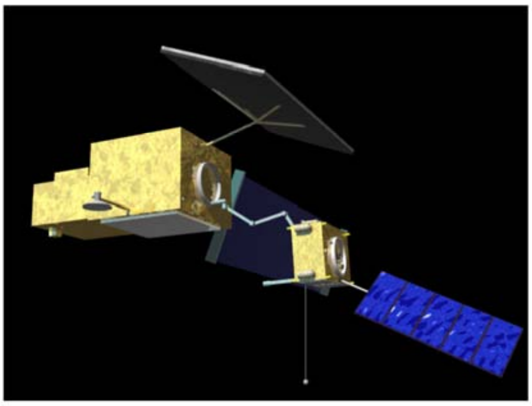

Figure 15. Concept of the reusable system

4.3 Mitigation Guideline

JAXA made a leading role in publishing the IADC Space Debris Mitigation Guideline, in cooperating with other member of IADC.

5. CONCLUDING REMARKS

Japanese space debris related activities were overviewed. The problems of space debris have been acknowledged and some possible measures to mitigate them have been applied to Japanese space projects, recently. And, also, the circle of the researchers for space debris problems has been stretching in Japan. IADC has been the forum for the discussion, coordination and cooperation to understand and to solve the space debris technical problems and UN, also, become the place for that and for the political related issues. Japan will continuously cooperate with other nations to understand and to solve the space debris problem to keep the space environment clean.

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