C10

衛星搭載パルスレーザーによる軌道離脱サービス

End-of-Life Deorbit Service with a Pulsed Laser Onboard a Small Satellite

○福島 忠徳, 平田 大輔, 足立 数馬, 板谷 優輝, 山田 淳（スカパーJSAT）、
津野 克彦, 小川 貴代, 和田 智之, 戎崎 俊一（理化学研究所）
○FUKUSHIMA Tadanori, HIRATA Daisuke, ADACHI Kazuma, ITAYA Yuki, YAMADA Jun (SKY Perfect JSAT), TSUNO Katsuhiko, OGAWA Takayo, WADA Satoshi, EBISUZAKI Toshikazu (RIKEN)

スカパーJSAT は、衛星からのレーザ照射により不用衛星を移動させて軌道離脱するサービスのための衛星の設計に着手した。レーザ照射により、材料物質が気化・プラズマ化する現象（アブレーション）を利用して、ターゲットとなる衛星に推力を生成する。JSAT と理研の共同研究では、アブレーション推力測定と概念検討を行い、その結果、約 200 W のペイロード電力の 150 kg クラスの小型衛星で、150 kg のターゲットを数 100 ㎞程度の高度変更が可能であるとの見解を得た。またレーザ方式は、4つの利点がある。（1）ターゲットに非接触で推力を生成可能なため、衝突リスクを低減可能。（2）任意のレーザ照射によりターゲットの回転調整が可能。（3）ターゲット外壁物質のアブレーションにより、推力が発生するため、サービス衛星がターゲット移動用の燃料保持が不要。（4）顧客の衛星に対して追加の仕様変更（キャプチャするためのハンドルなど）が不要。本発表では、EOL デオービットサービスのコンセプトと暫定スケジュールを紹介する。

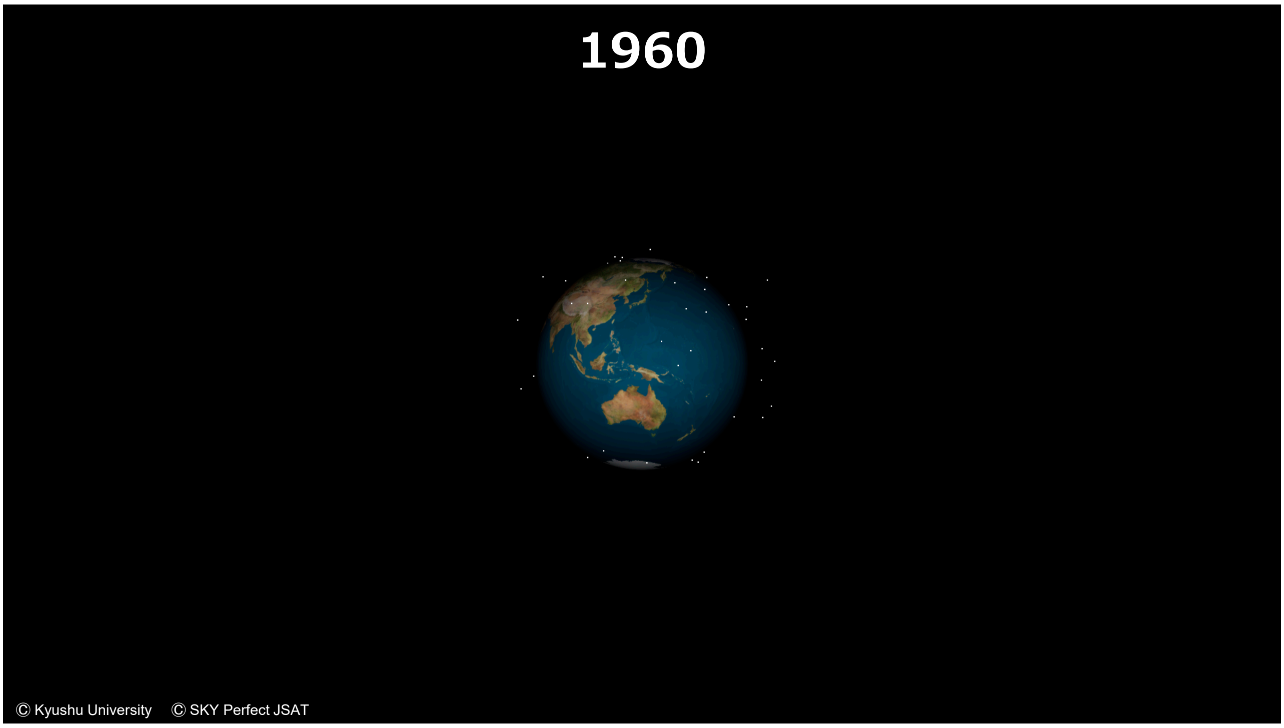
SKY Perfect JSAT Corporation has begun designing a brand-new end-of-life (EOL) deorbit service satellite to remove nonfunctional satellite targets from orbit. A service satellite with a laser system emits a focused laser beam to the target to generate laser ablation. The orbit and attitude (including rotational status) of the target can be changed sufficiently by the reaction force of the plasma/gas ejected from the target surface. Ground experiments, including high-precision measurements of the ablation reaction and a feasibility study of the service satellite, were performed in collaboration with JSAT and RIKEN. Our conceptual study shows that our service can deorbit a 150 kg target at an altitude of several hundred kilometers by means of a small laser satellite (150 kg) and a 200 W class Payload Power. We found four advantages of the laser ablation method over conventional active methods for the removal of nonfunctional satellites: (1) minimal risk of collision, since the laser satellite does not require any physical contact with the target; a high-intensity pulsed laser can ablate surface material of the target from a distance; (2) detumbling is also possible during the operation; (3) the service satellite is not required to carry additional fuel for the target because the required thrust is generated from vaporization and ionization of the target material; (4) additional specifications (e.g. a handle to capture) for customer satellites are not necessary. In this presentation, we present the concept and provisional schedule of our EOL deorbit service.

This document is provided by JAXA.

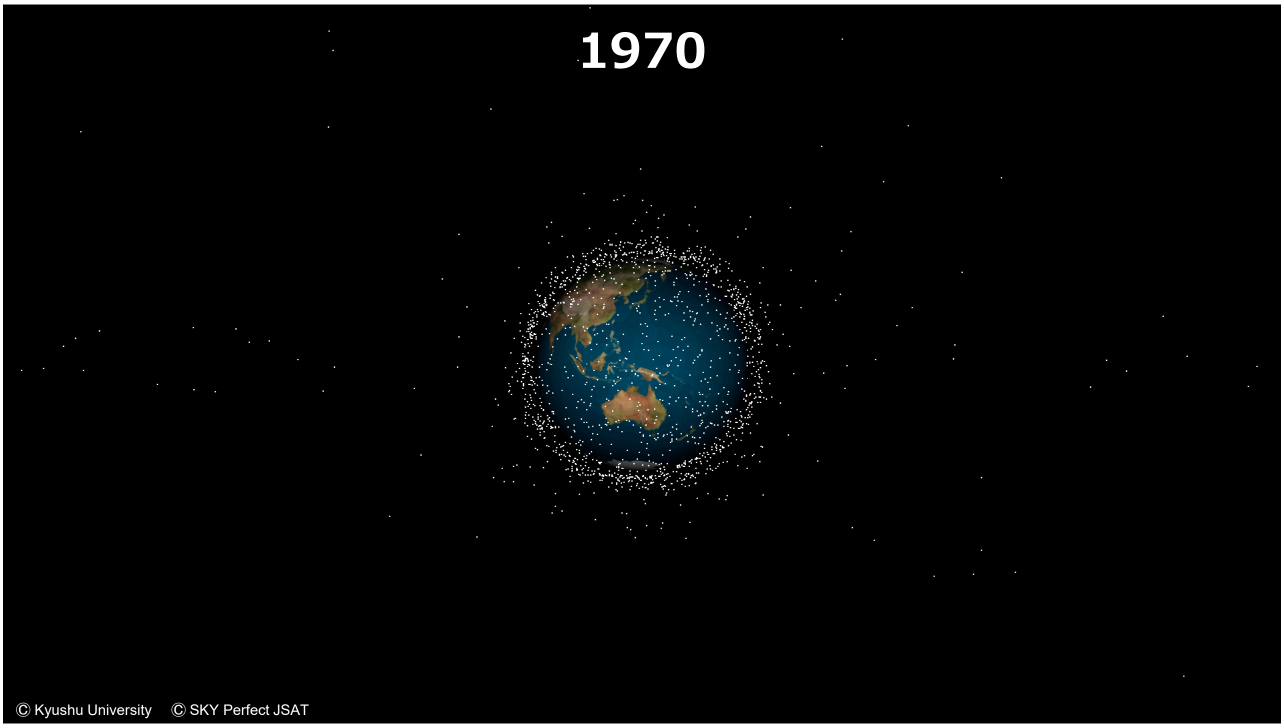
End-of-Life Deorbit Service with a Pulsed Laser Onboard a Small Satellite

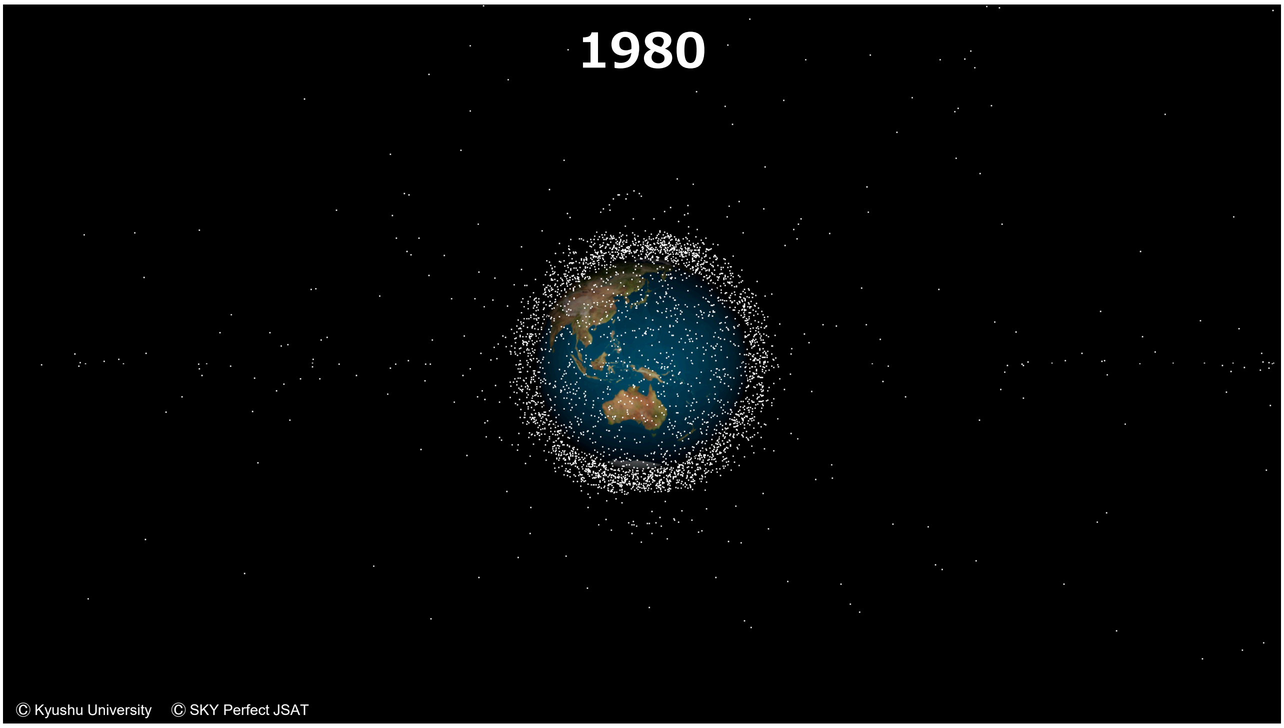
○ Tadanori Fukushima(†), Daisuke Hirata (†), Kazuma Adachi (†), Yuki Itaya (†), Jun Yamada (†)
Katsuhiko Tsuno(‡), Takayo Ogawa (‡), Satoshi Wada (‡), Toshikazu Ebisuzaki (‡)
(†): SKY Perfect JSAT, (‡): RIKEN

9th Space Debris Workshop 26 Feb, 2021

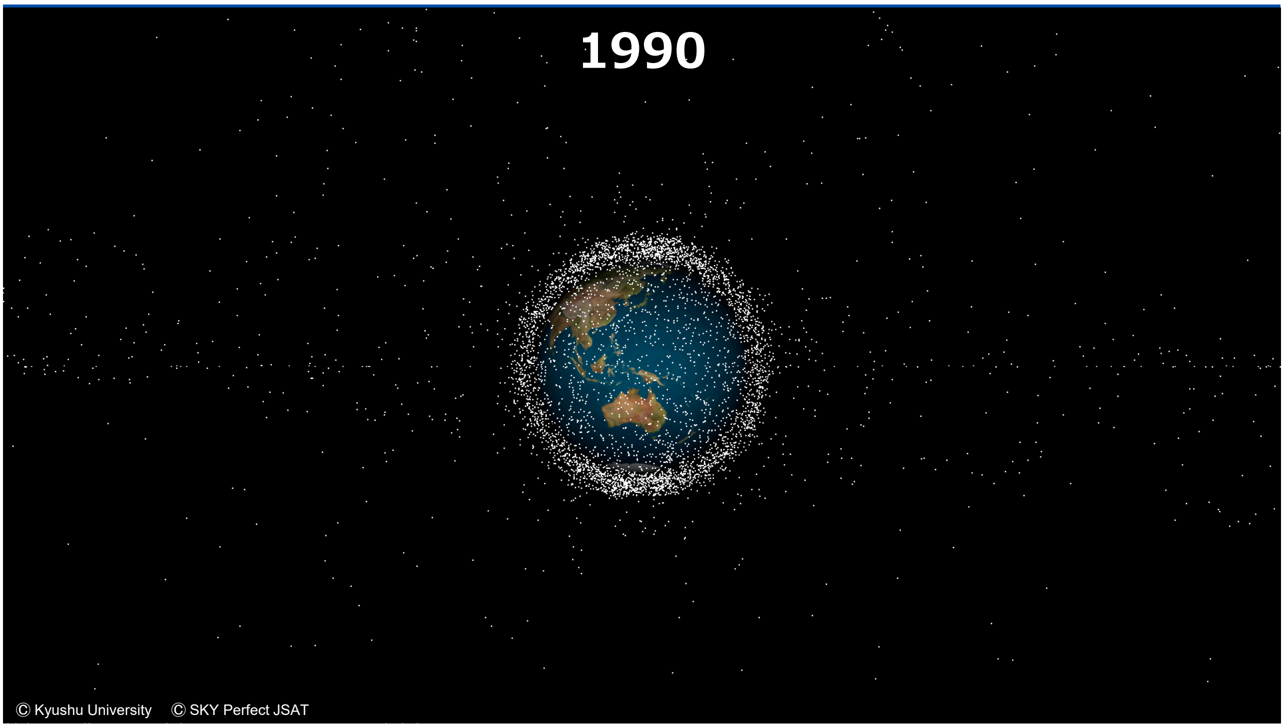


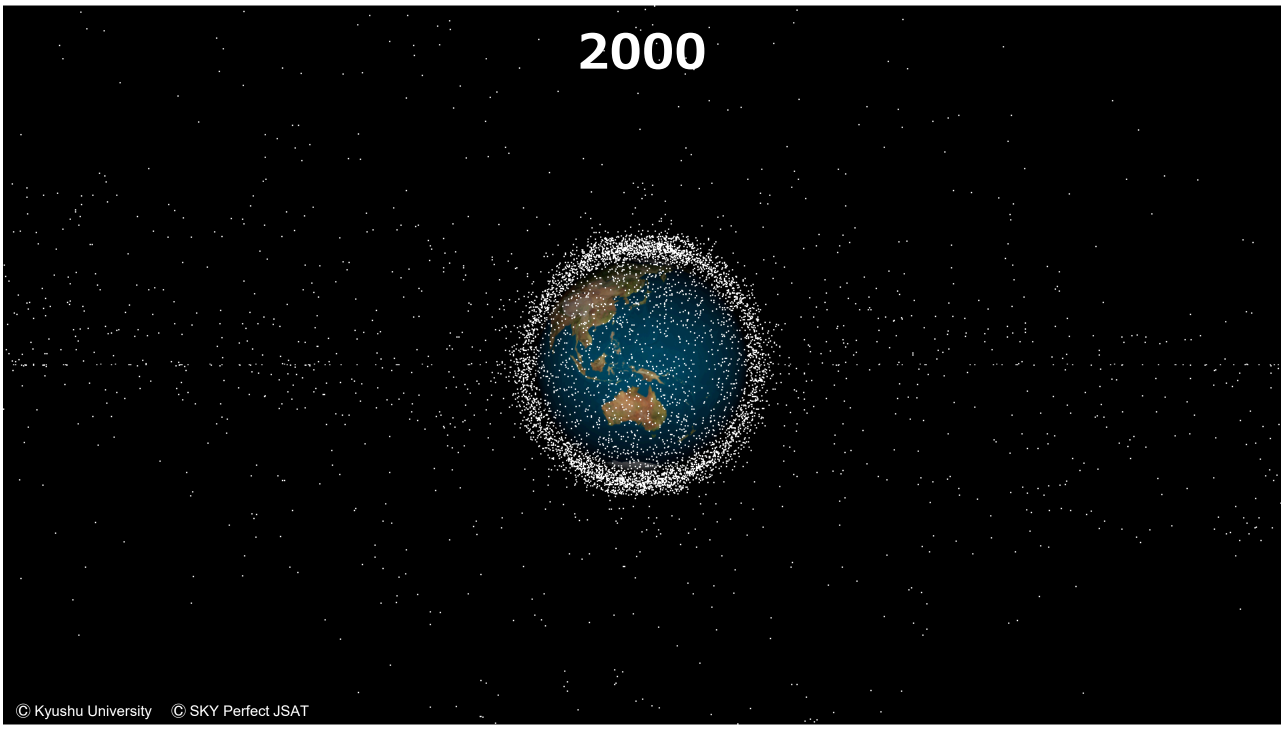
This document is provided by JAXA.



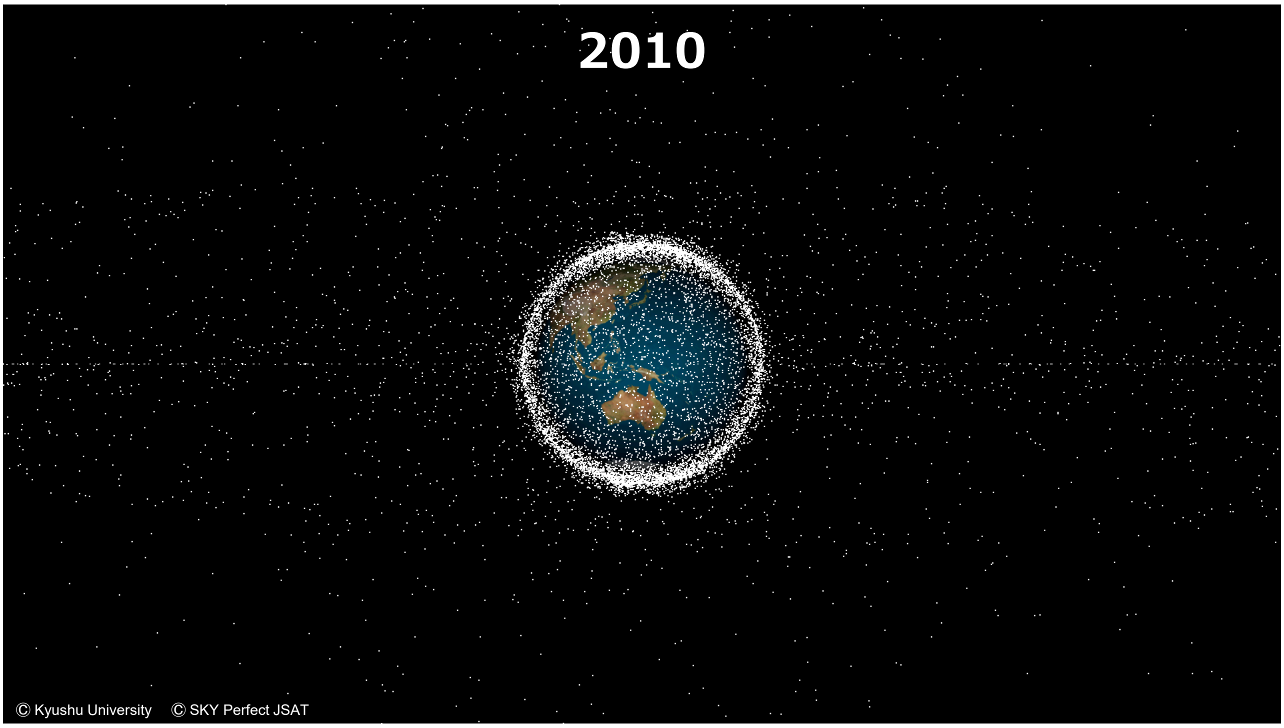


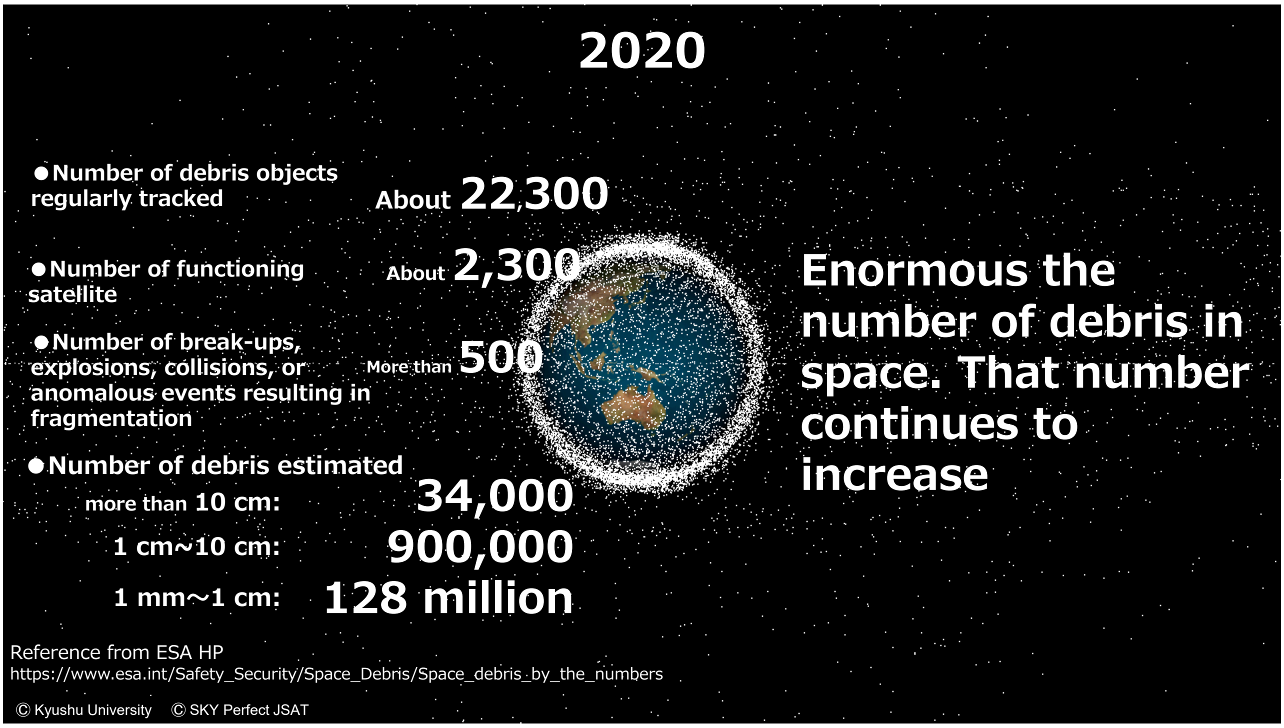
This document is provided by JAXA.





This document is provided by JAXA.





This document is provided by JAXA.

LEO Environment Projection of the number of space debris (>10cm)

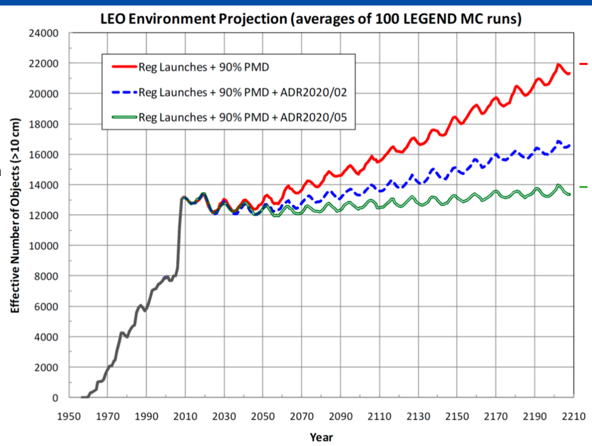
Removing five objects per year can stabilize the LEO*1 environment*2

*1 LEO: Low Earth Orbit
LEO is an Earth-centred orbit with an altitude of 2,000 km or less

*2 Active Debris Removal and the Challenges for Environment Remediation
By J.-C. LIOU1

https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20120013266.pdf

Fig.6. Projected increases of the future LEO populations (objects ≥10 cm) based on three different scenarios. Each projection is the average of 100 LEGEND MC simulations.



90% Post Mission Disposal

90% Post Mission Disposal
+
5 active debris removals per year

9[th] Space Debris Workshop 26 Feb, 2021 SKY Perfect JSAT Corp. Proprietary JSAT 9

Activation of space use in next 10 years

The number of Objects Launched into Outer Space
(1957～Apr-2020)

9,386 satellites

United Nations Office for Outer Space Affairs
http://www.unoosa.org/oosa/osoindex/search-ng.jspx

The number of satellite for Mega-constellation
(in house investigation from news resources)

More than 50,000 satellites

OneWeb: more than 6,000
SpaceX: more than 42,000
Telesat： more than 300
Amazon：more than 3,000
other start up･････････

The satellites that will be launched in the next 10 years Significantly surpasses the number of satellites launched by humankind in the last 60 years

Congestion of satellites rapidly progresses in low earth orbit

9[th] Space Debris Workshop 26 Feb, 2021 SKY Perfect JSAT Corp. Proprietary JSAT 10

This document is provided by JAXA.

The number of debris considered constellations

[*]: , 6700 satellites in 1000- to 1325-km altitudes with different inclinations and orbital planes, assumed to continue for 50 years.

+590% debris **582 catastrophic collisions in 200 year**

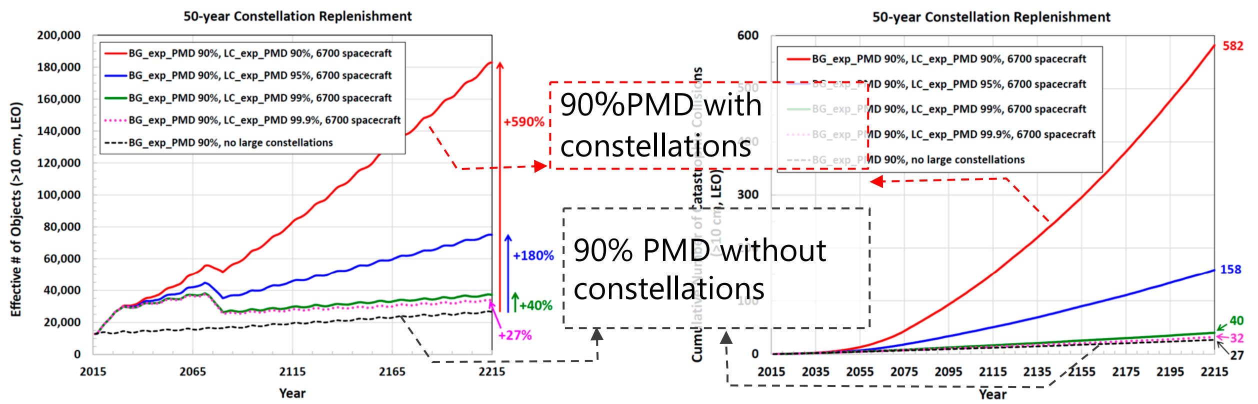


Figure 6. Results from LC scenarios where the LCs maintain full operations with spacecraft replenishment for 50 years. The total number of spacecraft in 3 LCs is 6700. The differences between the top four curves and the black-dashed curve in 2215 are +590% (red), +180% (blue), +40%(green), and +27% (purple-dotted), respectively.

Figure 7. Results from LC scenarios where the LCs maintain full operations with spacecraft replenishment for 50 years. The total number of spacecraft in 3 LCs is 6700. The total numbers of catastrophic collisions in 200 years for the 4 curves are (top to bottom) 582, 158, 40, 32, and 27, respectively.

Reference: National Aeronautics and Space Administration(NASA) Orbital Debris Quarterly News Vol 22, Issue 3 Sep 2018

Summary of space debris problem

Background
- Increasing the number of space debris
- Worse due to constellation

Problem
- Increasing mission ending risk due to collision of space debris

In case no improvement

Problem actualized
- Affect of space use, civilian life

Solution
- Achieve high PMD
  - End Of Life deorbit(*1)
- Active debris removals(*2)

Many countries and companies are in progress of active debris removal technology

*1: End Of Life deorbit: Service for post mission disposal at mission ending for a satellite

*2: Active debris removals: remove space debris

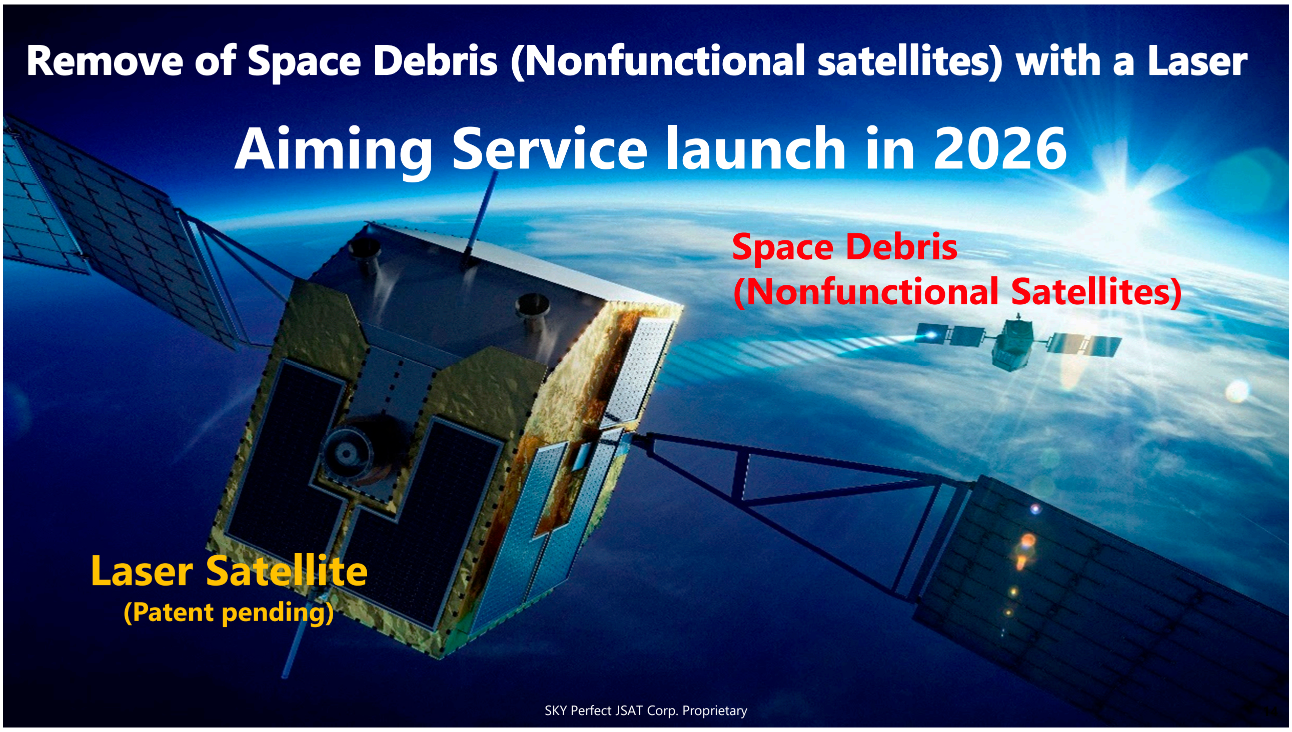
This document is provided by JAXA.

The Solution of SKY Perfect JSAT

9th Space Debris Workshop 26 Feb, 2021

SKY Perfect JSAT Corp. Proprietary

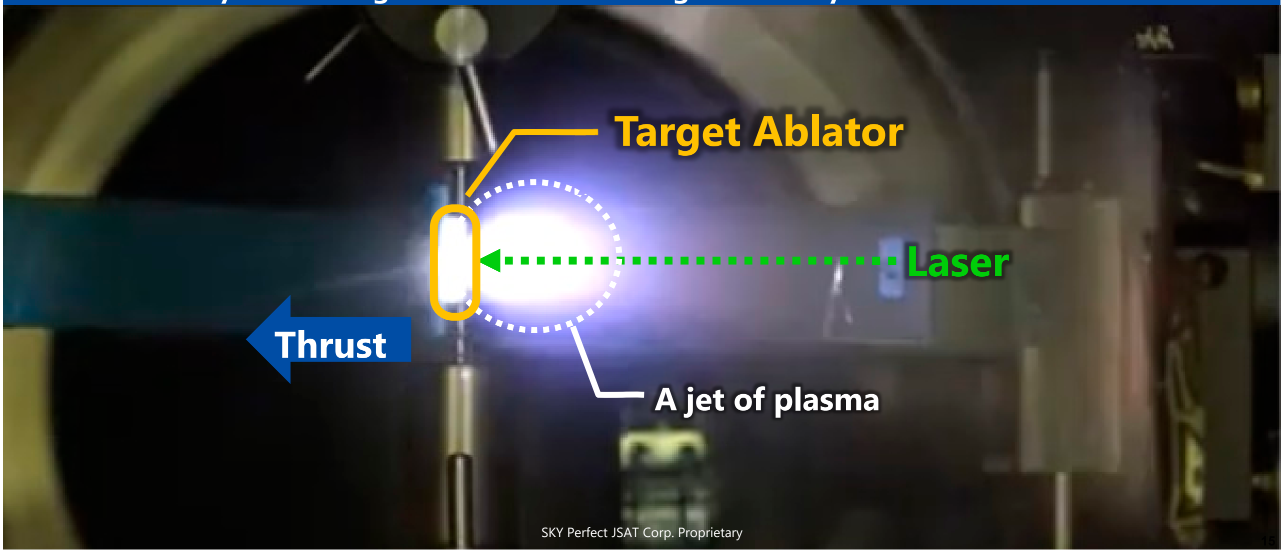
13



This document is provided by JAXA.

Key Technology: Laser Ablation

Laser ablation is the process of removing material as vaporized or ionized state from a solid surface by irradiating a material with a high-intensity laser beam.



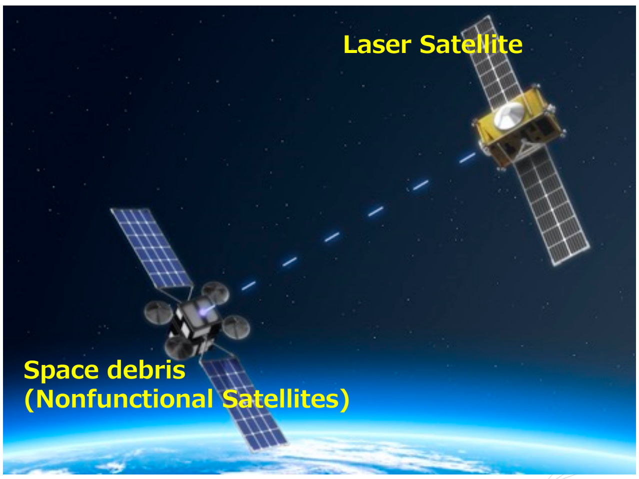
Advantages of Laser Method

❶Safety

- Move nonfunctional satellites from a distance with no physical contact
- Detumbling is also possible

❷Economy

- Laser satellite is not required to carry additional fuel for nonfunctional satellites
- No Additional Specifications (e.g. a handle to capture) for customer satellites



This document is provided by JAXA.

Thrust Performance for Aluminum

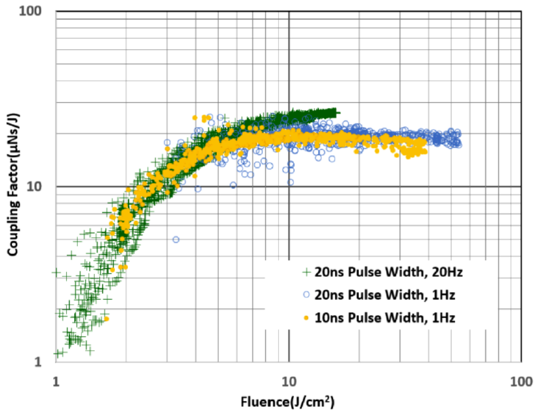


Fig. 4. Momentum-coupling factor for a 7075 aluminum target under three different conditions. Each data point corresponds to an individual laser pulse. See Data File 1 for underlying values for individual conditions.

Aluminum ablation Impulse (Coupling Factor) ≒ 20 μNs/J in the range more than 5 J/cm^2

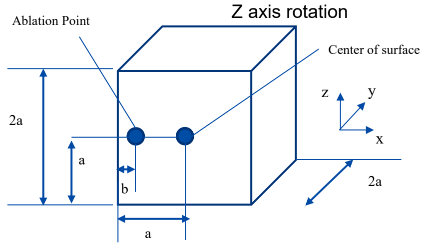
If 1 pulse with 1 J at 50Hz, 50W Laser output and 1mN Thrust.

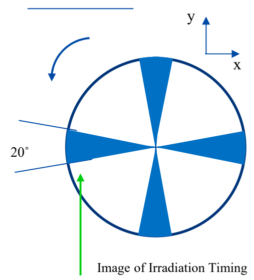
Reference: Vol. 28, No. 18 / 31 August 2020 Optics Express
Impulse measurement of laser induced ablation in a vacuum (Tsuno et al.)

Detumbling Feasibility (Ideal cube type Target)

The torque generated by the laser ablation thrust have a capability of stopping the rotation at a sufficiently realistic speed.

	Item	Value
Pre-Condition	Satellite Mass, M	150 kg
	Initial Angular Velocity	1 rpm
	Length of a side of cube, 2a	1 m
	Ablation Point, b	0.1 m
	(*)Ablation Thrust, F (1J*36Hz)	0.72mN
	Irradiation timing efficiency for rotating objects	20°/90°
Result	Irradiation time	9000sec
	Operating time until rotation stops	0.5 day





(*) The ablation thrust value was tentatively used for this feasibility study. 36 W output laser power requires 180 W payload power if 20 % efficient from payload power to laser output. This Payload power would be sufficient small to mount to small satellite

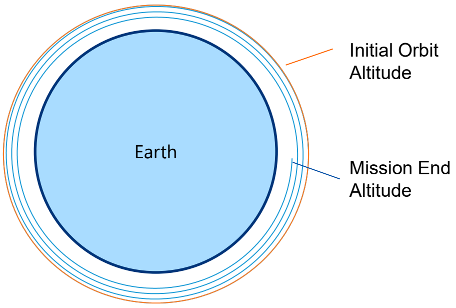
This document is provided by JAXA.

Deorbit Feasibility

- Small Altitude change such as delta 10 km can be possible quickly.
  - Risk Mitigation of Collision to their operational constellation satellites
  - Reduce collision avoidance operation for other operational satellites.
- Approx. 2 years of Laser ablation would be required to deorbit target satellite in IADC guideline orbit (25 years stay to reentry to atmosphere). It leads to the significant reduction of orbital time

Example of deorbit period of a certain satellite

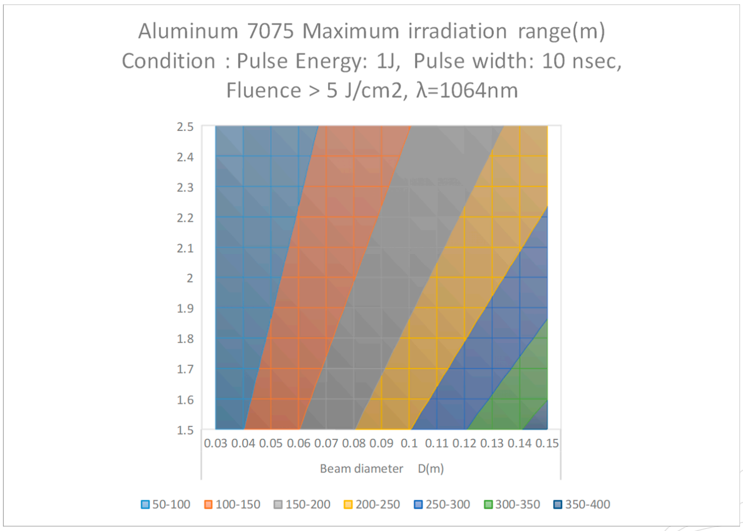
Item	Delta -10km	Delta - 600km
Satellite Mass, M	150kg	150 kg
Initial Orbit Altitude	1200 km	1200 km
(*1)Mission end Altitude	1190 km	600 km
(*2)Required Delta V	5 m/s	305 m/s
(*3)Ablation Thrust, F (1J*36Hz)	0.72mN	0.72mN
Operating days for deorbit	11 days	725 days



(*1) The mission end orbit altitude was a value tentatively determined for an orbit to re-enter the atmosphere in 25 years described IADC guideline. It should be determined by customer request.
(*2) Required Delta V was calculated by using Hohmann orbit equation with 1 km step, which is like spiral orbit
(*3) The ablation thrust value was tentatively determined for this feasibility study.

Irradiation Range (50m ~ several hundred meter)

- **Irradiation Range is determined by following condition**
  - Beam diameter at telescope
  - Beam Quality
  - Pulse Energy
  - Safe rendezvous distance between Laser satellite and Target object
  - Others..
- **It is possible to irradiate a laser with an intensity generating ablation from a distance of several hundred meters with a realistic beam diameter, pulse energy, and beam quality.**
- **The actual operating distance will be determined prior to design Fixed**



This document is provided by JAXA.

Summary and Conclusion

- **Feasibility study showed End Of Life Deorbit with Pulse laser is sufficiently feasible**
  - Detumbling can be performed at a sufficiently realistic speed.
  - Deorbit
    - Small Altitude change such as delta 10 km can be possible quickly such several weeks.
    - Approx. 2 years of Laser ablation would be required to meet IADC guideline orbit (25 years stay to reentry to atmosphere). It leads to the significant reduction of orbital time
  - Irradiation Range
    - Laser Irradiation from several hundred meters can be feasible with a realistic beam diameter, pulse energy, and beam quality.
- **By developing a laser irradiation method that can improve laser ablation thrust and improving the payload power that can be used with a laser, it is possible to handle even heavier objects**

This document is provided by JAXA.