

C07

静止軌道太陽光発電衛星実現に向けたデブリ衝突時のイジェクタ評価 Ejecta Evaluation of Debris Impact for Realization of Geostationary Earth Orbit Photovoltaic Satellite

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微小宇宙こみやメテオロイドが人工衛星の表面に衝突すると、イジェクタと呼ばれる二次デブリが発生する。高高度軌道では、衝突確率が低いため現時点では大きな問題とみなされていない。一方で、近年静止軌道でも太陽発電衛星等の大型構造物が検討されており、大型衛星が増え続けると衝突確率が無視できなくなる可能性がある。このため、イジェクタ発生を抑制／防止に向けた対策の1つとしてバンパ構造が提案されている。そこで著者らは、静止軌道上での大型構造物の実用化に先立ち、静止軌道での高速衝突現象の基礎的知見の蓄積を図るとともに、バンパ構造実現に向けた衝突特性の把握を計画している。具体的には、静止軌道太陽光発電衛星で使用が予想される構造材料に1mmのアルミ球を衝突させた際に発生するイジェクタ量の計測実験を計画している。本講演ではこの実験計画ならびに実験結果の速報値を紹介する予定である。

When small space debris or meteoroids impact the surface of a spacecraft at hypervelocity, secondary debris called “ejecta” are generated. Currently, ejecta are not considered a major issue due to the low collision rate in high-altitude orbits. However, recently, large-scaled structures such as space solar power satellites (SSPS) in geostationary orbit (GEO), have been studied, and if the number of large satellites continues to increase, the collision rate of small debris cannot be ignored. For this reason, a bumper structure has been proposed as one of the measures for preventing ejecta. Before large-scaled structures on geostationary orbit are developed, we have an experimental plan to examine the hypervelocity collision characteristics for future design of “Bumper Structures” using space materials which might be used in the future SSPS on GEO. In this talk, quick reports of some preliminary experimental results will be addressed in advance to protection design of “Bumper Structures” against small debris impacts.

静止軌道太陽光発電衛星実現に向けた デブリ衝突時のイジェクタ評価

Ejecta evaluation of Debris Impact for Realization of Geostationary Earth Orbit Photovoltaic Satellite

*大保颯野、赤星保浩、内田岳志、北黒裕麻、藤井理紀、高良隆男 (九工大)、
河本聡美、上土井大助、木本雄吾、長岡 信明、原田隆佑 (JAXA研開部門)、
泉山卓、福重進也 (IHI)、
北澤幸人

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赤星研究室

研究背景 Research background

Space Solar Power Systems(SSPS)

太陽光エネルギーをマイクロ波またはレーザー光に変換して地球に伝送するシステム

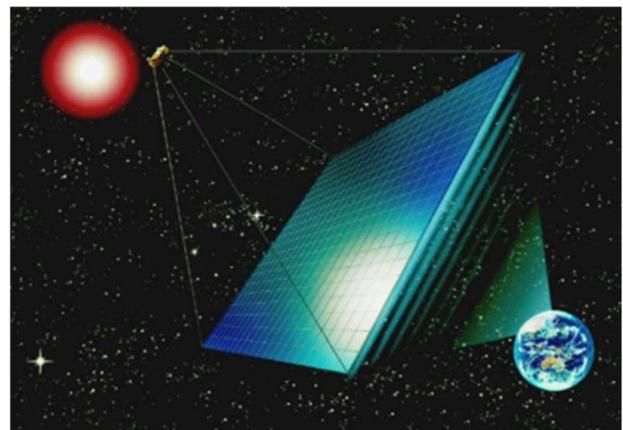
Converting solar energy into microwave or laser light into microwave or laser light and transmit it to the earth.

SSPSの特徴

feature of SSPS

○静止軌道上に数km四方の面積を要する

SSPS need several kilometers square in Geostationary Earth orbit(GEO).



s.Kawamoto, IAC-22-B6.5.10,(2022)

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研究背景 Research background

低軌道でのデブリは大気圏に突入

Debris in LEO enters the atmosphere

→自然除去が可能

Natural removal is possible

一方、静止軌道でのデブリは、大気抵抗が少なく永久的に残り続ける可能性がある

On the other hand, debris in GEO has less atmospheric resistance and may remain permanently

→自然除去が見込めない

Natural removal is not expected.



静止軌道での宇宙構造物では、
デブリ発生抑制を検討する必要がある
Space structures in GEO must control debris generation

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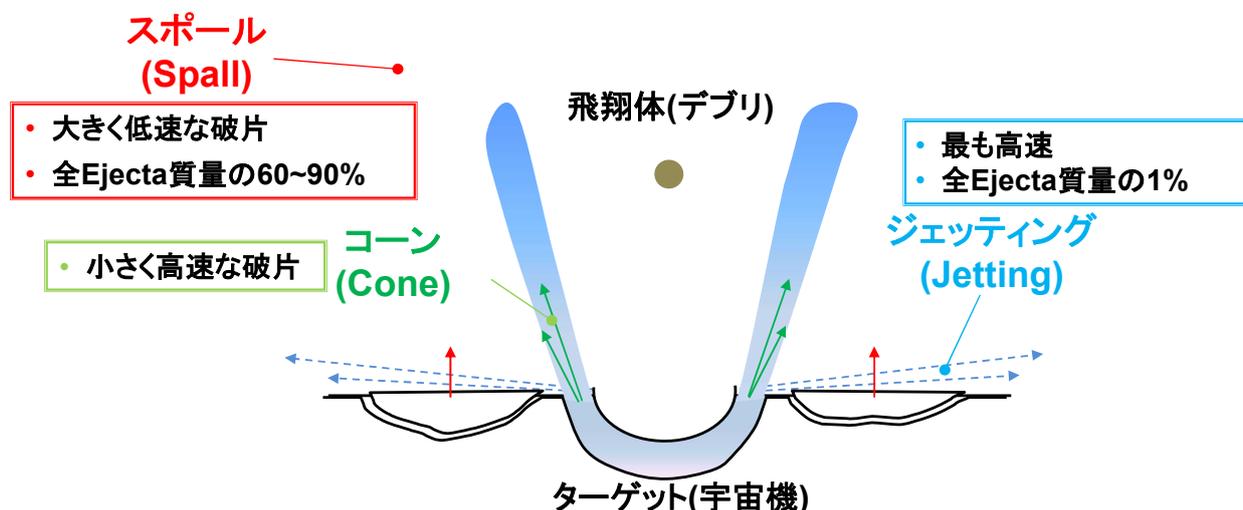
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研究背景 Research background

Ejecta

スペースデブリが宇宙機等に衝突した際に生じる二次的なデブリ

Secondary debris created when space debris impact with spacecraft, etc.



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研究背景 Research background

静止軌道でのデブリ環境モデル

Debris flux in (GEO)

SSPSの面積が6km²場合

If SSPS area is 6 km²

MMODとの衝突

Impact between SSPS and MMOD

○100μm以上 数千万回

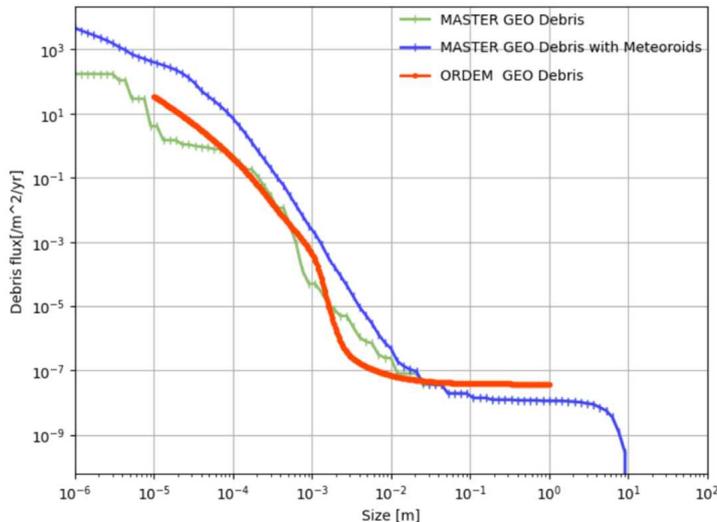
100 μm or more

Tens of millions of times

○1mm,1cm以上 数千回

1mm,1cm or more

Thousands of times



Debris flux in GEO analyzed with different debris environment models

S.Kawamoto, IAC-22-B6.5.10,(2022)

Ejecta発生の可能性
Possible Ejecta Occurrence

研究背景 Research background

静止軌道でのデブリ環境モデル

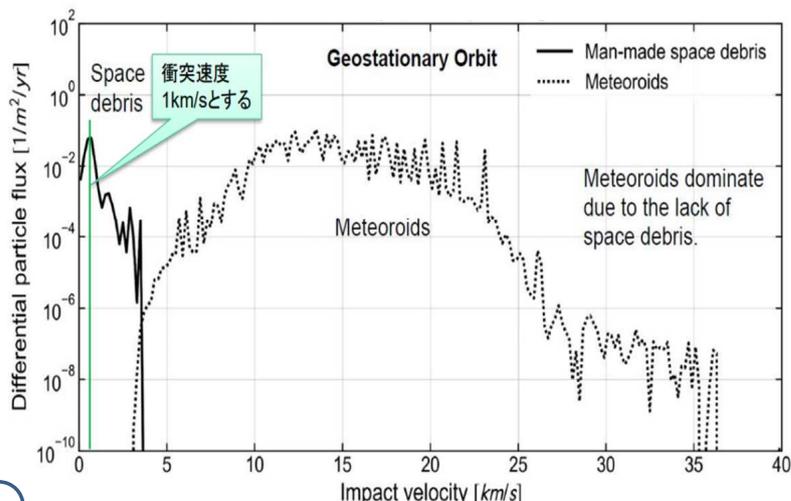
Debris flux in (GEO)

静止軌道では
衝突速度1km/sにおいて
衝突確率頻度が高い

Impact velocity of debris
at the largest debris flux
in GEO is about 1km/s



衝突速度1km/s付近での
イジェクタ評価が必要



ESA MASTER-8Model

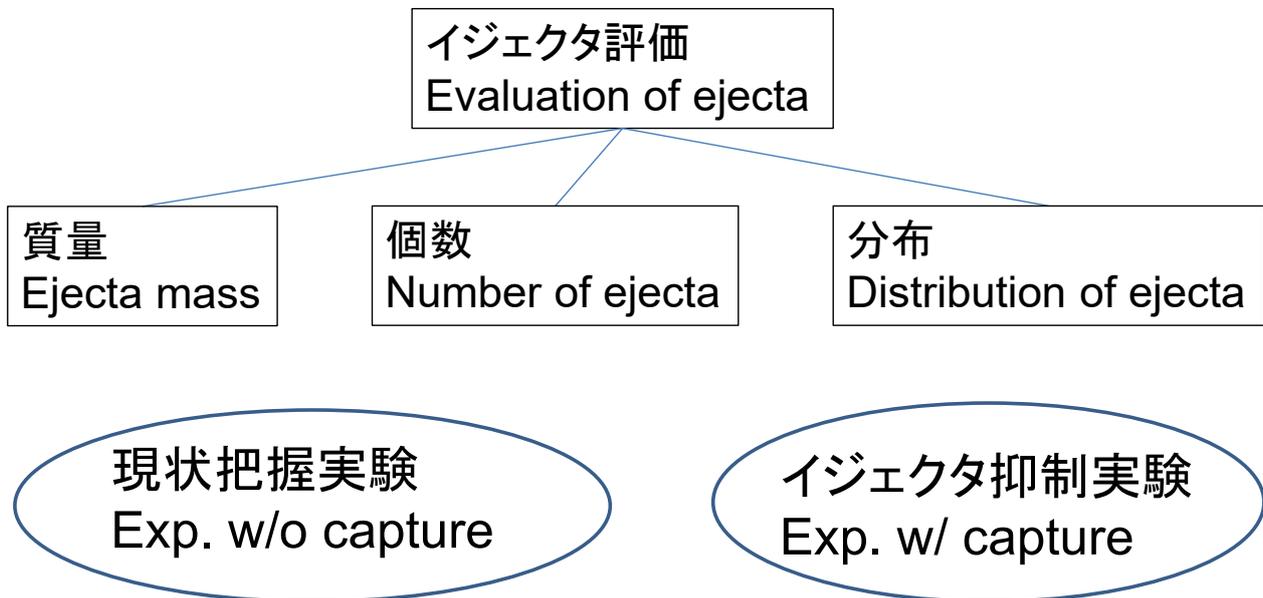
Differential mean flux (11/2015-11/2016), objects>0.1mm
Earth-oriented GEO (35,786km), leading front surface

C.Widermann et al., 9th Space Debris Workshop(2021)

研究目的 Research Purpose

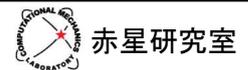
衝突実験を用いた静止軌道上でのイジェクタ評価

Evaluation of ejecta in GEO using impact experiments



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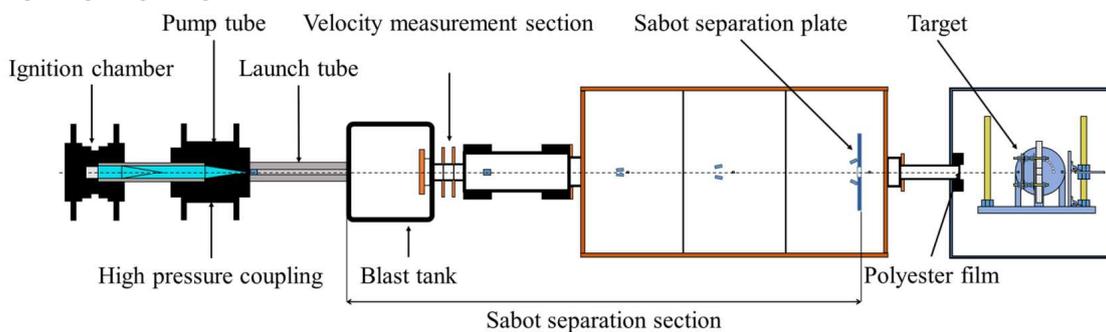
6



実験装置 Experimental equipment

二段式軽ガス銃

Two stage light gas gun



Material : A2017
Diameter : $\phi 1.0 \pm 0.1 \text{ mm}$
Mass : 1.5 mg

Projectile

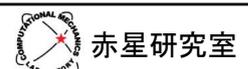


Material : PC
Diameter : $\phi 6.0 \text{ mm}$
Mass : 120 mg

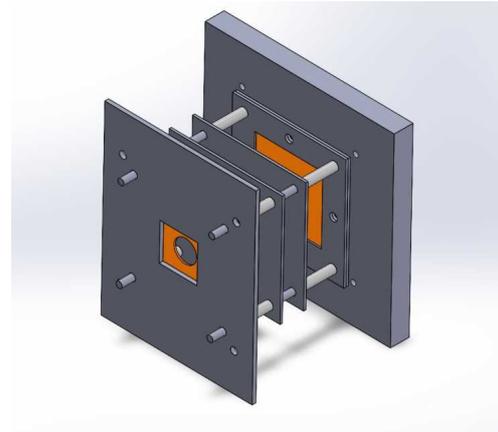
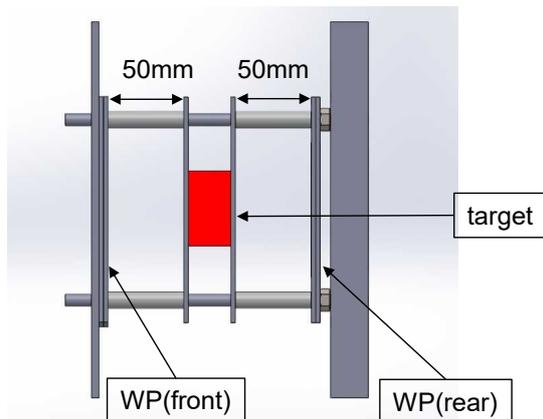
Sabot

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実験条件 Experimental conditions



Target	Spacecraft Materials
Impact Velocity	$1.2 \pm 0.2 \text{ km/s}$
Witness Plate	Copper Plate (C1100-O)

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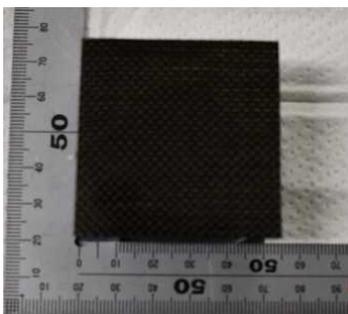
8



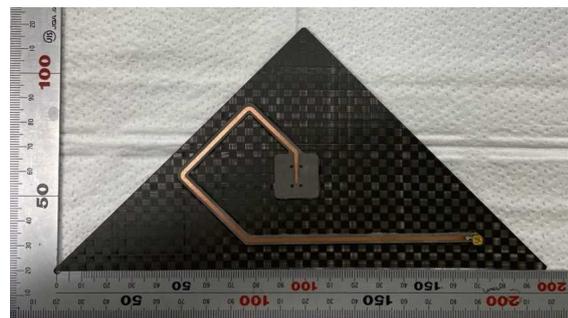
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実験条件 Experimental conditions

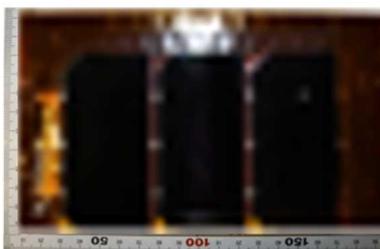
Target



Honeycomb



Triangular antenna



Solar cell front



Solar cell rear

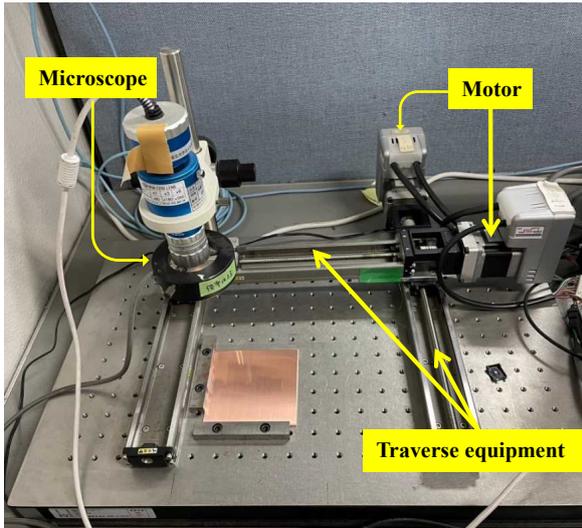
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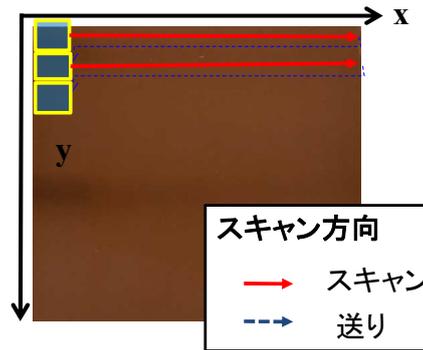
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WP解析方法 WP Analysis Method



Microscope Systems

Magnification	Resolution [pixels]
60 ~ 360	1600 x 1200



Analysis Procedure

Scanning of the entire surface of the Witness Plate before and after the experiment

Differential processing before and after experiment

Detect impact scar coordinates and size

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実験結果 Experimental results

現状把握実験(Exp. w/o capture)

Experiment Number	Target	Impact Velocity[km/s]
#1STS22-40	Honeycomb	
#2STS22-41	Antenna	
#3STS22-42	Solar cell (front→rear)	1.2±0.2
#4STS22-46	Solar cell (rear→front)	

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実験結果 Experimental results

#1(honeycomb)
STS22-40

Impact Velocity(km/s)	1.23
Projectile mass(mg)	1.5
Ejecta mass(mg)	0.5
Penetrating hole(mm)	
front	0.967 × 0.949
rear	0.813 × 0.700

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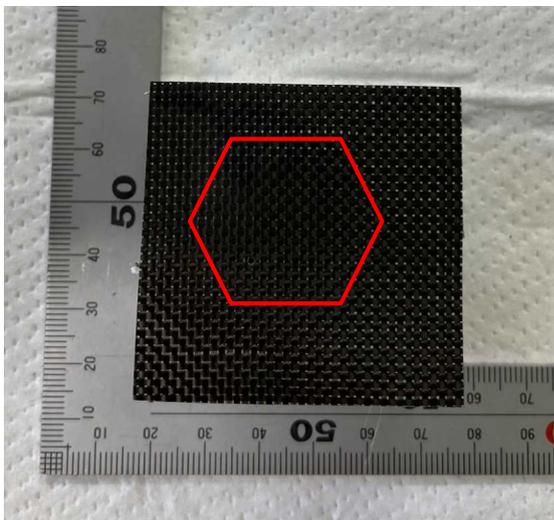


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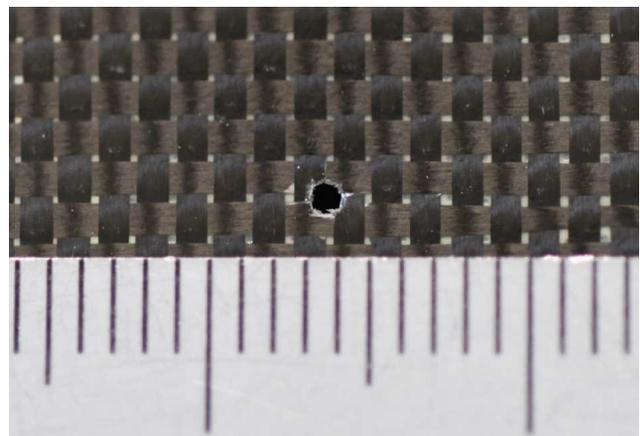
実験結果 Experimental results

#1(honeycomb)
STS22-40

Front hole
0.967 × 0.949mm



Overall view



impact side

Enlarged view

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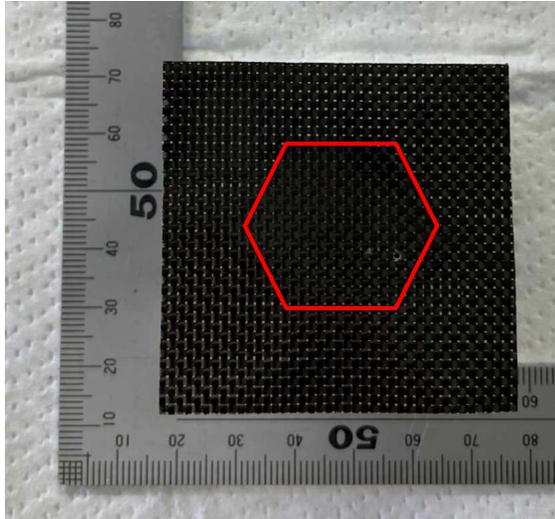


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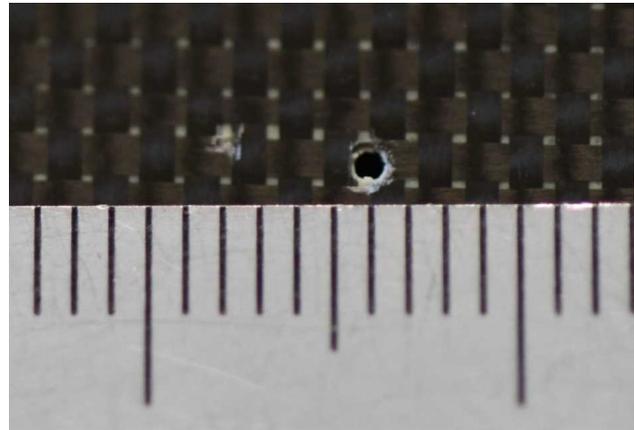
実験結果 Experimental results

#1(honeycomb)
STS22-40

Rear hole
0.813 × 0.700mm



Overall view



rear side

Enlarged view

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実験結果 Experimental results

#2(Antenna)
STS22-41

Impact Velocity(km/s)	1.19
Projectile mass(mg)	1.5
Ejecta mass(mg)	2.5
Penetrating hole(mm)	
front	0.750 × 0.717
rear	0.803 × 0.755

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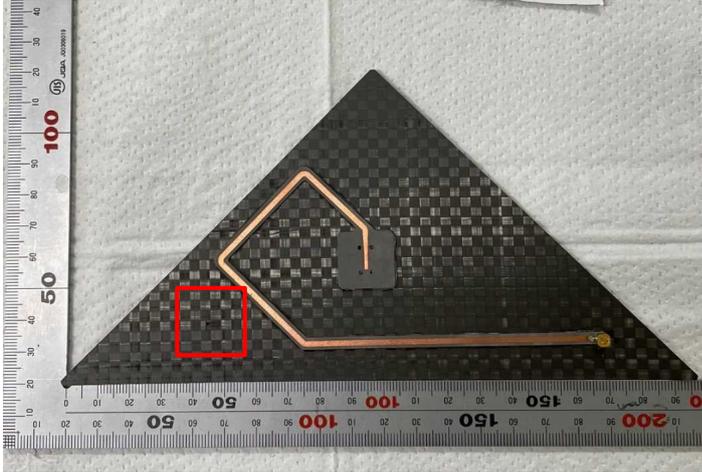


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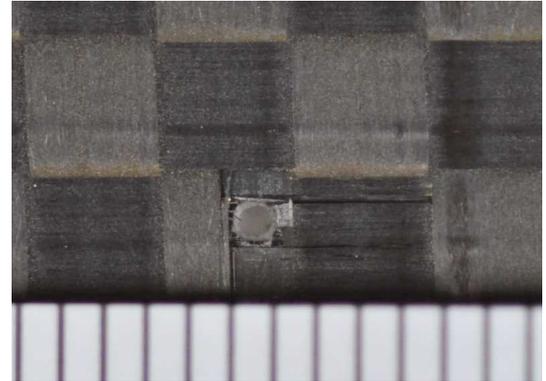
実験結果 Experimental results

#2(Antenna) STS22-41

Front hole
0.750 × 0.717mm



Overall view



Enlarged view

impact side

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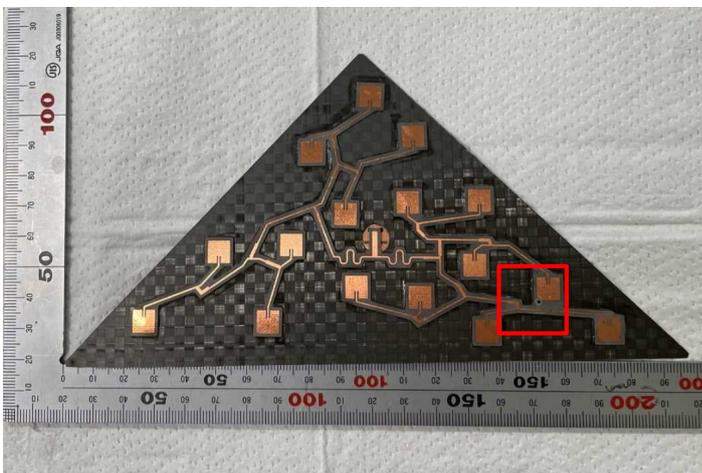


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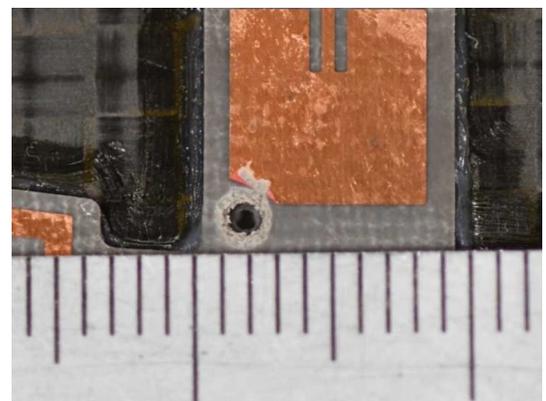
実験結果 Experimental results

#2(Antenna) STS22-41

Rear hole
0.803 × 0.755mm



Overall view



Enlarged view

rear side

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実験結果 Experimental results

#3(Solar cell front→rear)
STS22-42

Impact Velocity(km/s)	1.07
Projectile mass(mg)	1.5
Ejecta mass(mg)	2.9
Penetrating hole(mm)	
front	0.477 × 0.468
rear	2.194 × 2.296

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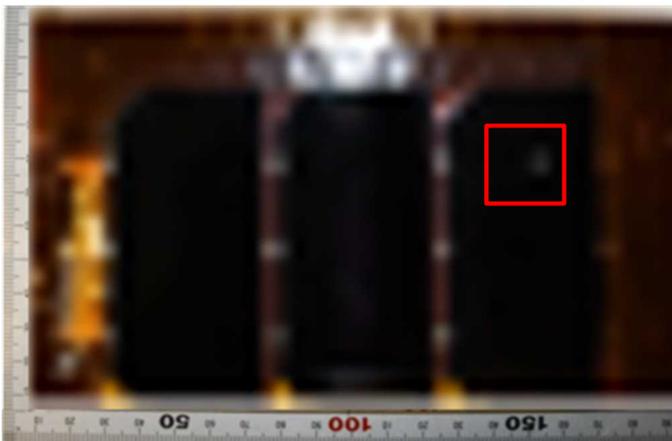


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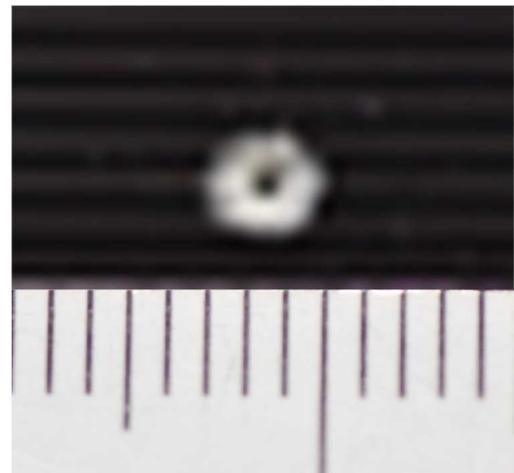
実験結果 Experimental results

#3(Solar cell front→rear)
STS22-42

Front hole
0.477 × 0.468mm



Overall view



Enlarged view

impact side

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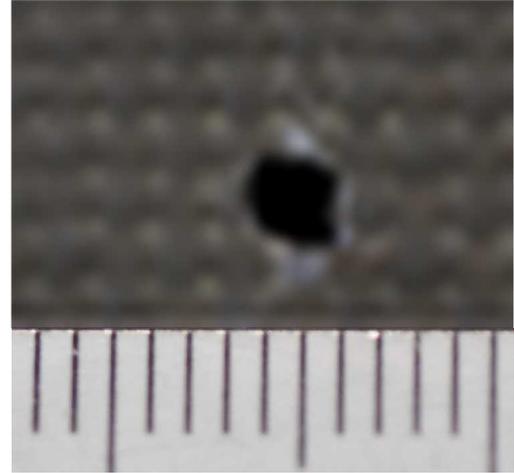
実験結果 Experimental results

#3(Solar cell front→rear) STS22-42

Front hole
2.194 × 2.296mm



Overall view



Enlarged view

rear side

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実験結果 Experimental results

#4(Solar cell rear→front) STS22-46

Impact Velocity(km/s)	1.35
Projectile mass(mg)	1.5
Ejecta mass(mg)	7.5
Penetrating hole(mm)	
front	0.986 × 0.976
rear	0.608 × 0.608

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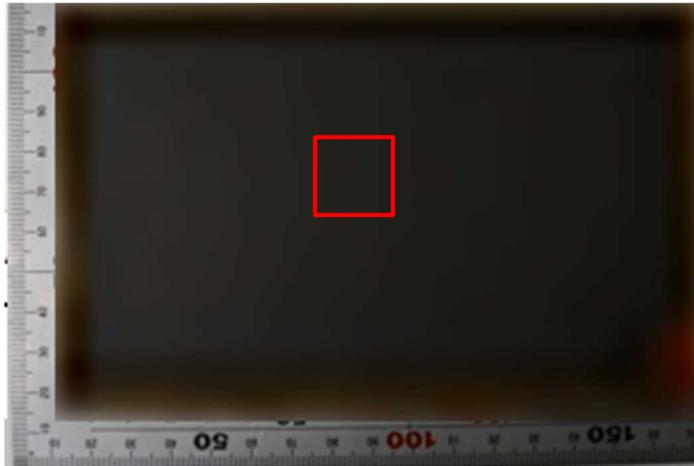


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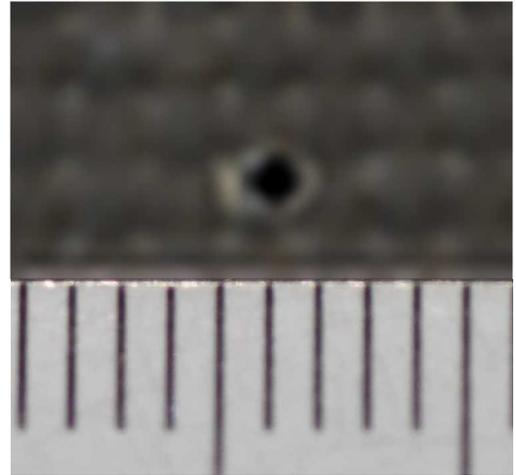
実験結果 Experimental results

#4(Solar cell rear→front)
STS22-46

Front hole
0.986 × 0.976mm



Overall view



Enlarged view

impact side

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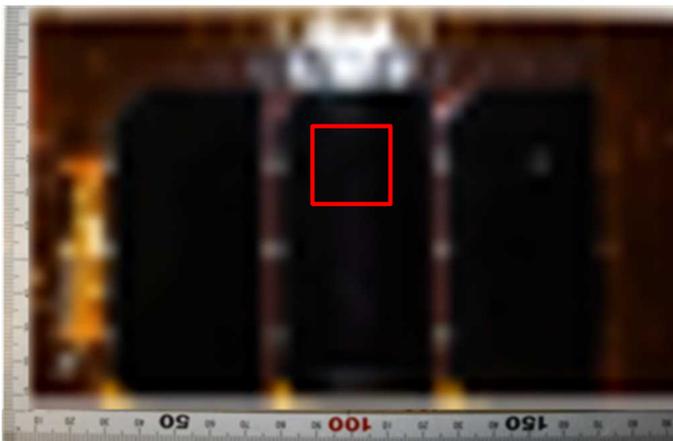


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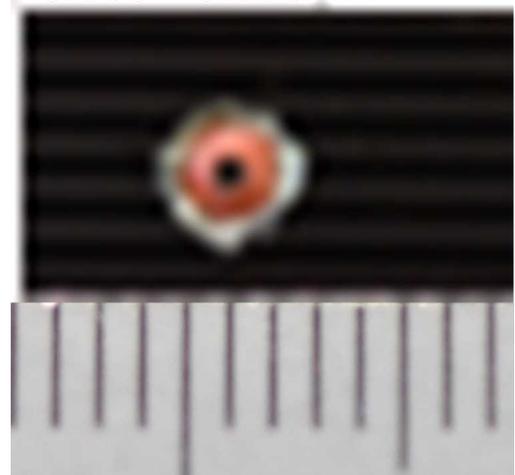
実験結果 Experimental results

#4(Solar cell rear→front)
STS22-46

Front hole
0.608 × 0.608mm



Overall view



Enlarged view

rear side

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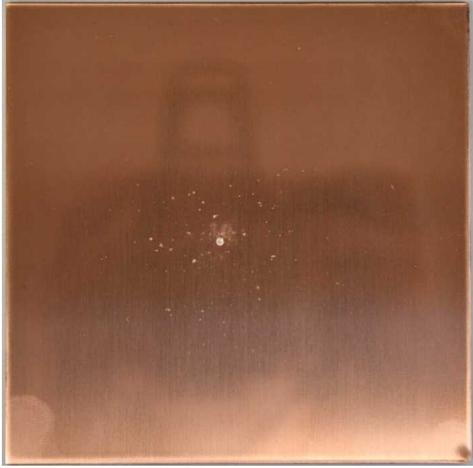


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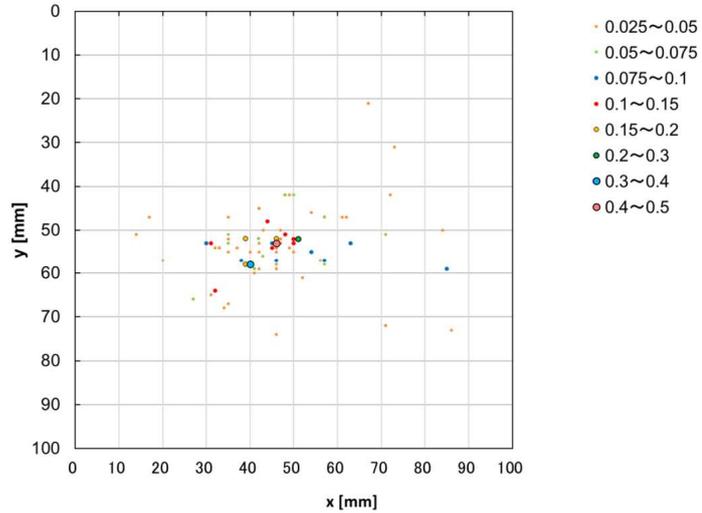
実験結果 Experimental results

WP分布図

#2(Antenna)STS22-41



WP Overall view



crater distribution on WP

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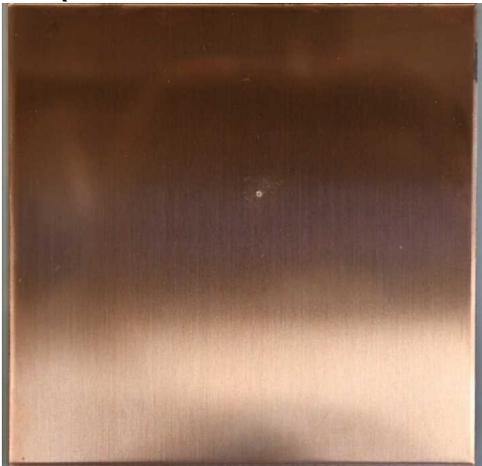


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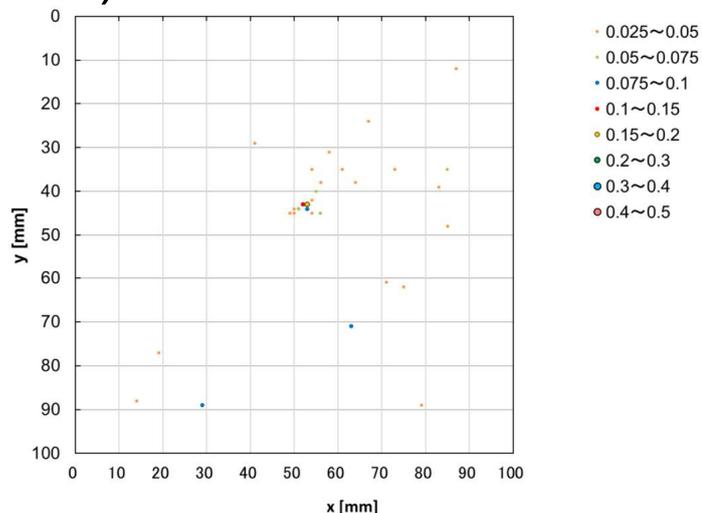
実験結果 Experimental results

WP分布図

#3(Solar cell front→rear)STS22-42



WP Overall view



crater distribution on WP

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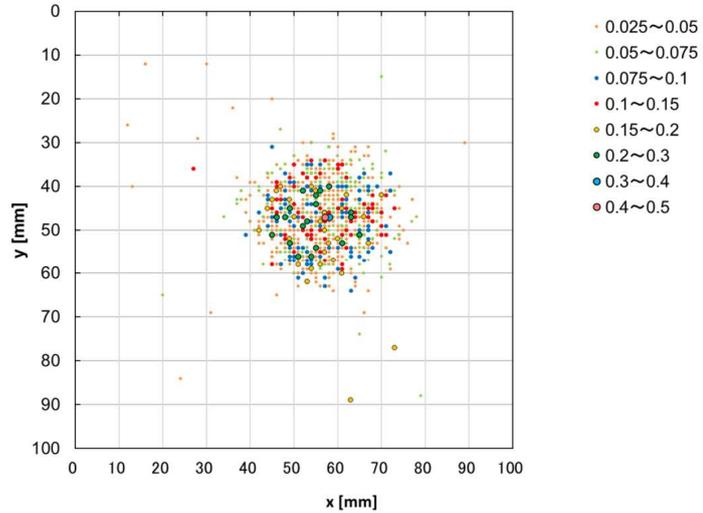
実験結果 Experimental results

WP分布図

#4(Solar cell rear→front)STS22-46



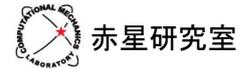
WP Overall view



crater distribution on WP

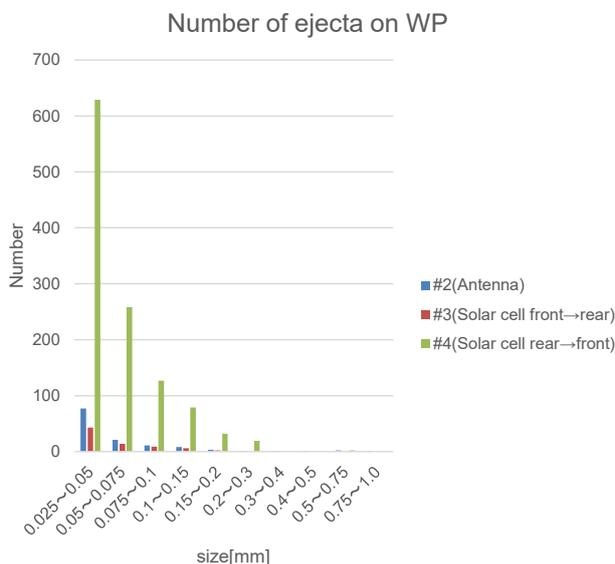
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実験結果 Experimental results

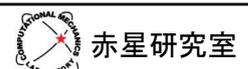
Number of ejecta on rear WP



Ejecta size(mm)	Number of Ejecta		
	#2(Antenna)	#3(Solar cell front→rear)	#4(Solar cell rear→front)
0.025~0.05	77	43	629
0.05~0.075	21	14	258
0.075~0.1	11	9	127
0.1~0.15	8	6	79
0.15~0.2	3	2	32
0.2~0.3	1	0	19
0.3~0.4	1	0	1
0.4~0.5	1	0	1
0.5~0.75	2	0	2
0.75~1.0	1	0	0

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実験結果 Experimental results

Ejecta mass and number

Experiment number	Ejecta mass(mg)	Number of ejecta on rear WP(0.1 mm or more)
#1(Honeycomb)	0.5	-
#2(Antenna)	2.5	17
#3(Solar cell front→rear)	2.9	8
#4(Solar cell rear→front)	7.5	134

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今後の実験計画 Plan of experiment

	Target	Impact Velocity[km/s]
現状把握実験 (Exp. w/o capture)	Honeycomb	About 3.5
	Antenna	
	Solar cell (front→rear)	
	Solar cell (rear→front)	
	Irradiated honeycomb	
	Irradiated Solar cell (front→rear)	
	Irradiated Solar cell (rear→front)	
イジェクタ抑制実験 (Exp. w/ capture)	Solar cell + capture	1.2±0.2

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