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Simultaneous Measurements of Electrical Phenomena Induced by Space Debris Impact

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Space debris impact (i.e. hypervelocity impact) generates not only mechanical phenomena such as generations of a crater and secondary debris but also electrical ones such as plasma generation, radiofrequency emission, impact flash, and variation in electrical potential of the impacted target. We conducted hypervelocity impact experiments using the two-stage light gas gun installed at ISAS/JAXA. We used a high-speed video camera, a photodetector, a strike camera spectroscopy, plasma probes, and microwave receivers to measure electrical phenomena induced by hypervelocity impact at the same time. Plasma from hypervelocity impact is generated during dozens of microseconds and may trigger to an electrical discharge of spacecraft. For instance, an impact on the solar paddle or the power harness of satellites may generate a sustained discharge via plasma interaction and a short-circuit path is created in the worst case. In terms of the radiofrequency emission, the microwave emission from hypervelocity impact have been confirmed. The microwave with intermitted pulses with a periodic time of several nanoseconds is emitted until several milliseconds. The mechanism of the microwave emission is still unknown, but we expect the energy estimation of space debris impact using microwave remotely as one of the application techniques.

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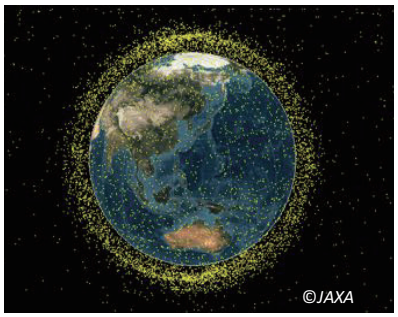
Physical Phenomena from Space Debris Impact

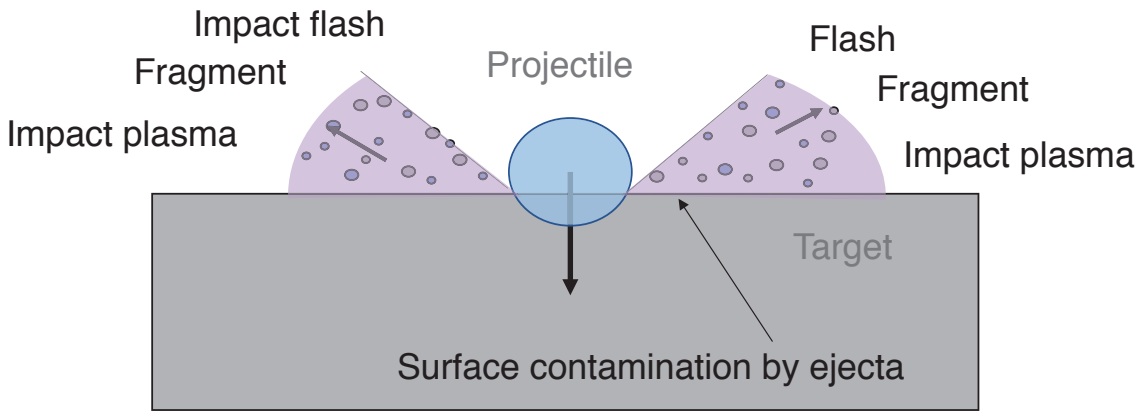
- Space debris: abandoned man-made satellites, rocket bodies, and their fragment
- Debris travels at a speed of 7-8 km/s in a low Earth orbit (i.e. hyper-velocity).
- It is hard to detect debris with size of less than 1 cm by telescope and radar system



Mechanical Phenomena	Electrical Phenomena
• Cratering	• Impact plasma
• Impact fragmentation	• Impact flash
	• Radiofrequency (RF) emission

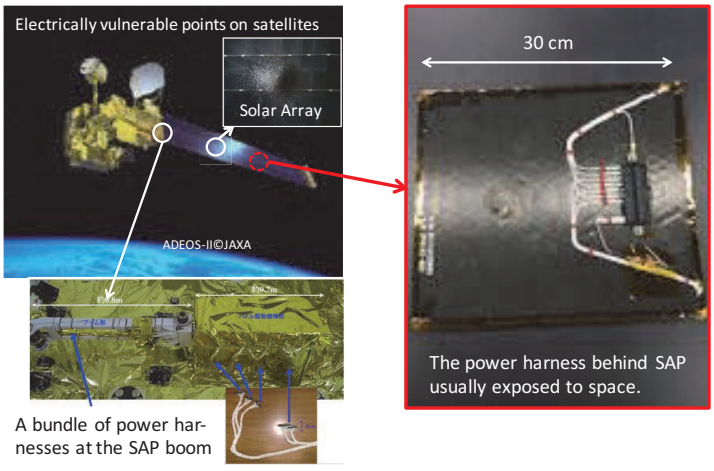
Plasma and Flash Induced by Hypervelocity Impact

- **Ejecta:** fragment, neutral gas, and ionized gas (i.e. plasma)
- **Fragment:** expansion of mechanical failure to spacecraft.
- **Neutral and ionized gas:** surface contamination, induction to discharge via plasma interaction



Risk of Plasma Generation

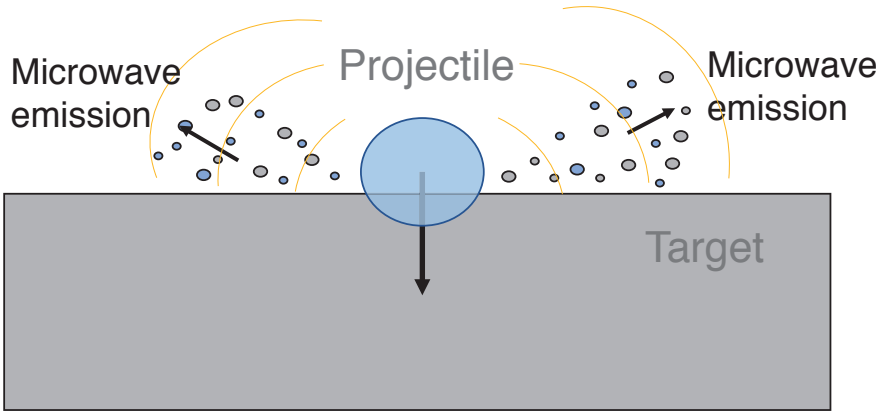
- Impact on the solar array or the power harness may generate a sustained discharge via plasma interaction and a short-circuit path is created in the worst case[1-3].



[1] T. Hirai, et.al., Hypervelocity Impact Symposium, 2016.
[2] 東出, 他, 宇宙科学連合会, 2018.
[3] S. Kawakita, 2nd International Energy Conversion Engineering Conf.,2004.

Radiofrequency Emission from Hypervelocity Impact

- Radiofrequency emits with a wide band from several kHz to microwave bands[4,5].
- Microwave Emission includes a sequent of pulses with a periodic time of several *ns* for several *ms*[6].



[4] R. Bianchi, et al., Nature, 1984.
[5] T. Takano, et al., Journal of Applied Physics, 2002.
[6] Y.Mando, 69th International Astronautical Congress, 2018.

Objective

- Organizing each electrical phenomena **by simultaneously measuring plasma, flash, and microwave emissions.**
- Investigating the electrical phenomena from the impact on **various kinds of aluminum plates, which are commonly used for the metal of spacecraft's structure.**

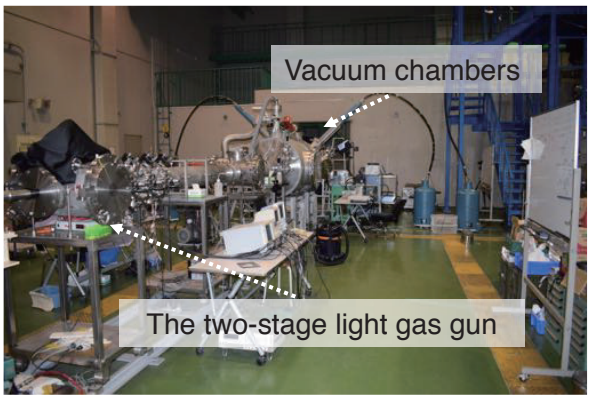
Methods

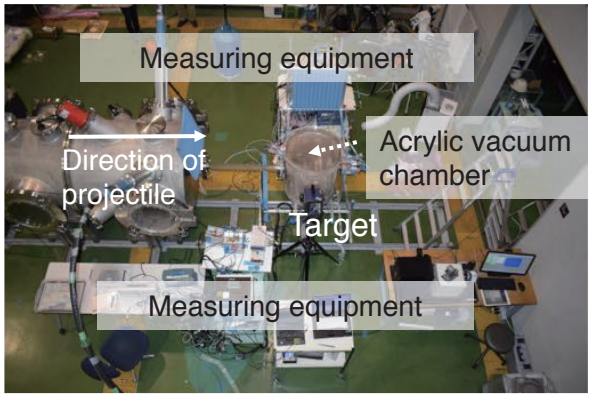
- To simulate space debris impact, the ground-based experiment using **the two-stage light gas gun** was used.

- Electrical phenomena induced by the impact was measured by using **the high-speed video camera, the photodetector, the streak camera spectroscopy**, **plasma probes, and microwave receivers**.

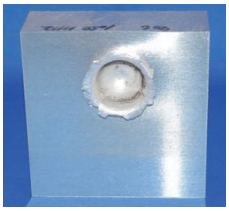
Experimental Setups

The two-stage light gas gun installed in ISAS/JAXA





Targets and Projectile

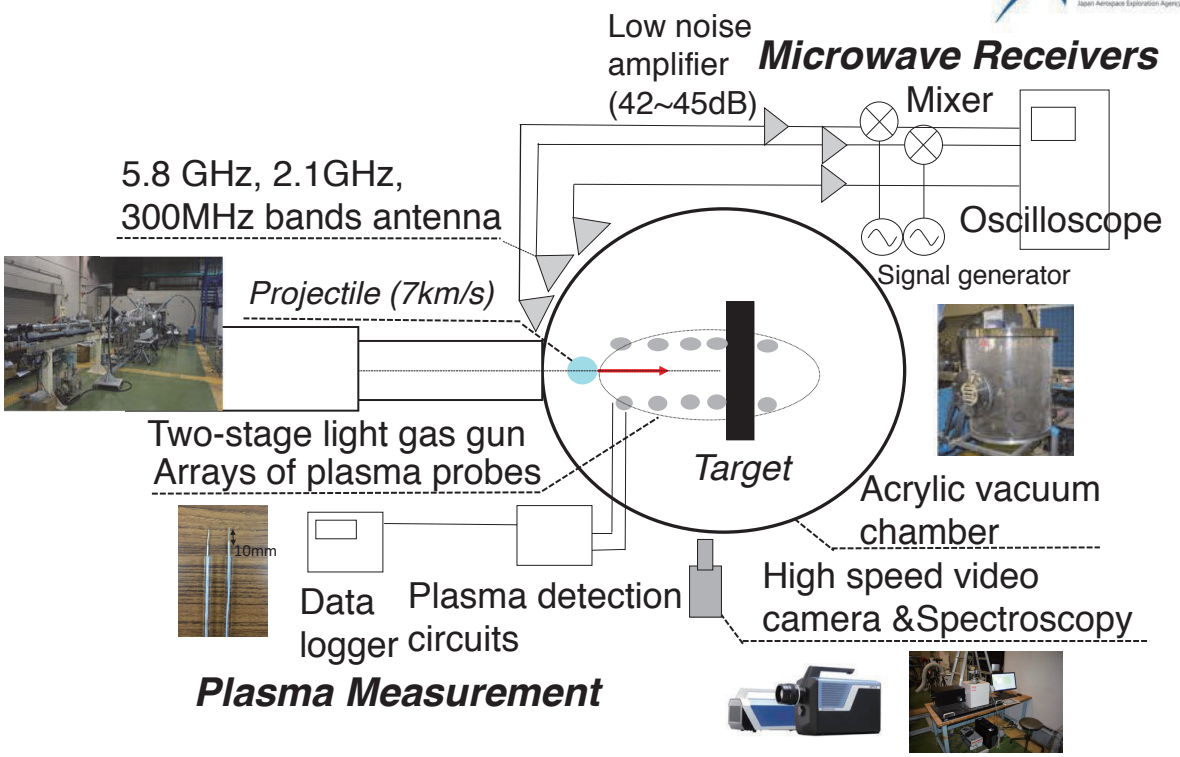


Target: Aluminum Plates
(1050, 5052, 6061, 7075)
(size: 110mm*110mm*t40mm)

Chemical Composition
1050: Pure Aluminum(99.5%-)
5052: Al, Mg(2.2-2.8%)
6061: Al, Mg(0.8-1.2%), Si(0.4-0.8%)
7075: Al, Zn(5.1-5.6%), Mg(2.1-2.9%)

Projectile:
Nylon sphere
(Velocity: 7km/s)

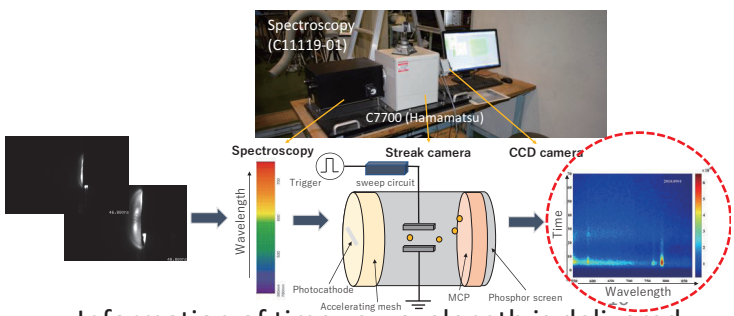
Experimental Setup



Observation of Luminous Cloud

High-speed video camera	
Specification	
Flame Speed	2 μs
Num. of flames	100 flames
Obs. time	100 μs
Objective	Propagation of the luminous cloud

Streak camera spectroscopy	
Specification	
Wavelength	547-872 nm
Time resolution	0.1 μs
Observation time	100 μs
Objective	Temperature Estimation
	Emission line identification

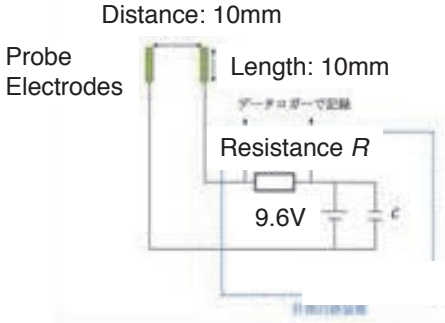


Information of time vs wavelength is delivered.

Plasma Diagnosis

Double Probe Method

- Constant voltage of 9.6V is applied.
- Assume that the applied voltage is enough to get the plasma current I_{io}.



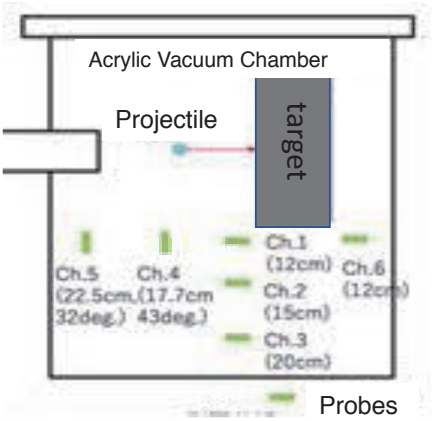
Measurement circuit

$$I_{io} = 0.61 N_e e S \left(\frac{kT_e}{m_i}\right)^{1/2}$$

I_{io}: Probe current; N_e: Electron density; T_e: Electron temperature; m_i: Mass of ion

Arrangement of Probes

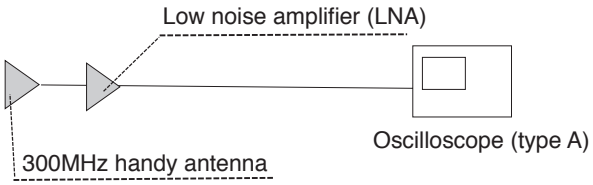
To investigate propagation of plasma, arrays of probes are arranged.



Microwave Receivers

300MHz receiving system

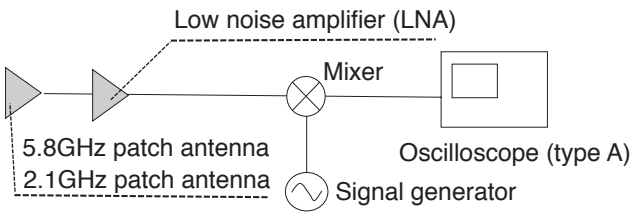
- The amplified signals are directly recorded to the oscilloscope.



(a) 300MHz receiver

2.1G and 5.8GHz receiving systems

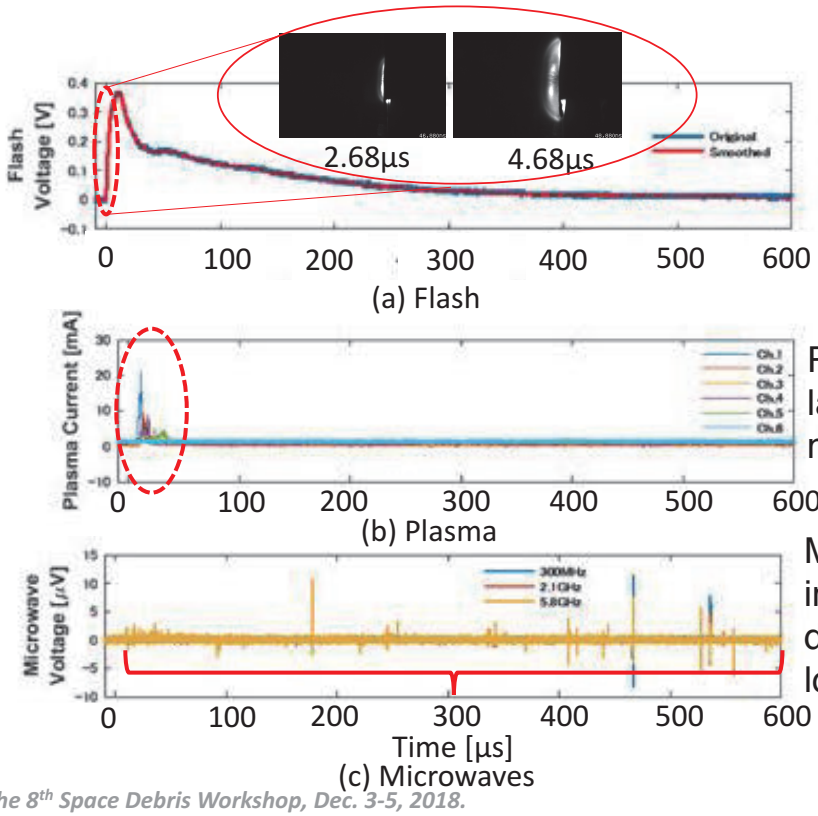
- Due to limiting the frequency range of oscilloscope, the heterodyne system is applied.



(b) 2.1GHz and 5.8GHz receivers

The oscilloscope set observation time of 10ms and the sampling rate not less than 500MSa in order that it is enough to measure signals.

Simultaneous Measurements

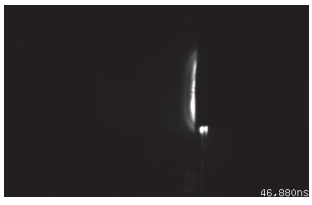


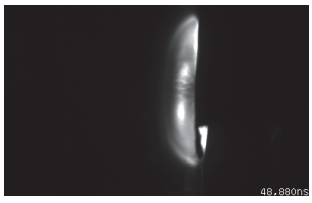
Plasma phenomenon lasts for dozens of microseconds.

Microwave emits intermittently and the duration time is much longer than one of plasma.

Propagation of Impact Flash

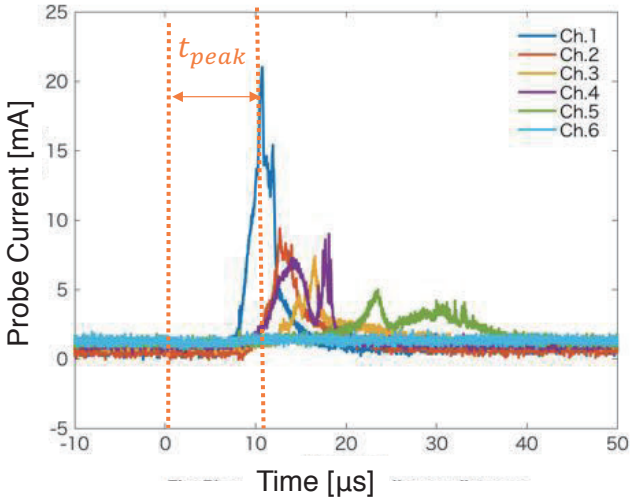
Photos by high-speed video camera

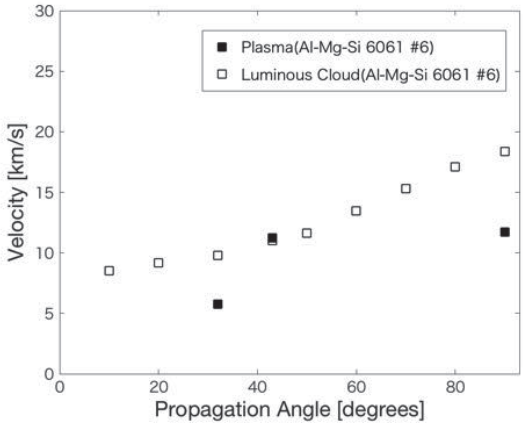

2.68μs


4.68μs

- Luminous cloud generates and suddenly propagates from the impact point.
- The propagation of the luminous cloud seems to be different depending on the angle.

Comparison between Propagation Velocity of Plasma and One of Flash

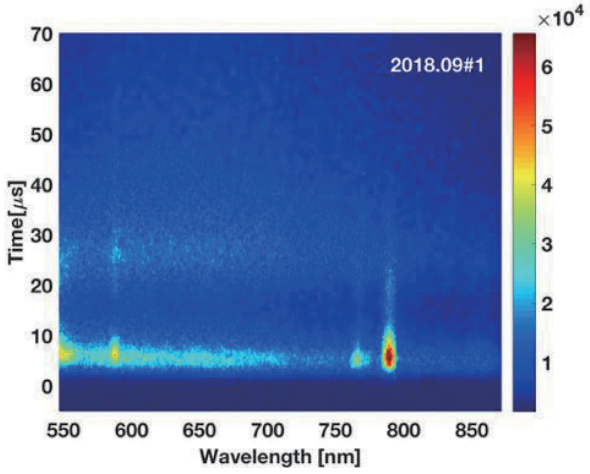




- Plasma propagation velocity was calculated from the time reached at the maximum current at each probe.
- The velocity of impact flash is similar to the one of plasma velocity. It means that impact flash includes the ionized gas (i.e. plasma).
- The propagation velocity is generally the highest along the surface of the target and decreases with the angle from the surface.

Spectroscopic Measurement

Line Emission Identification



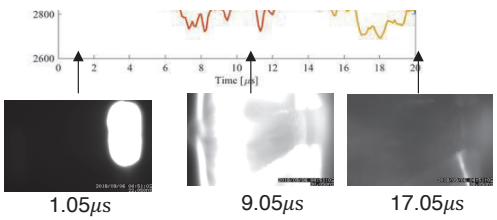
Temperature Estimation

Fitting with data points under the Plank Radiation Formula

$$B(\lambda) = \frac{8\pi hc}{\lambda^5}\left\{exp\left(-\frac{hc}{\lambda k_B T}\right) - 1\right\}$$

Temperature

Temperature from approximately 2800 to 3700K was obtained.

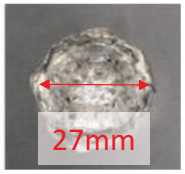


1.05μs 9.05μs 17.05μs

The information is useful to estimate the plasma density more precisely in case of combinations of different target and projectile materials.

Microwave Emissions from Al-Zn-Mg (7075) Aluminum Plate

Short Duration

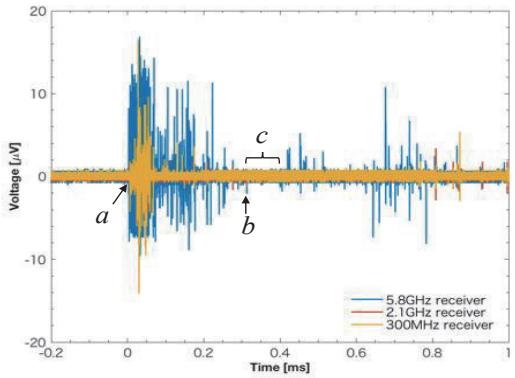


The crater scar

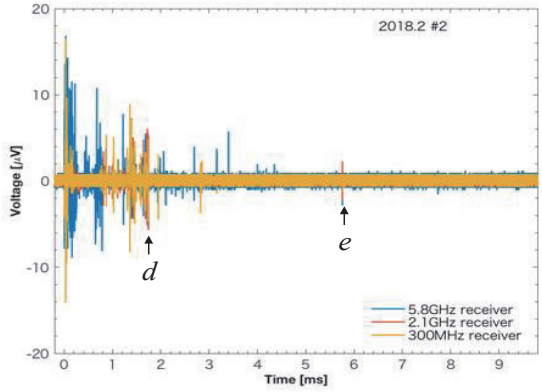
- Pulse signal at each frequency band firstly appeared at several microseconds.
- The sequence of pulses continues intermittently at 0.31ms of point *b.*

Whole duration

- Pulse signals with large and small amplitude repeatedly emit and become sparse from 1.74ms of point *d.*
- The emission continues till 5.76ms of point *e*.



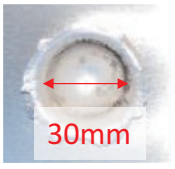
(a) Short duration



(b) Whole duration

Comparison of Microwave Emissions from other aluminum plates

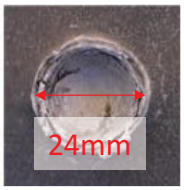
In case of the Al (1050) plate



The crater scar

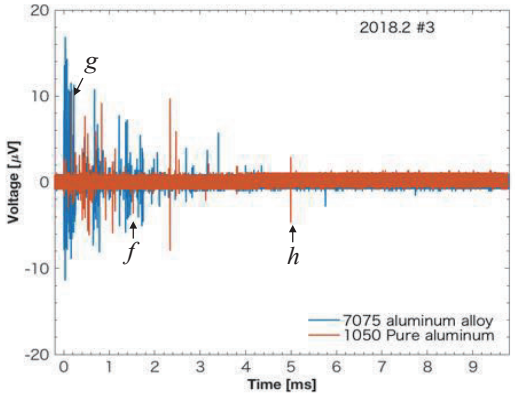
- The first pulse signal appeared at 2.55μs.
- The sequence of weaker pulse signals continues at 1.53ms of point f.
- The duration time is 5.0ms at point *h*.

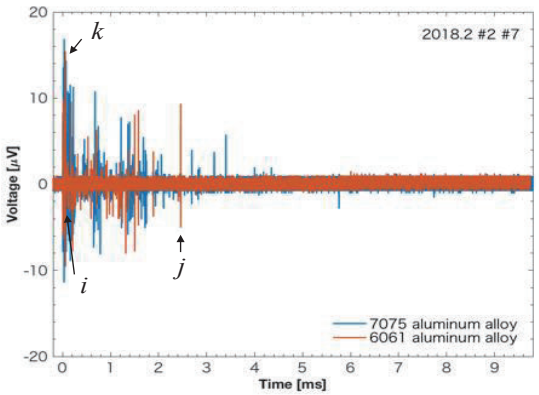
In case of Al-Mg-Si (6061) plate



The crater scar

- The first pulse signal appeared at 3.67μs.
- The sequence of pulse signals continues at 65.8μs of point *I* and then becomes sparse.
- The duration time is 2.46ms at point *f*.





Conclusions & Future works

Hypervelocity impact experiments were conducted. Each electrical phenomenon could be measured and observed at the same time.

1. Phenomena of plasma generation and microwave radiation are totally difference in duration time.
2. Propagation and line emission of flash and plasma were investigated. We will expect to estimate the plasma density more precisely in case of combinations of different target and projectile materials.
3. From various aluminum plates, there are three kinds of pulse signals and the periodic time ranges from 4 to 14ns. The duration time is several ms but the timing of pulse appearance depends on target materials.
4. As a future perspective, the different combinations of target and projectile materials will be researched.