Introduction to Space Debris and Hypervelocity Impact Test Facilities at Kyushu Institute of Technology

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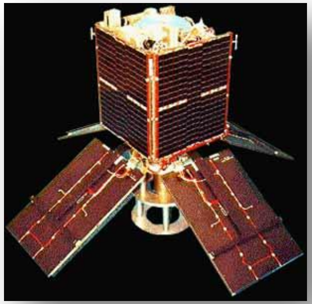
Introduction to Space Debris

Space Debris?

Space Debris?

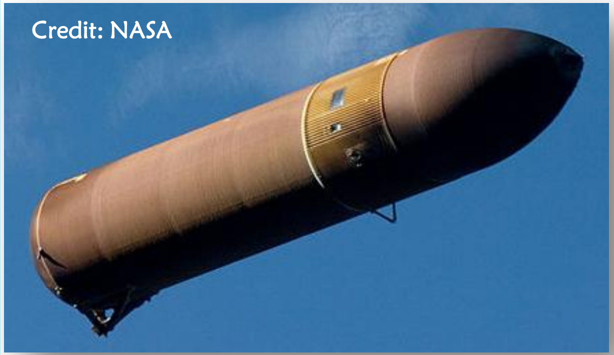
Useless man-made space objects in Earth's orbit or re-entering the Earth's atmosphere

Spent satellites, upper stages, fuel tanks



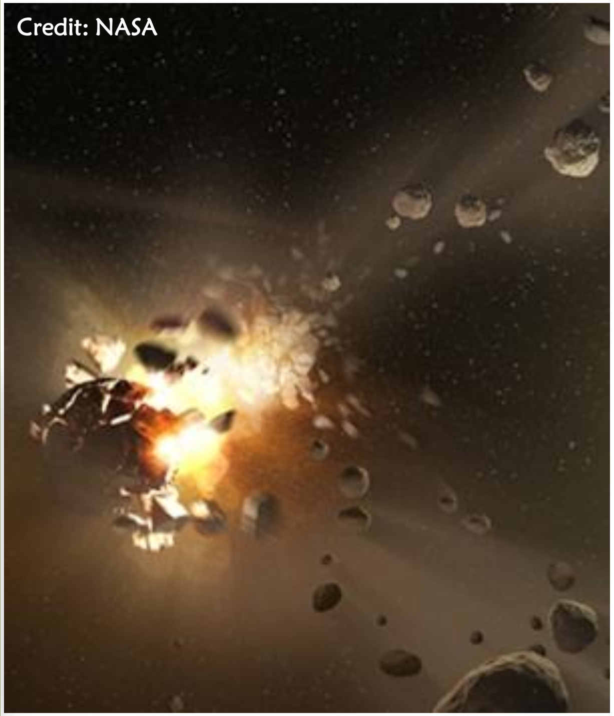
Cerise

Upper stages



Discovery STS-124

Explosions and Collisions Fragments



Mission Related Objects

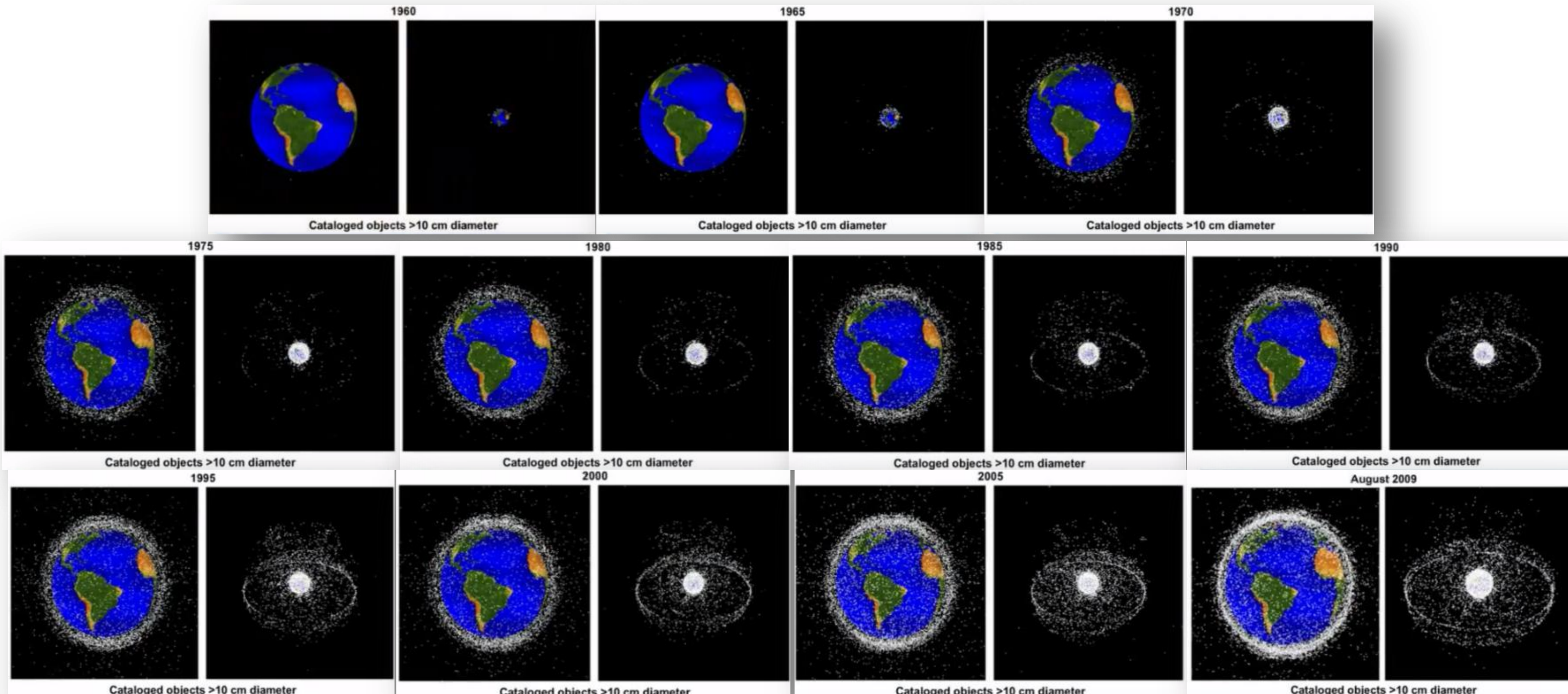
Introduction to Space Debris

How Many Are Out There?

How Many are Out There?

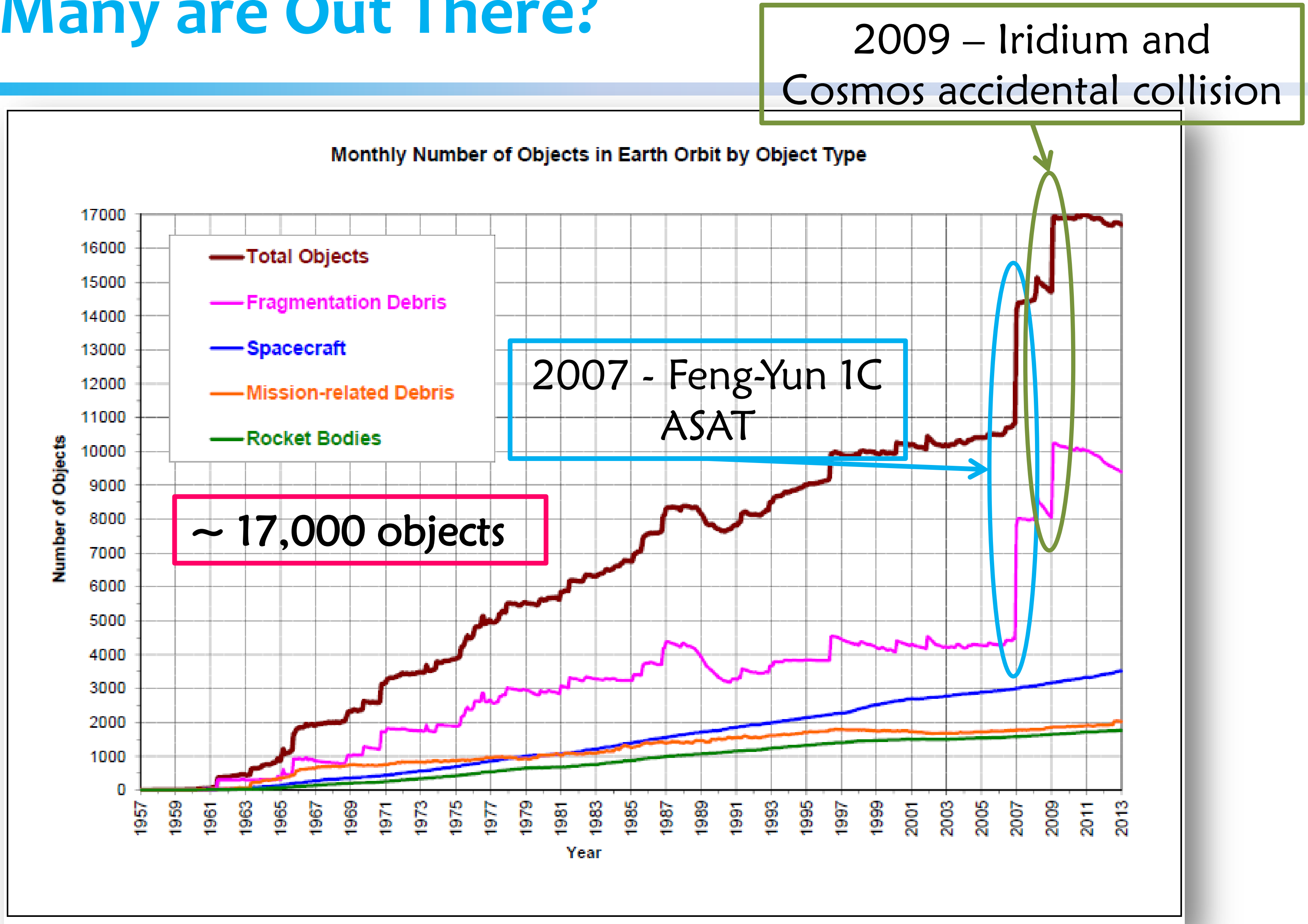
- Space debris vs. Catalog objects

  Catalog objects are space debris that can be tracked by ground observations



Source: The Greening of Orbital Debris – NASA Academy of Program/Project and Engineering Leadership[1]

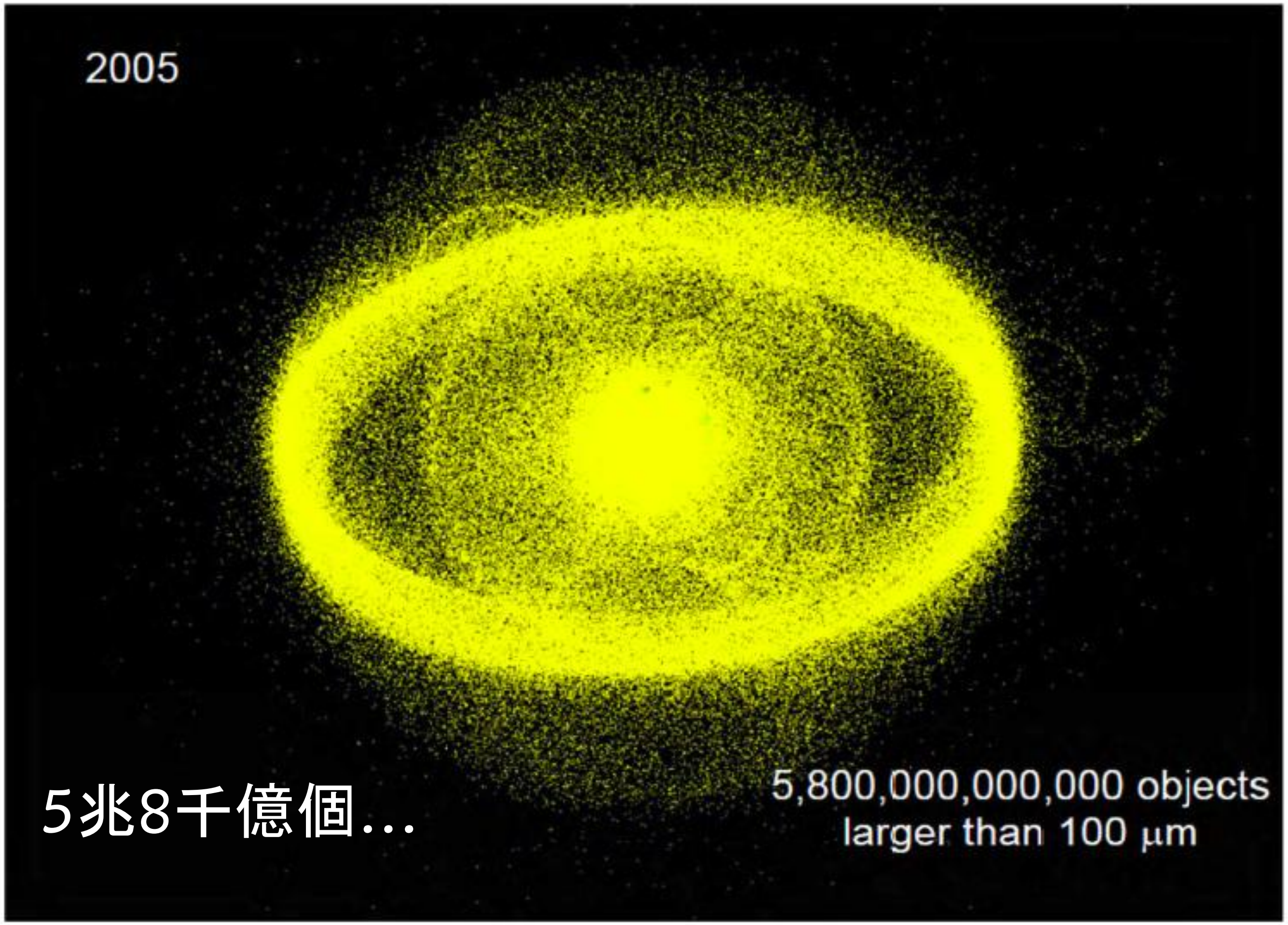
How Many are Out There?



Source: NASA Orbital Debris Quarterly News – January 2013[2]

How Many are Out There?

Space debris > 100 μm



J. Gelhaus, et al., Validation of the ESA-MASTER-2009 space debris population,, 28. Sept. 2010 , IAC Conference 2010, Prague[3]

Introduction to Space Debris

Are Space Debris an Urgent Threat?

Are Space Debris an Urgent Threat?

- Are space debris **a threat?**

  Large space debris (>10 cm) case

  - Since Sputnik about 38,000 catalogued objects in orbit
  - 22,000 objects have re-entered in the atmosphere without causing damage
  - Re-entries with fragments reaching the ground
    - Kosmos-954, 1978
    - Skylab, 11 July 1979
    - Kosmos-1402, 1984
    - Salyut-7 / Kosmos-1686, 7 Feb. 1991
    - Numerous rocket bodies

Fragment of a Delta second stage found in Texas on 22 Jan. 1997 (main propellant tank made of stainless steel, 250 kg)

Are Space Debris an Urgent Threat?

- Are space debris **a threat?**

Large space debris (>10 cm) case

- Since Sputnik about 38,000 catalogued objects in orbit
- 22,000 objects have re-entered in the atmosphere without causing damage
- Re-entries with fragments reaching the ground
- Risk on ground can be minimised by controlled re-entry

January 2011 – Successful re-entry of H-IIB upper stage[4]

Are Space Debris an Urgent Threat?

Small space debris case

- Average orbiting velocity: 7 - 8 km.s^{-1}
- Average impact velocity: 10~15 km.s^{-1}
- Energy equivalences (aluminum sphere)
  - **Ø 1 mm:** tennis ball at 70 km.h^{-1}
  - **Ø 1 cm:** 181 kg safe at 95 km.h^{-1}
  - **Ø 10 cm:** small car at 1,300 km.h^{-1}

10 cm

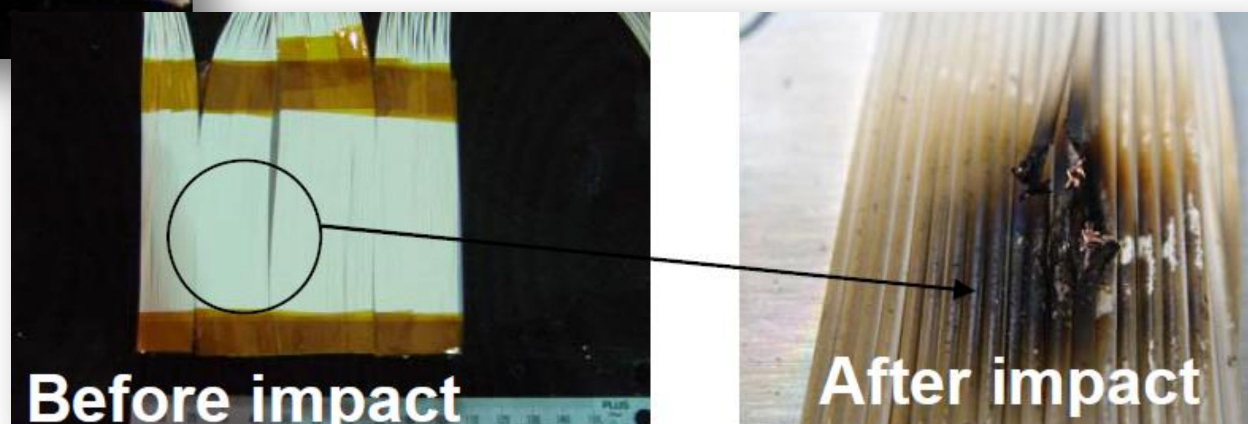
1 mm

1 cm

Are Space Debris an Urgent Threat?

Small space debris case

- Example



Projectile diameter: 0.3 mm, velocity: 4 km.s^{-1}[5]

Are Space Debris an Urgent Threat?

- Are space debris a threat?

  Large or small, debris possible impact on our lives cannot be neglected

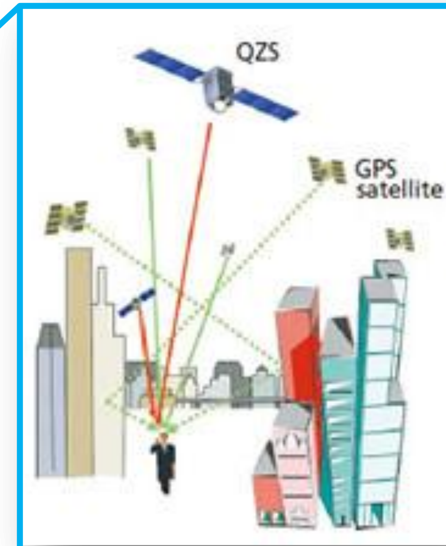
Kizuna - Internet

Michibiki - GPS

Kodama – Data Relay

Shizuku - EO

All pictures' credit: JAXA



- Television
- Telephones
- Navigation
- Business and finance
- Weather
- Climate and environmental monitoring
- Safety
- Science

Are Space Debris an Urgent Threat?

- Are space debris an urgent threat?
  - Operational spacecraft = 6%
    - 94% of debris in space…
    - Area-to-mass ratio factor

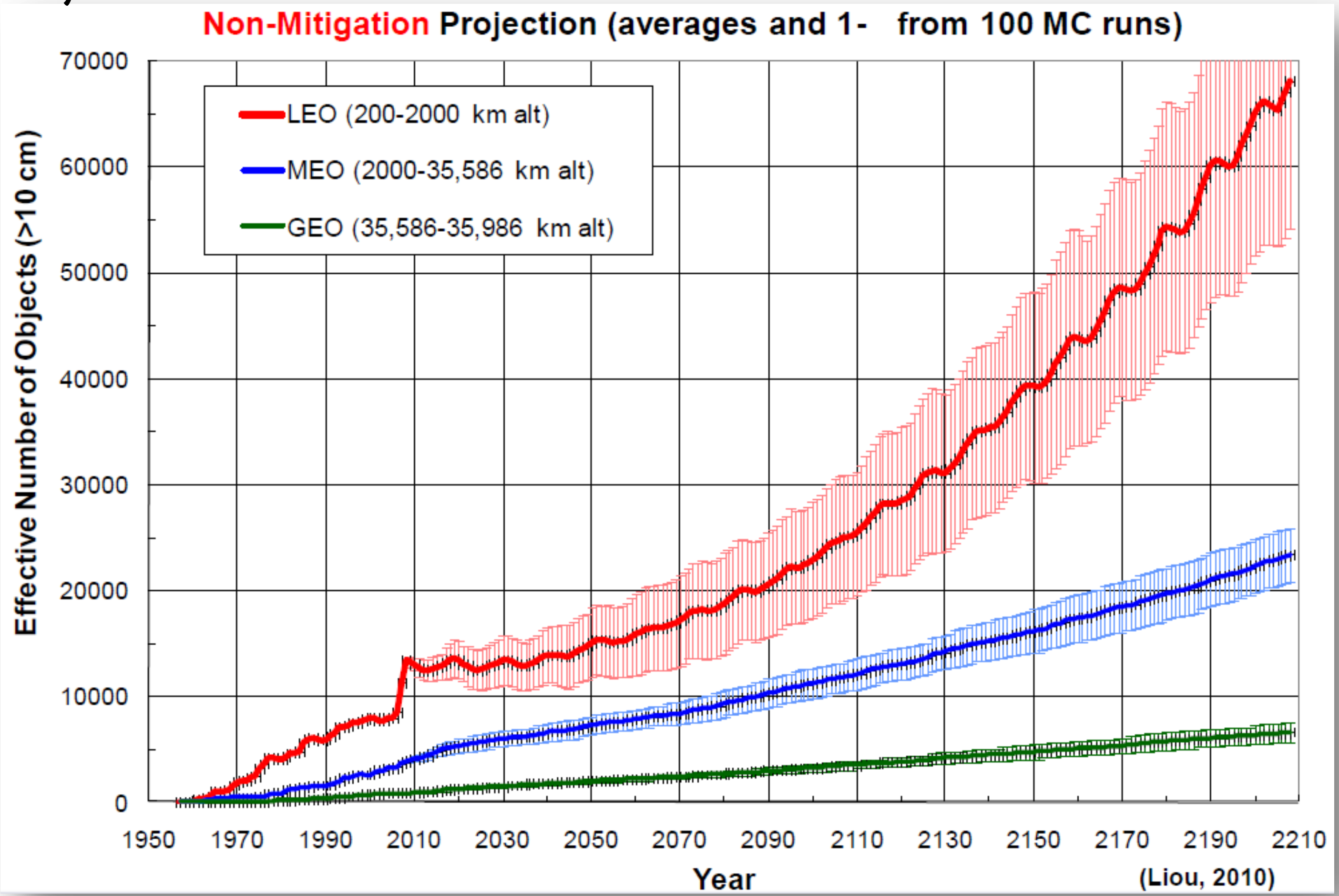
Operational satellites	6%
Intact spacecraft	22%
Rocket bodies	11%
Mission-related objects	7%
Fragments	60%

→ **45% of total debris mass is in LEO**, 28.8% in GEO[6]

→ 34.8% of total debris' cross-section in LEO, **40.9% in GEO**[6]

Are Space Debris an Urgent Threat?

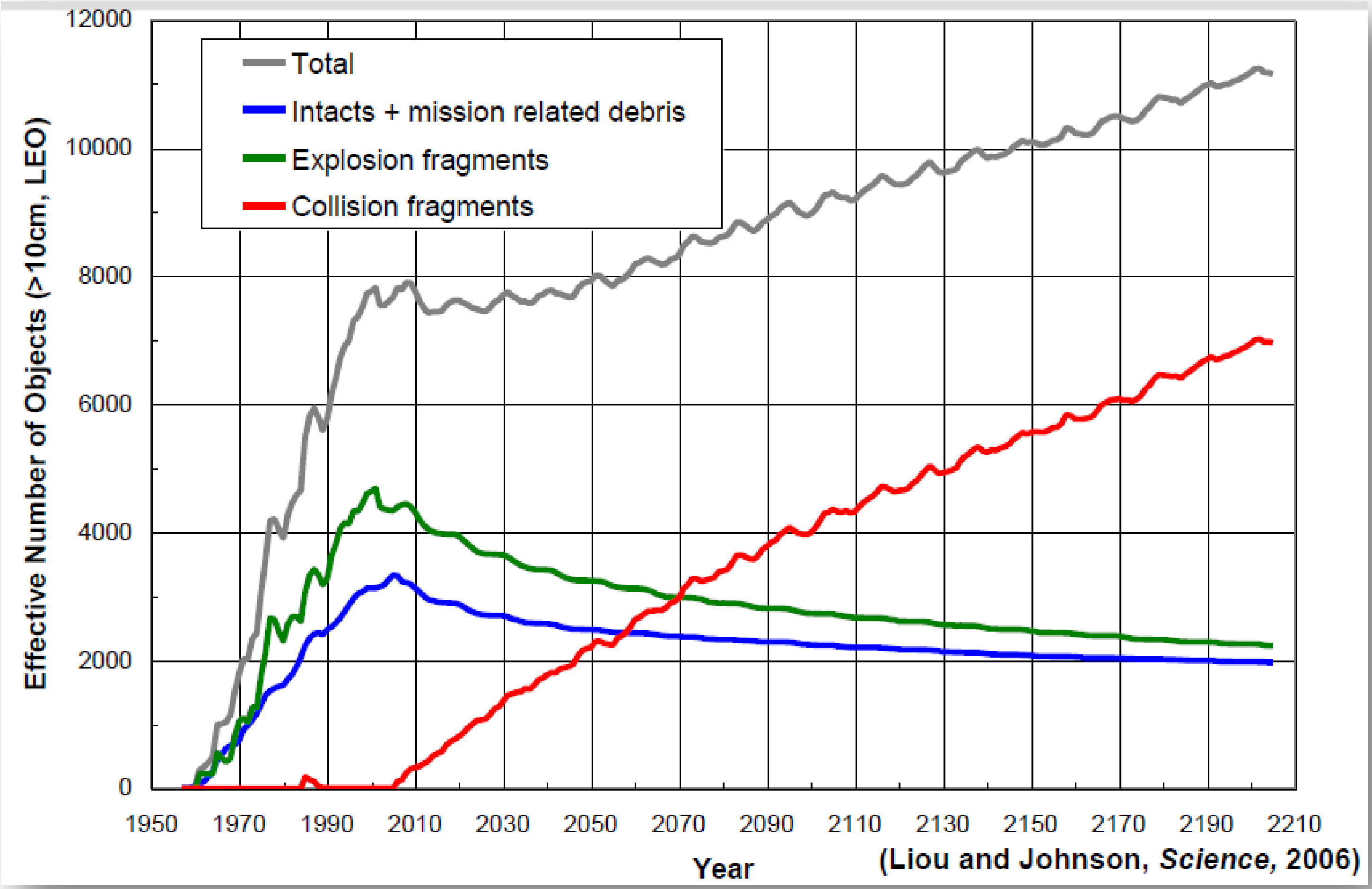
- Are space debris an urgent threat?
  - Kessler syndrome



Future debris population growth (no mitigation measures)[7]

Are Space Debris an Urgent Threat?

- Are space debris an urgent threat?
  - Kessler syndrome



Future debris population growth (no new launches from January 1, 2006)[7]

Are Space Debris an Urgent Threat?

- Are space debris an urgent threat?

  Even without new launches, debris population will critically increase in LEO and active measures have to be taken and applied

"The current debris population in the LEO region has reached the point where the environment is unstable and collisions will become the most dominant debris-generating mechanism in the future."

" Only remediation of the near-Earth environment – the removal of existing large objects from orbit – can prevent future problems for research in and commercialization of space."

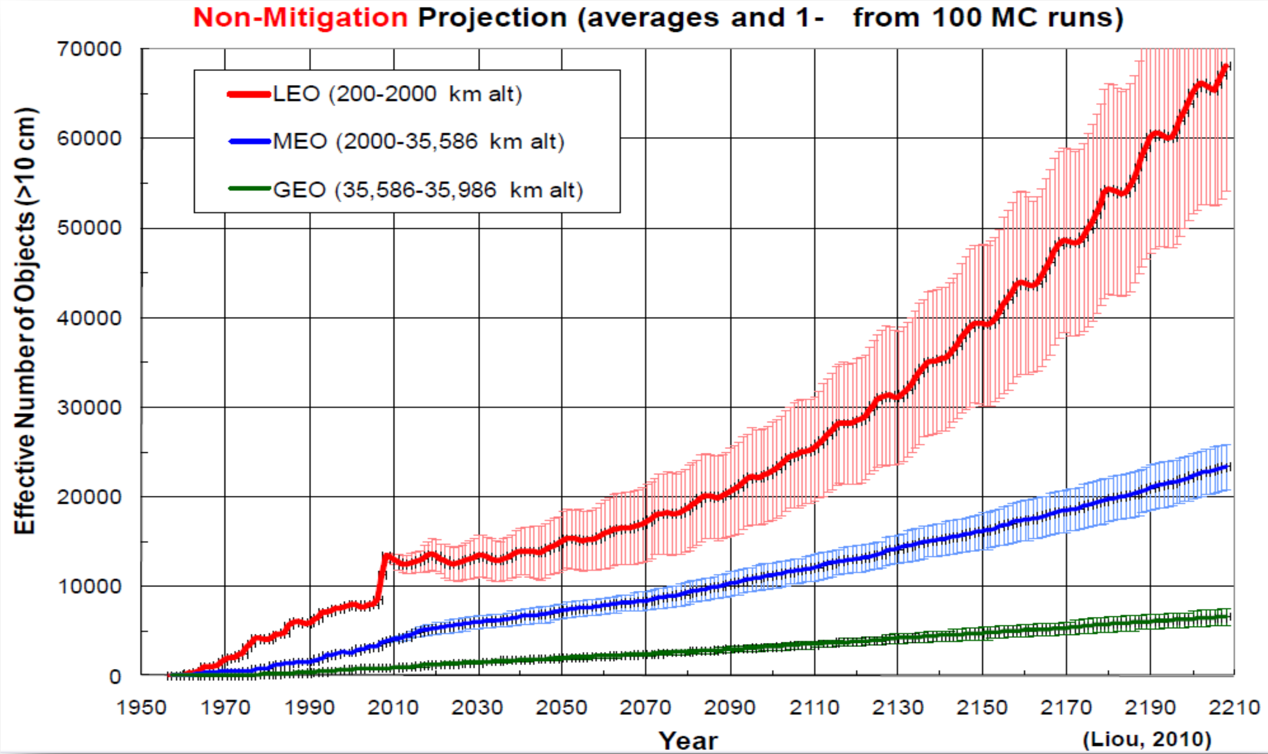
Liou and Johnson, *Science, 20 January 2006*

Introduction to Space Debris

Research on Space Debris

Research on Space Debris

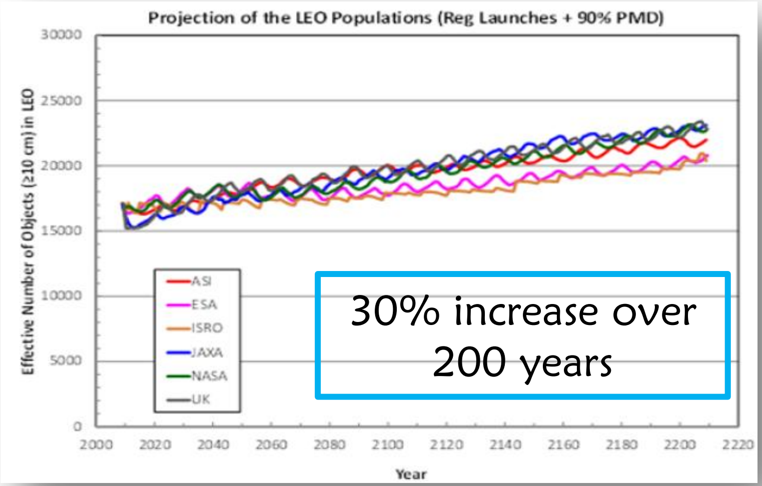
- Mitigation
  - IADC guidelines
    - 25-year rule
    - Passivation

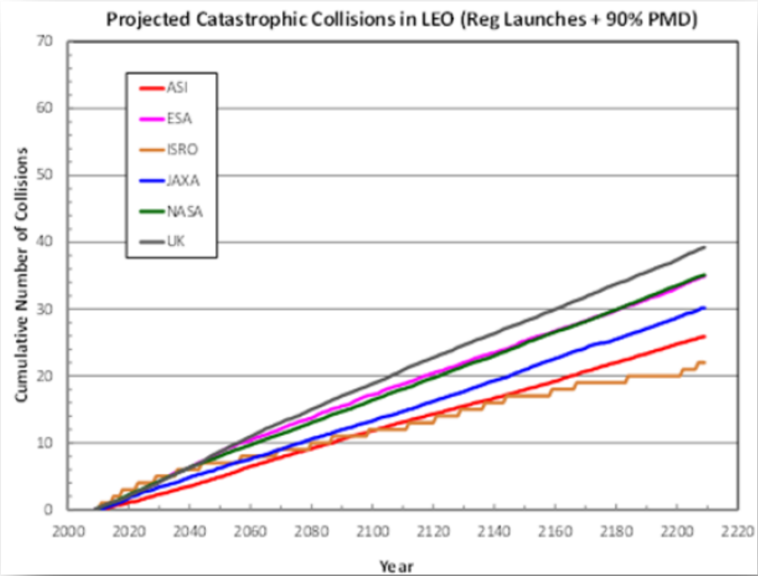


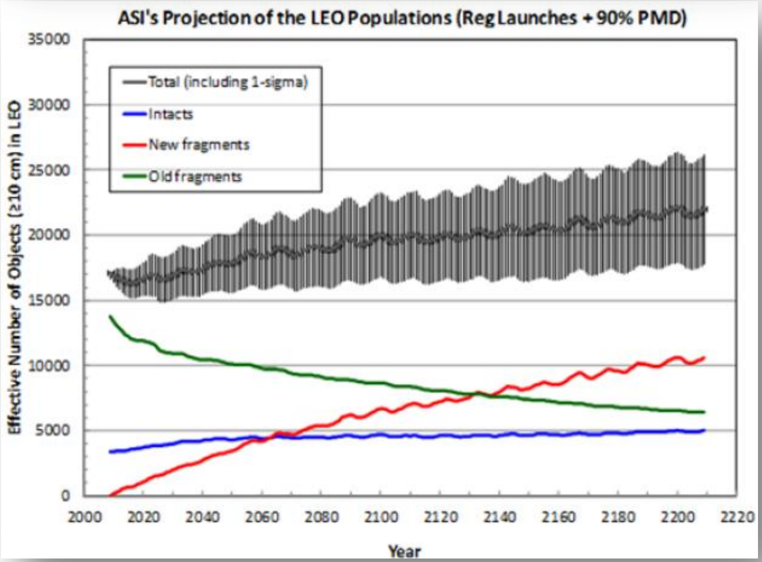
Future debris population growth (no mitigation measures)[7]

Research on Space Debris

- Mitigation
  - IADC guidelines
    - 25-year rule
    - Passivation







Projection of LEO population with 90% compliance with mitigation measures[8]

Research on Space Debris

- Mitigation measures needed, but not sufficient…

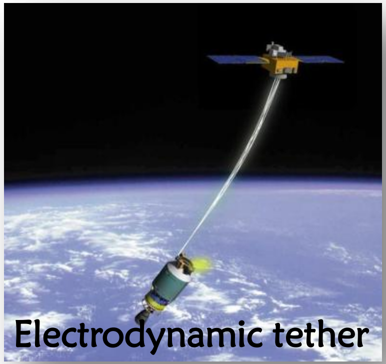
2007 - ASAT	2009 - Accidental Collision	
 Feng-Yun 1C (Source: globalsecurity.org)	 Iridium 33 (Source: space.skyrocket.de)	 Cosmos 2851 (Source: nationalgeographic.com)
~ 3,000 new objects	~ 2,000 new objects	

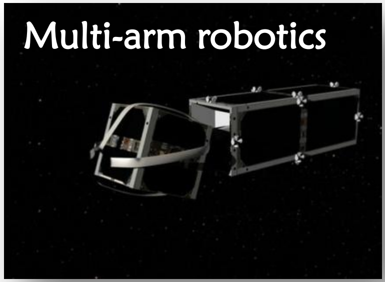
- Active debris removal needed!

Research on Space Debris

- Active debris removal (ADR)
  - In which portion of space should it be applied?
  - Which object to target first?
  - What are the objectives?
  - How to do it?
  - Who will pay?
  - Technical vs. economical vs. political challenges

Need a few more years for technical maturity and economic viability

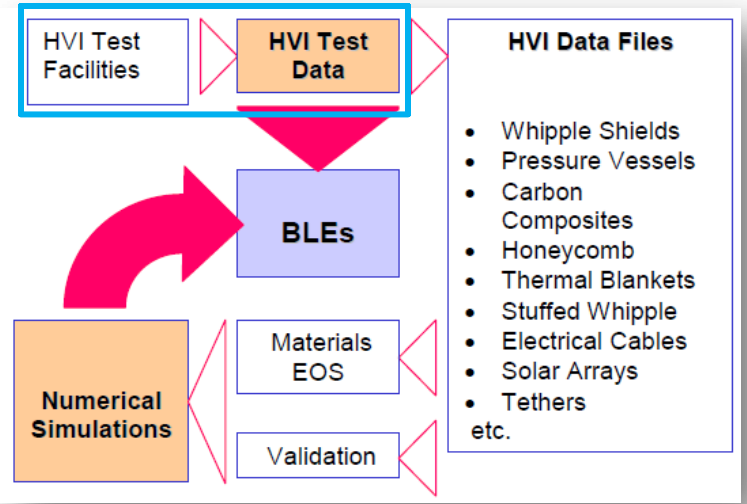




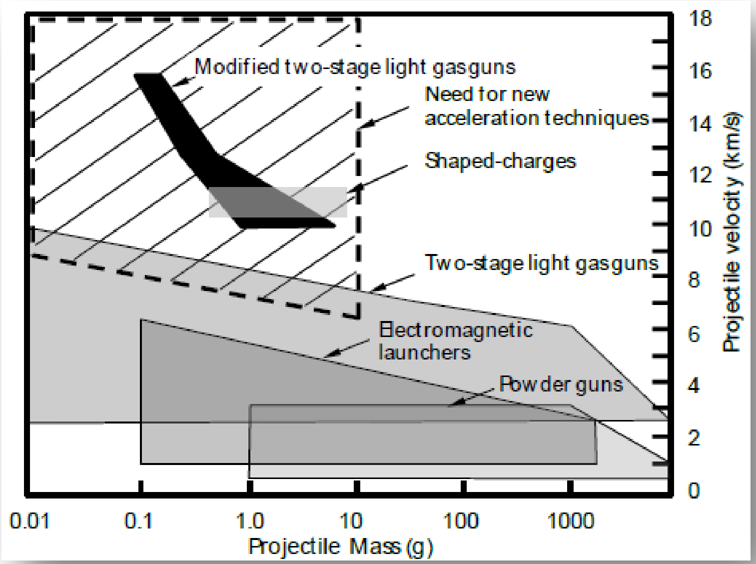
Source: ISU SSP12 Space Debris Team Project's executive summary[9]

Research on Space Debris

- Small space debris oriented research
  - Better assess small space debris population
  - Better assess small space debris threat
  - Hypervelocity impact testing



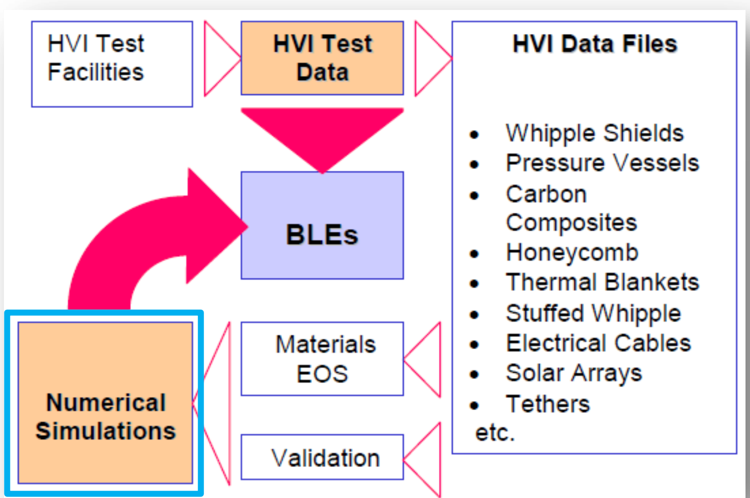
Role of HVI experiments[10]



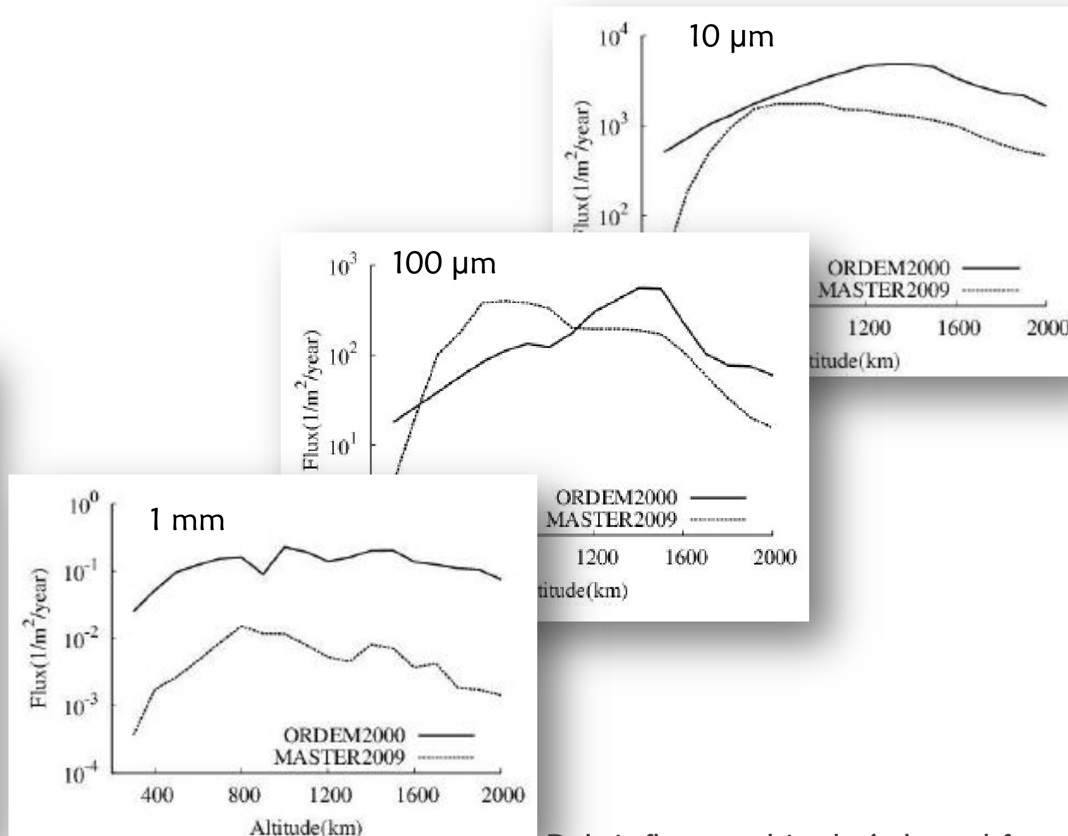
Hypervelocity launchers performance ranges[10]

Research on Space Debris

- Small space debris oriented research
  - Better assess small space debris population
  - Better assess small space debris threat
  - Hypervelocity impact testing
  - Modeling



Role of HVI experiments[10]



Debris flux vs. altitude (adapted from Kanemitsu *et al.*[11])

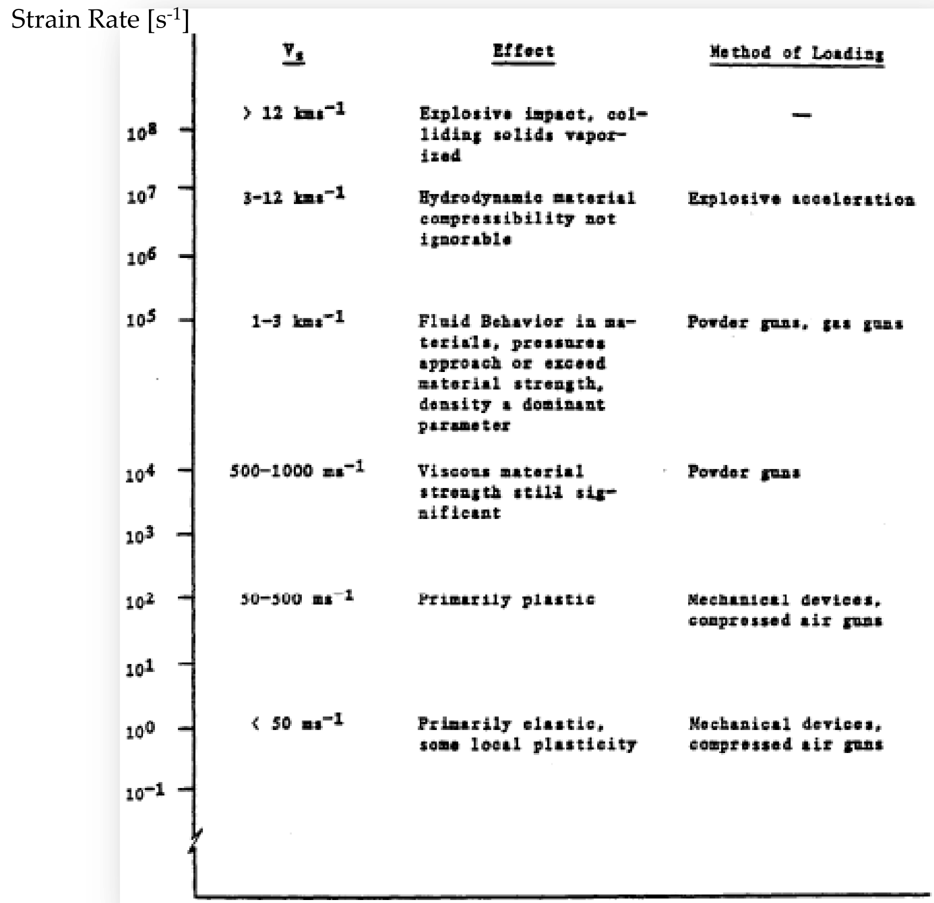
Research on Space Debris

Introduction to KIT's Hypervelocity Impact Test Facilities

What is Hypervelocity?

Hypervelocity?

- Velocity greater that the sound velocity in a given material, ~ 7 km.s^{-1}
- Impact regime definition
  - Velocity (Jonas and Zukas, 1979)



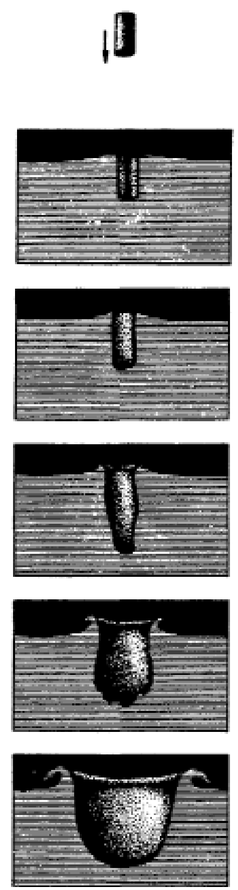
Strain Rate [s^{-1}]	V_s	Effect	Method of Loading
10^8	> 12 kms^{-1}	Explosive impact, colliding solids vaporized	—
10^7	3-12 kms^{-1}	Hydrodynamic material compressibility not ignorable	Explosive acceleration
10^6			
10^5	1-3 kms^{-1}	Fluid Behavior in materials, pressures approach or exceed material strength, density a dominant parameter	Powder guns, gas guns
10^4	500-1000 ms^{-1}	Viscous material strength still significant	Powder guns
10^3			
10^2	50-500 ms^{-1}	Primarily plastic	Mechanical devices, compressed air guns
10^1			
10^0	< 50 ms^{-1}	Primarily elastic, some local plasticity	Mechanical devices, compressed air guns
10^{-1}			

Is the velocity alone sufficient to characterize an impact?

Hypervelocity?

- Velocity greater that the sound velocity in a given material, ~ 7 km.s^{-1}
  - Is the velocity alone sufficient to characterize an impact?

Increasing velocity



- Low velocity – Projectile slightly deformed
- Projectile erodes – Crater depth increases
- Projectile erodes – Crater depth increases and start to enlarge
- High velocity – Projectile completely disintegrated, crater **enlarges BUT DOESN'T go deeper**
- Crater enlarges

Hypervelocity?

- Velocity greater that the sound velocity in a given material, ~ 7 $km.s^{-1}$
- Impact regime definition
  - Velocity (Jonas and Zukas, 1979)
  - Material (Johnson, 1972)

$$\frac{\rho v^2}{Y}$$

ρ: material density, ν: impact velocity; Y: mean flow stress

  - Projectile and target strength (Wilbeck, 1985)

$$\frac{\rho v^2}{\sigma_P} \qquad \frac{\rho v^2}{\sigma_T}$$

σ: yield stress; $\rho v^2 = P$, hydrodynamic pressure

Hypervelocity?

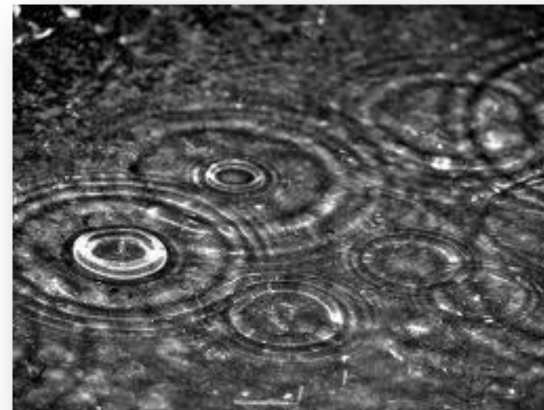
- Velocity greater that the sound velocity in a given material, ~ 7 km.s^{-1}

- Impact regime definition
  - Velocity
  - Material
  - Projectile and target strength

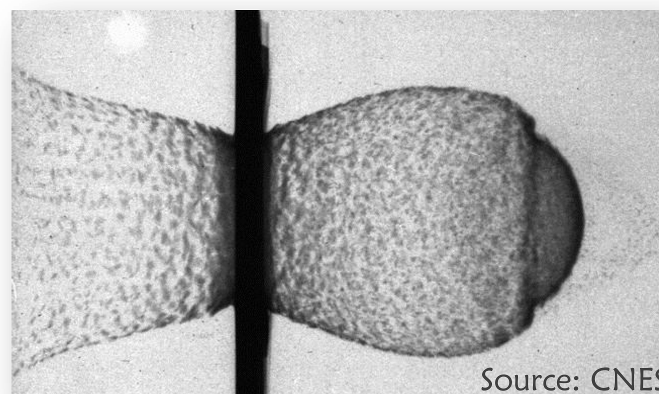
- Materials considered as fluids

	$\frac{P}{\sigma_T} << 1$	$\frac{P}{\sigma_T} \sim 1$	$\frac{P}{\sigma_T} >> 1$
$\frac{P}{\sigma_P} << 1$	1	2	3
$\frac{P}{\sigma_P} \sim 1$	4	5	6
$\frac{P}{\sigma_P} >> 1$	7	8	9

Hypervelocity regime



Source: Mendo Coast Current

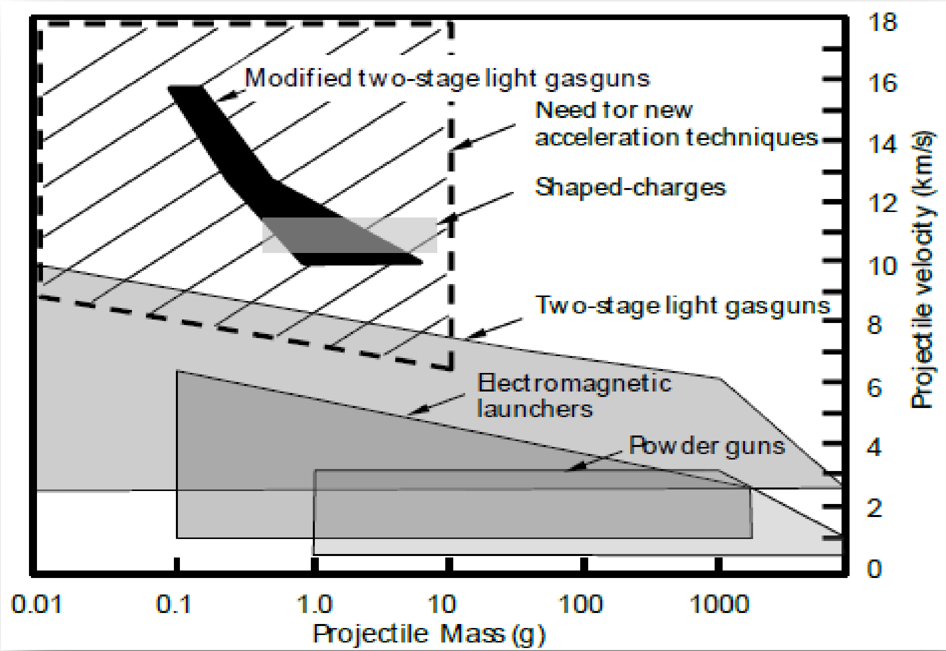


Source: CNES

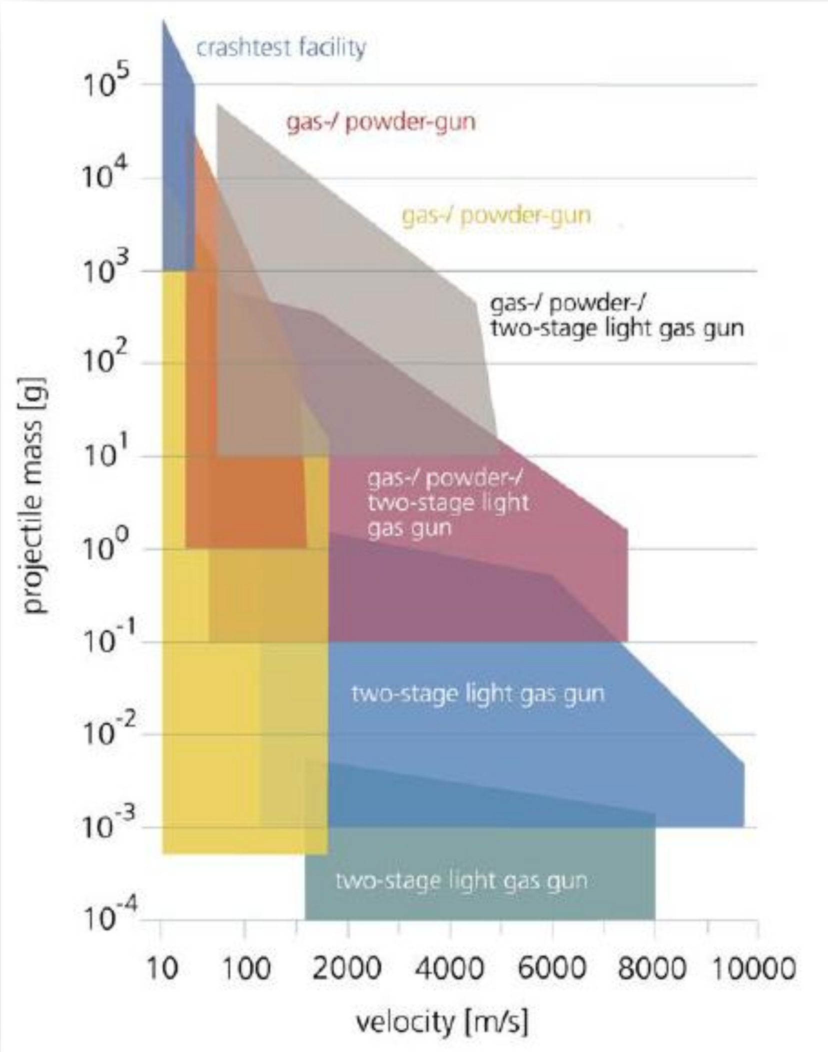
Introduction to KIT's Hypervelocity Impact Test Facilities

Launchers Overview

Launchers Overview



Hypervelocity launchers performance ranges[10]

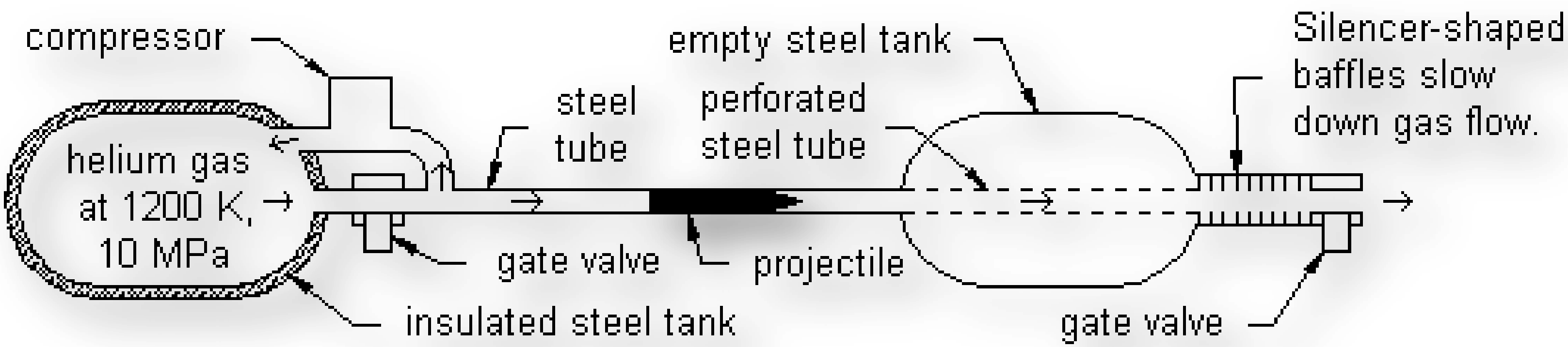


Performance diagram of all EMI facilities[10]

- Pneumatic launcher
- Blast launcher
- Hybrid launcher
- Electromagnetic launcher

Launchers Overview

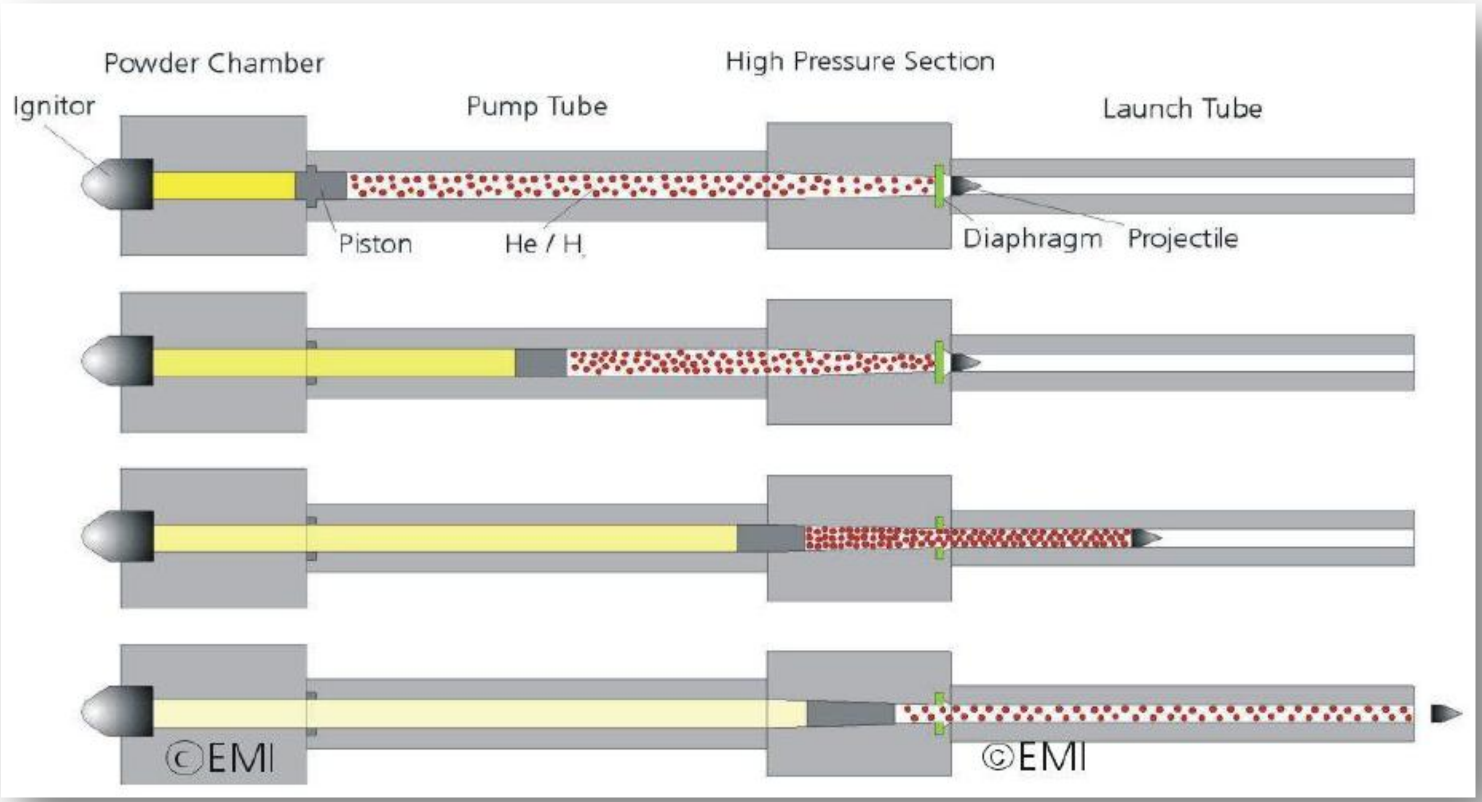
- Pneumatic launcher
  - One-stage light gas guns (~2 to 3 $km.s^{-1}$)



Working principle of one-stage light gas gun[13]

Launchers Overview

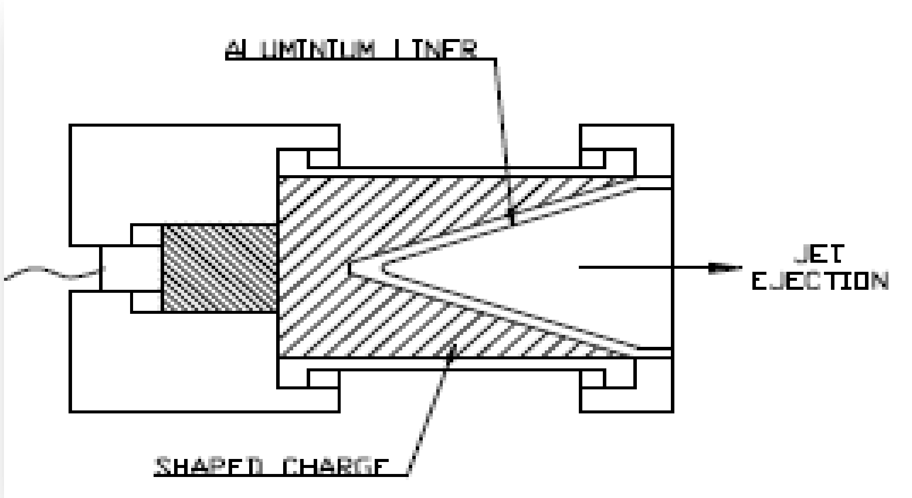
- Pneumatic launcher
  - One-stage light gas guns (~2 to 3 km.s-1)
  - Two-stage light gas guns (~ 7 km.s-1)



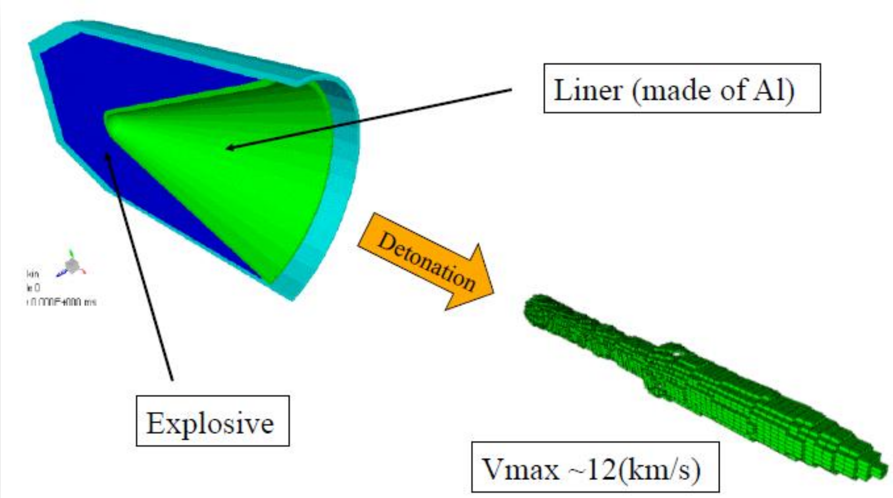
Working principle of two-stage light gas gun[10]

Launchers Overview

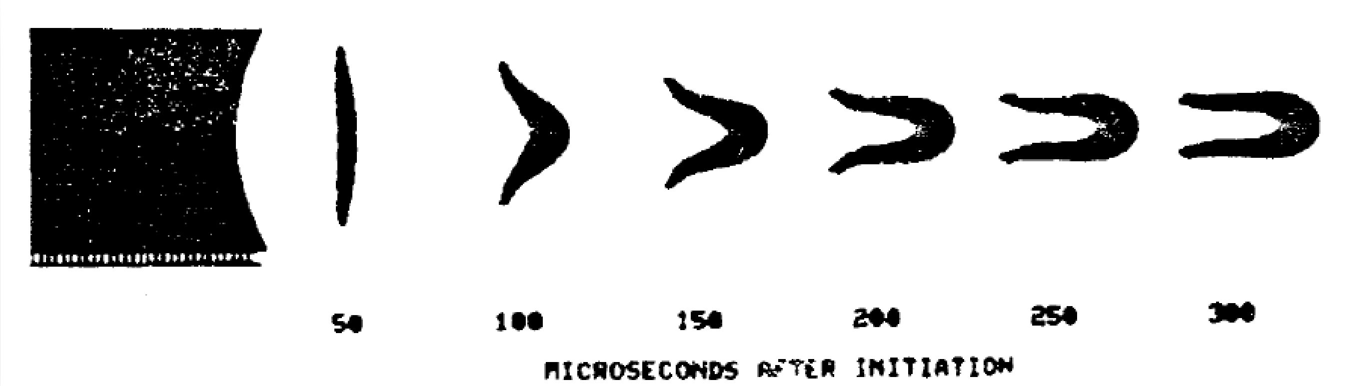
- Blast launcher – Shaped charge (~12 $km.s^{-1}$)



Conical shaped charge launcher[10]



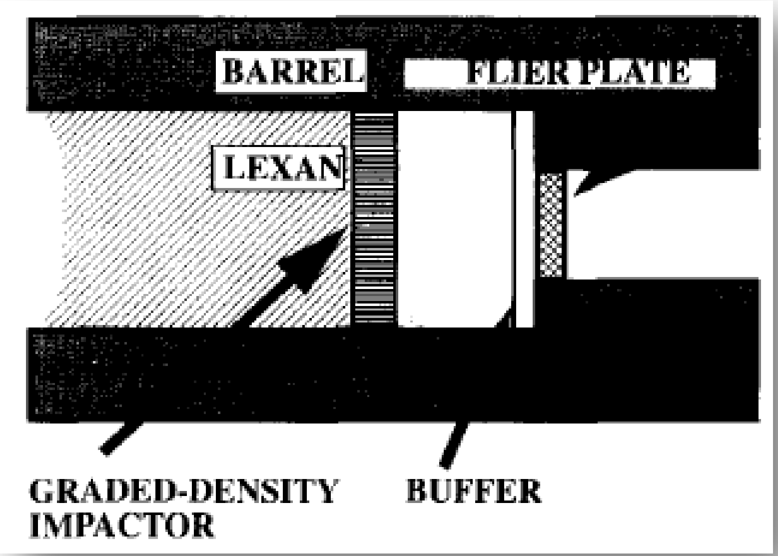
Jet shape[13]



Computer simulation of shaped charge projectile[14]

Launchers Overview

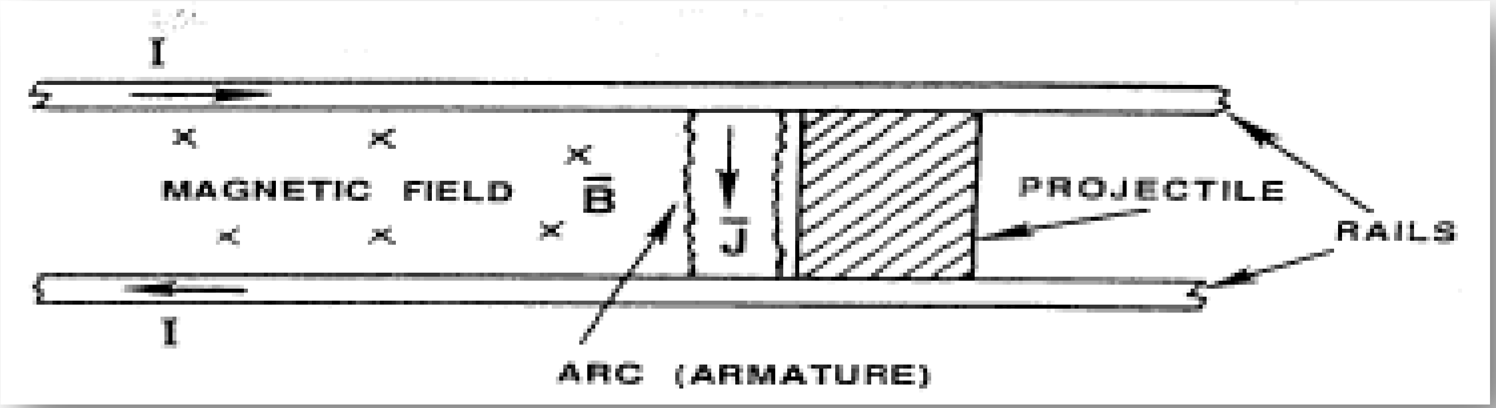
- Hybrid launcher – Flyer plate launcher (~ 15 km.s^{-1})
  - Additional stage to two-stage guns
  - Graded-density materials focus shock wave on flyer plate
  - Disk-shaped projectiles only



Flyer place launch schematic[15]

Launchers Overview

- Electromagnetic launcher – Rail guns (~ 15 to 20 km.s^{-1})
  - Lorenz force used to accelerate metallic or plasma armature, which will then propel the projectile
  - 3rd stage of light gas gun to increase final output velocity
  - Arc formation must be synchronized to the propellant exhaustion



Electromagnetic launcher working principle – Rail Gun[10]

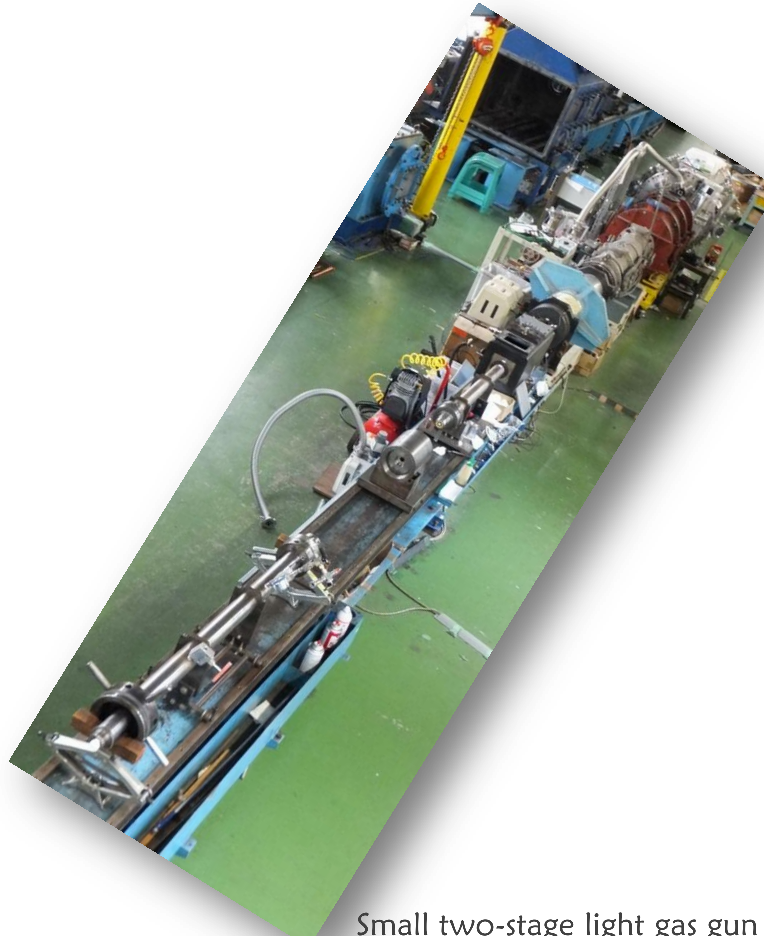
Introduction to KIT's Hypervelocity Impact Test Facilities

KIT Launchers and Associated Researches

KIT Launchers

- Two-stage light gas gun
  - Large two-stage light gas gun (transformable into one-stage gun)
  - Small two-stage light gas gun

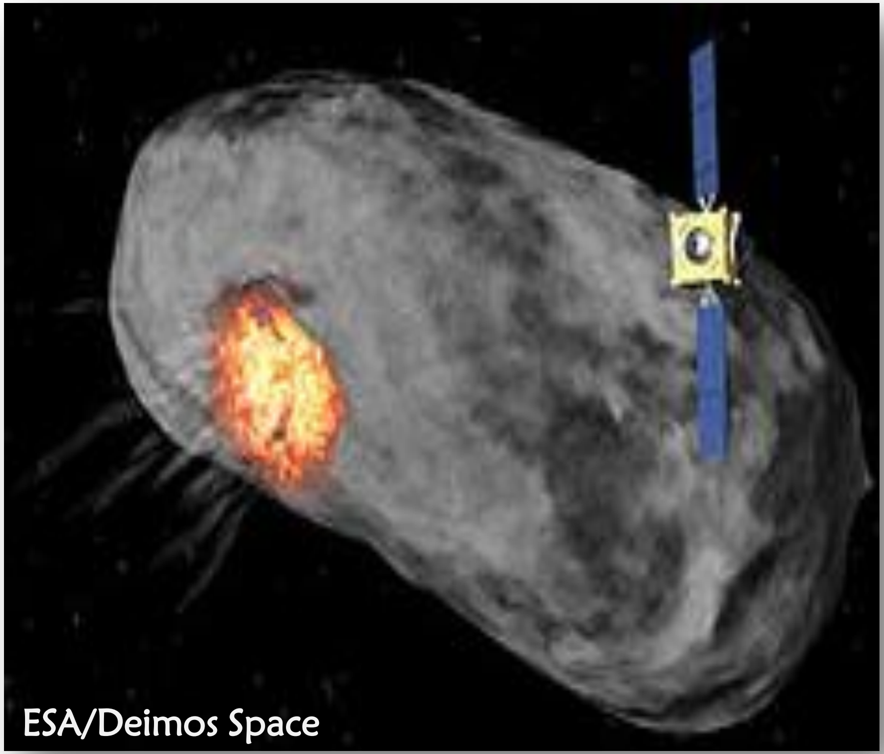
Large two-stage light gas gun



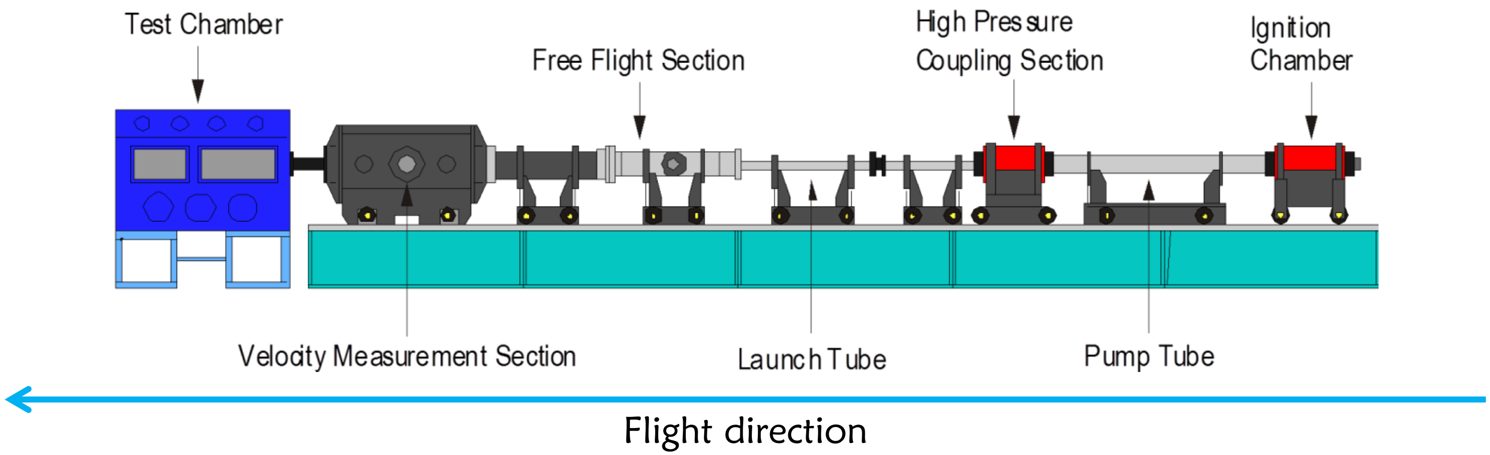
Small two-stage light gas gun

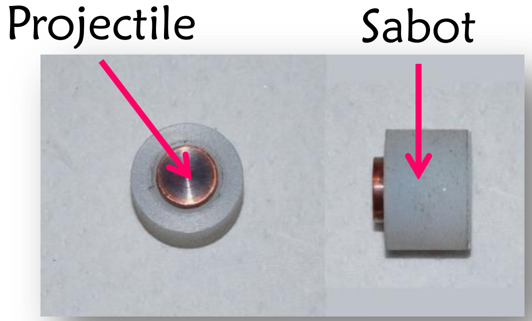
KIT Launchers – *Large TSLGG*

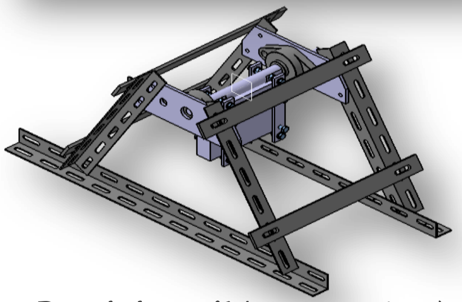
- Large two-stage light gas gun
  - Asteroid deflection - Study of near-Earth object deflection by hypervelocity impact



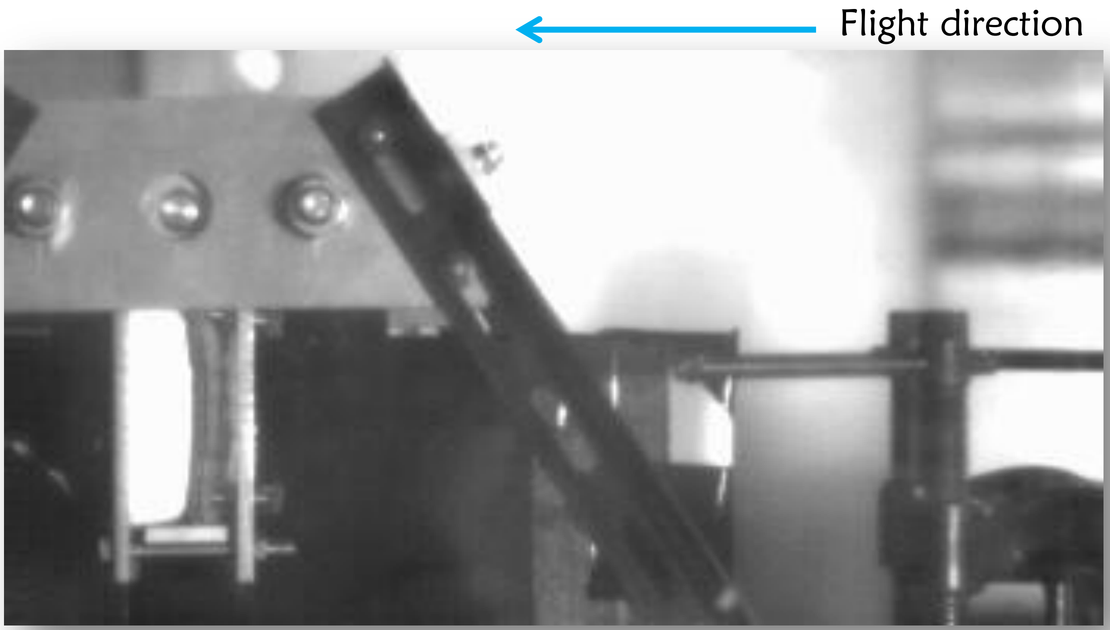
KIT Launchers – *Large TSLGG*







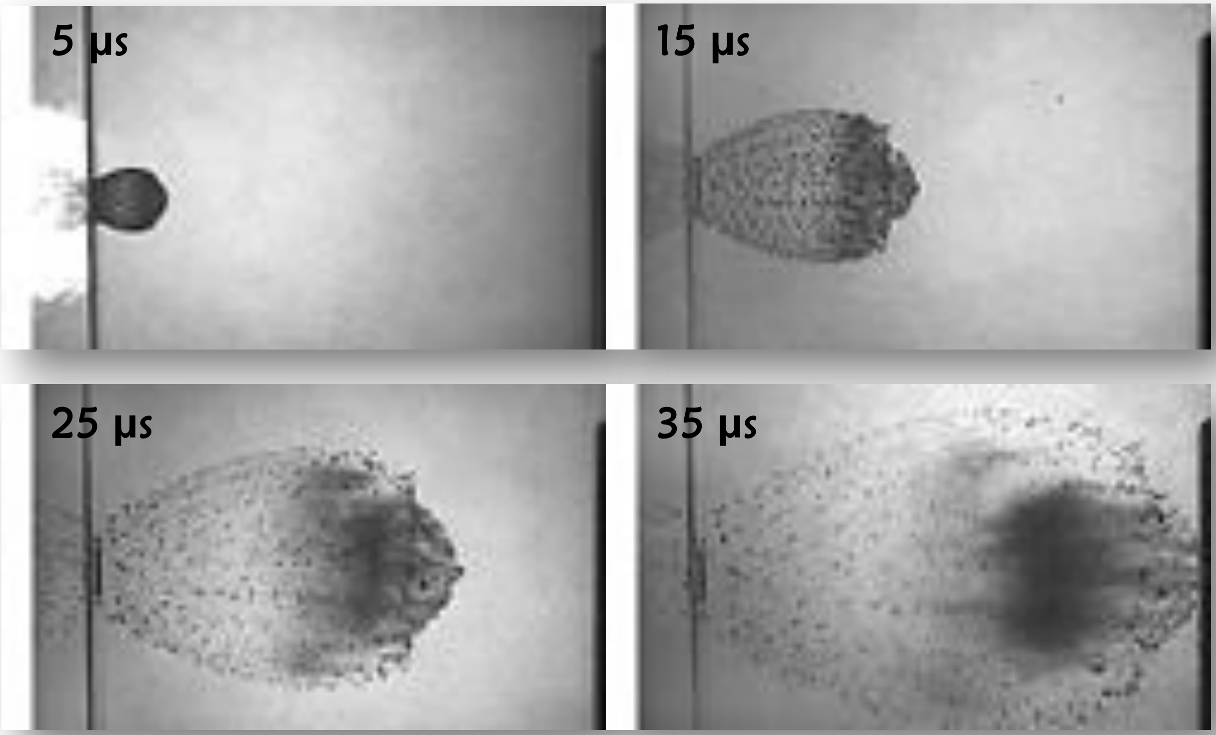
Pendulum (1st generation)



Projectile: PE ・ Target: plaster ・ Velocity: 200 $m.s^{-1}$

KIT Launchers – *Small TSLGG*

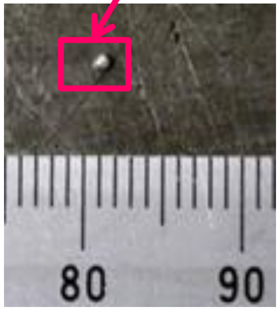
- Small two-stage light gas gun
  - Secondary space debris (= ejecta) evaluation - Study on ejecta evaluation experiment for international standardization

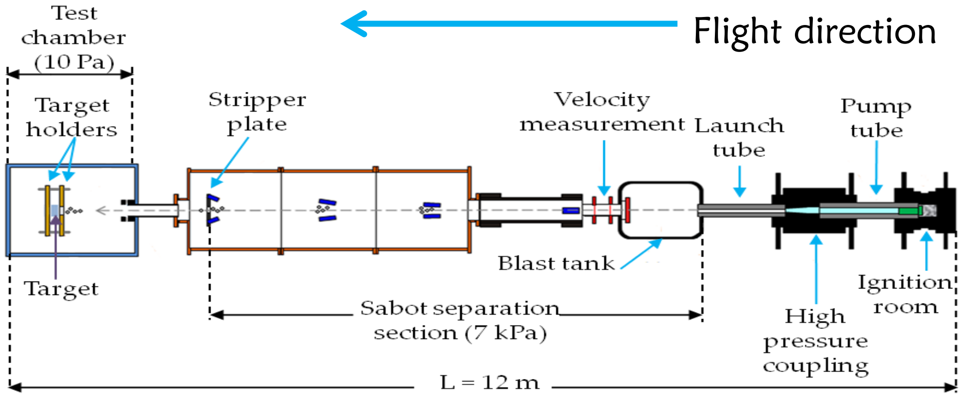


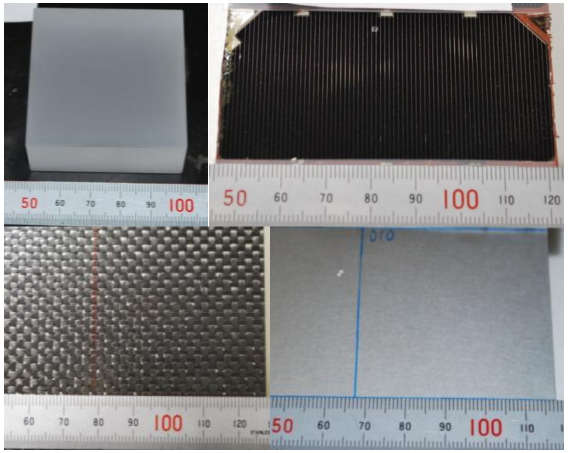
Credit: ESA. Projectile: 5 mm Al sphere ・ Velocity: 5.2 km.s^{-1}

KIT Launchers – *Small TSLGG*

Projectile
(1 mm Al sphere)







Targets. Top left: glass・Top right: solar cell・Bottom left: CFRP/Al honeycomb・Bottom right: Al honeycomb

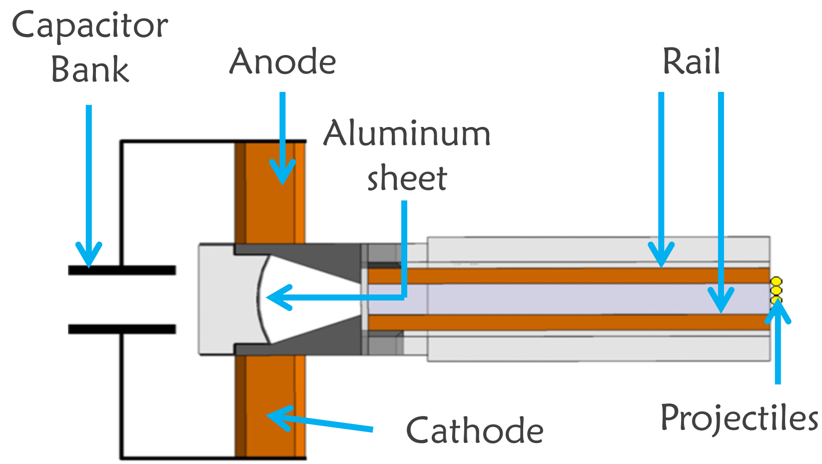
Projectile: 14 mm Al sphere・Velocity: 4 $km.s^{-1}$・Video: 460 kfps

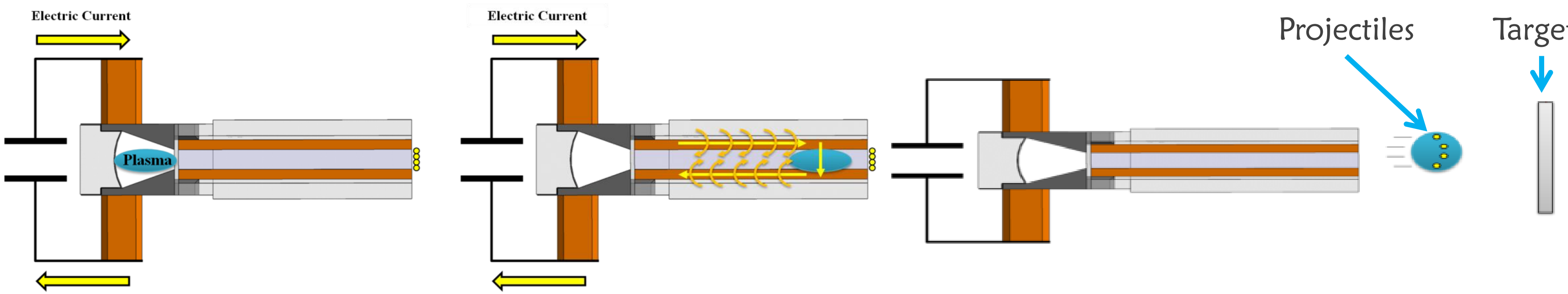
KIT Launchers

- Plasma gun
  - Accelerate small particles up to 10 $km.s^{-1}$ - Development of a plasma gun to accelerate micro-particles

KIT Launchers

- Plasma gun





Under high current changes Al sheet transformed into Al plasma

The plasma is accelerated by its own diffusion and the Lorenz force

Projectiles are pushed out and accelerated by the plasma

KIT Launchers

- Besides hypervelocity launchers…

Aeronautical Applications

Rail gun

Gas gun

Automotive Applications

Crash Box Testing

In a nutshell…

Space debris

- Useless man-made space objects in Earth's orbit or re-entering the Earth's atmosphere
- Catalog objects (> 10 cm): 17,000 debris
- All (> 100 μm): 5,800,000,000,000 debris!
- Ø 1 mm debris ≅ tennis ball at 70 $km.h^{-1}$ ・ soccer ball at 65 $km.h^{-1}$
- Mitigation and active debris removal

KIT HVI facilities

- 2 two-stage light gas guns: asteroid deflection and ejecta evaluation
- 1 plasma gun under development (objective: 10 $km.s^{-1}$)
- Other launcher: 1 gas gun (bird strikes on fan case investigation), 1 powder gun (crash box design for better energy absorption)

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Introduction to Space Debris and Hypervelocity Impact Test Facilities at Kyushu Institute of Technology

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