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発泡アルミに対する衝突実験：軽量デブリバンパの開発に向けて

Impact experiments on aluminum foam targets: as a favored candidate material for a light-weight space debris bumper shield

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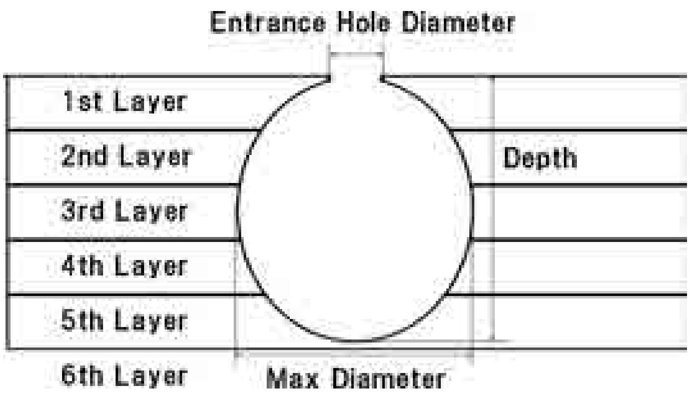
軽量デブリバンパの素材として提案するため，発泡アルミに対する衝突実験を行った．ターゲットは，直径数十μm のアルミ粒子を焼結させた板を積層させたものである．空隙率は 82 %，密度は 500 kg/m^3，呼び孔径は 0.3 mm である．呼び孔径が小さいため，比較的小さいサイズのデブリにも対応することができると考えられる．
模擬デブリとして，直径 0.3, 1.0 mm の金属球を 4 - 7 km/sec で衝突させ，貫通限界並びにクレータ形状の変化を調べた．クレータの入口は飛翔体直径の 2 倍程度であるが，内側には飛翔体直径の 7 – 10 倍の直径を持つ空洞が形成された．発泡アルミの貫通限界は，単位面積当たりの質量がひとしいアルミ板と比べて，40 %程度有利になる．実験を行った範囲では，衝突速度が上がるほど効率が上がること，飛翔体密度依存性がほとんど見られないことが判明した．高速度カメラの画像からは，高速度の放出物は見られなかった．

Aluminum Foam targets were tested as a favored candidate material for a light-weight space debris bumper shield. A target consists of layers of aluminum foam plates, and each plate was made of aluminum powder, tens of micro-meters in diameter. Their porosity, density, and nominal diameters of pores is 82 %, 500 kg/m3, and 0.3 mm, respectively. Metal spheres are employed as simulated debris and accelerated to 4 to 7 km/sec. Bulb shaped craters with small entrance holes are observed. No high-speed ejecta is observed by use of a high-speed video camera.



弾道を含む面で切断したターゲットの模式図

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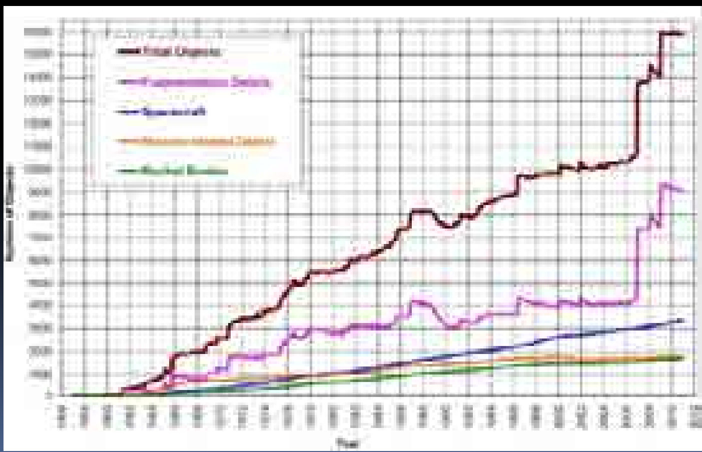
Japan Aerospace Exploration Agency,

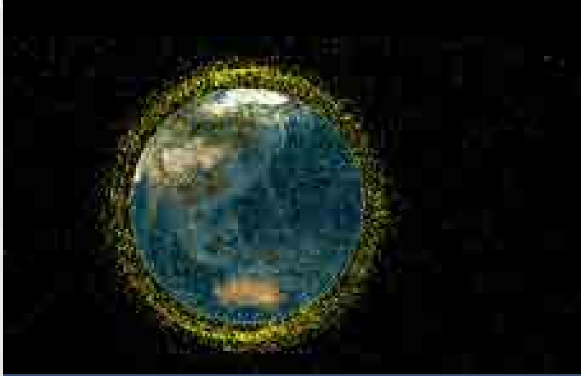
Overview

- Introduction
  - The number of debris has been increasing
  - Porous materials absorb shocks efficiently
- Experiments
  - Aluminum foam (Mitsubishi Materials)
  - Shapes of craters
  - Crater dimensions
  - Dependences of crater dimensions on
    - Particle Size , Impact velocity , and Particle density

Introduction: Number of debris

- Number of Space debris **increasing** year by year.
- Averaged impact velocity of debris in LEO is
  10 km/sec
- It is very dangerous for our satellites.





From NASA
The Orbital Debris Quarterly News

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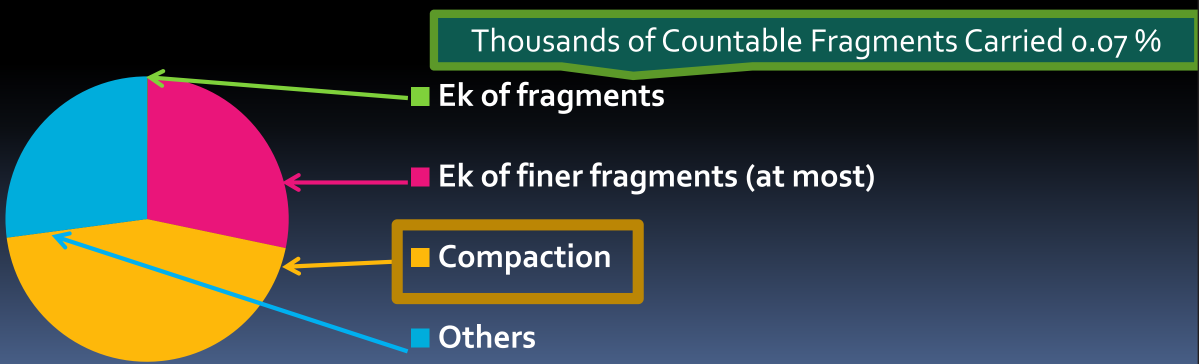
Introduction:
Energy absorption in Porous Matter

- Porous materials convert the impact energy into heat efficiently.

ex. Porous gypsum targets absorb 31 – 62 % of the impact energy, in impacts at 4 km/sec (Onose et al. 2008).



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Experiments

- Aluminum foam (Mitsubishi Materials)
- Hypervelocity Impact Experiments
- Shapes of craters
- Crater depths and Ballistic limits
- Dependences of BL on
  - Particle Size , Impact velocity , and Particle density

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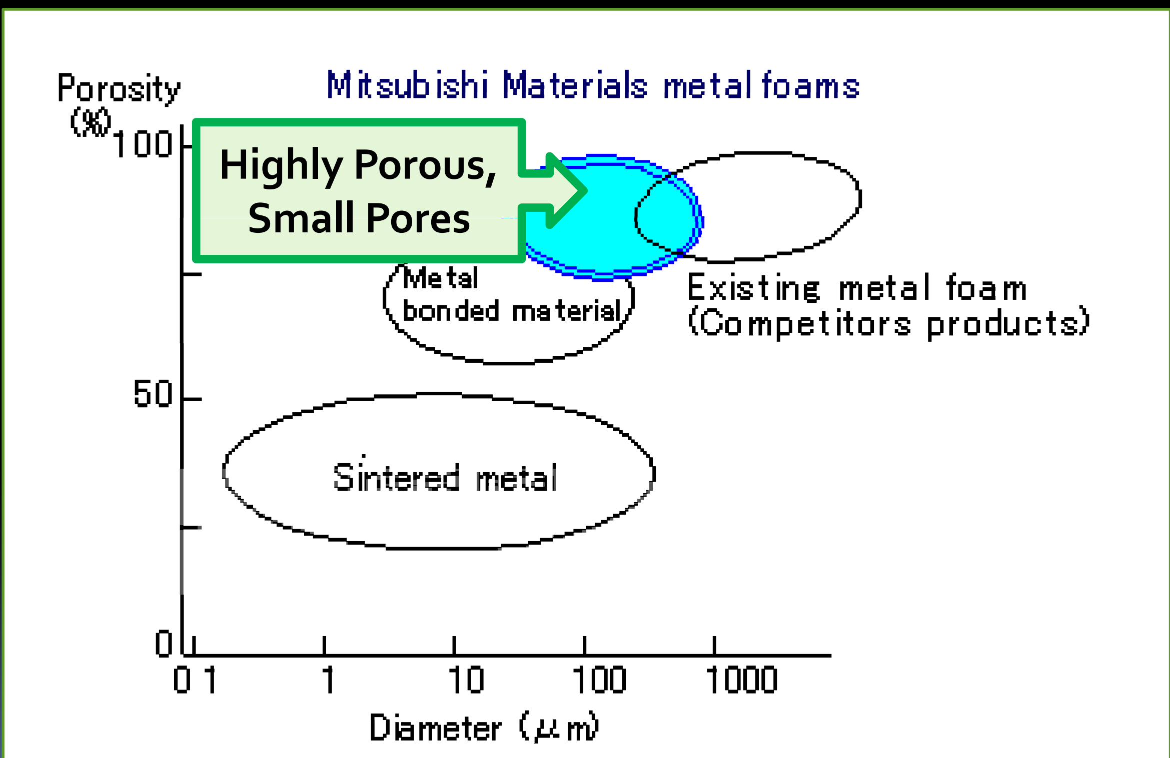
Aluminum foam I



from MITSUBISHI MATERIALS website

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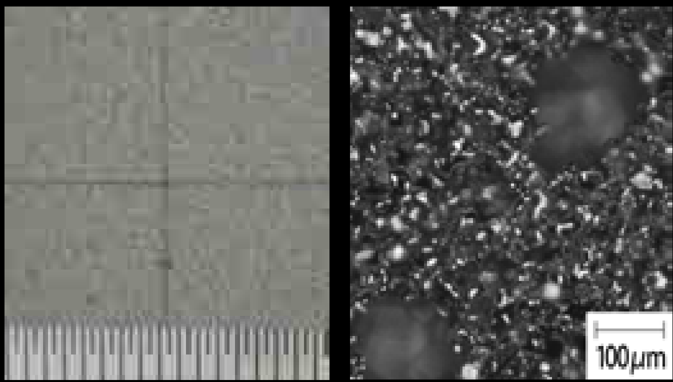
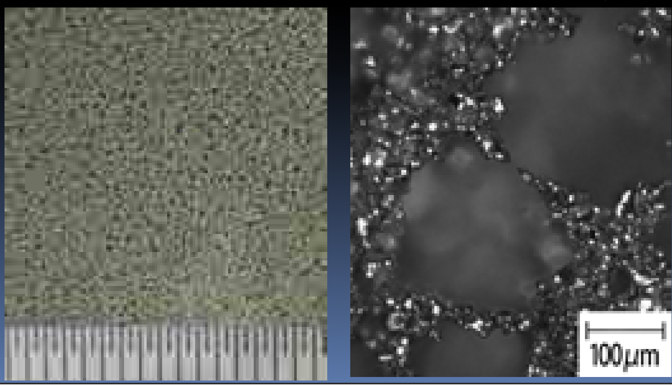
Aluminum foam II

obverse: size and number of pores are small



reverse: size and number of pores are large



- porosity: 82 %
- density: 0.5 g/cm^3
- pore diameter: 300μm in maximum
- thickness of each plate:

  0.4, 1.0, 2.0 mm

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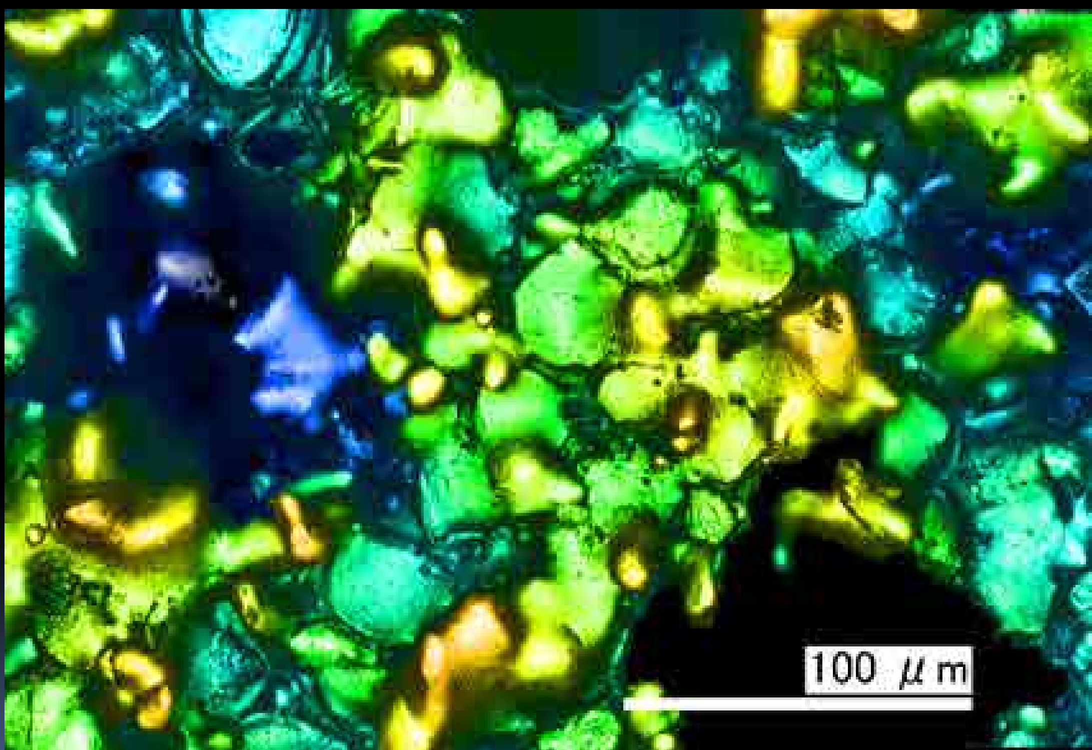
Aluminum foam III Obverse



height

High Low

キーエンス レーザー顕微鏡 VKX-100

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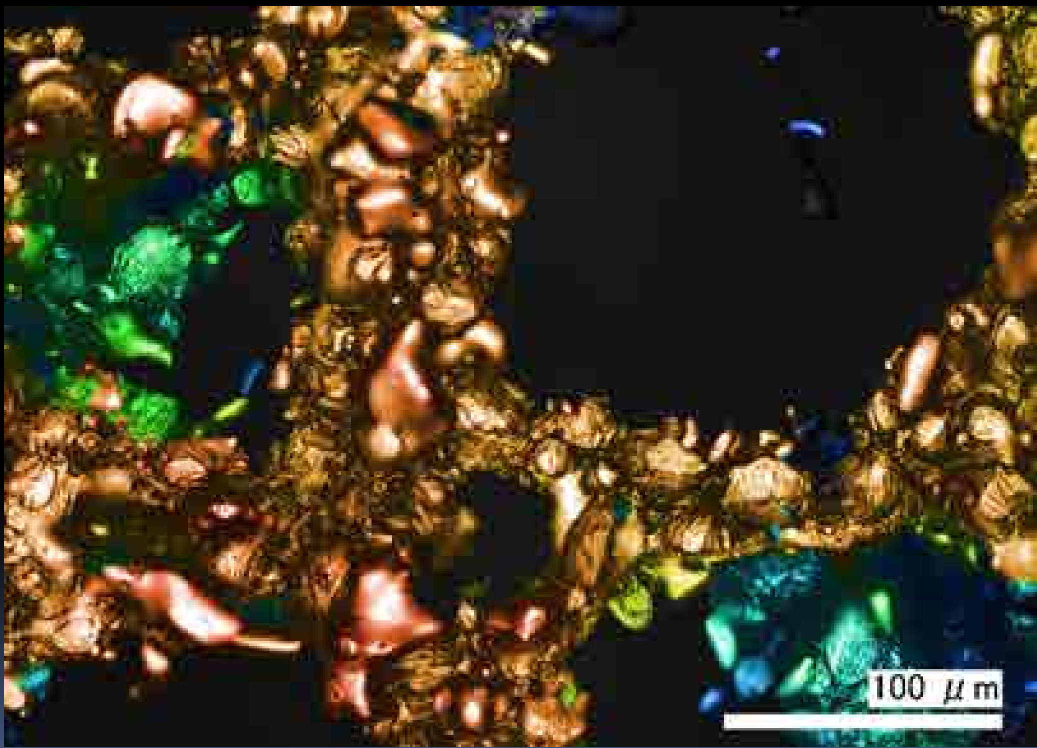
Aluminum foam IV Reverse



height

High ⟷ Low

キーエンス レーザー顕微鏡 VKX-100

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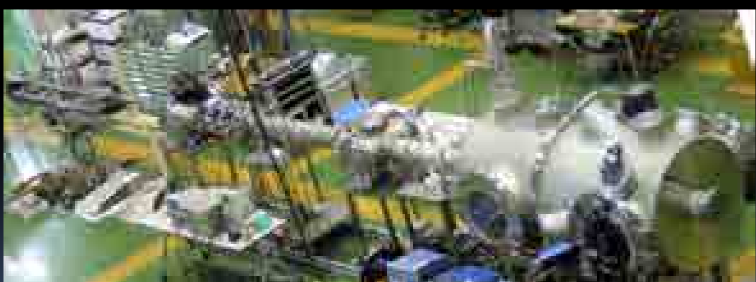
Hypervelocity Impact Experiments

- Target: Stacked plates of aluminum foam
- Projectile: Al, Sus, Cu spheres, 1 mm and 0.3 mm in diameter
- Impact velocity: 4 - 7 km/sec

(cf. averaged impact velocity of space debris in LEO: 10 km/sec)



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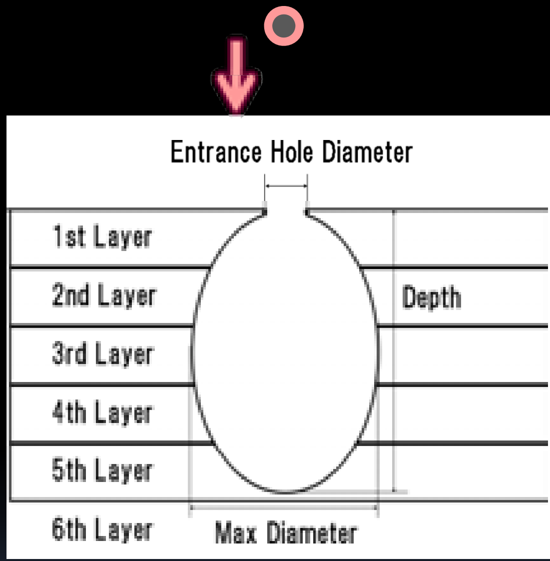
Crater Dimensions：Al 1 mm @6 km/sec

- Entrance Hole Diameter：
  1.8 mm ±0.3 mm
- Maximum Diameter：
  5.6 mm ±0.6 mm
- Depth： 9.8 mm ±1.01 mm
- Volume：0.20 mm³ ±0.02 mm³
- N = 4



Small entrance hole
＝ Little fragments are ejected

A Shape of a crater: A Result on each Target Plate

1st slice obverse

entrance hole

2nd slice obverse

maximum diameter

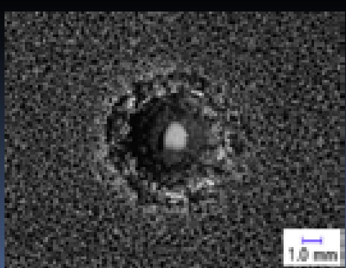
3rd slice obverse

maximum diameter

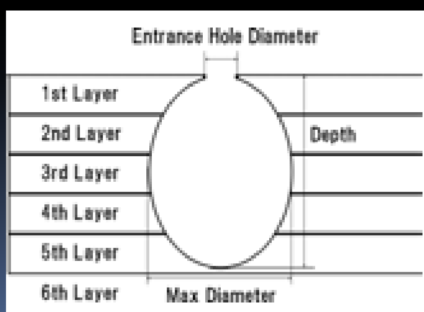
4th slice obverse

crater floor

1st slice reverse

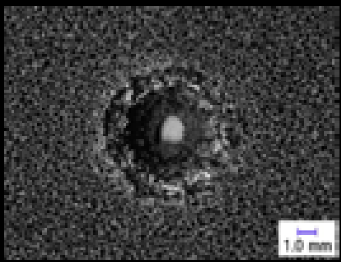


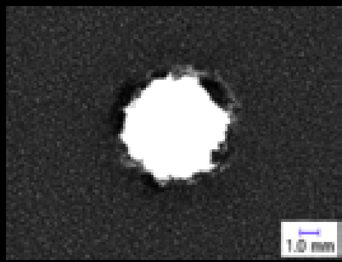
large cavity
deformation of pore



Where is the Material evacuated from the cavity

Compaction of Pores

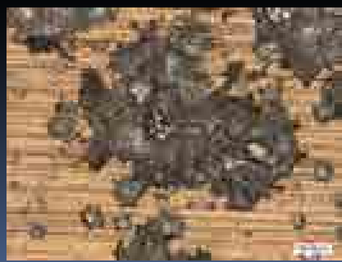




Melted and splashed toward downrange

nearly bottom layer of the crater

Melt on the crater floor



Splash on the witness plate

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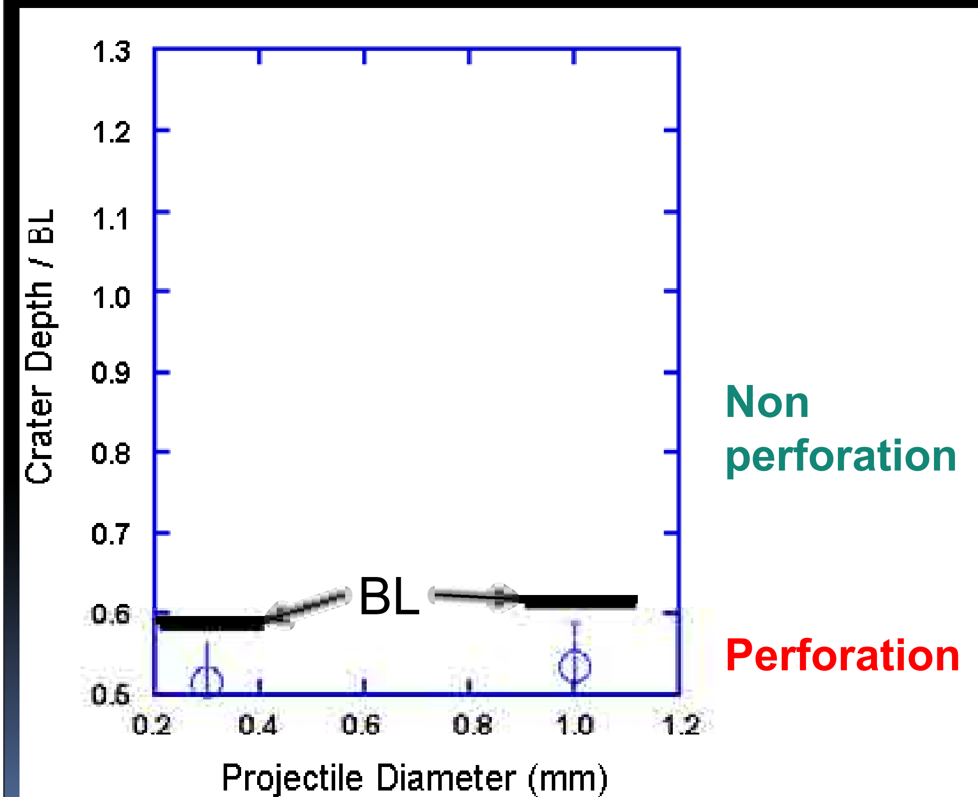
BL of aluminum foam



BL：Christiansenの式で同素材のアルミ板でのBLを計算し，これと単位面積当たりの質量が同等な発泡アルミの厚さ

実際の発泡アルミのBLは，アルミ板のBLから推定されるものより

40 % off

BLはCrater深さよりもやや大きい値をとる．

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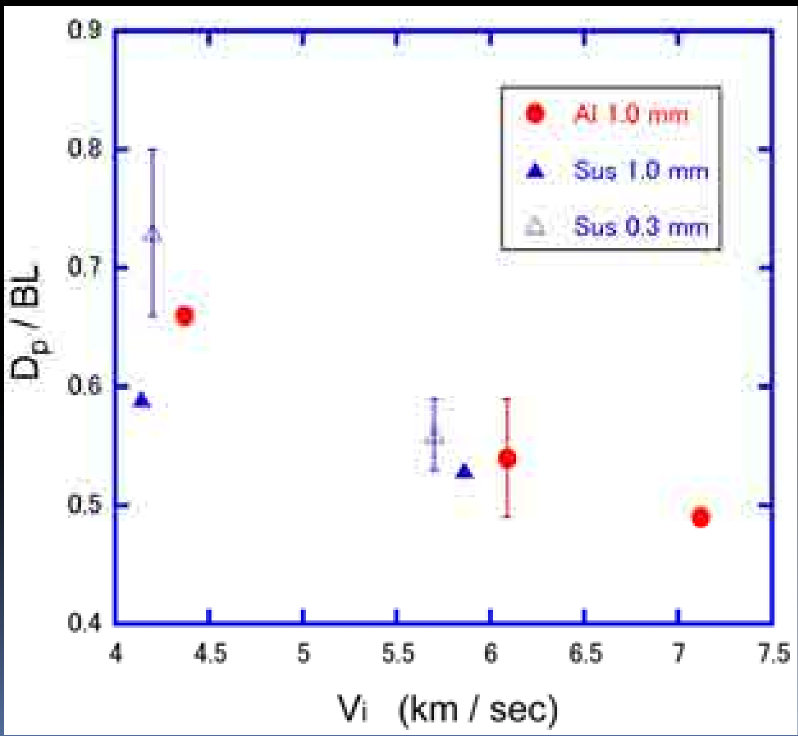
Impact velocity dependence：crater Depth/BL



BL：Calculated from the BL for an aluminum plate shearing the same weight per unit area as the aluminum foam, employing equations of Christiansen.

More effective for the higher velocity debris

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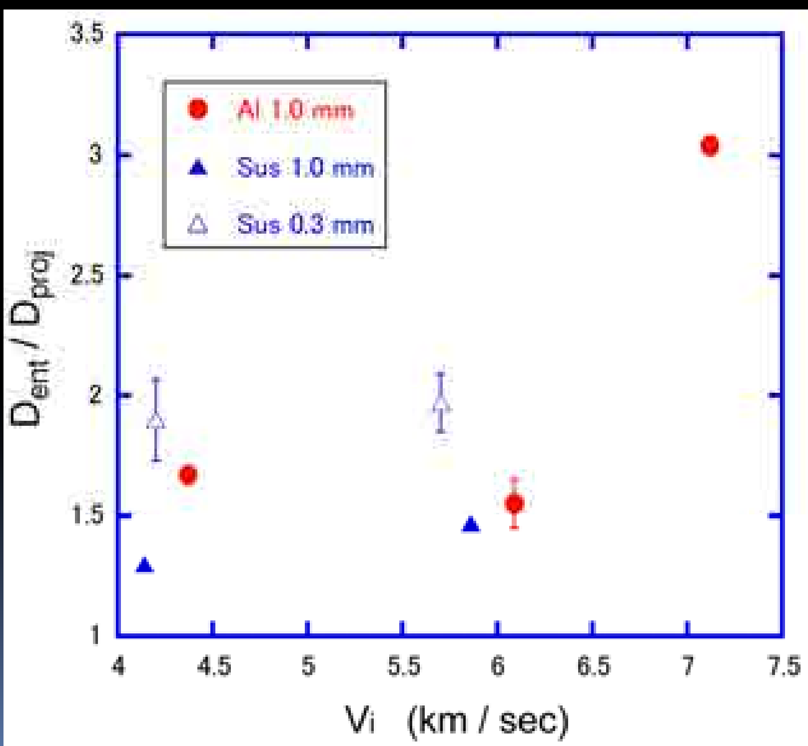
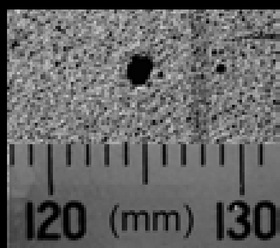
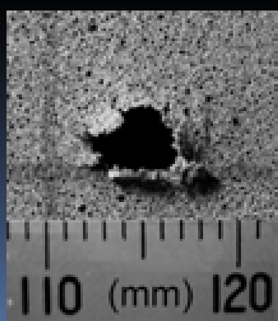
Impact velocity dependence：crater D_{ent}/D_{proj}



～6 km/sec：Small entrance hole



7 km/sec：Entrance hole is enlarged (posssively because of the blust at the impact)



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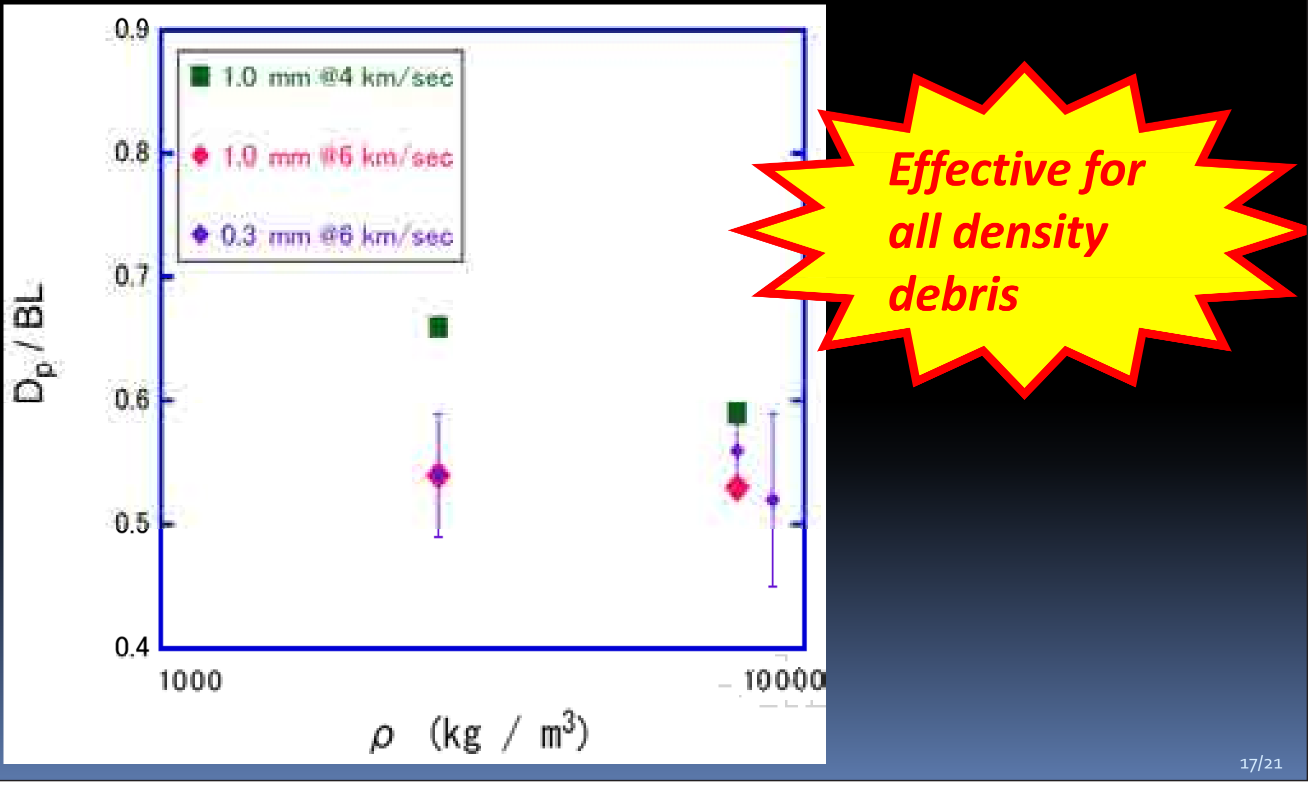
Projectile density dependence：crater Depth/BL



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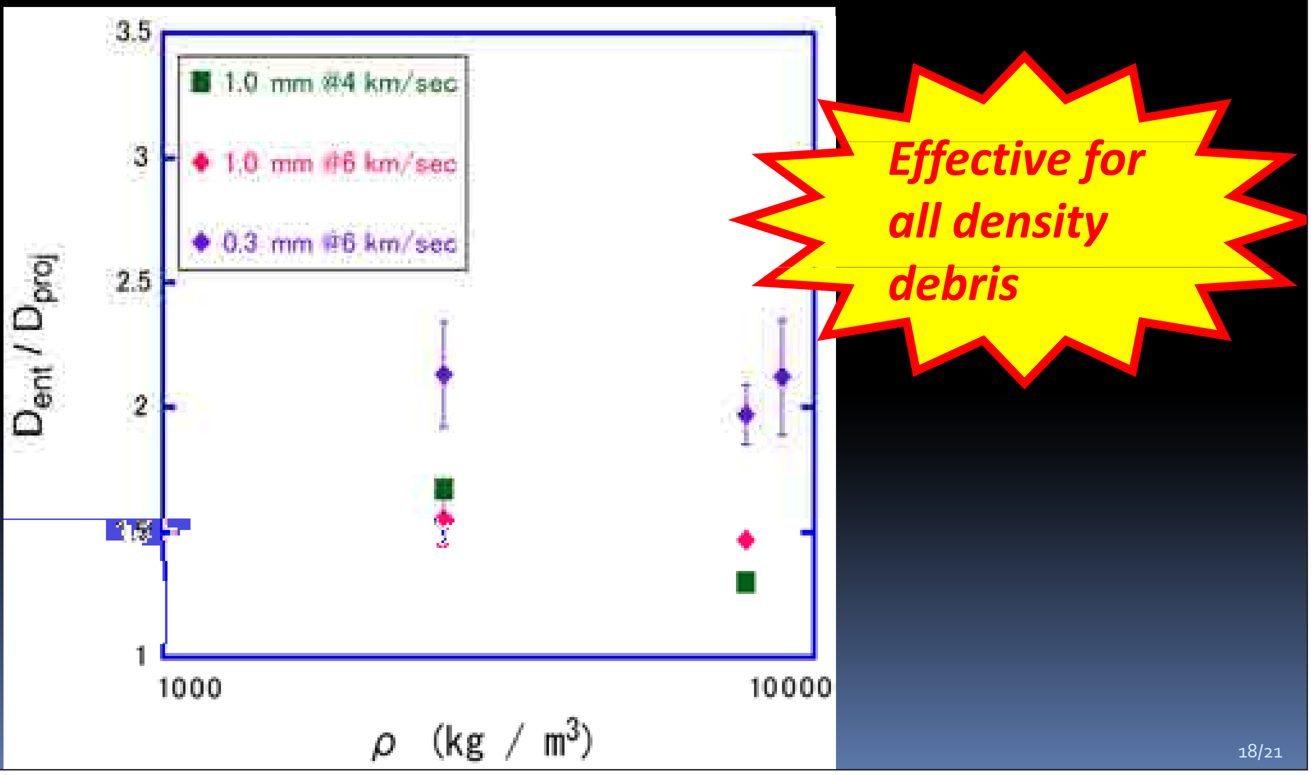
Projectile density dependence：crater D_{ent}/D_{proj}



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Conclusion

- Impact Cratering on Aluminum Foam, 82 % in Porosity, Result in a Bulb Shaped Crater
- Melting and Deformation of The Target was observed
- Aluminum foam is more effective in the higher velocity debris
- Aluminum foam can stop debris made of aluminum, Sus, and Cu.
- The entrance hole of the crater was enlarged in the case of the impact at 7 km/sec

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Conclusions

- Aluminum foam is a favored candidate material for a light-weight space debris bumper shield !

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