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Collisional Disruption of Sintered Snowball with Various Porosities

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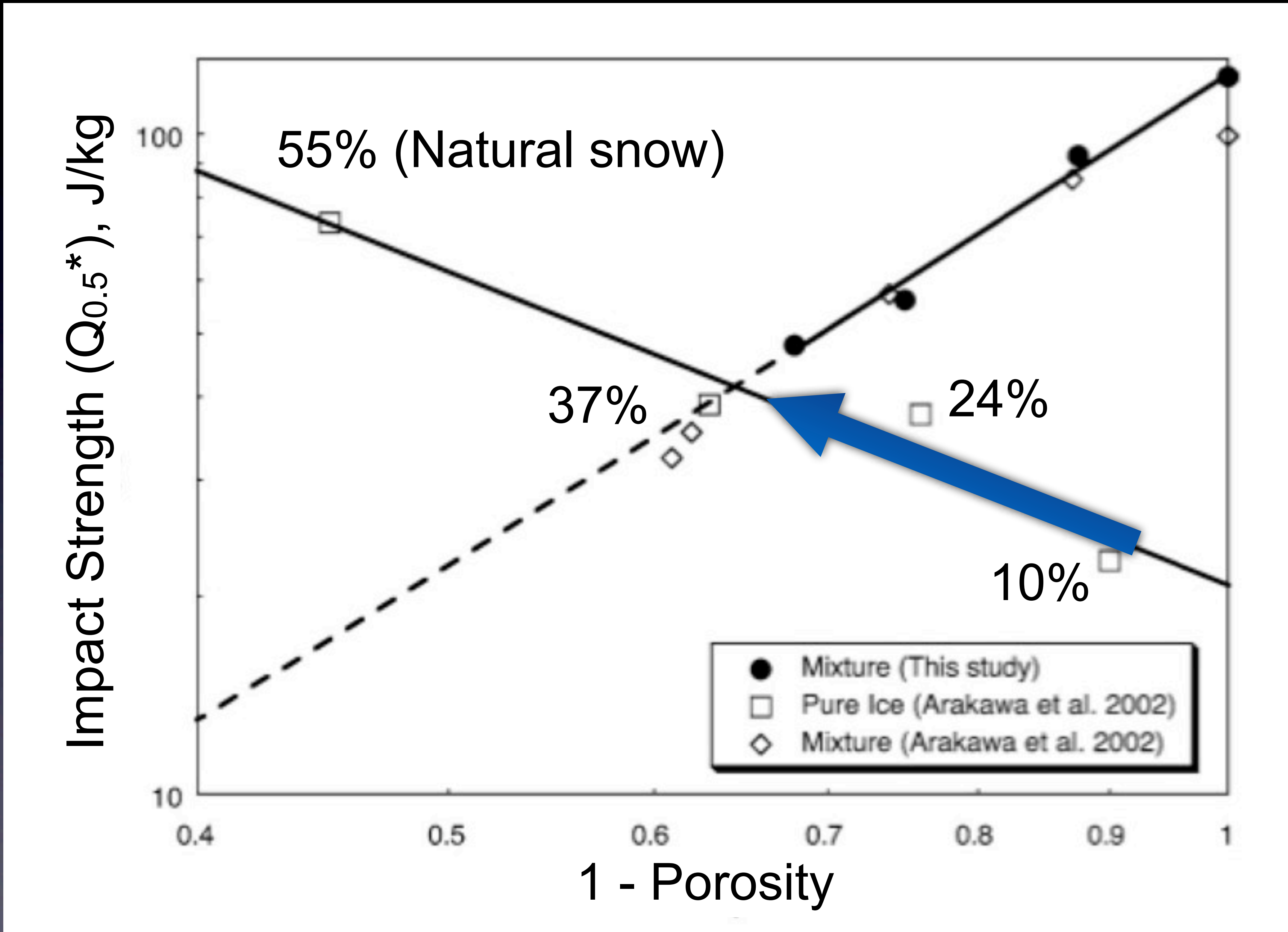
Introduction



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Purposes

- Further problems on the previous study

1. Constant sintering duration for the same

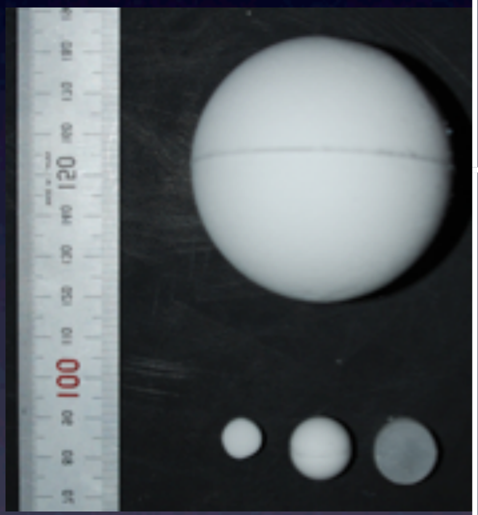
1. To study impact conditions for collisional outcomes such as sticking, rebound, and disruption.
   - Projectile penetration into porous icy bodies.
2. To study dependence of impact strength on
   - Sintering duration
   - Porosity over 40%

- Collisional outcomes such as sticking, rebound and disruption

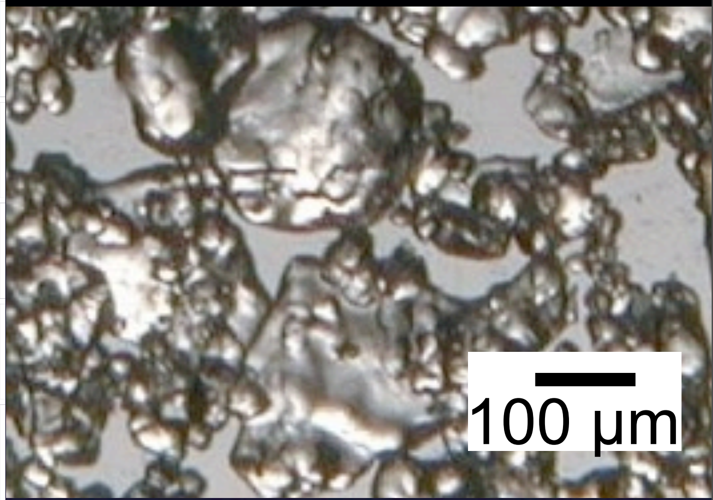
Experimental Methods

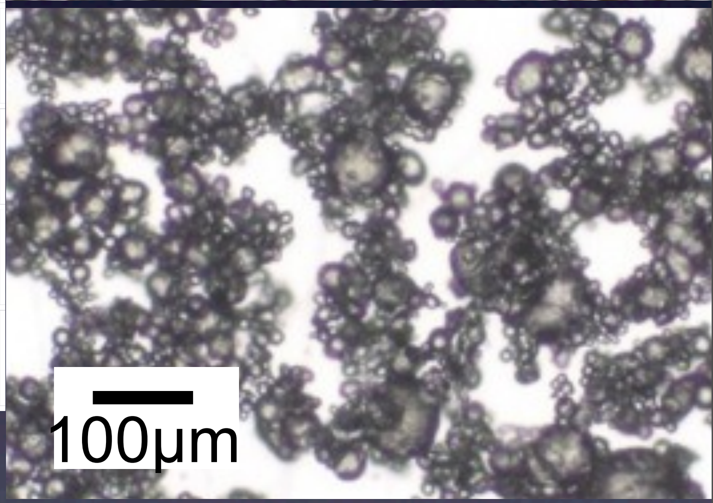
Cold room (**-15℃**) (Institute Low Temp. Sci., Hokkaido Univ.)

Target
(60mm)



Ice particle	Porosity	M_t, g	Sintering duration
~100 μm	40%	62.2	1 hour
			1 day
			3 days
			1 month
~10 μm	40%	62.2	(1 hour to 1 month)
	50%	51.9	(1 day)
	60%	41.5	(1 hour to 1 month)
	70%	31.1	(3 days)





Projectile
(10, 15mm)

	Porosity	m_p, g	Sint.
Snow cylinder	30%	0.4	1 day
Snowball	30%	1.1	1 day
Ice cylinder	0%	1.6	-

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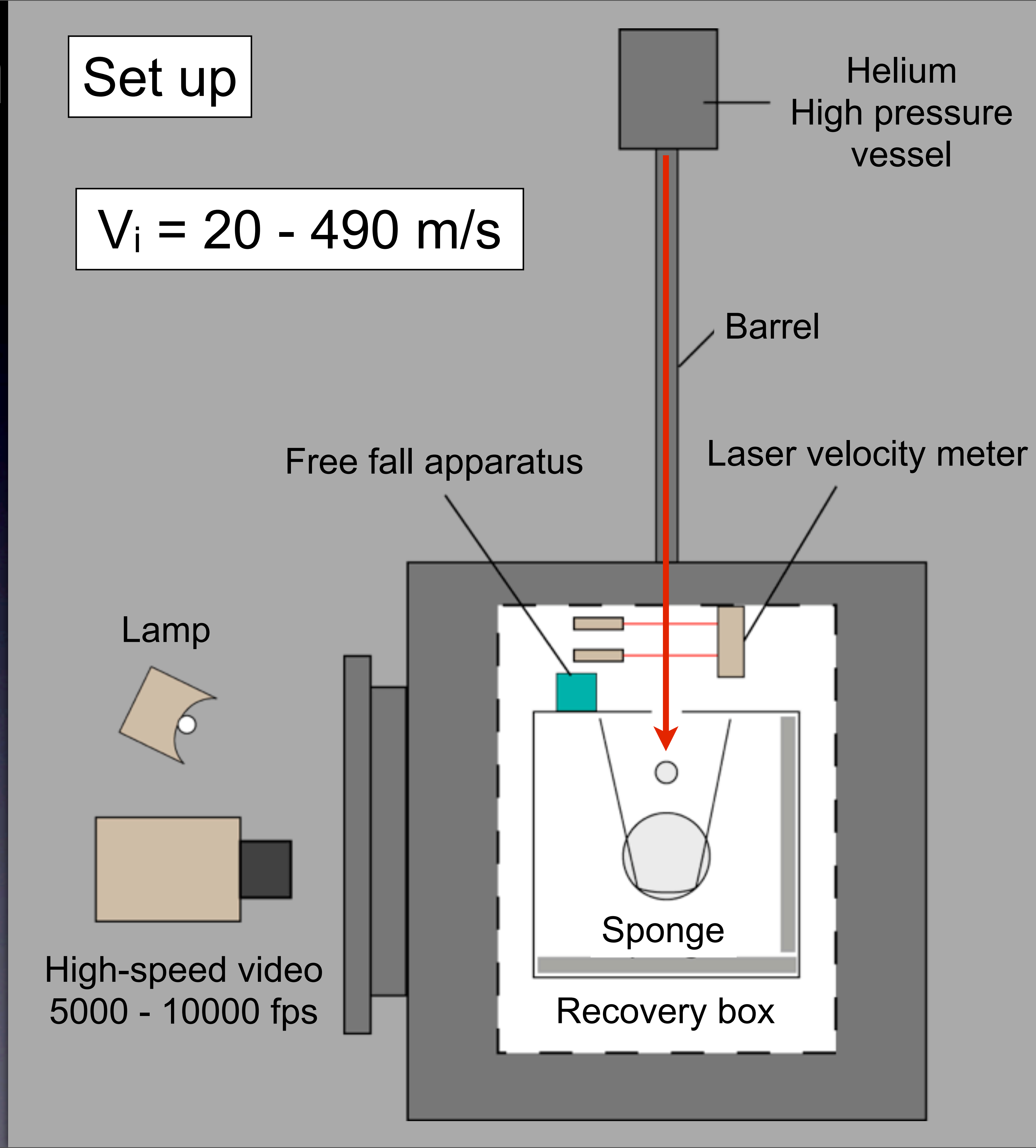
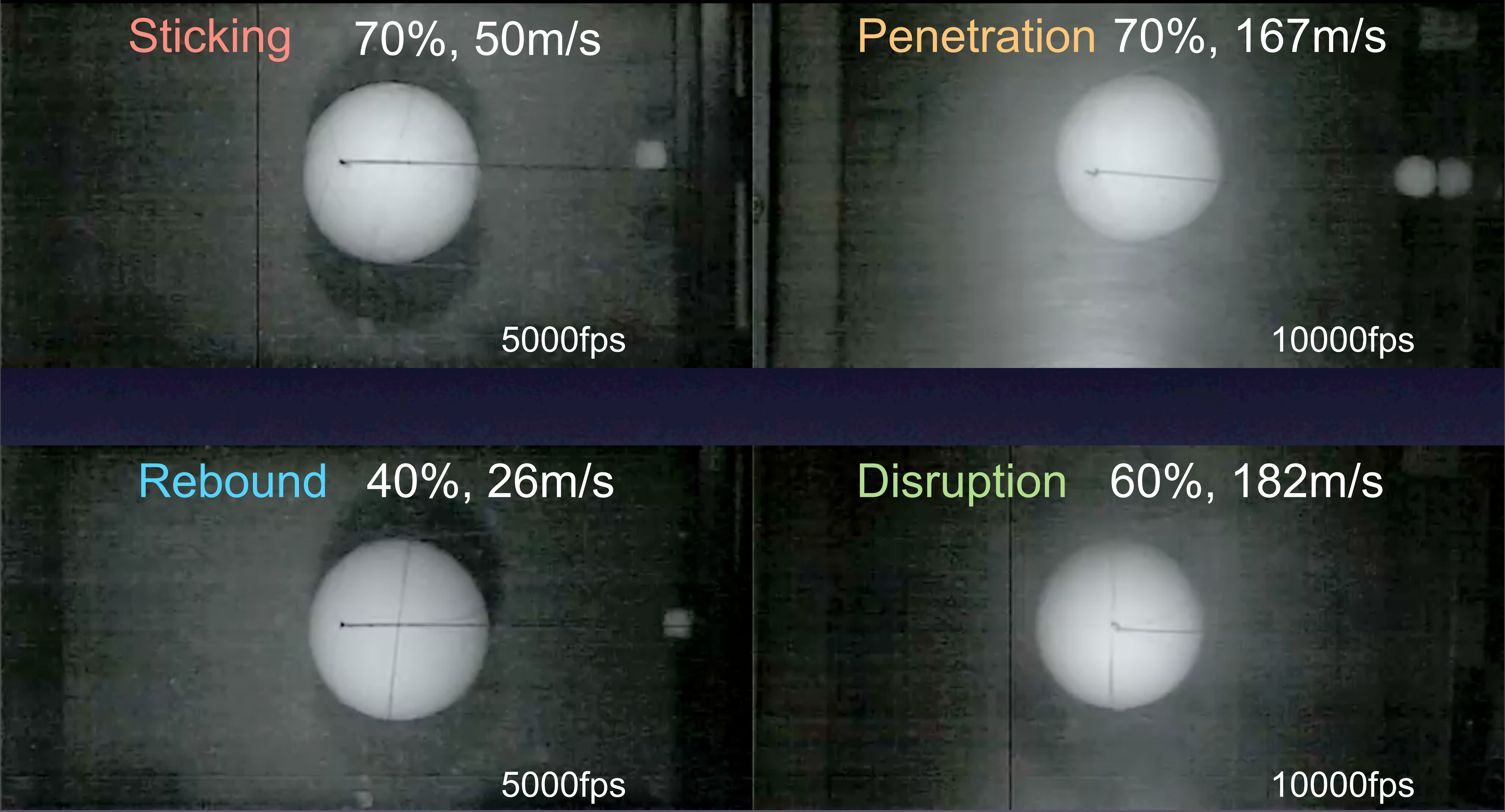
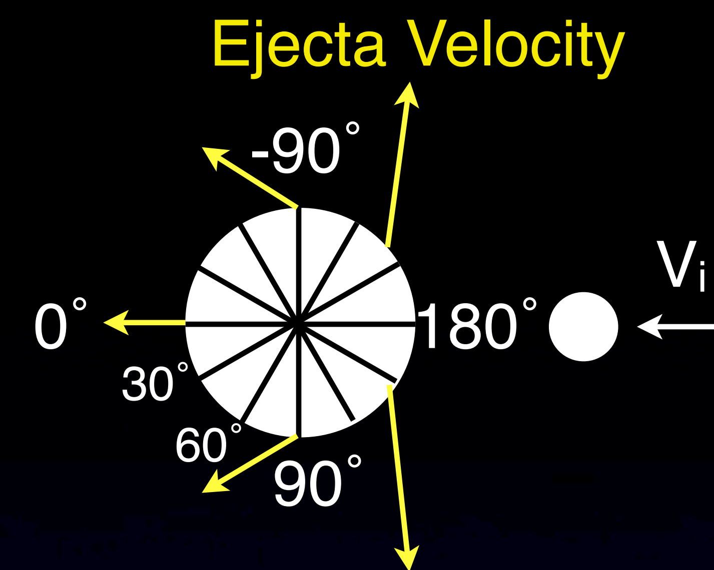


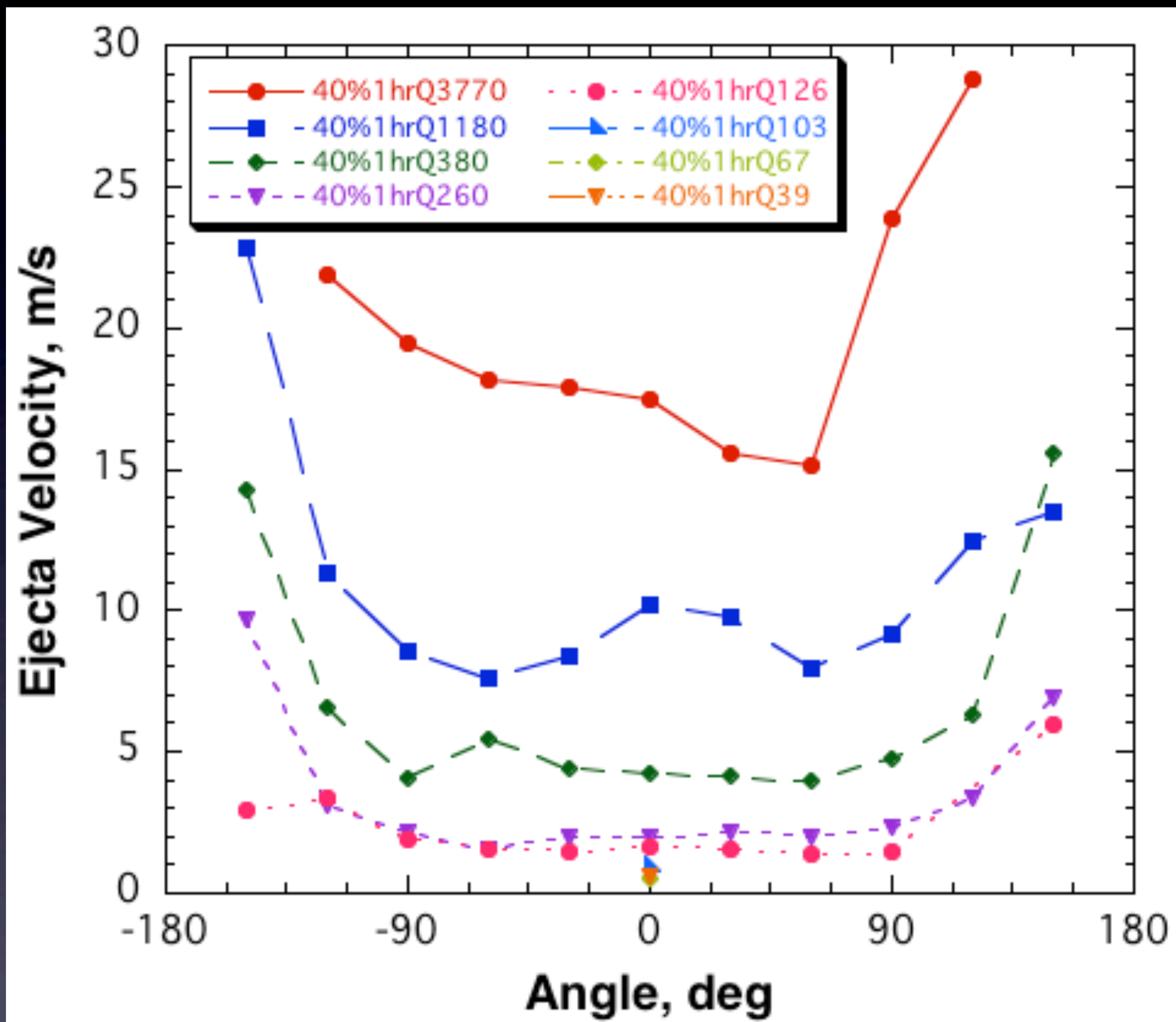
Set up
V_i = 20 - 490 m/s
Helium
High pressure
vessel
Barrel
Free fall apparatus
Laser velocity meter
Lamp
Sponge
High-speed video
5000 - 10000 fps
Recovery box

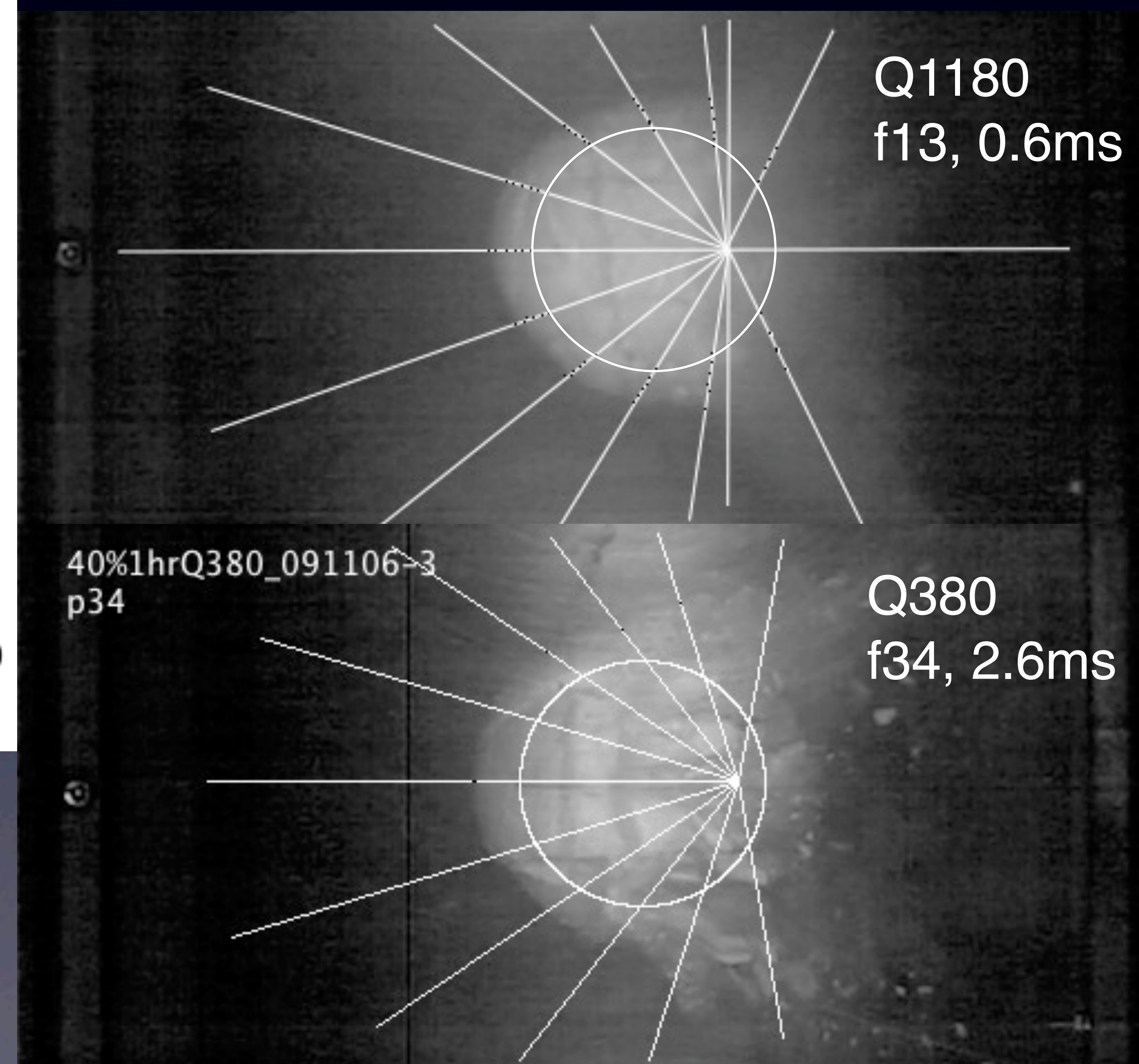
Movies of Impact Disruption



Ejecta velocity distribution : Φ=40%

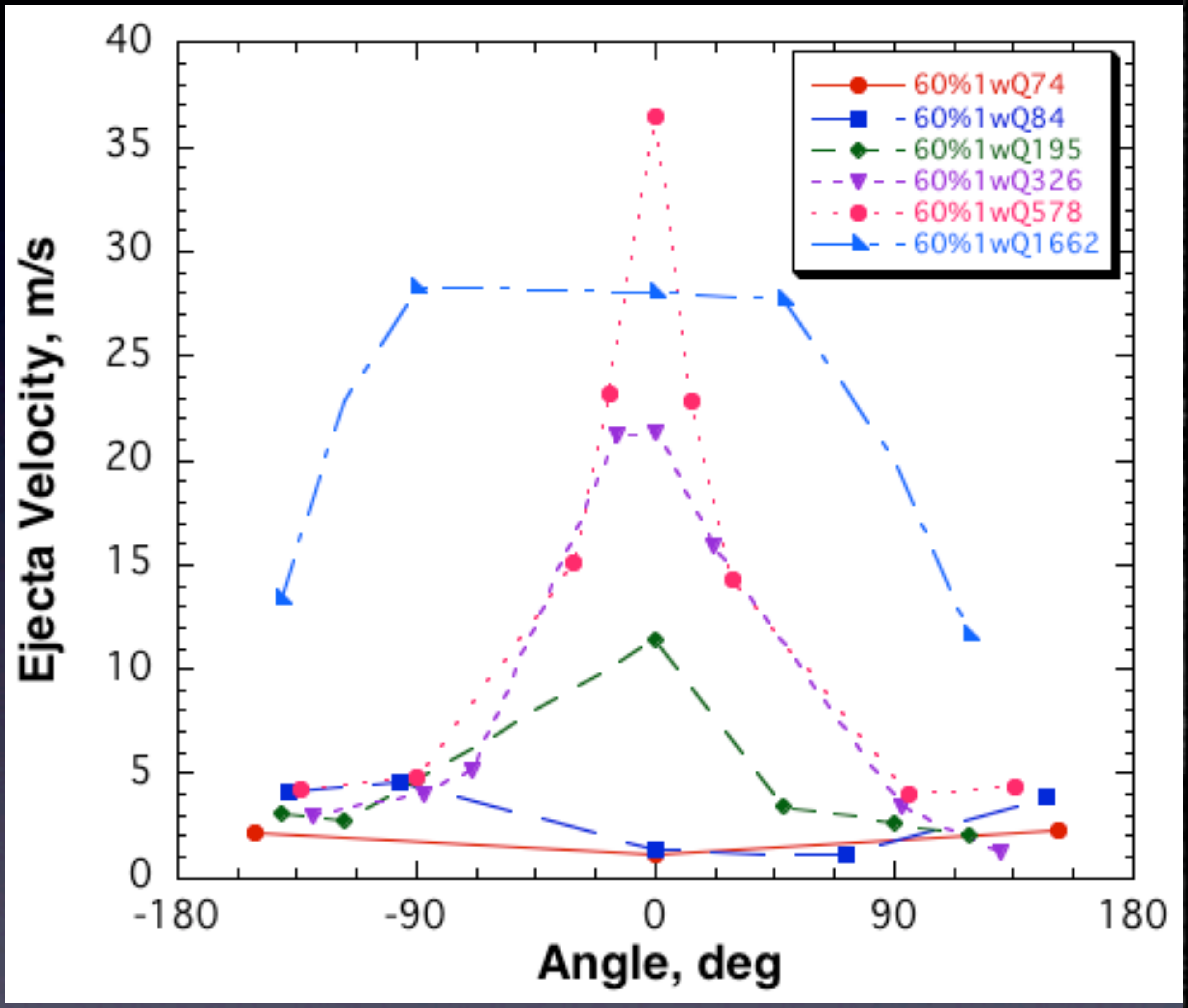


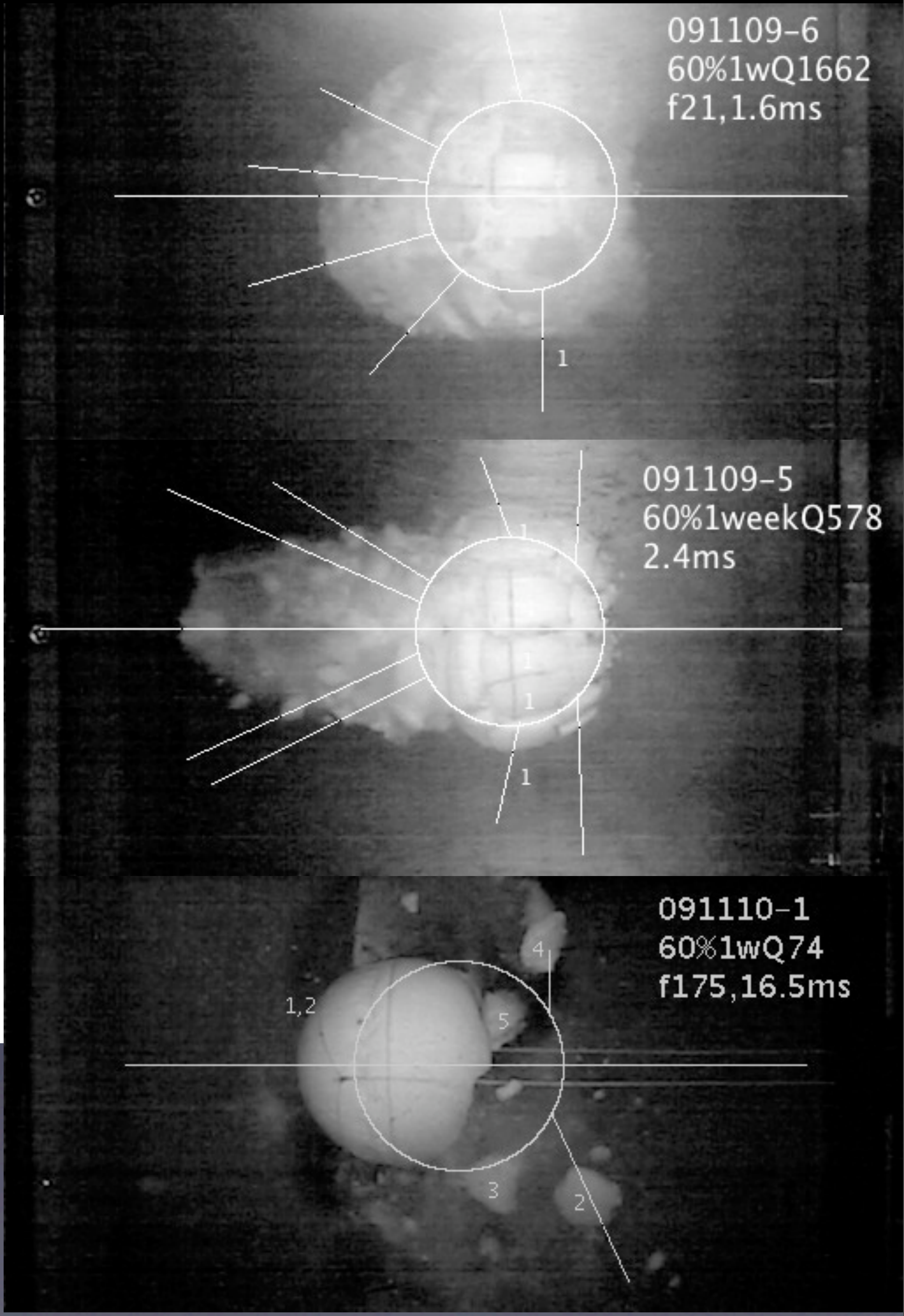




- +/-90° Flat : Disruption

Ejecta velocity distribution : Φ=60%

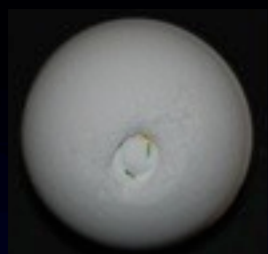




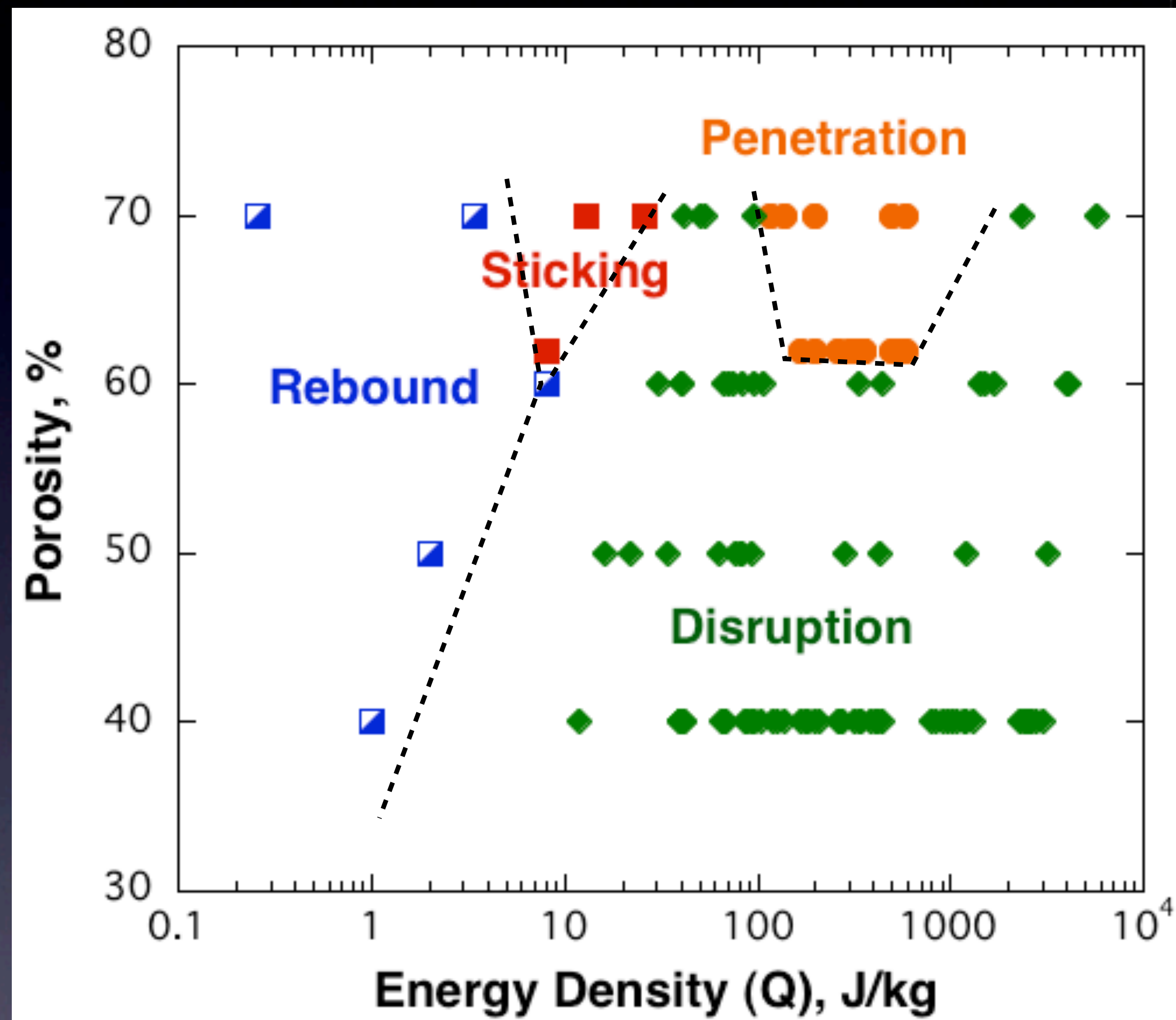
- 0° Sharp peak : Penetration
- +/-90° Flat : Disruption

Collisional outcomes

Sticking

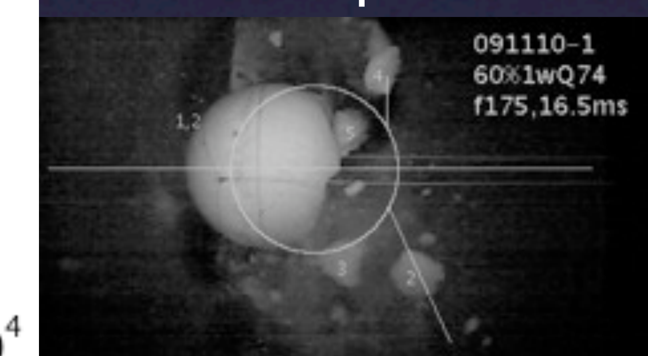


Penetration



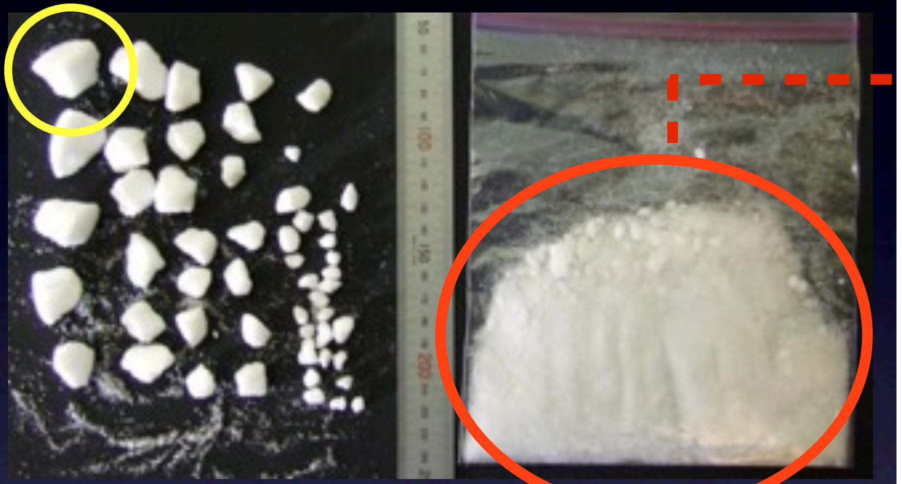
Rebound

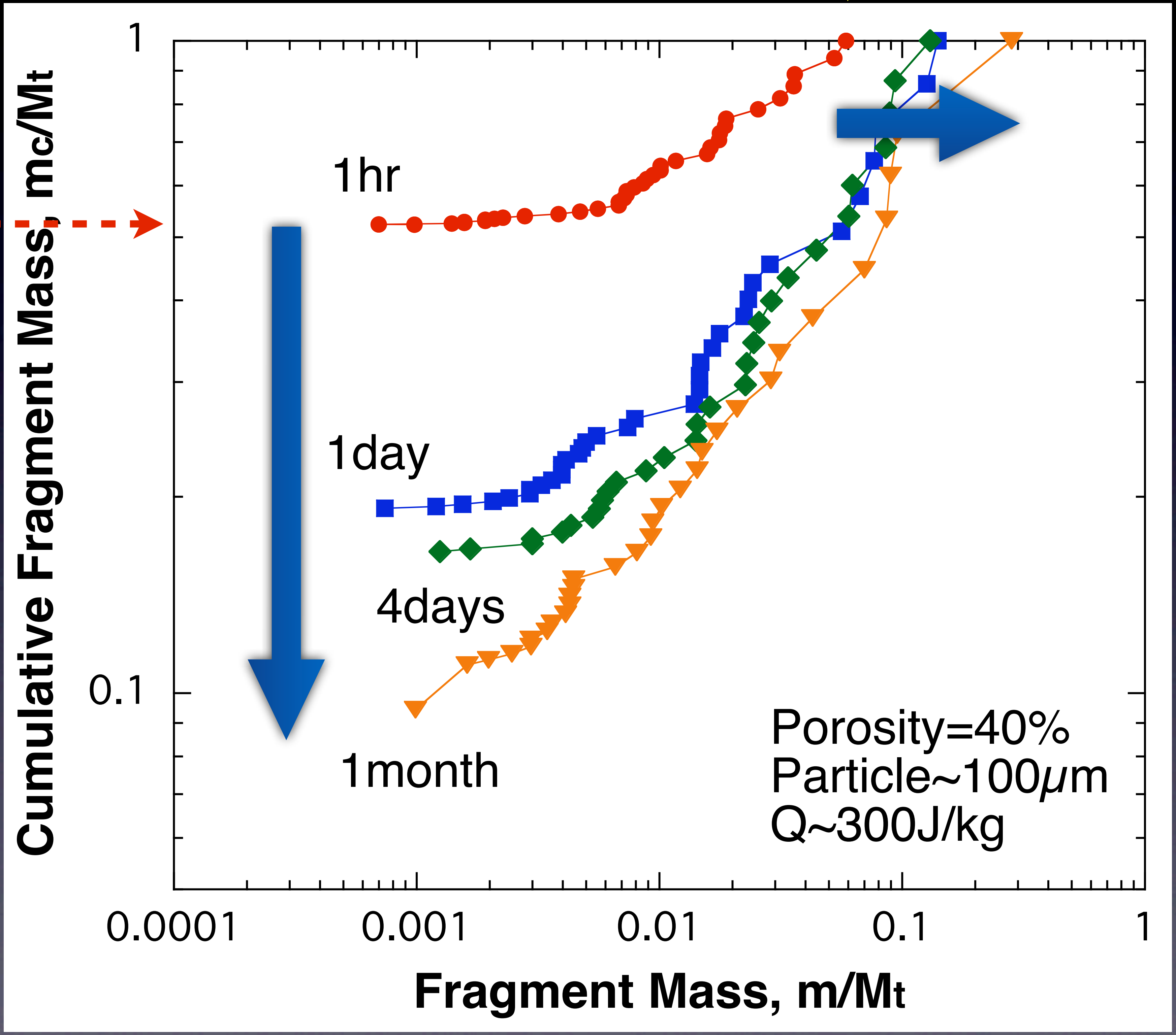
Disruption



$$Q = \frac{m_p V_i^2}{2M_t}$$

Recovered Fragments : particle size:~100μm





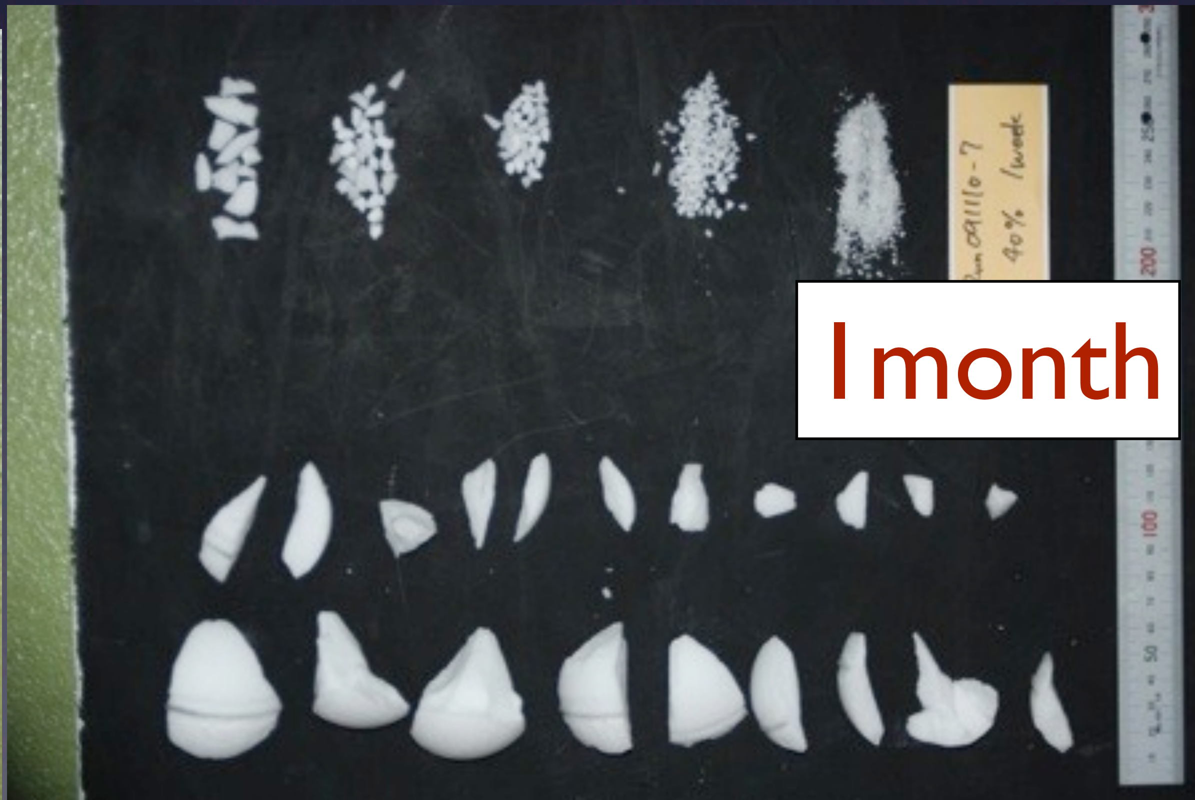
m: fragment mass
M_t: target mass
m_c: cumulative fragment mass
m_l: largest fragment mass

Recovered Impact fragments: ϕ=40% particle size: ~10μm

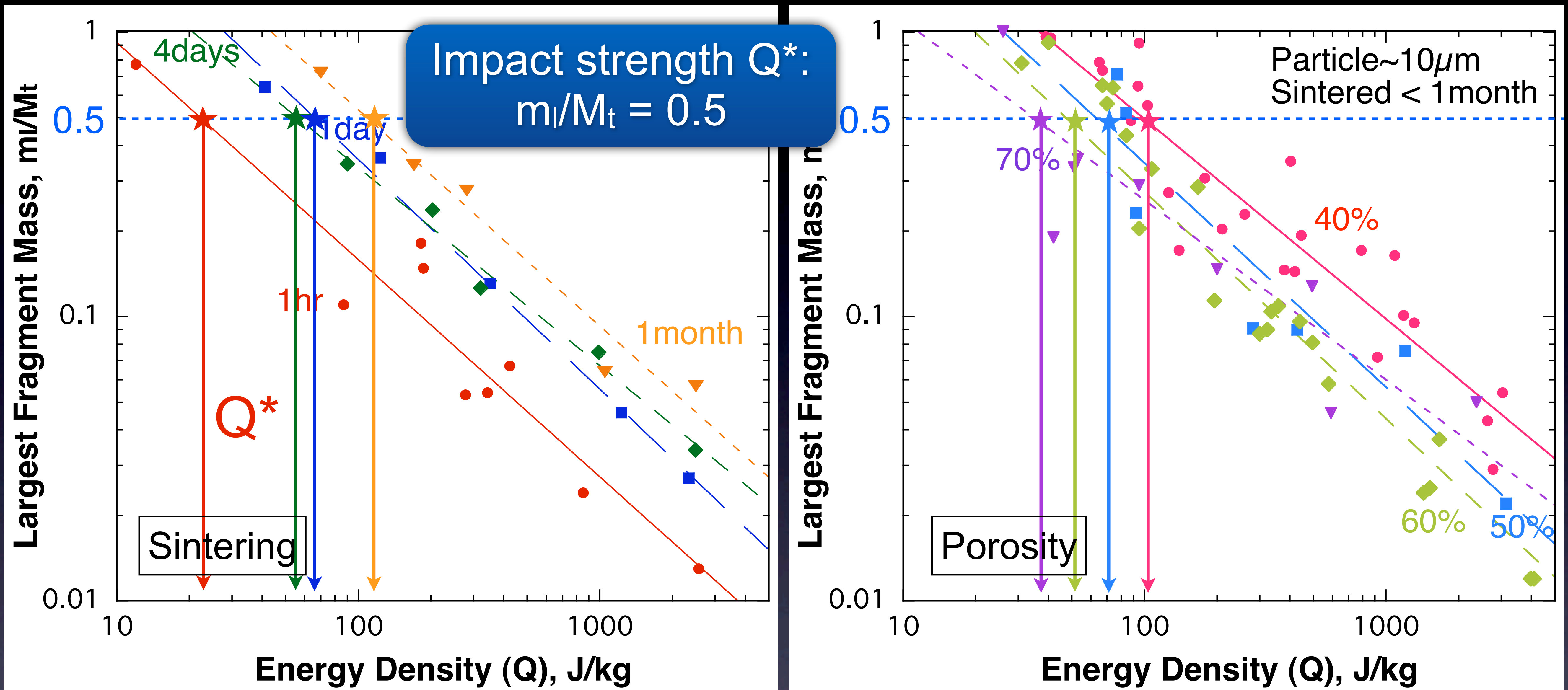
Dependence on sintering duration : →small

We only considered a porosity dependence for 10μm particle targets.

40%, Q=150J/kg



Largest Fragment Mass

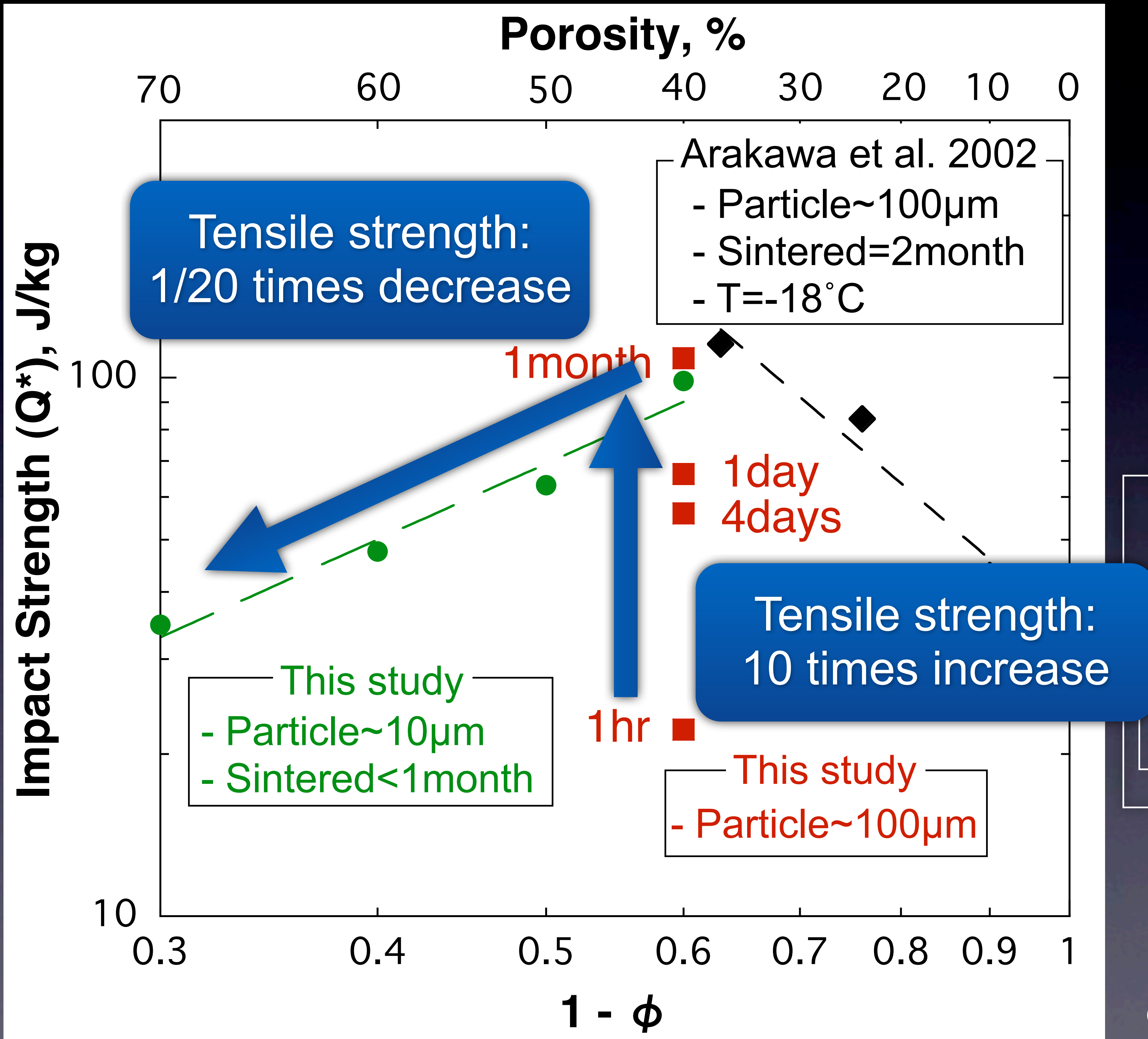


$$m_1 / M_t = p \cdot Q^q$$

40% 100μm	p	q
1hour	5.3	-0.76
1day	14.8	-0.81
4days	8.2	-0.70
1month	17.7	-0.76

10μm <1month	p	q
40%	12.6	-0.70
50%	13.1	-0.79
60%	10.9	-0.80
70%	4.7	-0.63

Impact Strength



Porosity=40%
Particle~100μm
T=-15℃

$$Q^* = 50.5 \cdot t^{0.21}$$

Q^* [J/kg]
t [day]

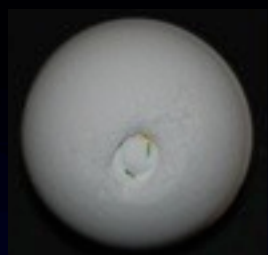
Particle~10μm
Sintered<1month
T=-15℃

$$Q^* = 189 \cdot (1-\phi)^{-1.8}$$

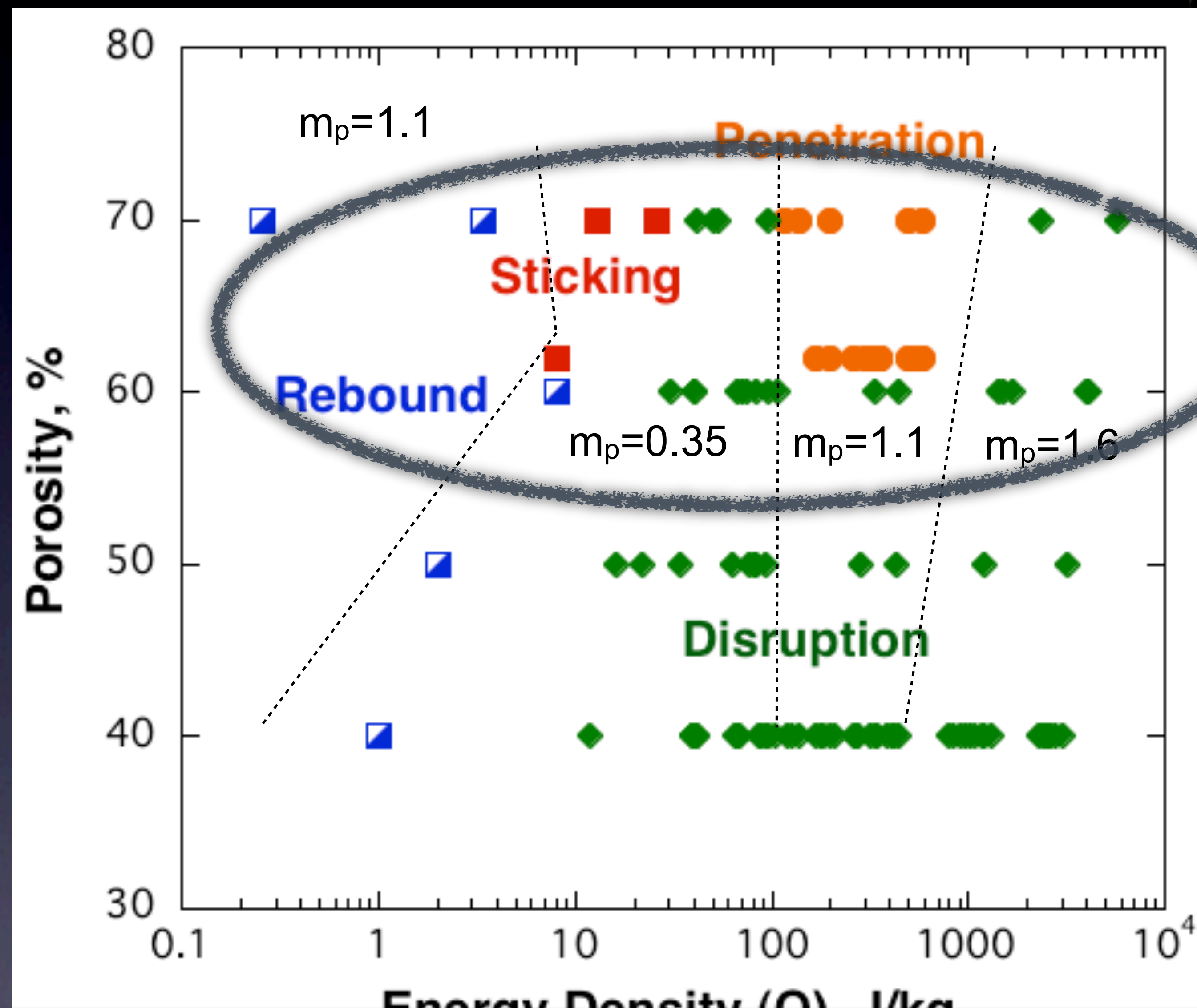
Φ: porosity

Collisional outcomes

Sticking



Rebound



Penetration

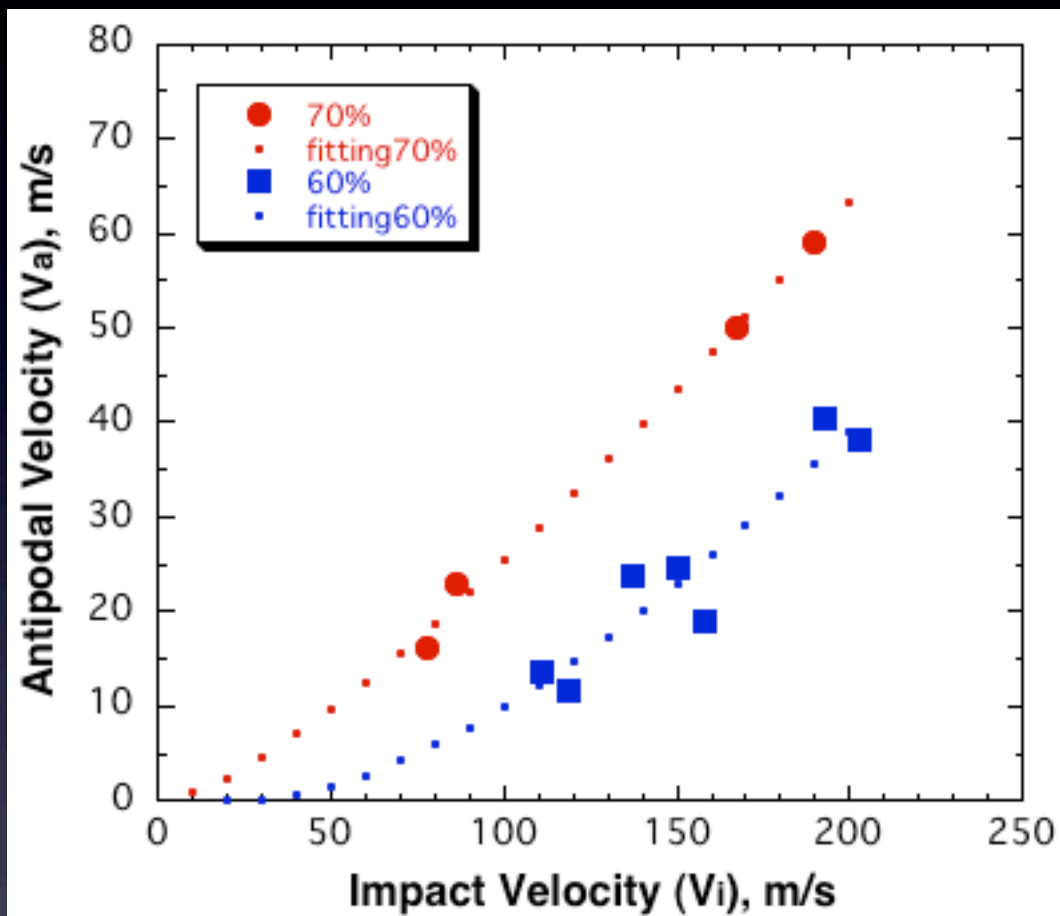
Disruption

We construct a physical model to explain each boundary with the consideration of **projectile mass**

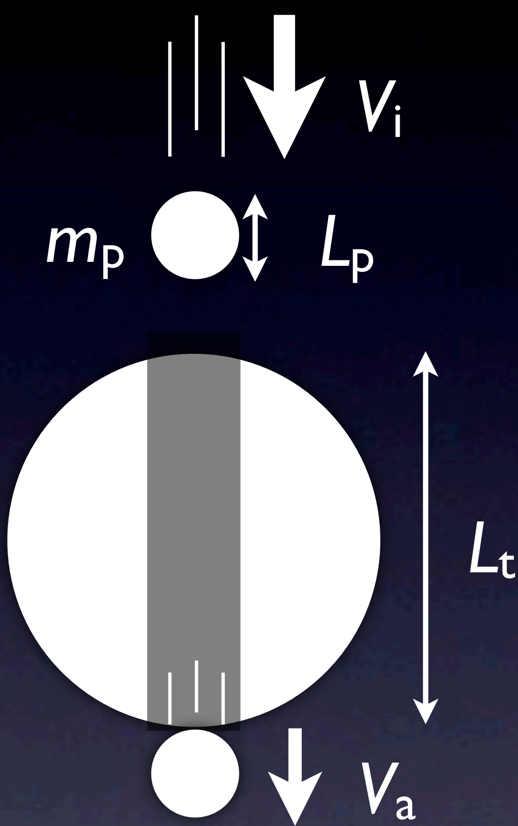
→Physical model of **projectile penetration**

Motion of projectile

- V_i vs V_a at penetration



Porosity	n	k
70%	1.78	261.5
60%	1.65	641.6



Drag force depends on

- **Impact velocity**
- **Projectile area**

$$m_p \frac{dv}{dt} = -kL_p^{\ 2} v^n$$

$$V = \left(V_i^{2-n} - \frac{kL_p^{\ 2}(2-n)L}{m_p} \right)^{\frac{1}{2-n}}$$

→We determine k, n by substituting $V=V_a$, $L=L_t$

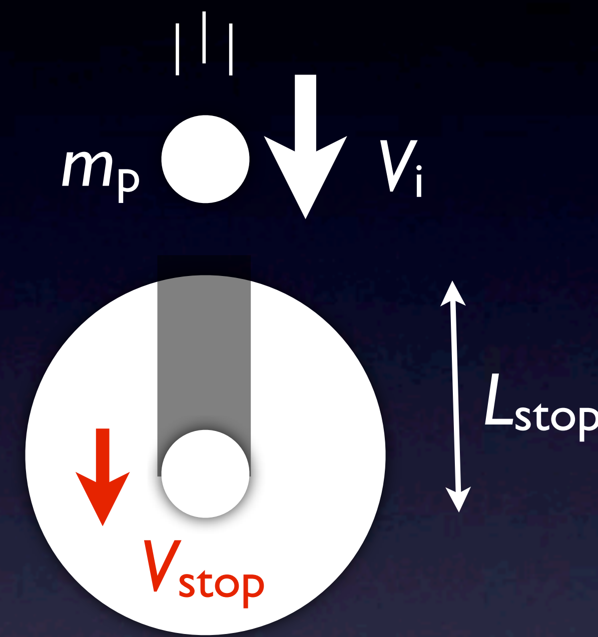
m_p : projectile mass
V_i : Impact velocity
L_t : Target length
L_p : Projectile length

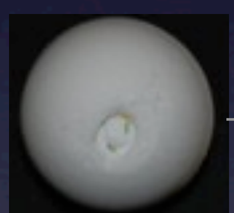
Sticking condition

- Projectile velocity penetrating through the target

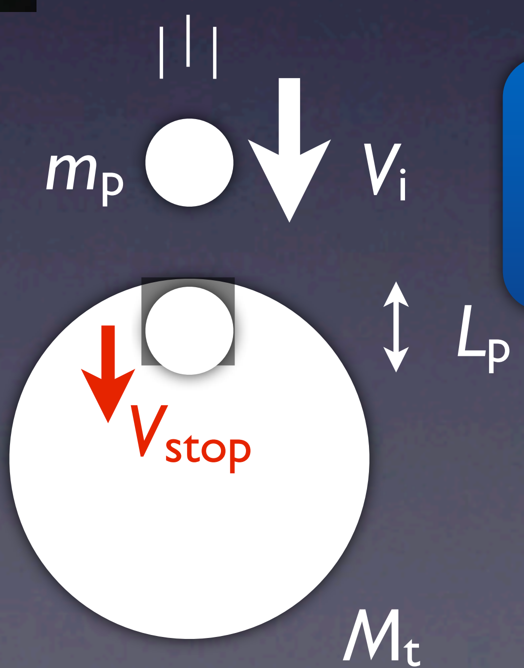
$$V = \left(V_i^{2-n} - \frac{k L_p^{\ 2} (2-n) L}{m_p} \right)^{\frac{1}{2-n}}$$

We assume that Projectile stops at $V=V_{stop}$, we can obtain V_{stop} from the penetration depth L_{stop}





Porosity	m_p [g]	V_i [m/s]	L_{stop} [mm]	V_{stop} [m/s]
70%	0.35	50	17	**25.9**
60%	0.35	44	11	**24.2**



Sticking condition : when $V=V_{stop}$ at the penetration depth equal to projectile length, $L=L_p$.

$$V_i = \left(\frac{6k(2-n)}{\pi \rho_p} + V_{\mathrm{stop}}^{2-n} \right)^{\frac{1}{2-n}}$$

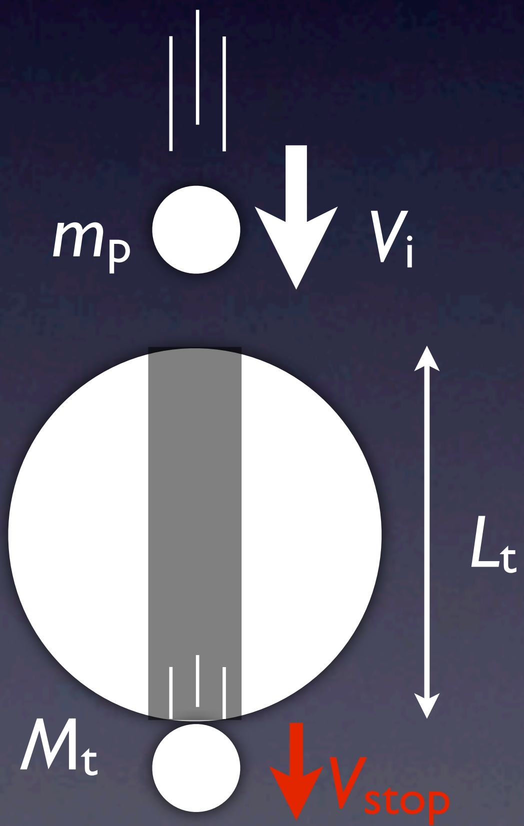
$$m_{\mathrm{p}} = \frac{4\pi \rho_{\mathrm{t}} (L_{\mathrm{p}}/2)^3}{3}$$

Penetration condition

- Projectile velocity penetrating through the target

$$V=\left(V_i^{2-n}-\frac{kL_p{}^2(2-n)L}{m_p}\right)^{\frac{1}{2-n}}$$

Penetration condition : when $V=V_{stop}$ at the penetration depth equal to a target length, $L = L_t$.



$$V_{stop}=\left(V_i^{2-n}-\frac{6k(2-n)L_t}{\pi\rho_p L_p}\right)^{\frac{1}{2-n}}$$

$$\frac{m_p}{M_t}=\frac{\rho_p}{\rho_t}\left(\frac{6k(2-n)}{\pi\rho_p(V_i^{2-n}-V_{stop}{}^{2-n})}\right)^3$$

Disruption condition

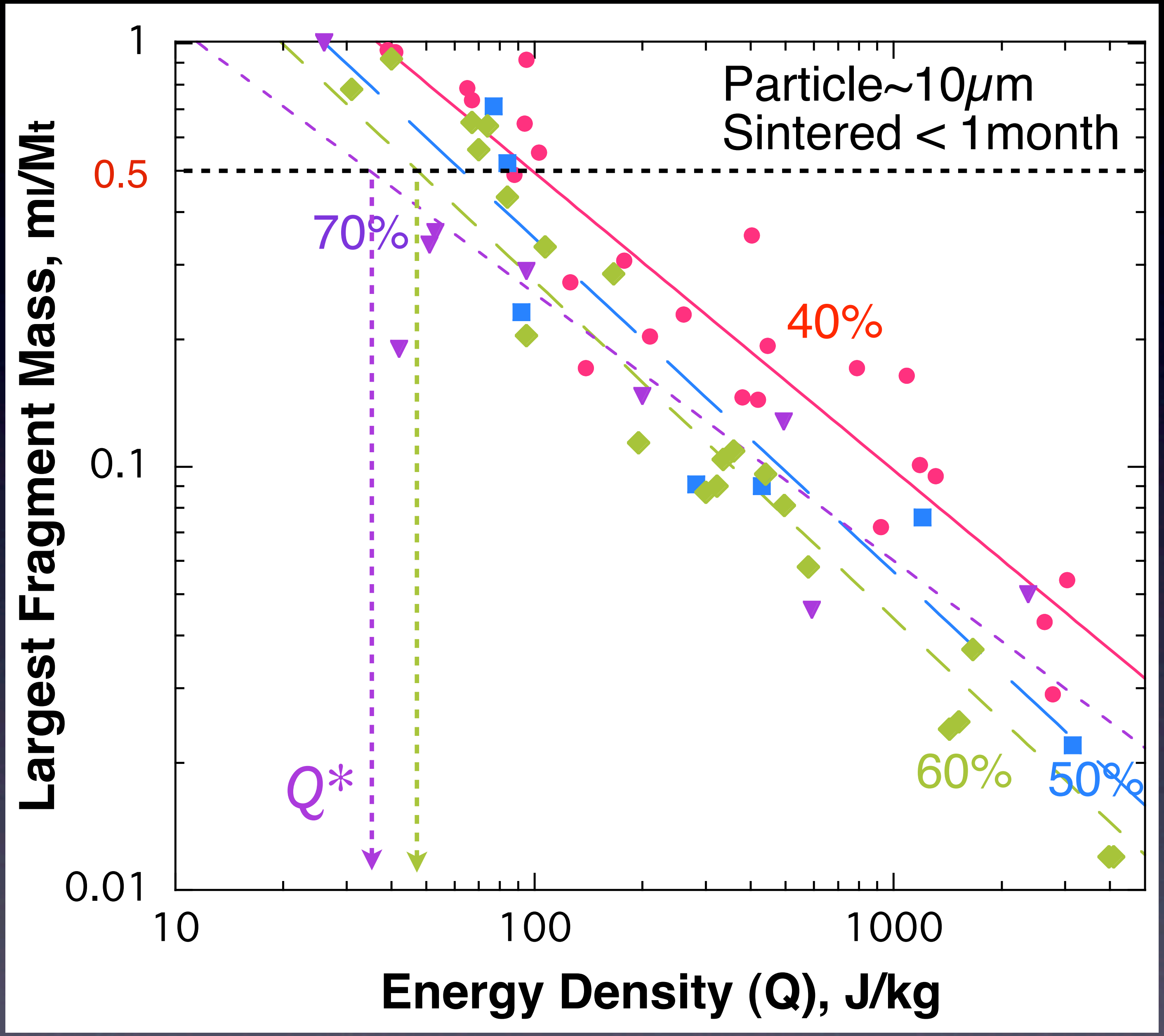
Disruption condition : Largest fragment mass is a half of an original target mass

＝Impact strength **Q***

： Q at $m_l/M_t = 1/2$

Porosity	Q* [J/kg]
70%	34
60%	47

m_l ： Largest fragment



$$Q^{*} = \frac{m_p V_i^2}{2 M_t}$$

Collisional outcomes for porous icy bodies

disruption

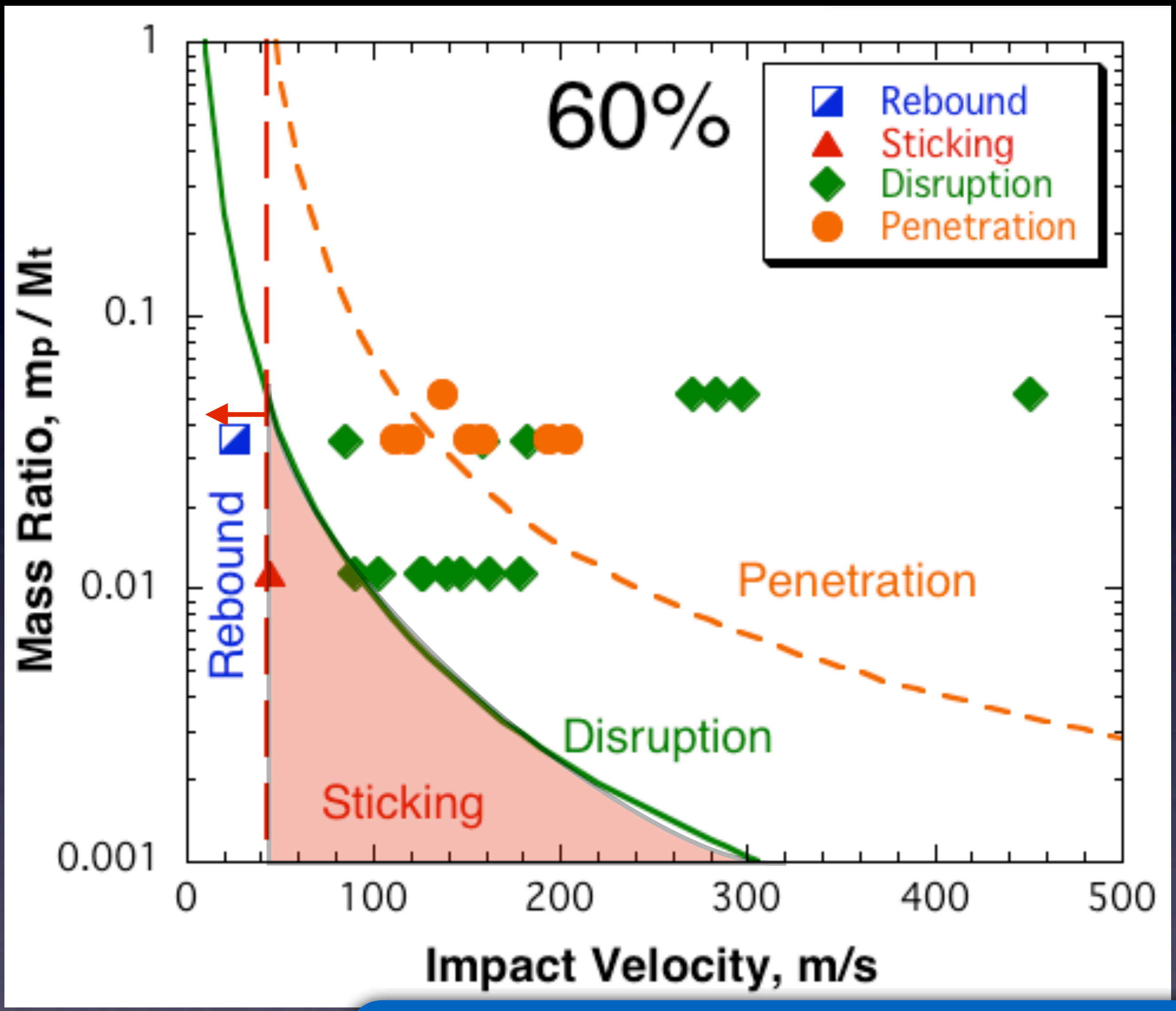
$$m_p / M_t = \frac{2Q^*}{V_i^2}$$

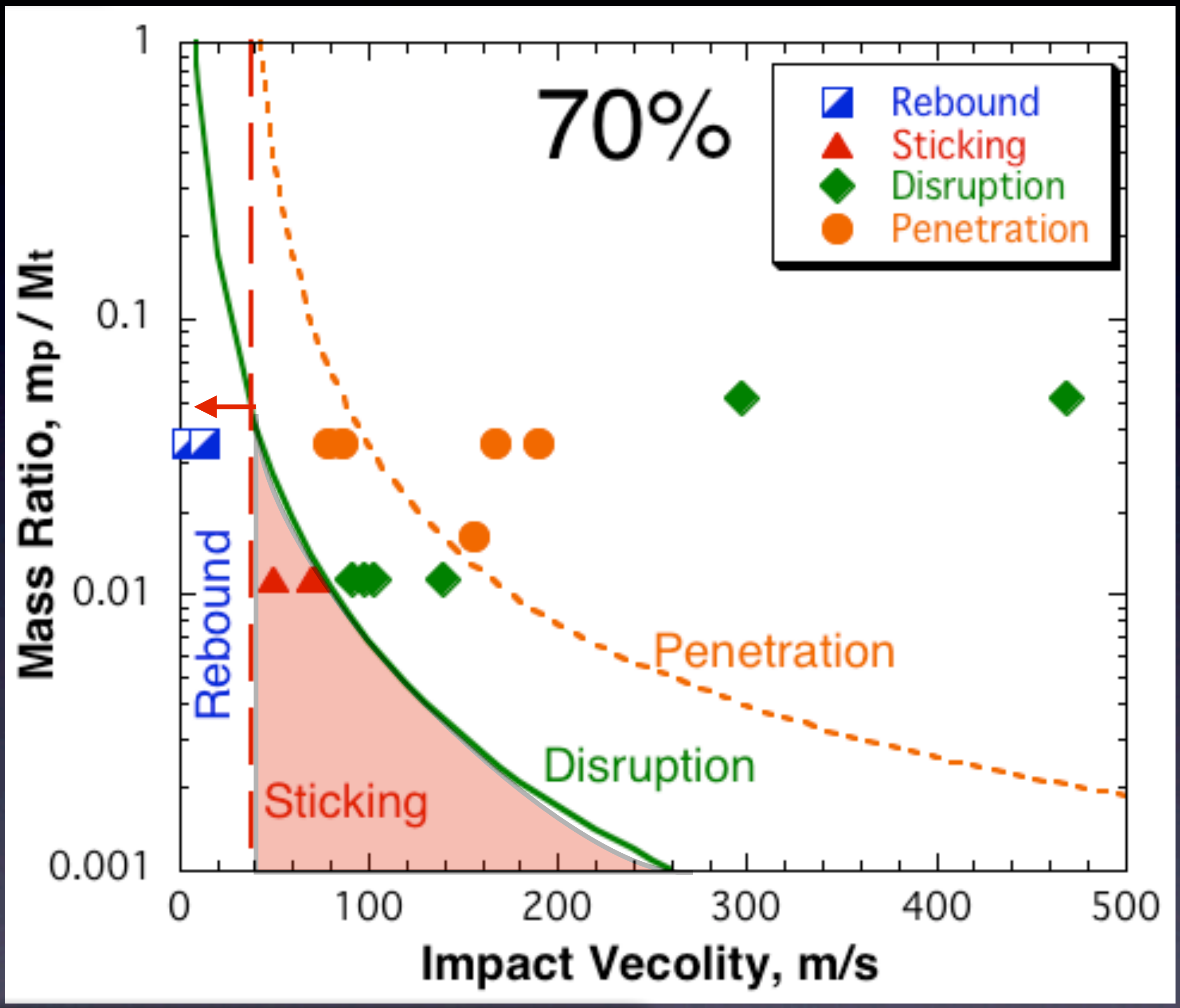
sticking

$$V_i = \left(\frac{6k(2-n)}{\pi \rho_p} + V_p^{2-n} \right)^{\frac{1}{2-n}}$$

penetration

$$\frac{m_p}{M_t} = \frac{\rho_p}{\rho_t} \left(\frac{6k(2-n)}{\pi \rho_p (V_i^{2-n} - V_p^{2-n})} \right)^3$$





Boundary condition for sticking : $m_p/M_t < 0.04 = 1/25$

→$L_p/L_t \sim 1/3$

→Direct sticking is difficult at large $L_p/L_t > 1/3$.

Summary 1

- Impact experiments on sintered snowball with various sintering duration and porosity
  - Sticking, penetration: over 60 %
  - Impact strength
    - for sintering: t = 1 hour to 1 month

$$Q^* = 50.5 \cdot t^{0.21}$$

    - for porosity: Φ = 40 to 70 %

$$Q^* = 189 \cdot (1 - \phi)^{-1.8}$$

Summary 2

- Impact experiments on snow balls with the porosities of 40-70% were conducted to study the physical condition for boundary each collisional outcome.

- Projectile penetration : $$m_p \frac{dv}{dt} = -kL_p^{\,2} v^n$$

Porosity	*n*	*k*
70%	**1.78**	**261.5**
60%	**1.65**	**641.6**

- Sticking condition : $$V_i = \left(\frac{6k(2-n)}{\pi \rho_p} + V_p^{2-n} \right)^{\frac{1}{2-n}}$$

✦ Direct sticking is difficult at the size ratio $(L_p/L_t) > 1/3$.

- Disruption condition :

✦ Impact strength Q*

Porosity	Q* [J/kg]
70%	34
60%	47

end