Survival of the impactor during hypervelocity collisions: an analogue for low porosity targets

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Laboratory Impact Experiments:

➡ spacecraft protection
➡ asteroid collisions

TARGET

✓craters
✓ejecta
✓catastrophic disruption, Q*

PROJECTILE

➡ survival
➡ fragmentation
➡ scaling laws

?

➡ Implanted mass

The problem:

Dark material on Vesta

McCord+2012
Reddy+ 2012

Black Boulder on (25143) Itokawa
Hirata & Ishiguro,2011

2008 TC3

Jenniskens+ 2009
Bischoff+ 2010

Gayon-Markt+ 2012

2008 TC3

- ✓ discovered 19h prior to its entry
- ✓ disrupted high in the atmosphere
- ✓ found 700 meteorites
- ✓ very diverse lithology

loosely bound material

Impactor contamination is suggested to be a possible explanation of the origin of dark materials on several asteroids.

We will try to show that impactors material survives at higher collisional speeds!

Project:

:> for different combinations of **materials**:

… for several impact **speeds**:

… Estimate the projectile's **mass** which is embedded on the crater.

… Measure the **size** distributions of the projectile's fragments that escaped.

… Examine the **state** of the largest survived fragments.

Shots summary:

materials **target:** low porosity (<10%) water-ice (-50C)

projectiles: 3 mm Mg-rich peridot (Forsterite olivine ($(Mg,Fe)_2SiO_4$))
2-2.4 mm synthetic basalt spheres

speeds **0.378 – 3.5 km/s**

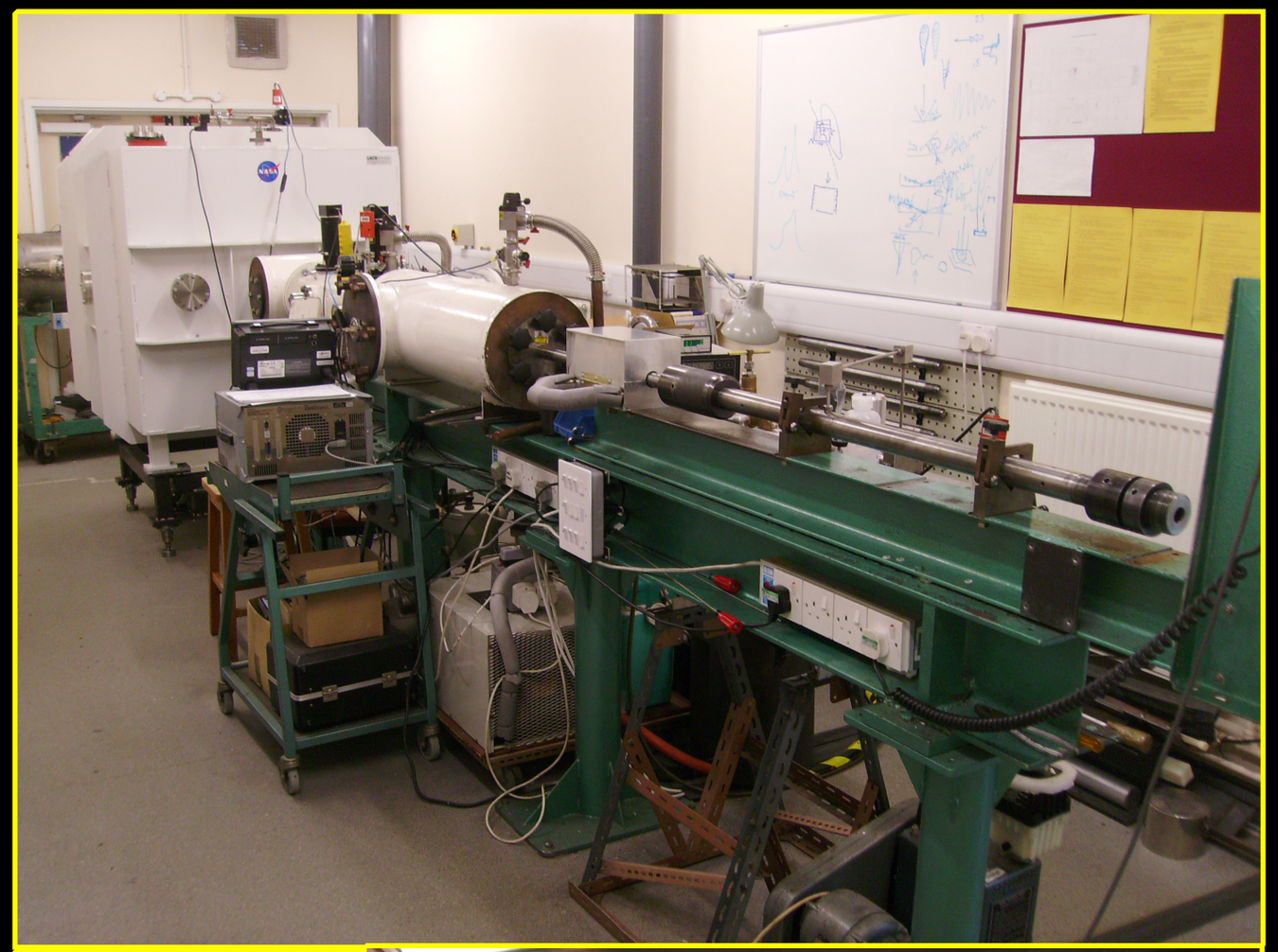
✓ **We have fired 11 successful shots.**

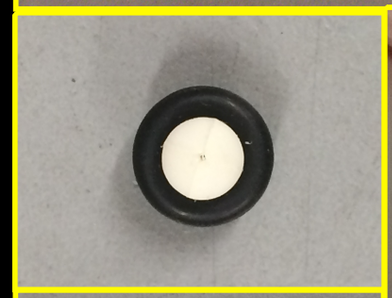
✓ **We recovered relative large fragments for 9 of them.**

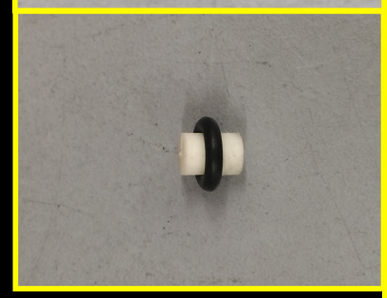
Instruments:

2 stage Light-Gas Gun

- ✓ horizontal gun
- ✓ several targets
- ✓ projectiles: dust, glass, metals, rocks, ice and any living creature does not have a spine!
- ✓ speed < 7.5 km/s
- ✓ vertical component soon!







Scanning Electron Microscope

Raman lasers

Analysis: [From shots to maps]

Ice from target and ejecta–funnel is melted and filtered. The goal is to study the fragments of the impactor which result into the ejecta, but also to have an estimation of the embedded mass on the target.

➡ Bigger guns fire cm-size projectiles
➡ Inefficient measure methods so far

Can we do something better?

Filters are mapped with (SEM).

1000s frames from the successful shots.

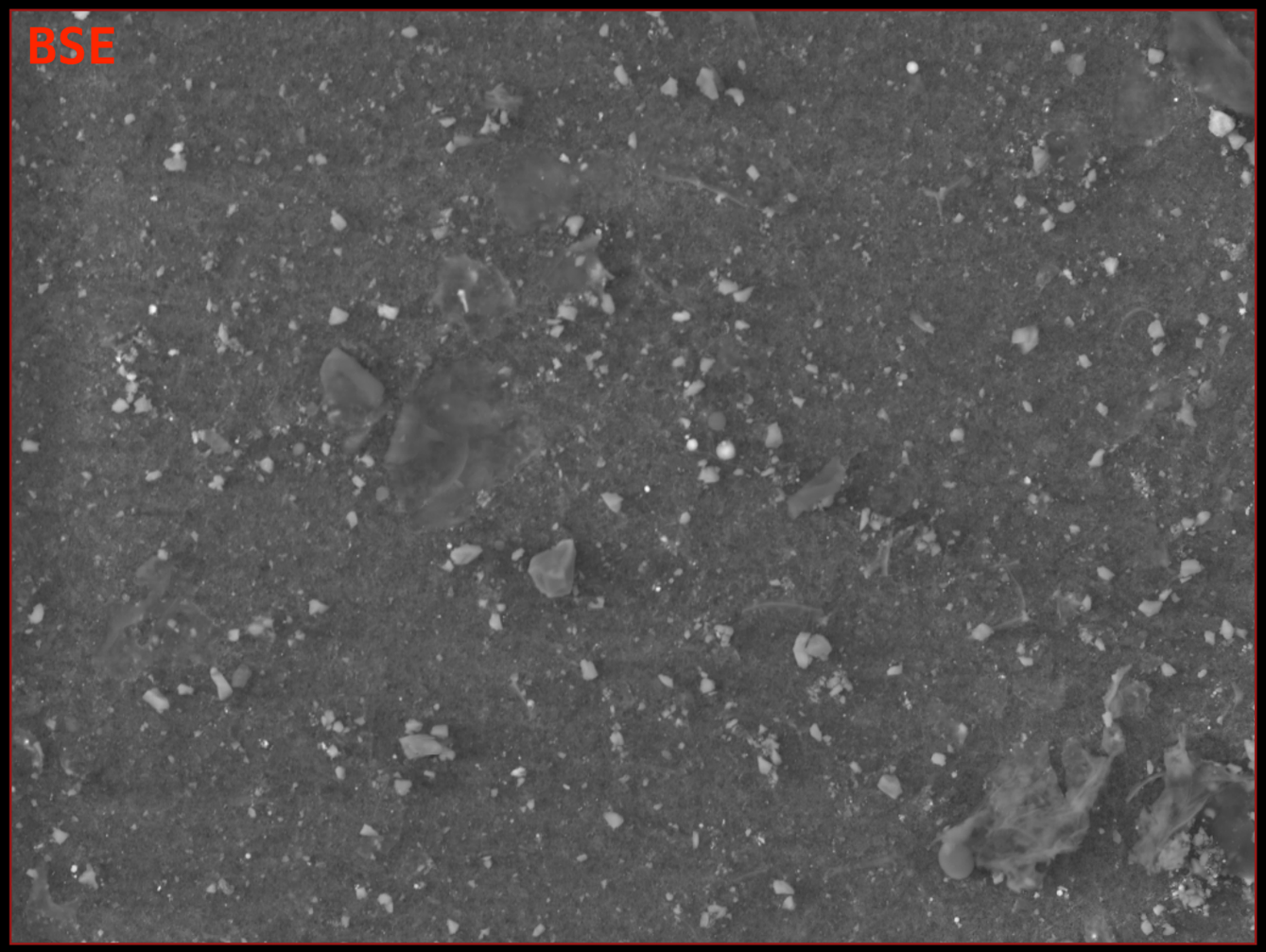
How to proceed?

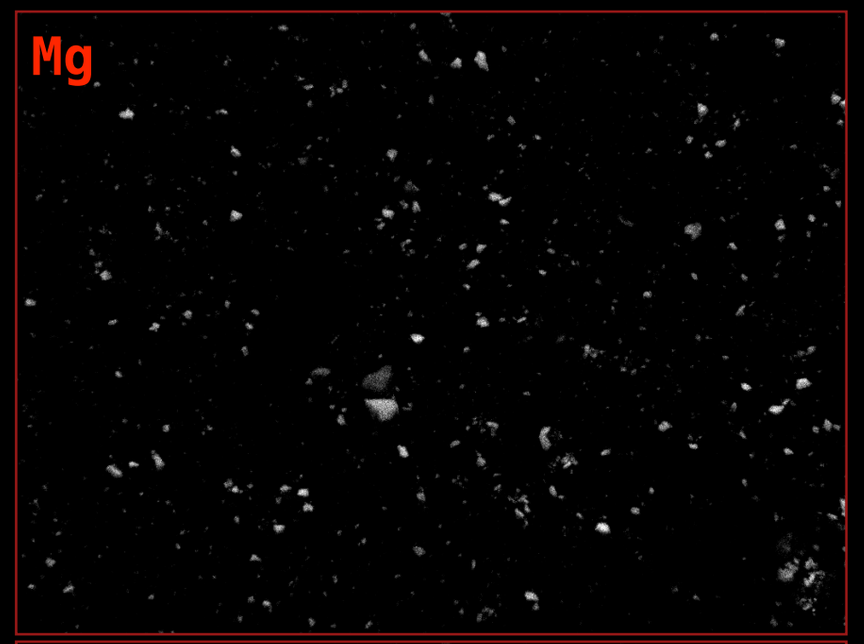
Analysis:
[From maps to distributions]

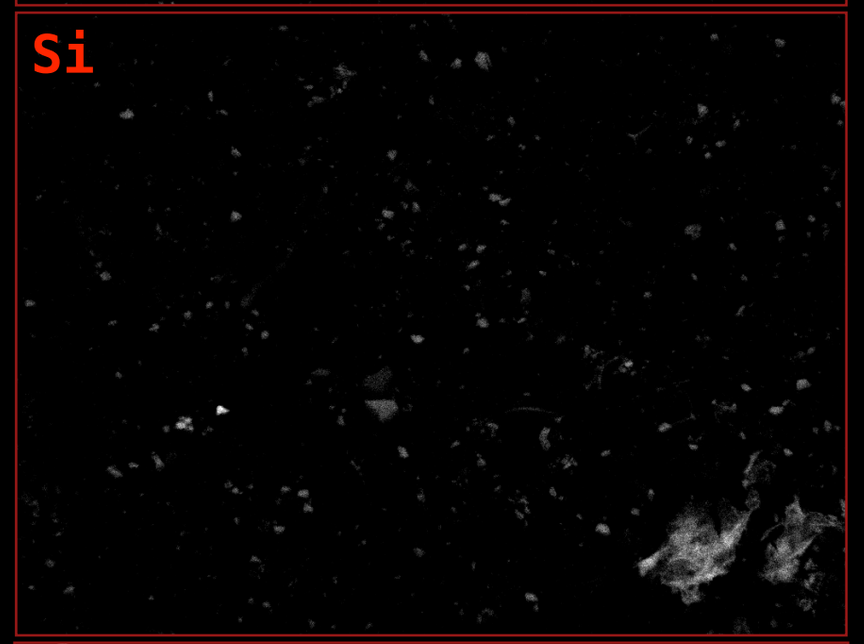
SEM–EDX

SEM and X-rays (EDX) provide light images and elementary maps of each field of view.

Fragments are blended with carbon, sand or iron from the gun we use only the Mg-maps to identify the olivine pieces.

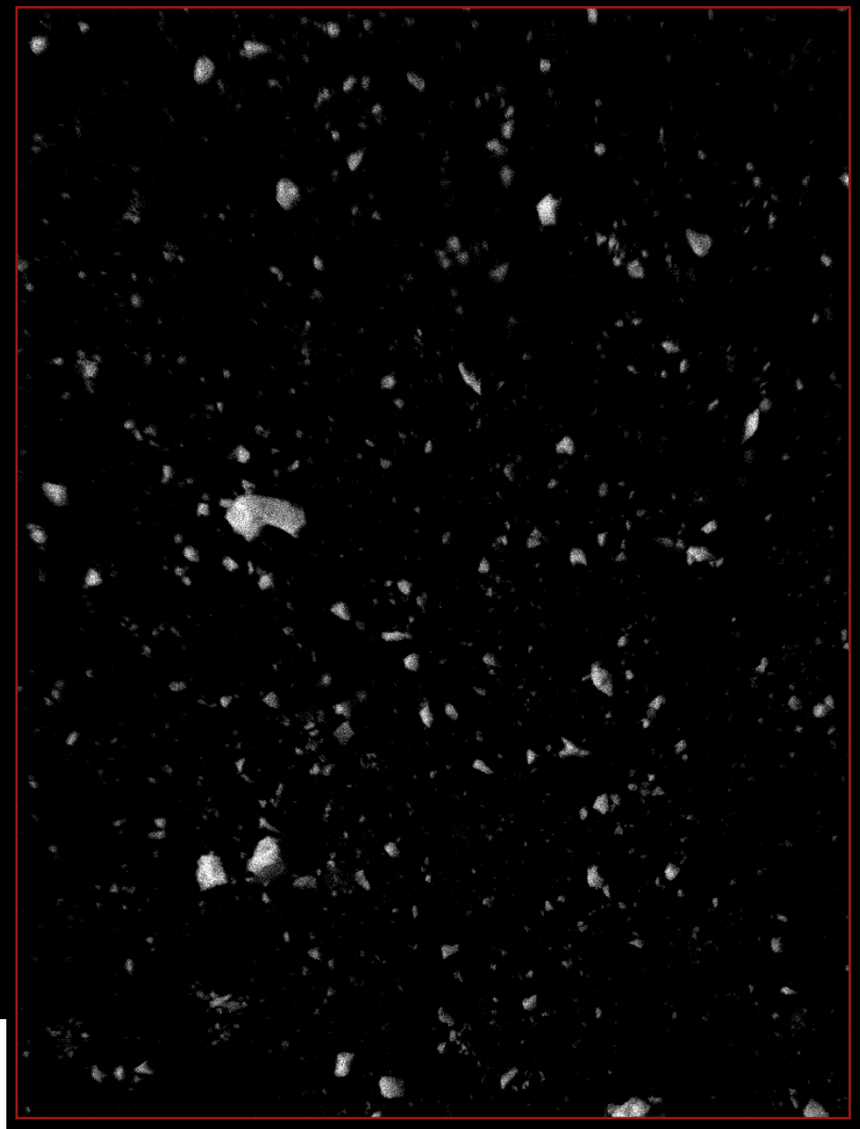






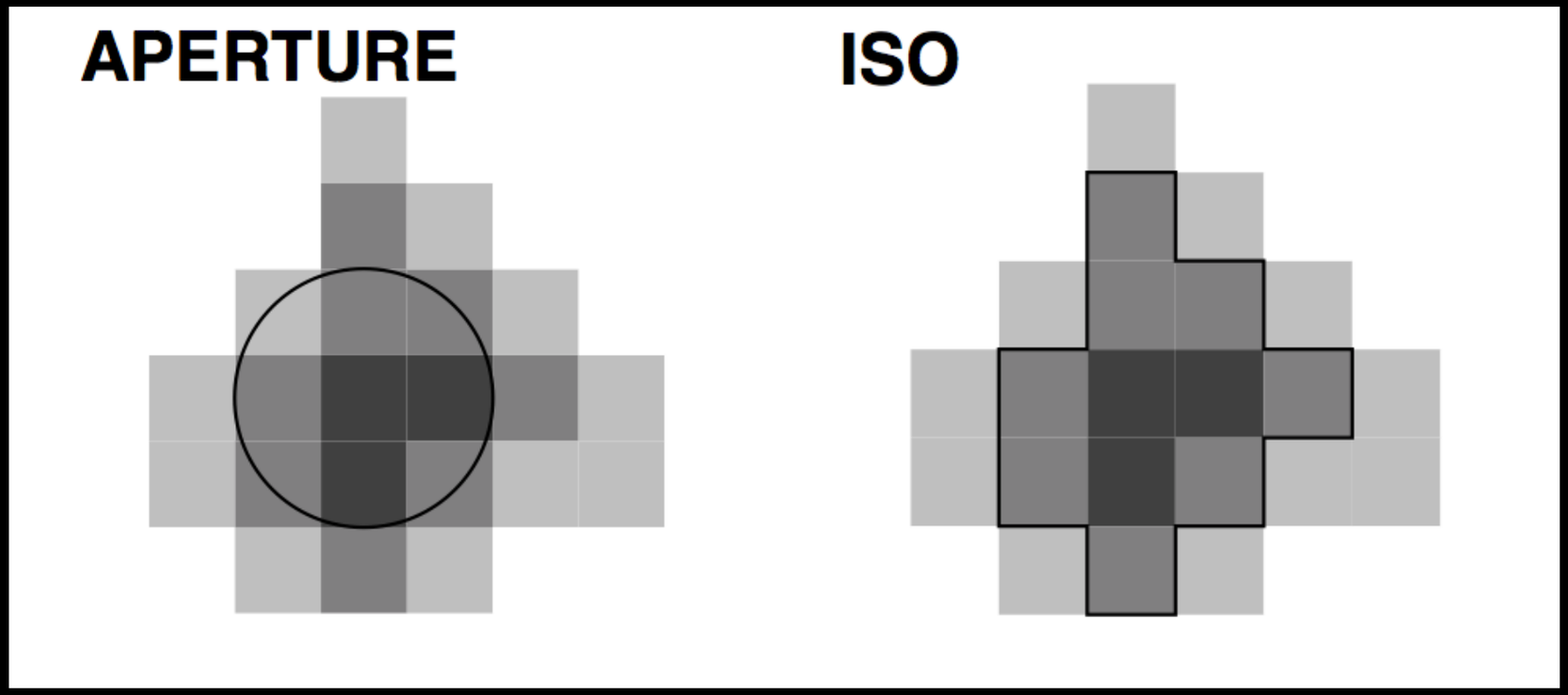
Analysis:
[From maps to distributions]

Still the fragments are uncountable!!!



SExtractor

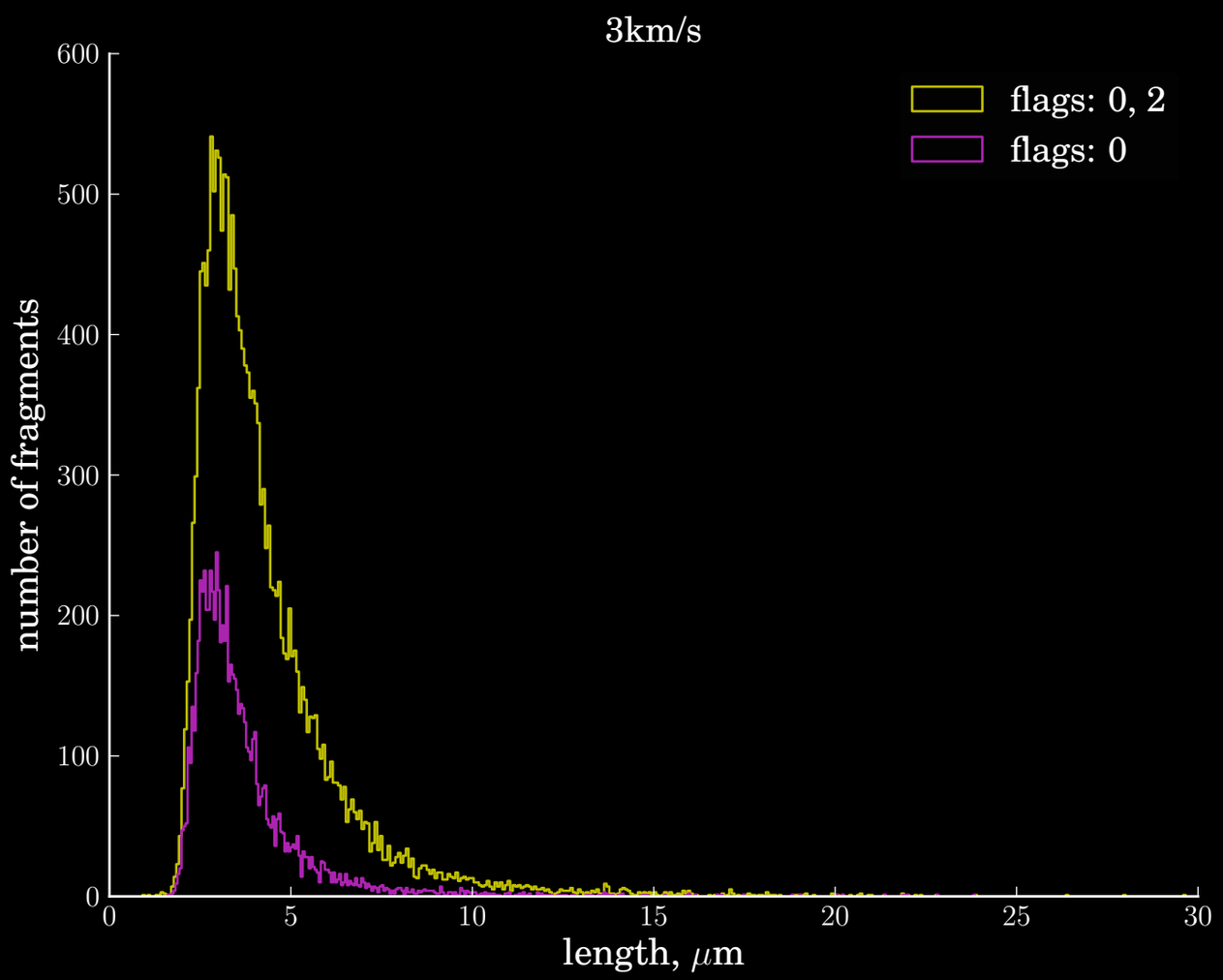
- → Consider fragments as light sources.
- → Apply astronomical photometry by choosing a desirable threshold above BG noise and a threshold in pxl to set the min detectable area.
- → Use ISO aperture able to identify irregular shapes.



Analysis:
[From maps to distributions]

SExtractor

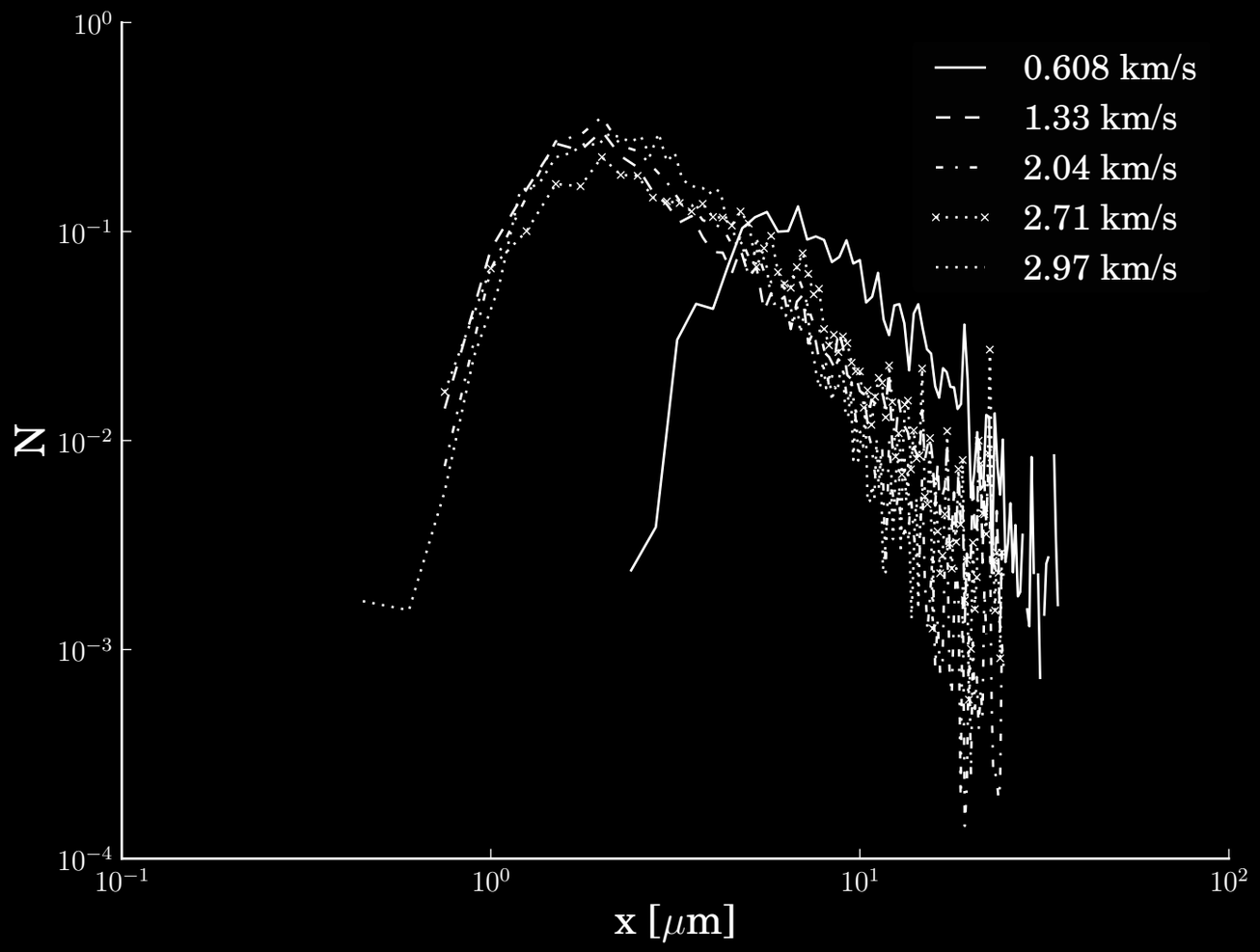
- ✓ Gives the total pxl area per fragment
- ✓ Lengths of x and y axes
- ✓ Elongation and ellipticity
- ✓ Flags to remove “problematic” fragments
- ✓ Total number of fragments



Maps have a limited resolution.
Pxl scale: 0.4microns/pxl.

Analysis:
[From maps to distributions]

SExtractor

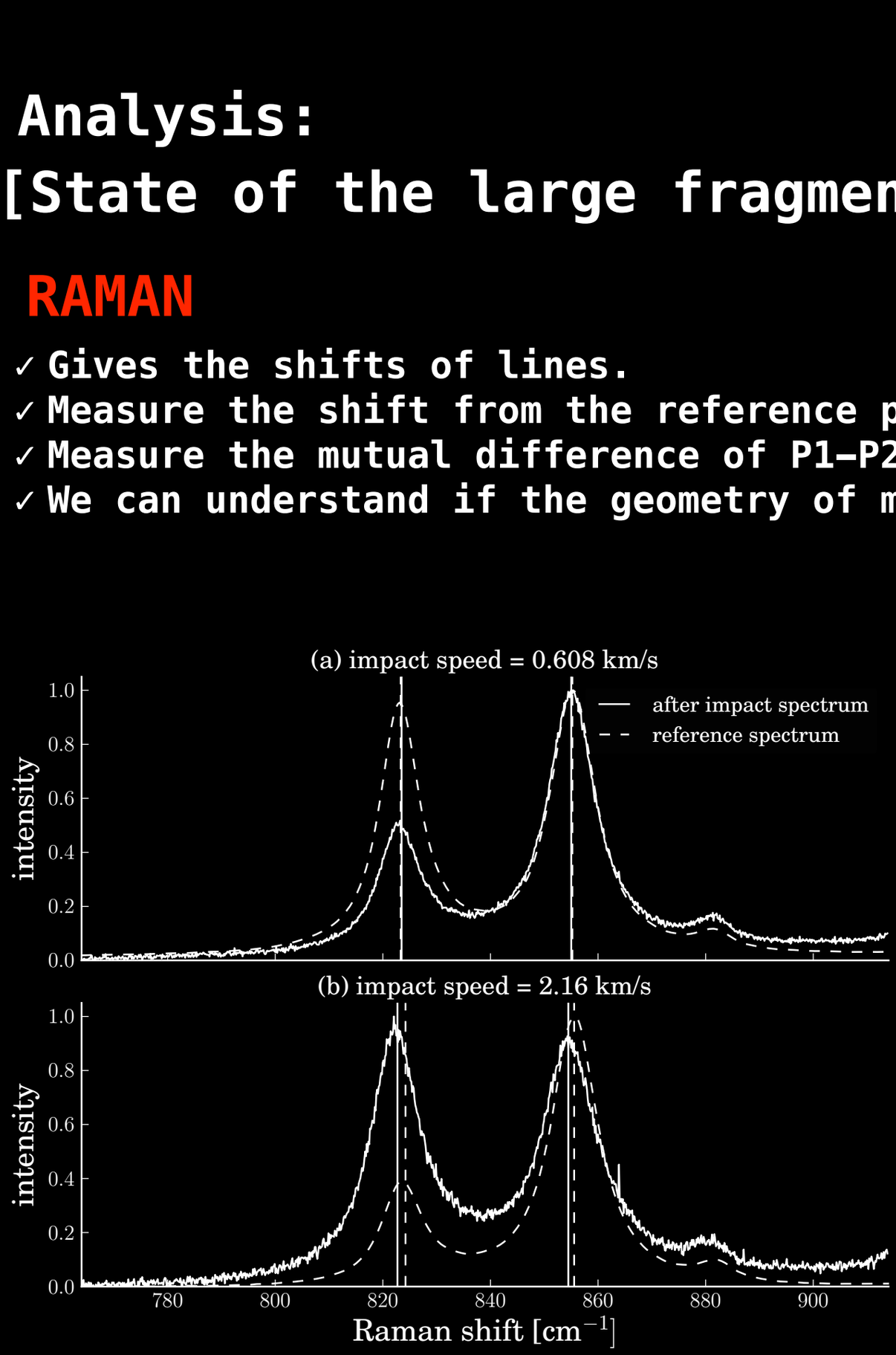


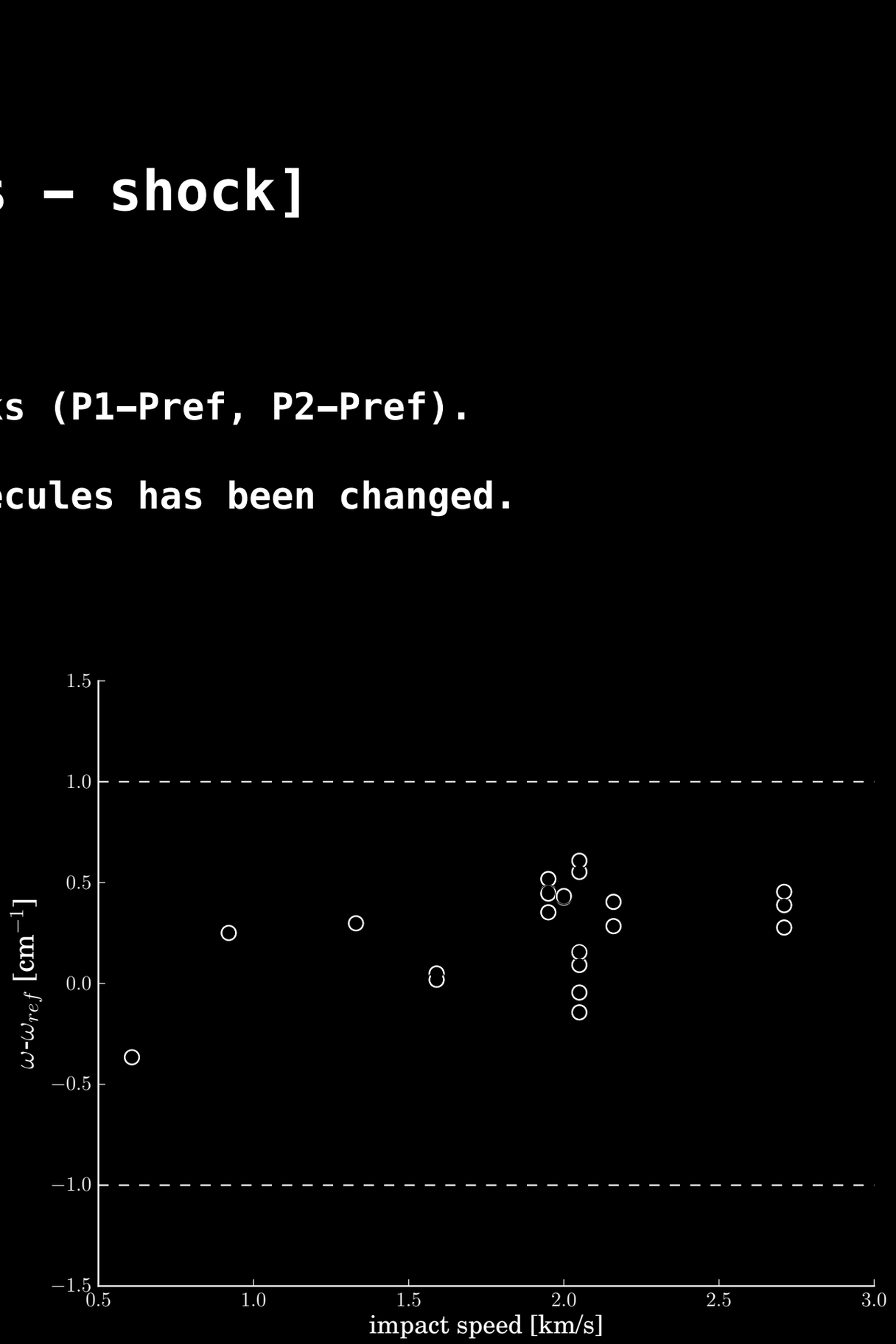
✓Real turnover
✓No change in slopes
✓No change in modes

Analysis:
[State of the large fragments – shock]

RAMAN

- ✓ Gives the shifts of lines.
- ✓ Measure the shift from the reference peaks (P1–Pref, P2–Pref).
- ✓ Measure the mutual difference of P1–P2.
- ✓ We can understand if the geometry of molecules has been changed.





Analysis:
[State of the large fragments – shock]

Hydrocode modelling

Olivine

speed	P	T	T	M	speed	P	T	T	M
[km/s]	[GPa]	[K]	[K]	[%]	[km/s]	[GPa]	[K]	[K]	[%]
0.38	**0.54**	301	293	100	1.49	0.8	360	307	77.4
0.60	1.21	298	293	86.2	1.68	1.0	401	302	70.9
0.92	1.64	297	294	65.5	2.07	1.29	433	303	63.2
1.33	2.84	302	295	29.5	2.14	1.32	436	303	66.3
1.60	3.75	312	296	19.3	2.17	1.33	440	303	77.0
1.95	4.83	330	297	7.8	2.70	2.97	463	308	5.4
2.00	4.94	331	297	13.4	3.03	4.58	522	317	1.3
2.05	5.06	342	297	3.2					
2.16	5.59	335	298	2.9					
2.71	7.13	397	299	0.02					
2.97	8.04	407	305	-					
3.50	10.20	**513**	**353**	-					

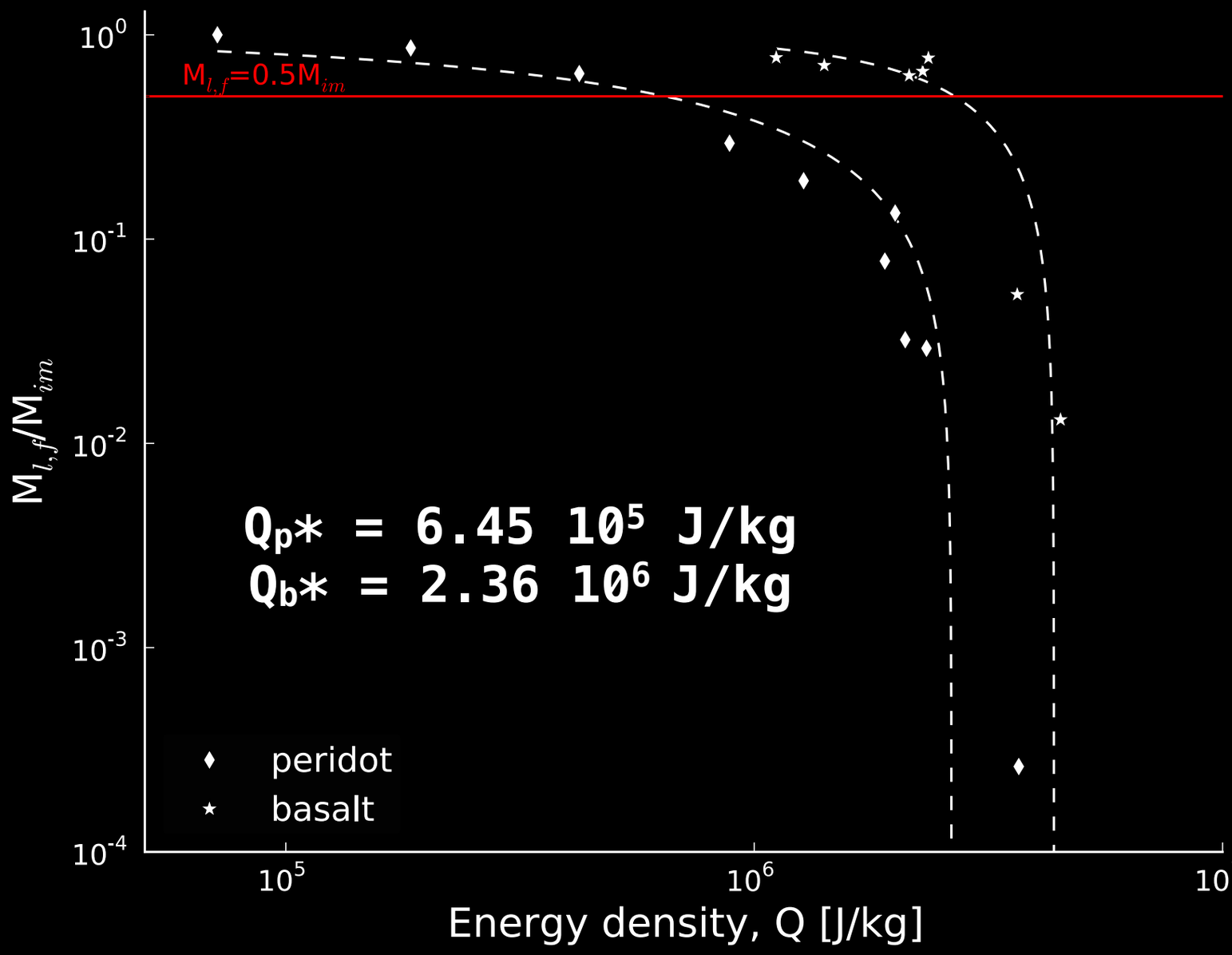
Basalt

Analysis:
[State of the large fragments – mass]

- **Q** is the **energy density [J/kg]** in the impact.

$$Q = \frac{0.5 M_{im} V^2}{M_{im} + M_t}$$

$$Q = \frac{0.5 M_{im} V^2}{M_{im}}$$



Analysis:
[Implantation in the target]

Followed similar analysis with the ejecta-filters.

Identify all olivine fragments.

Random resting position of the fragments on the filter.

Calculate size of each fragments. Assume cubic shapes. (ρ=3.17 gr/cm3)

Quantify the mass on the target.

- ✓ **Mass in all targets for olivine**
- ✓ **ongoing examination for basalt**

Current experiments:

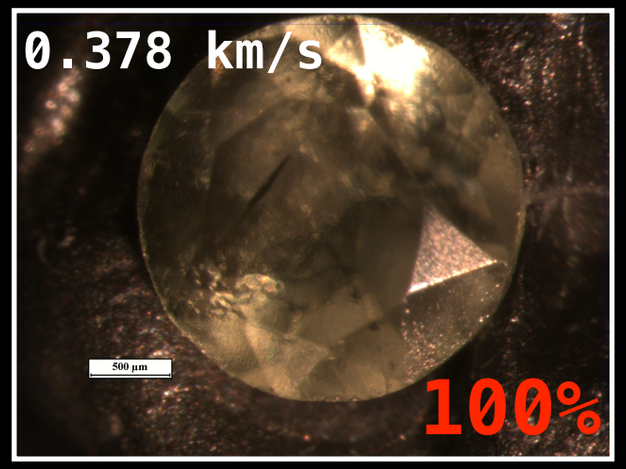
- Repeat the project using higher porosity water-ice targets (~40%).

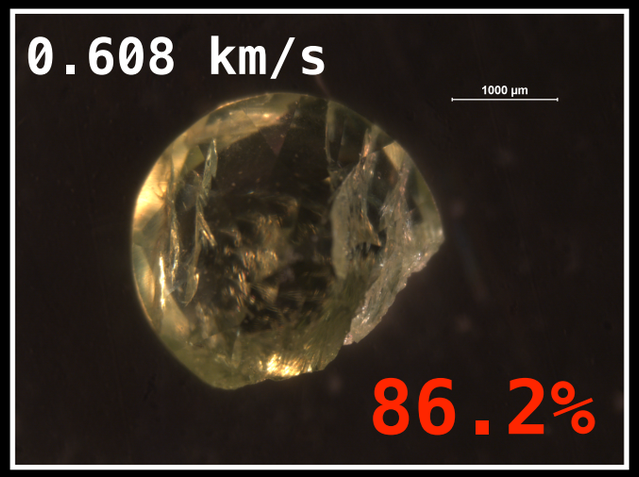
Future experiments:

- Repeat using peridot fired onto a rock. We need a pure rock without contamination of other materials. This is difficult with natural rocks.
  - ✓ A possible candidate is Icelandic crystal. It does not leave residues when dissolved.
  - Fire onto regolith-like surfaces.

Conclusions:

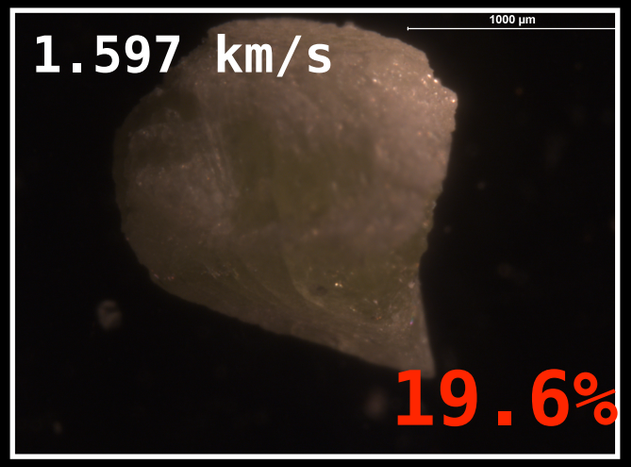
- No melt or alteration of the survived fragments.
- Hydrocode modelling in agreement with Raman results.
- Olivine does not show the fragmentation we expected.
- Q plots can give the catastrophic disruption energy density, Q*.
- Automated way to measure quickly ad accurately the fragments.


0.378 km/s
500 µm
100%


0.608 km/s
1000 µm
86.2%

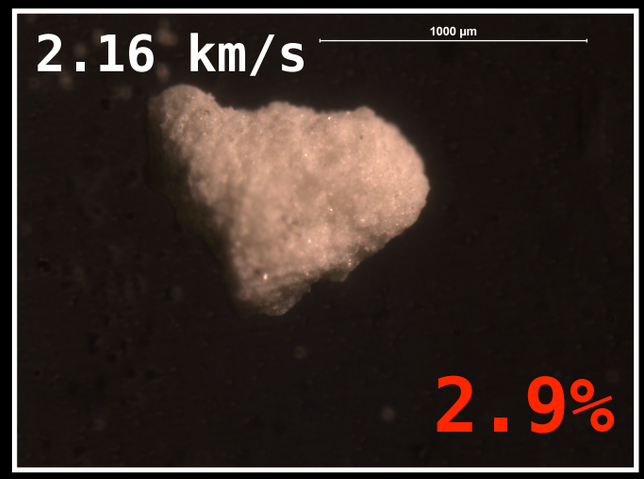

0.920 km/s
65.5%

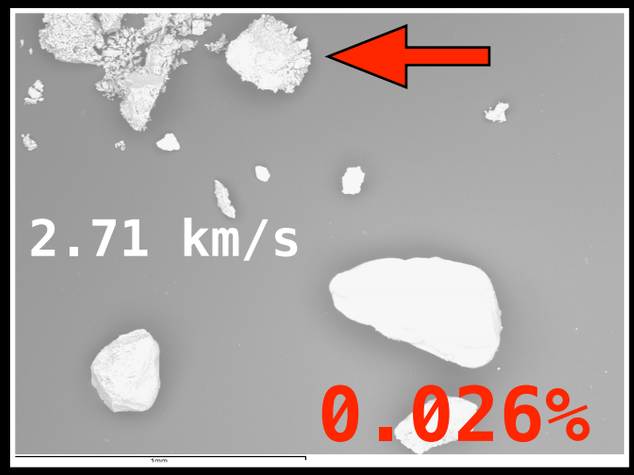

1.331 km/s
1000 µm
29.5%


1.597 km/s
1000 µm
19.6%


1.95 km/s
7.8%


2.05 km/s
500 µm
3.2%


2.16 km/s
1000 µm
2.9%


2.71 km/s
0.026%