Hypervelocity Dust Impact in Olivine: FIB/TEM Characterization and Comparison of Experimental and Natural Microcraters

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JOHNSON SPACE CENTER

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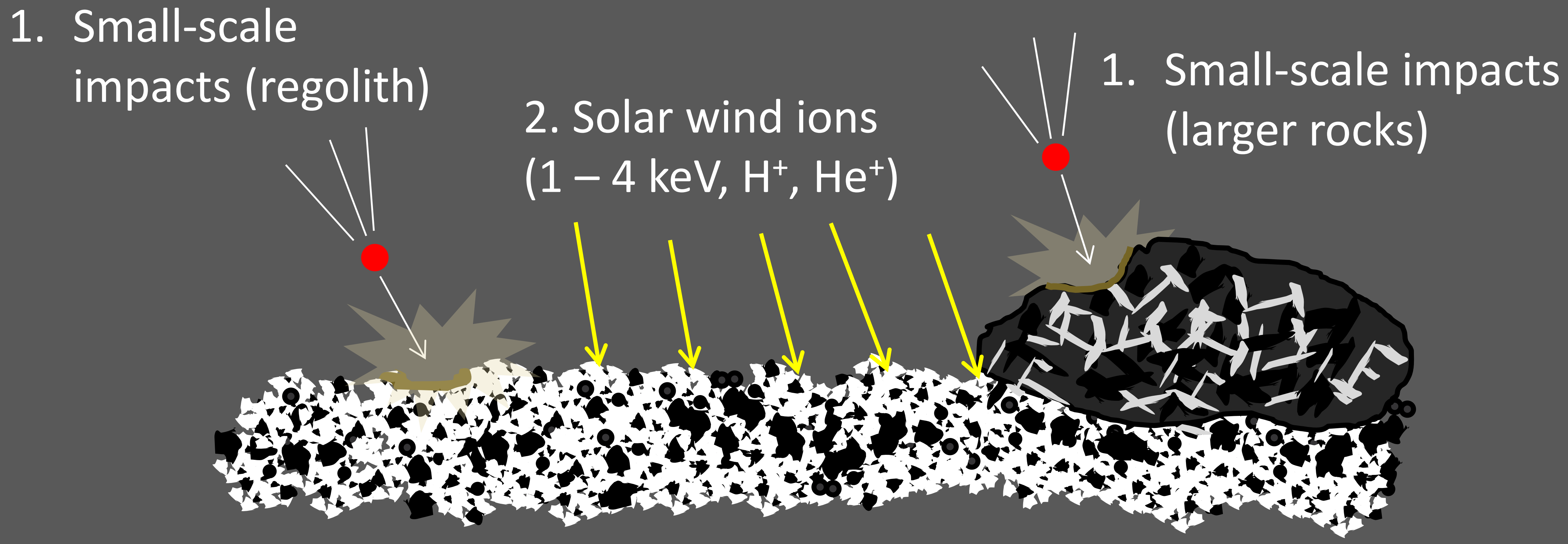
IMPACT

Role of Micrometeoroid Small-Scale Impacts in Space Weathering



A Fundamental Problem : Connect an "Input" to an "Output"

Input

Solar System Micrometeoroid "Complex"

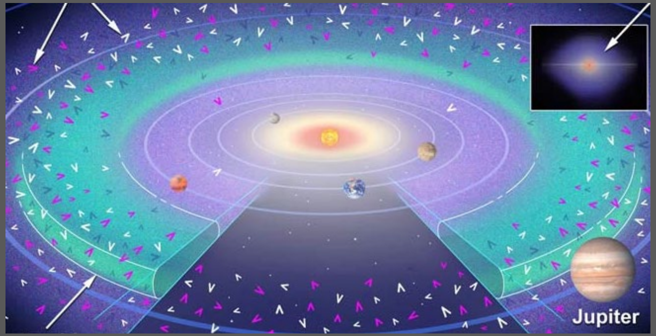


Image: Blanchard et al., Science (2010)

1. Size (mass) : **nm to 100's microns**

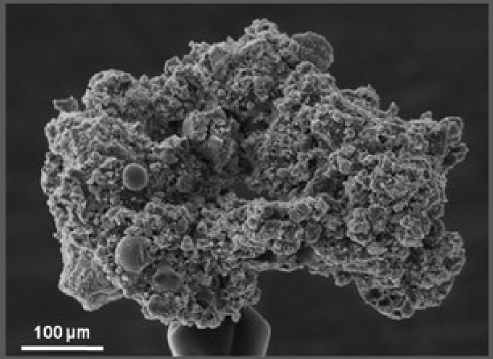
2. Speed distribution : **1 to 100 (?) km s^{-1}**

3. Flux : see **NASA MEM model** and Grun et al. (2011), Kruger and Grun (2014)

Output

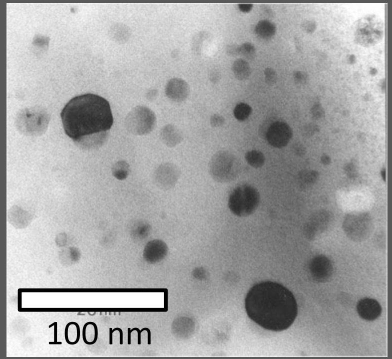
Space Weathering Products

1. Impact melting

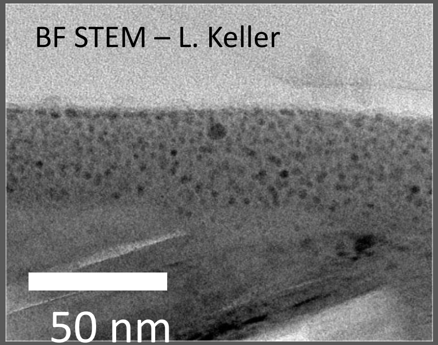


Agglutinates (C. Kiely)

"nanophase" Fe^0



2. Impact vaporization

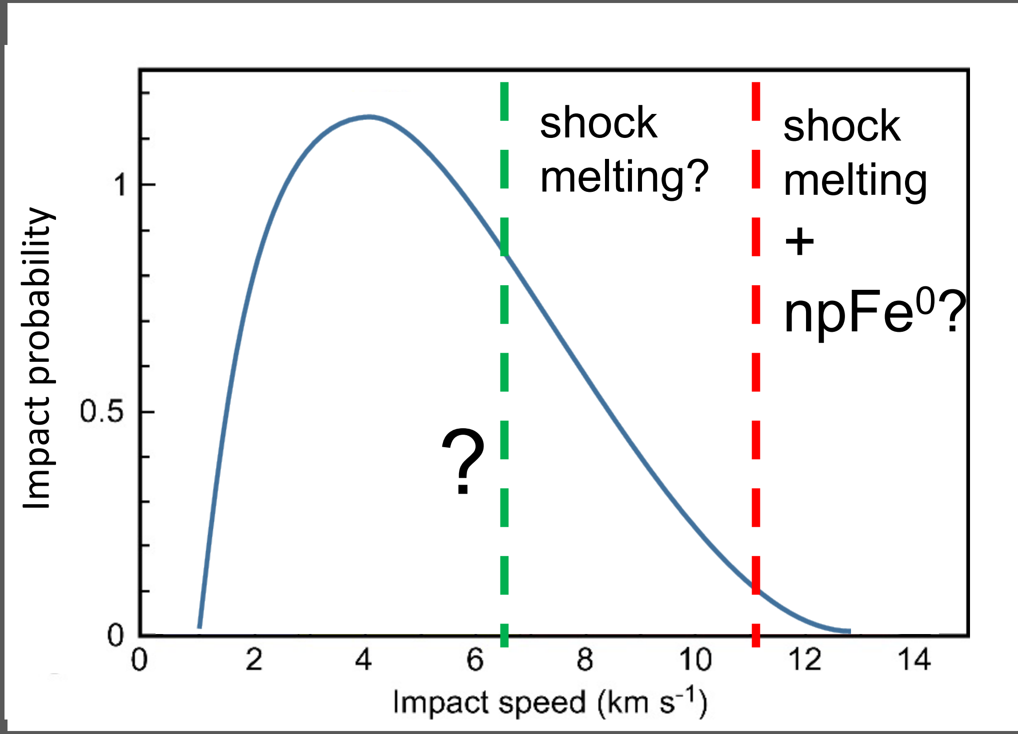


Impact vapor-deposited grain rim

A Simple But Difficult Question

What micrometeorite ranges of speed+mass (+density?) (1) melts regolith AND (2) makes nanophase Fe° in that melt?

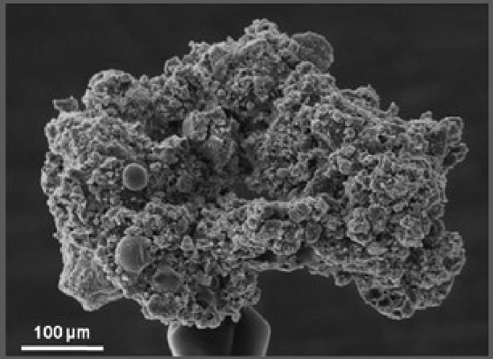
On the Moon? On asteroids?



Output

Space Weathering Products

1. Impact melting



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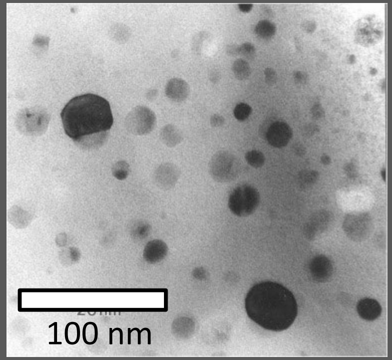
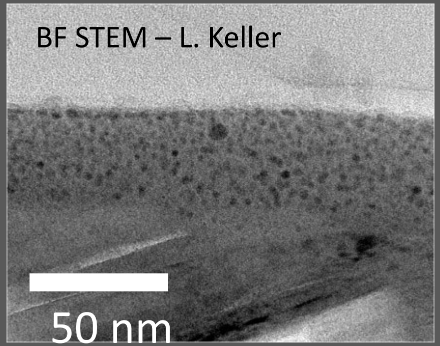


2. Impact vaporization

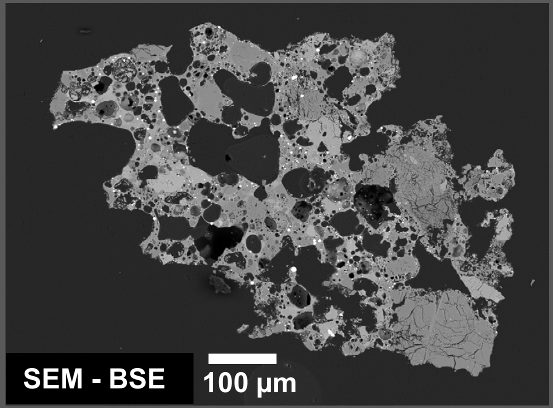


Impact vapor-deposited grain rim

Experimental Approaches and Options

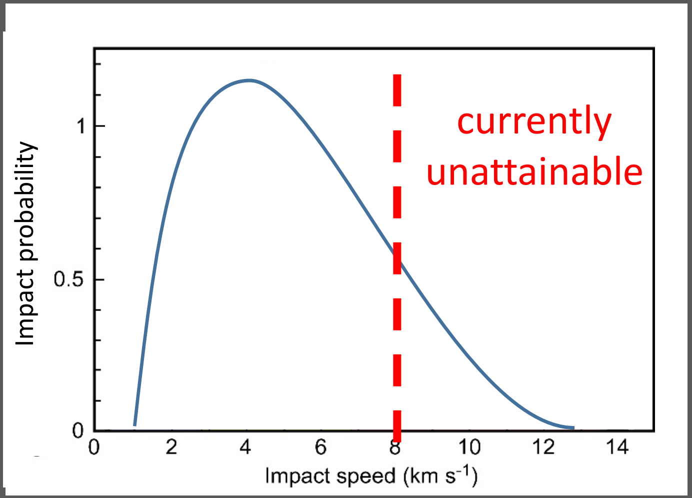
Chemical/gas projectile accelerator (e.g., Light Gas Gun NASA-JSC)

5 - 6 km/s

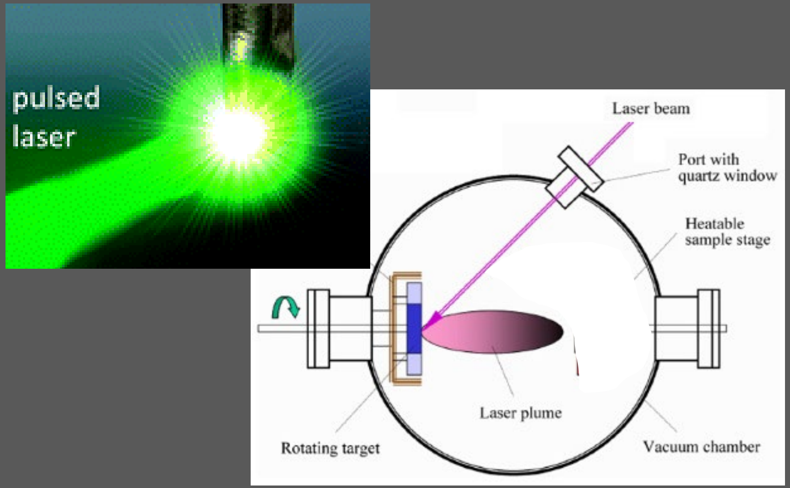


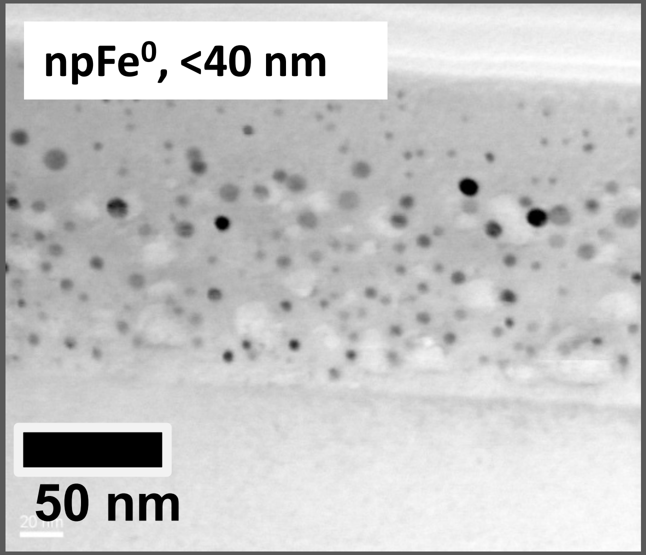
no npFe^{o} !

(See and Horz, 1988)



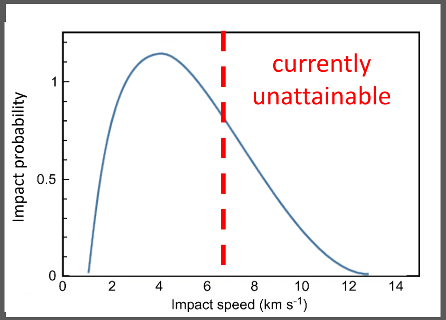
Nanopulsed lasers



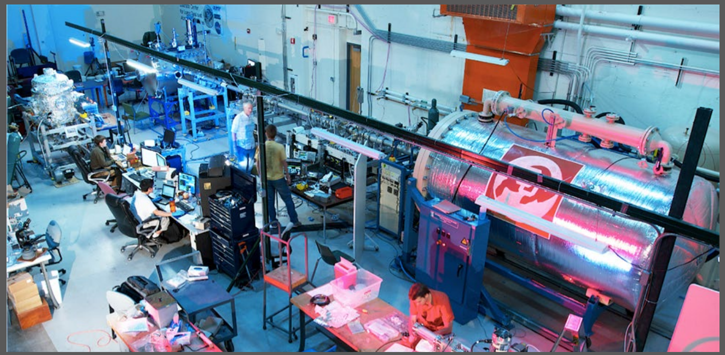


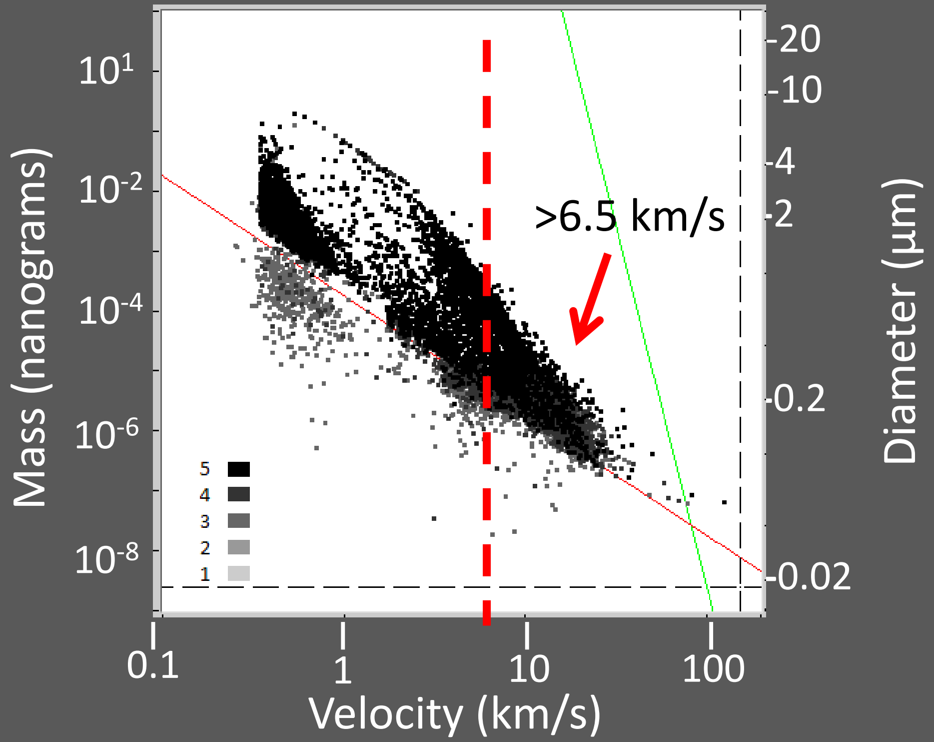
Finding a “Bridge” at LASP/IMPACT Dust Accelerator Lab

Chemical/gas projectile accelerator
(AKA Light Gas Gun)
– up to 6.5 km/sec

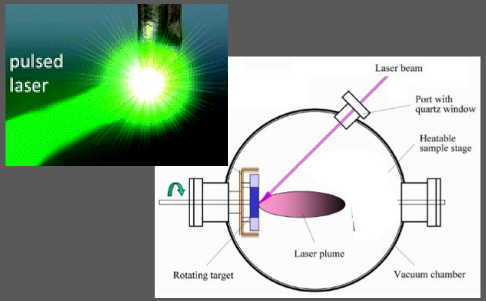


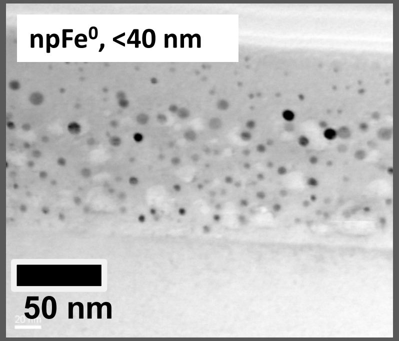
3 MV electrostatic dust accelerator





Nanopulsed lasers

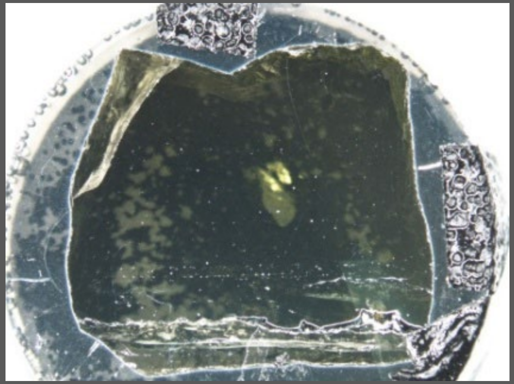




- **Velocities known as function of particle diameter from magical “beam profiler”**

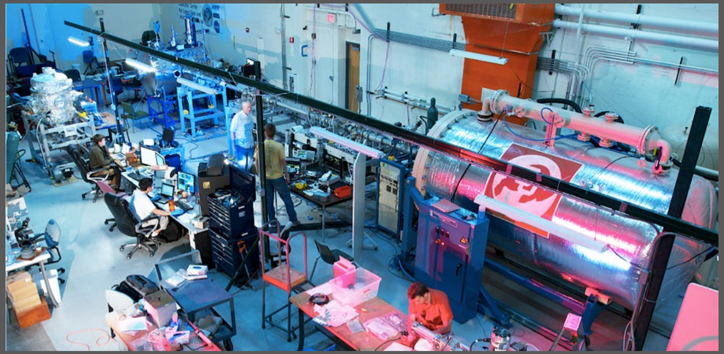
This Study : Dust Impact in Single-Crystal Olivine

Target: **San Carlos olivine** ($Mg_{1.8}Fe_{0.2}SiO_4$) single crystal, ~1 cm^2 polished surface.

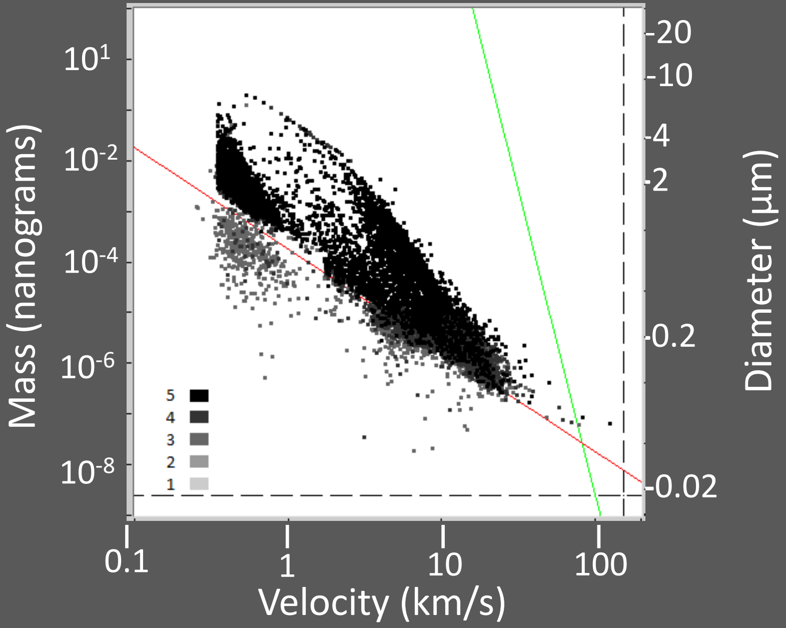


- Compare to Noble et al. (2016) lunar olivine microcrater TEM
- Central "mineral of interest" for asteroid space weathering
- Notoriously resistant to shock melting in light-gas gun experiments!

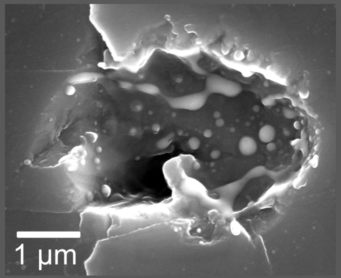
3 MV electrostatic dust accelerator

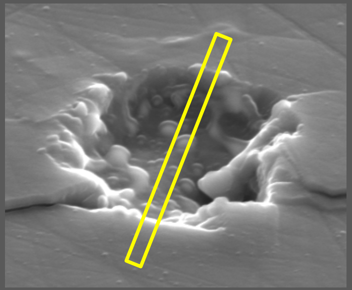


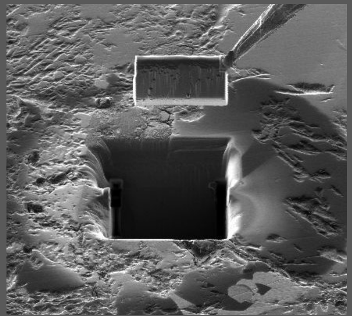
- Projectile: Fe metal "dust" 0.1 – 10 µm diameter



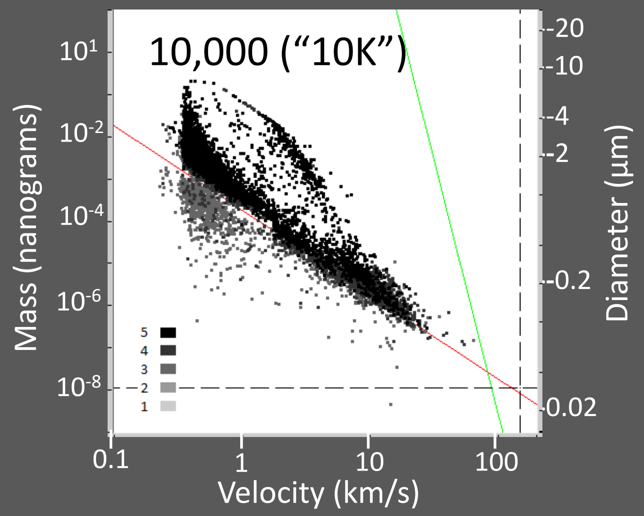
SEM and FIB/STEM Characterization

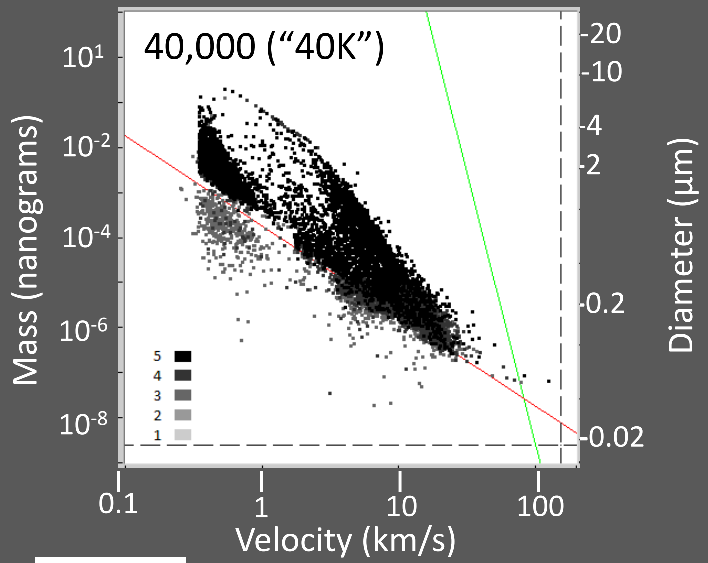


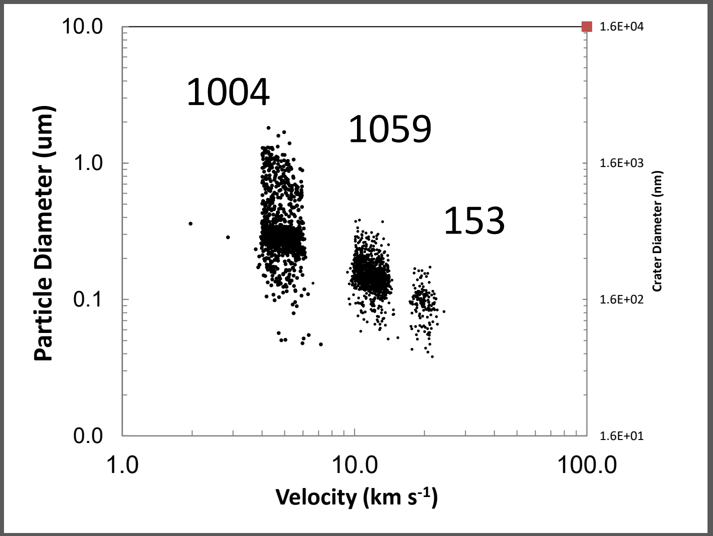


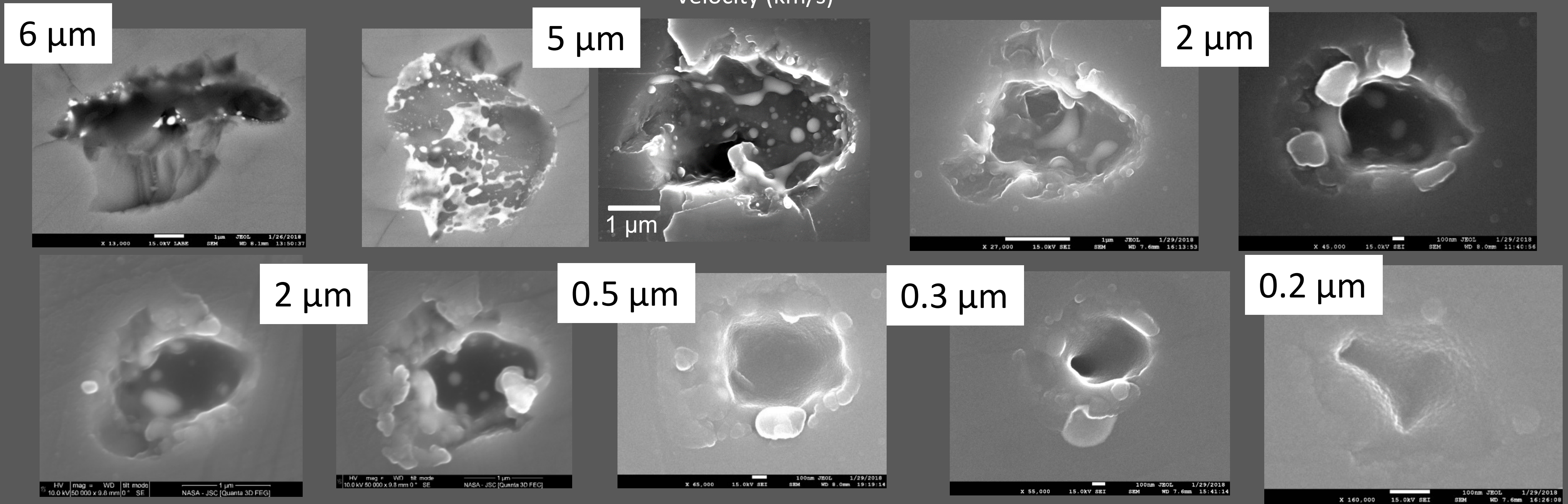


Experiments: Dust Impactor Size and Velocity Distributions









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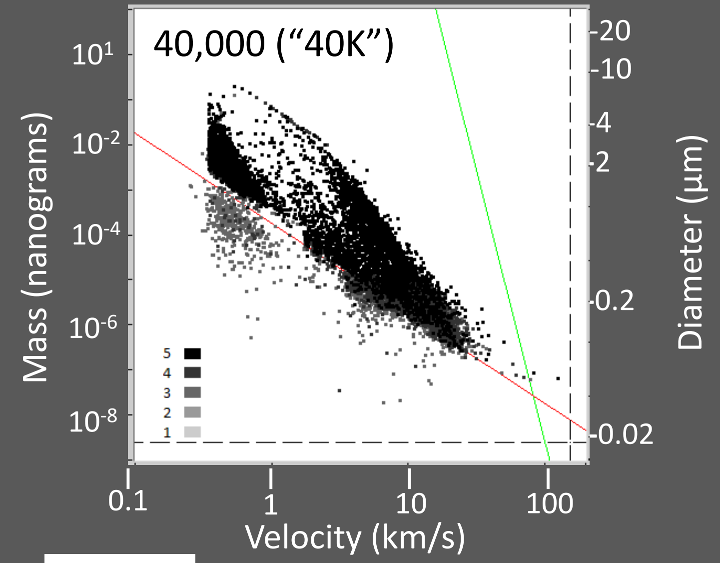

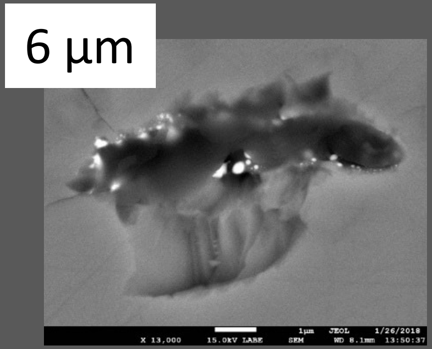

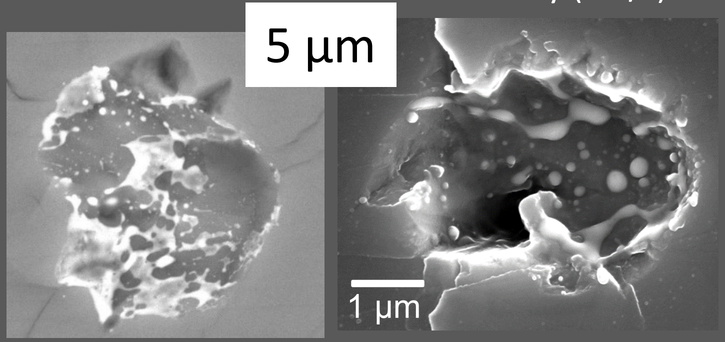

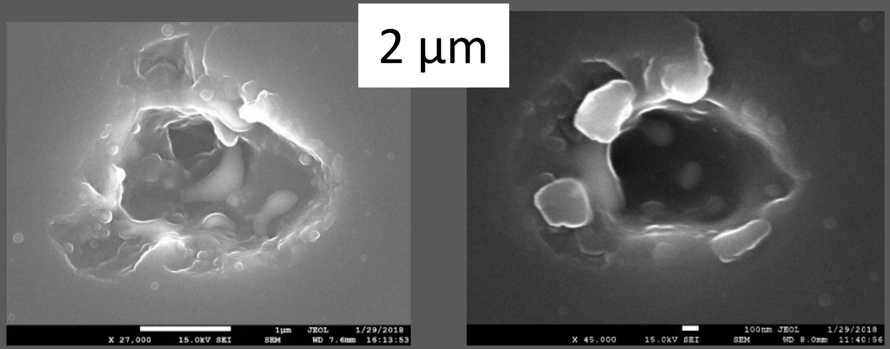

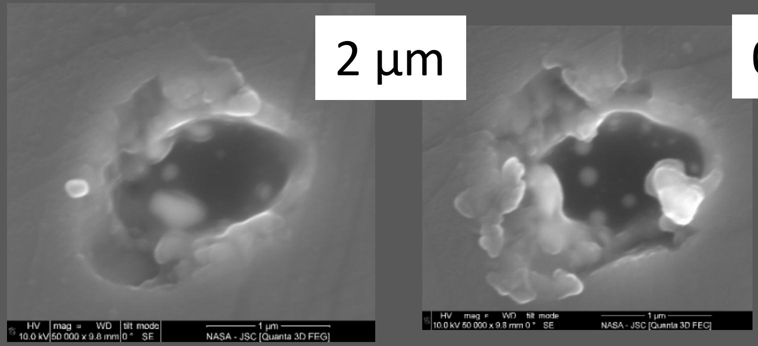

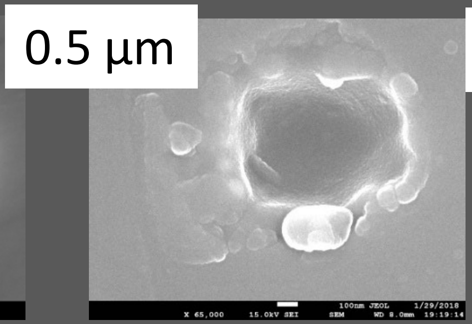

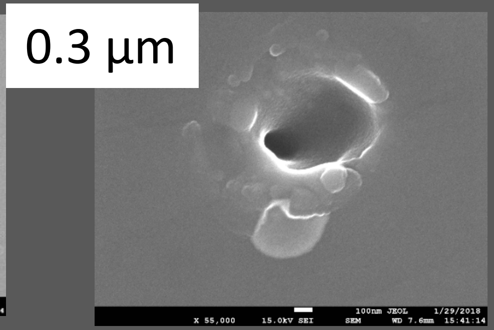

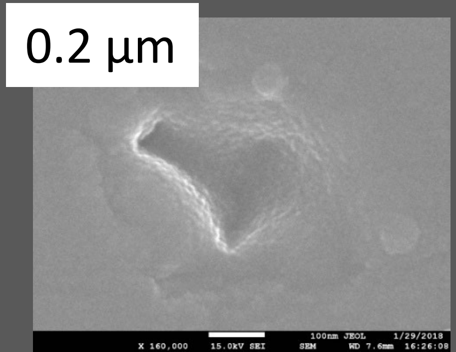

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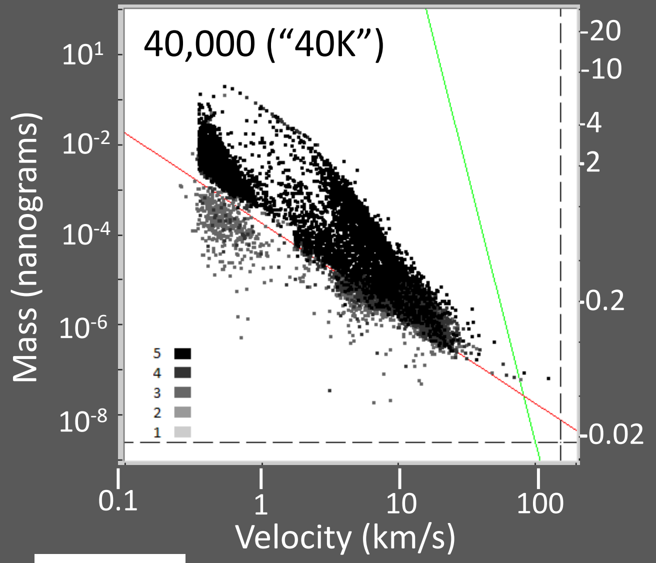
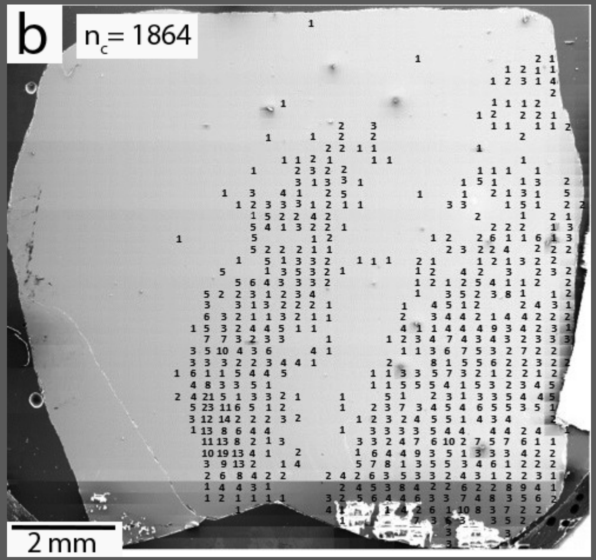
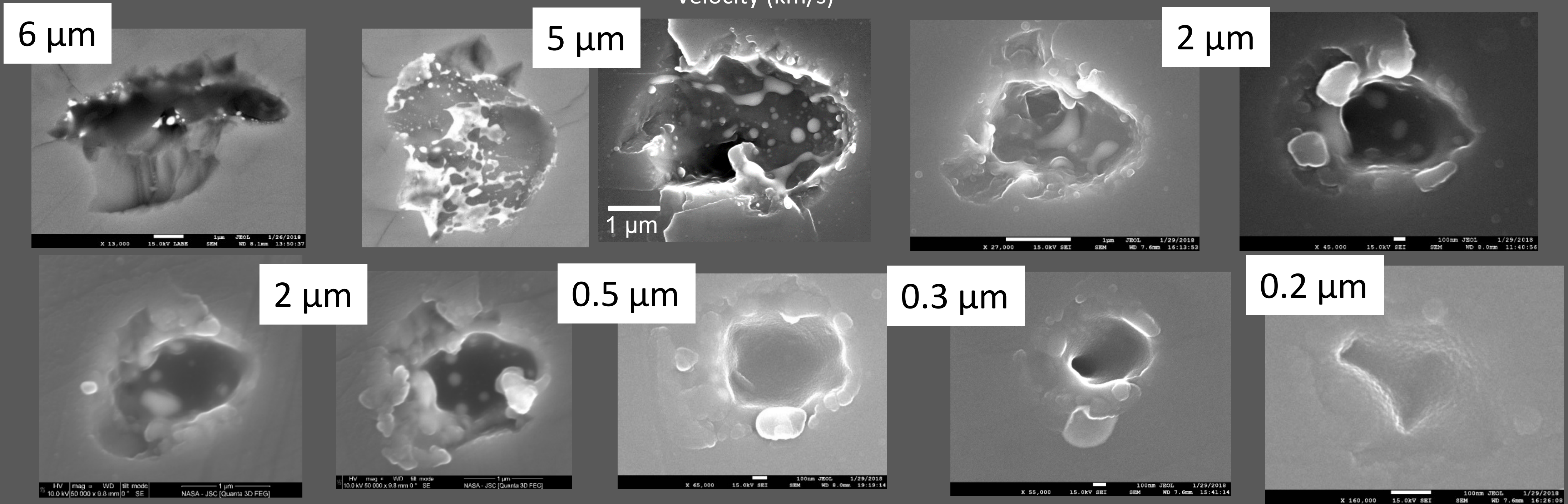
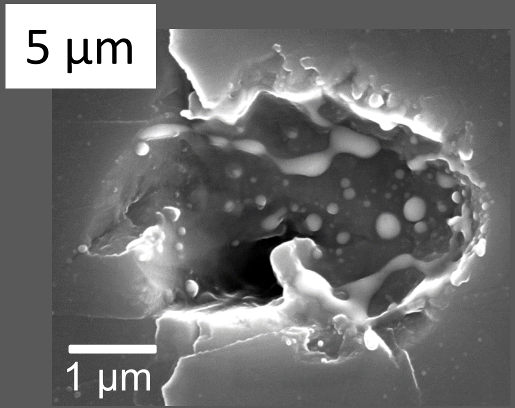
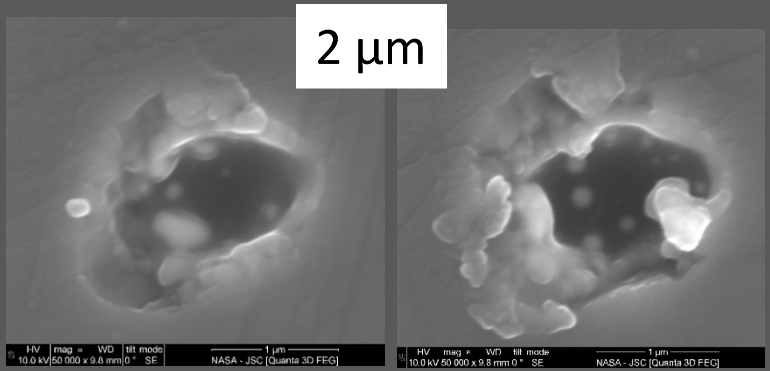


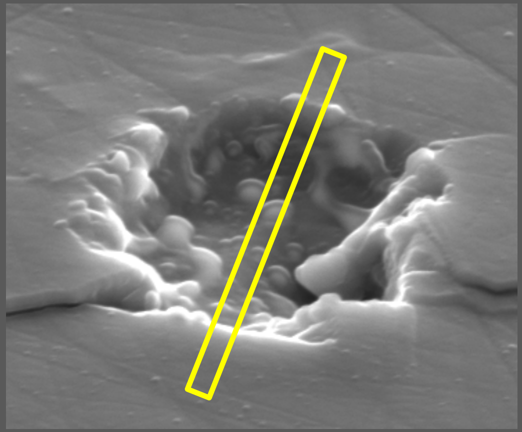


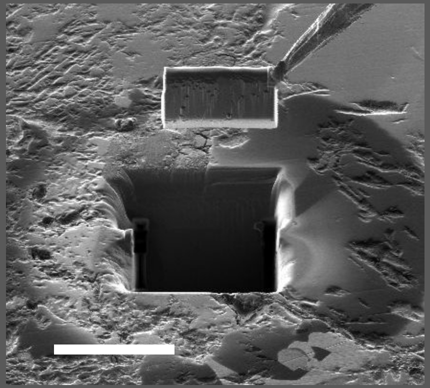


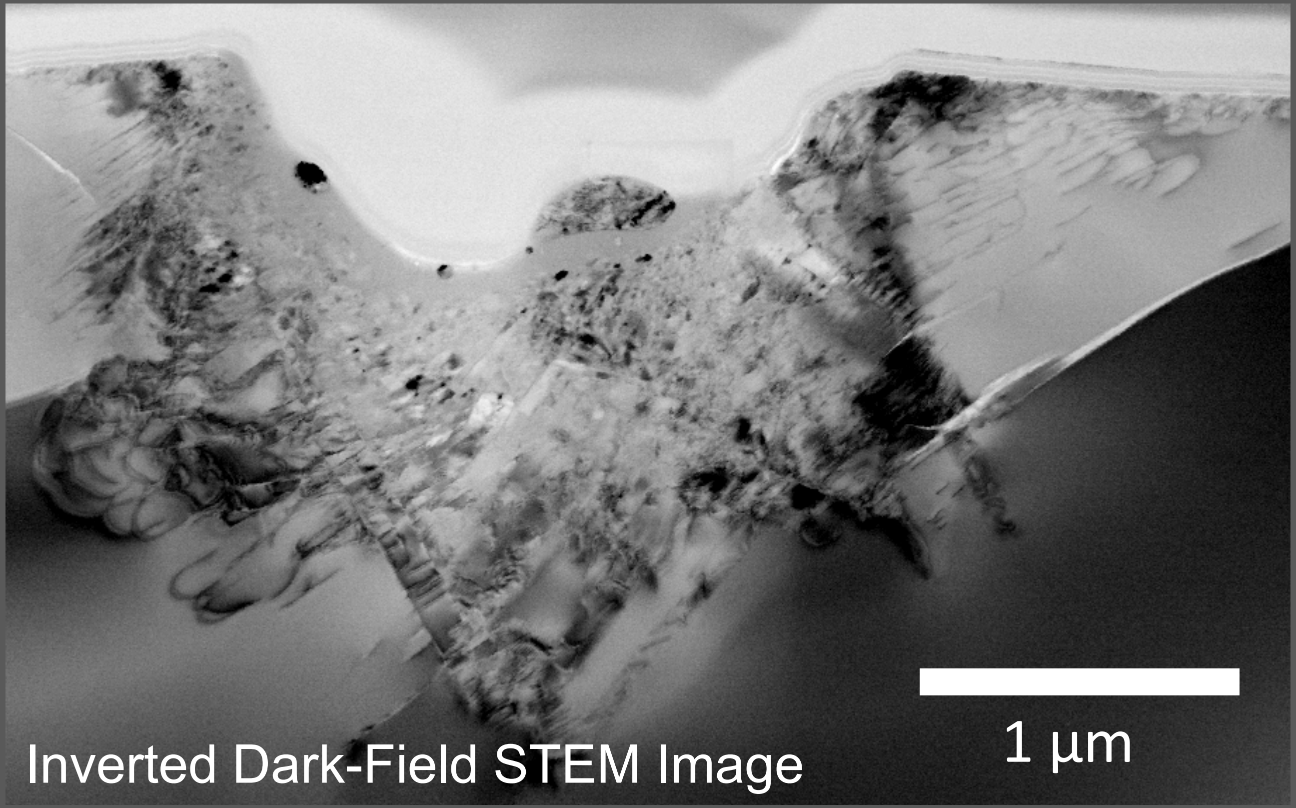
Field-Emission Scanning Transmission Electron Microscopy (FE-STEM)







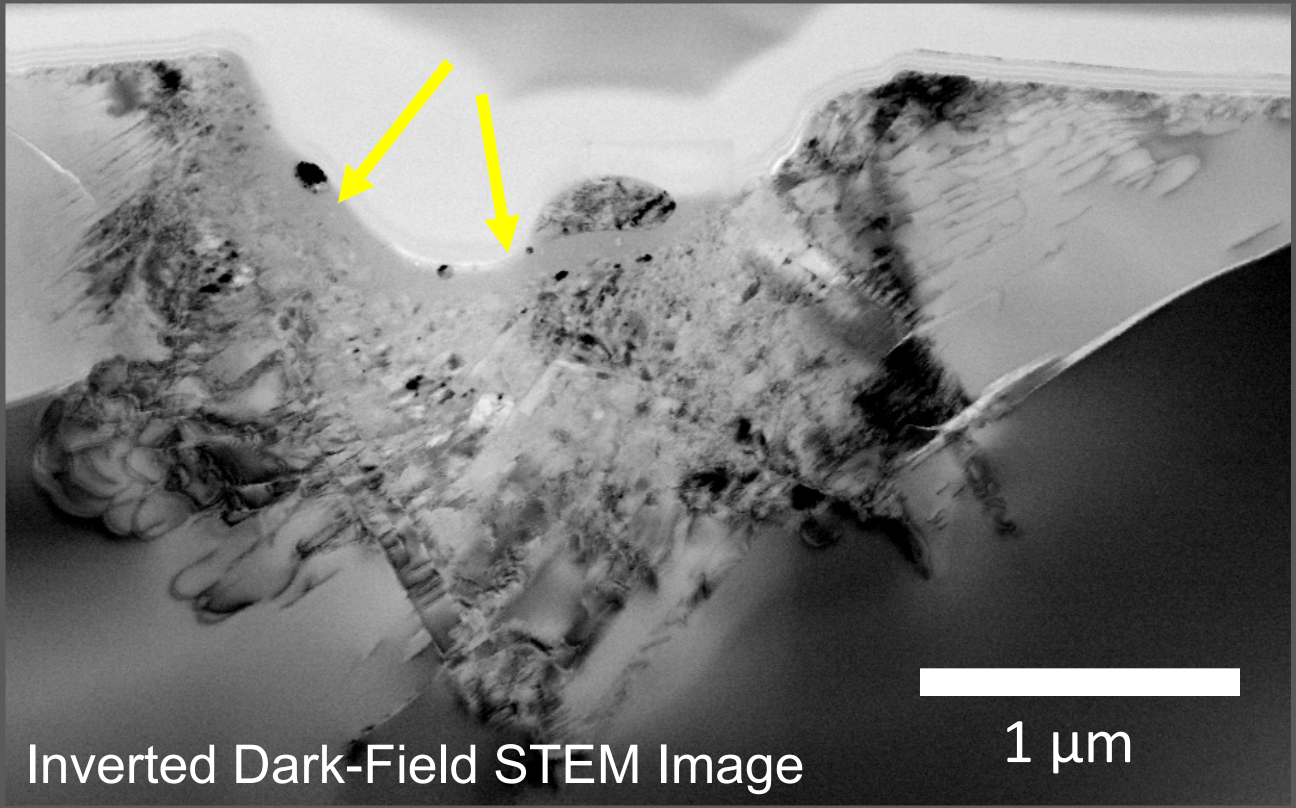


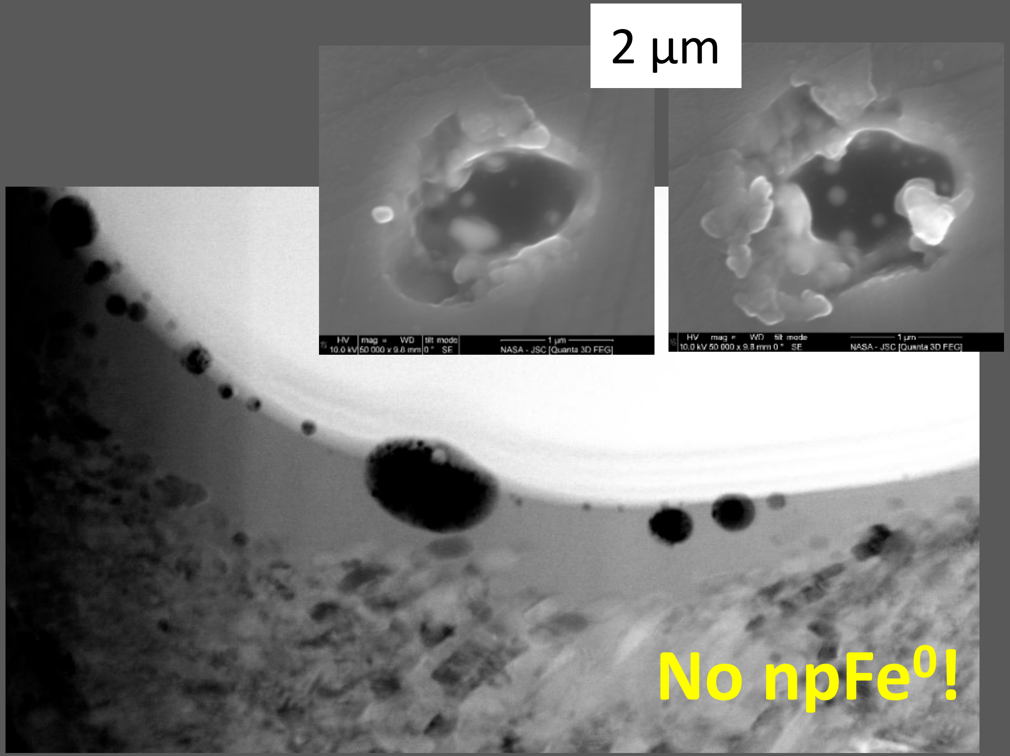


Inverted Dark-Field STEM Image

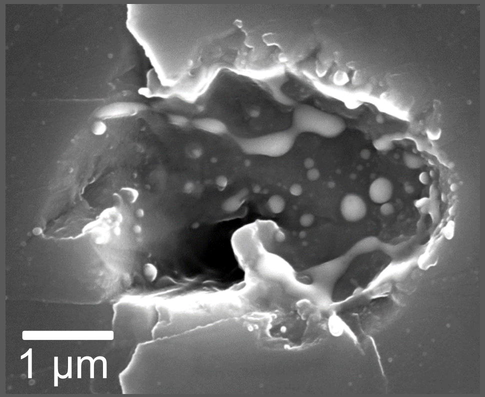
- Localized shock melting and shock-induced deformation features (in two smaller craters)
- Brittle: High density microfractures
- Ductile: High density of dislocations and dislocation arrays = intense structural change

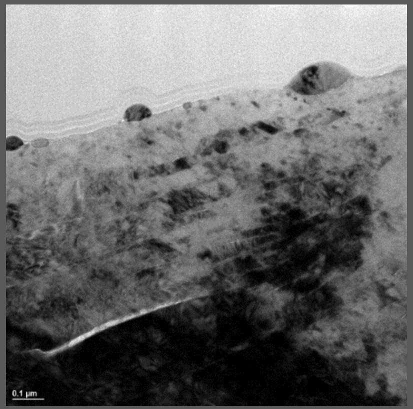
Shock Melt Lines Crater Cavity in Smaller Microcraters



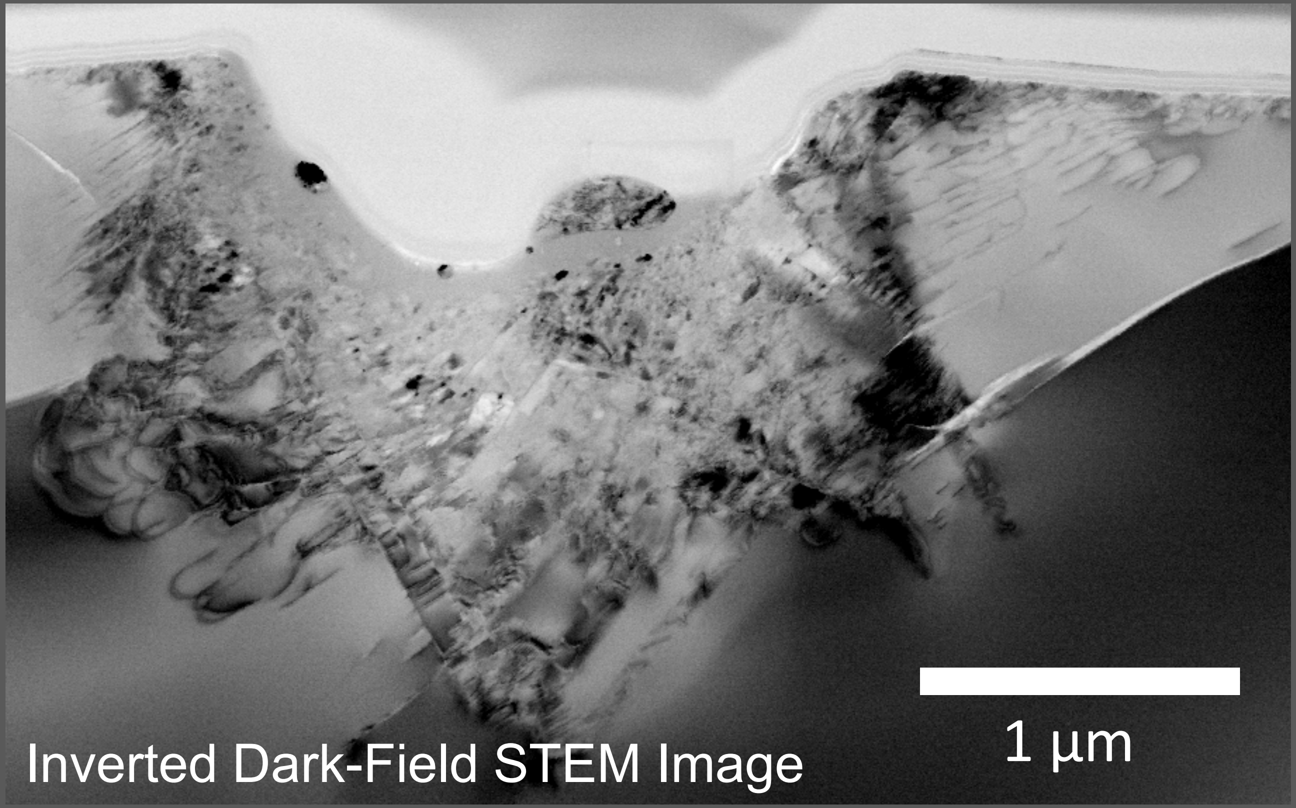


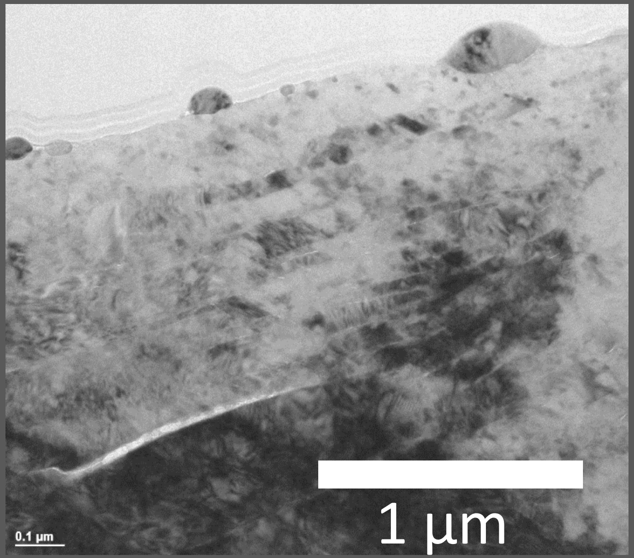
No melt in 5 µm crater.

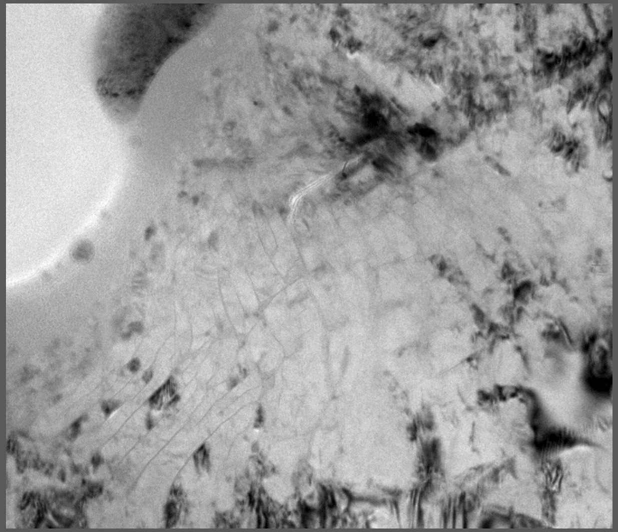




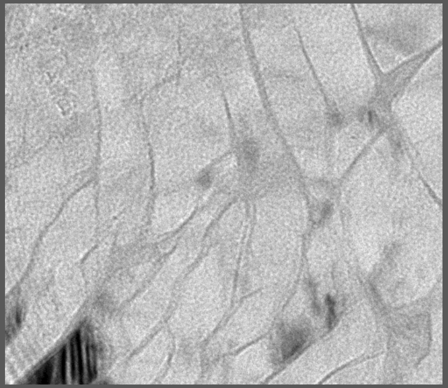
Complex Microfracture Networks in Unmelted Olivine Below Cavity





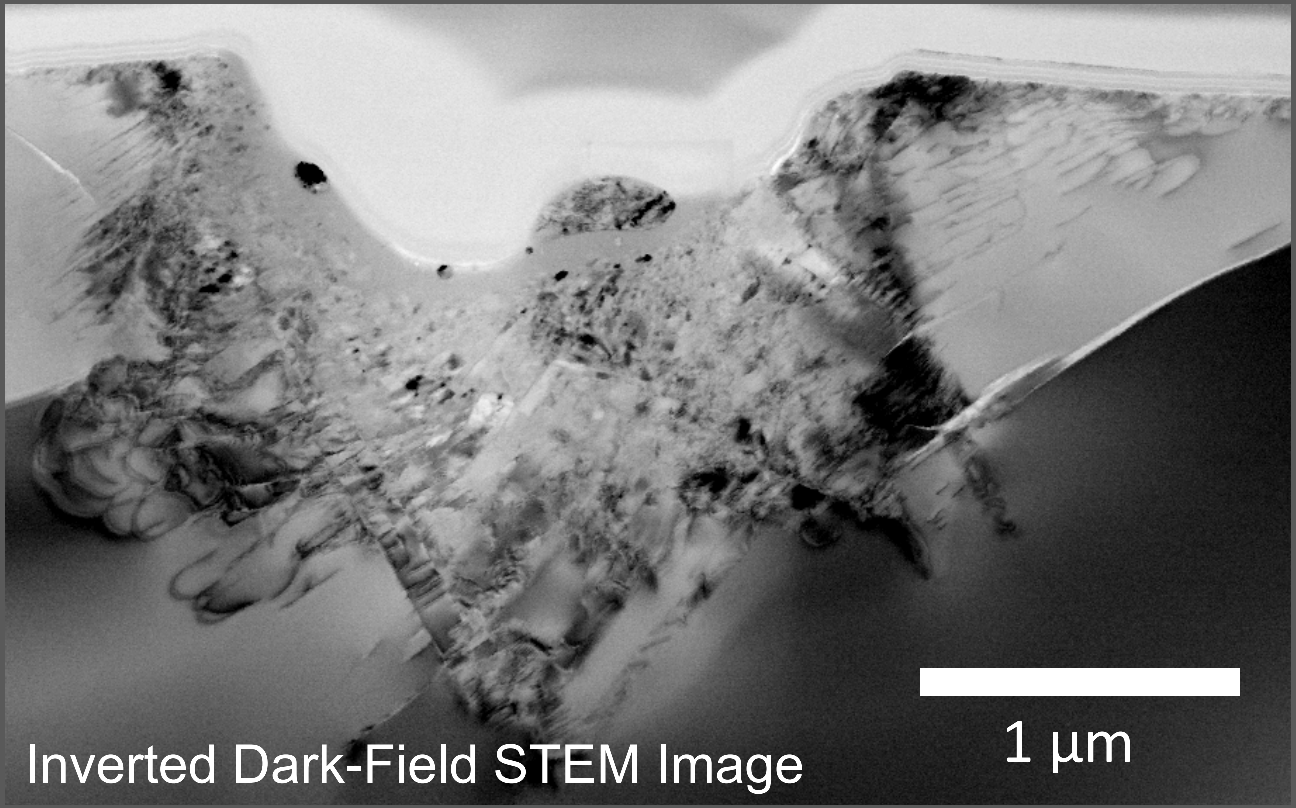


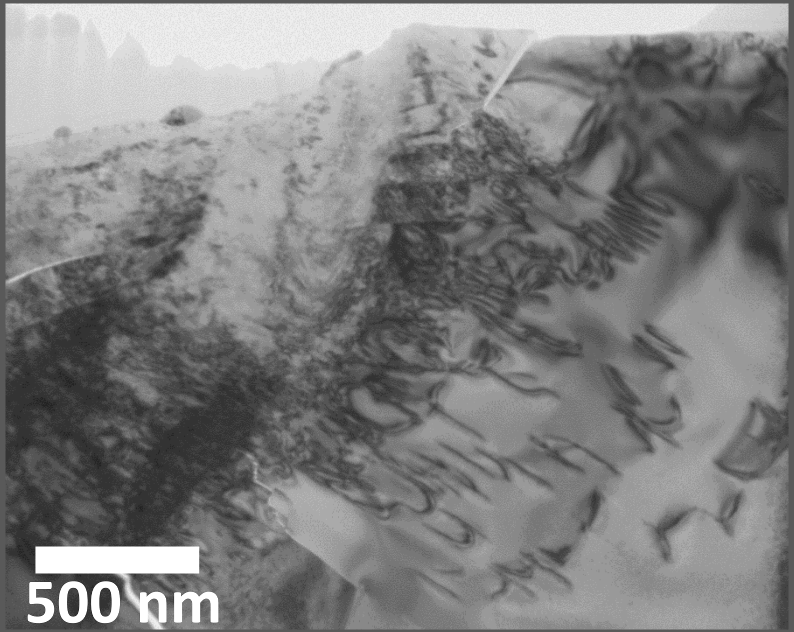
500 nm

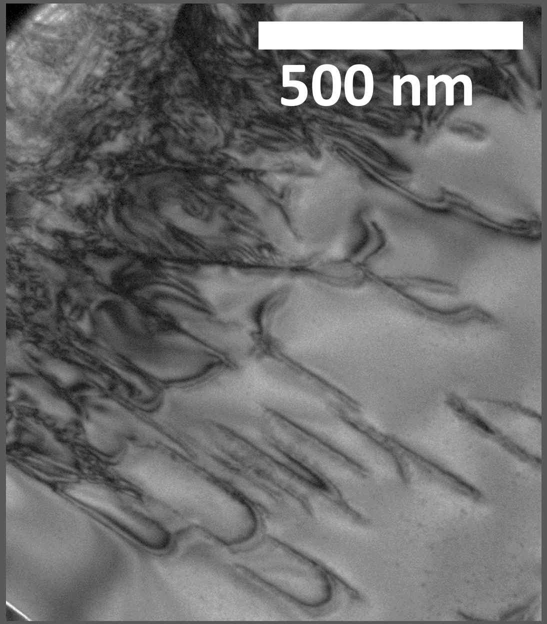


100 nm

Shock Deformation Accommodated by Dislocations Away From Cavity

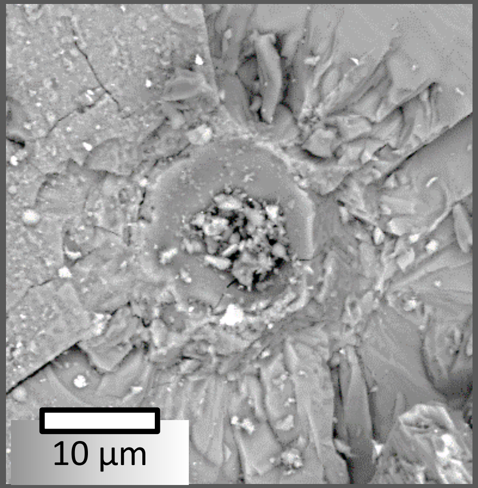




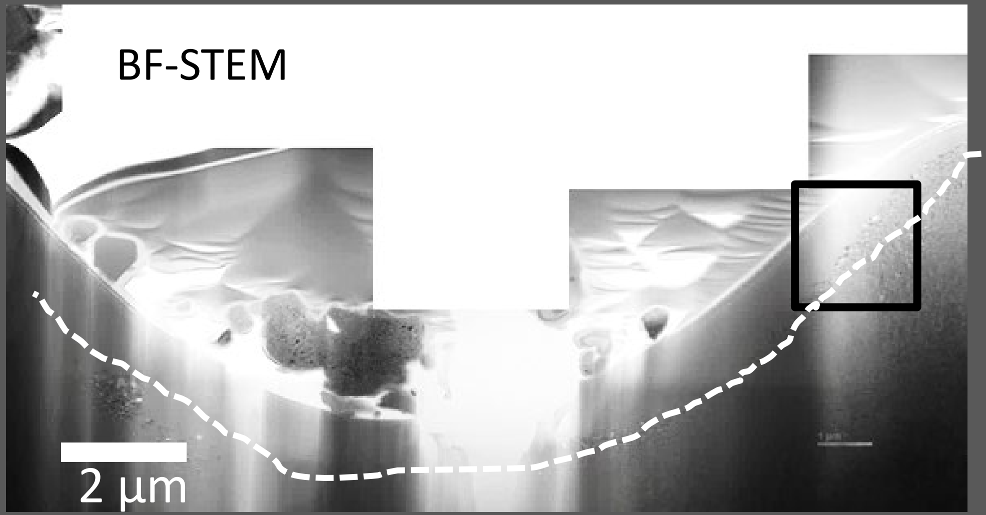


Convention Bright-Field TEM Images

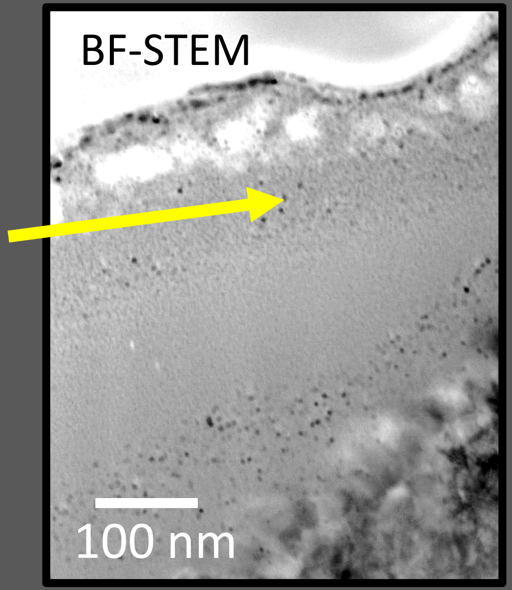
Comparison to Lunar Olivine Microcrater (Noble et al., 2016)



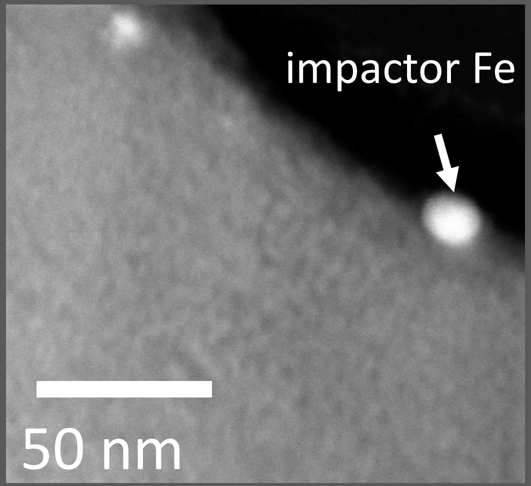
Lunar olivine microcrater
(Noble et al., 2016)

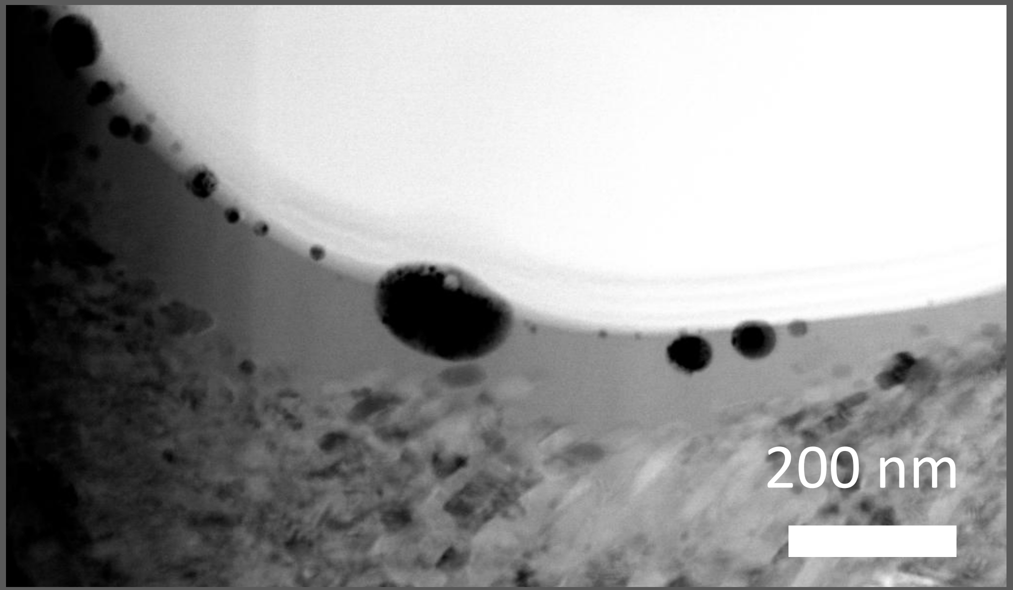


Shock melted microcrater wall with $npFe^0$



No $npFe^0$!





Comparison suggests perhaps a role for implanted solar wind H^+?

Or just a faster impact speed?

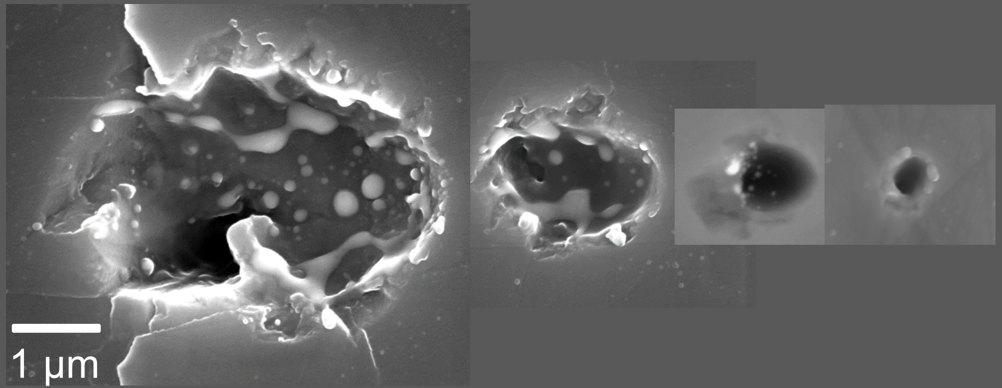
Conclusions

- For our olivine microcraters in the ~1 µm diameter range, shock melt lines the crater cavity in remarkable resemblance to the features in a natural lunar olivine microcrater. But no nanophase Fe^0 in the melt like the natural crater!

- Little/no shock melt in larger (~4 µm) microcrater.

Reflects larger-but-slower impactor?

Work in progress to check shock melting vs. crater size relation.



- BOTH mechanical shock and shock-coupled thermal effects similar to natural small impacts are produced. Shock defect microstructure (dislocations, microfractures) especially complex.

- Tremendous experimental/characterization leverage obtained by pairing the IMPACT Dust Accelerator with FIB-supported analytical FE-STEM techniques