Can Single Ion Strikes be Directly Observed in Relevant Time and Length Scales?

SAND2016-12728C

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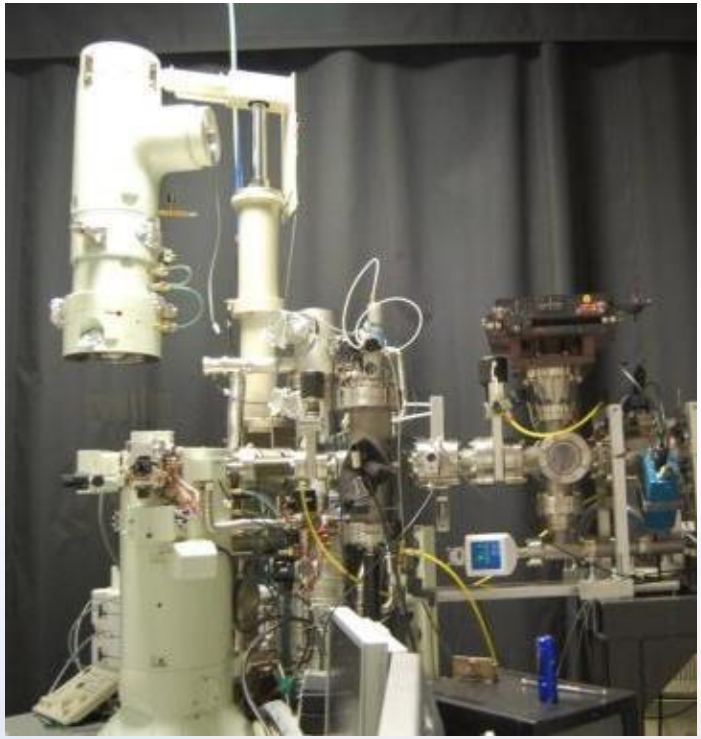
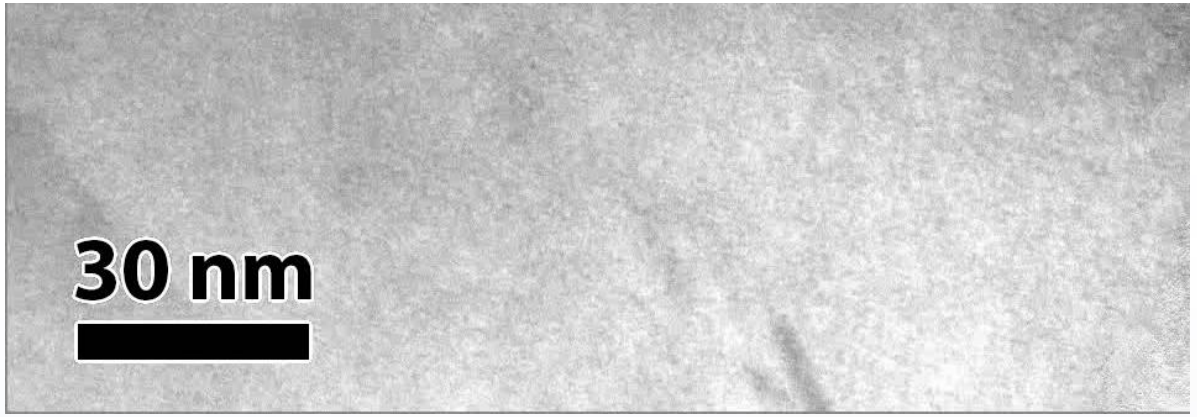
S.T. Park, B. Reed, & D. Masiel — IDES Inc.

December 15, 2016





1. Single ion strikes can be observed in relevant length scales utilizing Sandia's I^{3}TEM facility.
2. Work is underway to directly couple multiscale models and key experimental results
3. Can relevant time scales be achieved is still an outstanding question.

Collaborators:

- Sandia: M. Franco, M. Blair, D. Buller, G. Vizkelethy, B.L. Doyle, M.T. Marshall, D. Saiz, J.A. Scott, B.R. Muntifering, W. Wampler, R. Dingreville, &S. Foiles
- External: T. La Grange A. Lang, M. Taheri, W. Ji, A. Schleife

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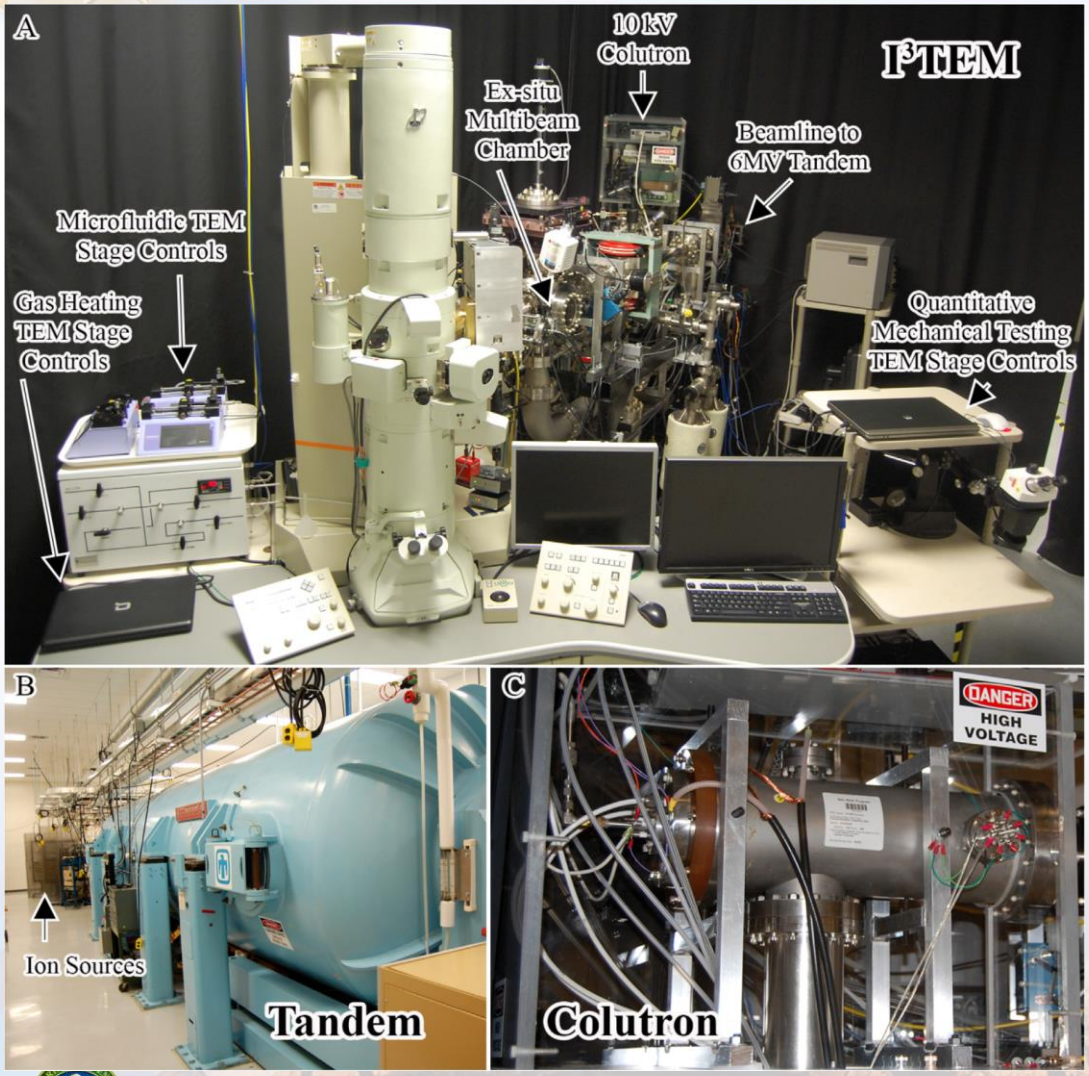
Radiation Characterization with Nanometer Resolution in Real Time



Hattar, K., D. C. Bufford, & D. L. Buller. "Concurrent in situ ion irradiation transmission electron microscope." *NIM:B* **338**, 56-65 (2014).

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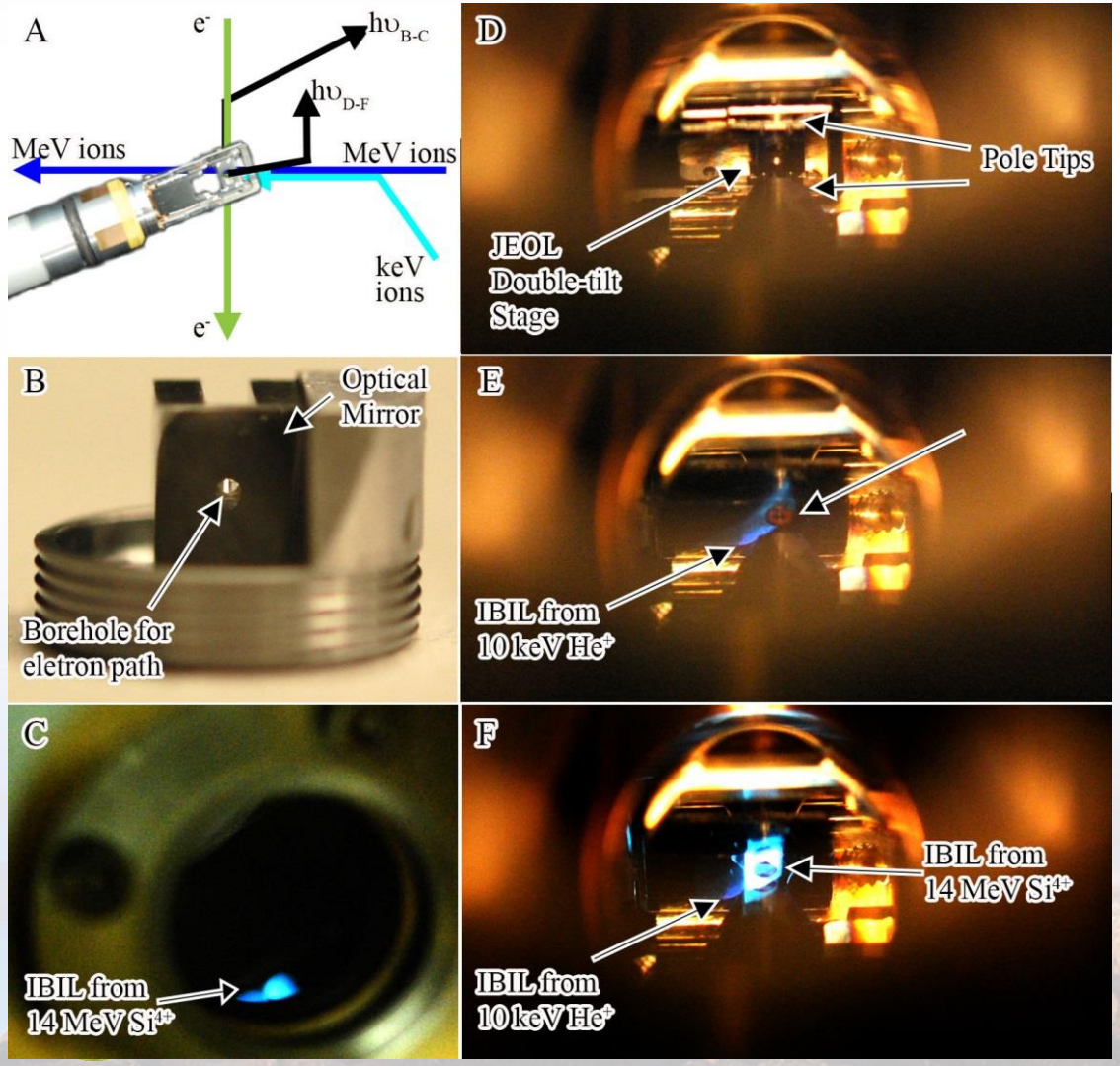
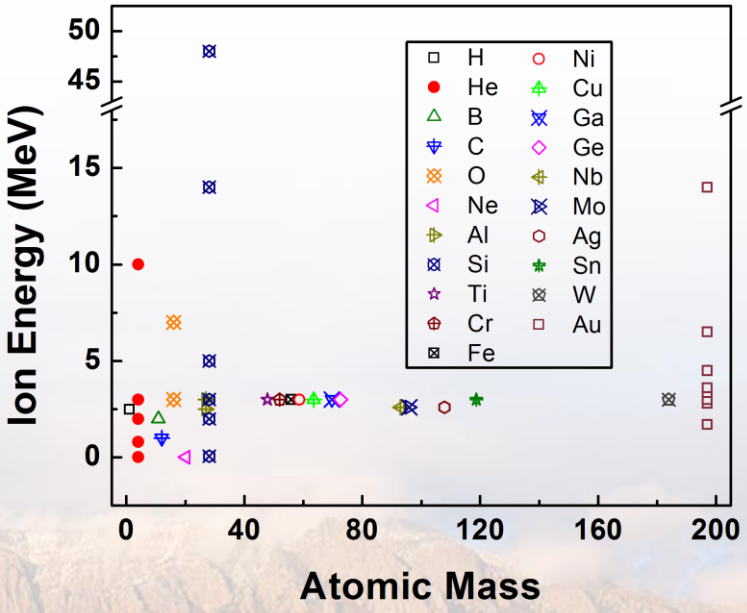
Visualizing Ion Beams in the TEM

IBIL from a quartz stage inside the TEM



Ion beam alignment at the sample confirmed using ion beam-induced luminescence

Ion species & energy introduced into the TEM



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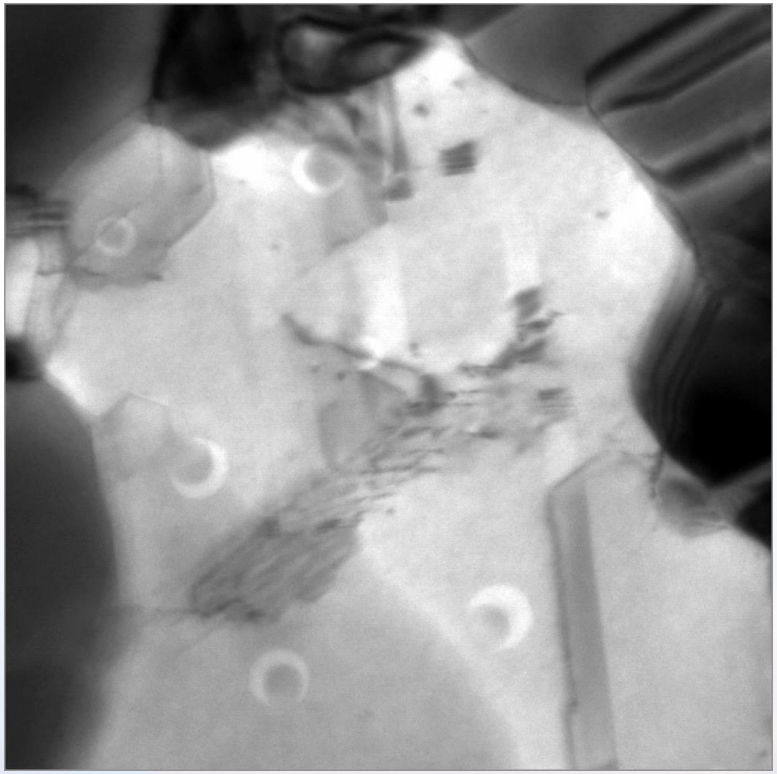
Overlapping Cascades vs. Single Ion Strikes

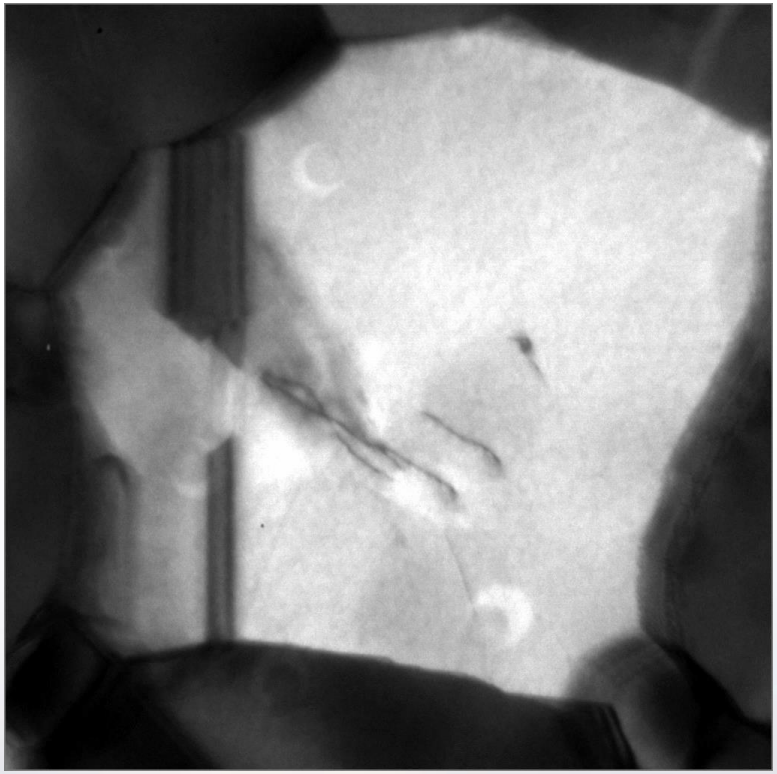
Collaborators: C. Chisholm , P. Hosemann, & A. Minor

7.9×10^9 ions/cm^2/s



vs.

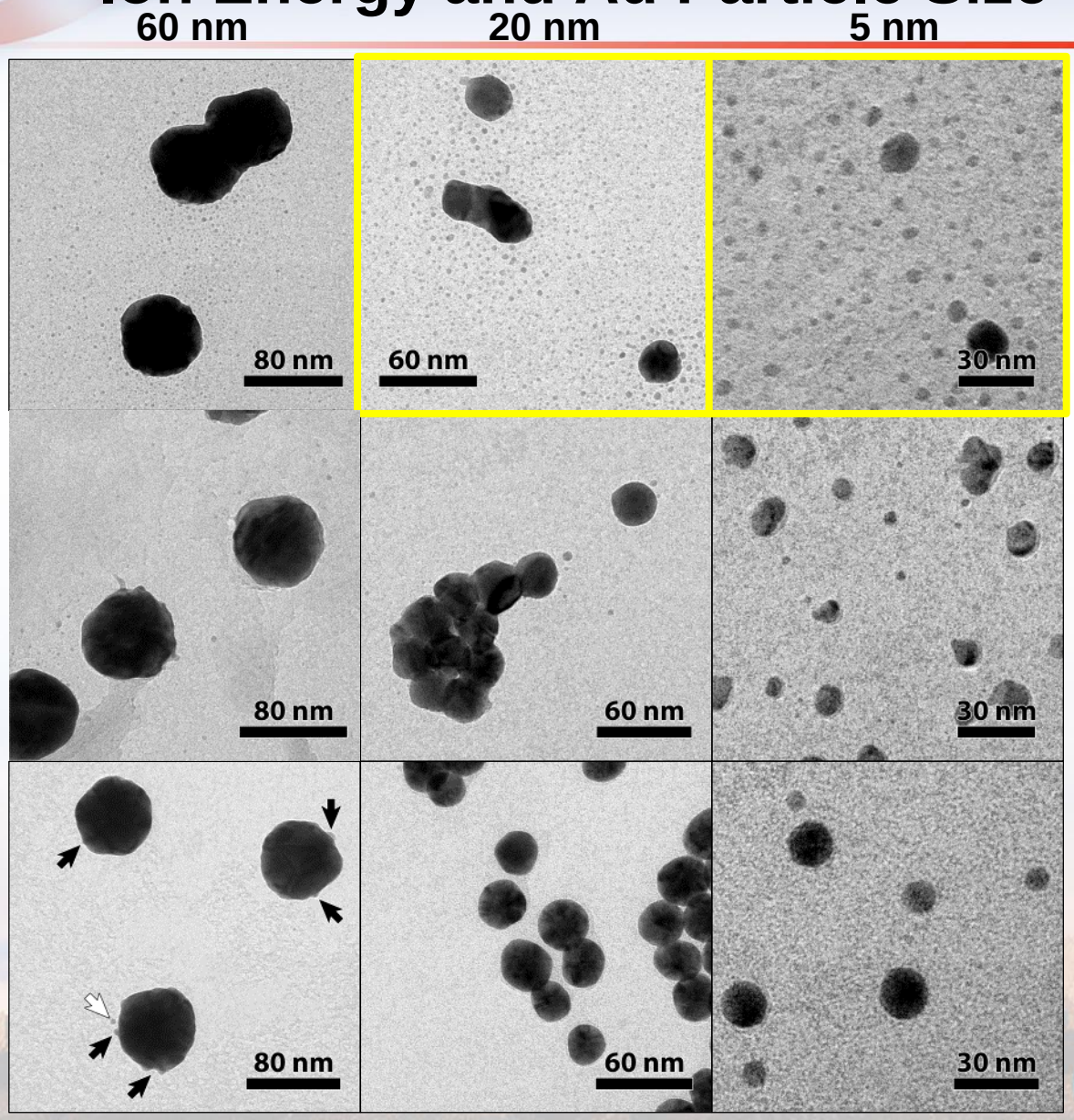
6.7×10^7 ions/cm^2/s



Improved vibrational and ion beam stability permits us to work at 120kx magnification or higher permitting imaging of single cascade events

Cumulative Effects of Ion Irradiation as a Function of Ion Energy and Au Particle Size

Collaborator: D.C. Bufford



Particle and ion energy dictate the ratio of sputtering, particle motion, particle agglomeration, and other active mechanisms

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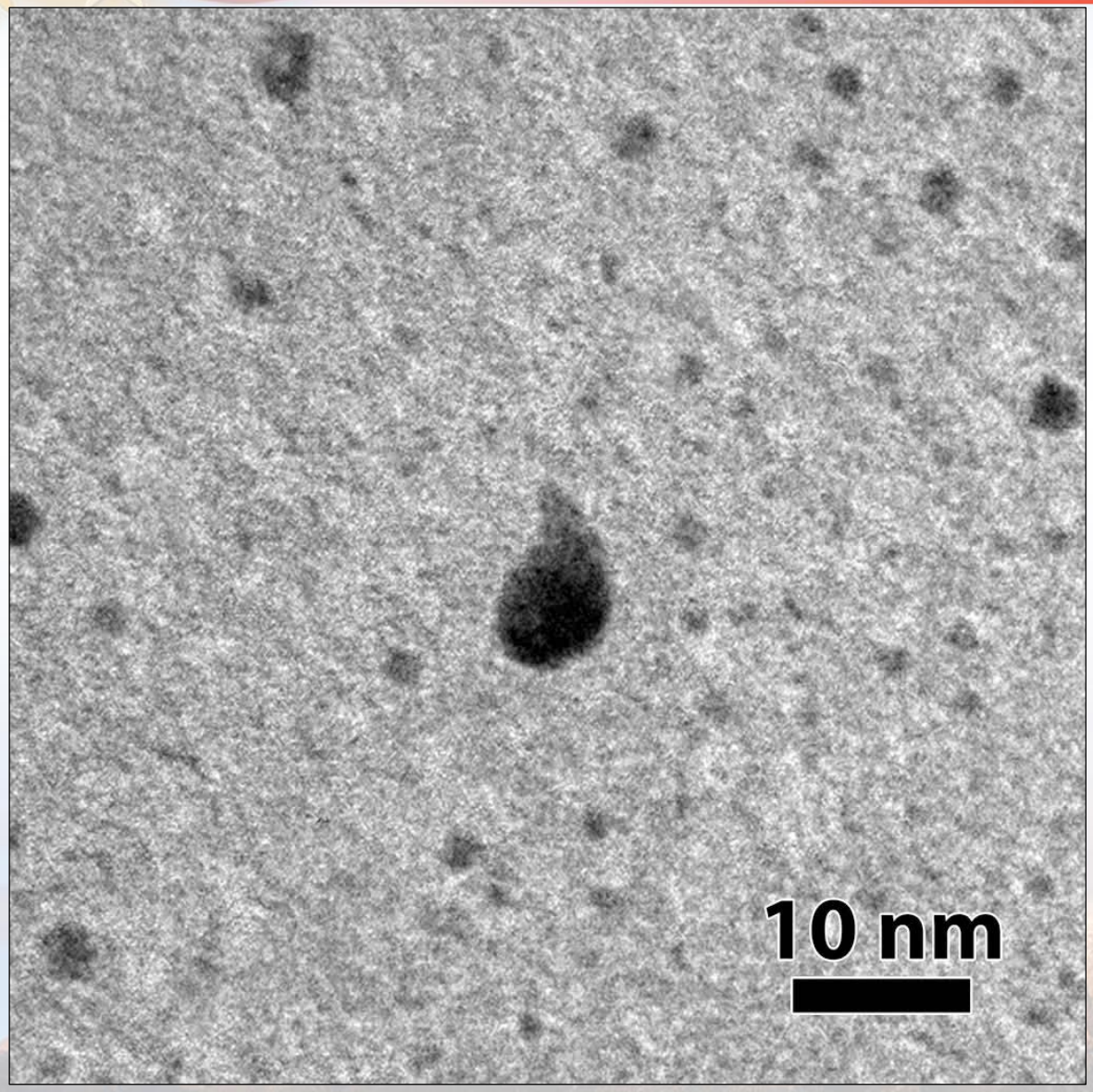
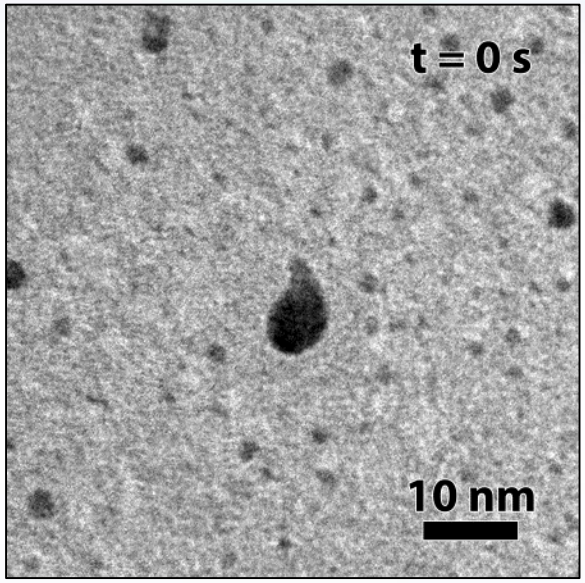
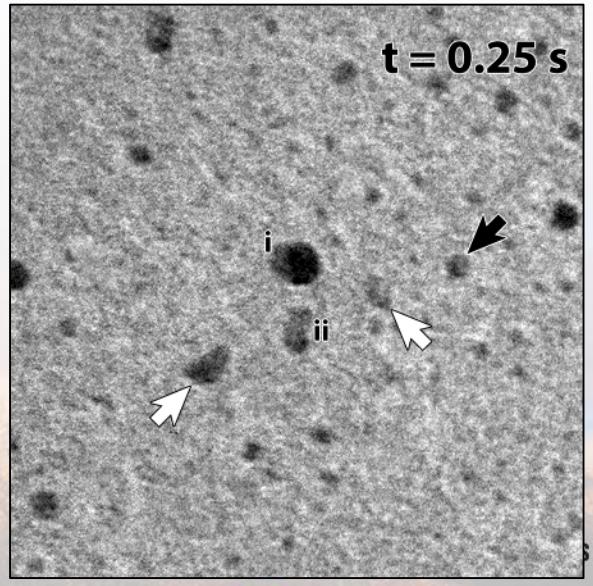
Single Ion Effects with 46 keV Au^{1-} ions: 5 nm

Collaborator: D.C. Bufford

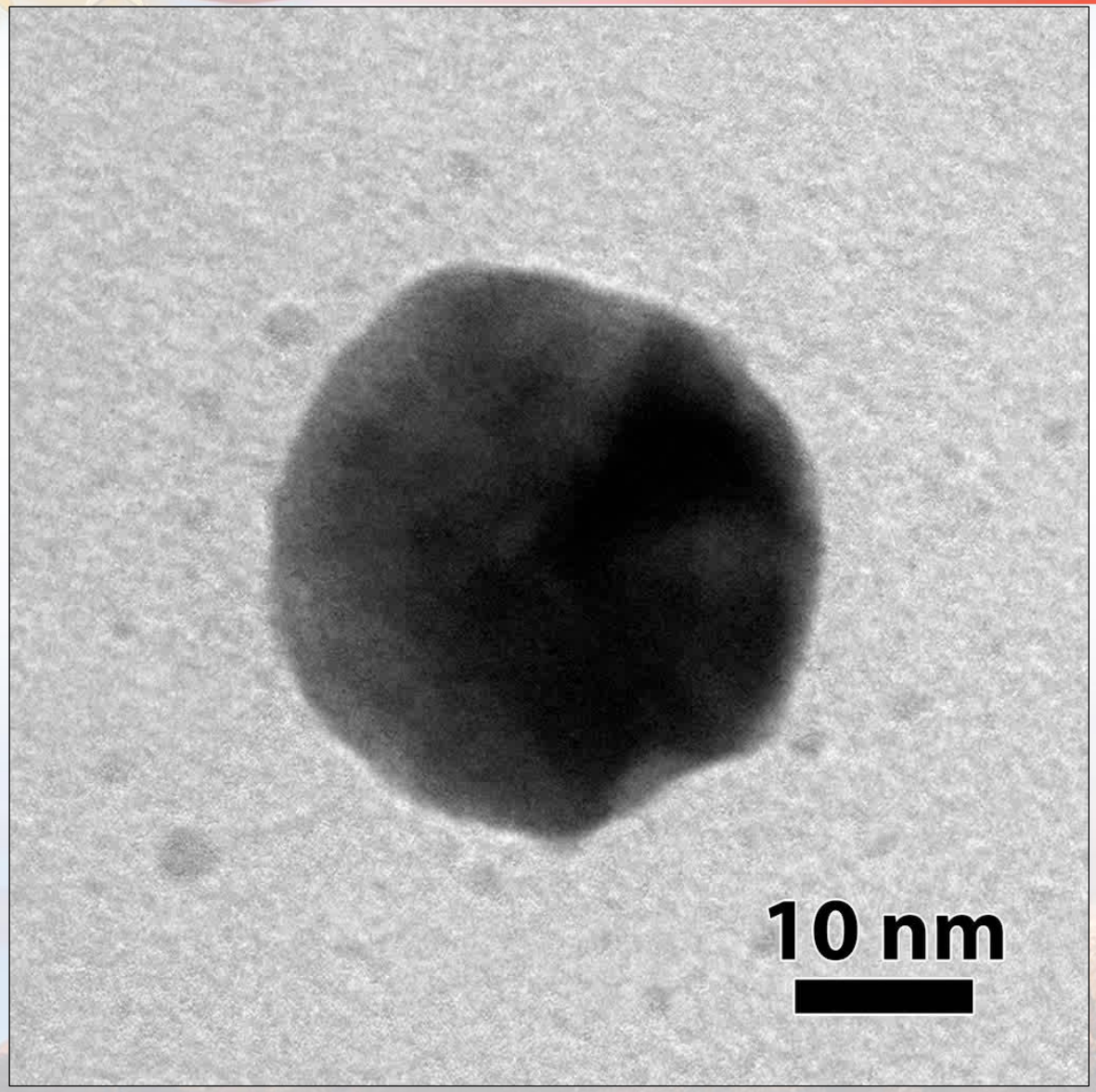


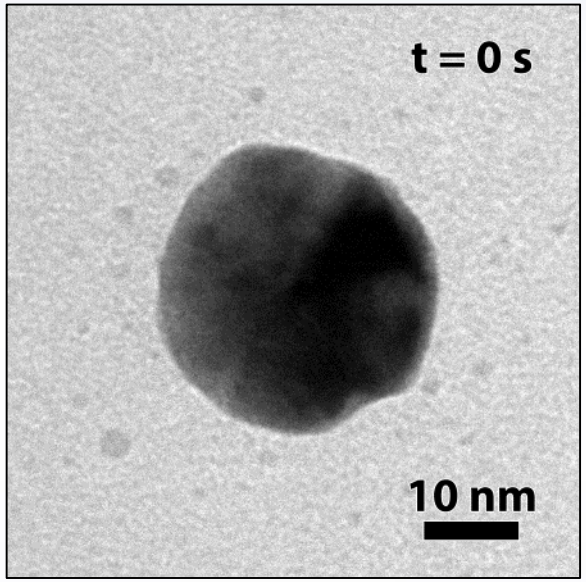


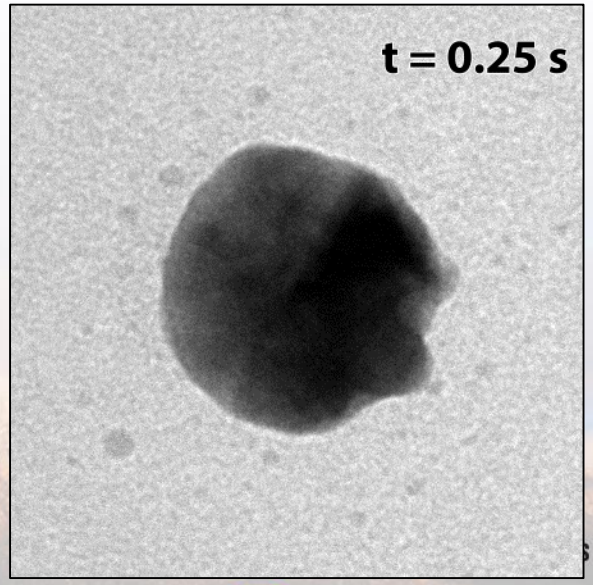


Single Ion Effects with 46 keV Au^{1-} ions: 20 nm

Collaborator: D.C. Bufford

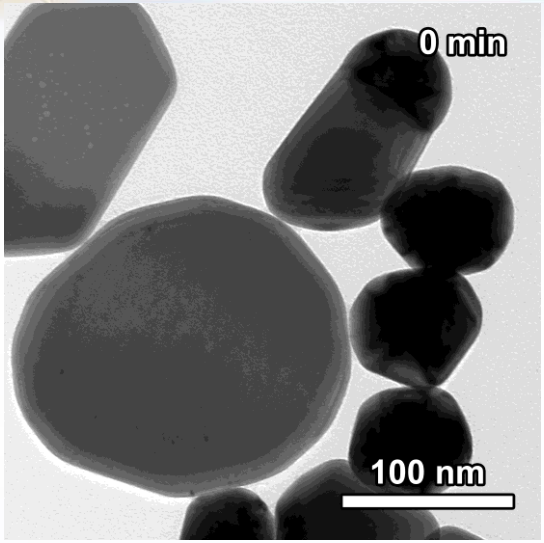


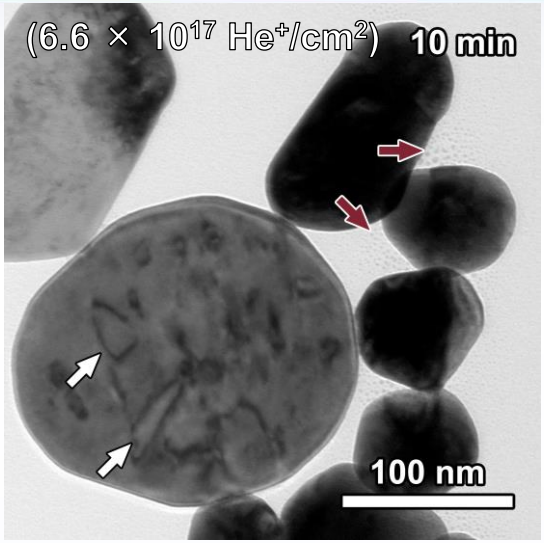


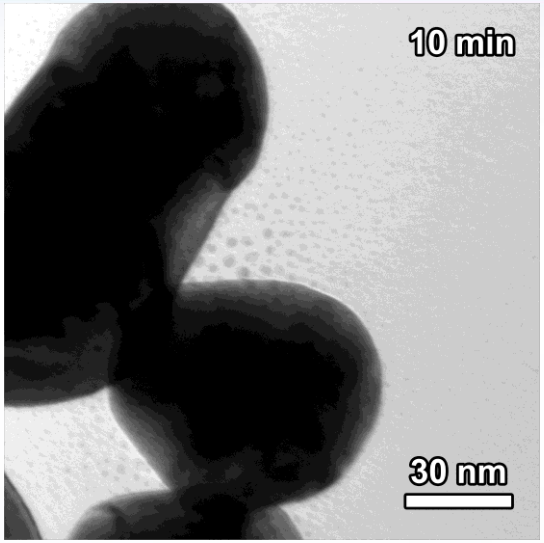


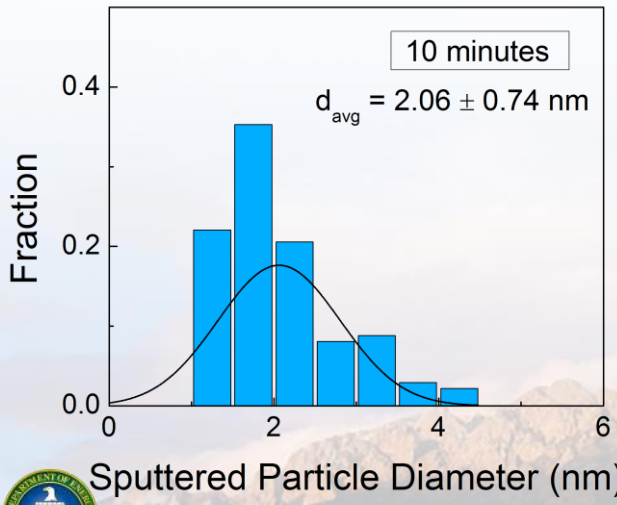
Formation of Dislocation Loops & Sputtered Particles due to He implantation

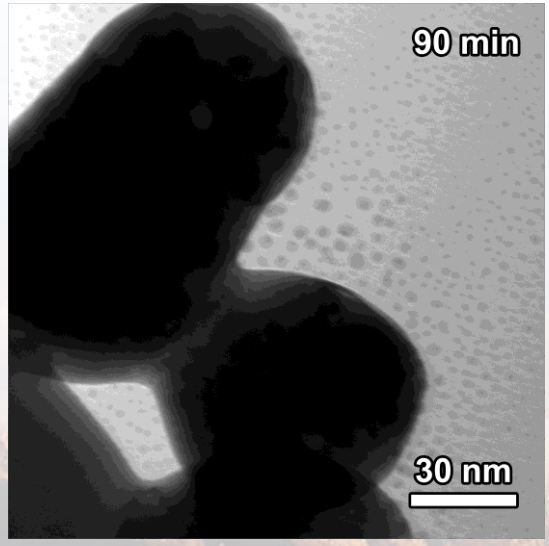
Collaborators: D.C. Bufford, S.H. Pratt & T.J. Boyle

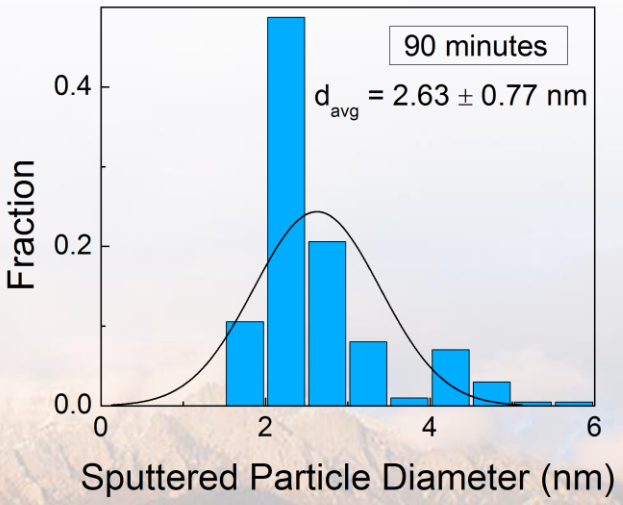












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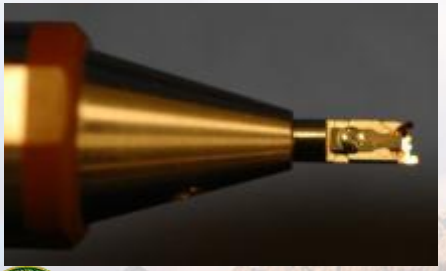
Advanced Microscopy Techniques Applied to Nanoparticles in Radiation Environments

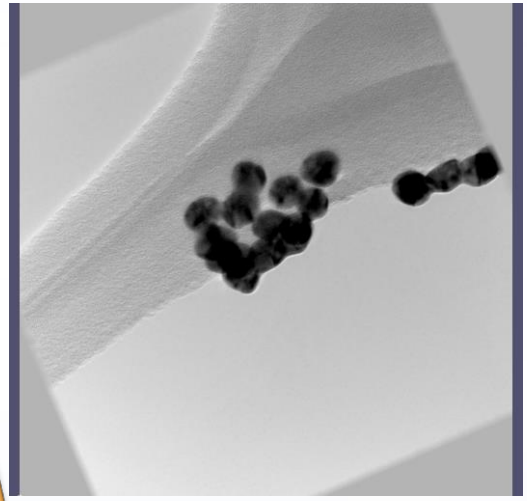
Collaborators: S.H. Pratt & T.J. Boyle

In situ **Ion Irradiation TEM (I^{3}TEM)**

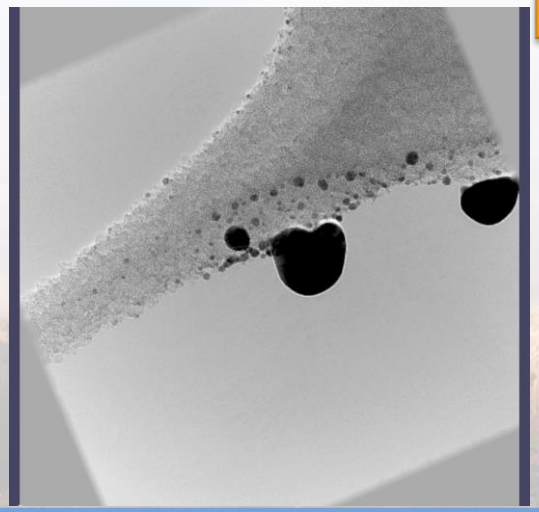
Hummingbird tomography stage



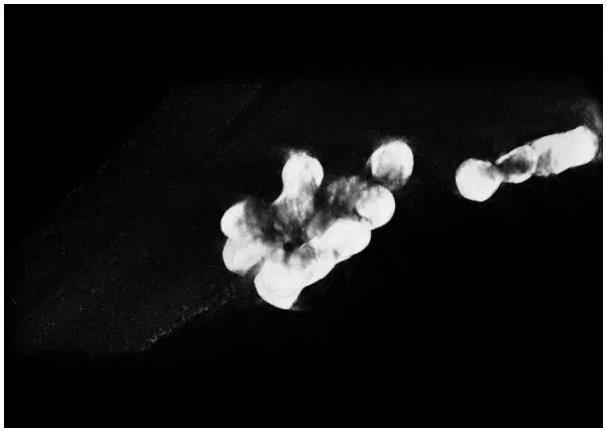
Aligned Au NP tilt series - unirradiated



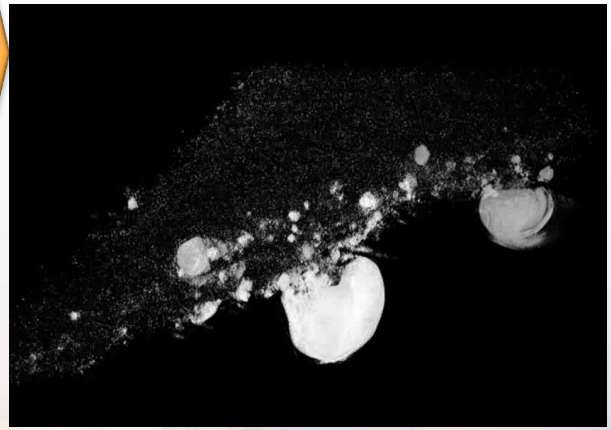
Aligned Au NP tilt series - irradiated



Unirradiated Au NP model



Irradiated Au NP model

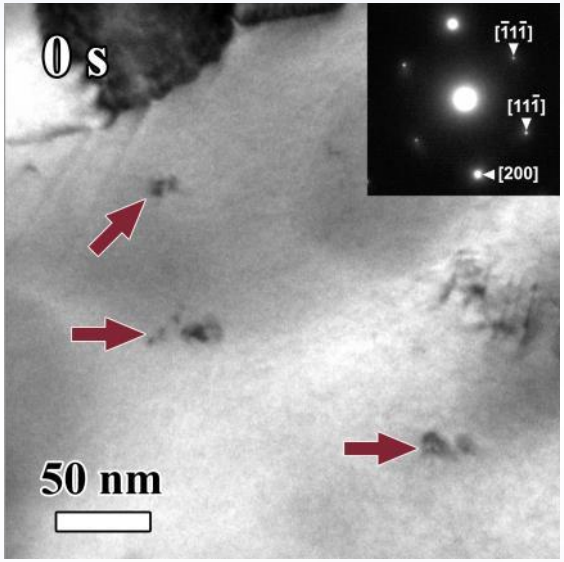


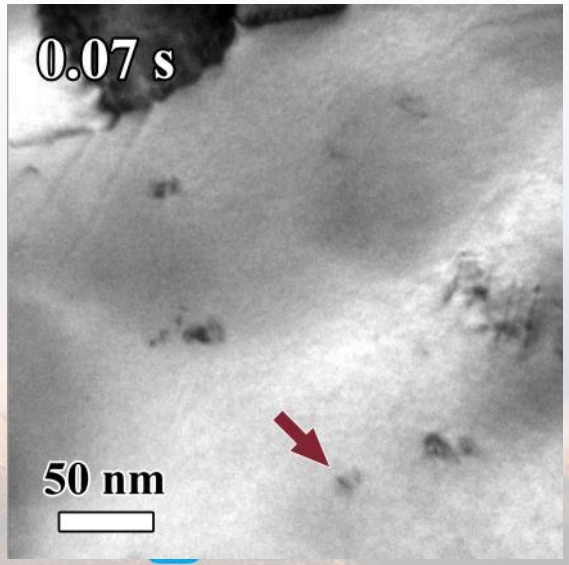
The application of advanced microscopy techniques to extreme environments provides exciting new research directions

Single 48 MeV Si Strikes into Au Thin Foil

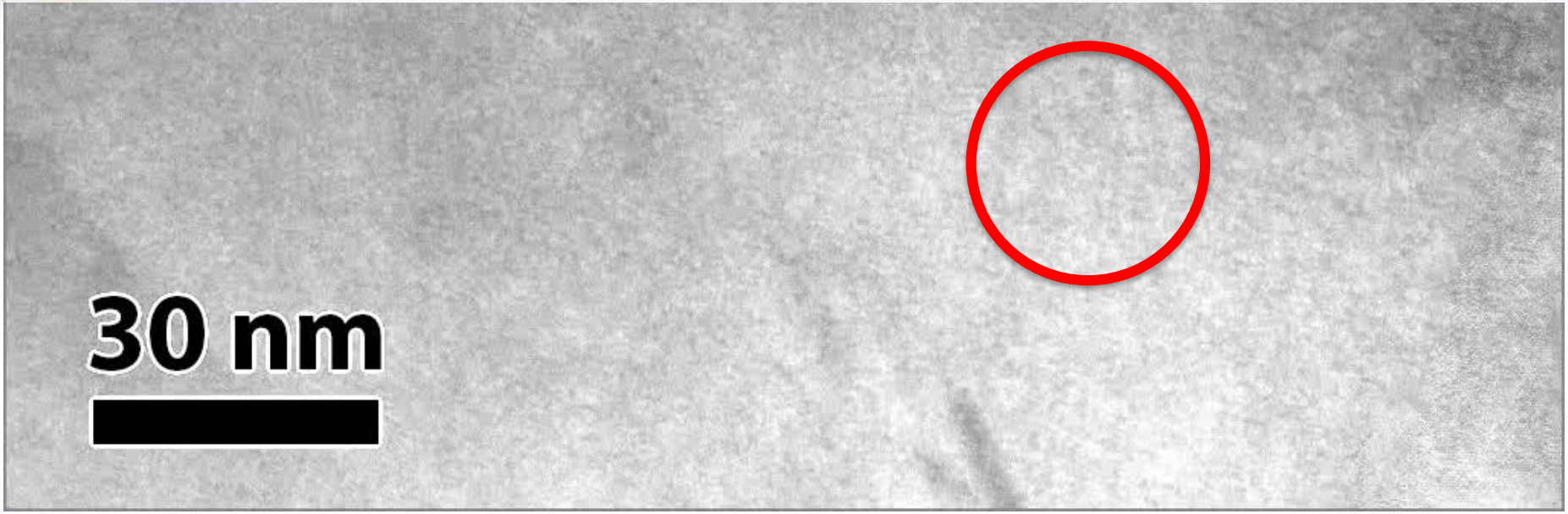
Sped up 8x

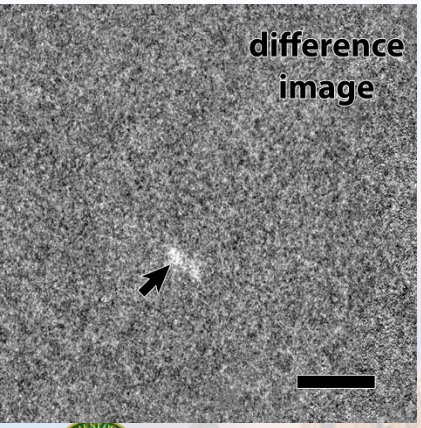
The majority of expected Si ion strikes are not observed. Those observed result in significantly smaller defect structures.





Demonstration of Single Ion Strikes in Si



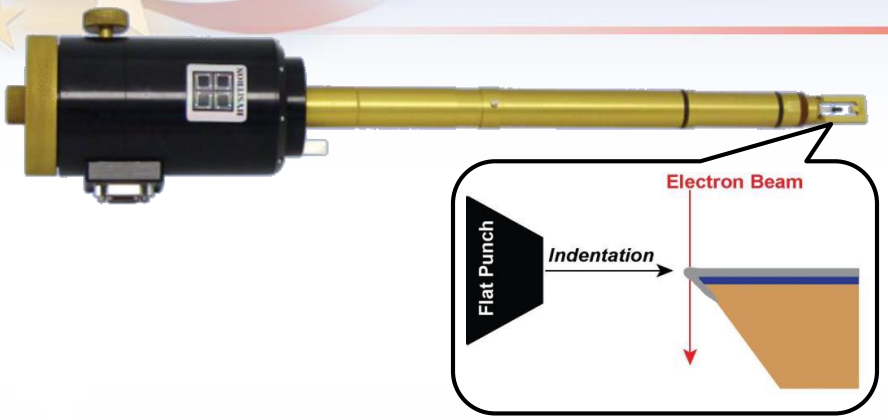


- 1.7 MeV Au into single crystal Si
- Single ion strikes can be observed in semiconductors
- Non-symmetric structure in contrast to the spherical approximation

Can we go beyond this to observe:

- **the important aspects of structural evolution as a function of time (ns to hrs.)?**
- **the evolution in more complex systems (GaAs)?**
- **Directly correlate it to key model parameters?**

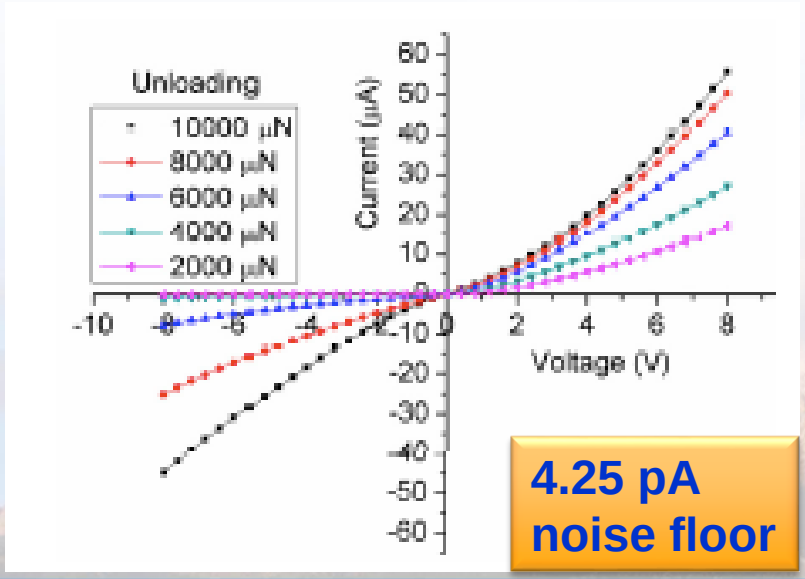
Controlling the Sample through TEM Stage Upgrades



- Electromechanical upgrade to Hysitron PI-95
- Gatan double-tilt liquid nitrogen stage

Range of Mechanical Testing Techniques

- **Indentation**
- **Compression**
- **Tension**
- **Wear**
- **Fatigue**
- **Creep**



4.25 pA noise floor

Cooling to 77K

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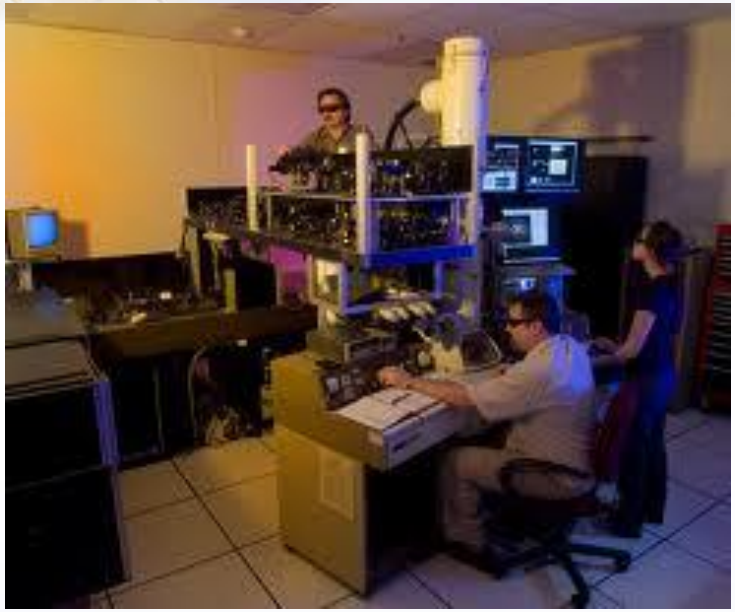
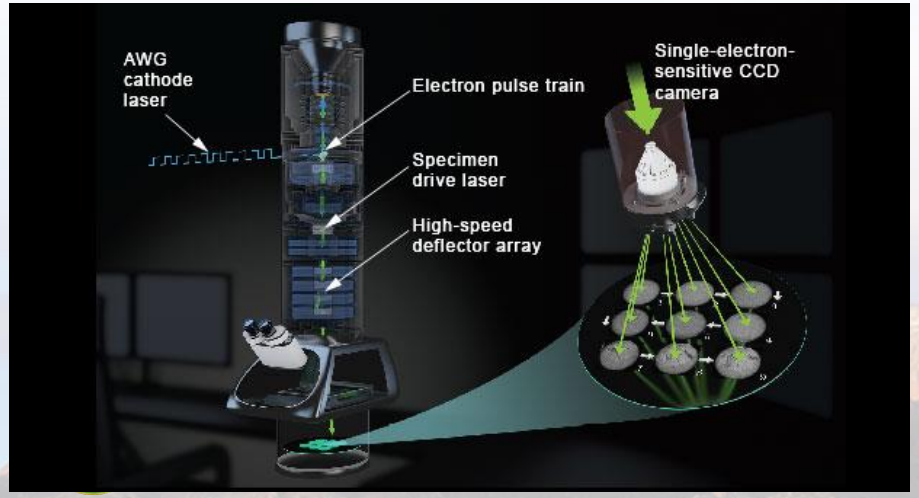
Can I^{3}TEM and DTEM systems be combined?

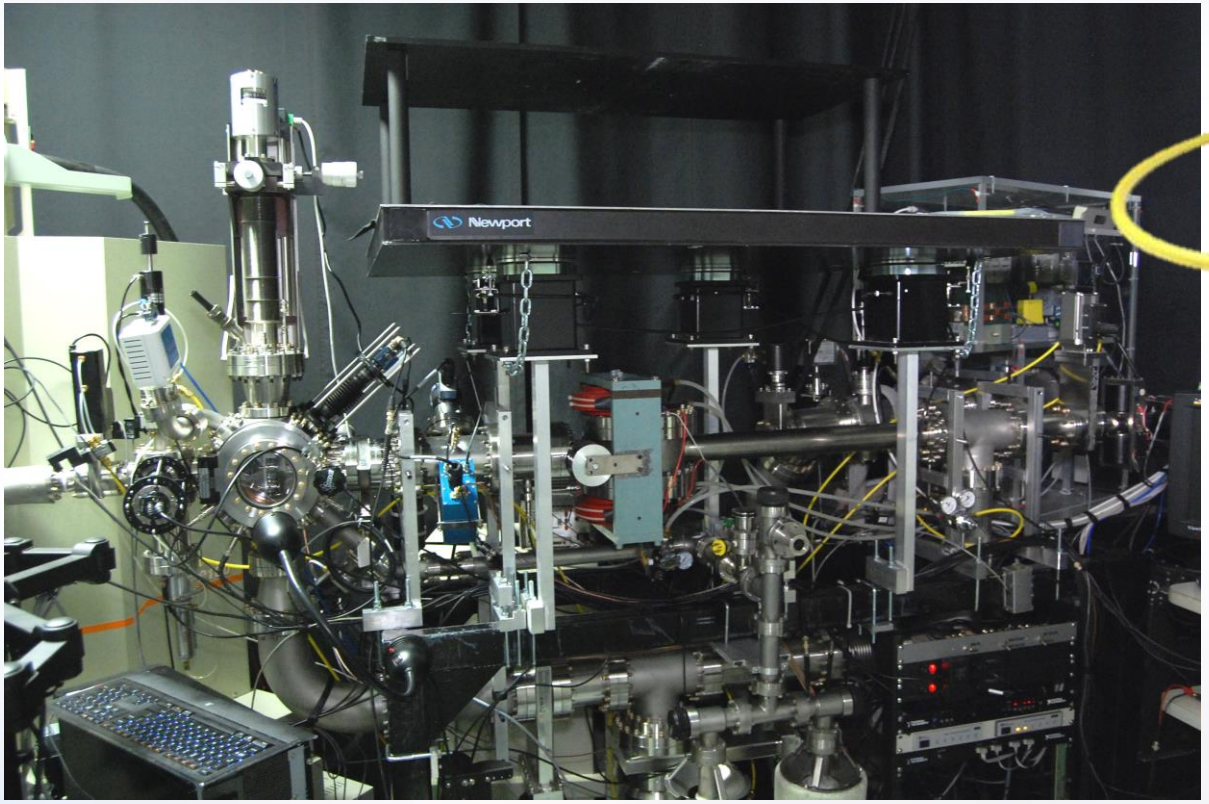


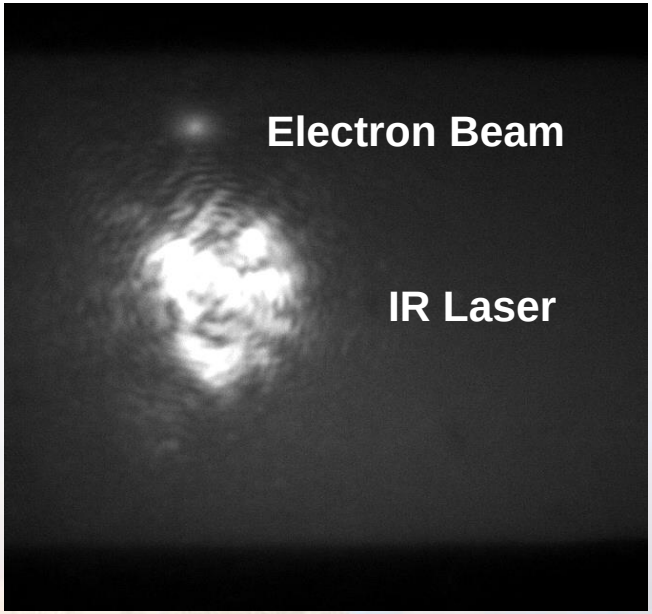


Goal:

To combine the state-of-the-art in microscopy developed at LLNL and SNL to elucidate the response of single radiation events and other extreme overlapping environments with adequate spatial and temporal resolution.

Instillation and Operation of IR laser within the TEM



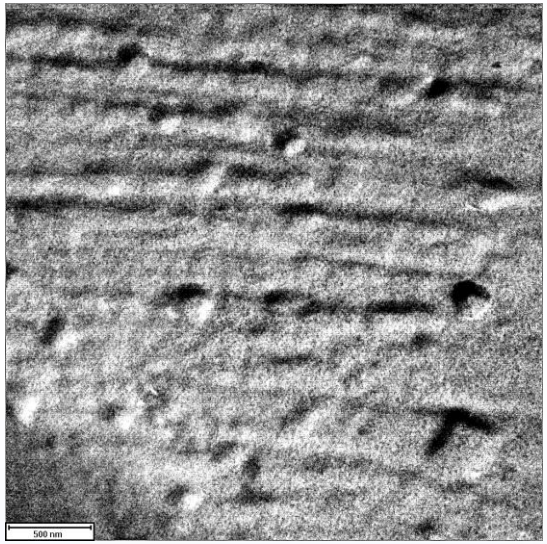


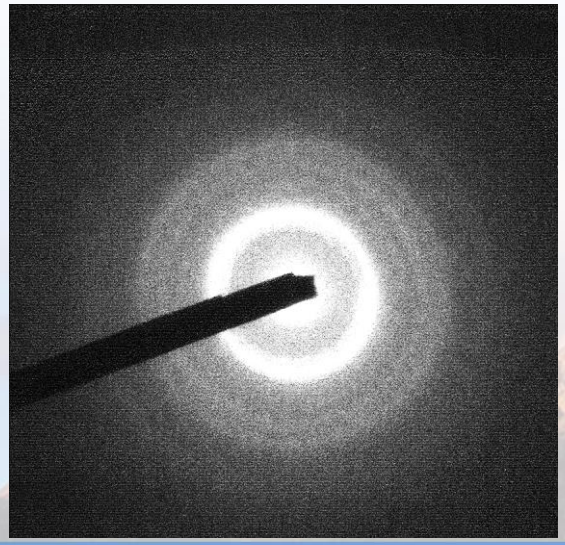
Both IR and UV lasers have been purchased, the optics are designed, the safety modifications and paperwork is complete, IR Laser is installed and operational for sample heating

Laser Initiation of Multilayer Reactive Foils

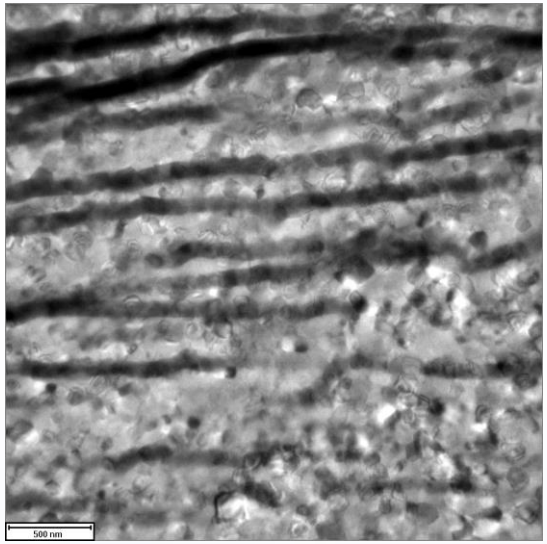
Collaborator: for work on this slide

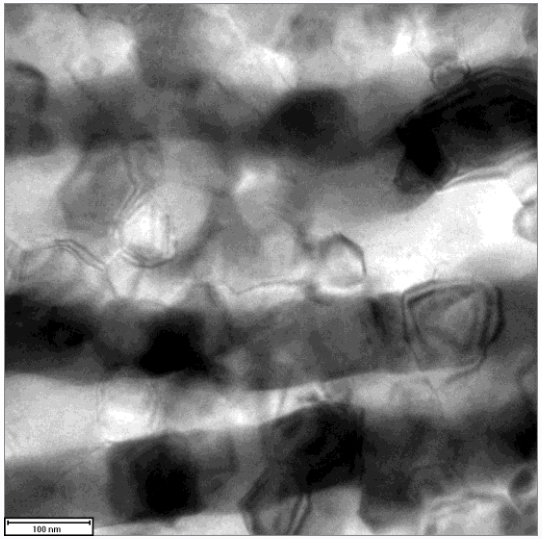
As Received Co/Al Multilayers

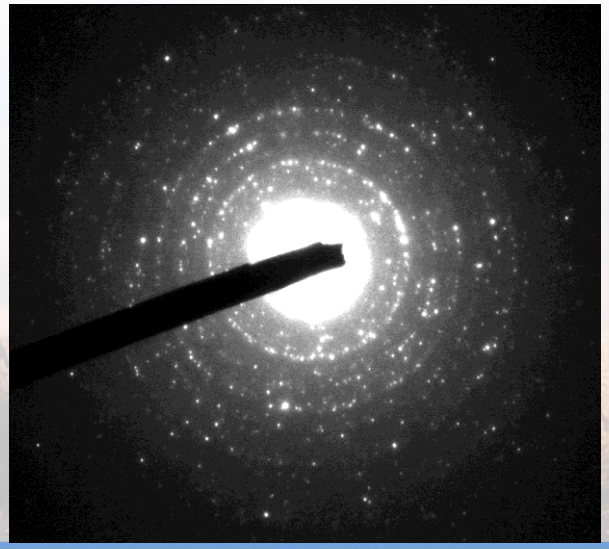




Foil After Laser Initiated Reaction







Laser Heating has been demonstrated 12/7/2016

The effects of laser, ion, and electron irradiation can all be probed in the same TEM

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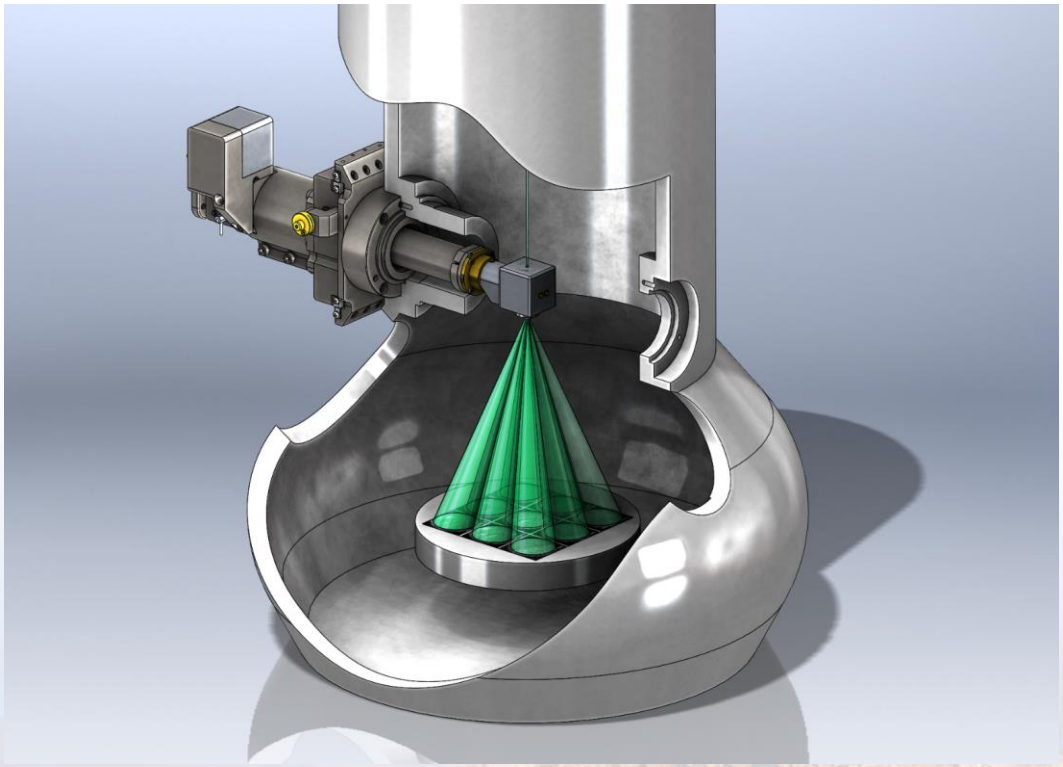
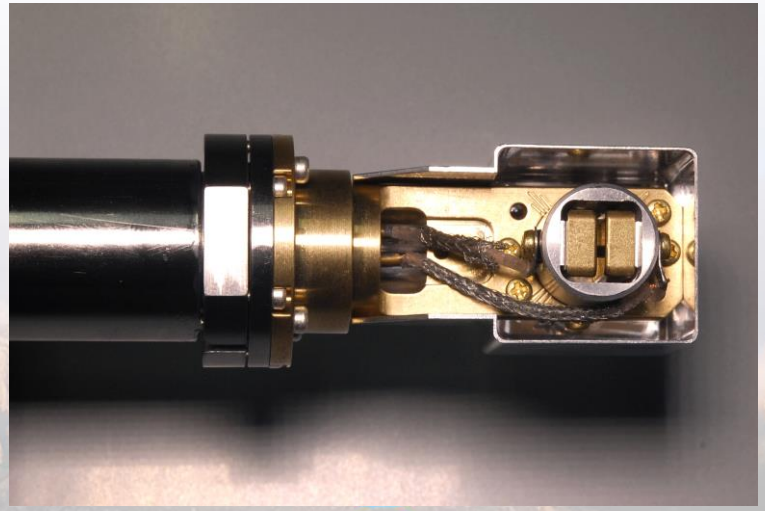
A Movie-Mode deflector to a conventional TEM can give you μs-scale resolution with a standard camera

fs ps ns **μs** **ms** **s**

16 to ∞ Images/Event

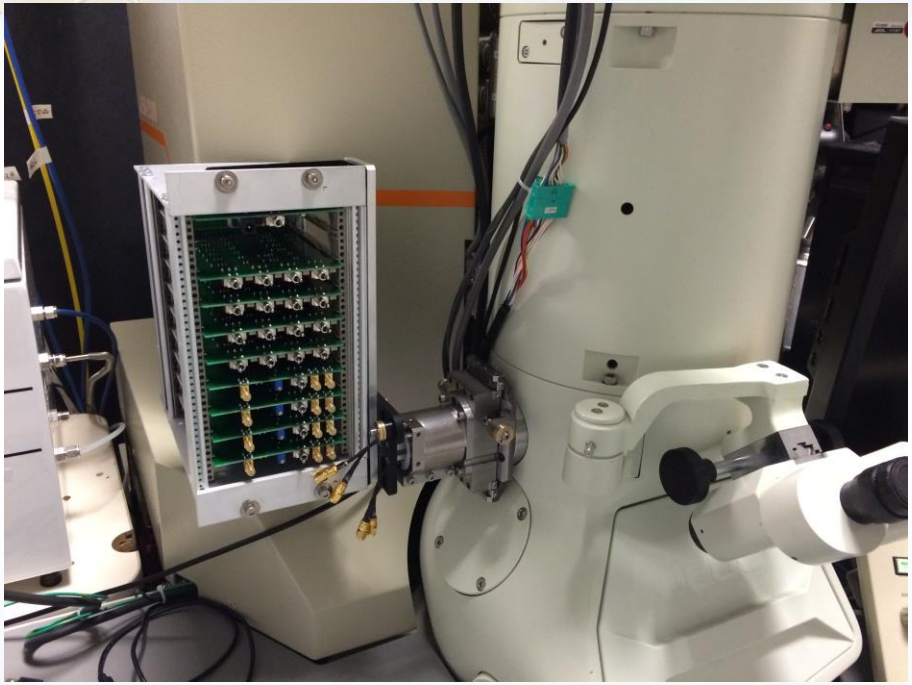


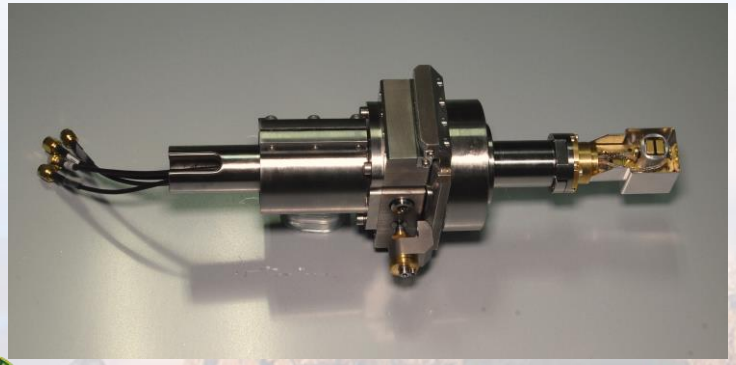
- **9-16 images per frame, spread over a large camera**
- **Any duty cycle up to the limits of the camera**
- **Ultimate limit is beam current/brightness**

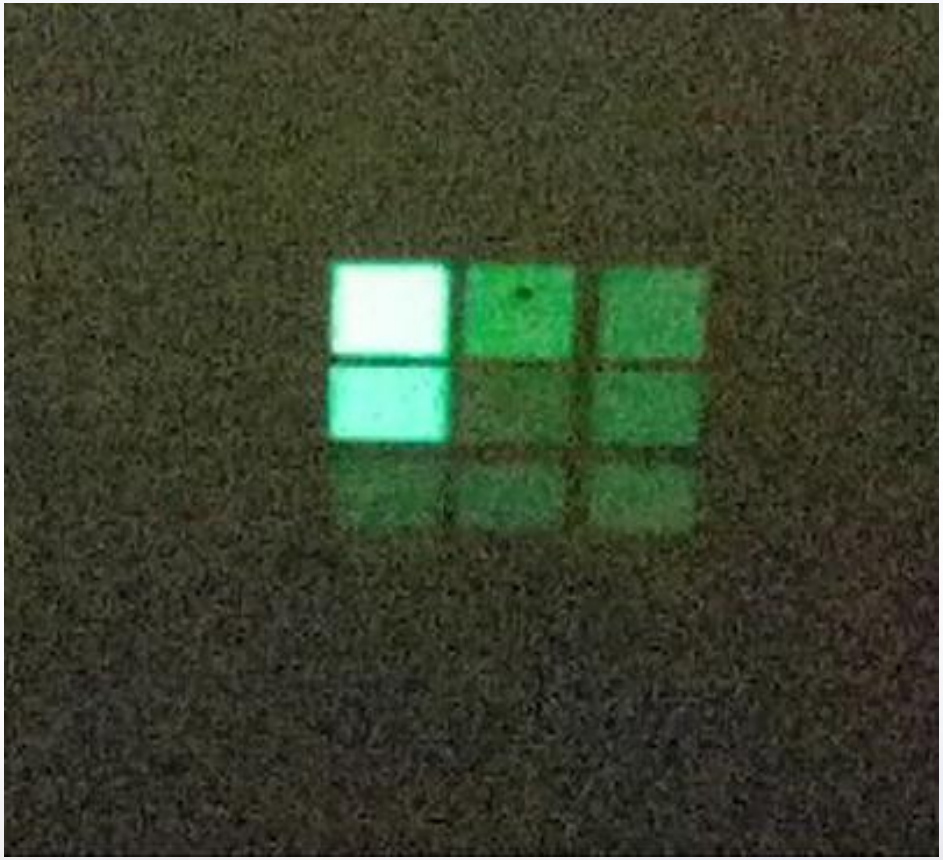


Can both Movie-mode and Photoemission source be done at the same time to further enhance the time resolution?

Status of the Movie-Mode Deflectors at Sandia







Temporal compressive sensing works! 54 frames of 500 Hz TEM video from a single camera acquisition

This system was installed and functional at Sandia in July 2016.

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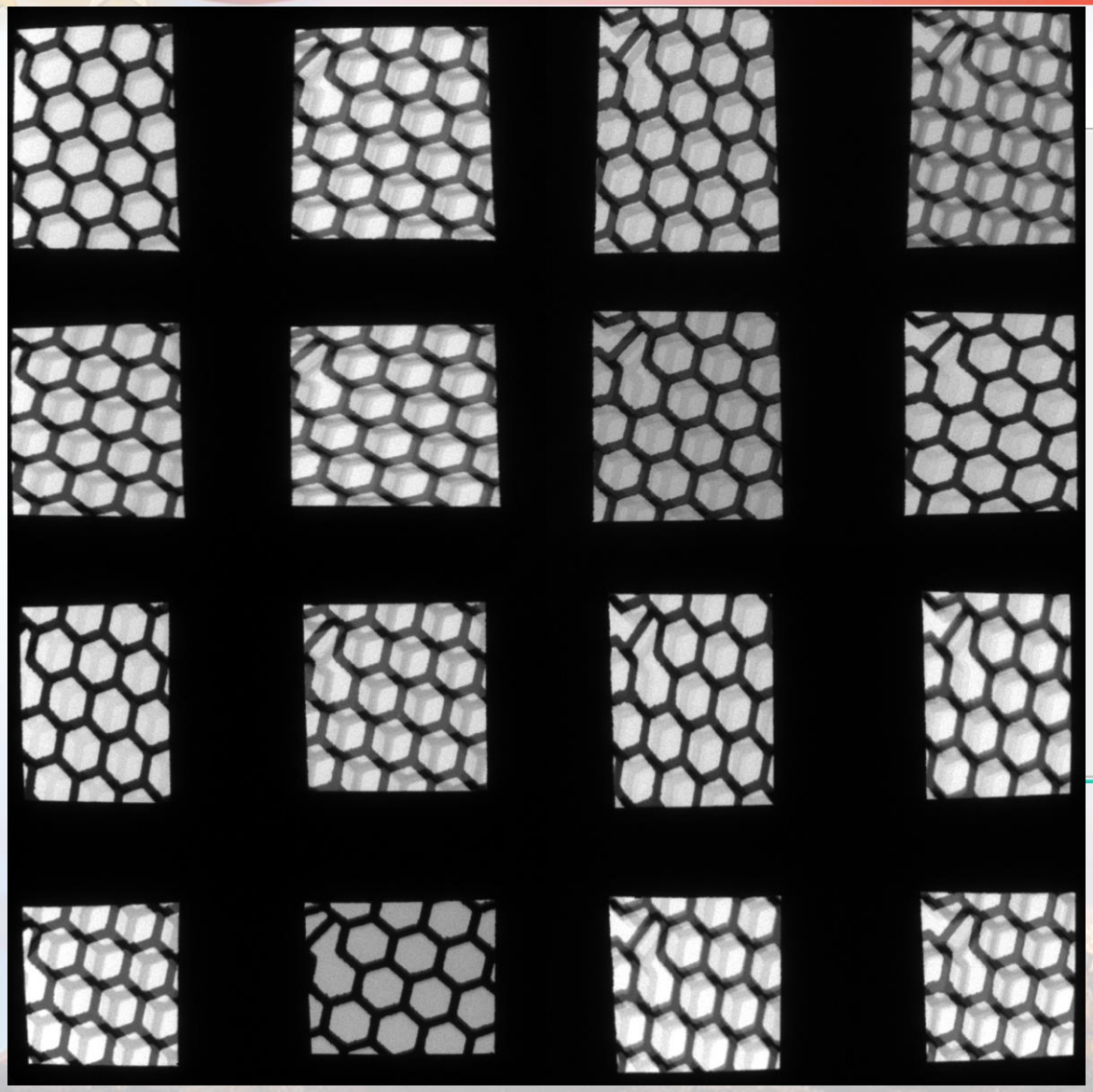
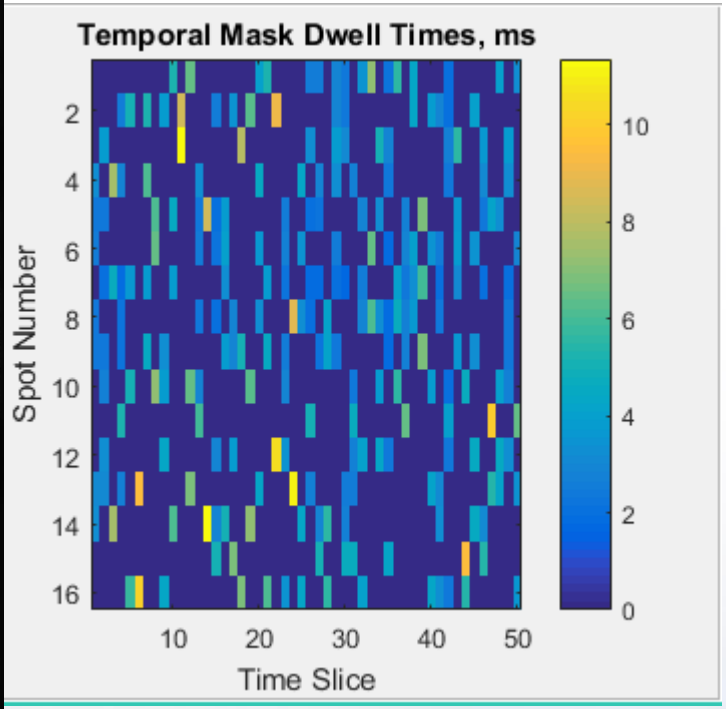
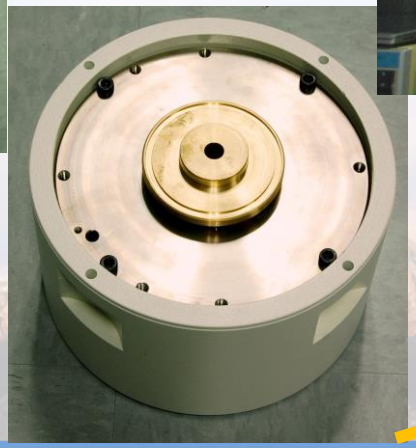
Demonstration of Movie Mode Deflectors

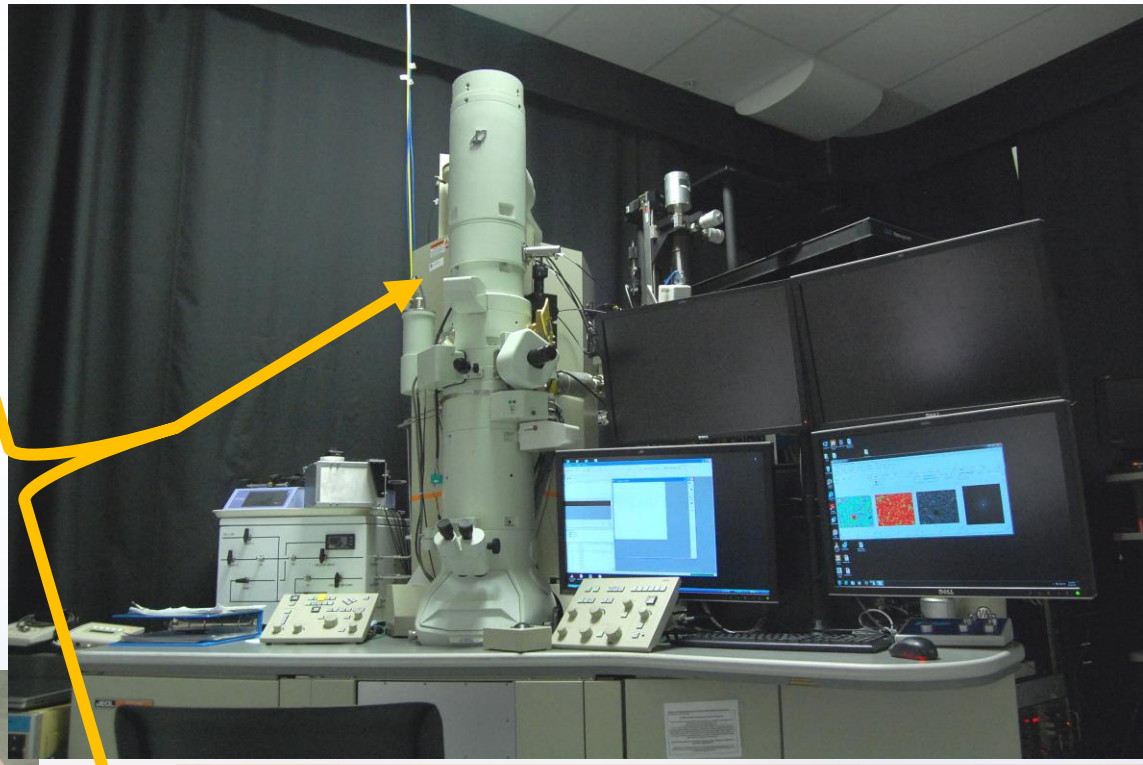




Demonstration of Relativity done 12/14/2016.

Next step: Plans to Increase the TEM Brightness





A standard TEM has on average 1 or 2 electrons in the column at a given time!

An laser port, additional condenser lens, and robust cathode must be added to increase electron current.

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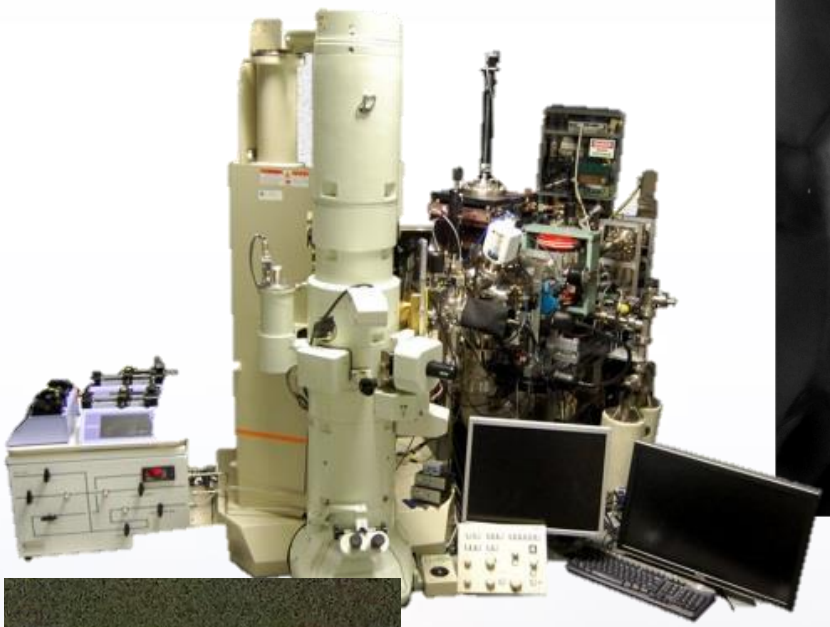
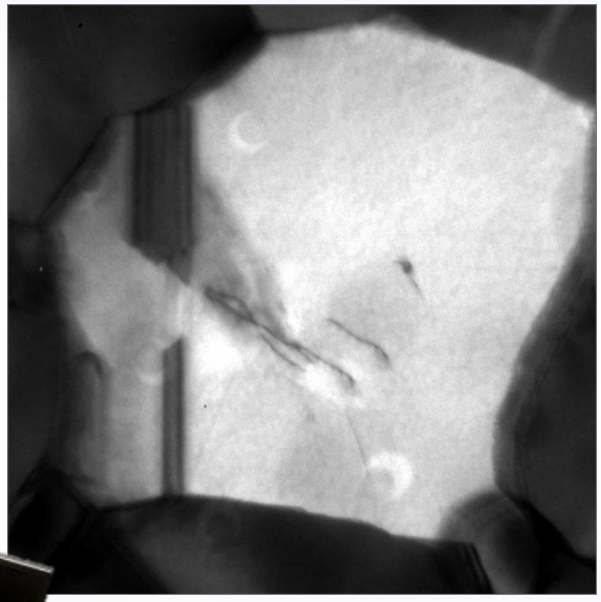
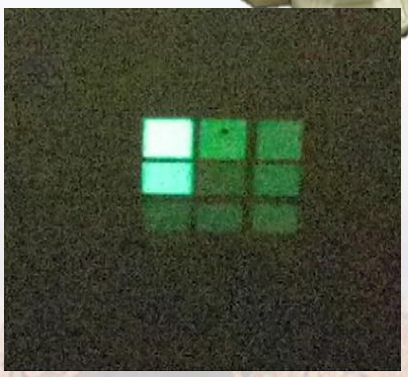
Summary

1. Single ion strikes can be observed in relevant length scales utilizing I^{3}TEM in:
    1. Range of metals
    2. Si
2. Relativity and IR laser heating systems are operational, but still needs to be optimized
3. C0 lens and Cathode laser are purchased and installs are planned for next year.
4. Can relevant time scales be achieved is still an outstanding question.







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