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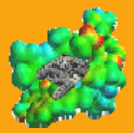

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HIP

Multiscale Modelling of Arcs and Sparks

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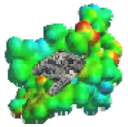
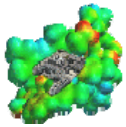


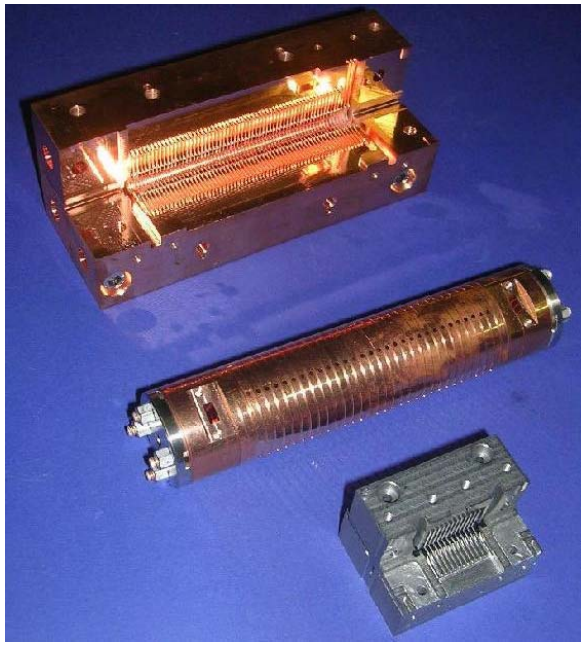
Outline

- Background & motivation
- Arcing and sparking: The mechanism
- Multiscale model
  - Particle-in-cell (PIC) simulations of the arc plasma
  - Molecular dynamics (MD) simulations of arc-induced surface damages
- Results:
  - Comparison of materials
  - Comparison with experiments
- Future plans



Motivation:
CLIC Accelerating Components

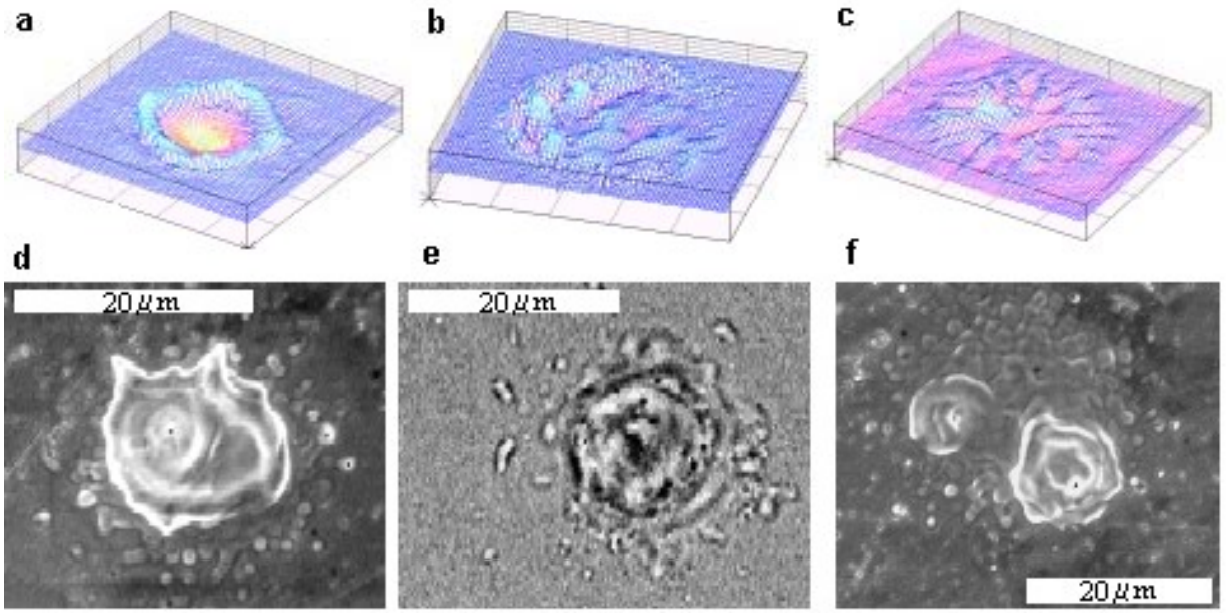
- Arcing and sparking can potentially
  - Destroy particle bunches
  - Cause surface damages ⇒ enhances arcing
- Too high breakdown rates have been measured
- A theoretical model shall give a deeper insight into the process of arcing



[W. Wünsch]

Background: Arc-induced Cratering

- Arcing is a plasma-wall interaction that causes erosion and can produce large (1 – 10 μm) craters.
  - Classical explanation: Surface heating by ions and electrons
    ⇒ massive evaporation



[http://www.uni-saarland.de/fak8/fuwe/fuwe_de/Forschung/electroden/Indexi.htm]

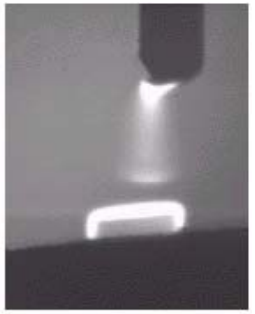
Arcs and Sparks

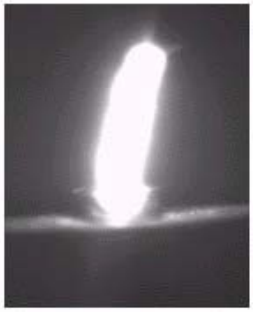
- Arcs or sparks are plasma discharges between electrodes (arc: continuous, spark: momentary)
- Understanding them is important in many different fields:
  - Fusion devices – active research since 1970's
  - Industry:

    Electrical discharge machining

    Arc welding

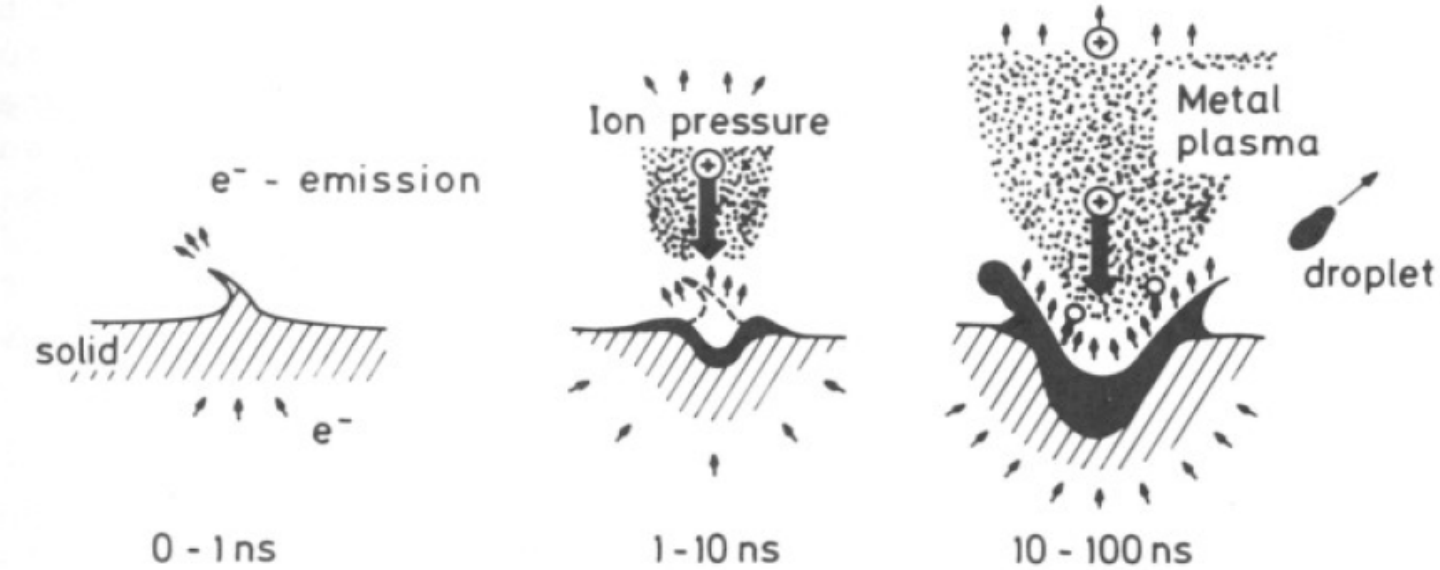
    Spark plugs for cars
  - CLIC



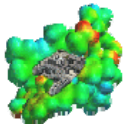


The Mechanism of Arcing

- Three phases are distinguished:
  - Onset of arcing: Some triggering effect resulting in thermal emission (due to Ohmic heating) or field emission (due to high electric field) of electrons
  - Ion and neutral densities build up, continuous discharge
  - Surface damage occurs: Erosion & cratering, new spots



[R. Behrisch, in Physics of Plasma-wall Interactions in Controlled fusion, NATO ASI series B 131 (1986) 495]



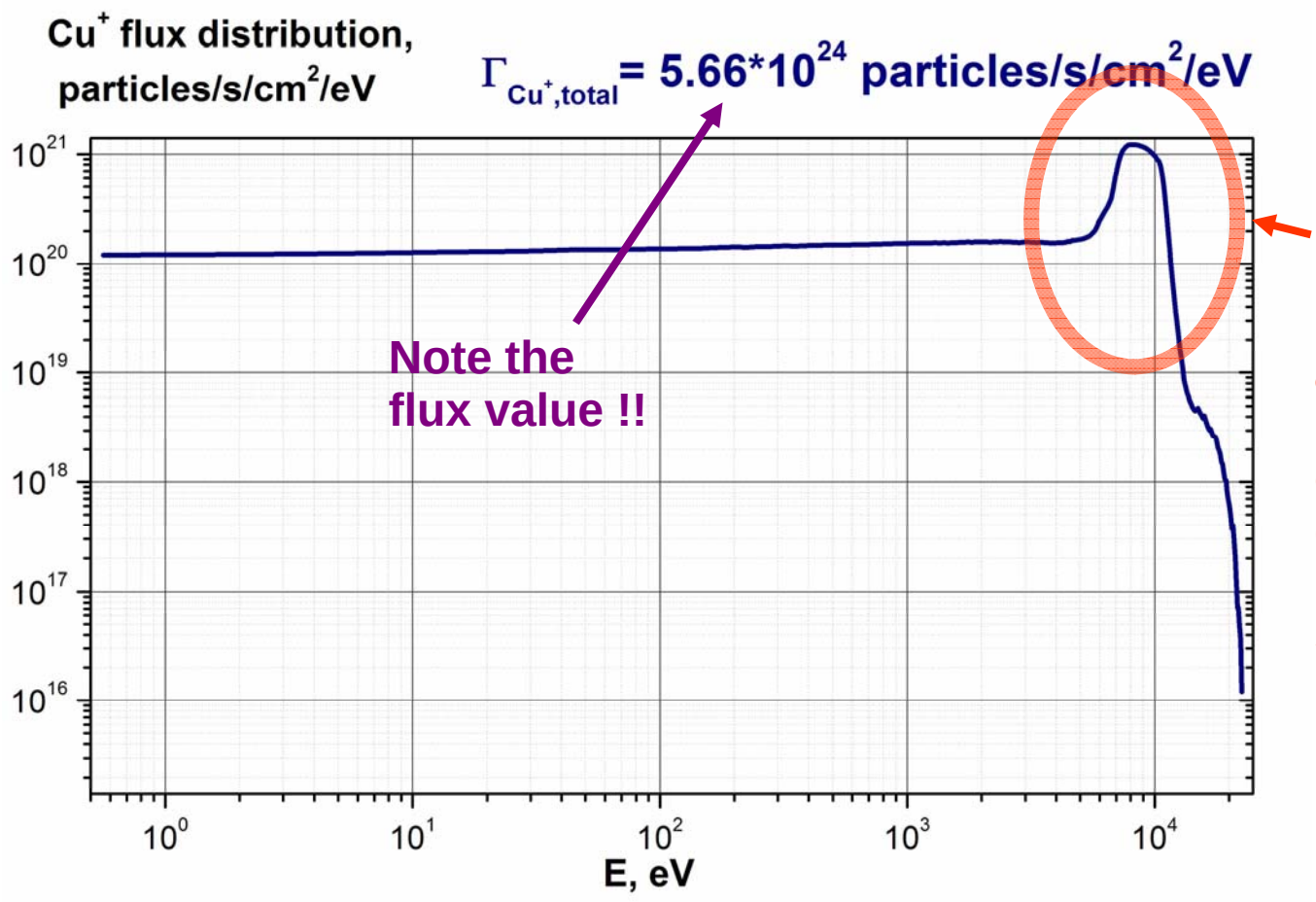
Multiscale Model

- Onset: In literature, not much understood yet
  - F. Djurabekova is modelling this phase
  - Possibly added to the multiscale model later

- To get insight into the phenomenon of arcing, we have started a two-step simulation approach:
  - Build-up of densities in the arc plasma: Particle-in-cell (PIC) method
    - Emphasis on the surface interaction model
  - Surface erosion & cratering: Classical molecular dynamics (MD) simulations of surface bombardment
  - Coupling between these two

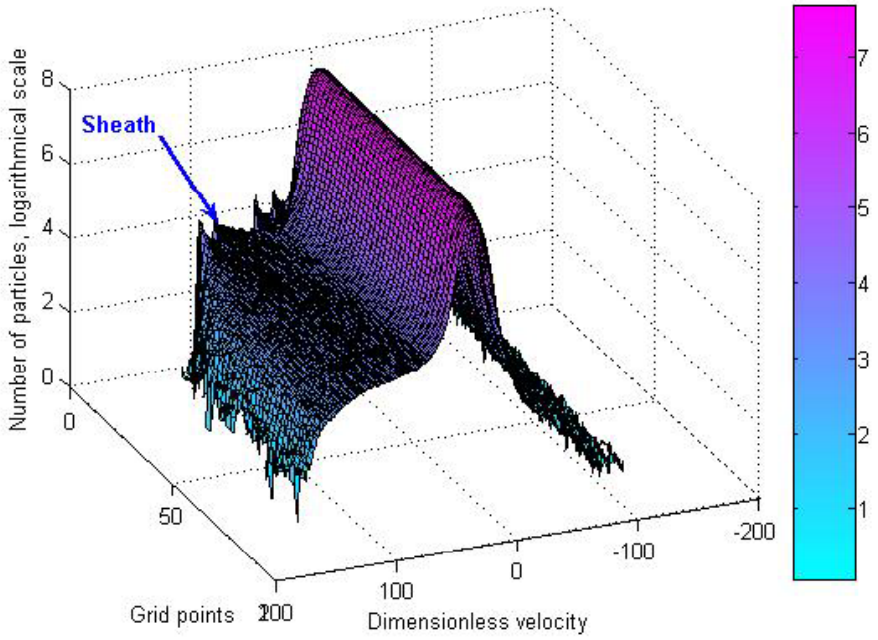
Multiscale Model: Coupling PIC and MD Simulations

- PIC simulations gave particle flux and energies for MD



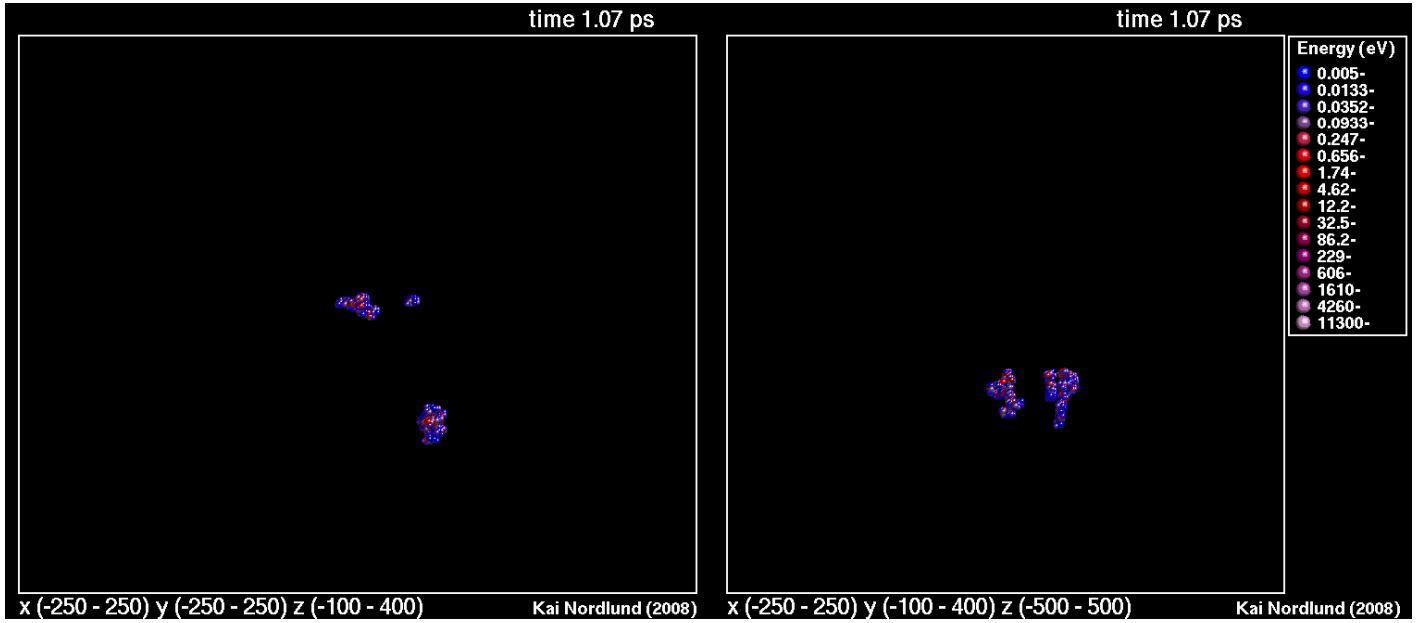
The Plasma Sheath

- Due to differences in ion and electron thermal velocities, equilibrium in the arc plasma is reached when an additional internal potential builds up
  - Accelerates ions, decelerates electrons



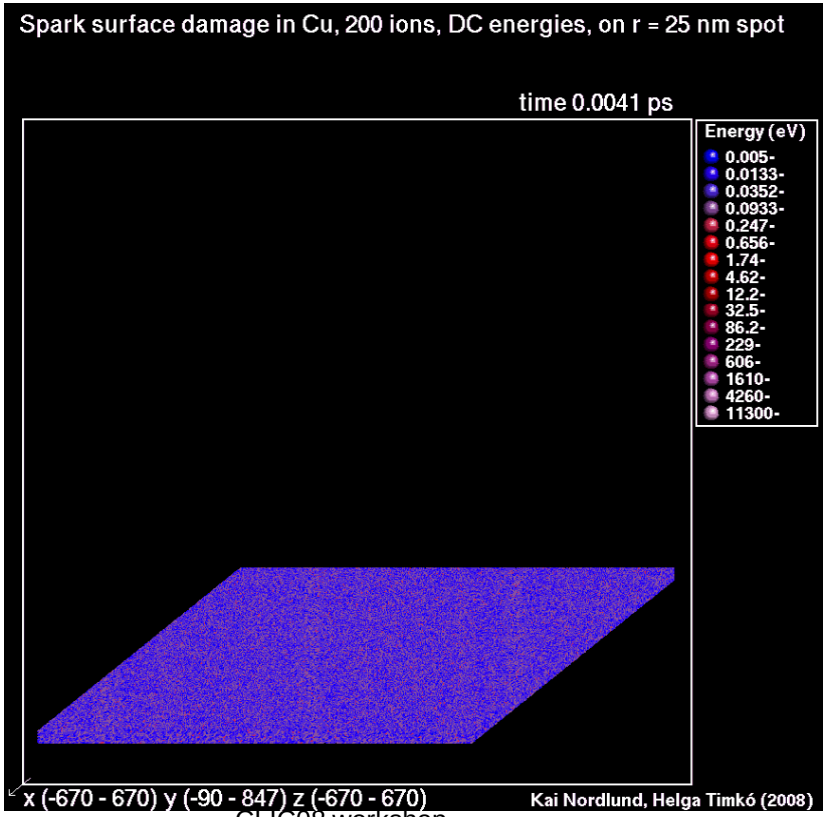
Multiscale Model: Classical MD Simulations

- We then carried out classical MD simulations of surface bombardment on a given area A
  - Ion flux and energy distribution corresponded exactly to that from PIC simulations!
  - Enormous flux of ~10^{25} prtcls/ s/cm^2 on eg. r=15 nm circle $\Rightarrow$ one ion/20 fs!!



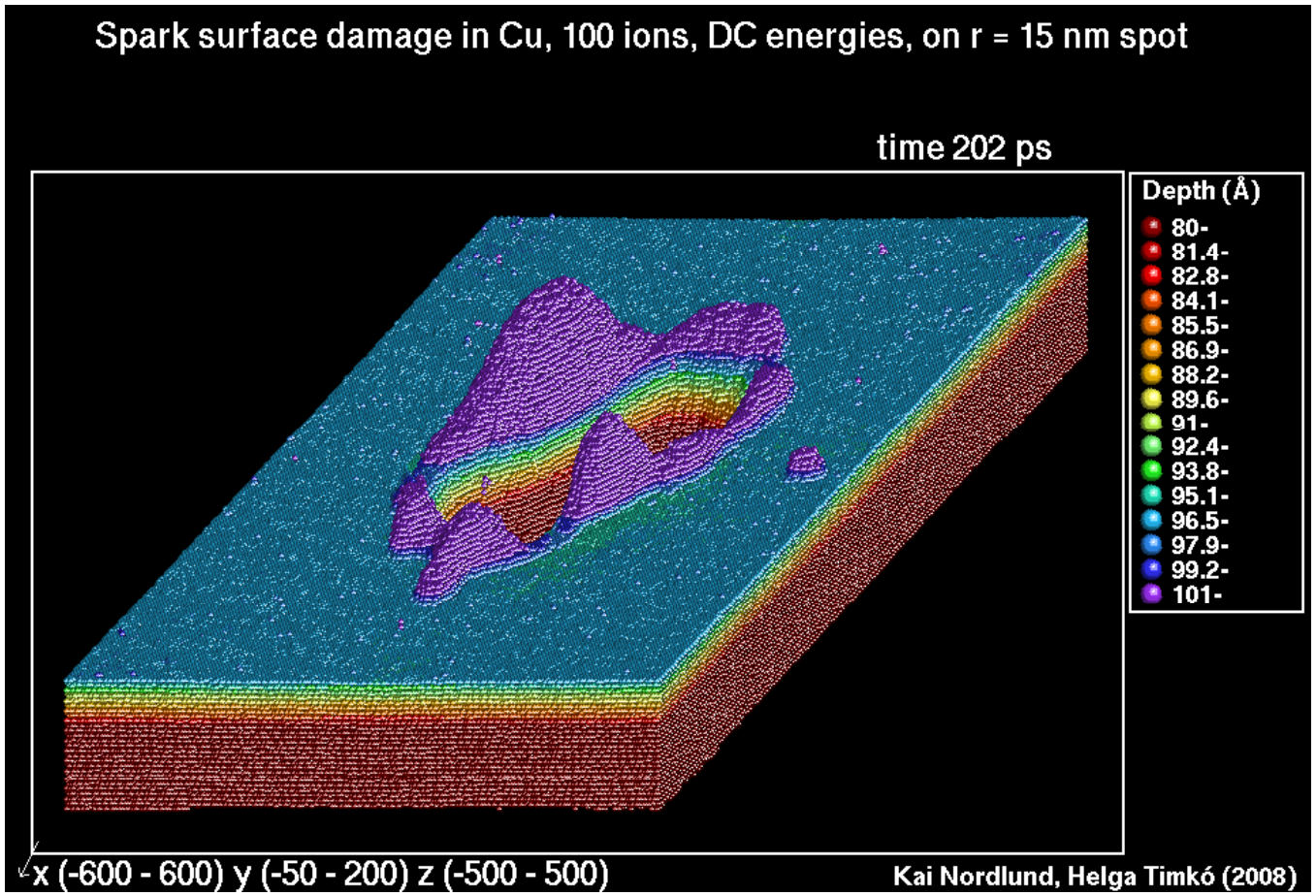
Multiscale Model: Classical MD Simulations

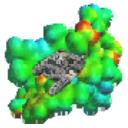
- With this flux and energy distribution, several overlapping cascades lead to huge heating and cratering
  - Ejection of metal droplets



Multiscale Model: Classical MD Simulations

- The end result is cratering





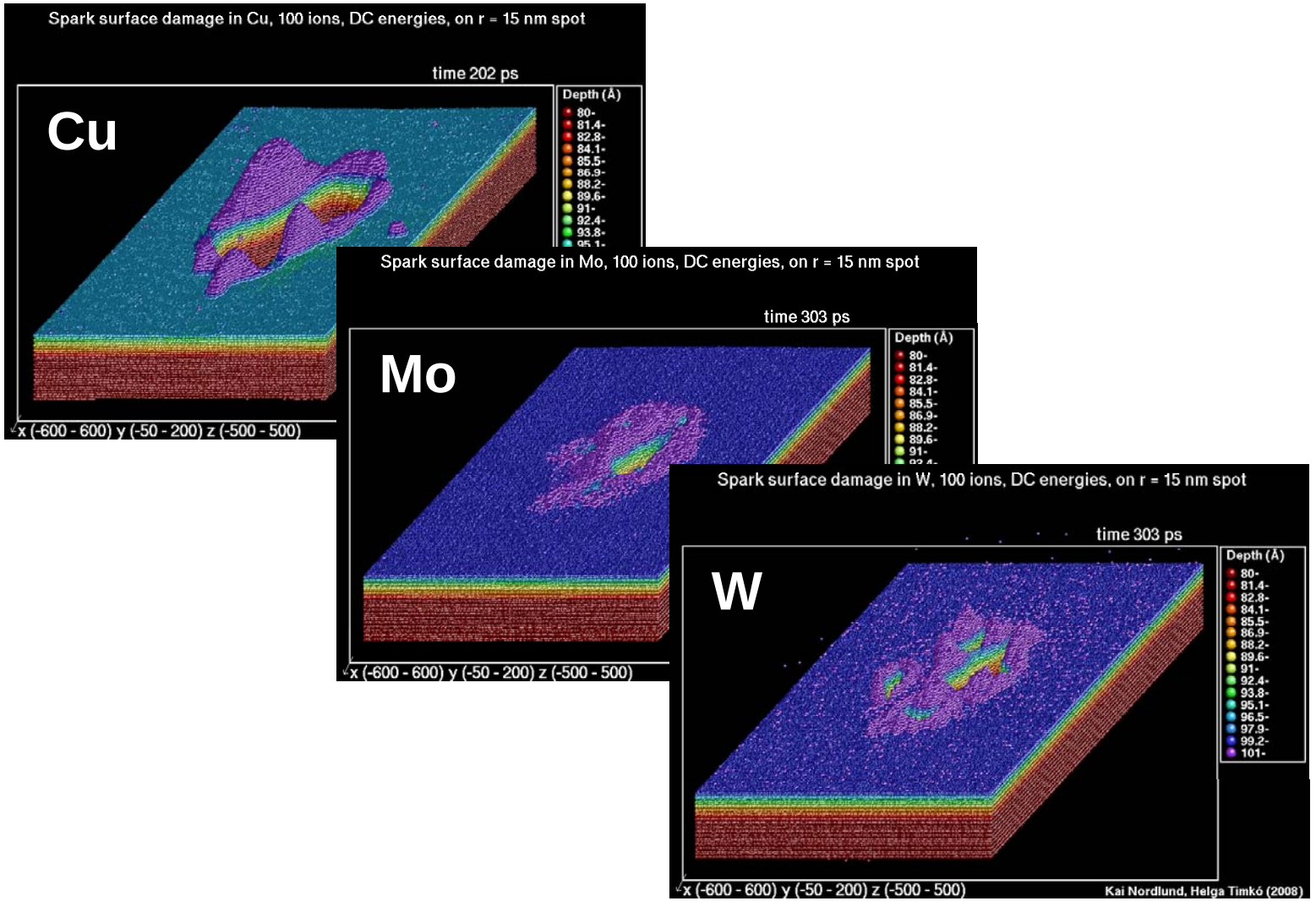
Multiscale Model: Comparisons Made

Material	$r\ (nm)$	N_{ions}	$E_{D,n}\ (keV)$	$E_{D,e}\ (keV)$	N_{vac}	N_{int}	N_{ad}	N_{sput}
Cu, DC	15	100	595	159	109668	9043	53272	45833
Cu, RF	15	100	362	91	19669	2121	13776	1581
Mo, DC	15	100	625	187	8511	66	8225	311
Mo, RF	15	100	362	102	2201	47	2024	225
W, DC	15	100	625	186	21140	82	15375	5741
W, RF	15	100	362	102	5779	62	4661	1148
Cu, DC	15	100	676	209	111397	3451	45791	60510
Cu, DC	25	200	1270	340	103652	7023	73332	20284
Cu, DC	25	200	1180	313	83908	9359	55759	17195

- Comparison of different (i) Impact radii,
  (ii) Energy distributions: DC, RF cases – less energy deposited for the latter
  (iii) Materials: Mo and W show less damage, since they have higher melting points

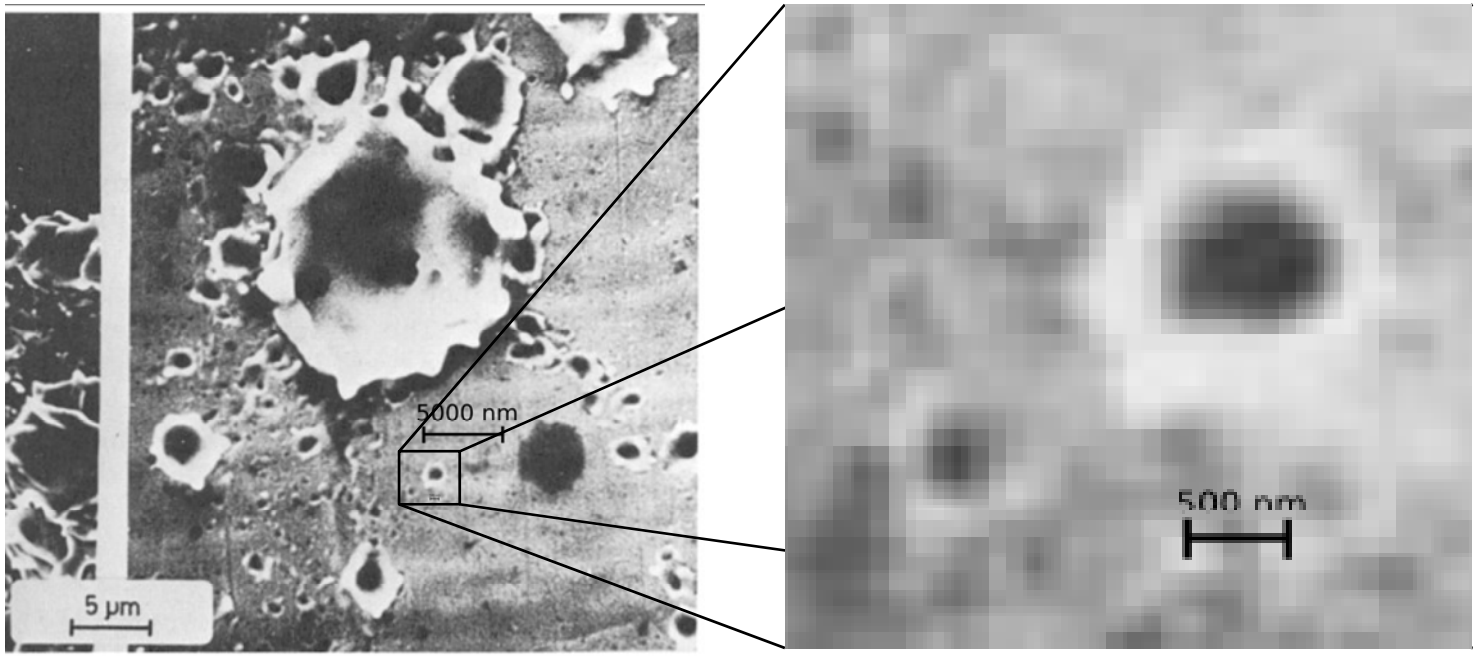
More information at: http://beam.acclab.helsinki.fi/~knordlun/arcmd/

Multiscale Model: Comparison of Materials



Comparison with Experiments

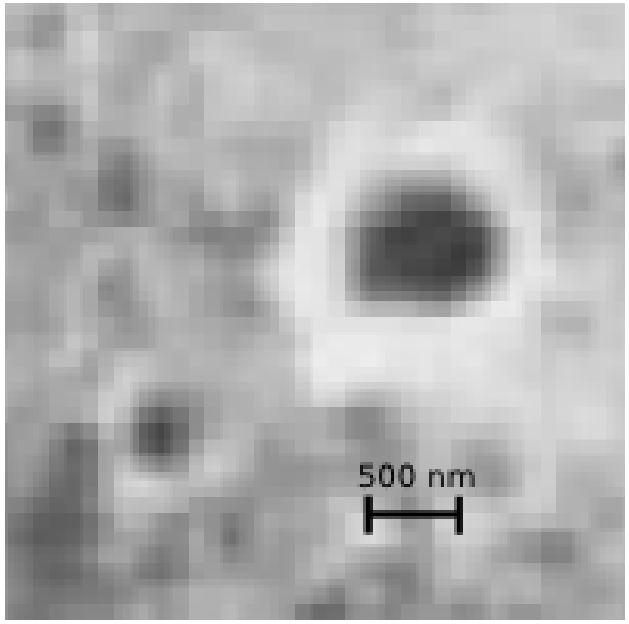
- Experiments show a wide variety of spark crater sizes
  - But they appear to be self-similar over size scales:



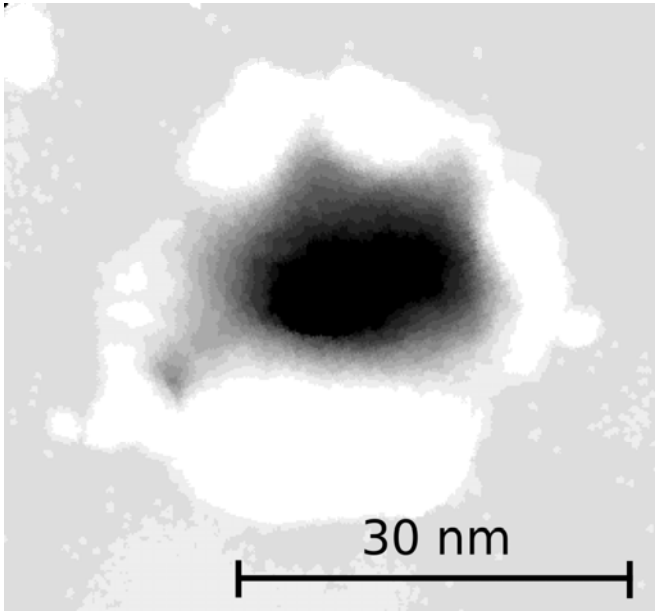
Comparison with Experiments

- Due to the self-similarity over size scales, we can compare our craters with experiments

Experiment



Simulation



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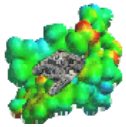

Future Plans

- Next step: Take over PIC simulations
  - Systematic runs of PIC
  - Gaining new inputs for MD
- Aiming scaling laws:
  - How does the system react on the change of parameters?
  - How to dim damage and reduce breakdown?