MICRO-PARTICLE IMPACT DETECTION BY PLASMA EFFECTS

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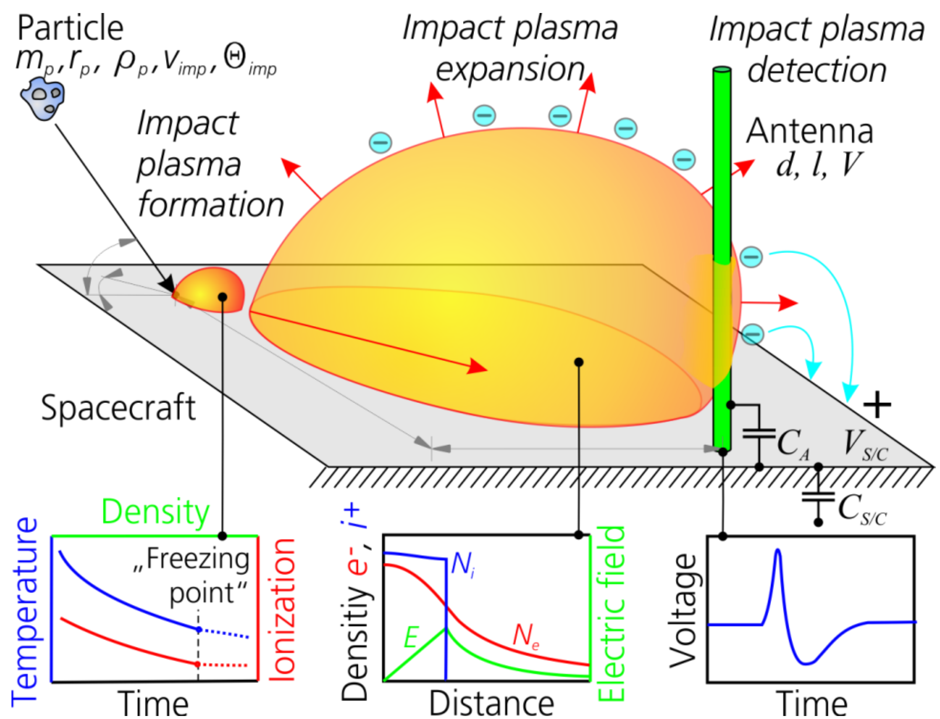


Martin Schimmerohn

MICRO-PARTICLE IMPACT DETECTION BY PLASMA EFFECTS

Content

- Fraunhofer EMI's Spacecraft Technology Group
- Motivation
- Modelling
- Analysis
- Conclusions

Fraunhofer EMI's Spacecraft Technology Group
Field of research

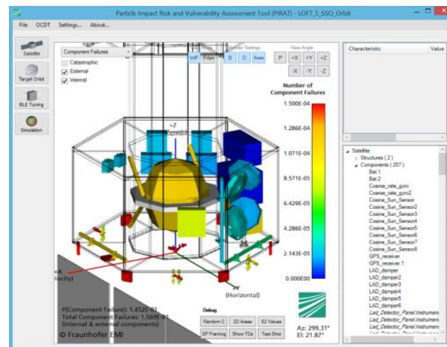
Fraunhofer EMI

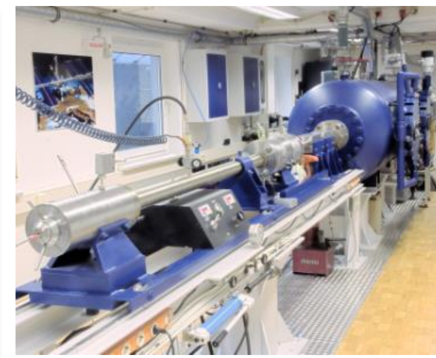
Study the dynamic behaviour of materials and structures under crash, impact and shock loads

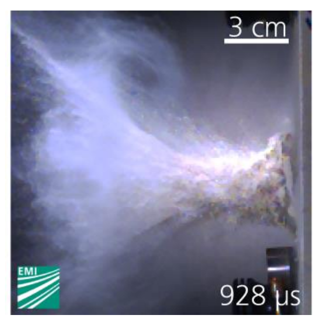
Spacecraft Technology Group

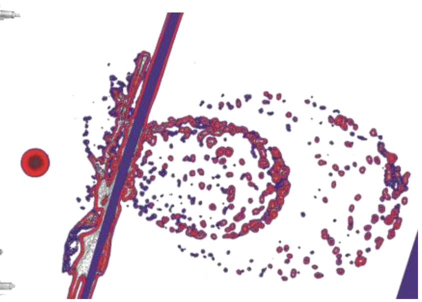
Experimental and numerical analysis of hypervelocity impact effects

- Space system shielding
- Component failure investigation
- Vulnerability analysis tools
- Asteroid impact research
- Fragmentation analysis





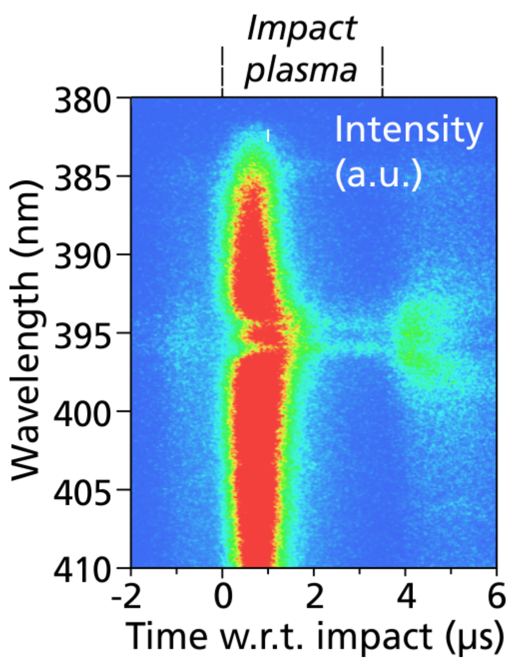


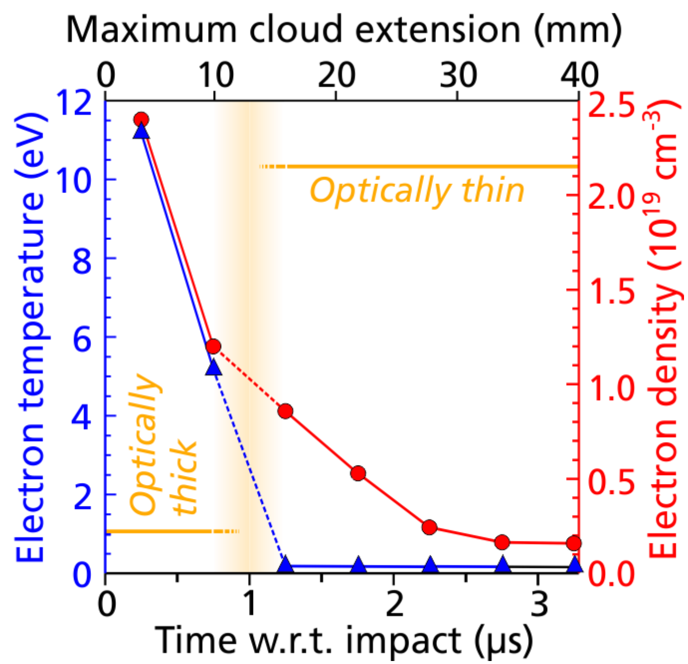


Fraunhofer EMI's Spacecraft Technology Group

Background on impact plasma

- Investigation of impact plasma induced discharges on solar arrays
- Measurement of impact plasma characteristics





Schimmerohn (2013)

Heunoske, Schimmerohn, Osterholz (2013)

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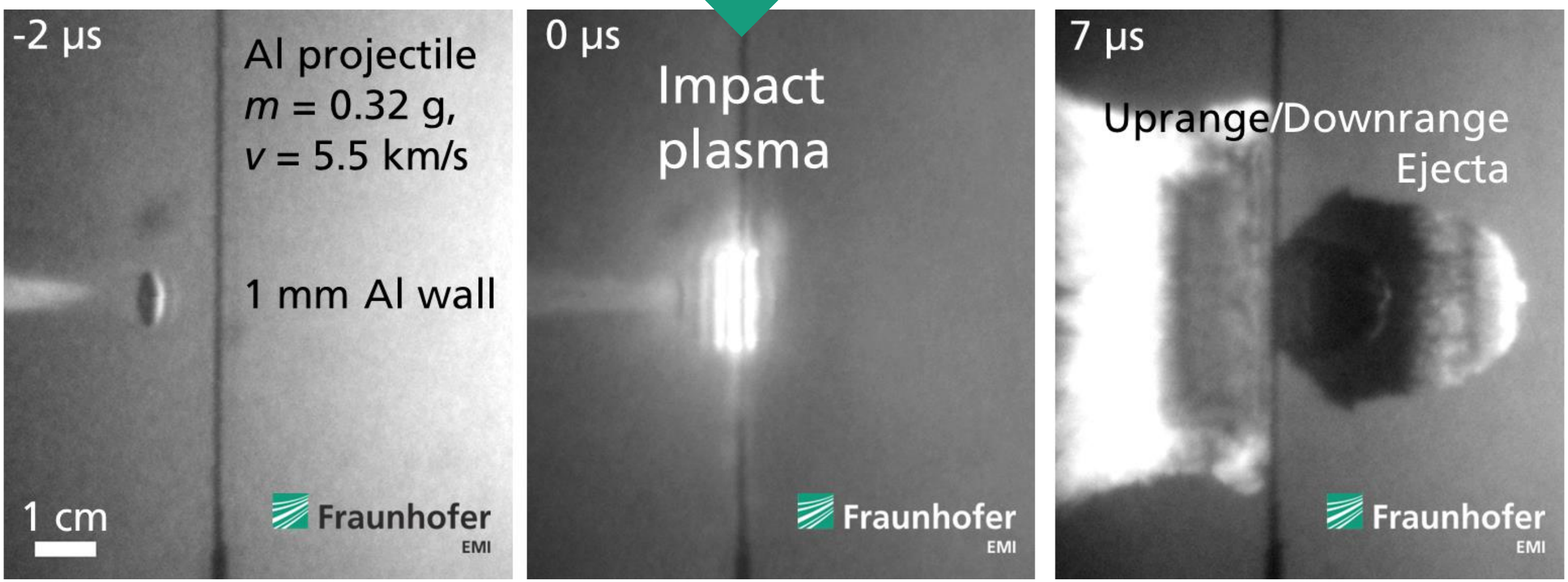
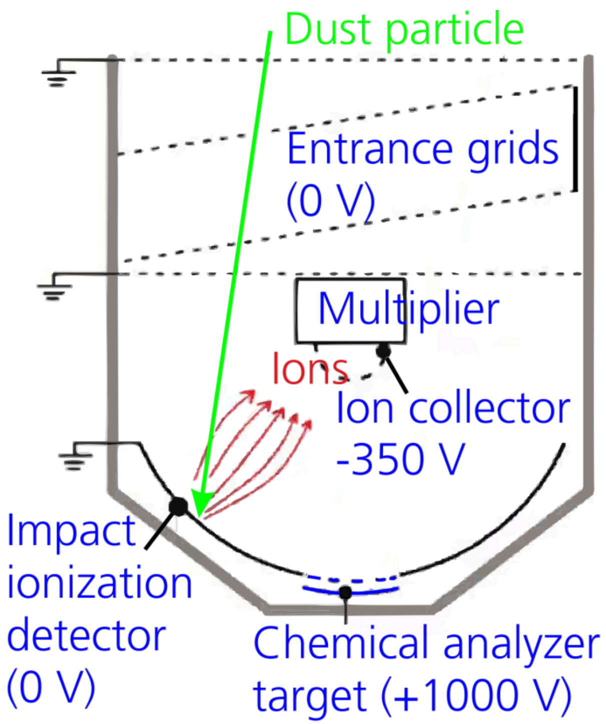
Motivation
Impact plasma

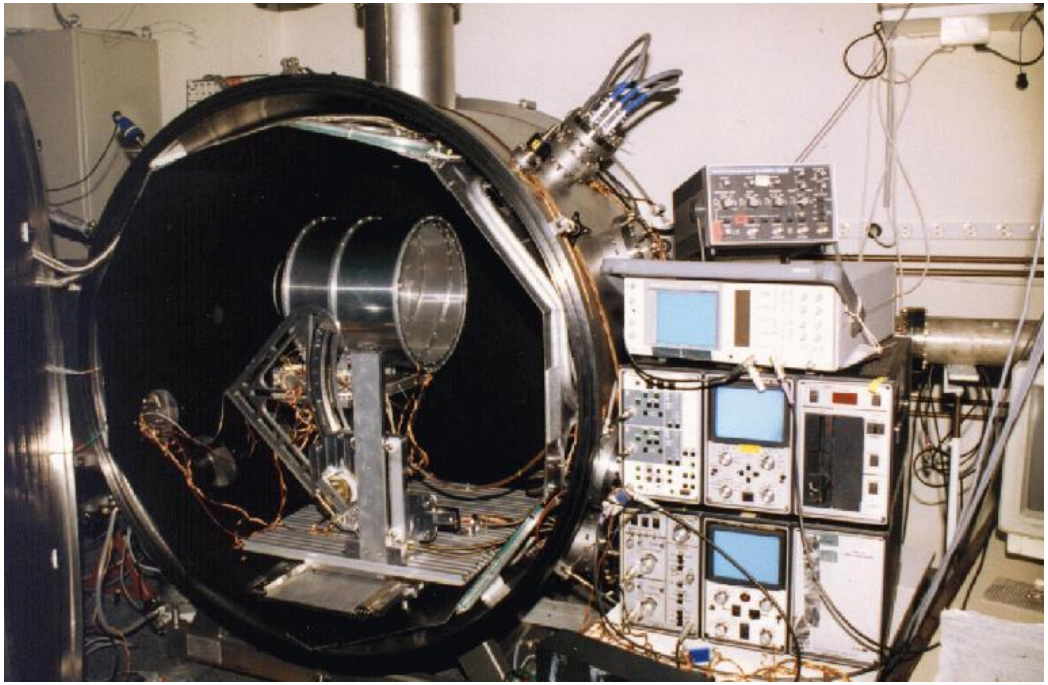
Initial conditions behind shock fronts:
temperature > 10^5 K, pressure > GPa



Motivation
Impact detection by plasma effects (1/2)

- Scientific charge detectors $Q = K \cdot m^{\alpha} \cdot v^{\beta}$





Cosmic Dust Analyzer, Cassini-Huygens *Stübig (2012)*

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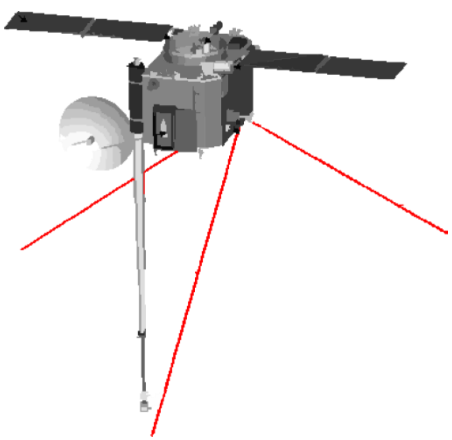
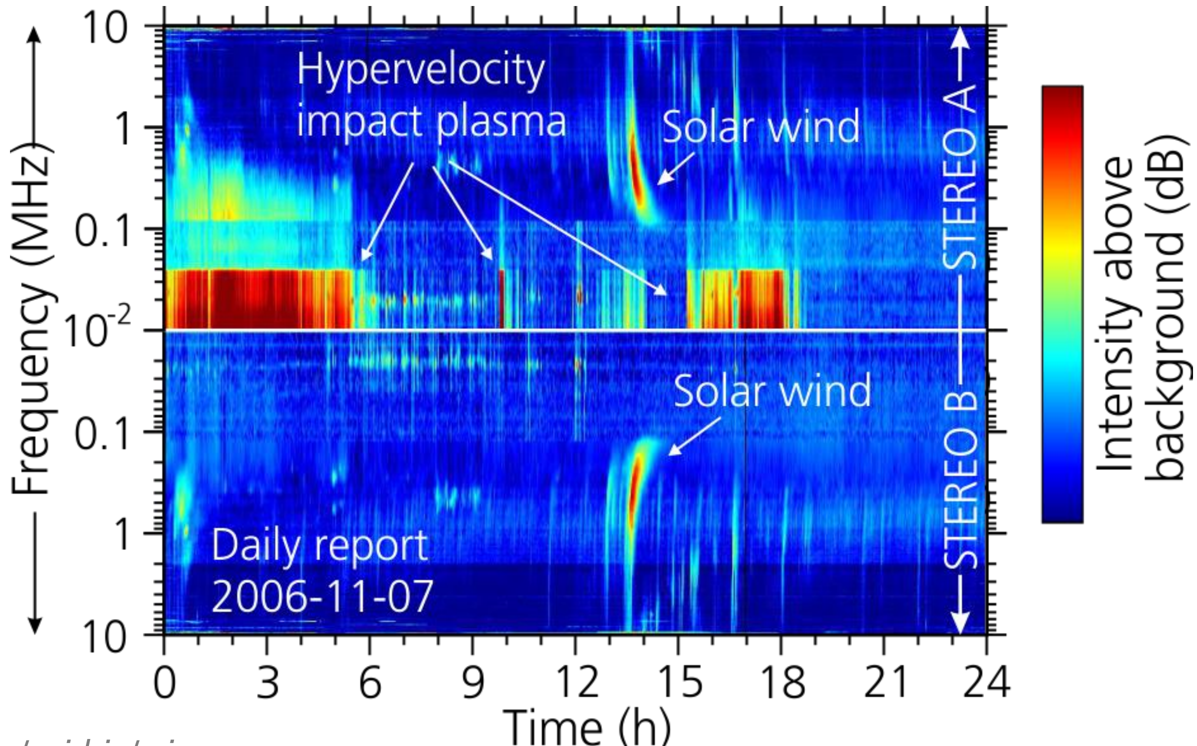
Motivation
Impact detection by plasma effects (2/2)

- Noise signals on plasma wave experiments





STEREO/WAVES
data from *http://swaves.gsfc.nasa.gov/cgi-bin/wimp.py*

Motivation
Study objectives and tasks

Study objective:

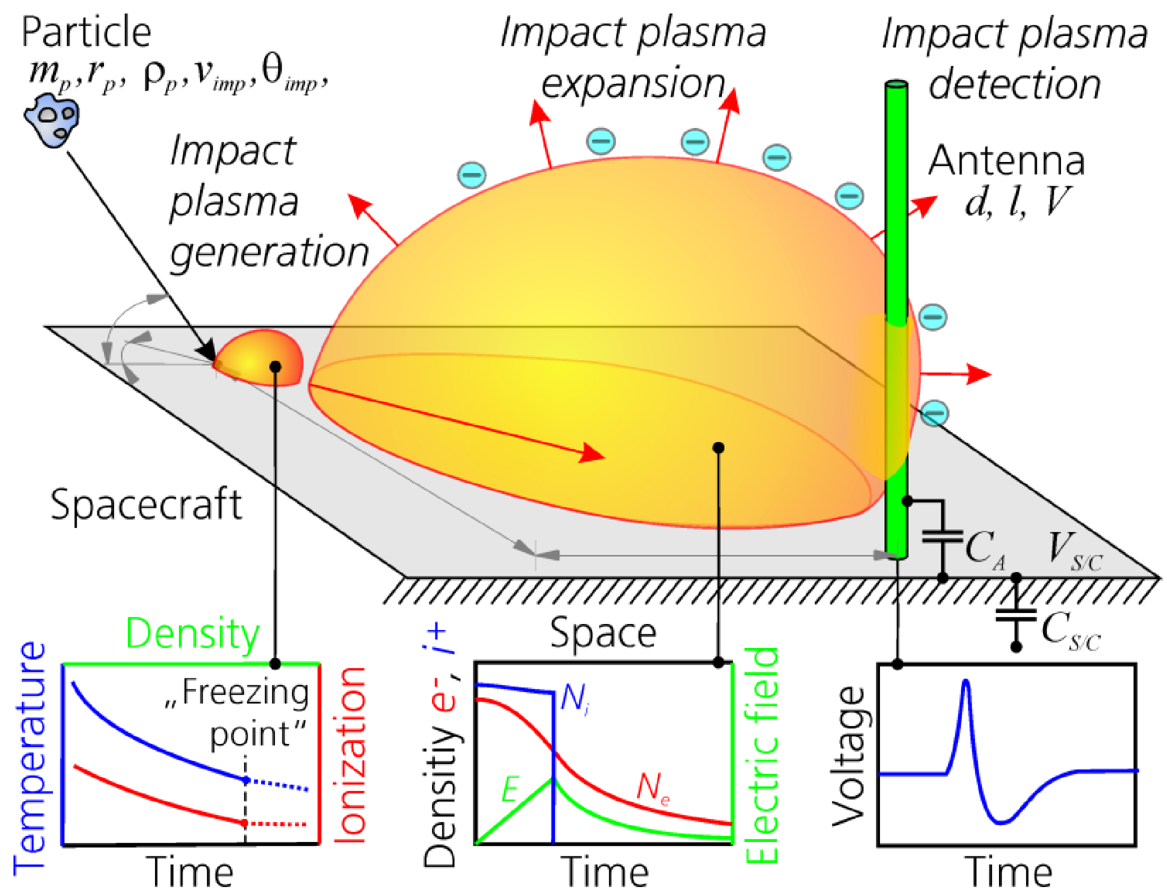
Assess the feasibility of, and the requirements for, being able to derive reliable quantitative information on the properties of microparticles (e.g. mass, velocity) with wave experiments.

Tasks:

1) Develop model for plasma generated by impact
2) Perform simulations to assess sensor response
3) Derive sensor requirements and outline roadmap

Modeling
Approach

1) Plasma generation
2) Characteristics of plasma cloud during expansion
3) Signal response of antenna interacting with plasma cloud



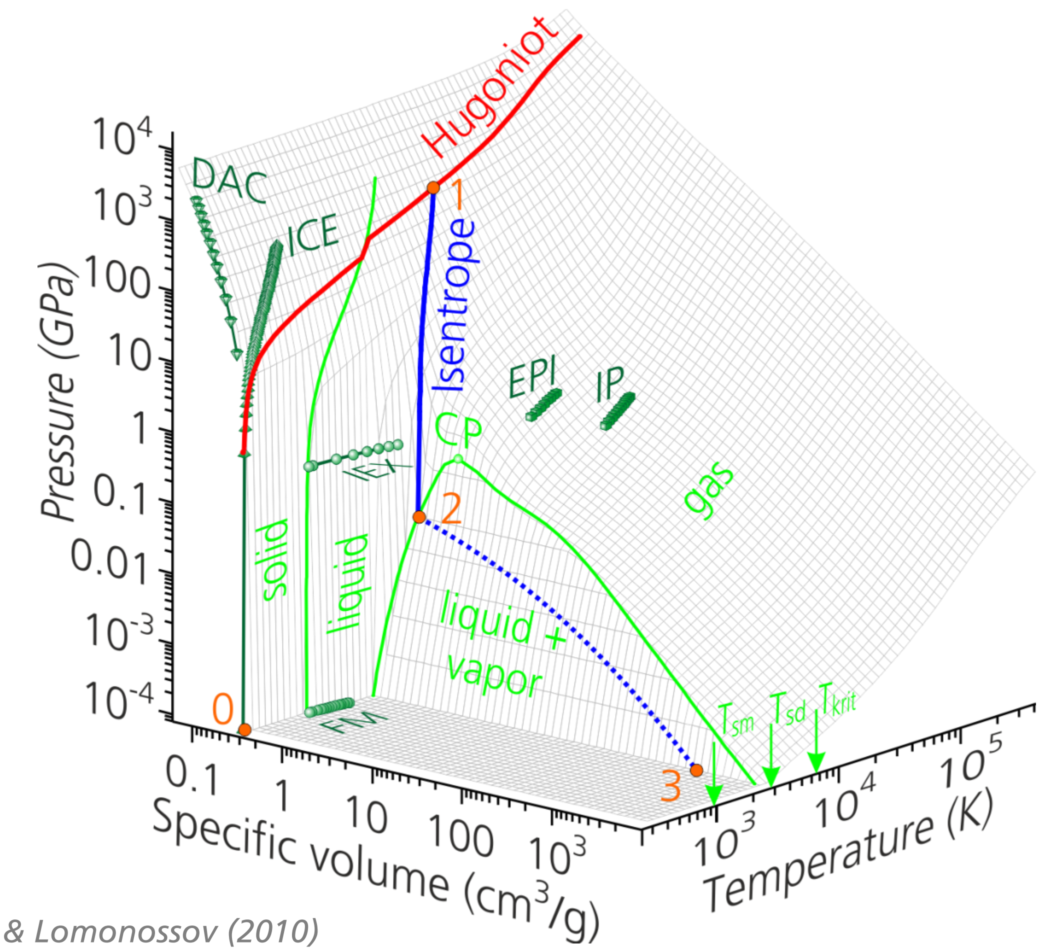
Modeling
Plasma formation regimes

1) **Thermal volume ionization (v_{imp} > 10-20 km/s)**
   - Dissociation and ionization of shocked material
   - Nominal model for this study based on approach by *Drapatz & Michel (1974)* and *Hornung (1981, 2000)*

2) **Surface ionization (v_{imp} < 10-20 km/s)**
   - Different qualitative but no quantitative models available
   - Study approach: Initial value problem using volume ionization model and empirical charge yield equations as boundary condition

Modeling
Plasma generation – shock state

- Semi-empirical model by *Sugita et al. (2012)* applied
- Specific heat most important modeling parameter

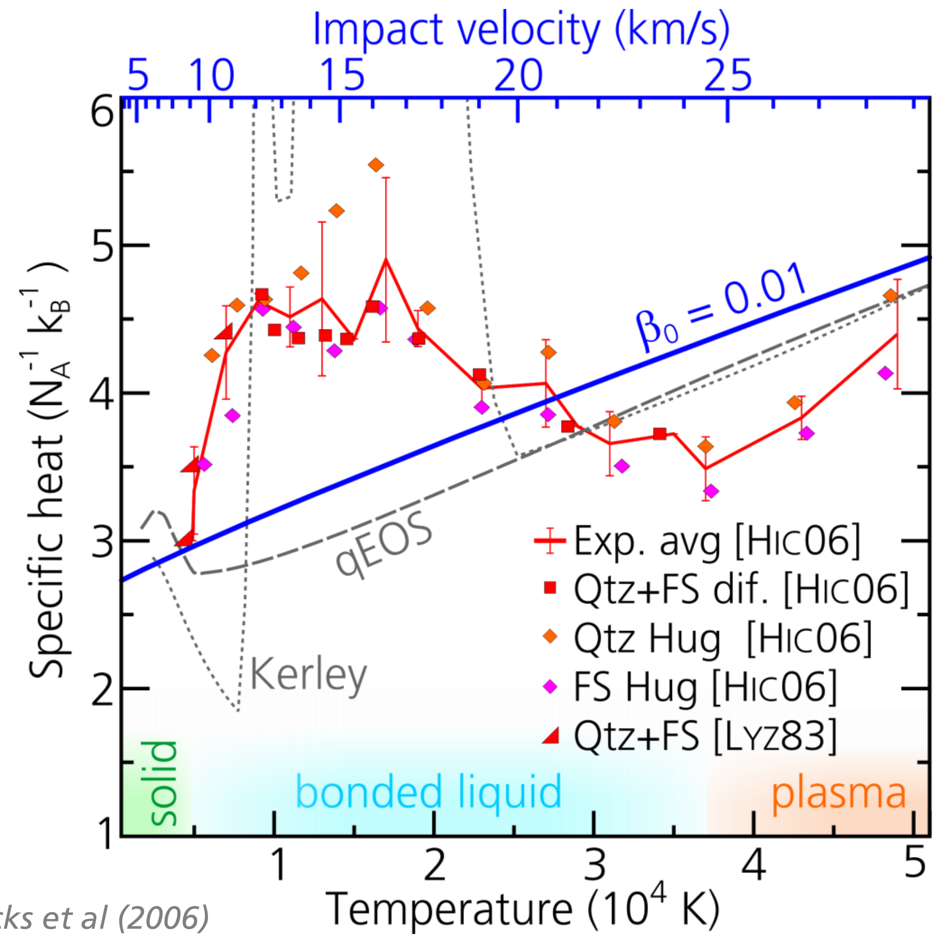


Al EOS surface from *Fortov & Lomonossov (2010)*

Modeling
Plasma generation – specific heat

- Tares dissipation of internal energy in temperature and entropy
- Electrons have high influence under extreme compressions
- Electron excitation processes act like endotherm reactions

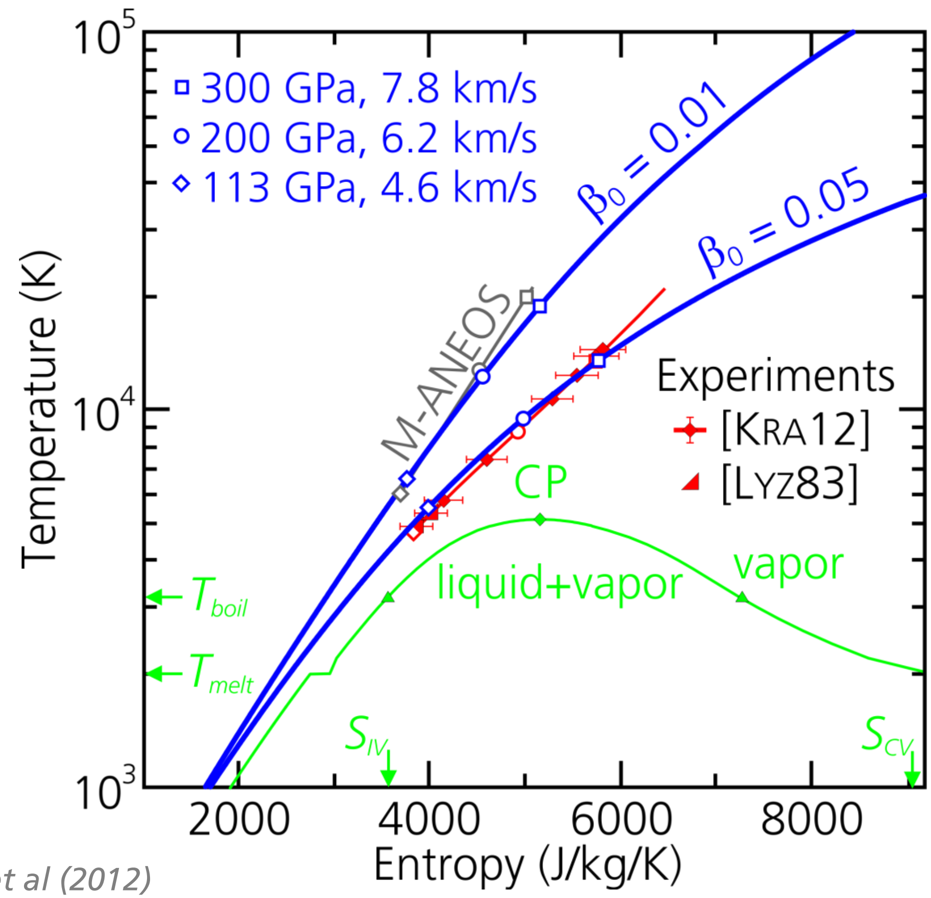
➡ Thomas-Fermi approach for free electron gas



Experimental and hydrocode data from *Hicks et al (2006)*

Modeling
Plasma generation – vaporization

- Isentropic decompression from shock state ($S_H = S_{gas}$)
- Entropy determines fraction of vaporized material of a finite volume shocked to a certain pressure

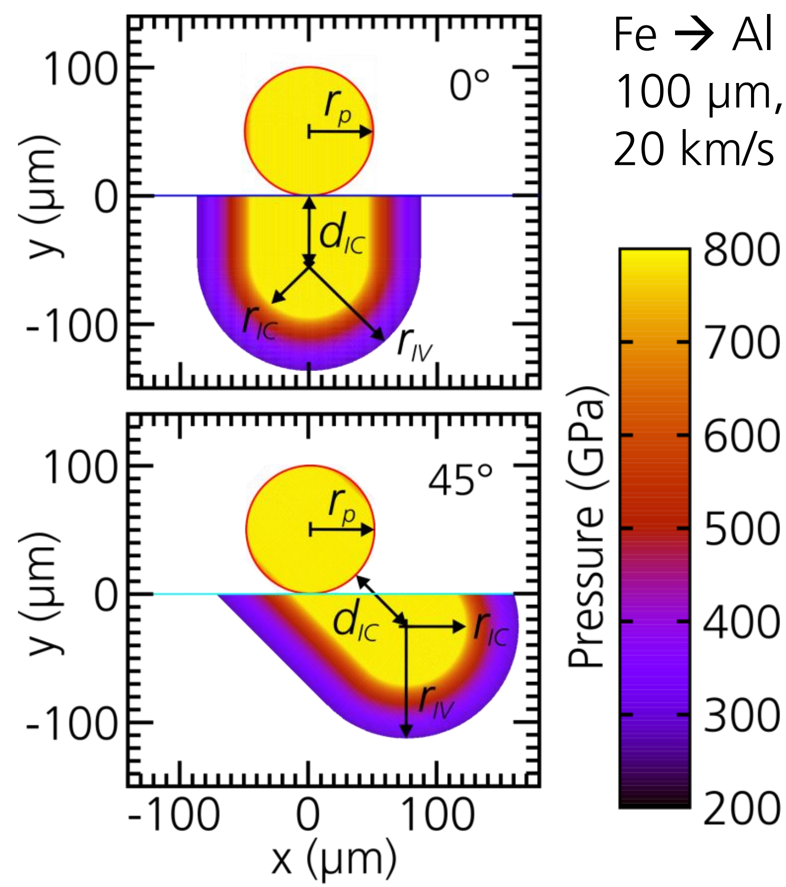


Reference data from *Kraus et al (2012)*

Modeling
Plasma generation – gas cloud formation

- Simplified geometric model of pressure contour with semi-empirical pressure decay law
- Mixing of vapors and averaging of states

➡ Idealized monoatomic gas

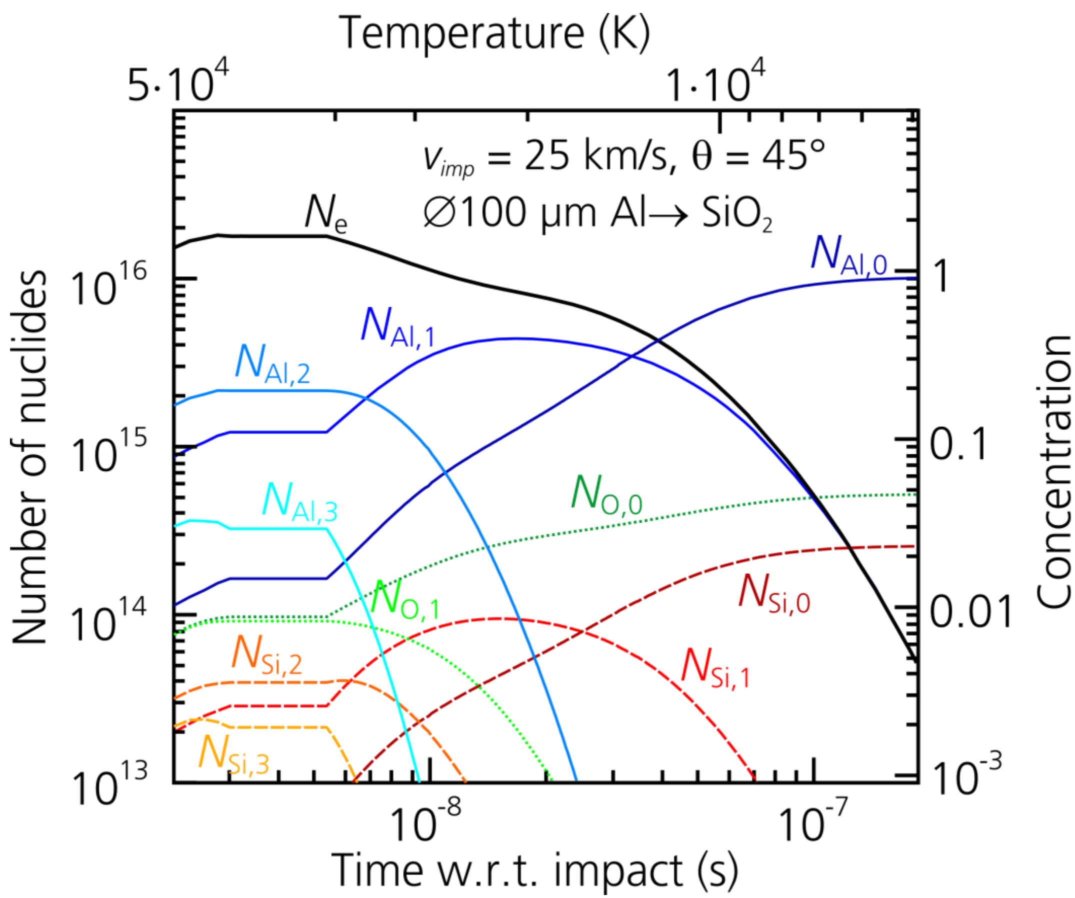


Modeling

Plasma cloud characteristics – ionization (1/2)

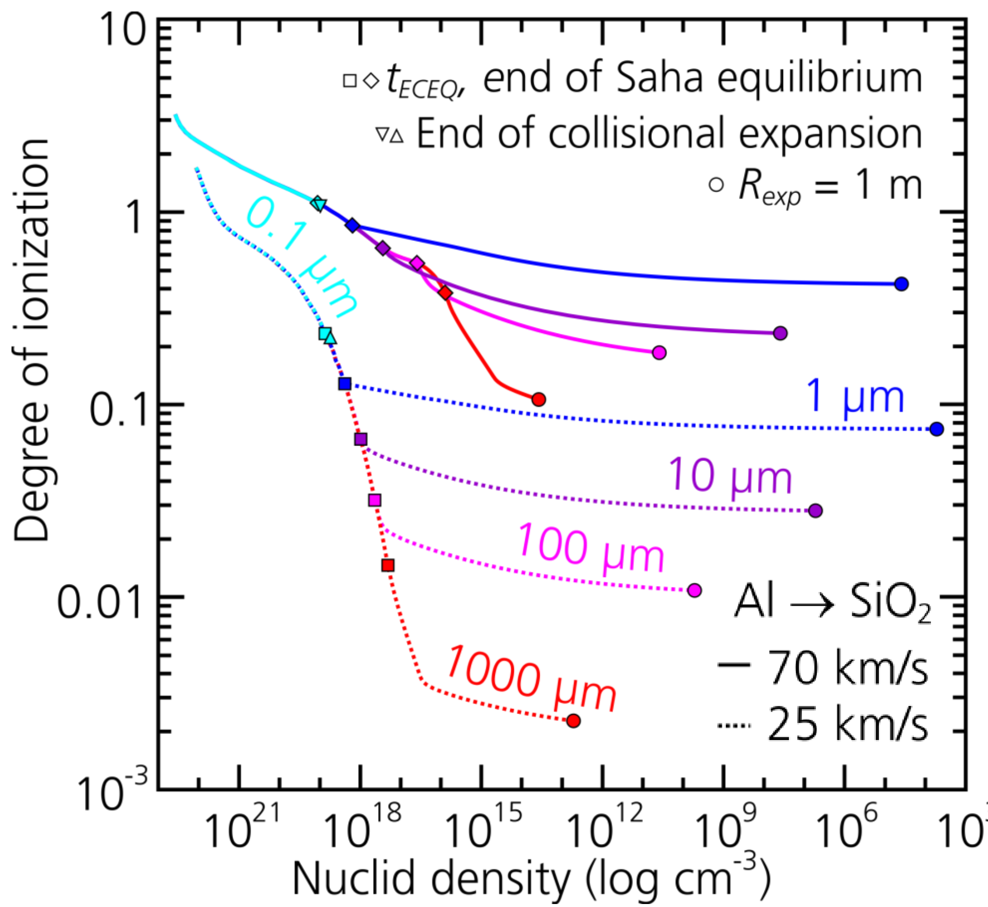
Saha equilibrium ionization for early plasma cloud

- Mixture concentrations
- Ionization potential lowering
- Canonical partition functions



Modeling
Plasma cloud characteristics – ionization (2/2)

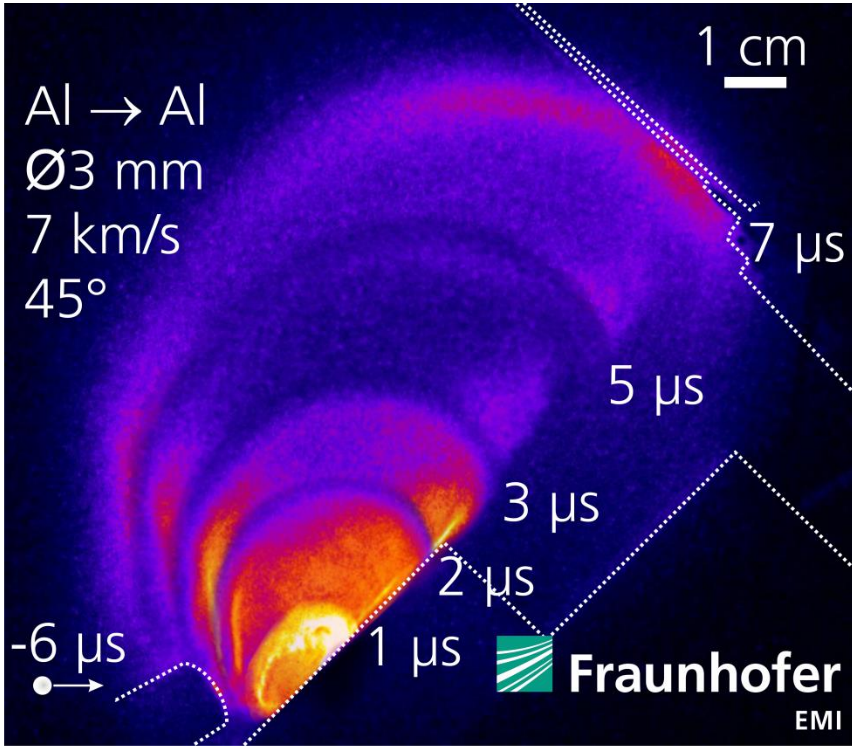
Non-equilibrium recombination according to *Kuznetsov & Raizer (1965)*



Modeling
Plasma cloud characteristics – expansion (1/3)

Spatial and temporal evolution of plasma cloud

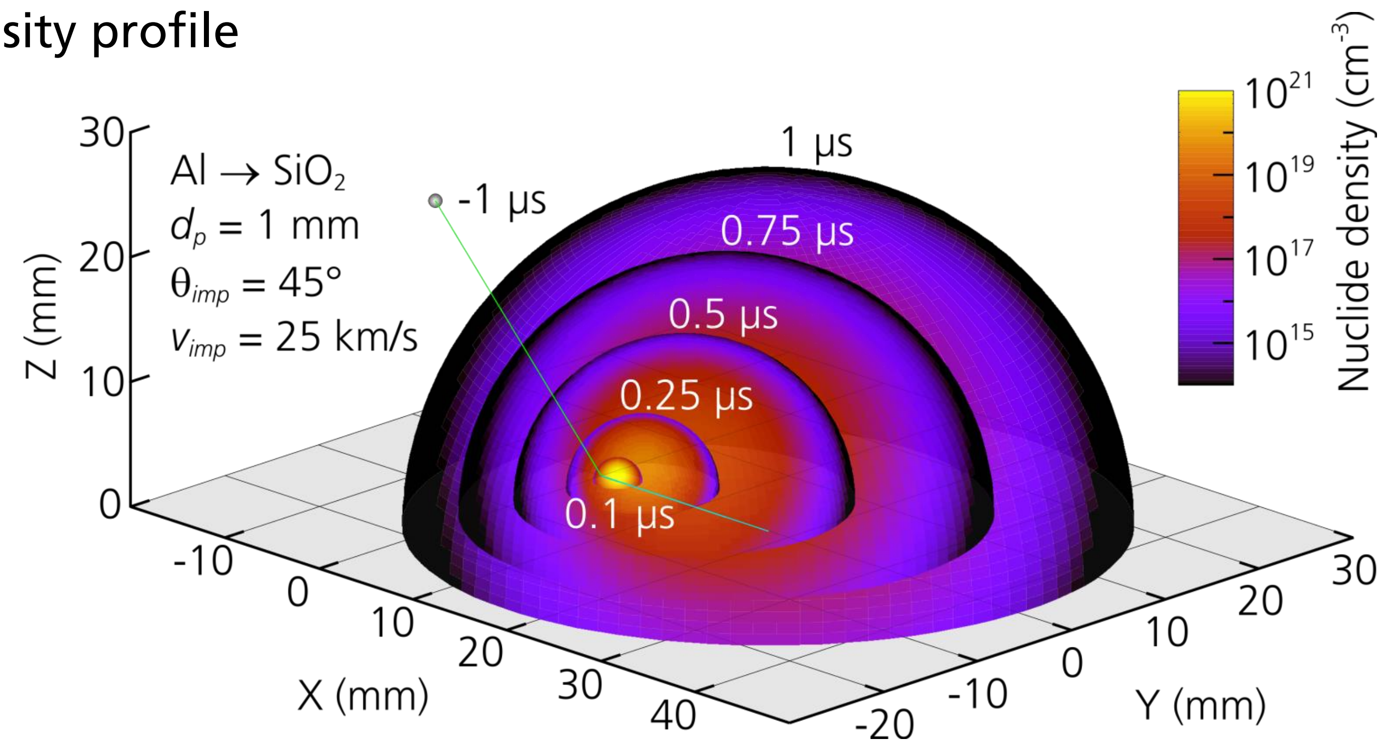
- Semi-spherical cloud boundary
- Self-similarity (geometric scale invariance)
- Spherical symmetry
- Isentropic expansion
- Horizontal velocity component



Modeling
Plasma cloud characteristics – expansion (2/3)

Collisional expansion

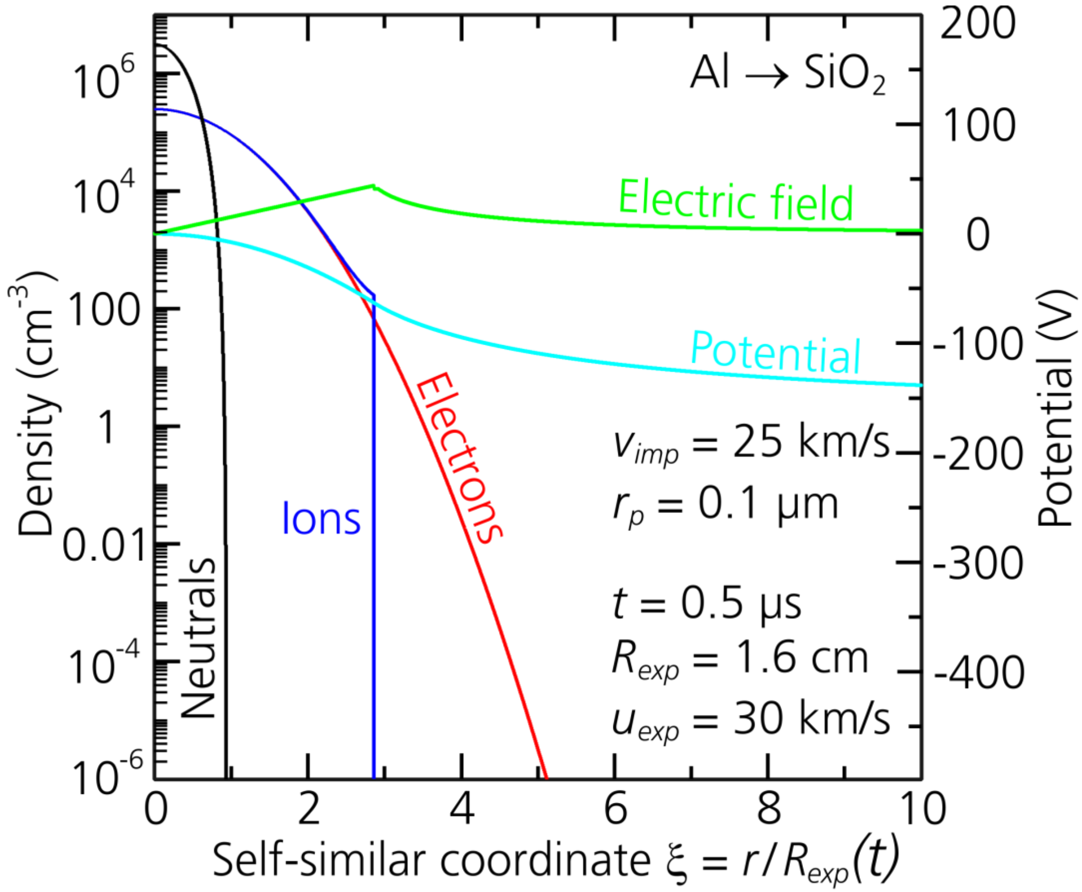
- Constant asymptotic expansion velocity
- Gaussian density profile



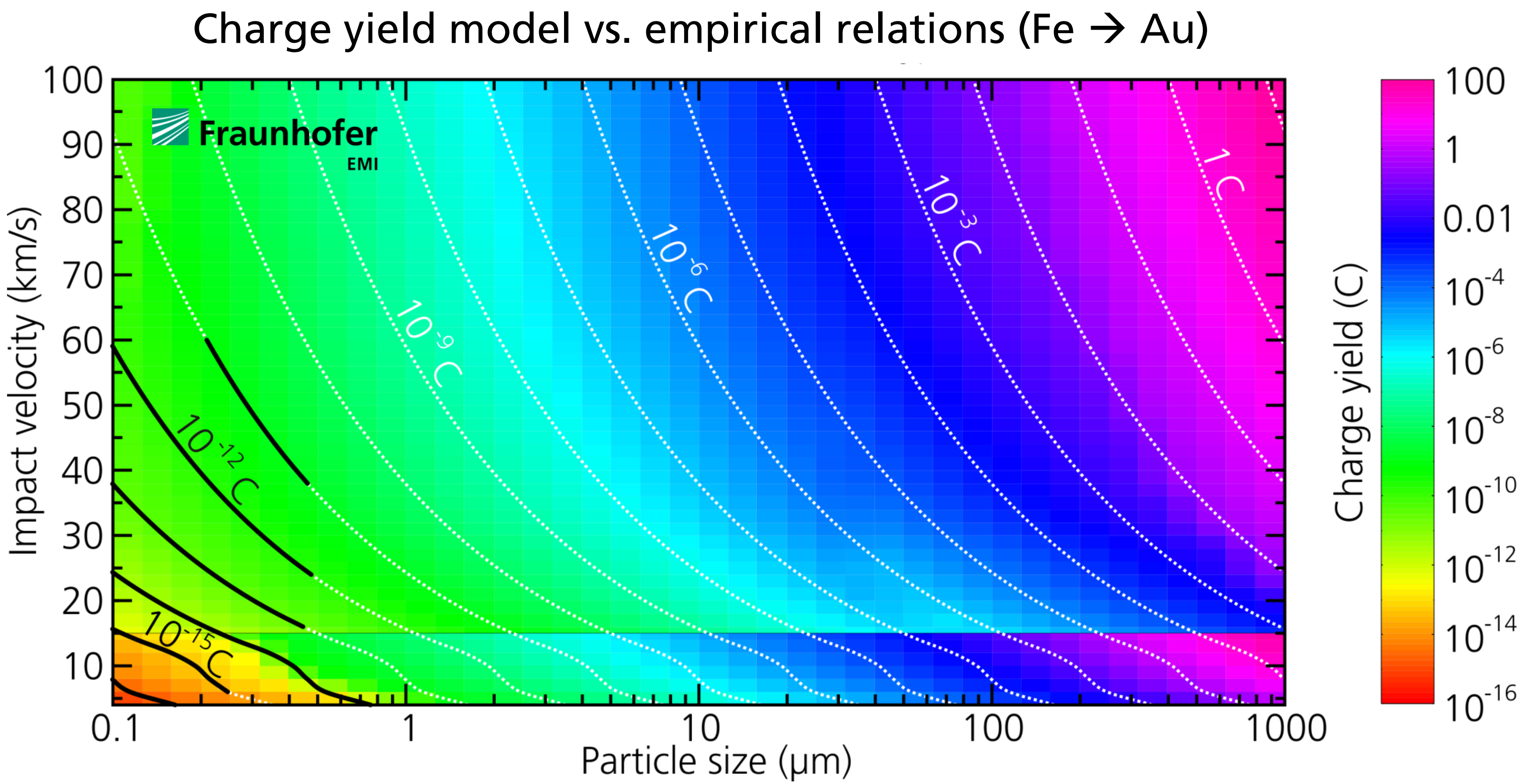
Modeling
Plasma cloud characteristics – expansion (3/3)

Collisionless expansion

- Charge separation at cloud boundary

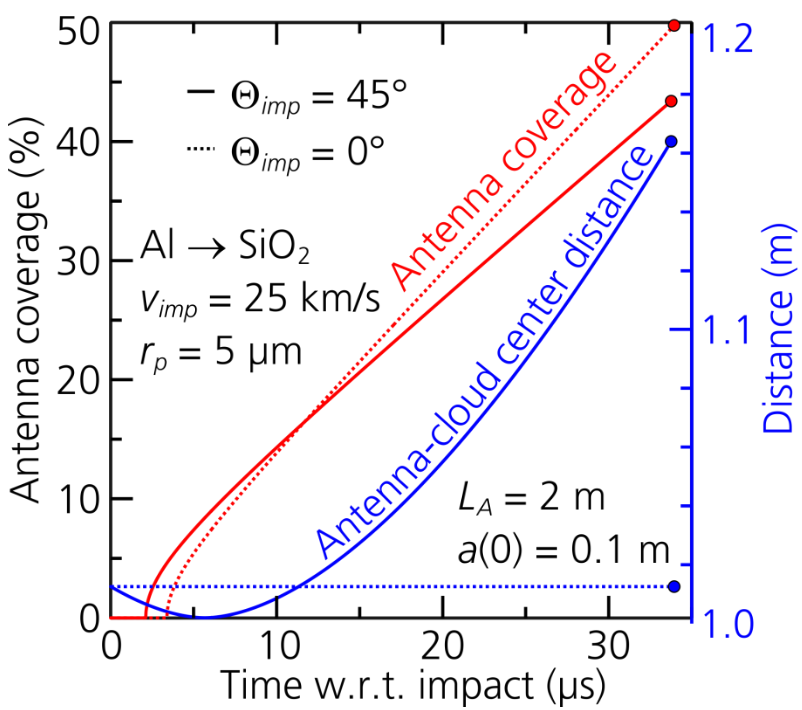


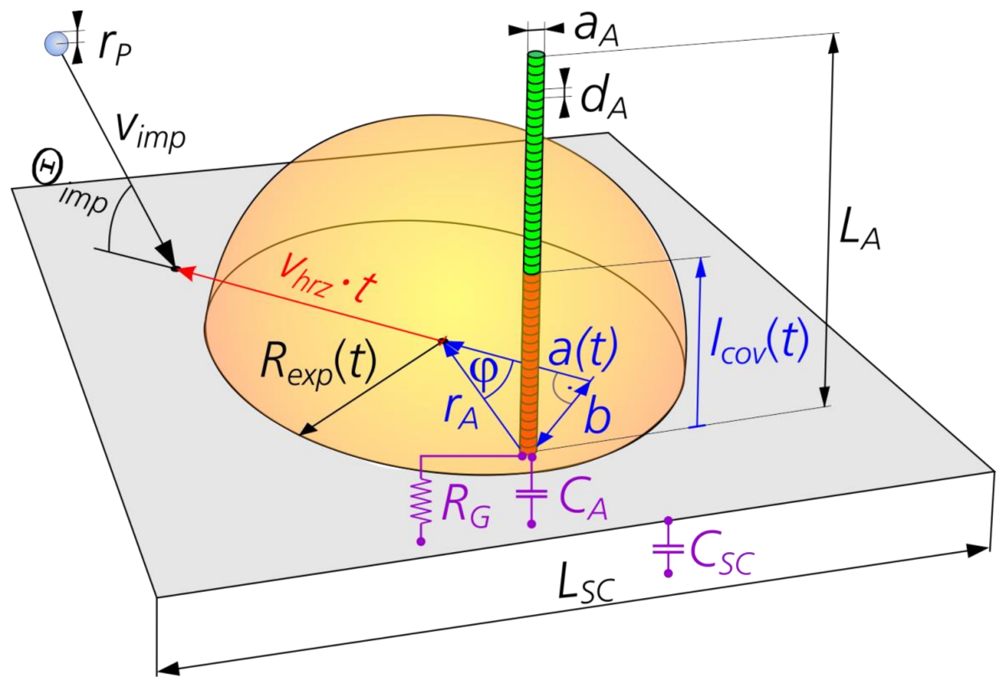
Modeling
Plasma model validation



Modeling
Antenna

- Direct collection of cloud charges at antenna or by spacecraft
- Disturbance of antenna potential





Modeling
Signal generation (1/2)

1) Direct sampling of cloud electrons at antenna
2) Indirect detection of charges recollected by spacecraft potential
3) Suppression of photo return current according to *Pantellini et al. (2012)*
4) Secondary electron emission at antenna through plasma cloud using standard SEE model according to *Dionne (1975), Whipple (1981)*

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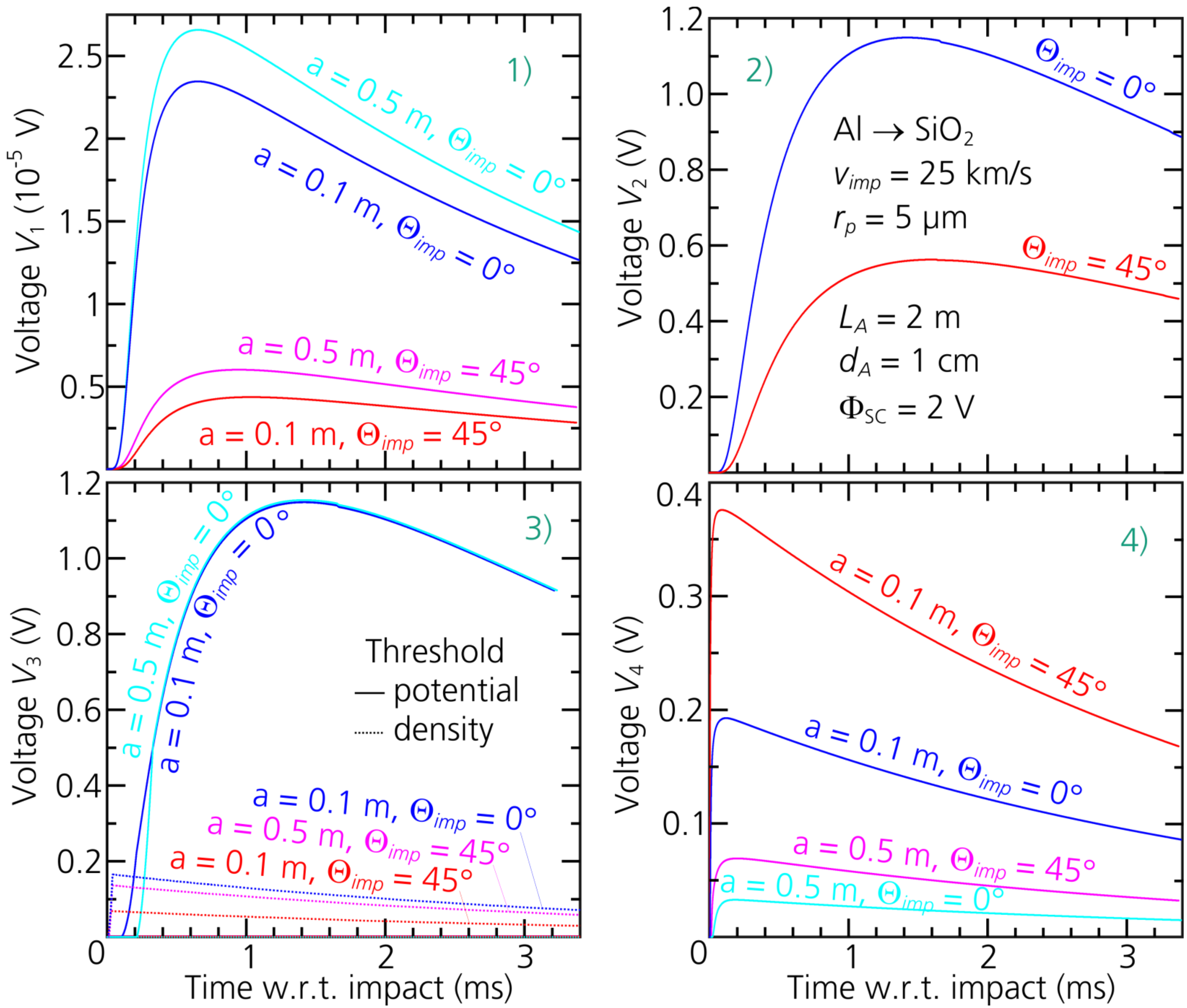
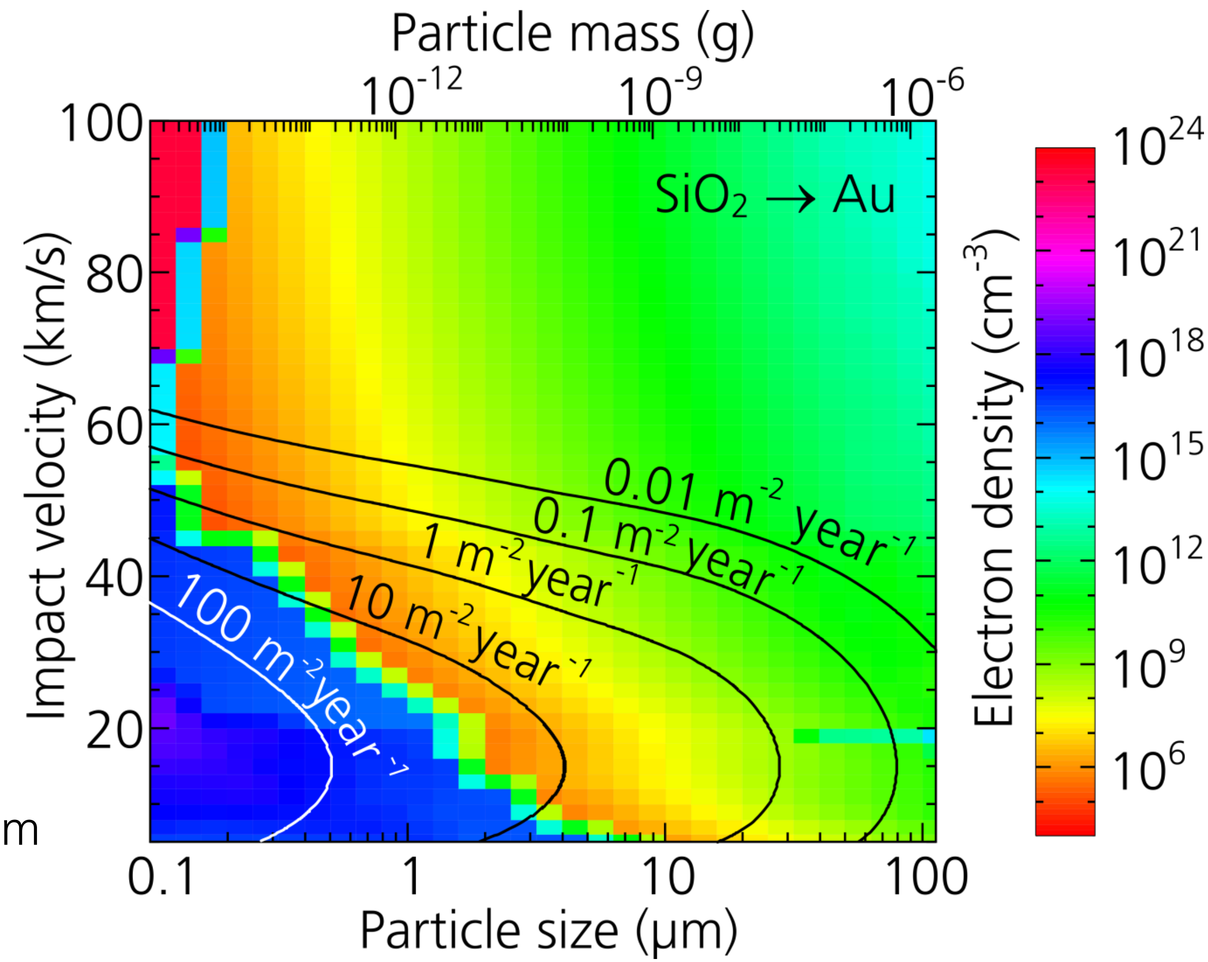
Modeling
Signal generation (2/2)

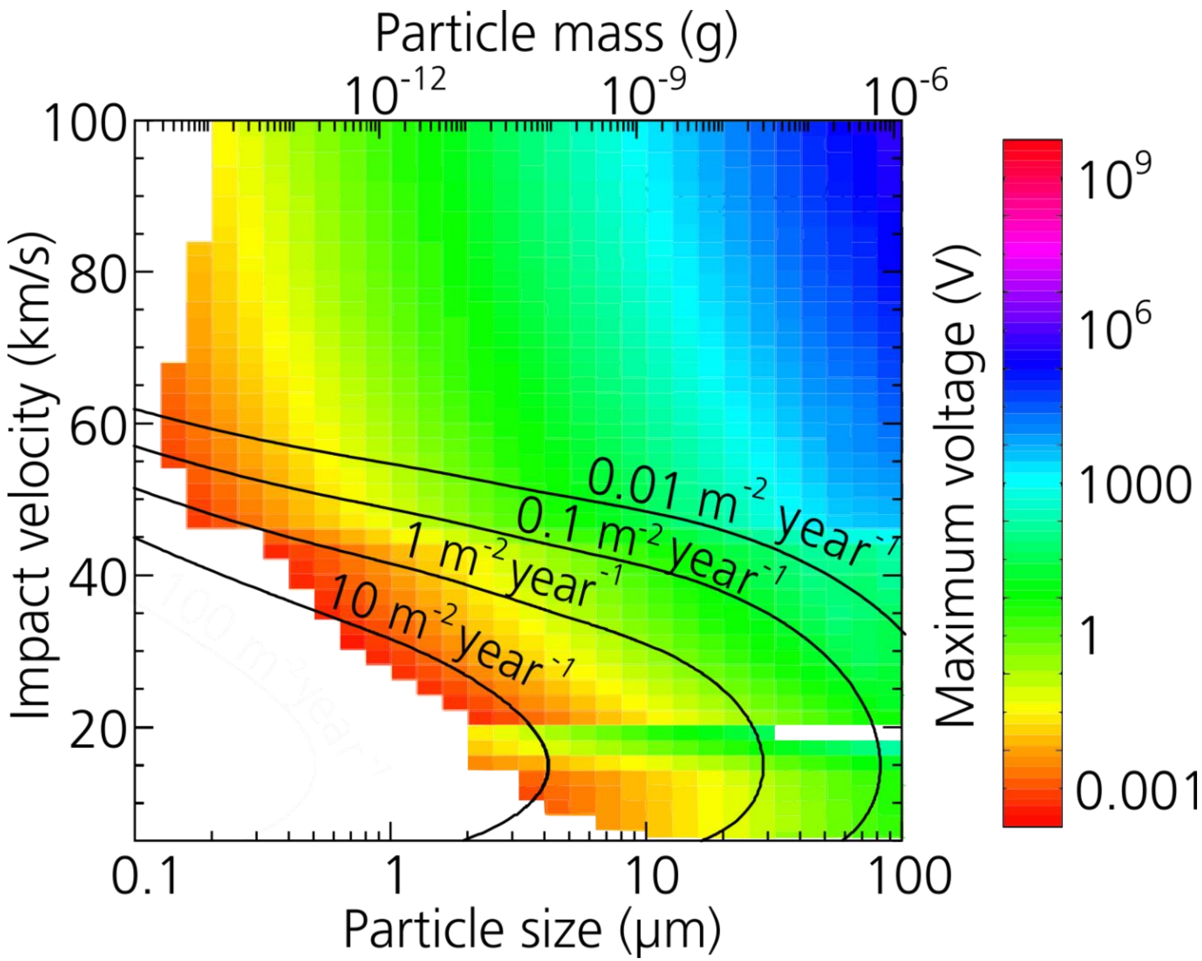


Analysis
Impact plasma

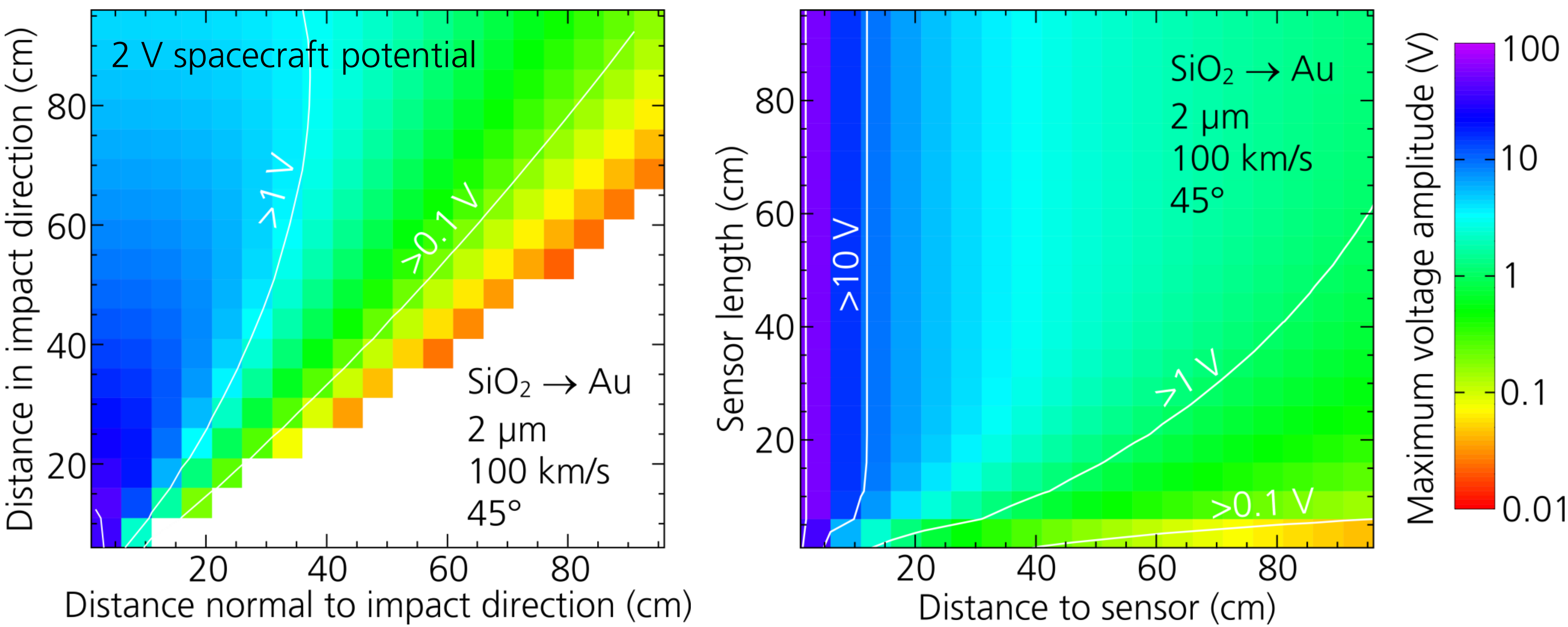


R_{cloud} = 10 cm

Analysis
Voltage amplitudes



Analysis
Sensor configuration



Conclusions and outlook

Fraunhofer EMI is currently investigating the feasibility of impact detection using antennas as simple charge detectors

- A comprehensive impact plasma model has been developed and implemented as software
- Simulations and parametric analysis of antenna configurations and impact parameter correlation are currently ongoing
- Sensor feasibility will be evaluated until end of June (project end)

Modeling
Plasma cloud characteristics – time scales