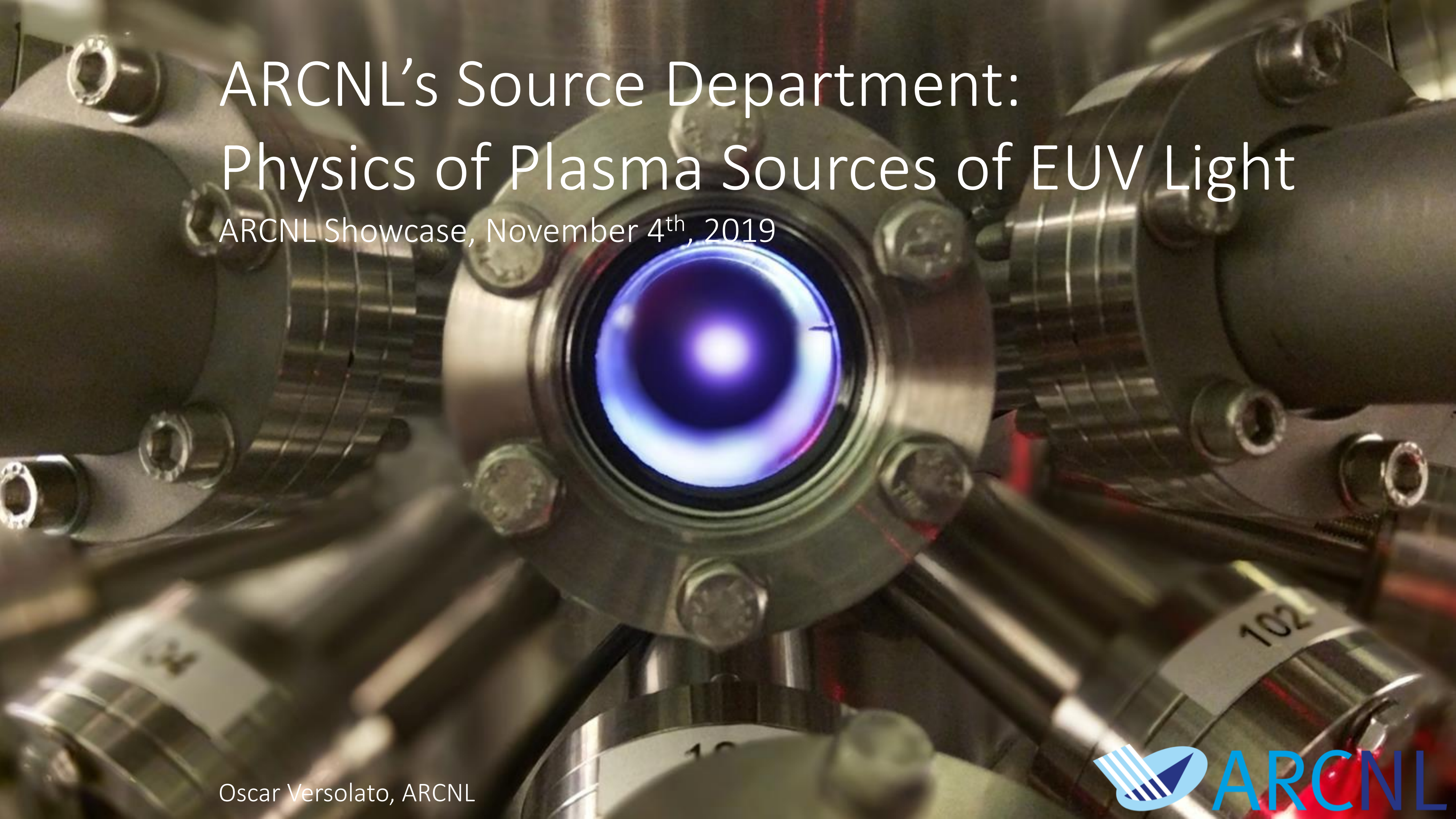
ARCNL’s Source Department: Physics of Plasma Sources of EUV Light

ARCNL Showcase, November 4th, 2019



Oscar Versolato, ARCNL

ARCNL

Team

ARCNL EUV Plasma Processes group:

Dmitry Kurilovich (ASML scientist)
Francesco Torretti (PhD, now at ASML)
Joris Scheers (PhD) talk S111
Subam Rai (PhD, RUG) talk S108
Ruben Schupp (PhD)
Jaap Hermens (TU/e MSc)
Job Duffhues (TU/e MSc)
Zoi Bouza (TKI PhD)
Bo Liu (VIDI PhD) talk S72
Lars Benhke (VIDI PhD) poster S77
Lucas Poirier (ERC PhD) poster S84
Javier Hernández (ERC PD)
Laurens van Buuren (technician)
Ronnie Hoekstra (group leader) talk S81
Wim Ubachs (group leader)
Oscar Versolato (group leader; dept. head) this talk S104

ARCNL EUV G&I group:

Tiago de Faria Pinto (PhD, now STFC)
Randy Meijer (PhD) talk S109
Zeudi Mazzotta (PD) poster S74
Jan Mathijssen (PhD) poster S56
Stefan Witte (group leader) talk S51
Kjeld Eikema (group leader)

SOURCE Plasma modeling team

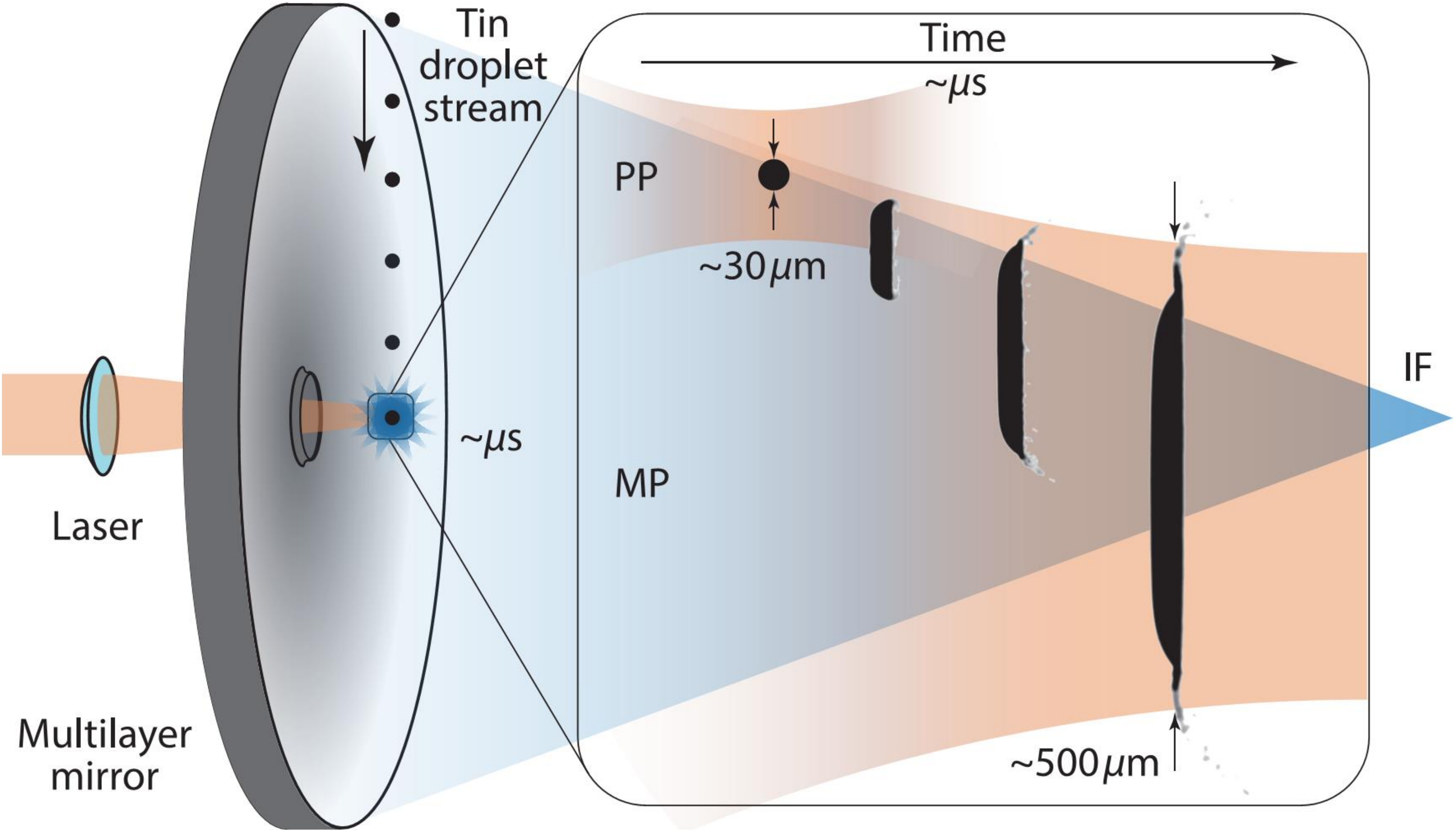
John Sheil (PD) talk S91
Diko Hemminga (PhD)

Academic collaborators:

A. Klein (UT, ASML)
S. Reijers (UT)
H. Gelderblom (TU/e) talk S71
J.R. Crespo López-Urrutia (MPIK)
H. Bekker (MPIK, now Col. Uni. NY)
A. Ryabtsev (ISAN)
M. Basko (KIAM, ISAN)
A. Borschevsky (Uni. Groningen)
J. Berengut (UNSW Australia)
Muharrem Bayraktar (Uni. Twente) poster S35
Fred Bijkerk (Uni. Twente)
James Colgan (LANL) talk S82

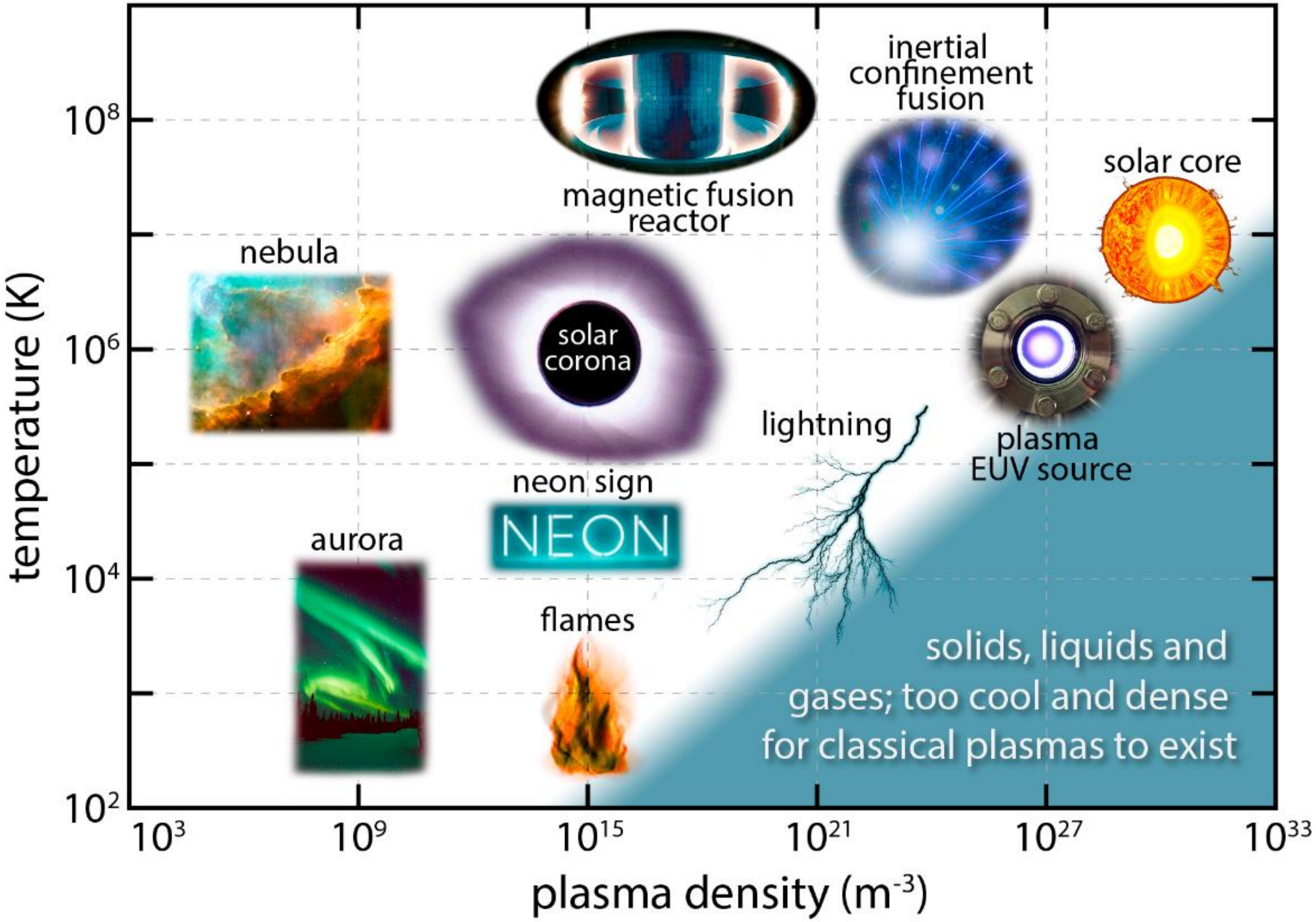
NWO erc AMOLF Universiteit van Amsterdam VU Vrije Universiteit Amsterdam Gemeente Amsterdam Provincie Noord-Holland ASML

Laser-produced plasma for nanolithography



D. Kurilovich, PhD thesis (2019); O. Versolato, PSST Topical Review **28**, 083001 (2019)

Position in the plasma universe



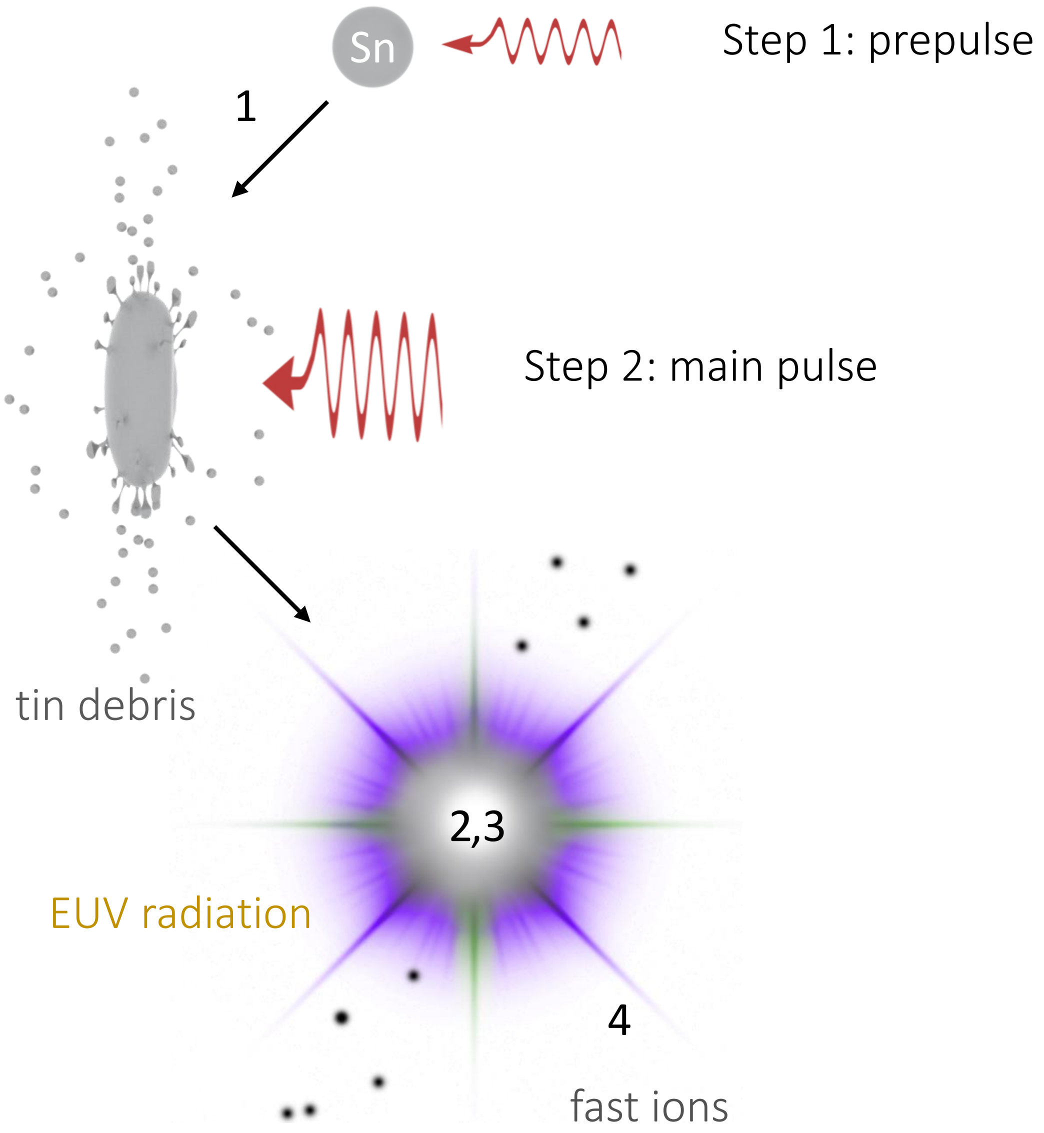
RALEF: talk S91

Nd:YAG (ARCNL)	CO_2 (ASML)
$\lambda = 1\mu m$	$\lambda = 10\mu m$
$T \sim 30eV$	$T \sim 25eV$
$n_e \sim 10^{21} e/cm^3$	$n_e \sim 10^{19} e/cm^3$
$Z \sim 12$	$Z \sim 12$

$$n_e \sim \lambda^{-2}$$

O. Versolato, PSST Topical Review **28**, 083001 (2019)

Physics challenges



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   - What determines deformation and fragmentation?
2. Key insights to enable source predictive modeling
   - What emits that EUV light?
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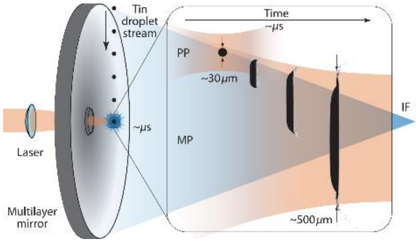
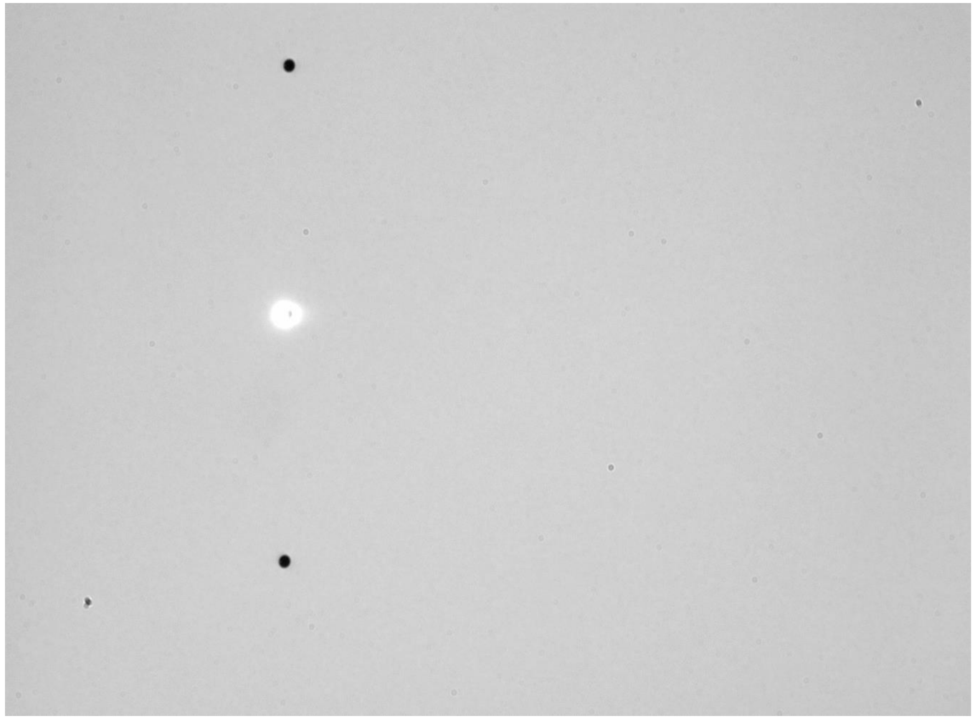
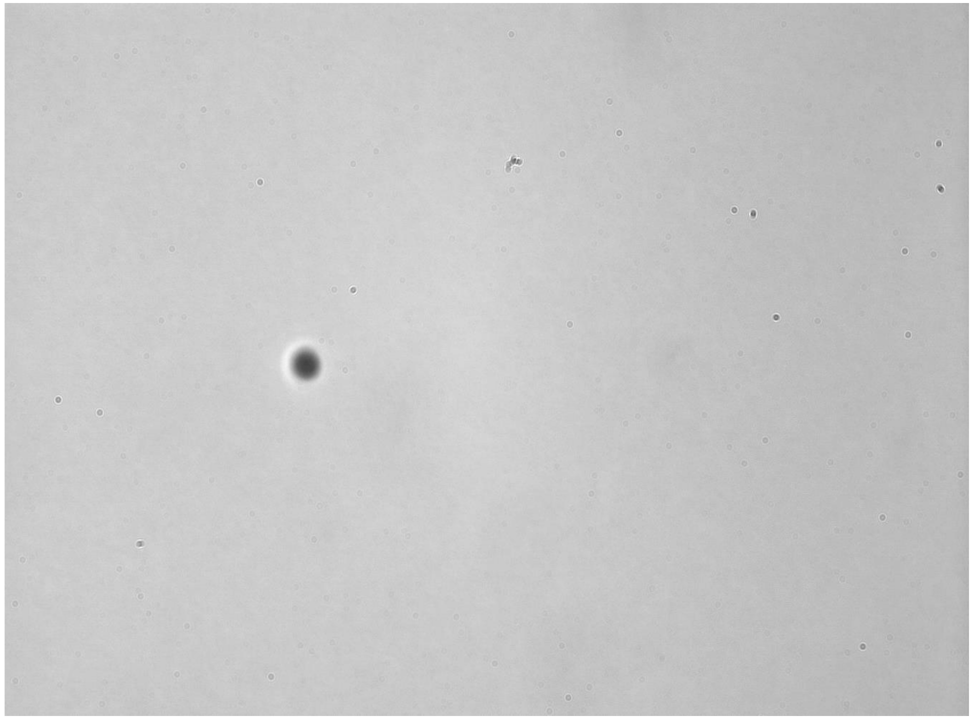
Mass loss from a stretching semi-transparent sheet of liquid tin

talk S72

talk S71



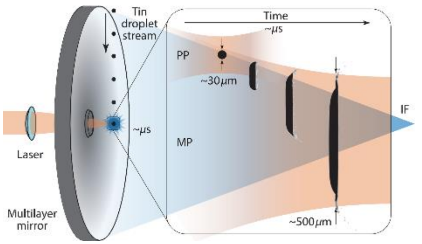


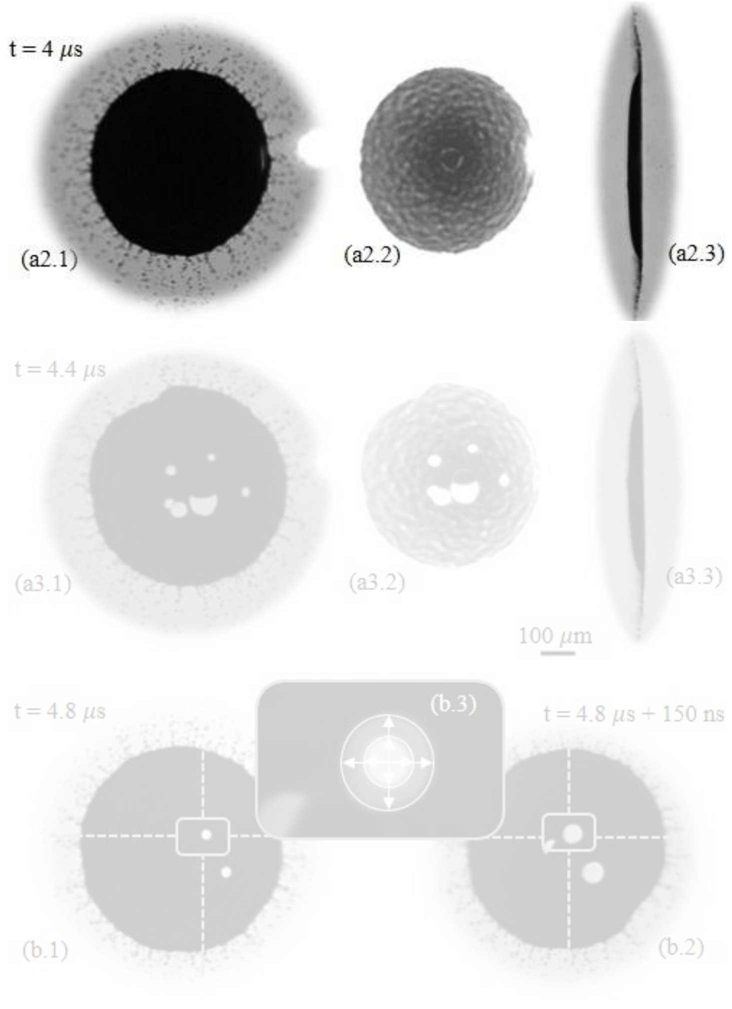


B. Liu et al, *submitted* , A. Klein et al, *submitted*; D. Kurilovich et al, Phys. Rev. Appl. **6**, 014018 (2016);
S. Reijers et al, J. Appl. Phys. **124**, 013102 (2018); D. Kurilovich et al, Phys. Plasmas **25**, 012709 (2018); Phys. Rev. Appl.**10**, 054005 (2018)

Mass loss from a stretching semi-transparent sheet of liquid tin

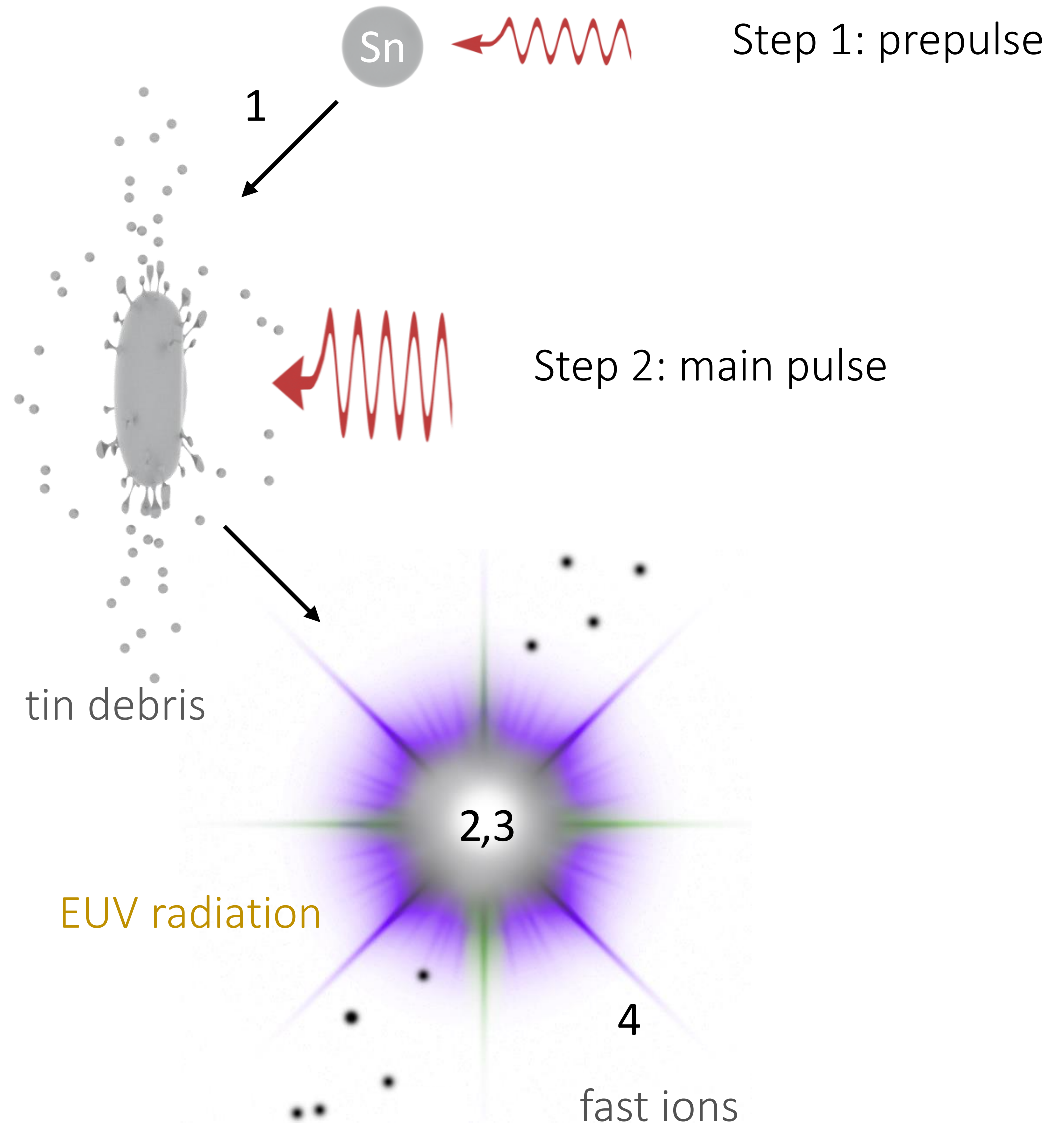
talk S72





B. Liu et al., *submitted*

Physics challenges



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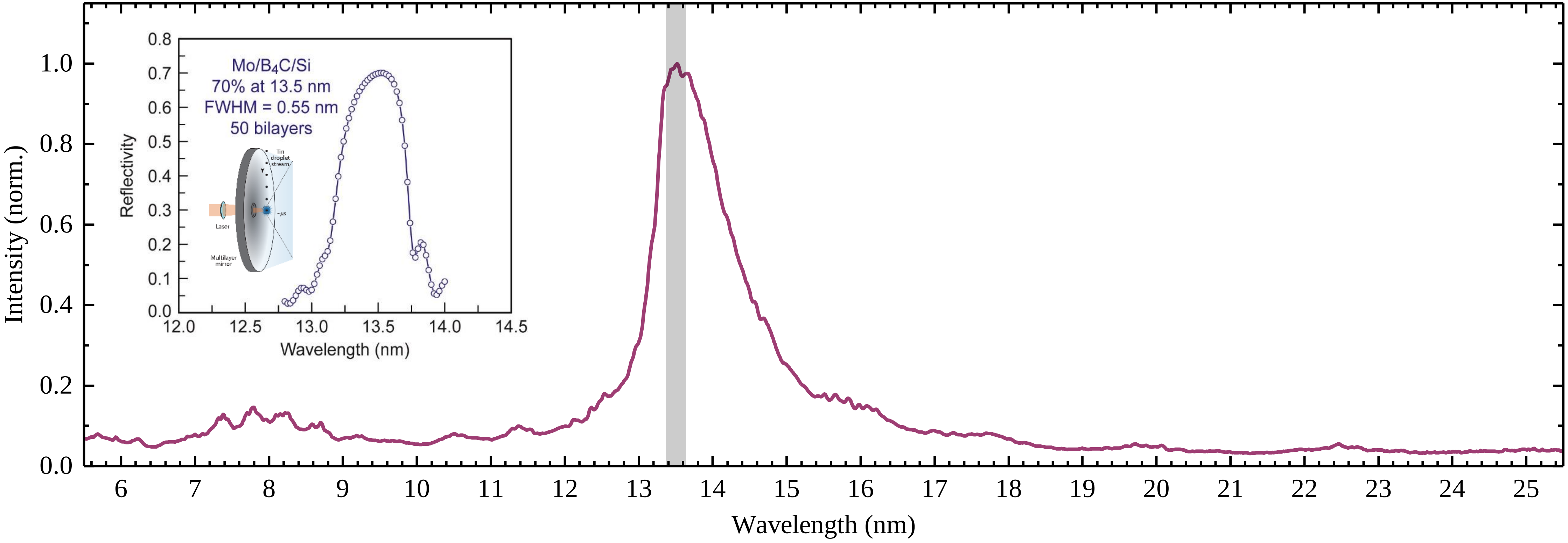
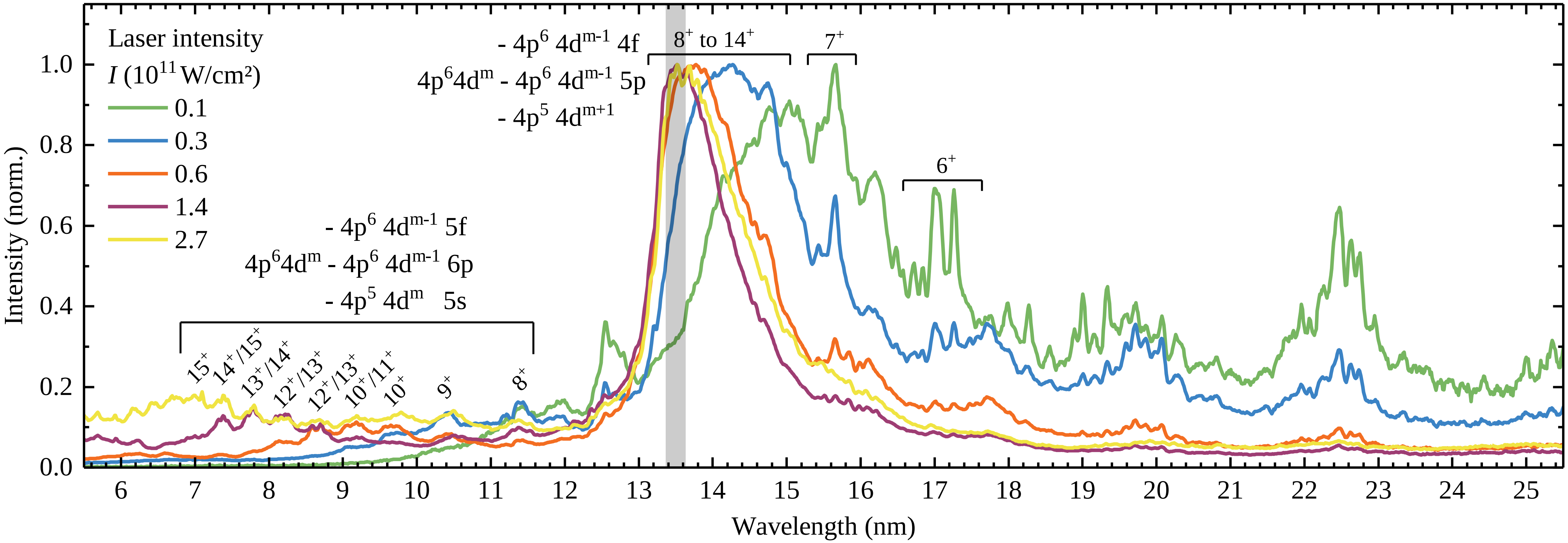
Spectrum of YAG-laser-driven tin plasma



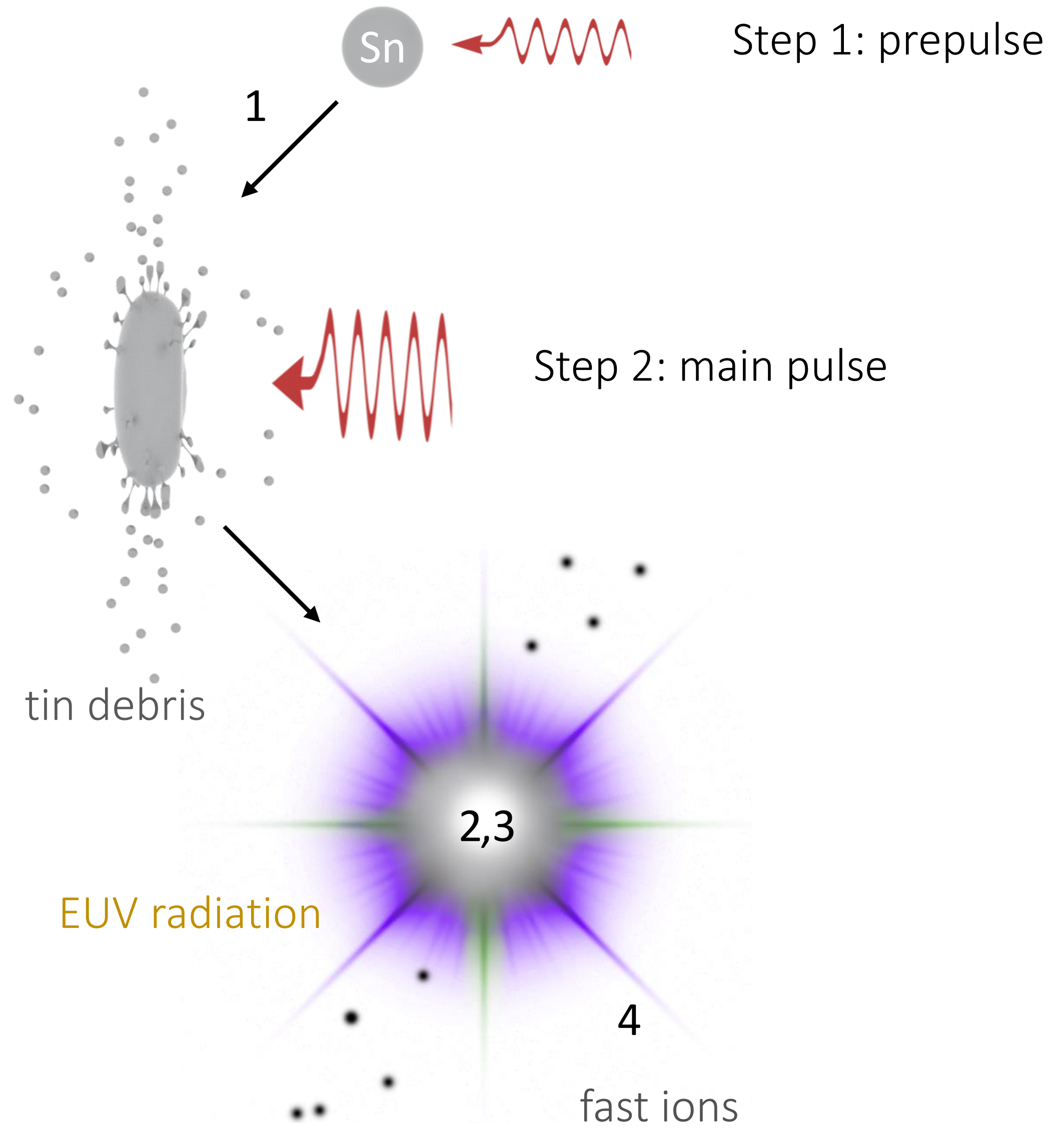
Reflectivity plot courtesy of Sasa Bajt (LLNL) reproduced from D. Attwood's *Soft X-Ray and Extreme Ultraviolet Radiation* (2000).

Spectrum of YAG-laser-driven tin plasma: line emission from highly charged tin ions



R. Schupp et al., Phys. Rev. Appl. **12**, 014010 (2019); also see R. Schupp et al., APL **115**, 124101 (2019)

Physics challenges



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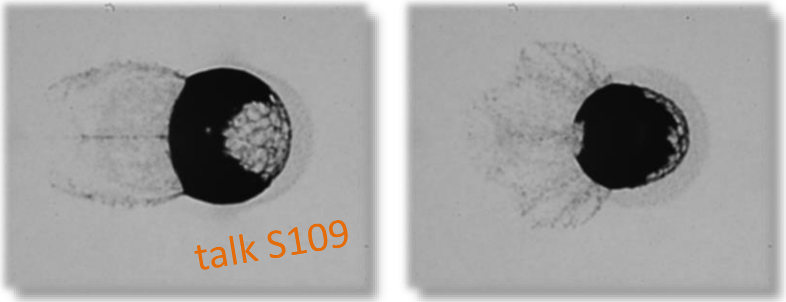
Laser development and EUV source physics

EUVGI team

poster S74

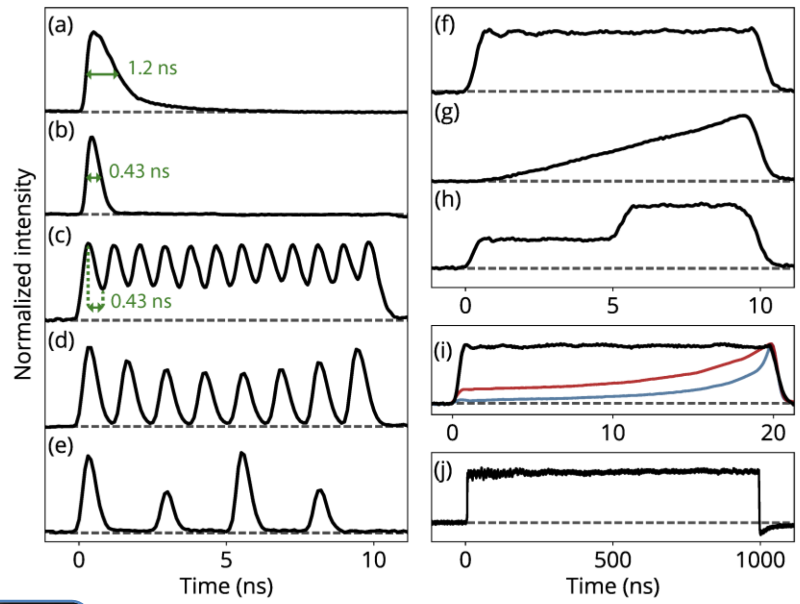


Collaboration with the EUV Plasma Processes group (Oscar Versolato)

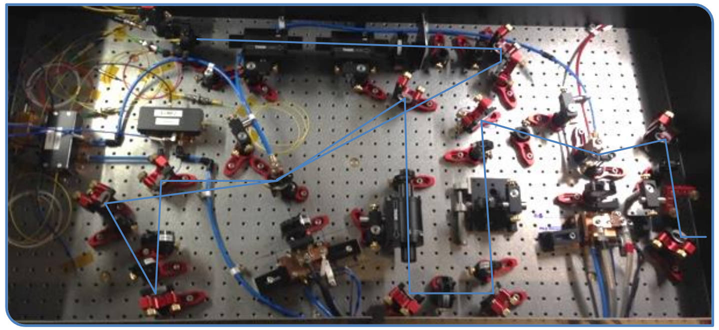
Main objective: Achieving control over LPP target shapes and emission properties through light-field control

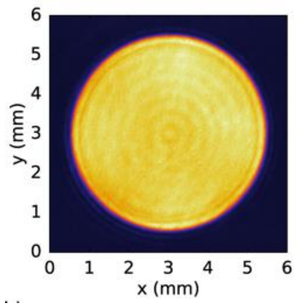
Developed laser systems (all single-shot up to 100 Hz):

- Nanosecond Nd:YAG system: 0.43 ns to 1 µs with arbitrary temporal shape, up to 430 mJ, 1064 nm
- Picosecond Nd:YAG amplifier: 15-110 ps, 25-190 mJ, 1064 nm
- Femtosecond parametric amplifier:
  1) signal: 200 fs to 30 ps, 10 mJ at 1.55 µm,
  2) idler: 4 mJ at 3.5 µm, 30 ps (in future also compressible to 200 fs)



Application example: Developing models for influence of pre-pulse parameters on debris generation and target shape (2-5 years).

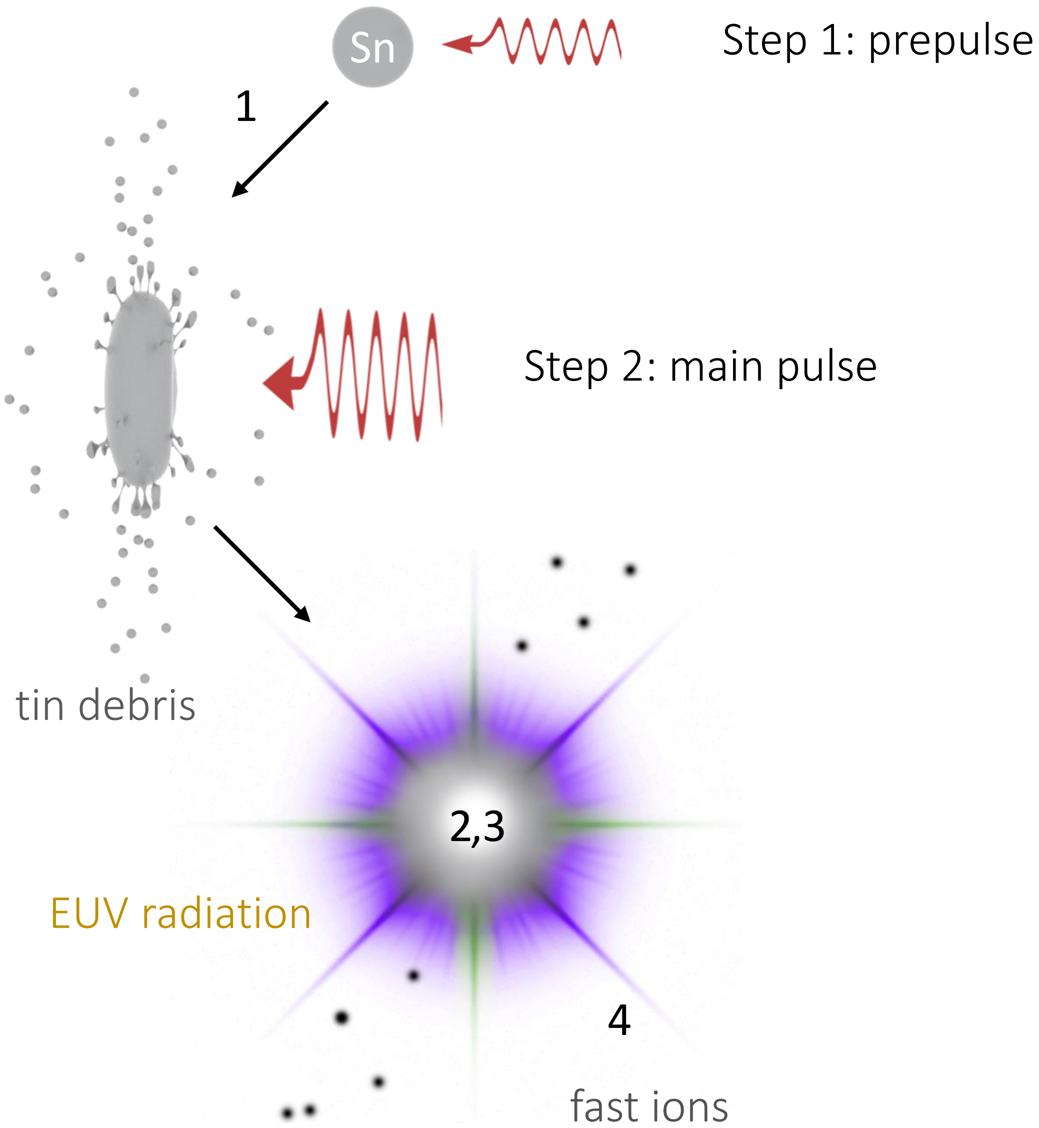




R. Meijer et al., Opt. Lett. **42**, 2758 (2017);
T. Faria Pinto, Opt. Express **27**, 2983 (2019)

ARCNL

Physics challenges



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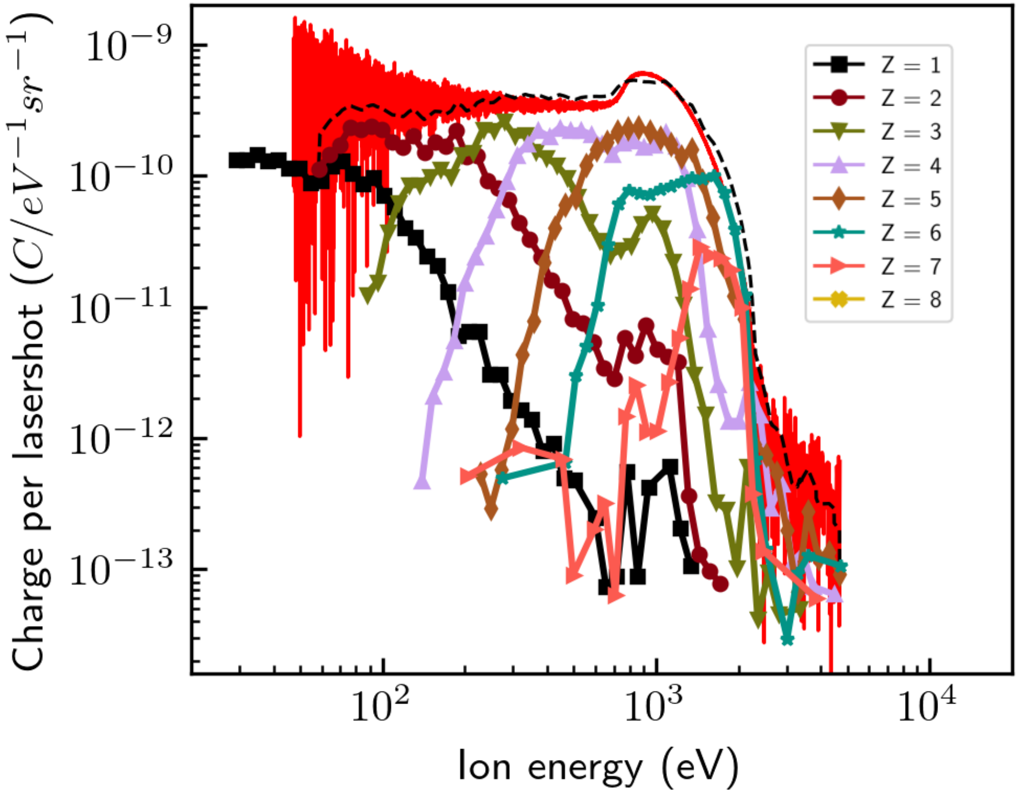
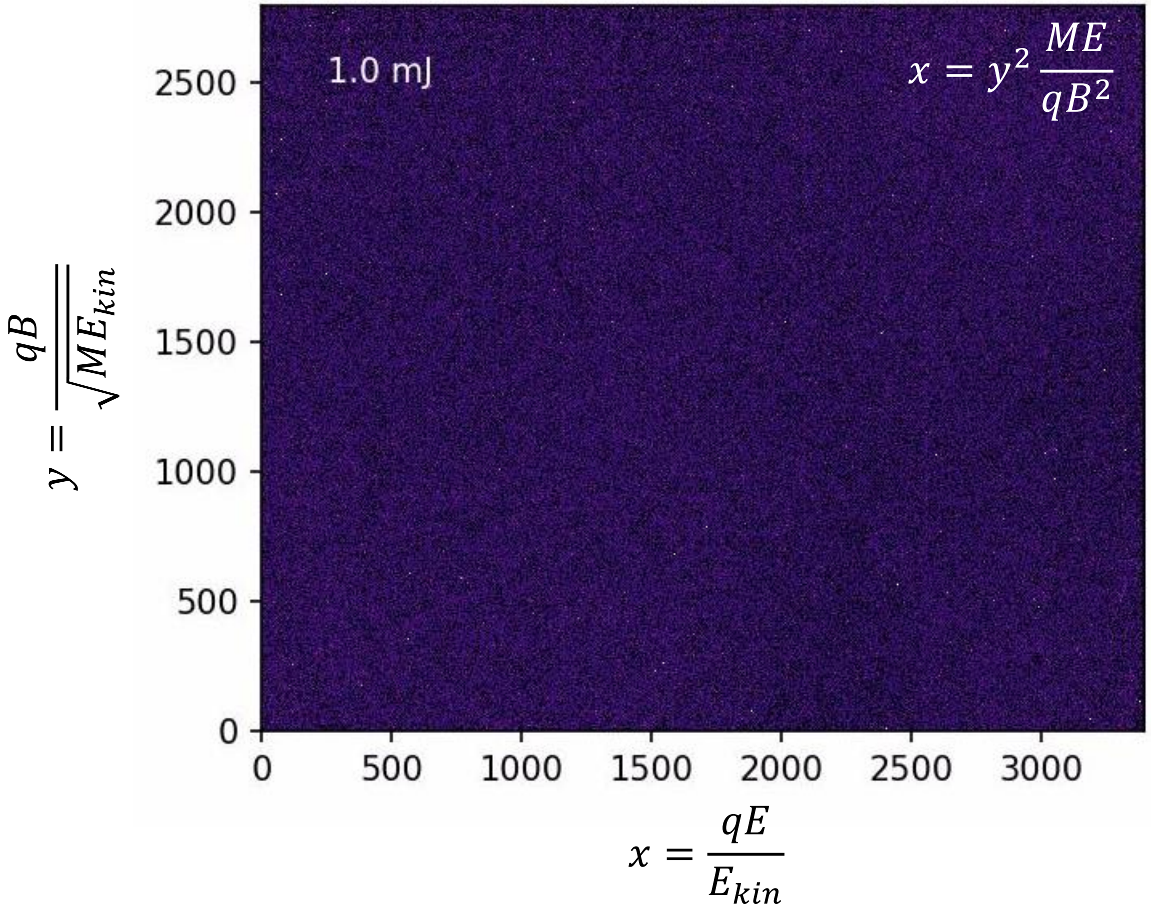
Plasma expansion: tools for charge-state-resolved ion energy spectroscopy

poster S84

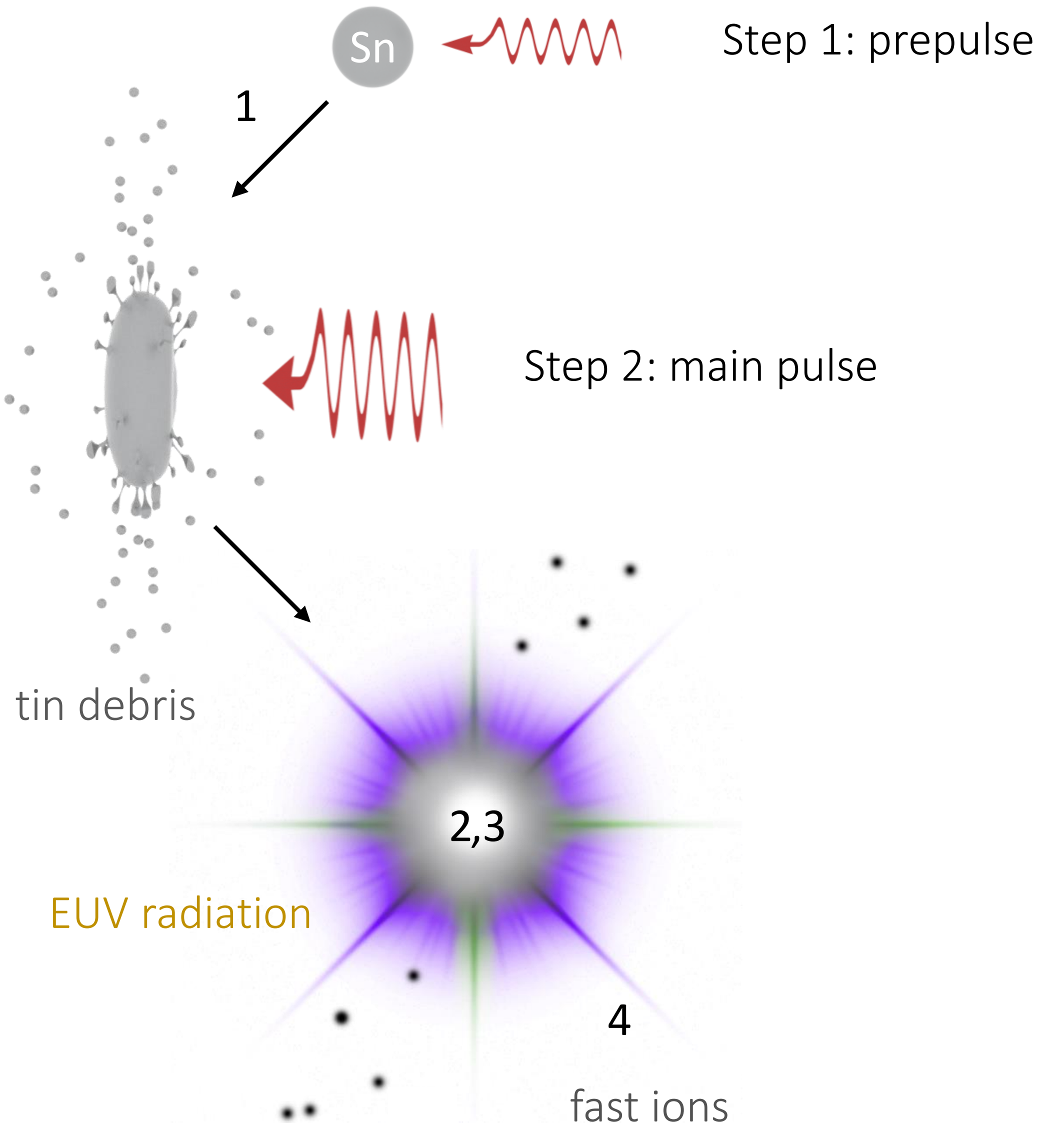
talk S108





A. Bayerle, L. Poirier, et al, *in preparation;* also see A. Bayerle, PSST **27**, 045001 (2018)

Physics challenges: outlook



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