POLITECNICO
MILANO 1863

Numerical simulations of Laser-Plasma interaction with nanostructured plasmas

Luca Fedeli

Salamanca, 22/06/2017

The ENSURE group at Politecnico di Milano

Matteo Passoni

Associate professor

ERC-2014-CoG No.647554
ENSURE

Ongoing collaborations with:

HZDR

OSAKA UNIVERSITY

SourceLAB

ERC-PoC: **INTER**

Queen's University Belfast

The ENSURE group at Politecnico di Milano

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Margherita Zavelani-Rossi
Associate professor

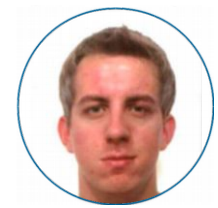
Valeria Russo
Researcher

4 Post-docs

D. Dellasega

A. Maffini

L. Fedeli



L. Cialfi

2 PhD students

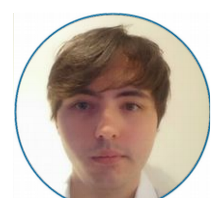
A. Formenti

A. Pazzaglia

3 Master's students

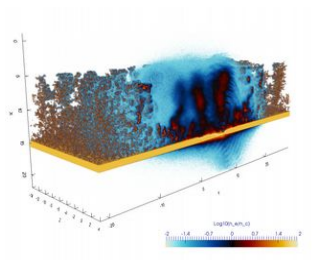
F. Mirani

A. Tentori



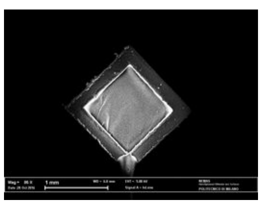
M. Sala

The ENSURE project



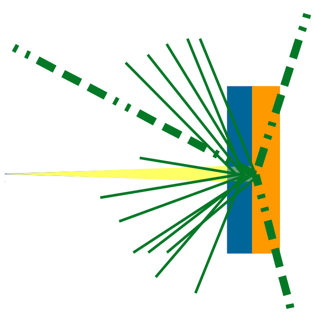
Laser-driven ion acceleration

Theoretical/numerical & experimental investigation



Materials science

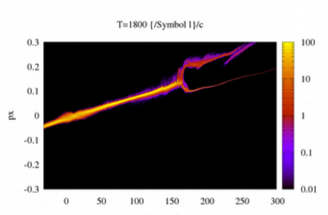
Development of low-density foams & advanced targets for laser-plasma experiments



Applications in materials and nuclear science

Materials characterization (e.g. PIXE) with laser-driven ions

Secondary neutron sources for radiography and detection[...]



Fundamental physics and laboratory astrophysics

Laser interaction with (near-critical) nanostructured plasmas

Collisionless shock acceleration of ions

People involved in numerical simulation activities

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Associate professor
ERC-2014-CoG No.647554
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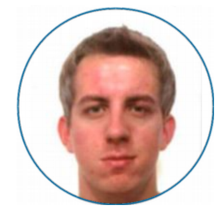

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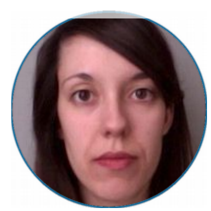

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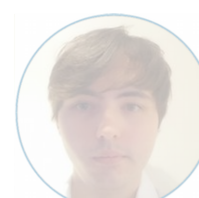


M. Sala

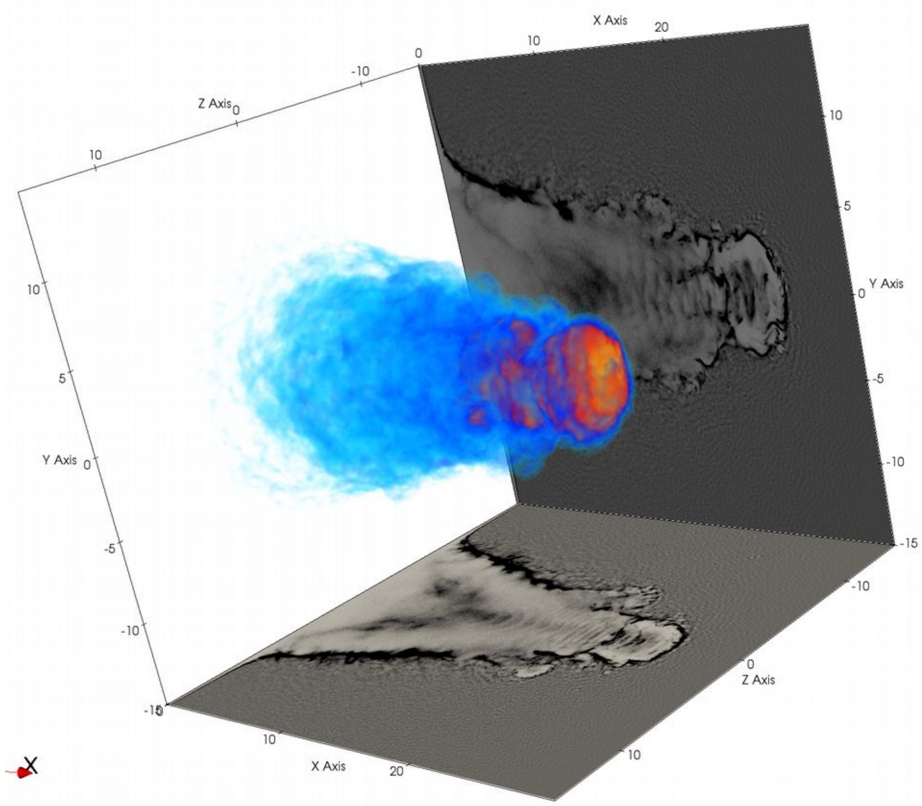
Our numerical tools

https://github.com/ALaDyn/piccante

MARCONI (12th in TOP500 as of Nov 2016)
CINECA Cluster, Intel Xeon Phi 7250 68C
1.4GHz, Intel Omni-Path (241.000 cores)
Linpack Performance: **6.2 PetaFlops**

Nanostructured near-critical plasmas

Laser interaction with near-critical plasmas is interesting for several applications...



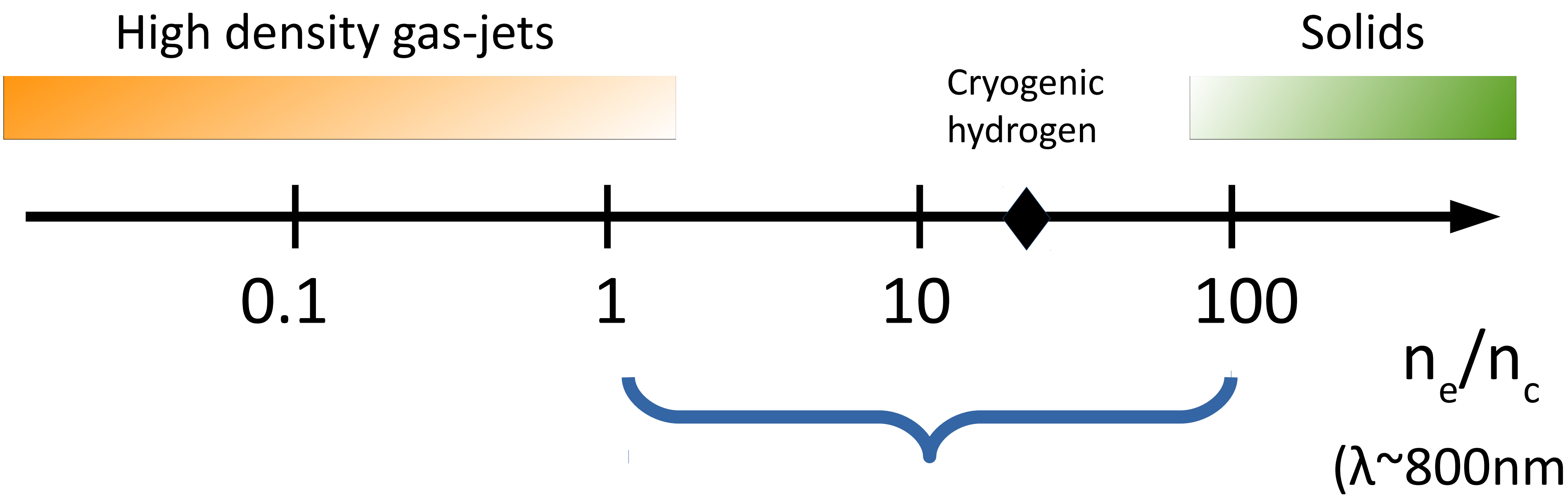
Why bother with near-critical plasmas?

Several interesting applications:

- Enhanced ion acceleration
- Laboratory astrophysics
- γ-ray sources
- Inertial confinement fusion
- Electron acceleration
- High angular momentum electron bunches

...

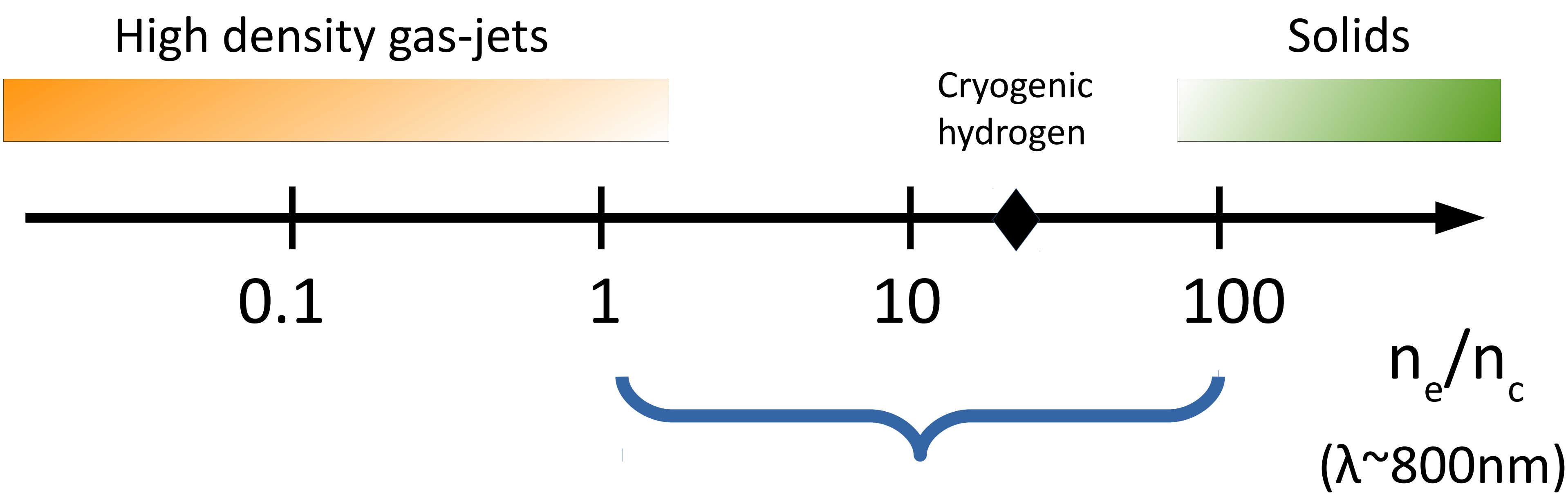
...but they are challenging from a “targetry” point of view!



How do we fill the gap?

- Pre-heating
- **Very low-density nanostructured materials**

...but they are challenging from a “targetry” point of view!



How do we fill the gap?

- Pre-heating
- **Very low-density nanostructured materials**
  - Aerogels
  - Nanotube arrays
  - **PLD Foams**

An example of a “foam-attached” target

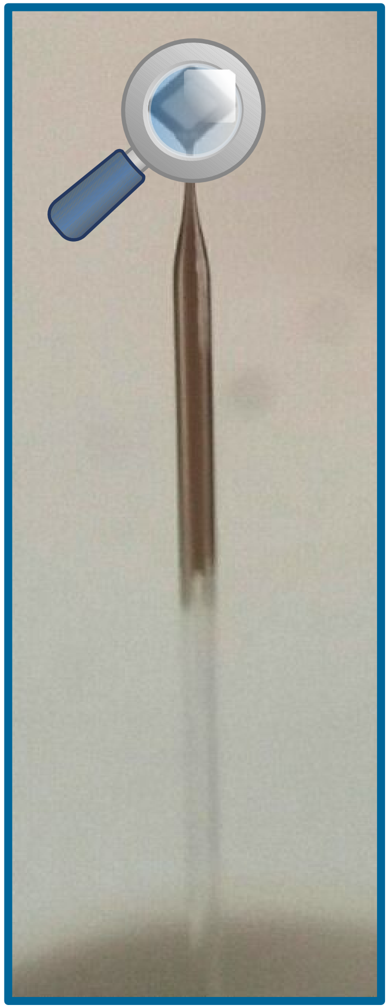
Target conceived for a collision-less shock experiment

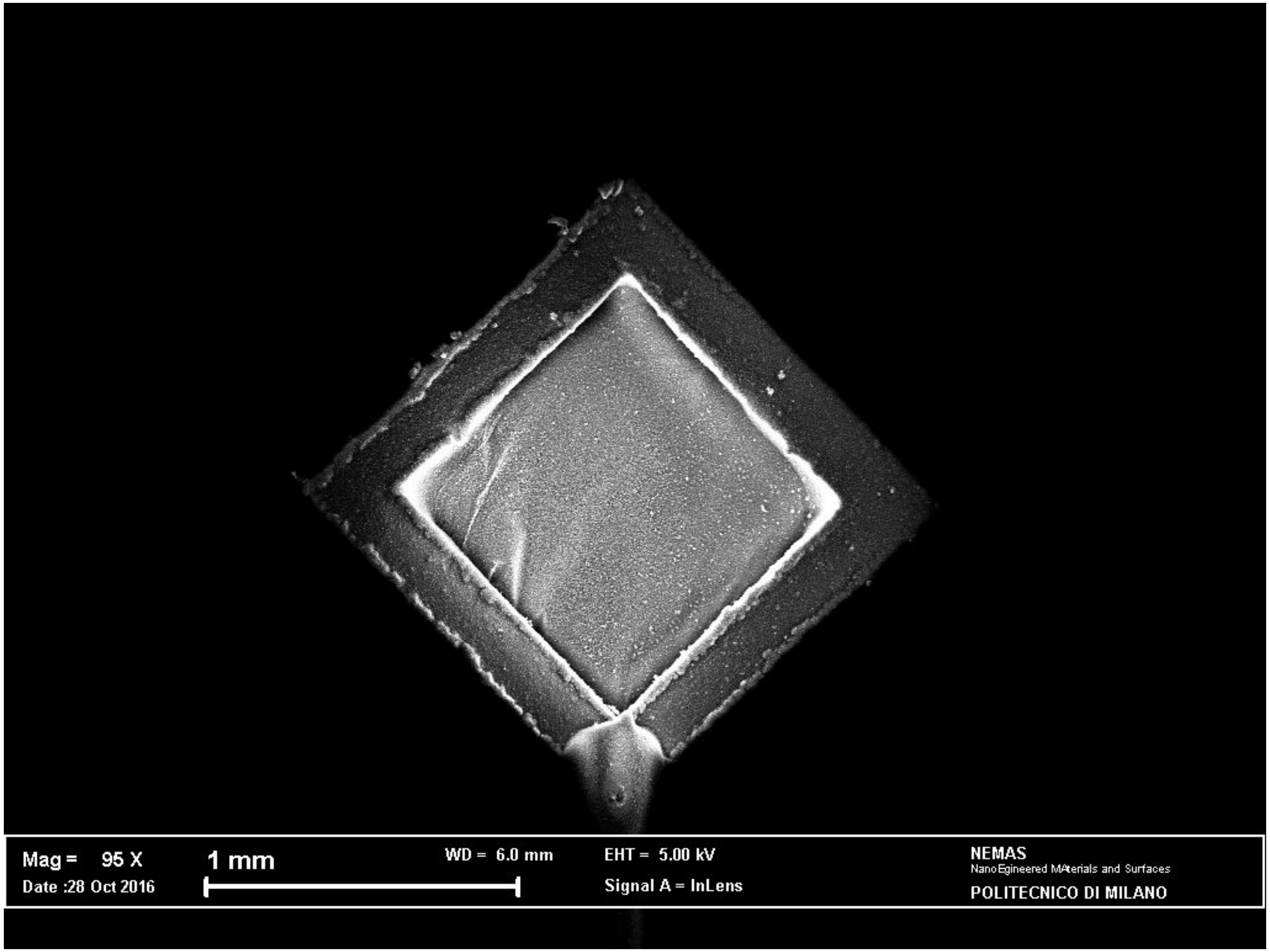
D. Dellasega

A. Maffini

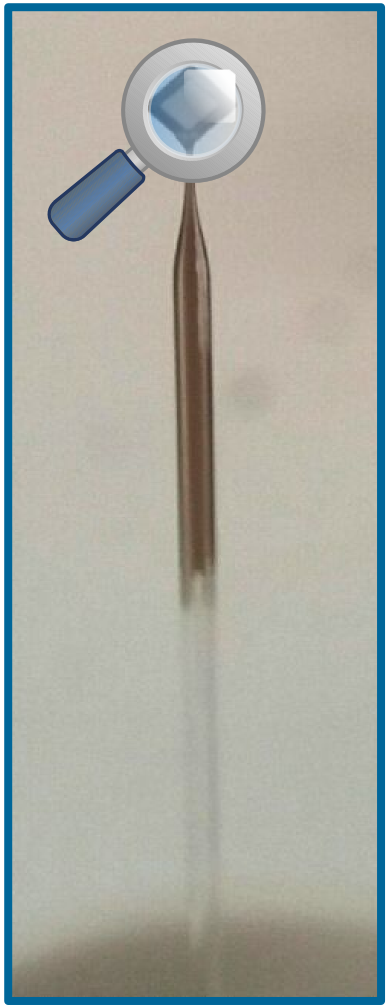
OSAKA UNIVERSITY

An example of a “foam-attached” target

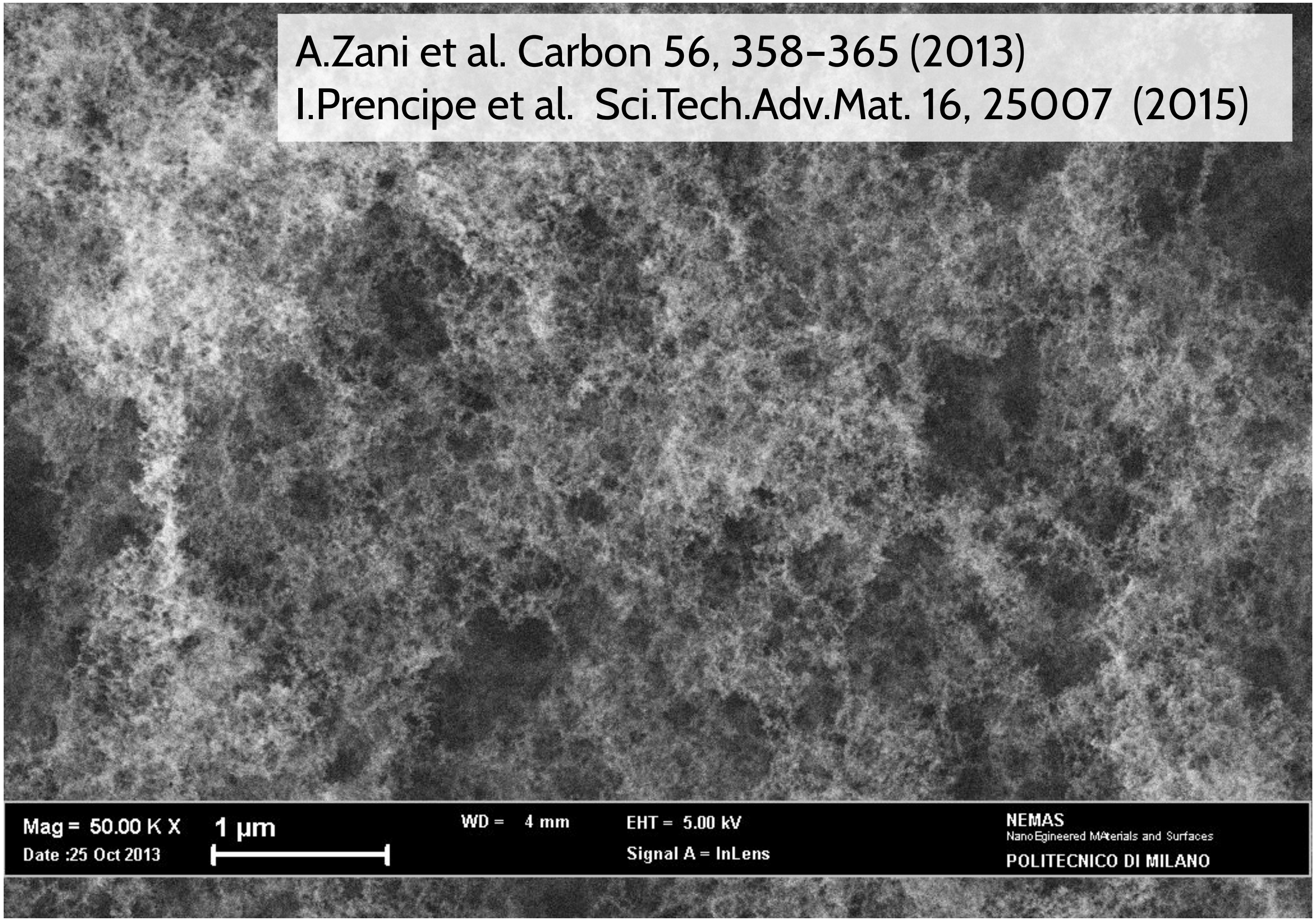




Foam has a porous, complex nanostructure

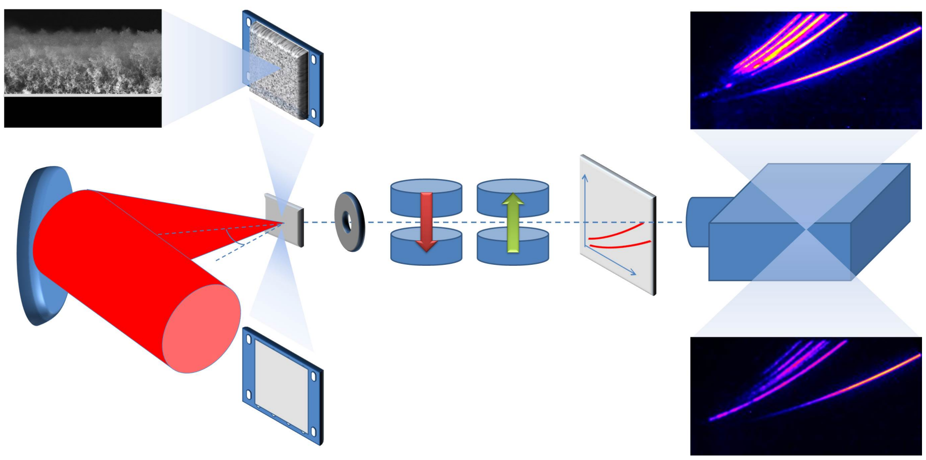


A.Zani et al. Carbon 56, 358–365 (2013)
I.Prencipe et al. Sci.Tech.Adv.Mat. 16, 25007 (2015)

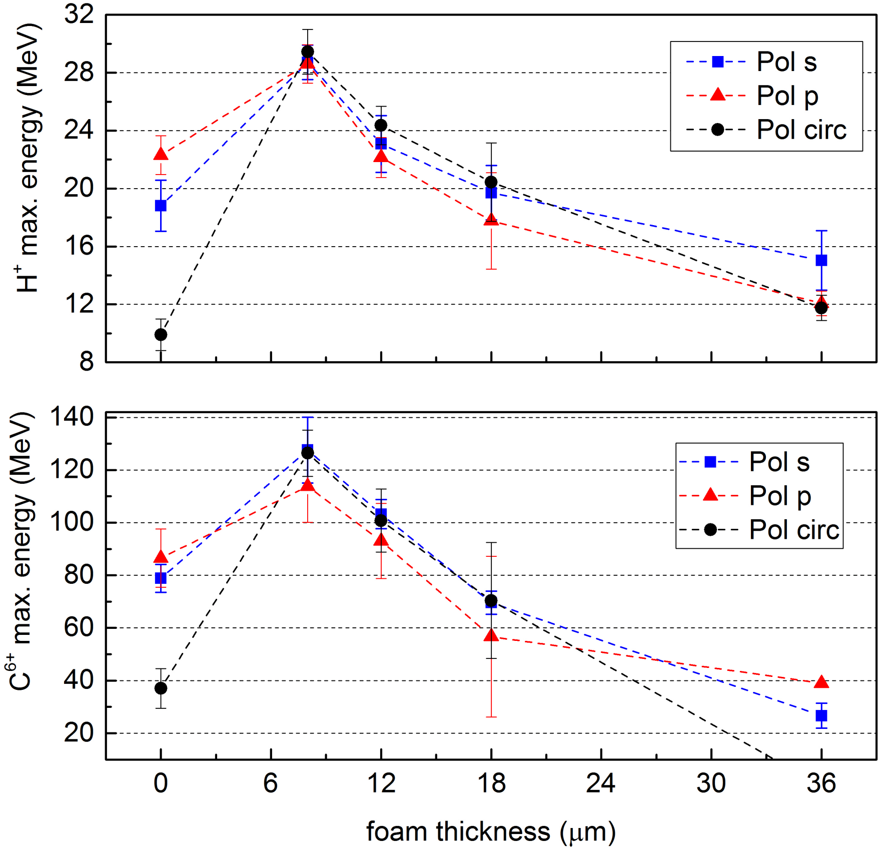


We’ve used these targets for some experimental activities...

2014/2015



PULSER laser at GIST
(Gwangju, South Korea)
$I \sim 5x10^{20}$ W/cm^2, $T_{FWHM} \sim 30$ fs



I.Prencipe et al. PPCF 58 (2016)
M.Passoni et al. PRAB 19 (2016)

And we still have several ongoing experimental activities involving foam-attached targets

HZDR

May 2017: ion acceleration, electron heating, foam homogenization, reflected light...

OSAKA UNIVERSITY

2017/2018: ion acceleration, collision-less shocks

Queen's University Belfast

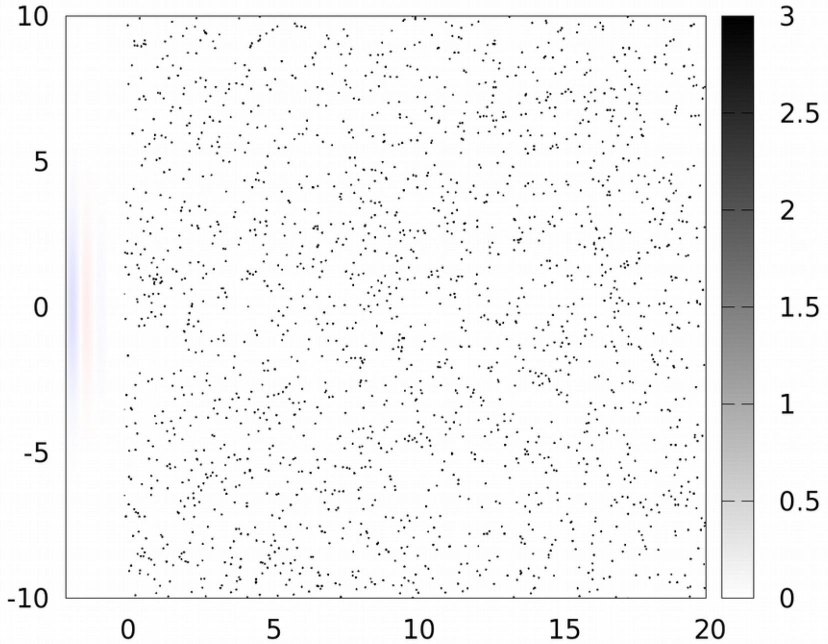
2017/2018 : pulsed neutron generation

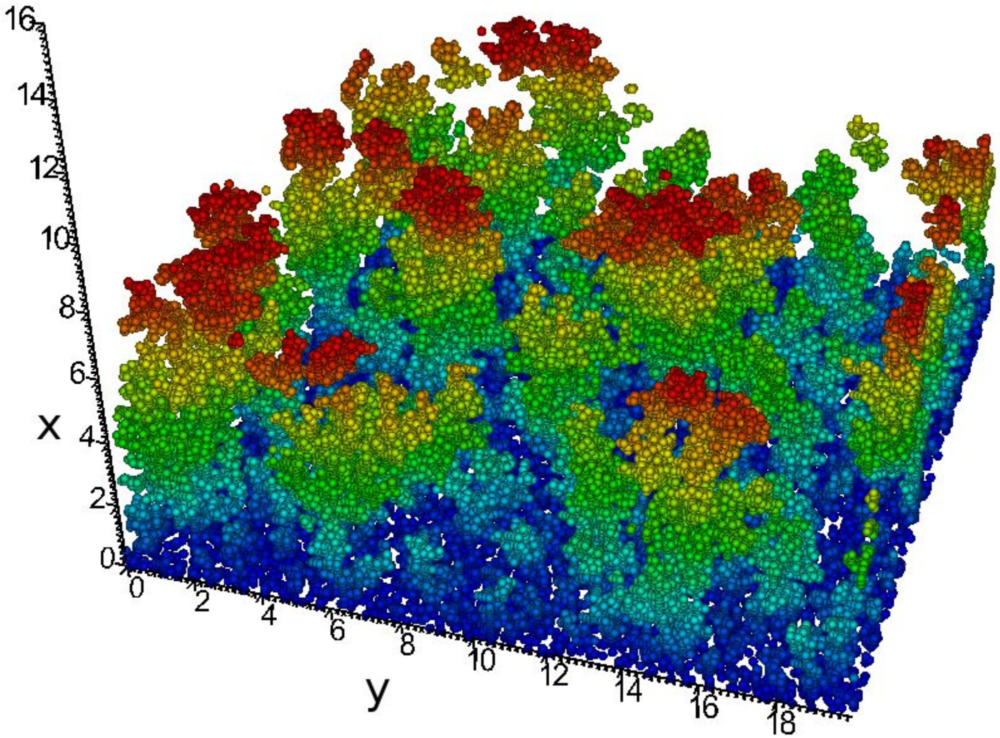
SourceLAB
erc ERC-PoC: **INTER**

2017/2018 : compact ion and neutron sources

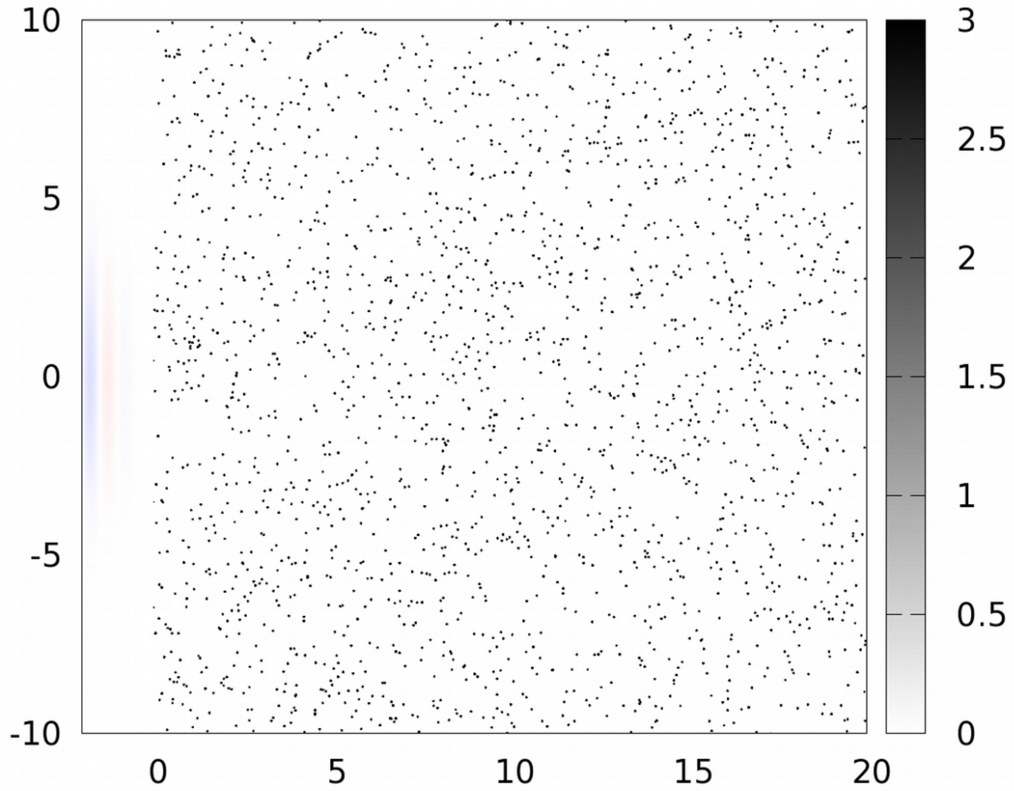
How do we simulate these targets?

Idealized modeling vs “realistic” modeling

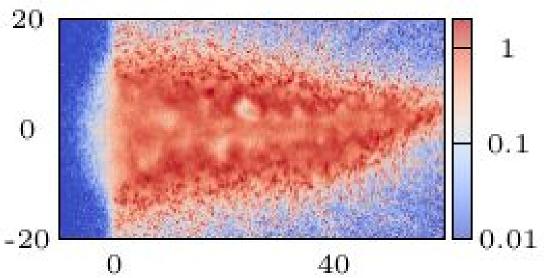




Idealized modeling

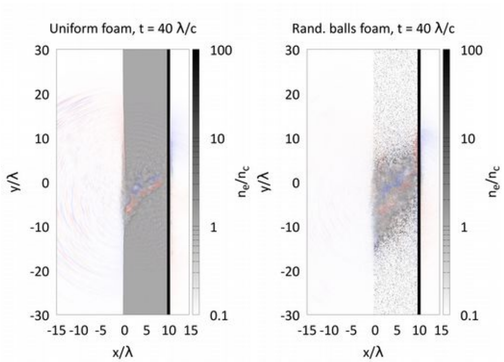


Idealized modeling



Laser propagation in uniform and nanostructured near-critical plasmas

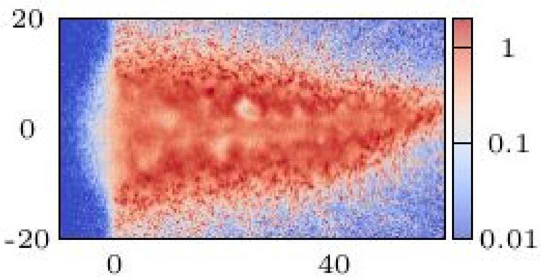
L.Fedeli, A.Formenti, C.E.Bottani & M.Passoni EPJD Topical Issue on “Relativistic Laser Plasma Interactions” (accepted) 2017



Electron heating in foam-attached targets

L.Cialfi, L.Fedeli & M.Passoni Phys.Rev.E 94 (2016)

Idealized modeling

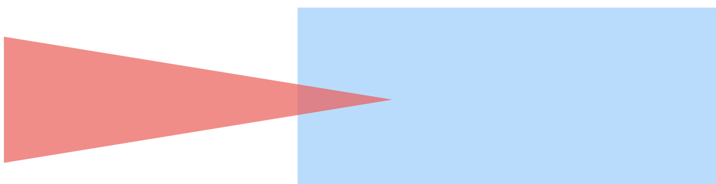


Laser propagation in uniform and nanostructured near-critical plasmas

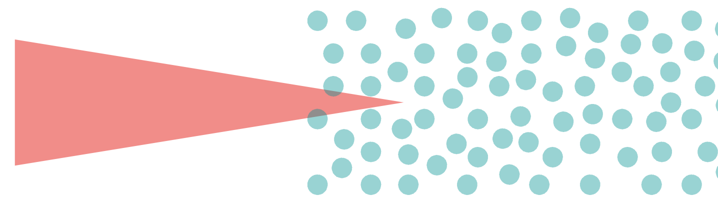
L.Fedeli, A.Formenti, C.E.Bottani & M.Passoni EPJD Topical Issue on “Relativistic Laser Plasma Interactions” (accepted) 2017

We studied three very idealized plasma models

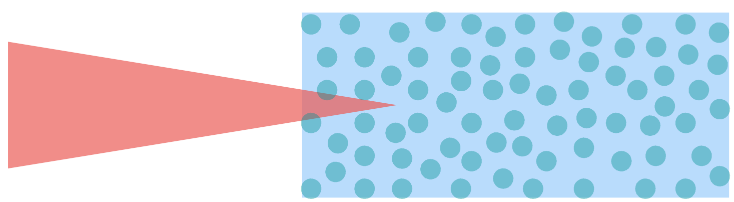
uniform plasmas



nanostructured plasmas

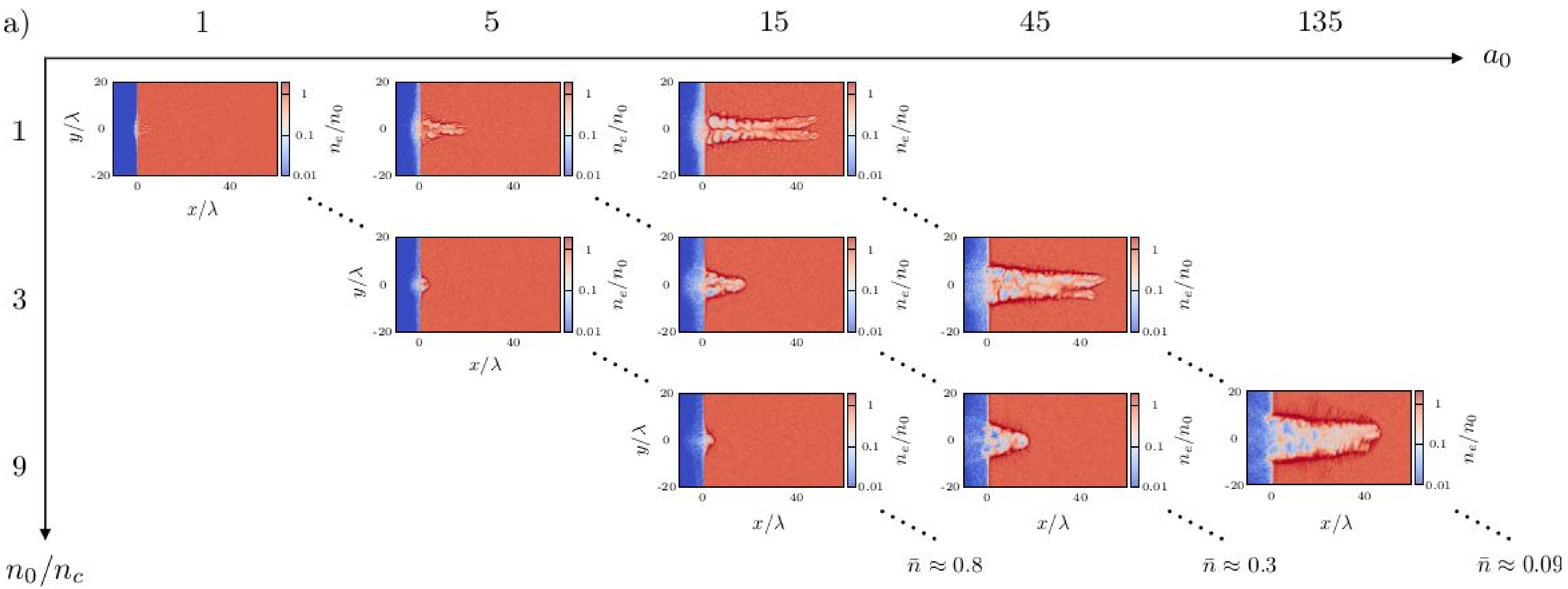


“mixed” plasmas



2D numerical simulation campaign

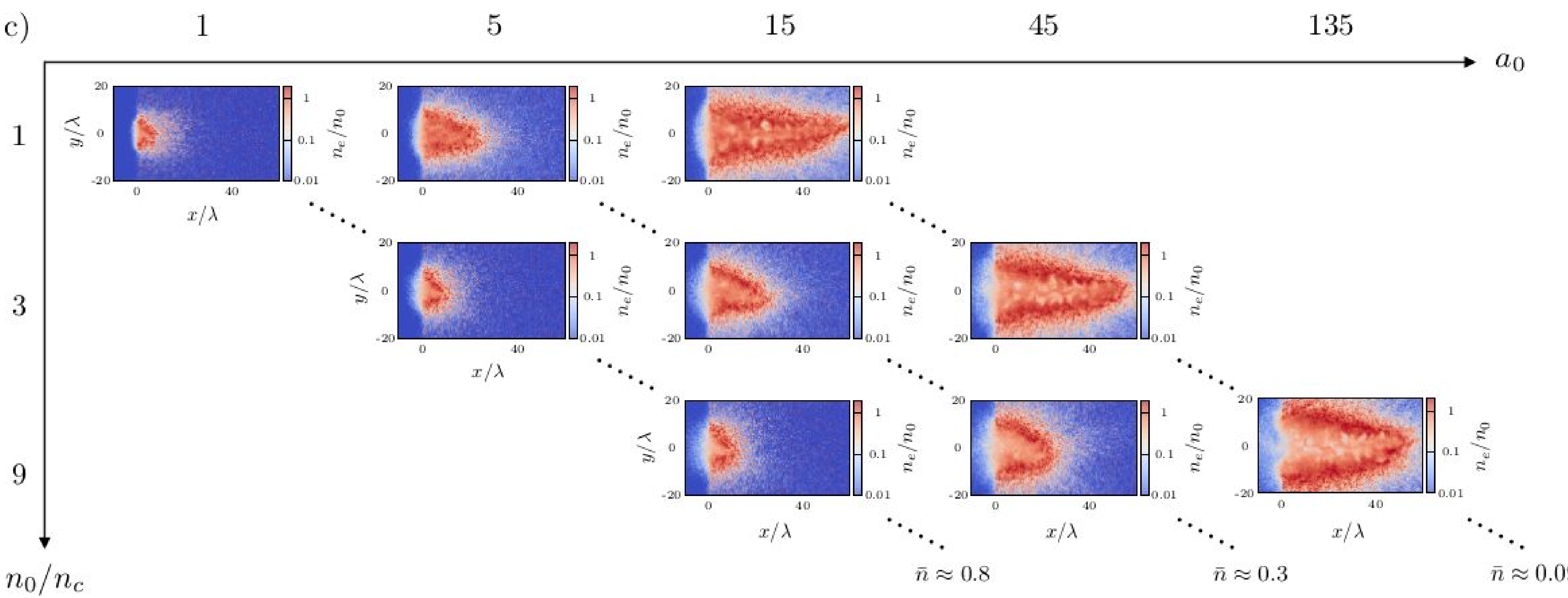
In a wide range of laser intensities and average densities



Uniform plasma

$$\bar{n} = \frac{n_e/n_c}{\sqrt{1+a_0^2/2}}$$

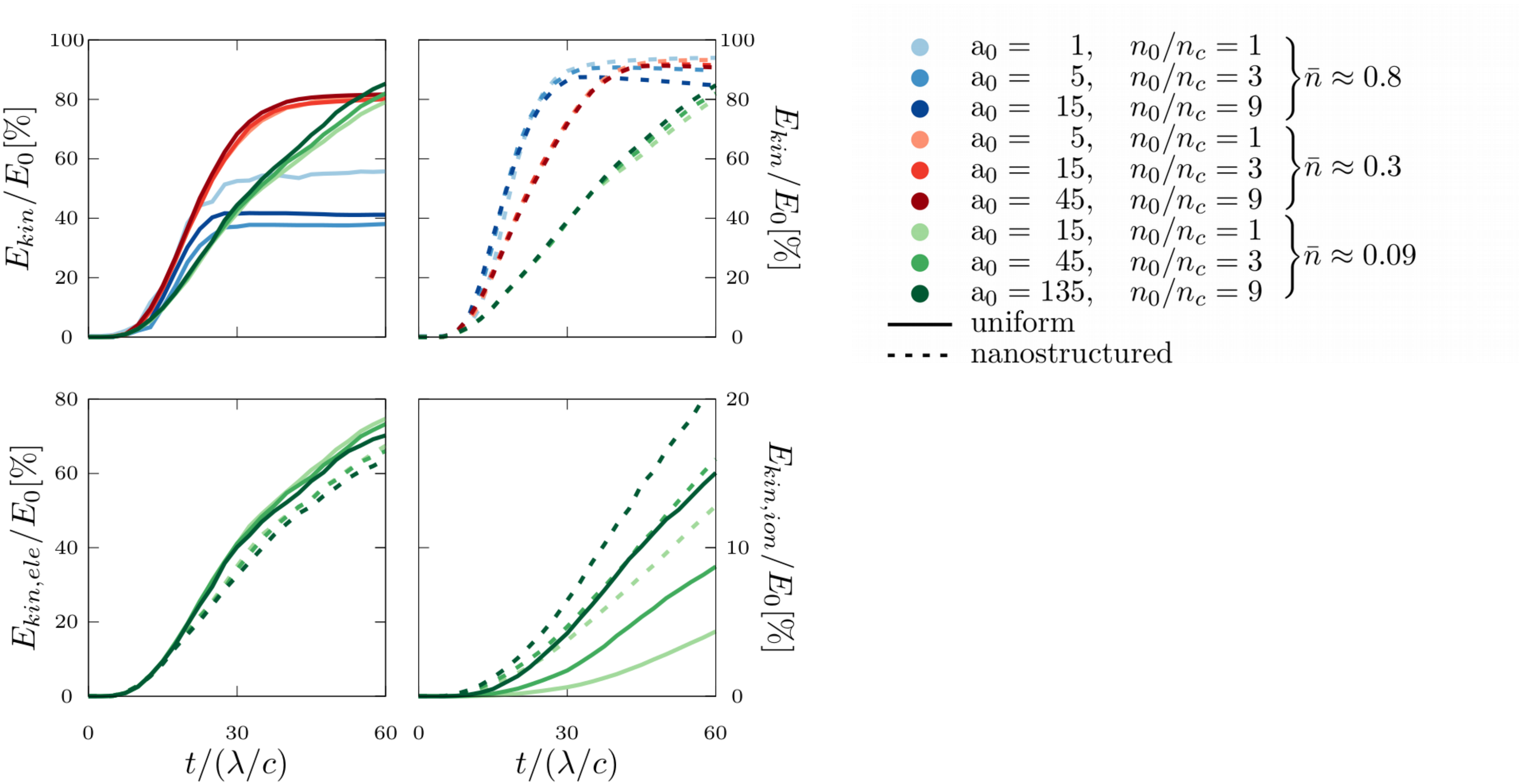
In a wide range of laser intensities and average densities



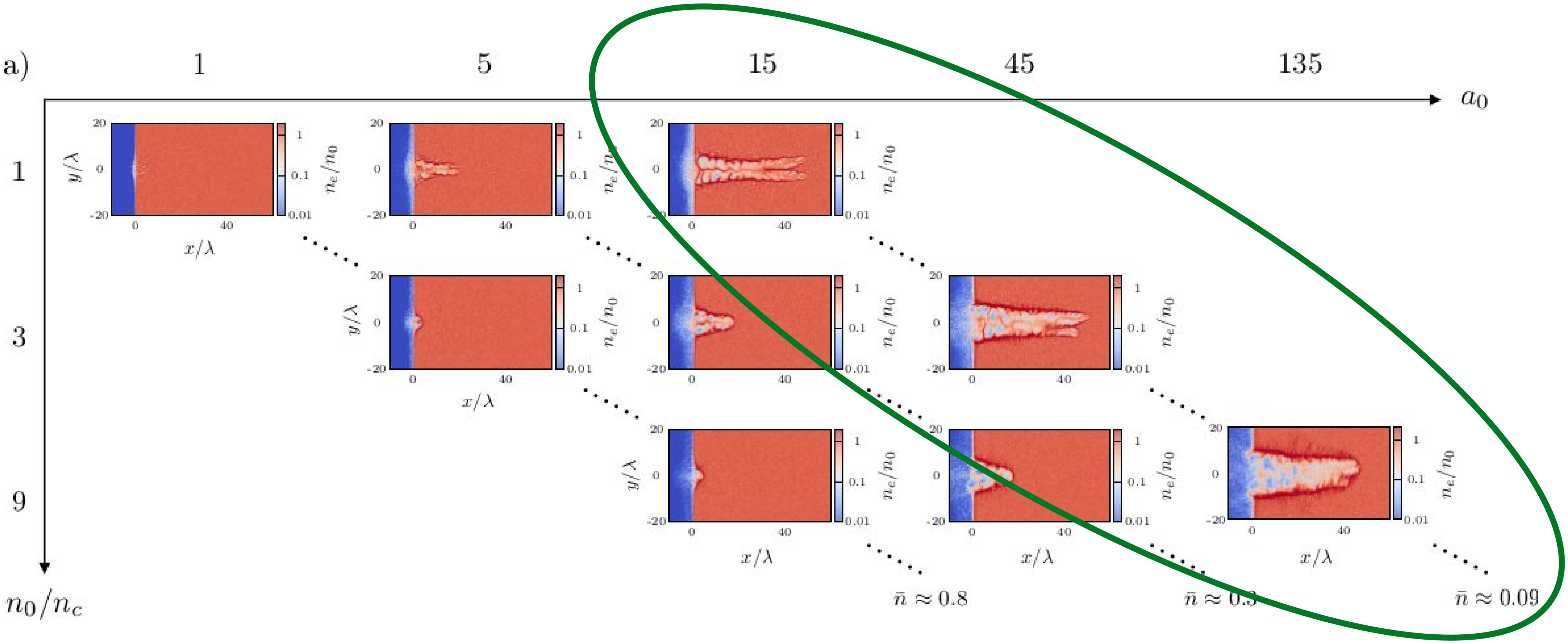
Nanostructured plasma

$$\bar{n} = \frac{n_e/n_c}{\sqrt{1+a_0^2/2}}$$

Main differences appear for partitioning of absorbed energy...

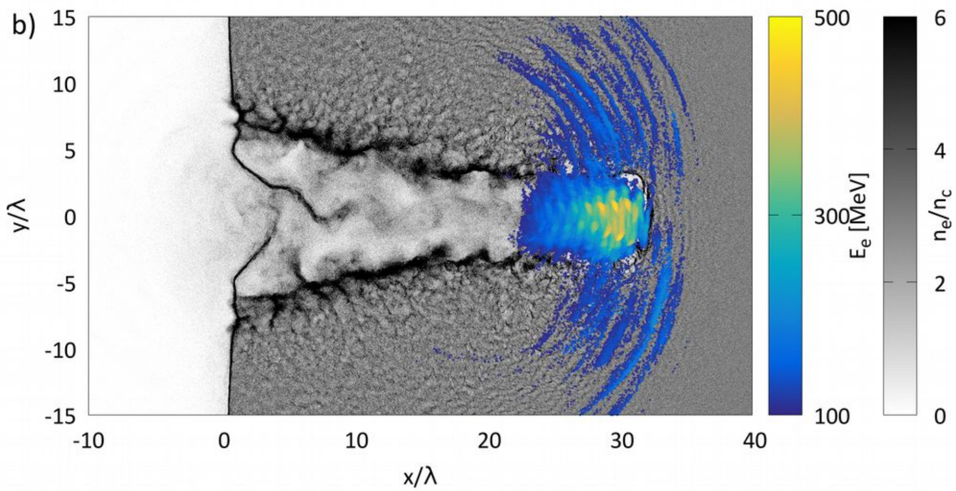


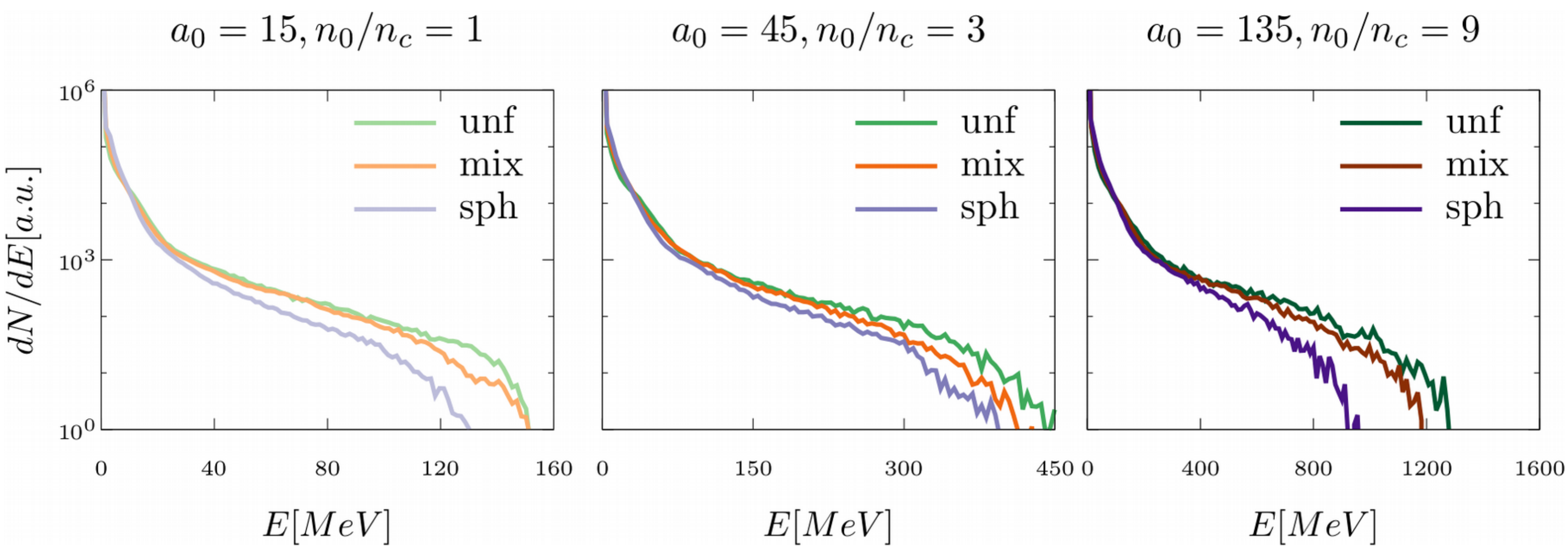
...and for the tail of electron energy spectra



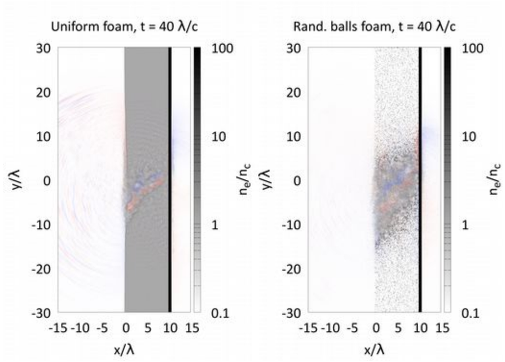
For electron energy spectra we restrict ourselves to this diagonal (highest transparency)

...and for the tail of electron energy spectra





A very similar approach was followed to simulated electron heating in near-critical foam-attached targets



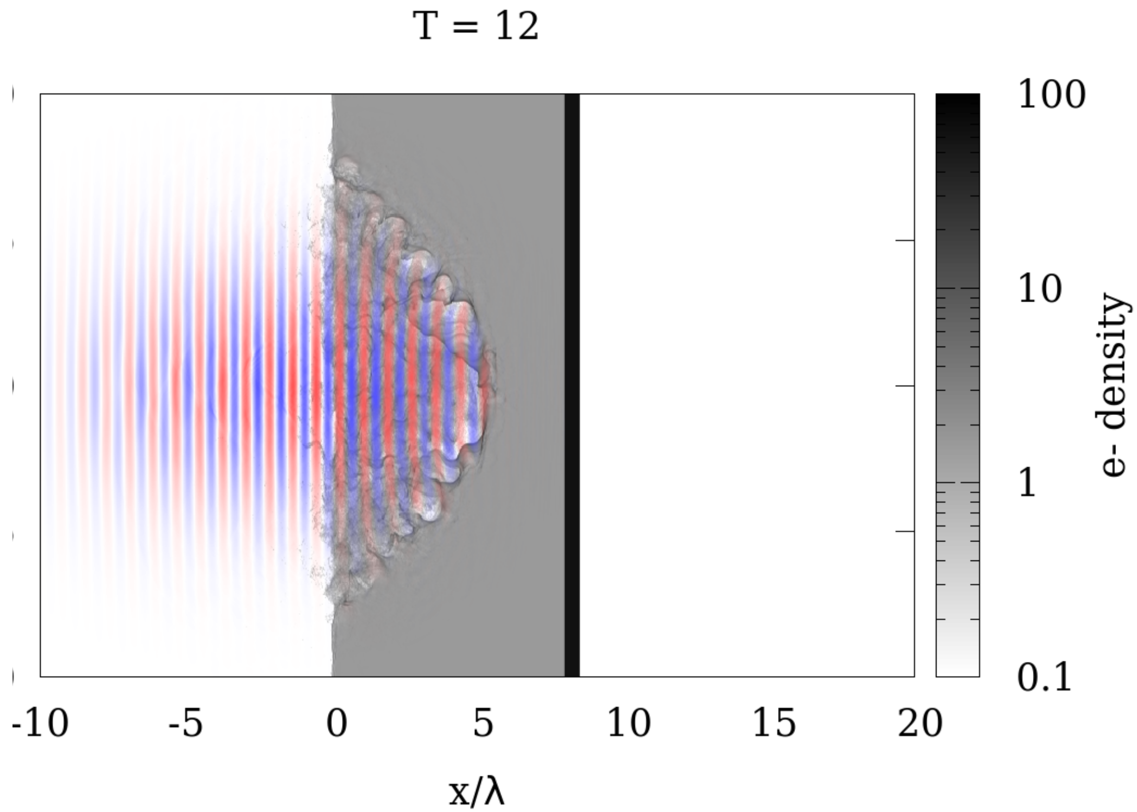
Electron heating in foam-attached targets

L.Cialfi, L.Fedeli & M.Passoni Phys.Rev.E 94 (2016)

A very similar approach was followed to simulated electron heating in near-critical foam-attached targets

Why foam-attached targets?

Why near-critical foam-attached targets?

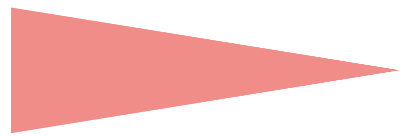


Enhanced coupling in the near-critical layer

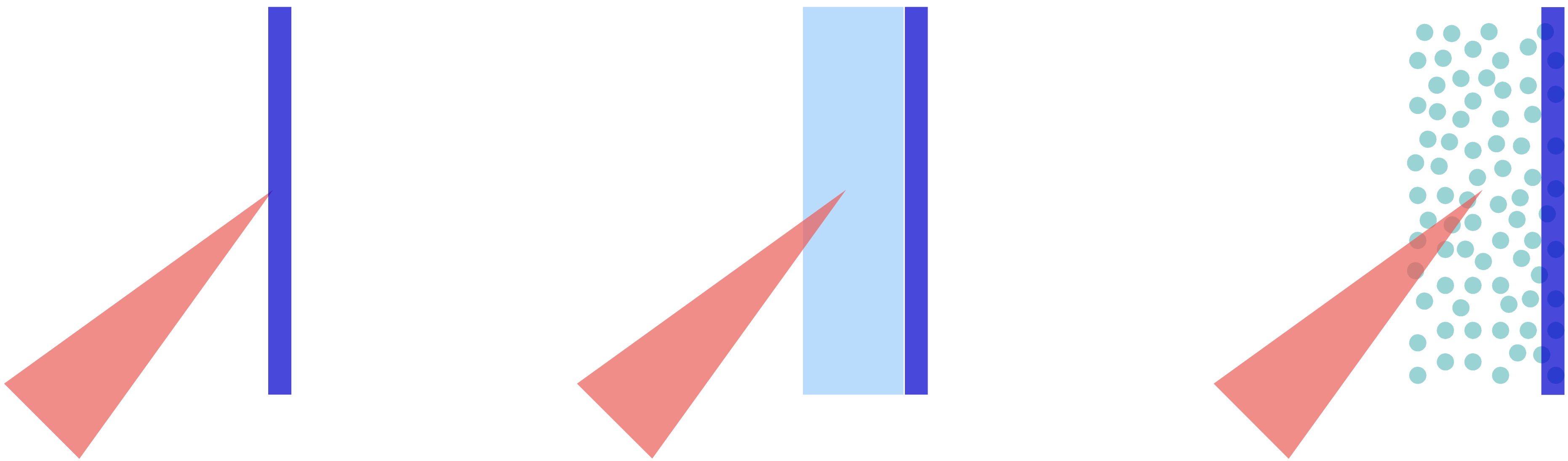
Higher laser absorption, higher electron temperature, enhanced ion acceleration...

Setup of the physical scenario

2D PIC simulations



Laser: p-polarized, a_0 = 1-15, 30° incidence,

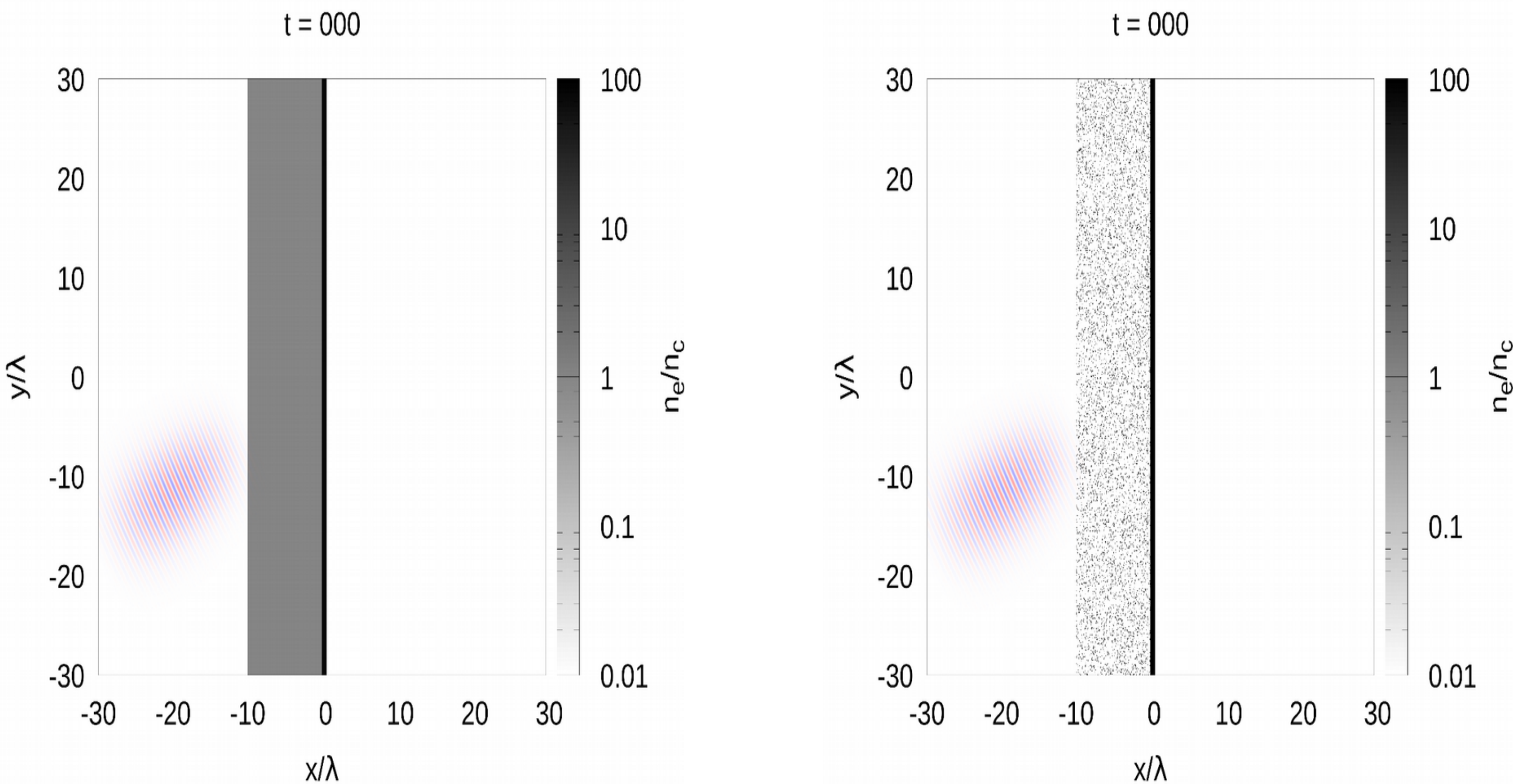


Simple flat target
80 n_c, 0.5 µm

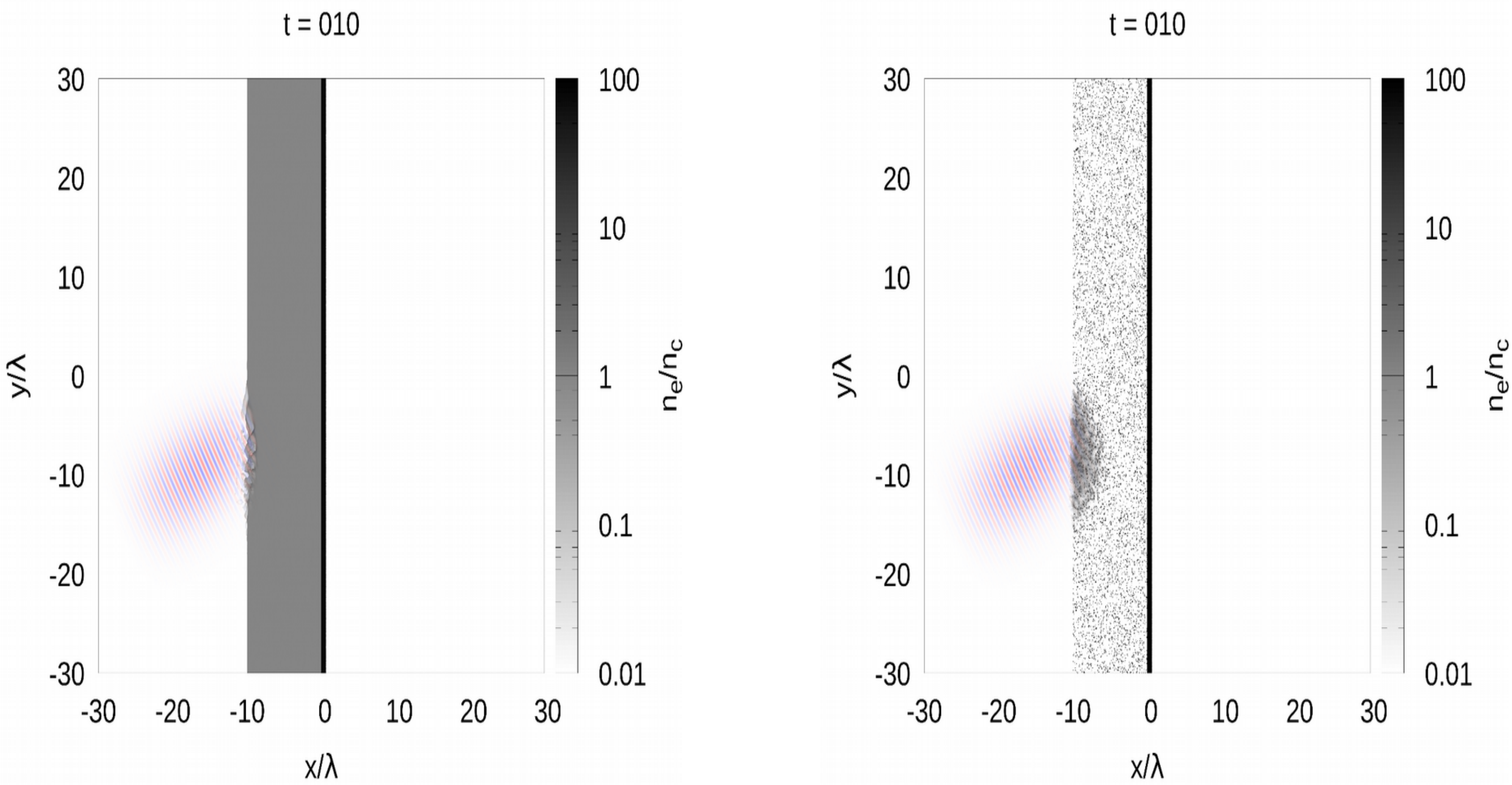
Unif. foam target
80 n_c, 0.5 µm +
1 n_c, 10 µm

Nanost. foam target
80 n_c, 0.5 µm +
balls r=10 nm, n_e=100 n_c
avg.1 n_c, 10 µm

Uniform foam vs nanostructured foam



Uniform foam vs nanostructured foam



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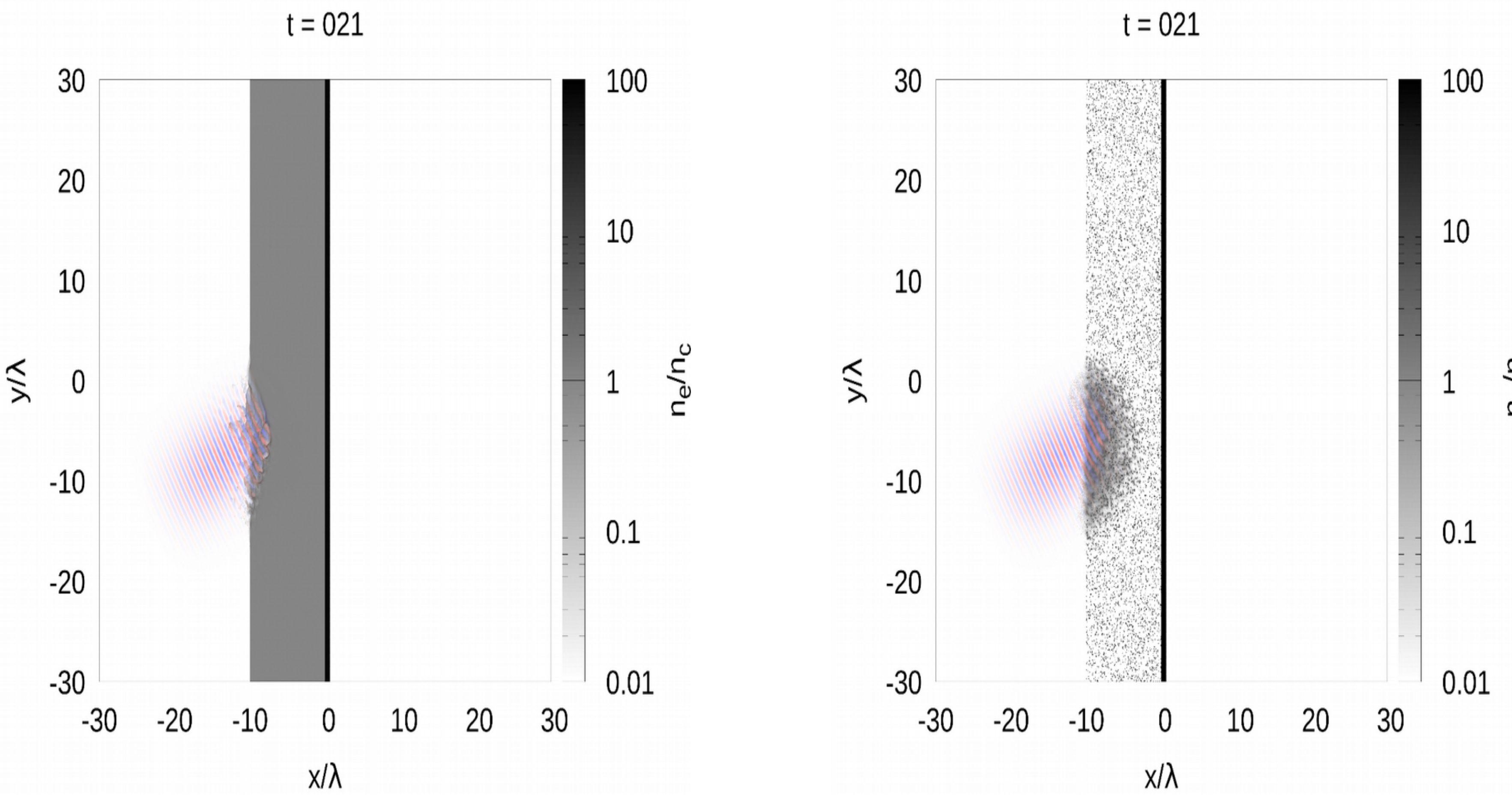

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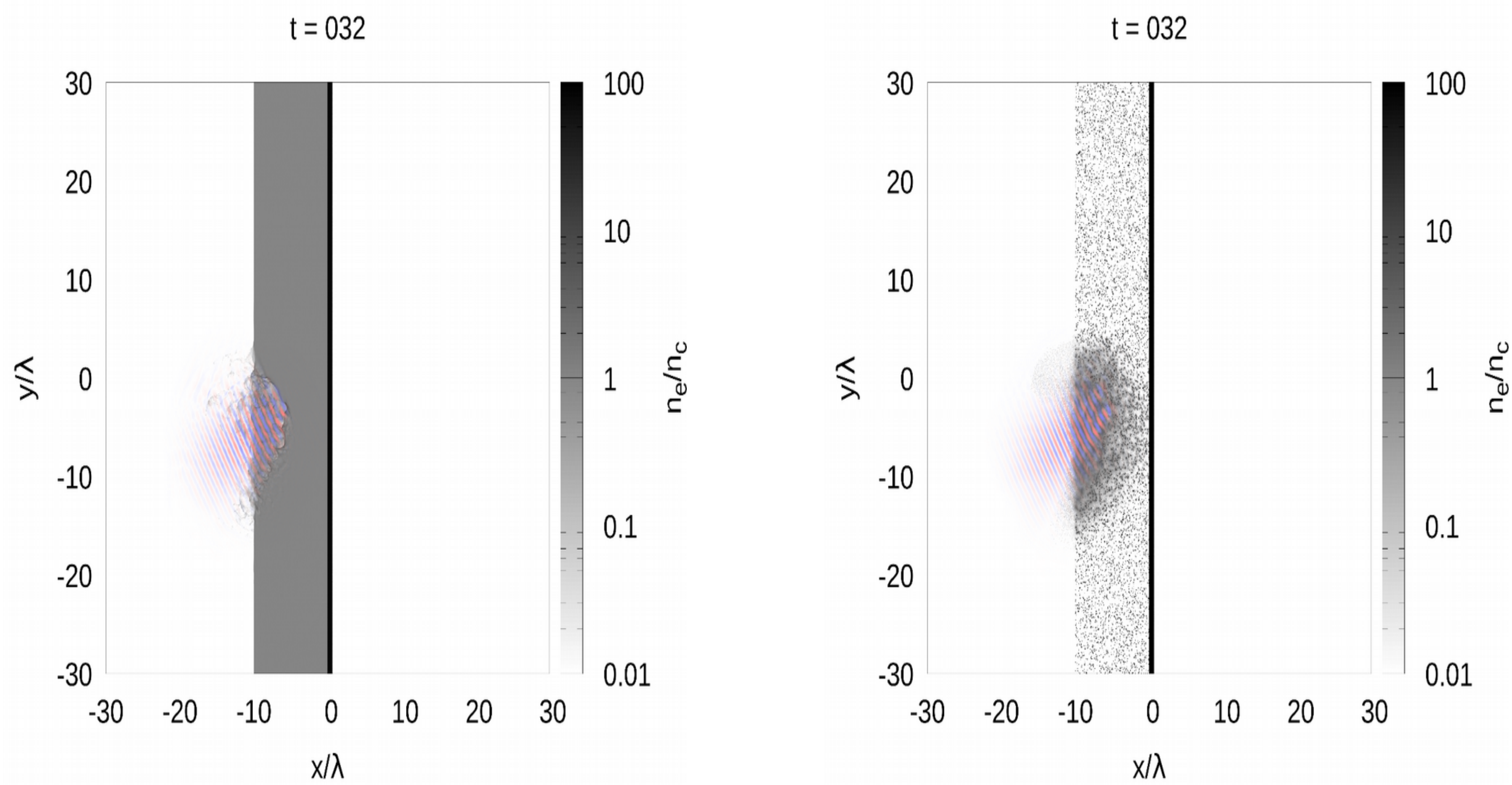

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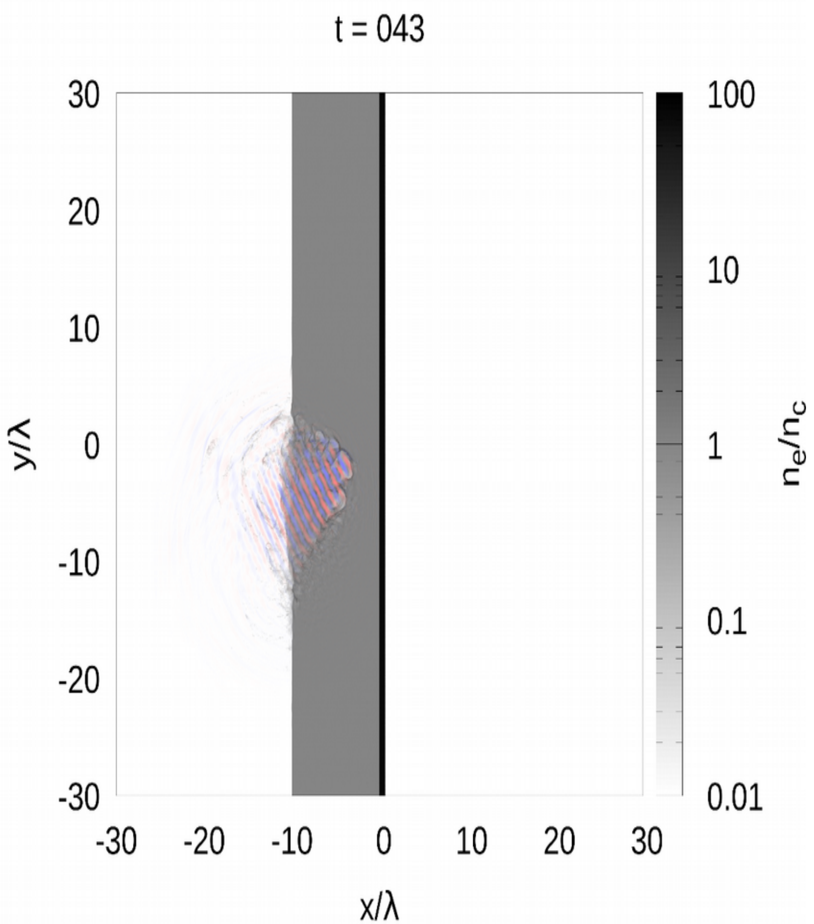

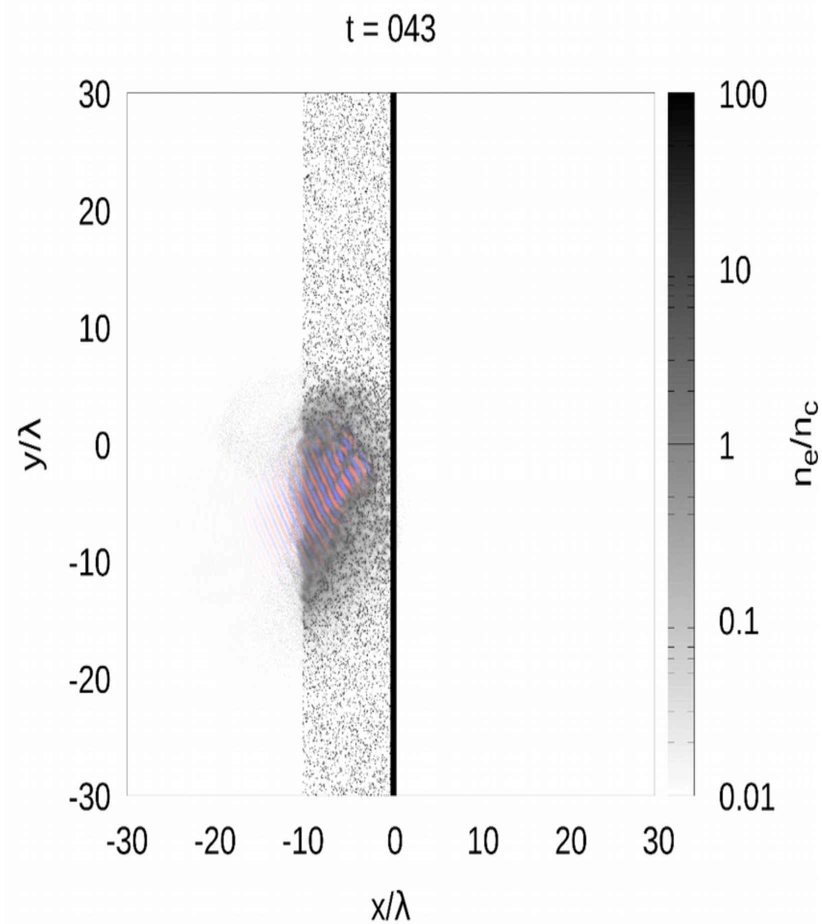

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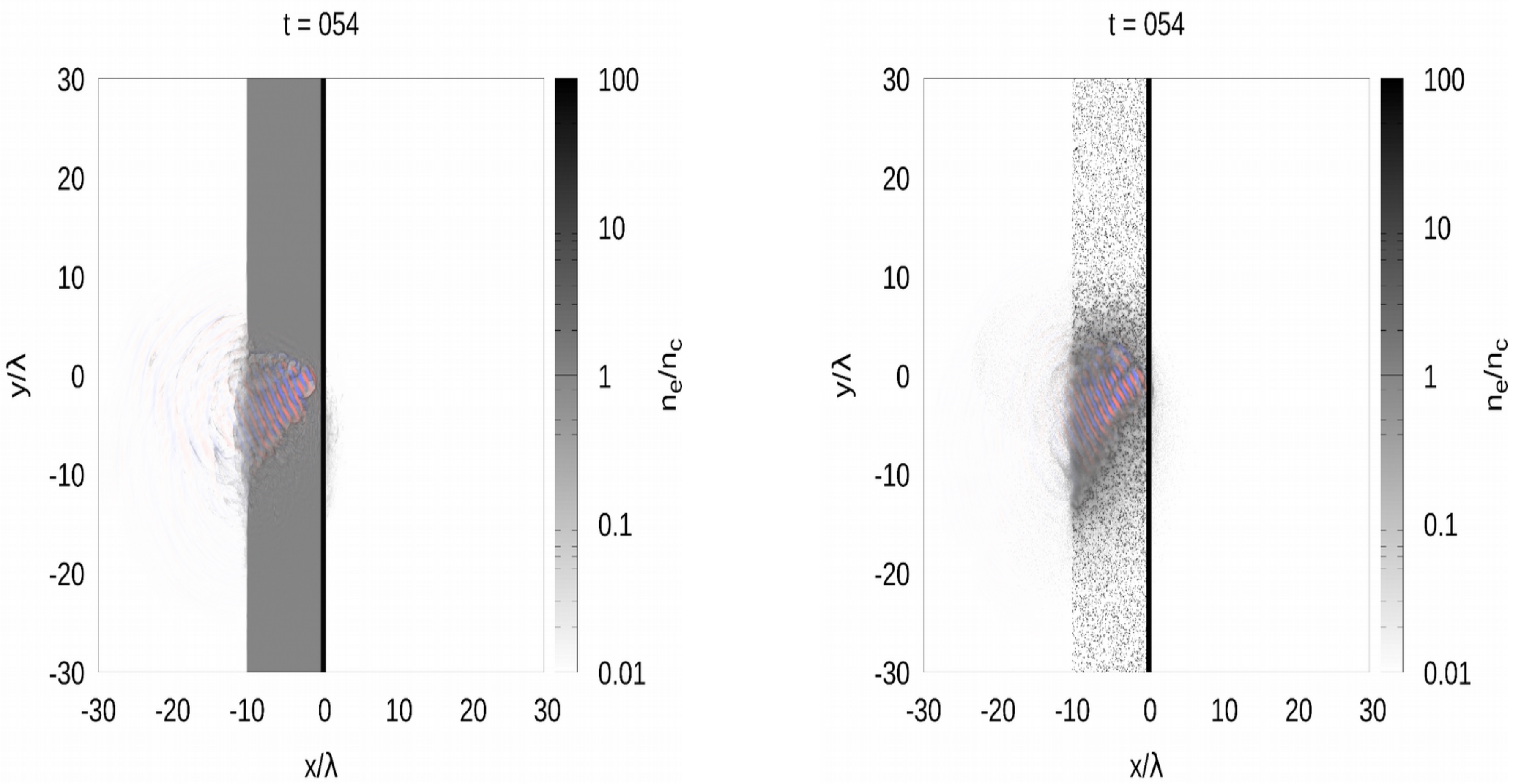

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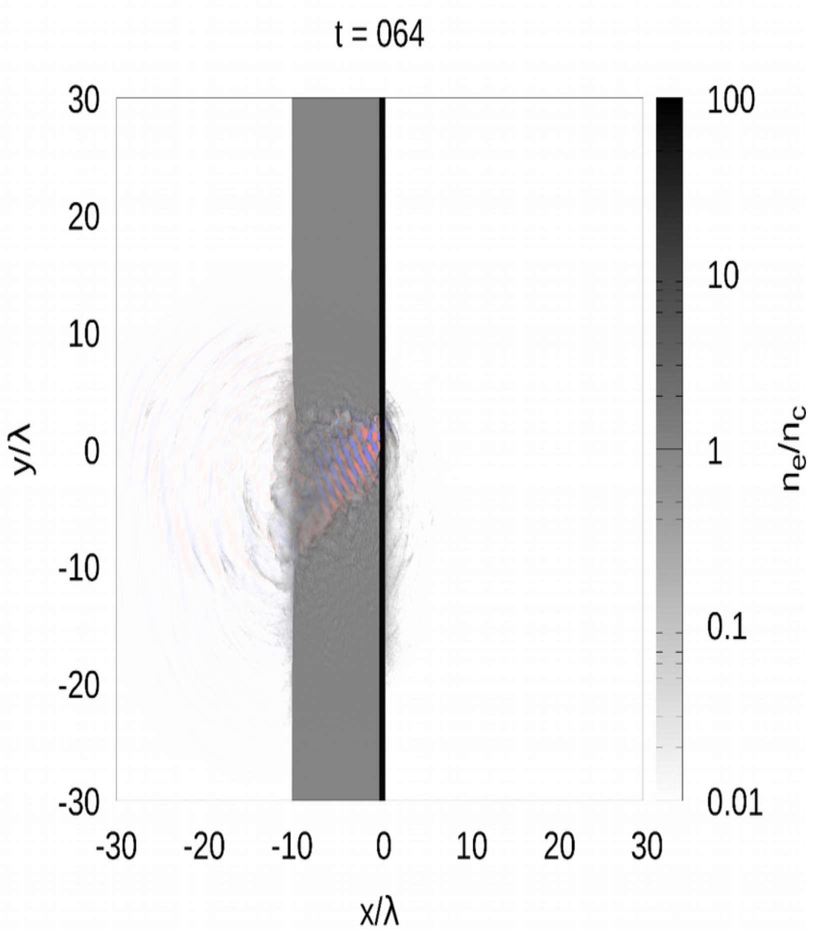

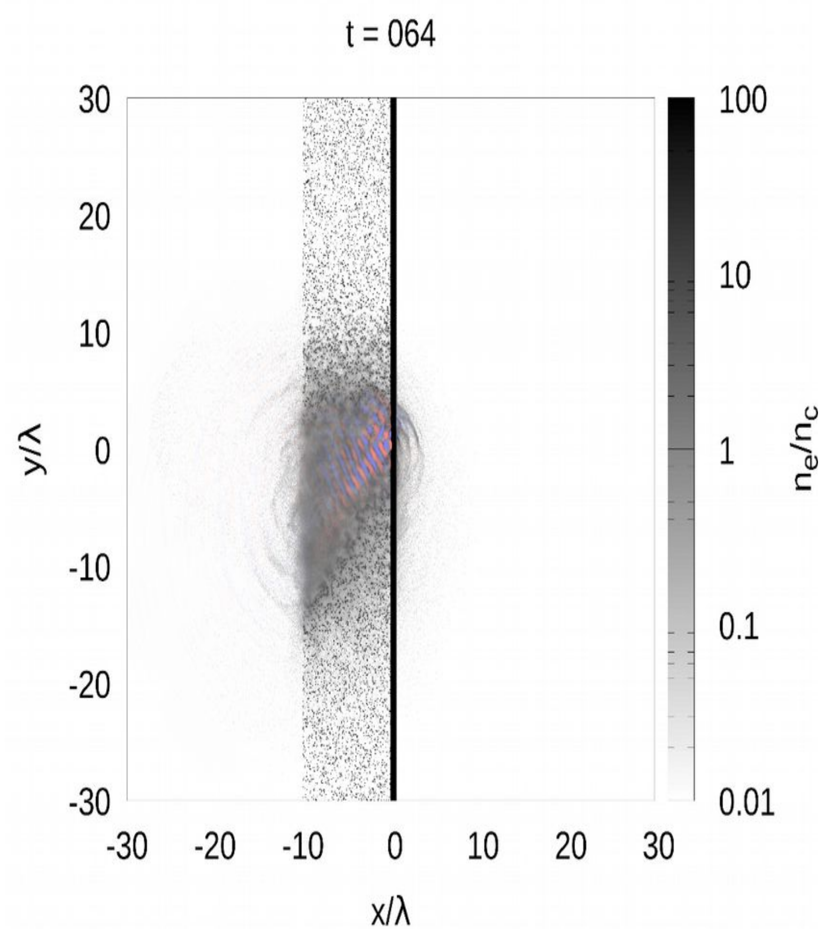

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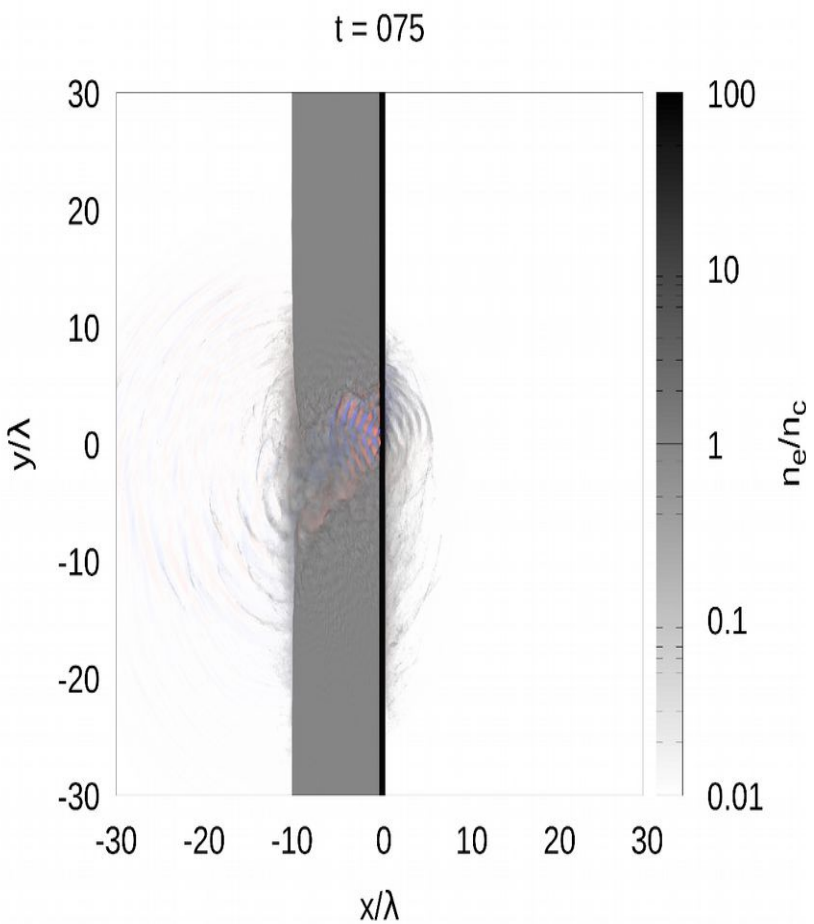
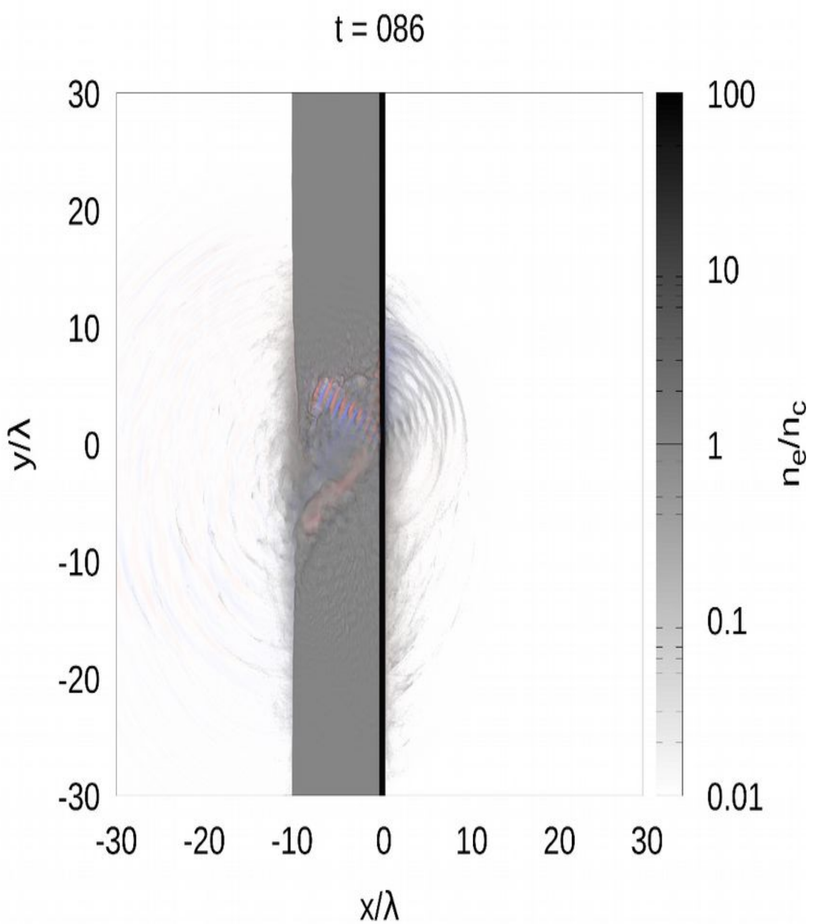
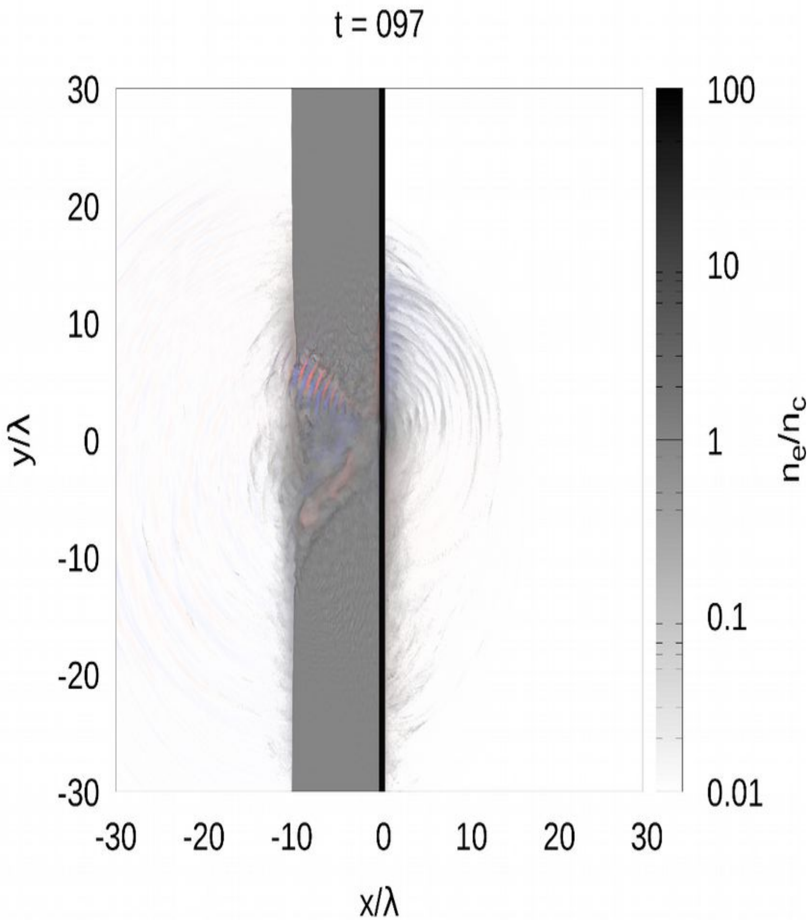
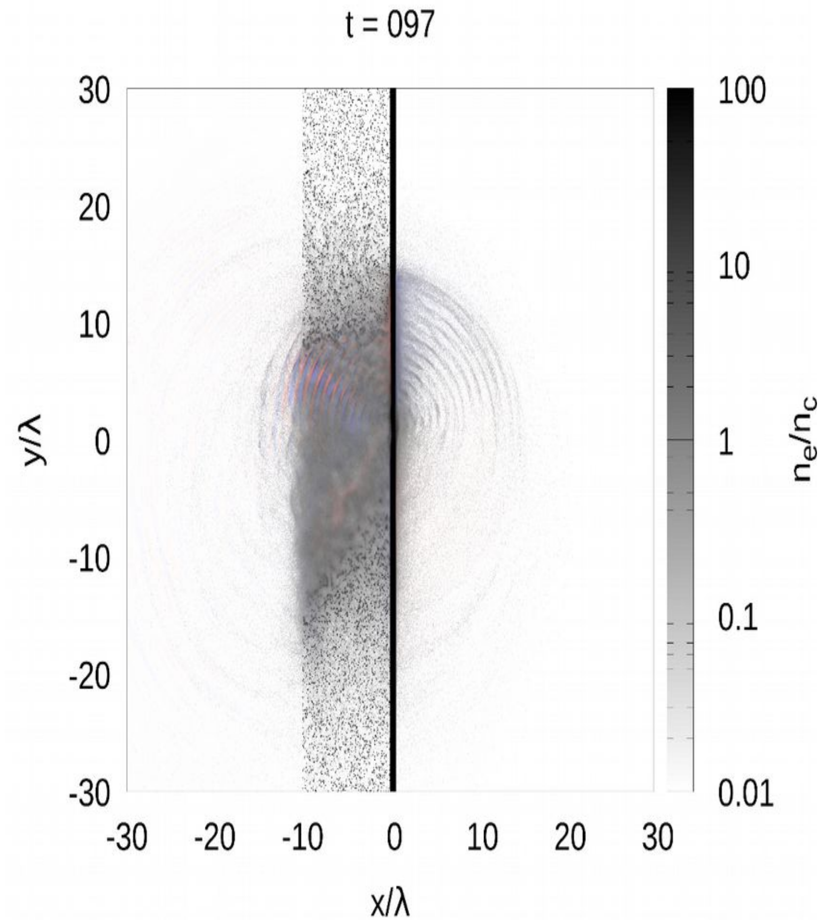


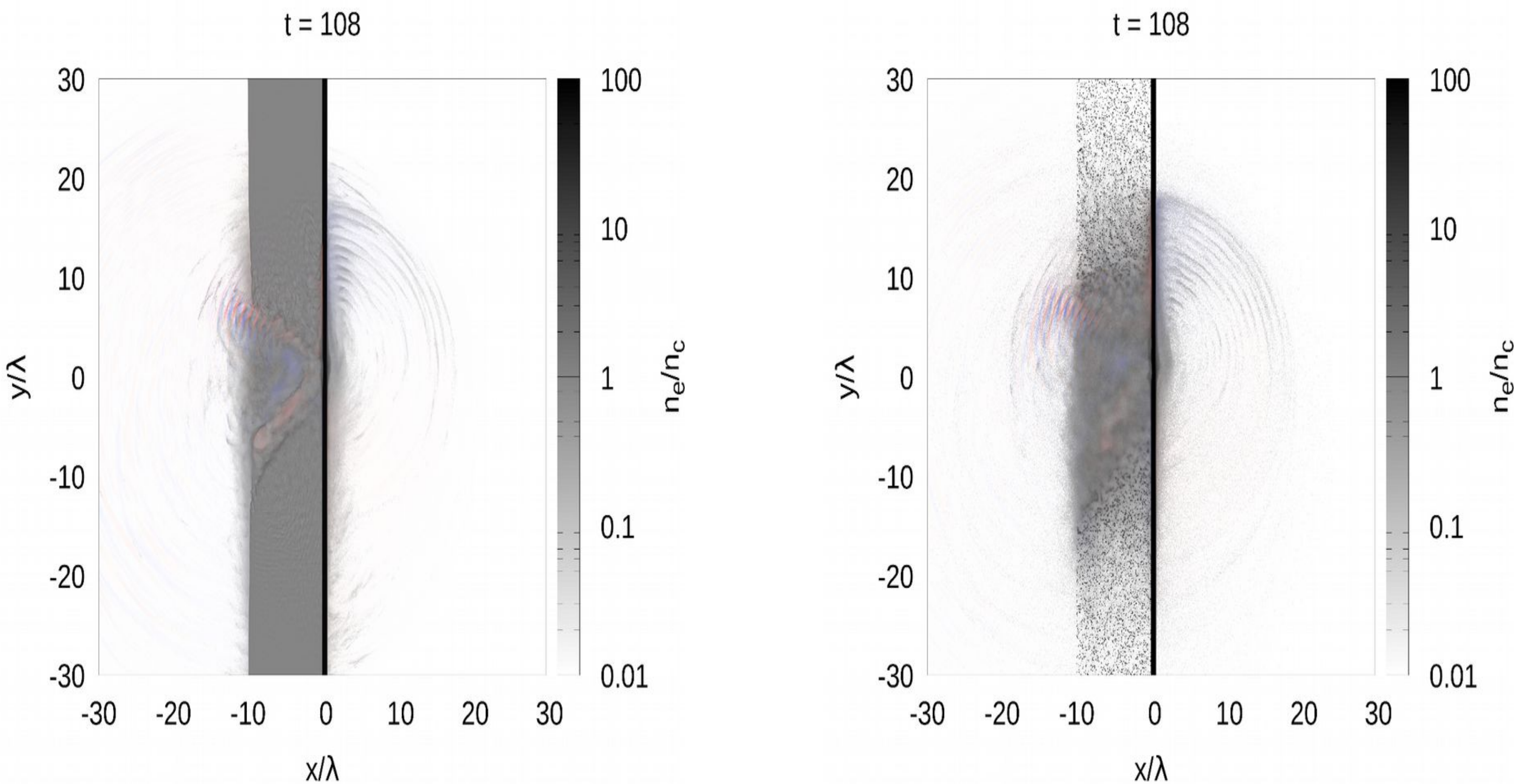
Uniform foam vs nanostructured foam



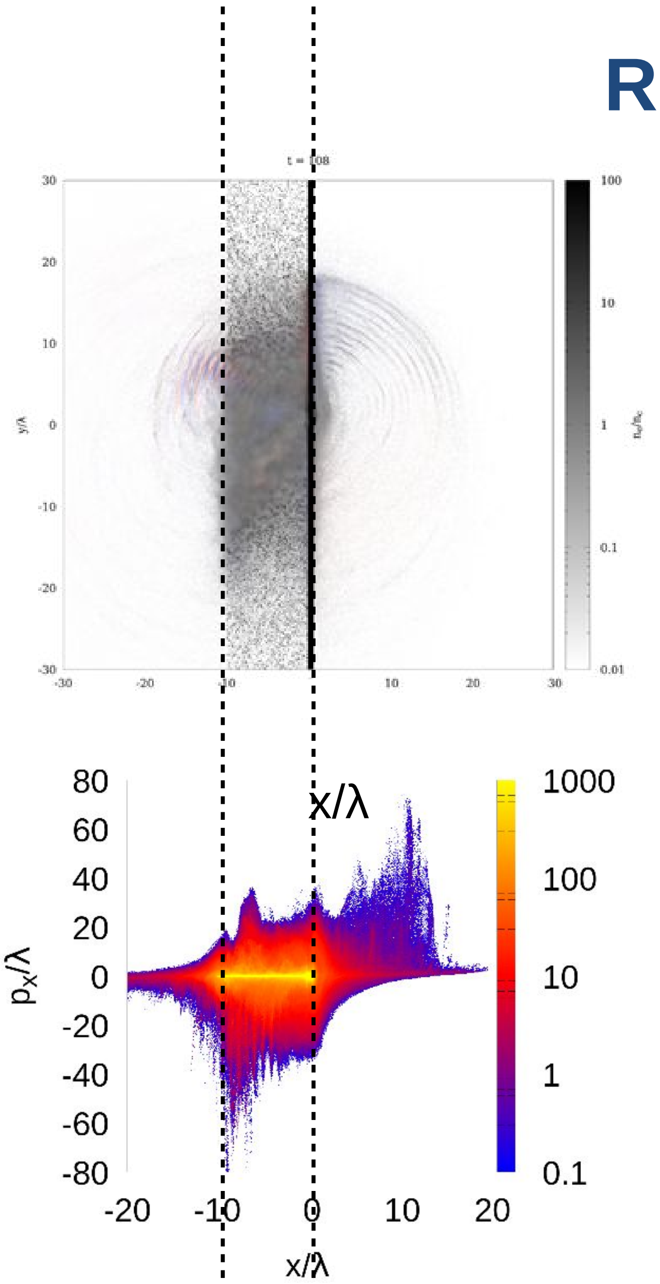

t = 097
30
20
10
0
-10
-20
-30
y/λ
-30
-20
-10
0
10
20
30
x/λ
100
10
1
0.1
0.01
n_e/n_c

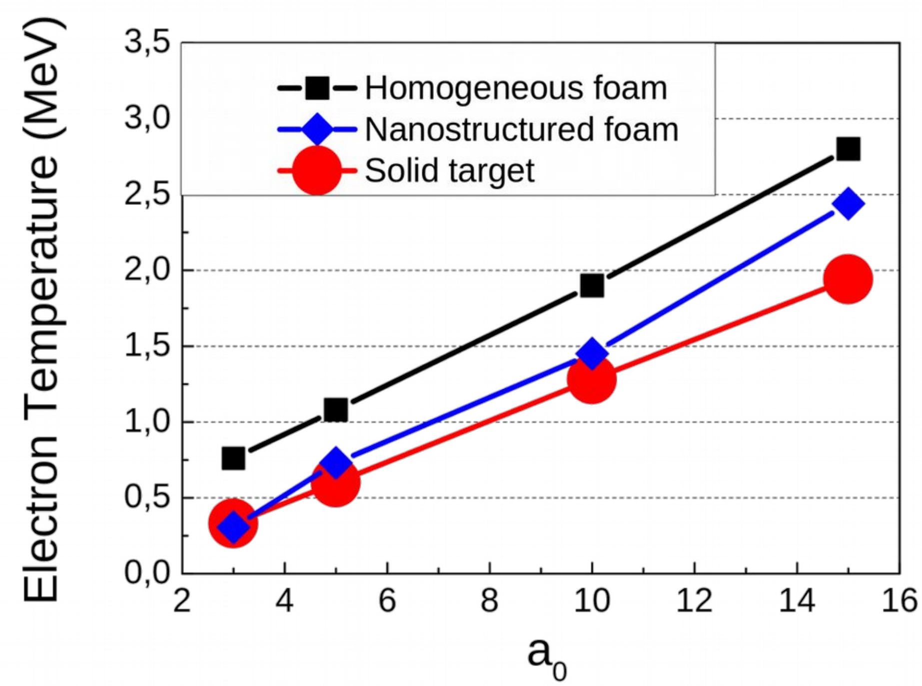

t = 097
30
20
10
0
-10
-20
-30
y/λ
-30
-20
-10
0
10
20
30
x/λ
100
10
1
0.1
0.01
n_e/n_c

Uniform foam vs nanostructured foam



Results: $T_{unif} > T_{nano} > T_{flat}$

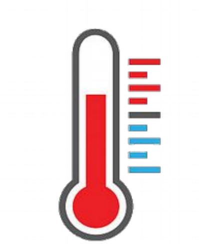




For foam-attached targets **we exclude the escaping fast-electron population**

Benchmark with experimental results

e^- temperature model



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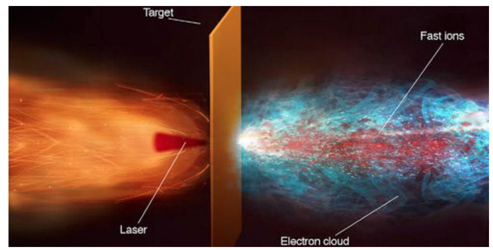
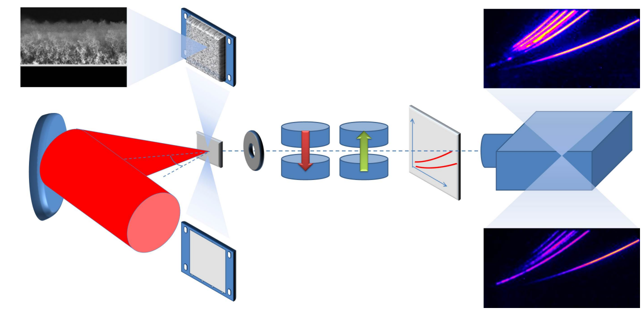
TNSA ion acceleration model*



Benchmark with exp.

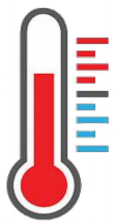


I.Prencipe et al. PPCF 58 (2016)
M.Passoni et al. PRAB 19 (2016)

*quasi-static
Passoni-Lontano model
Phys. Rev. Lett. 101 (2008)

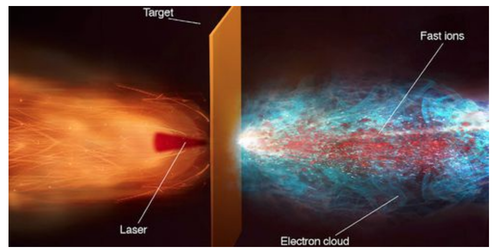
Benchmark with experimental results

e⁻ temperature model

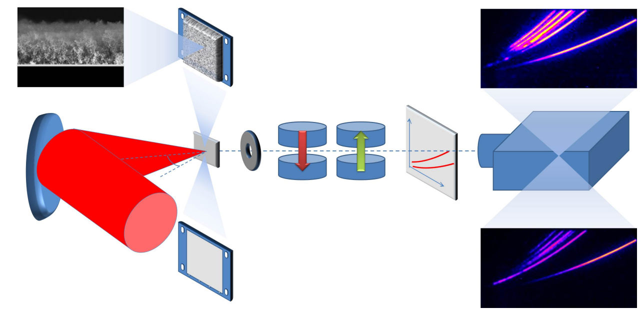


+

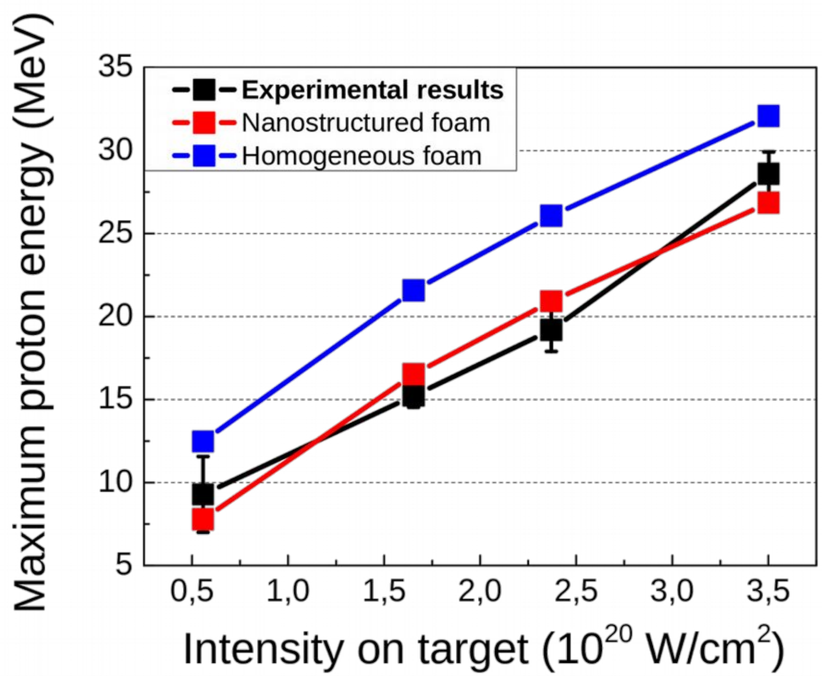
TNSA ion acceleration model*



Benchmark with exp.



I.Prencipe et al. PPCF 58 (2016)
M.Passoni et al. PRAB 19 (2016)



*quasi-static
Passoni-Lontano model
Phys. Rev. Lett. 101 (2008)

“Realistic” modeling

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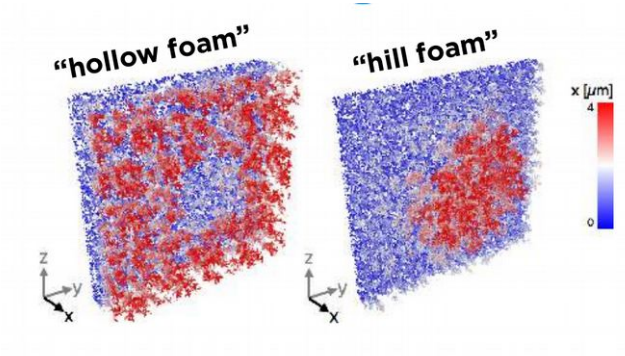


More realistic models

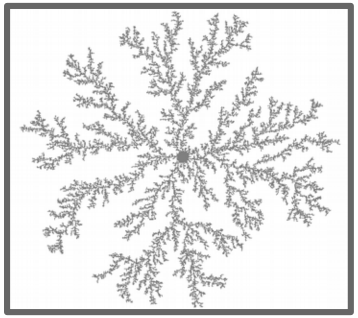
M.Passoni et al. PRAB 19 (2016)

I.Prencipe et al. PPCF 58 (2016)

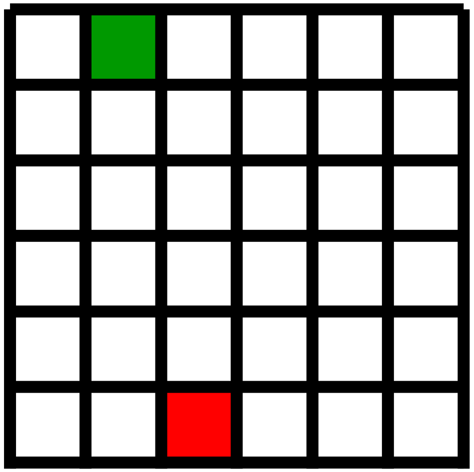
A.Formenti PhD thesis (2017-?)

“Realistic” modeling based on DLA

Diffusion Limited Aggregation (DLA)
A simple and very well studied model to reproduce structures resulting from aggregation phenomena.




Witten&Sander,PRL 47 , 1981



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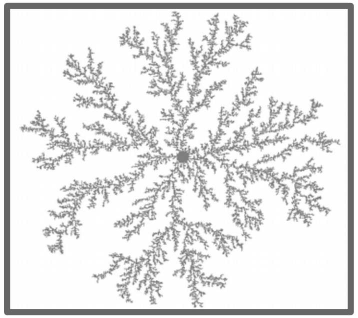

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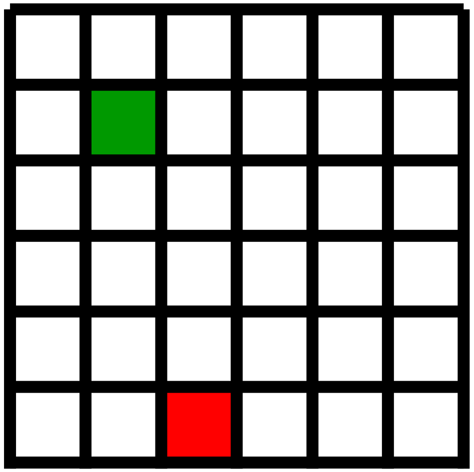

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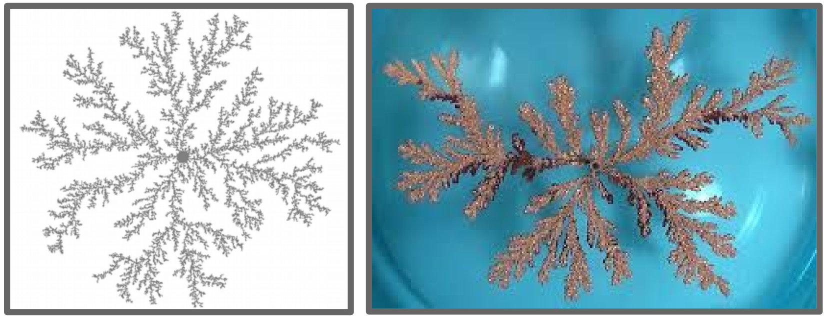

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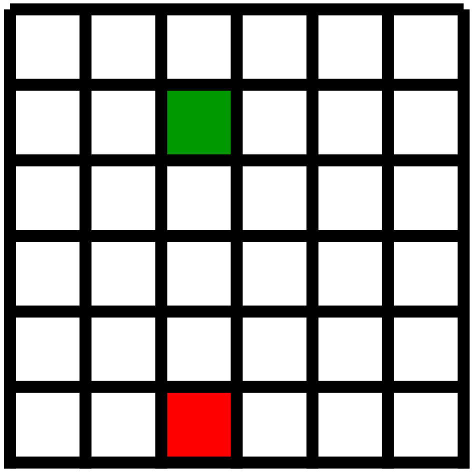

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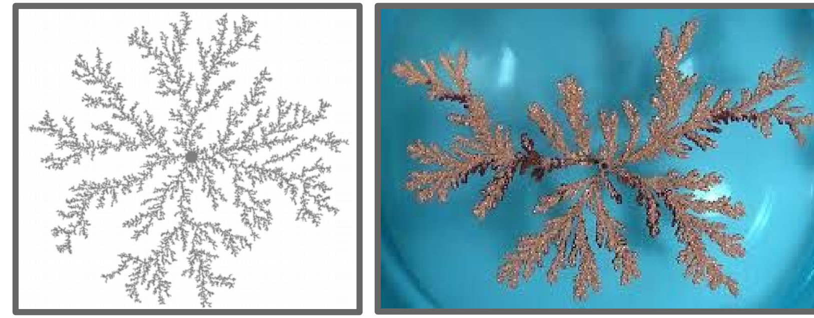

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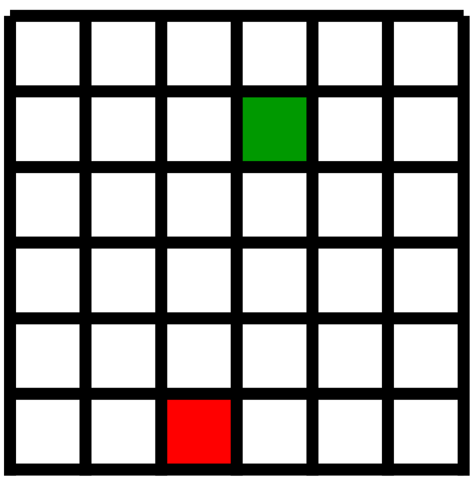

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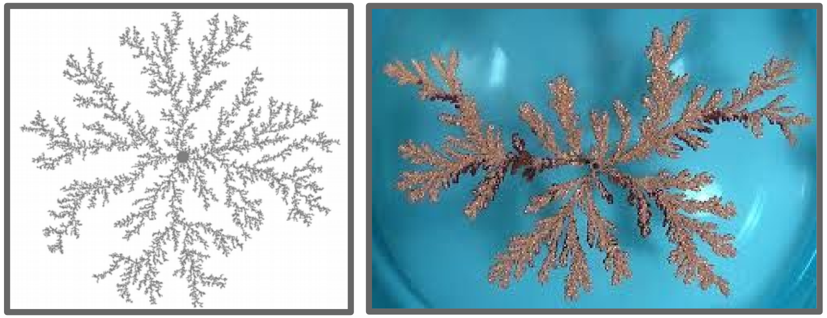

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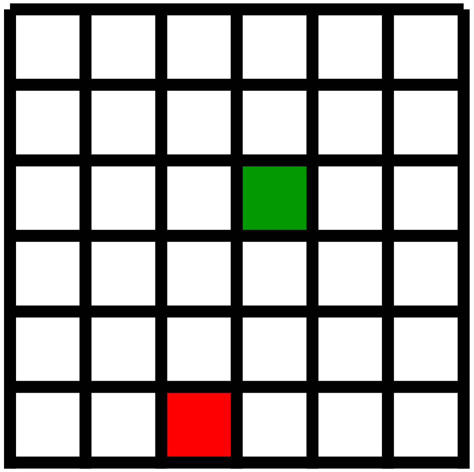

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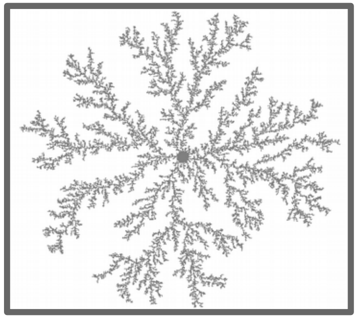

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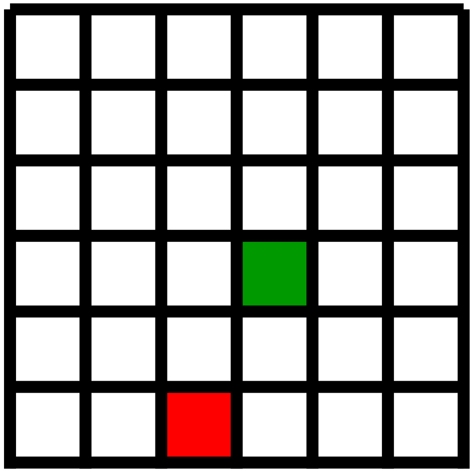

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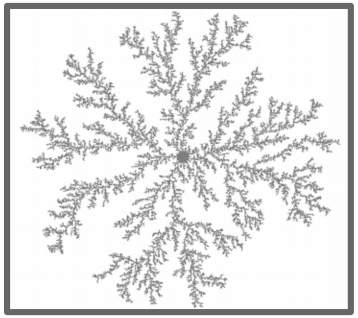


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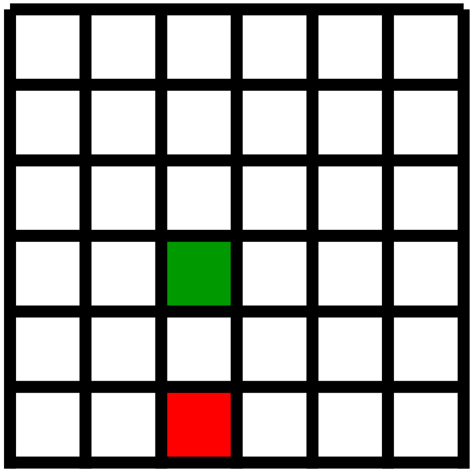

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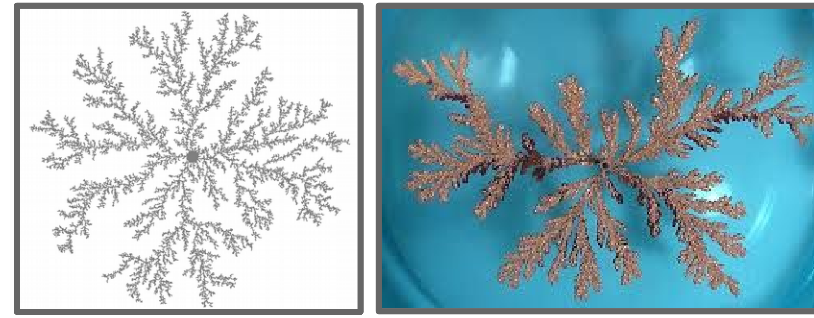

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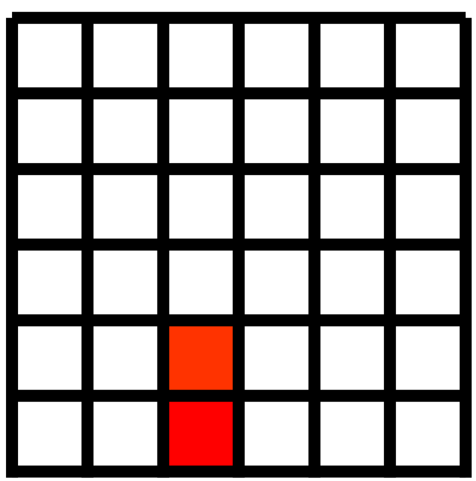

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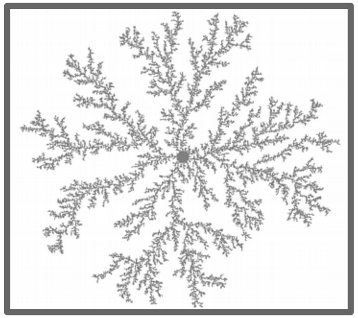

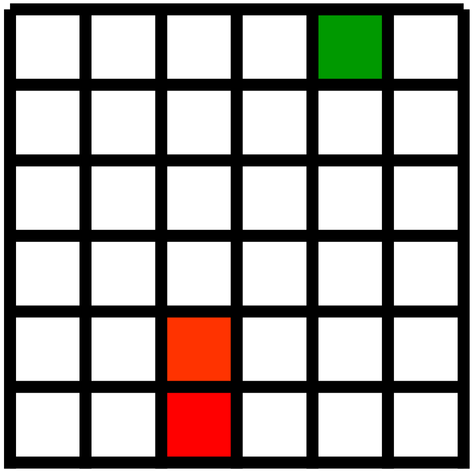

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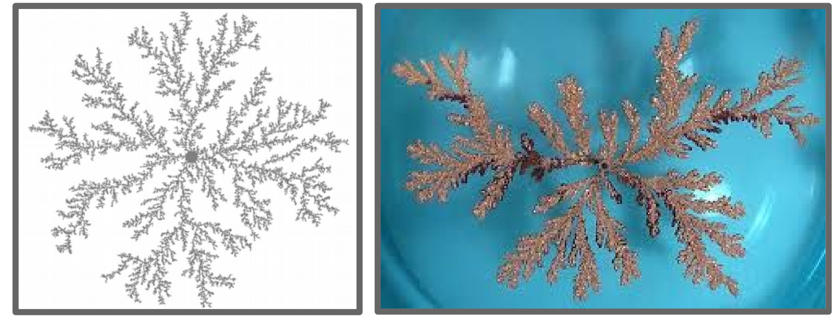

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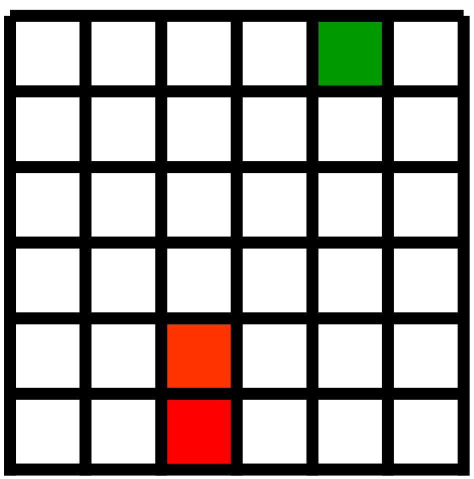

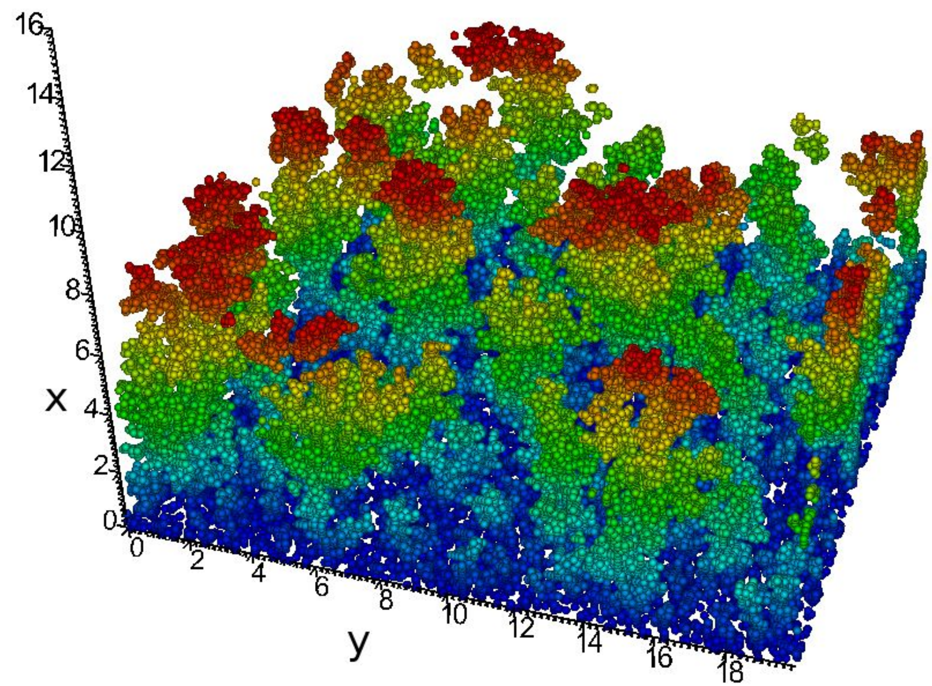

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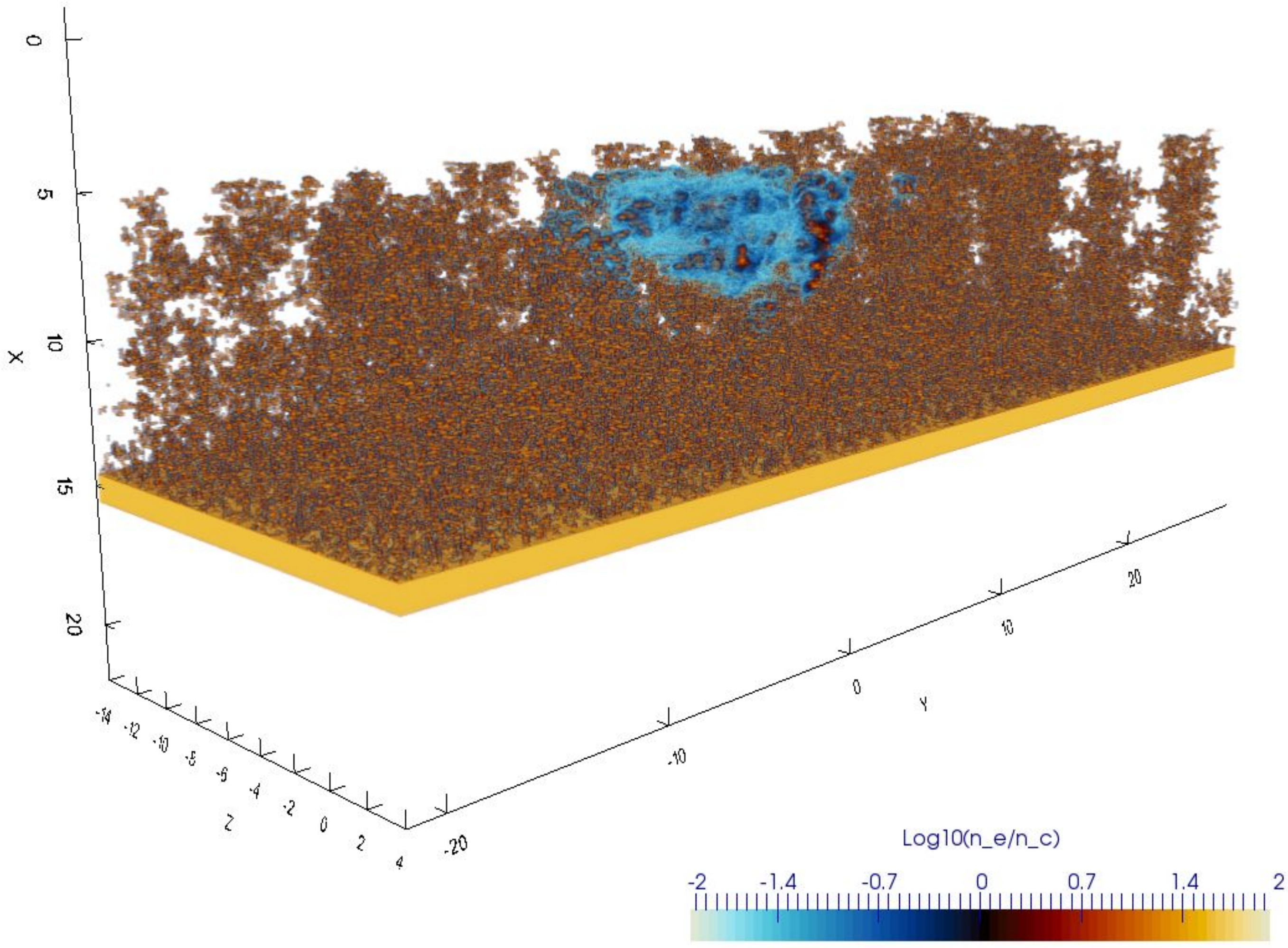

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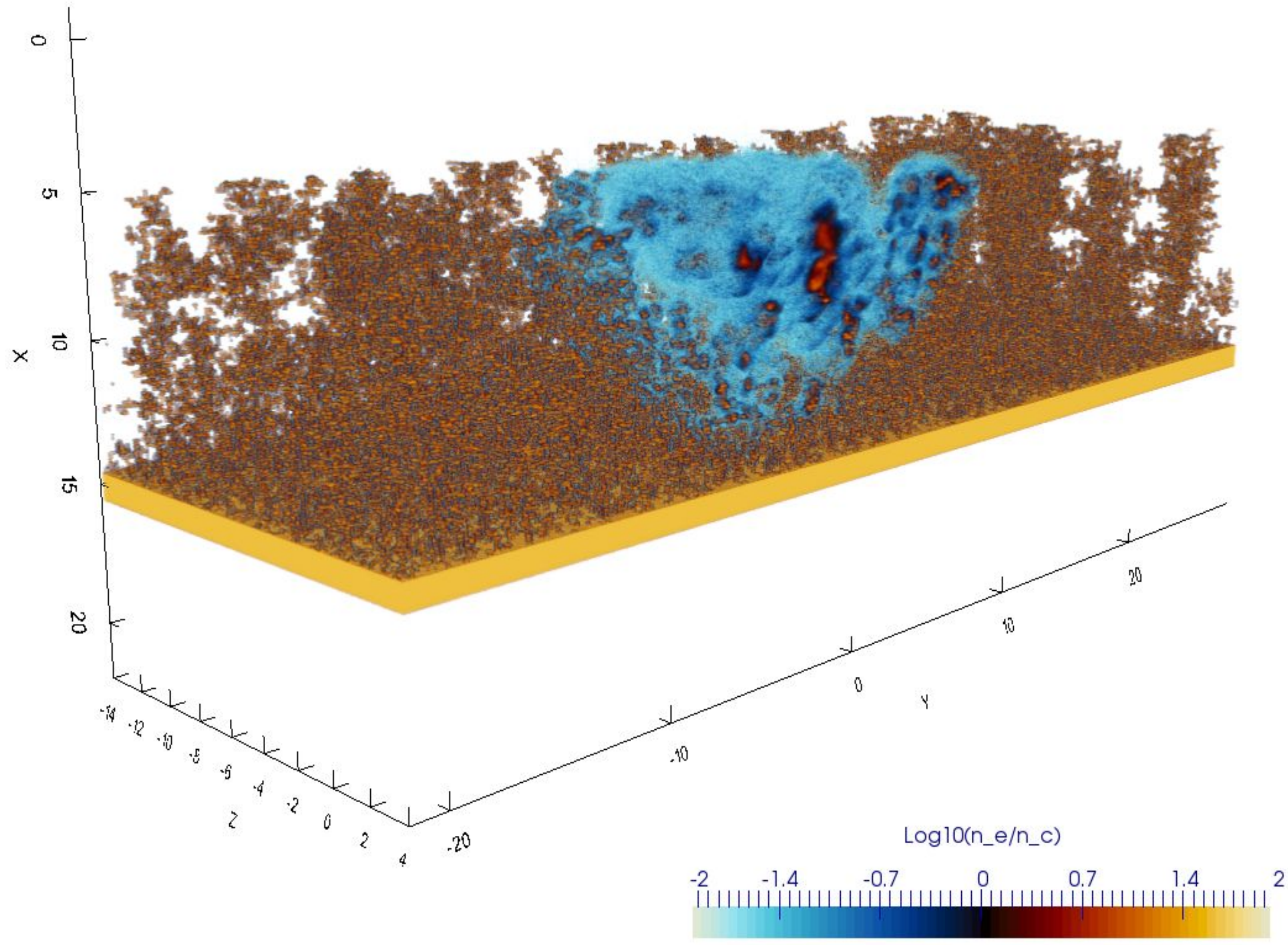

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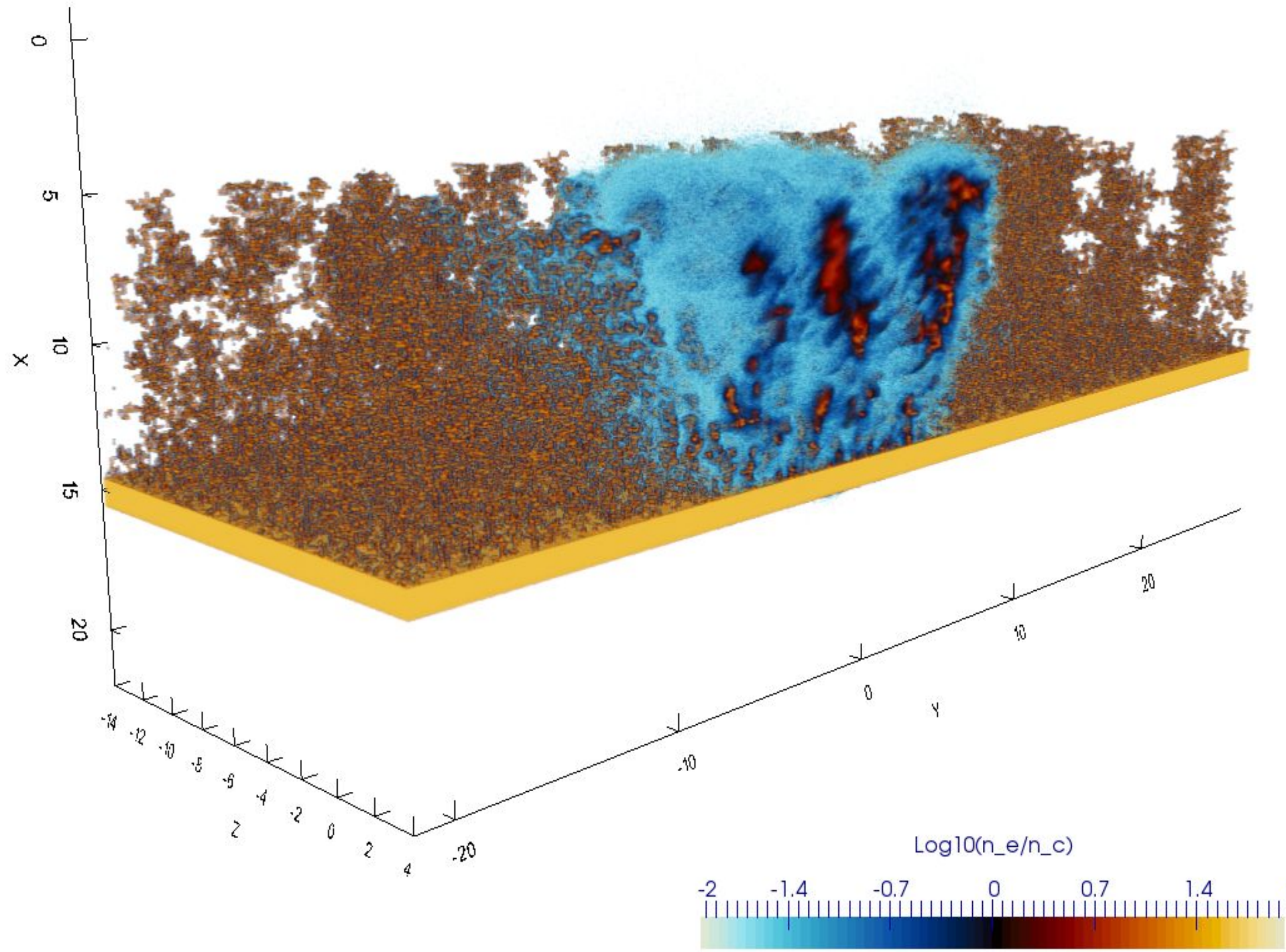

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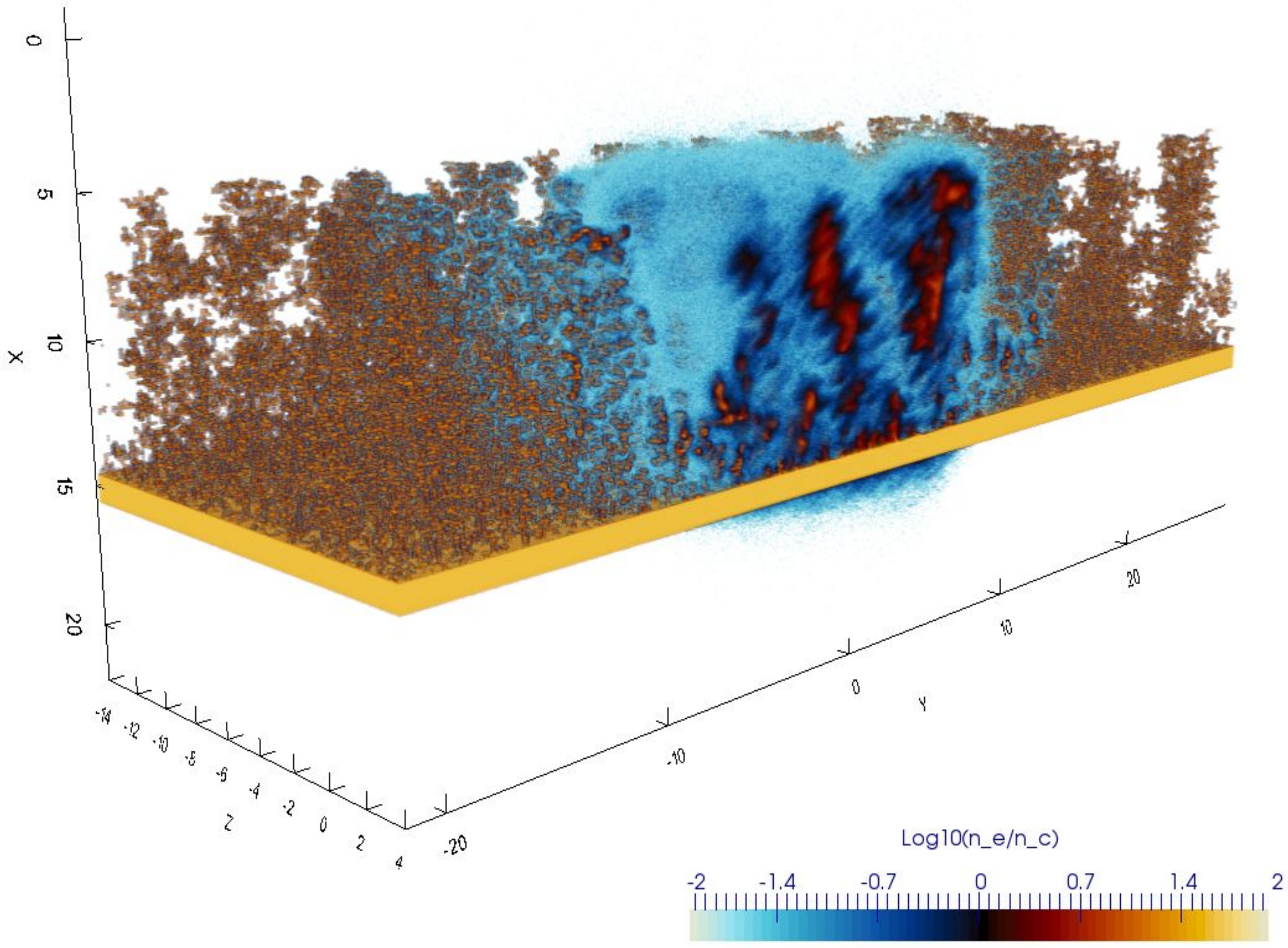

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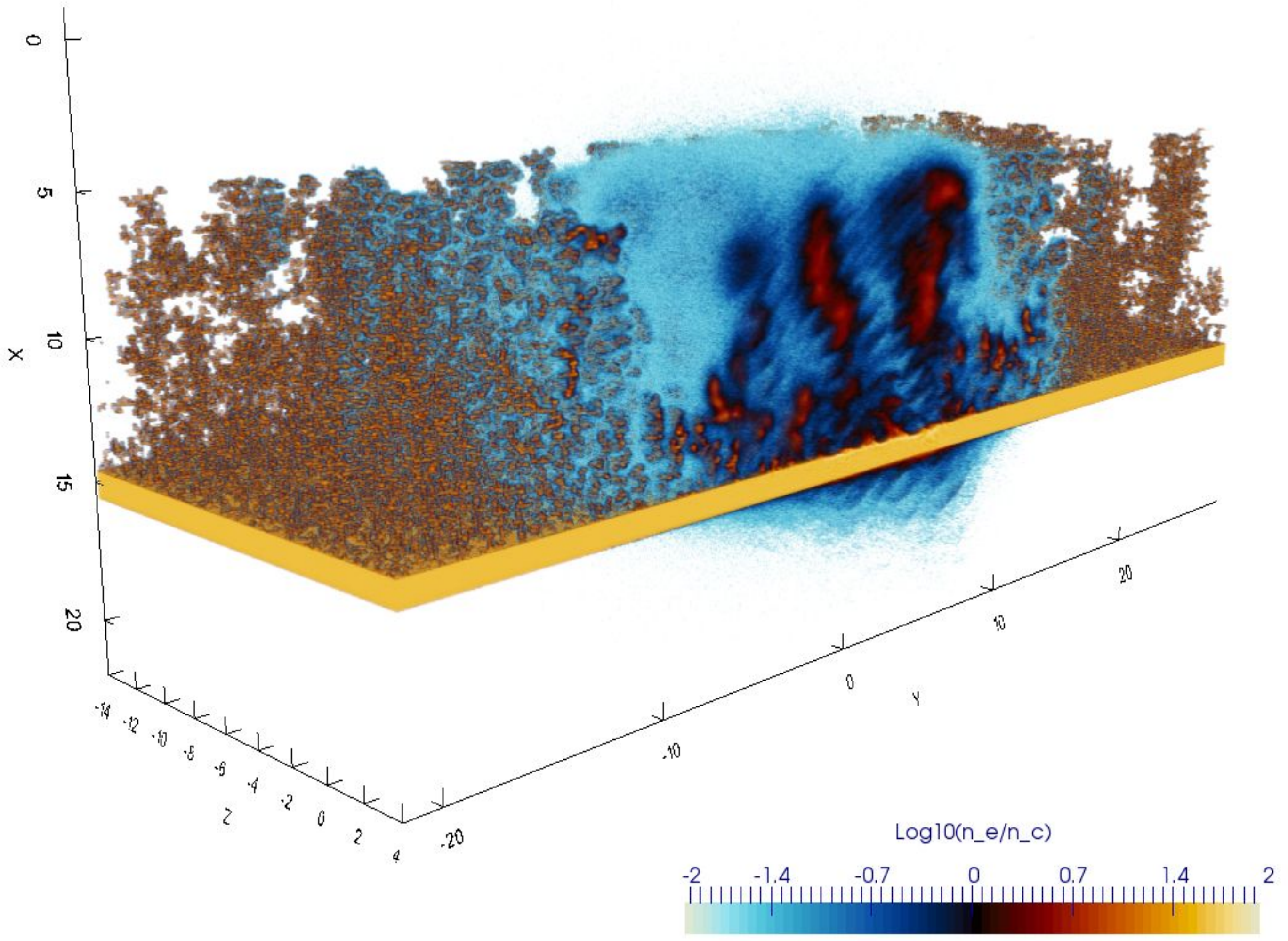

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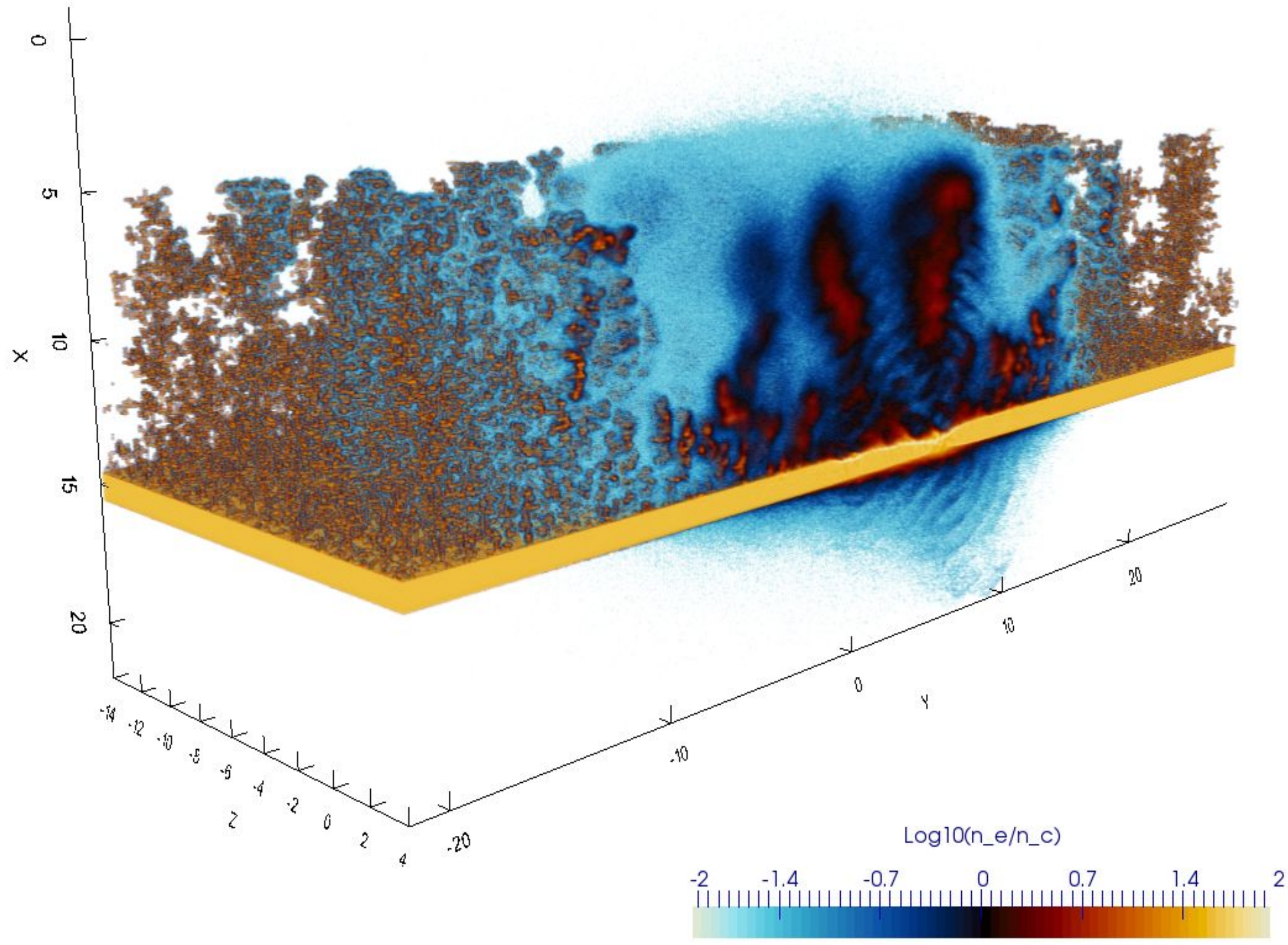

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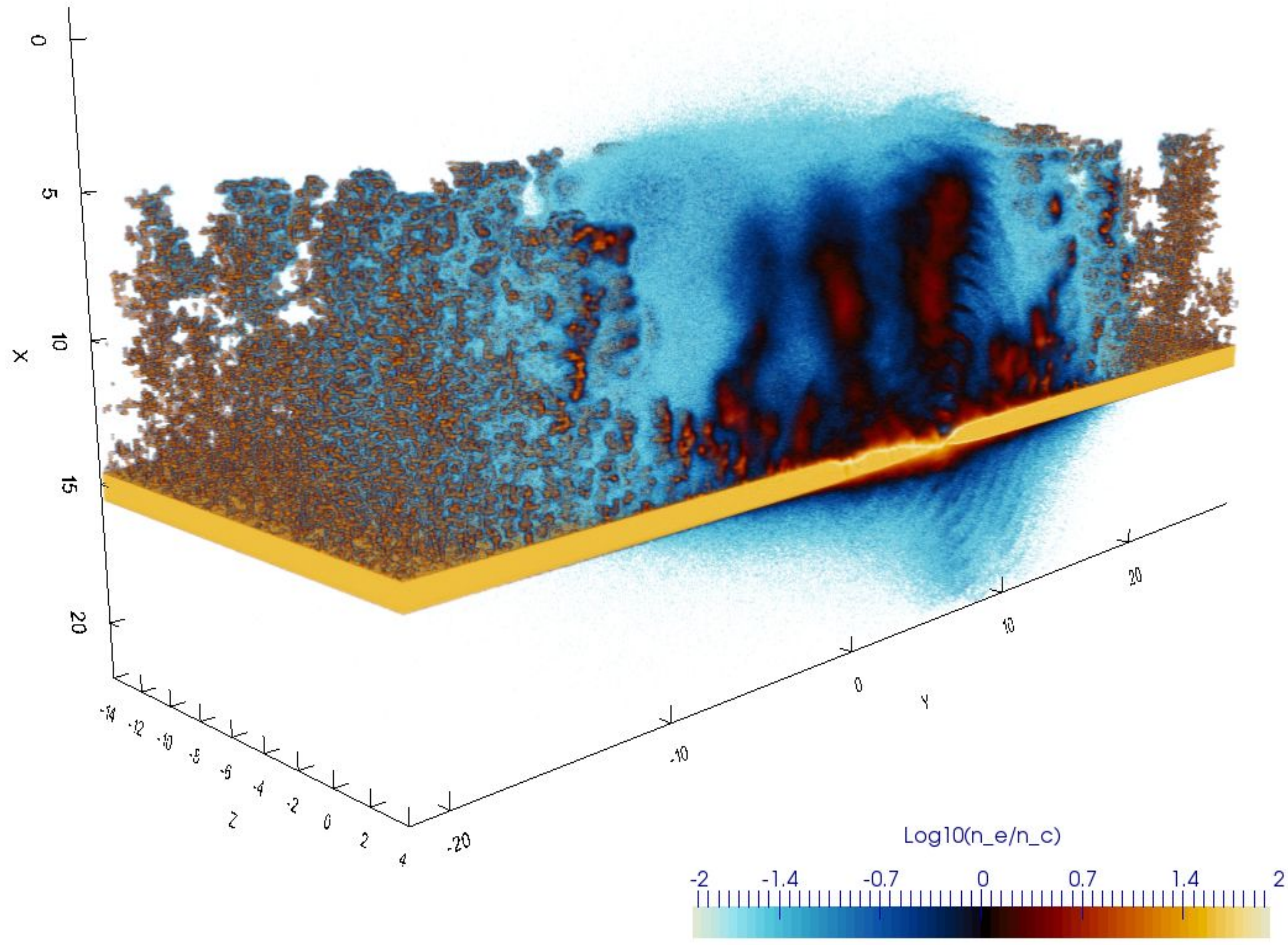

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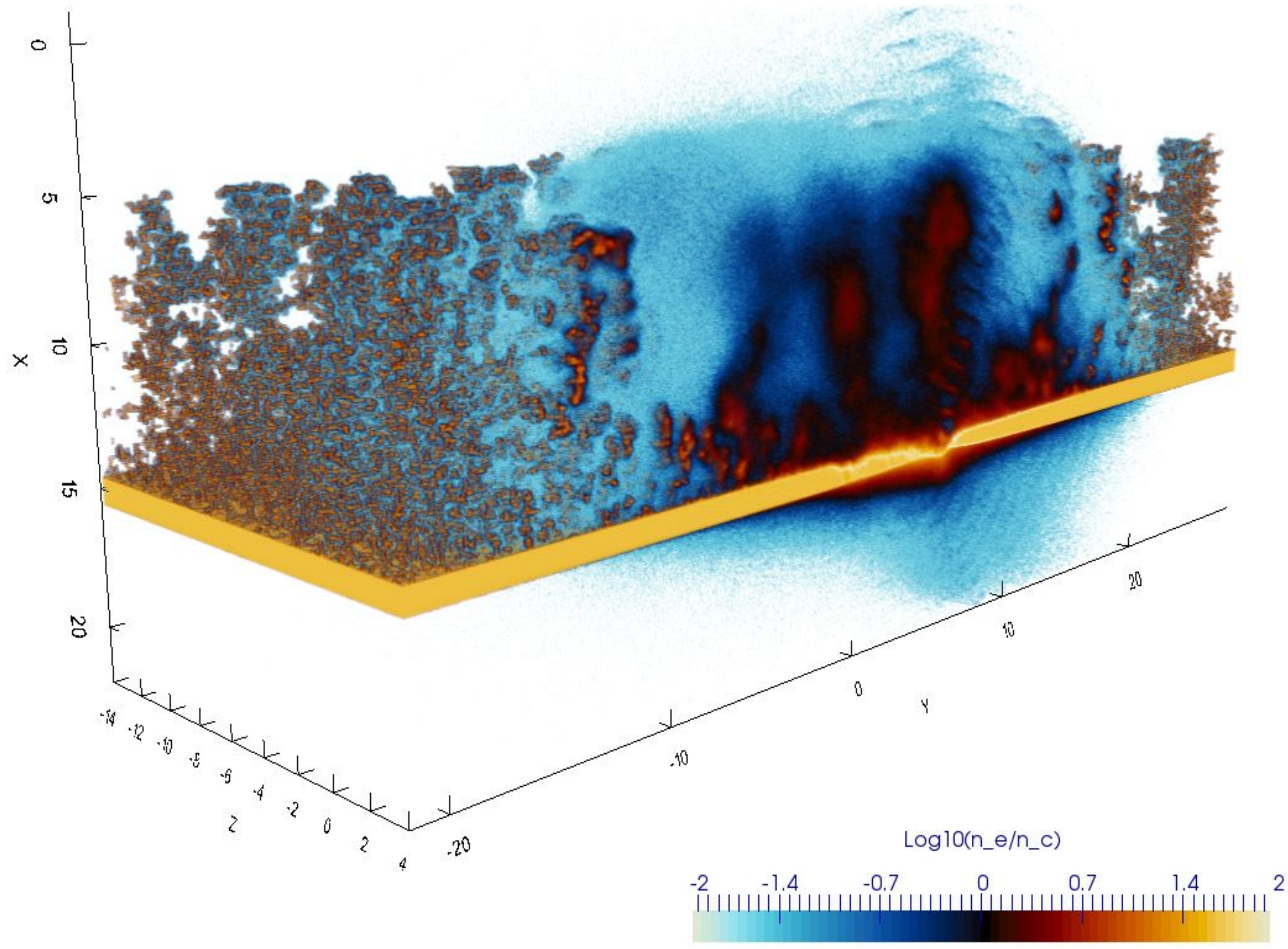

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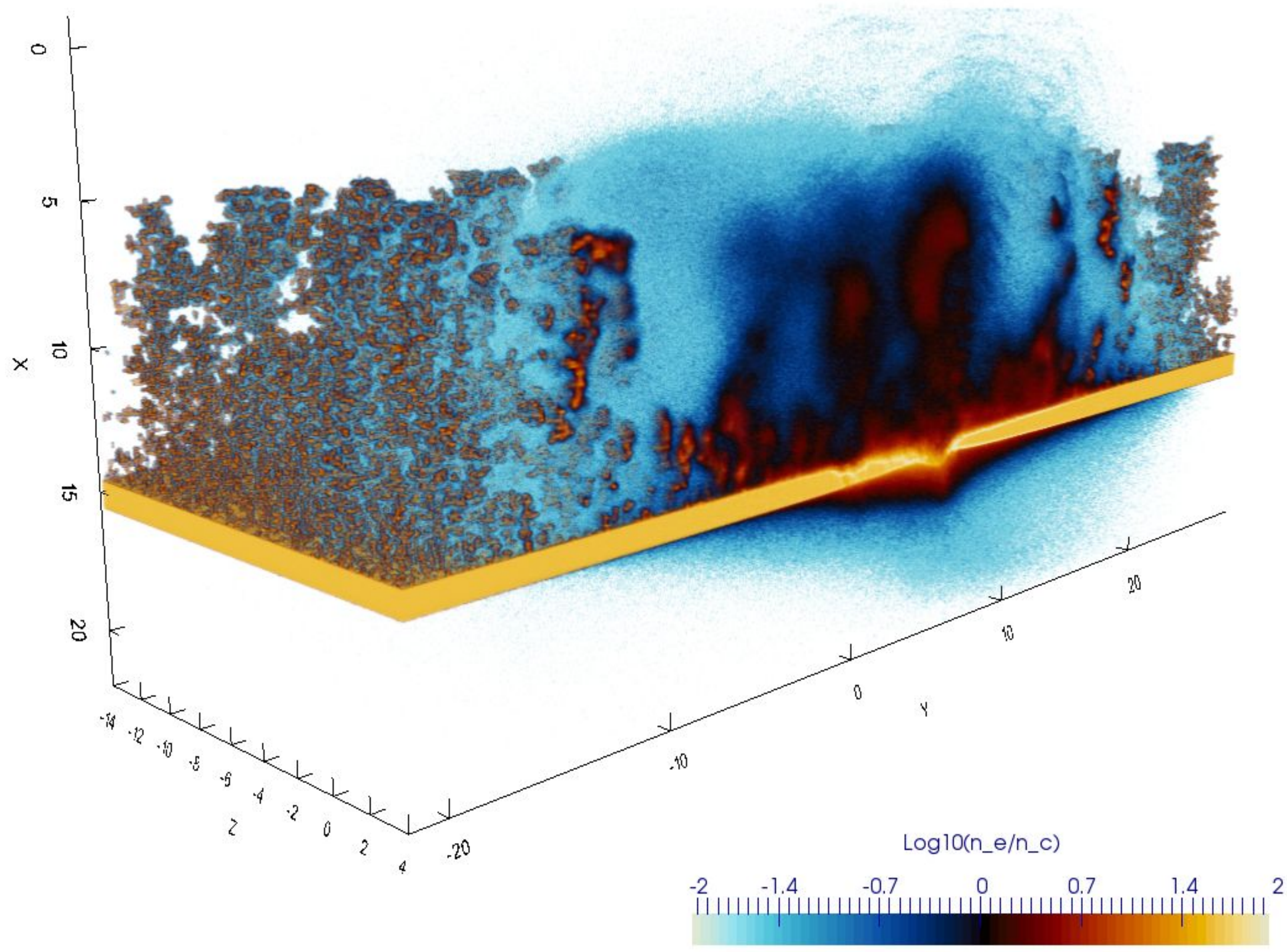
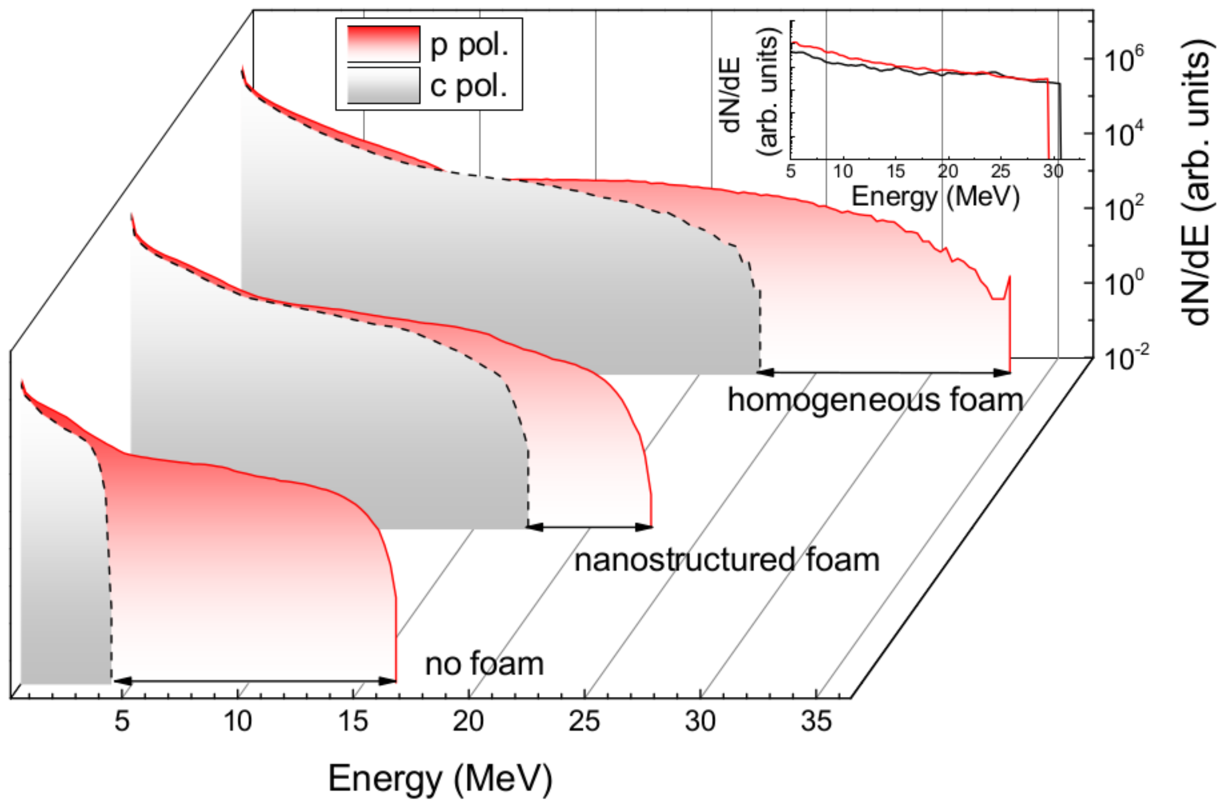


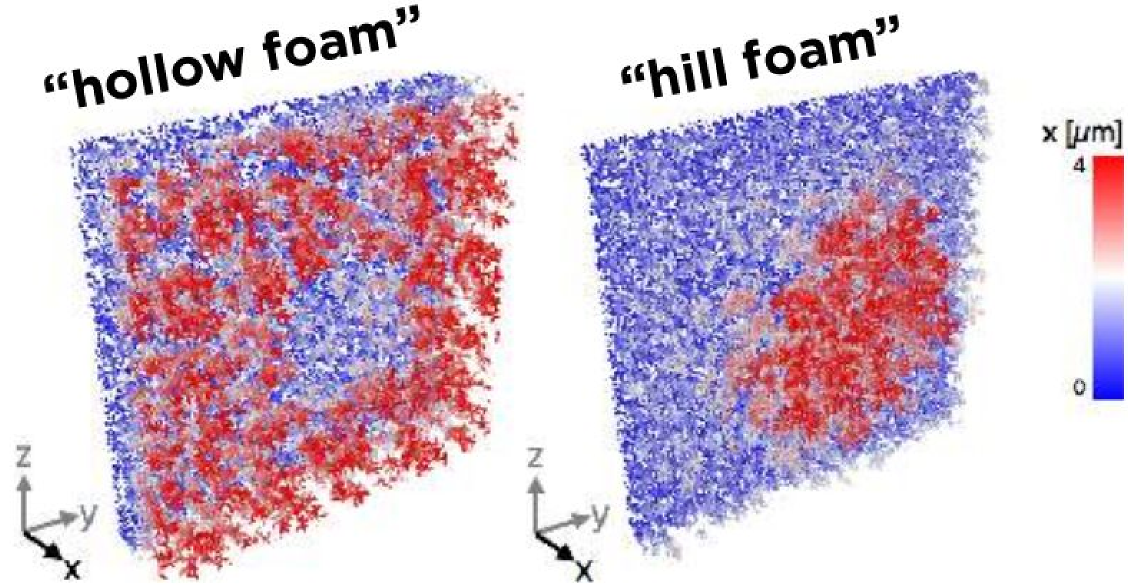
“Realistic” modeling based on DLA

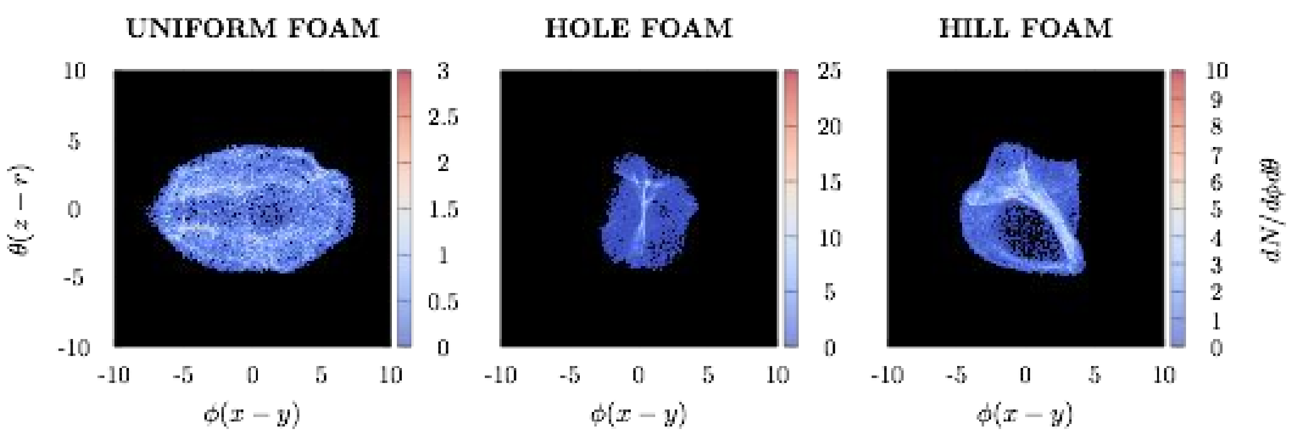
Differences in the simulated ion spectra



What’s next on this topic?

Simulated diagnostics for realistic configurations





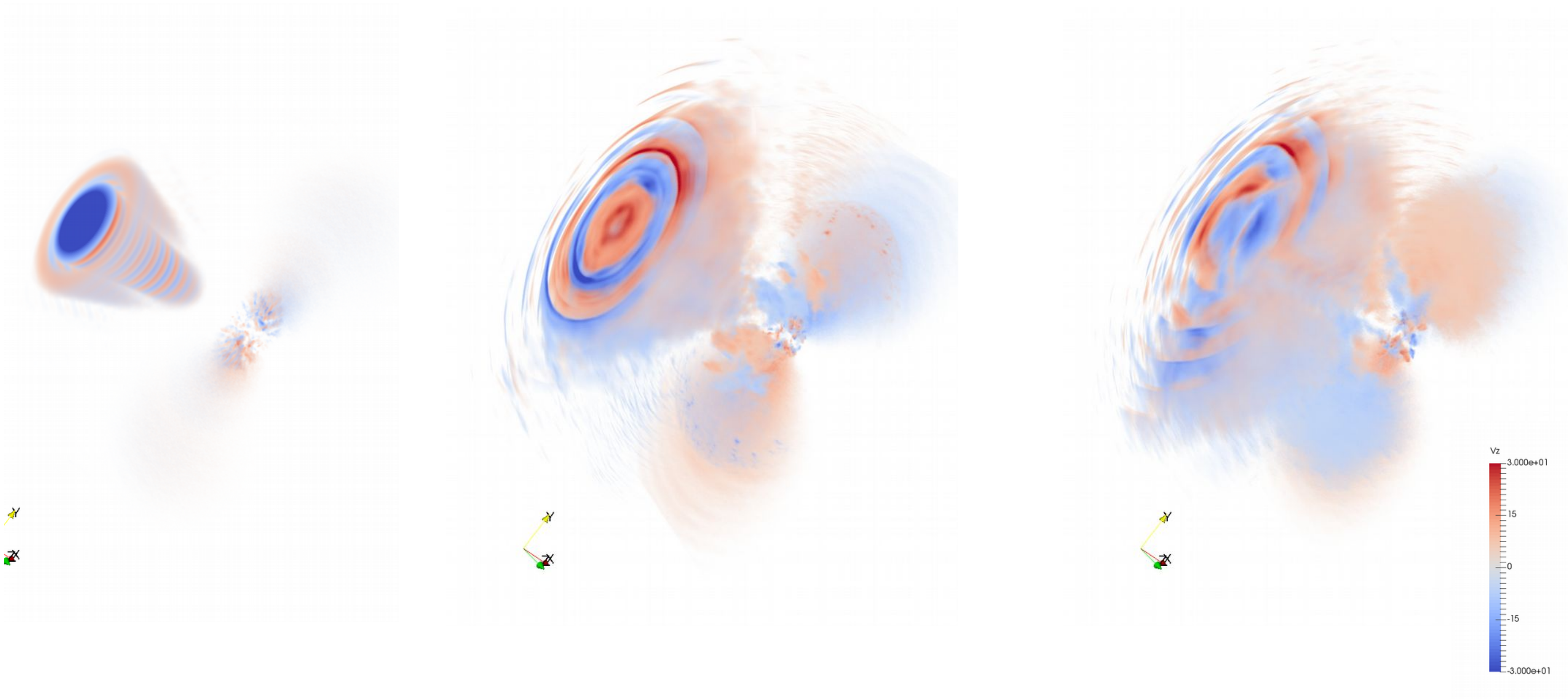
A. Formenti

Simulations of the reflected light

Flat target

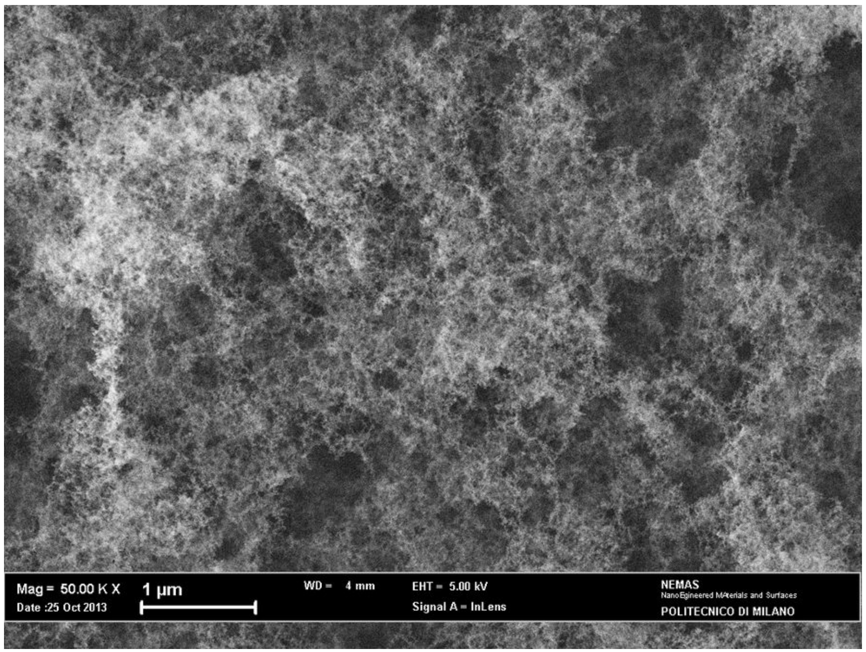
Uniform foam

DLA foam

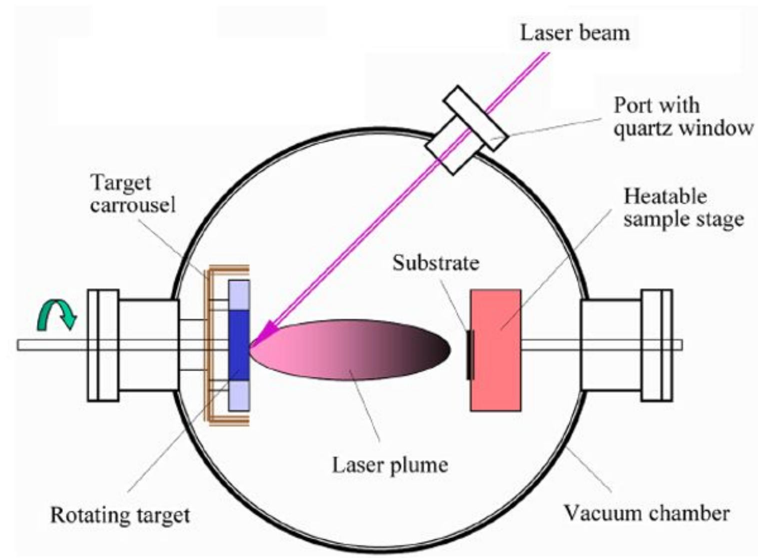


An improved realistic foam model

Real foam



Improved model



A. Pazzaglia

A model more closely based on the physics of Pulsed Laser Deposition

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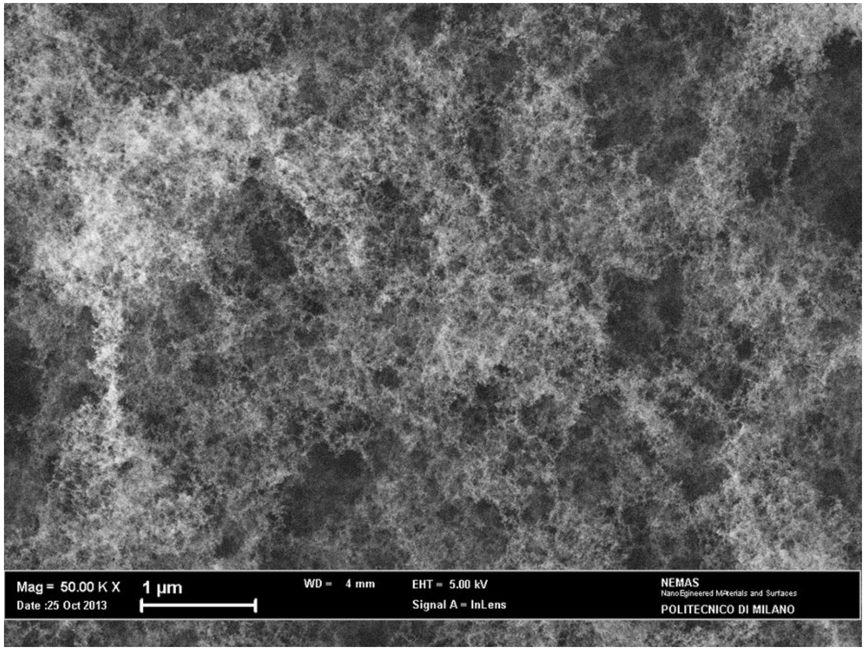

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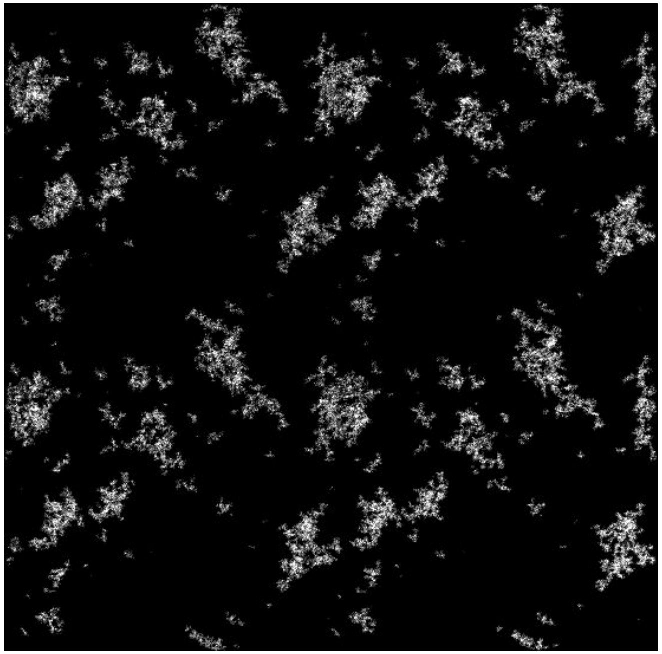

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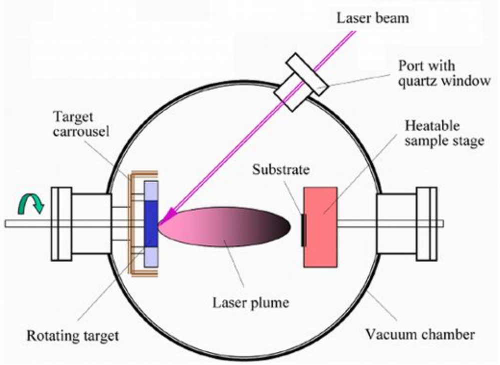

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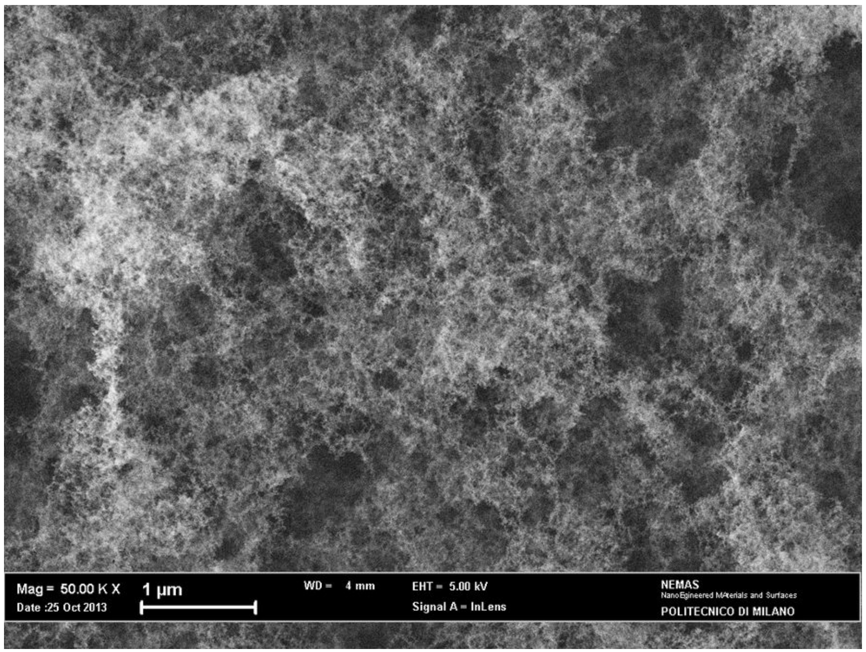

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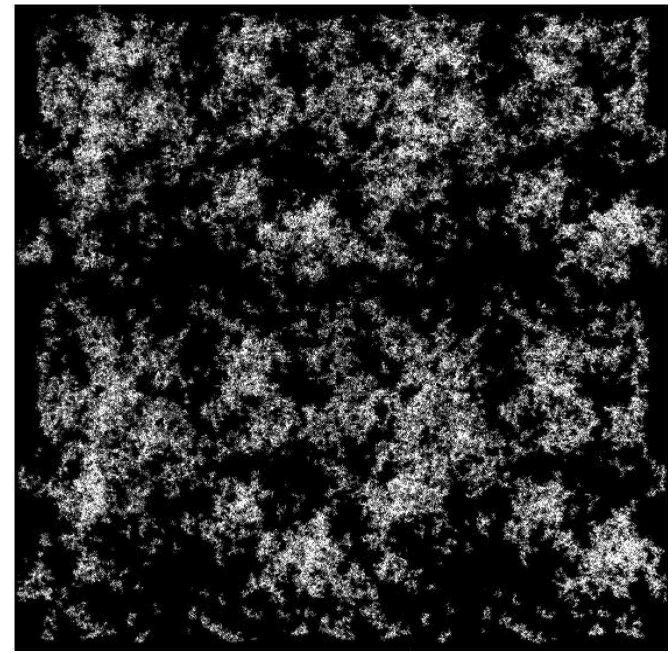

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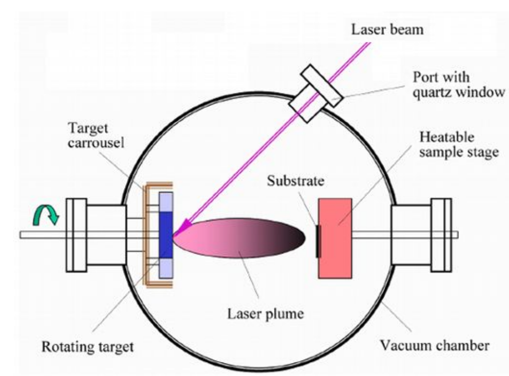

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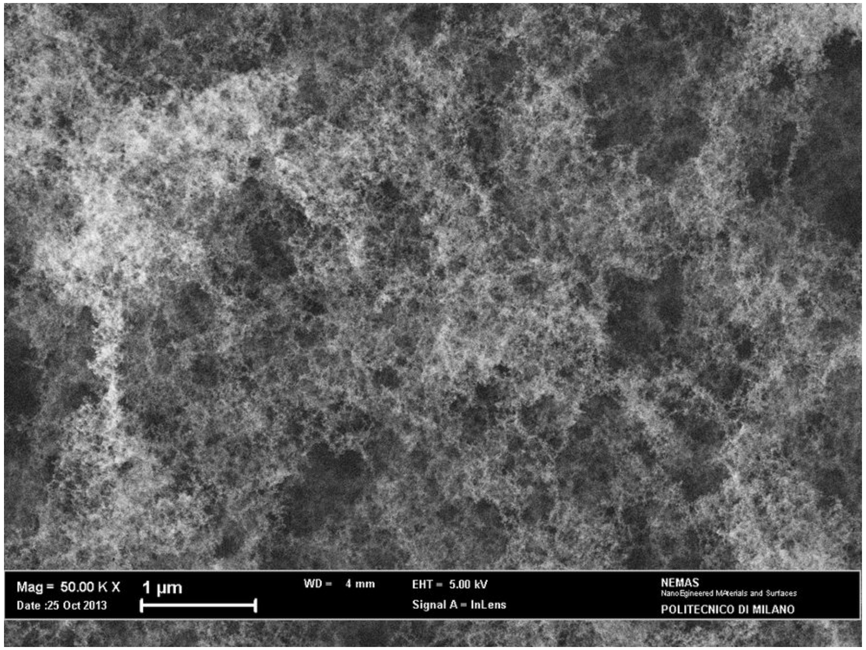

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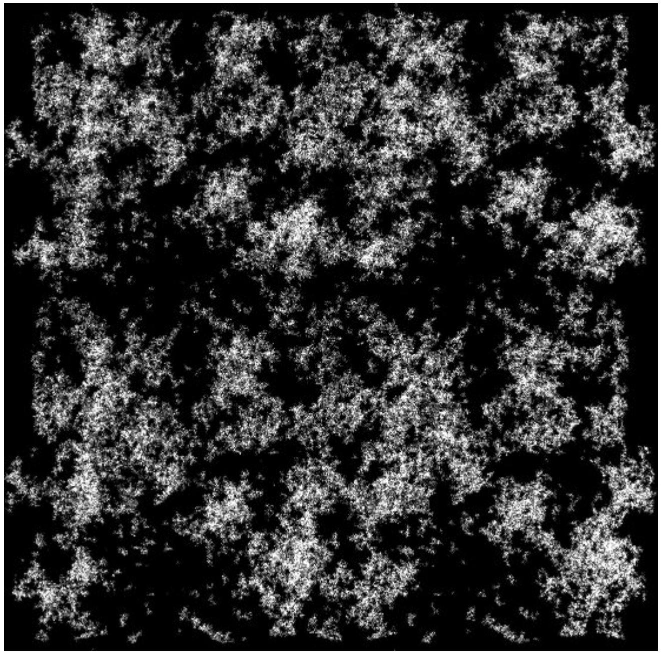

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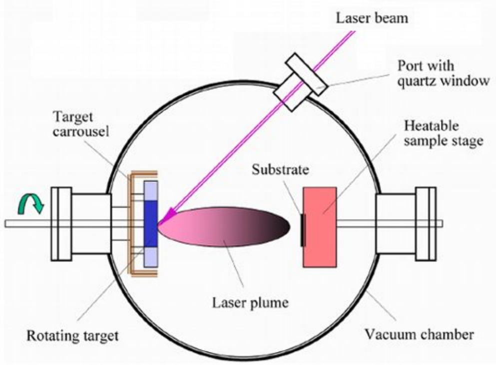

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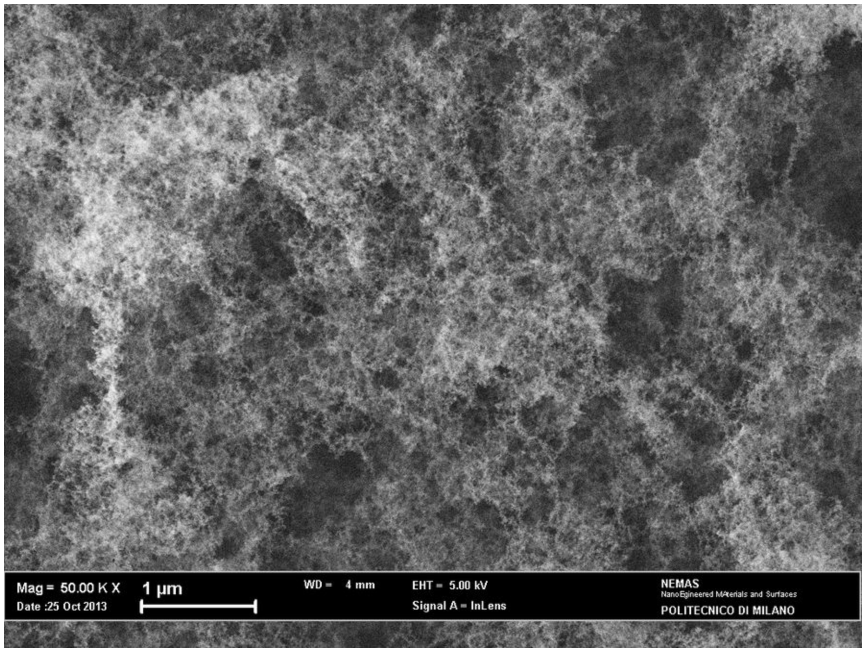

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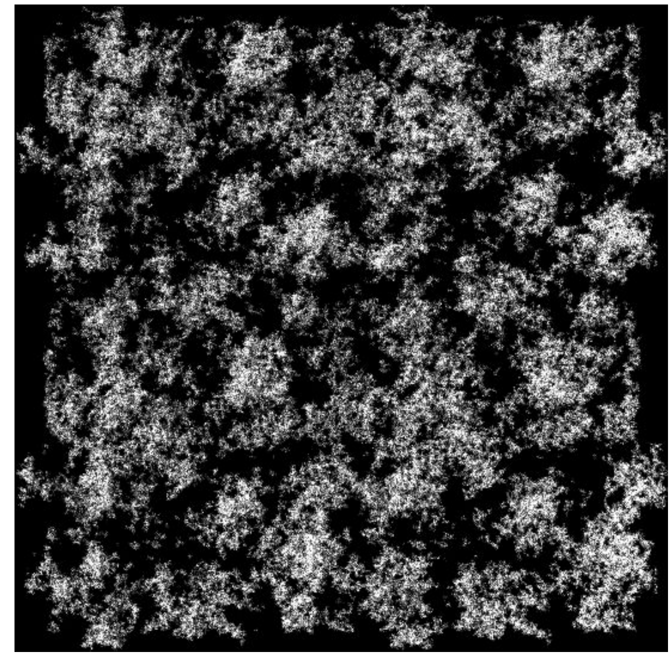

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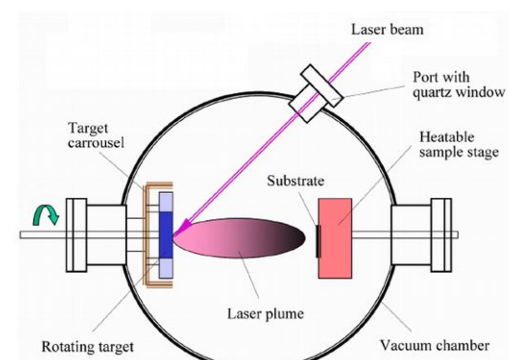

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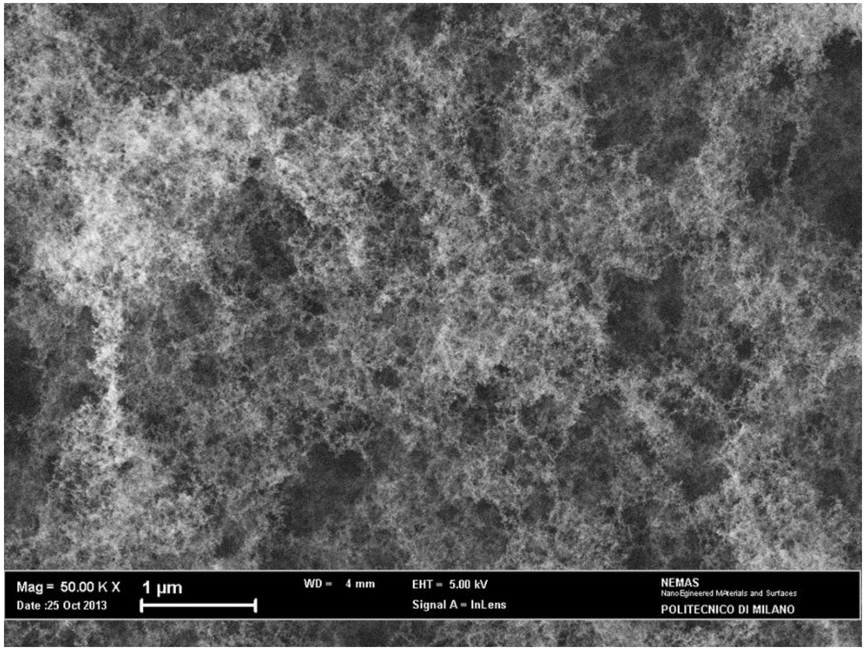

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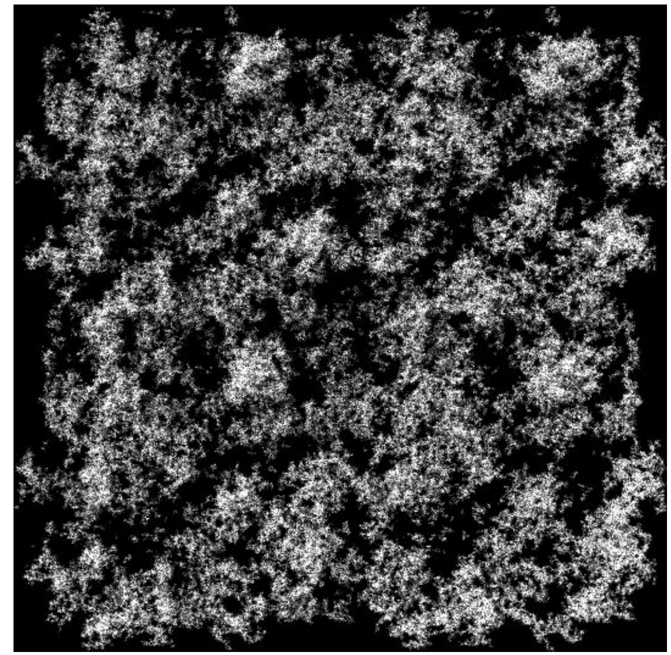

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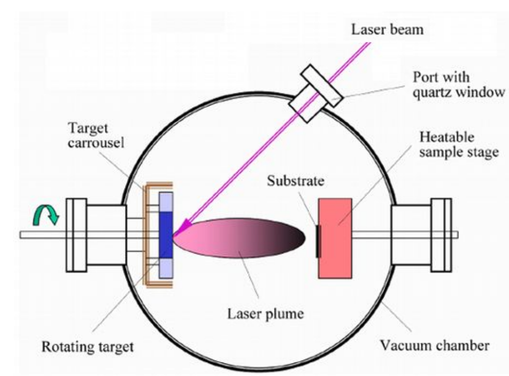

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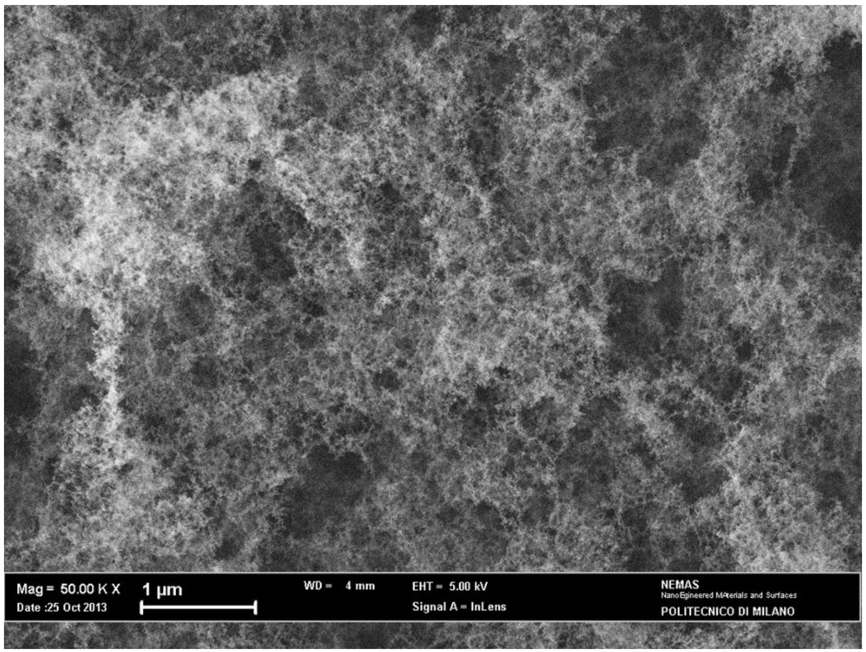

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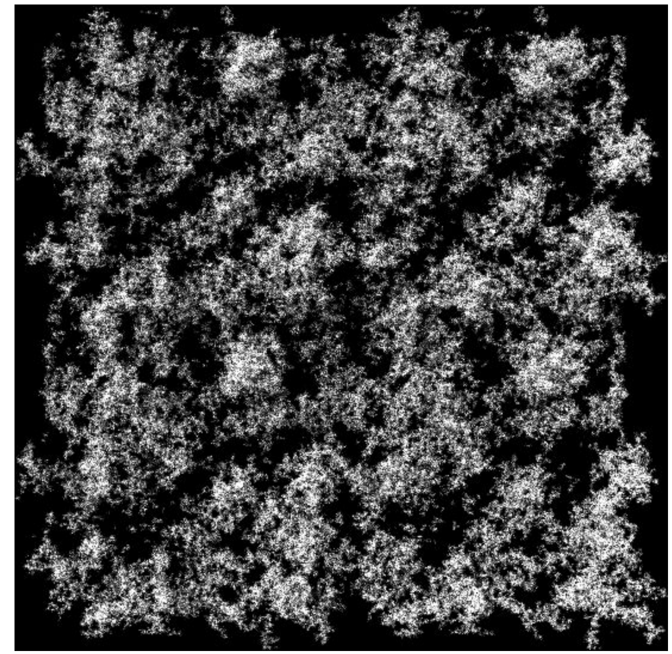

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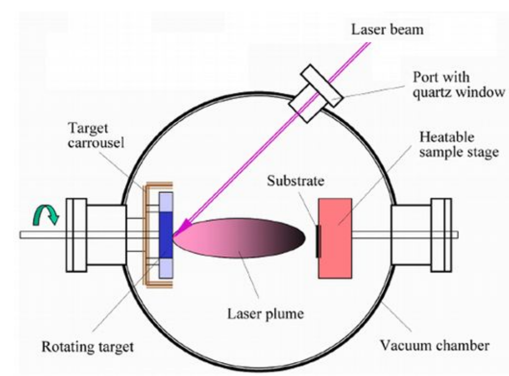

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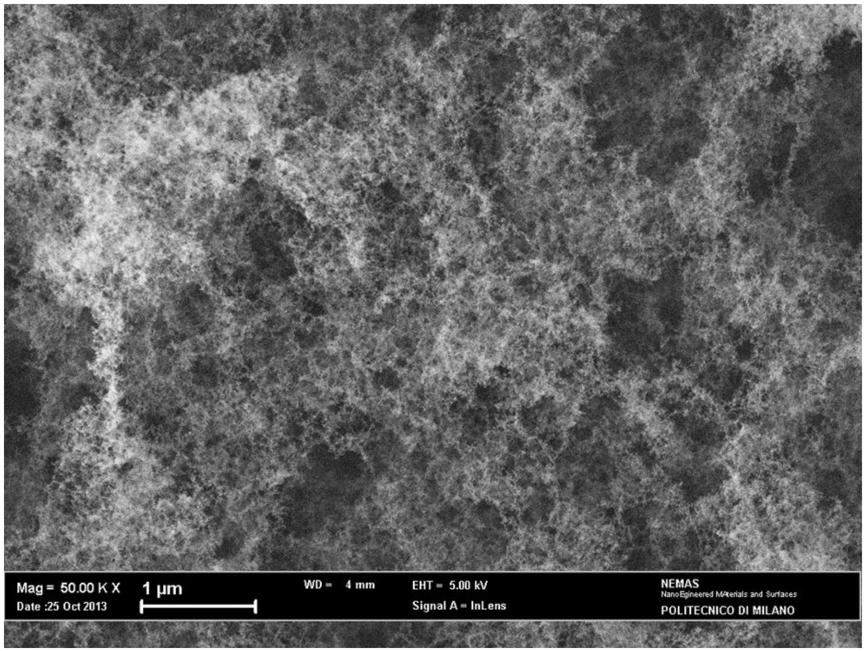

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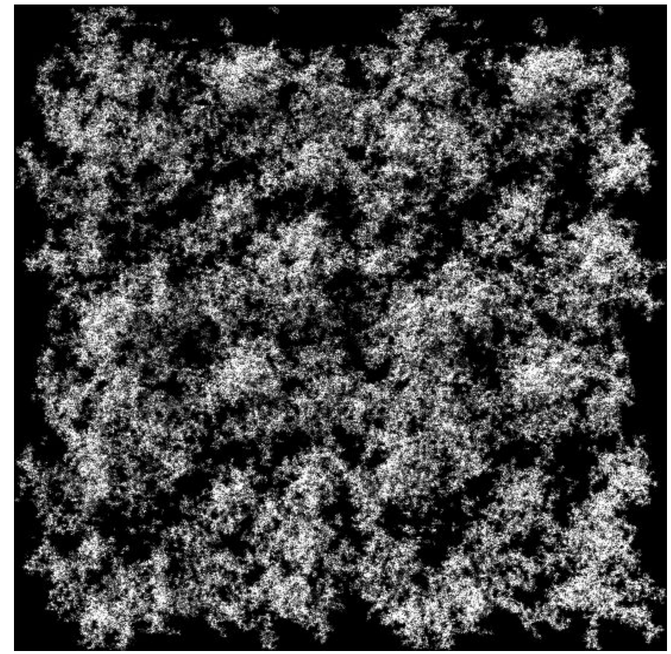

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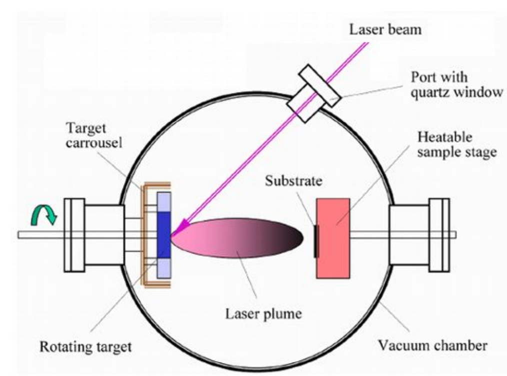

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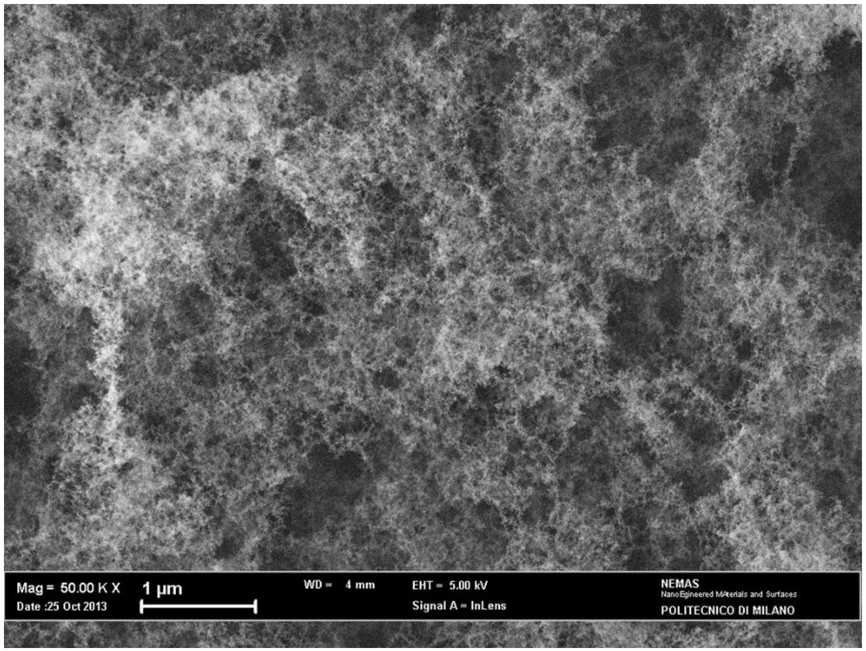

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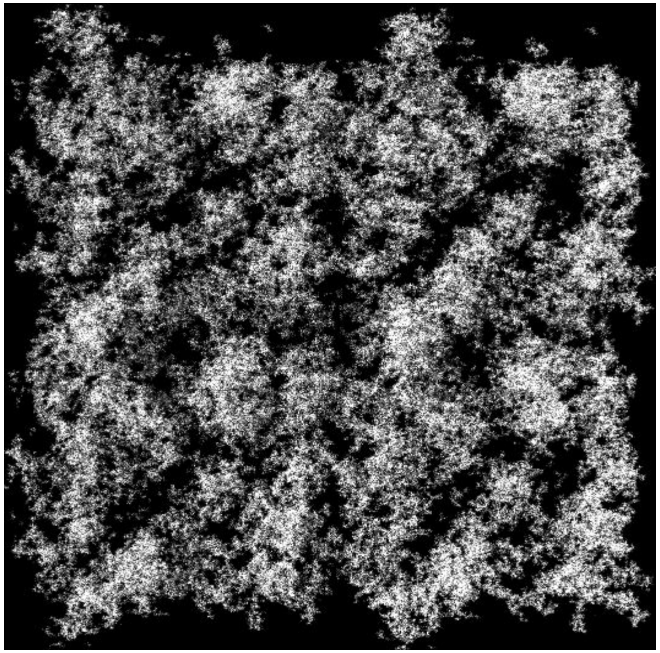

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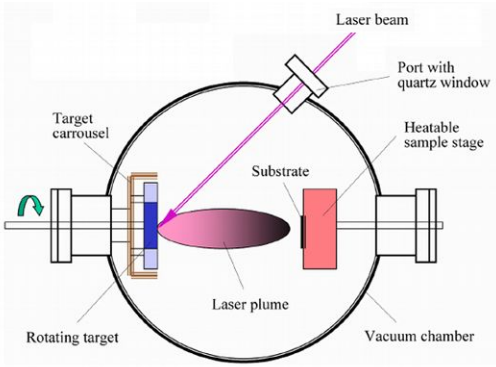

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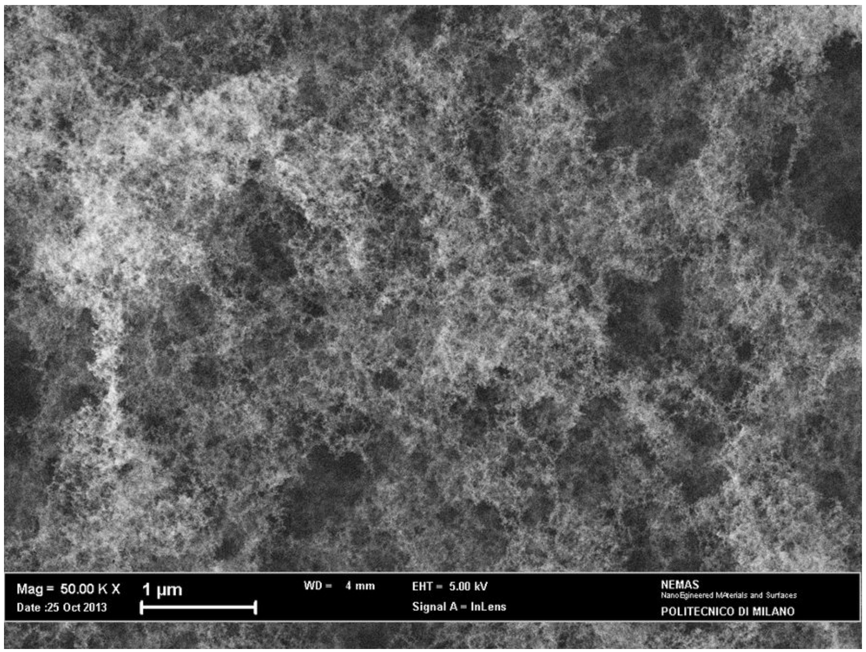

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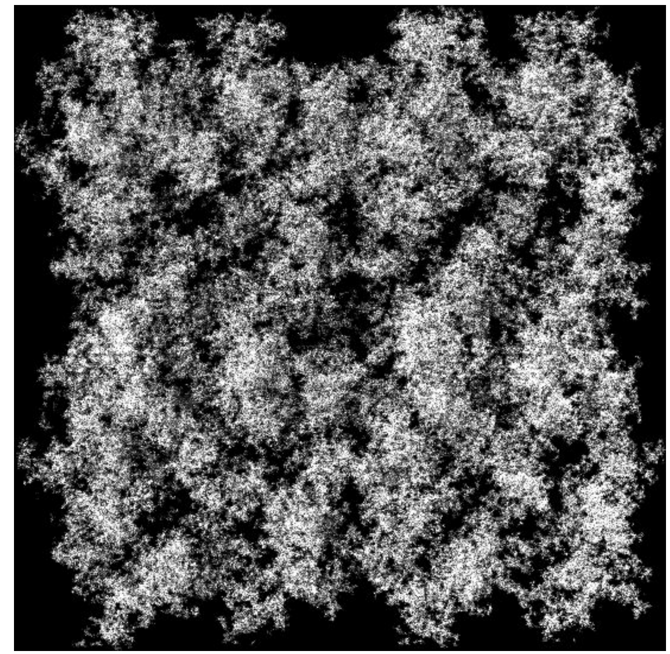

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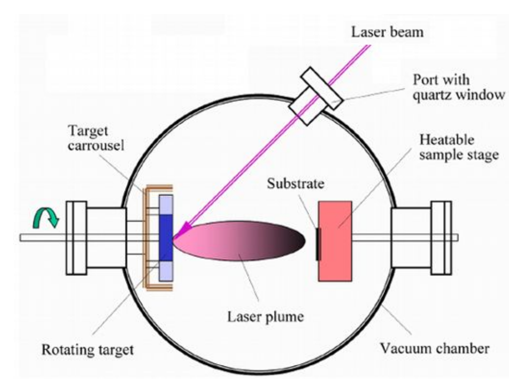
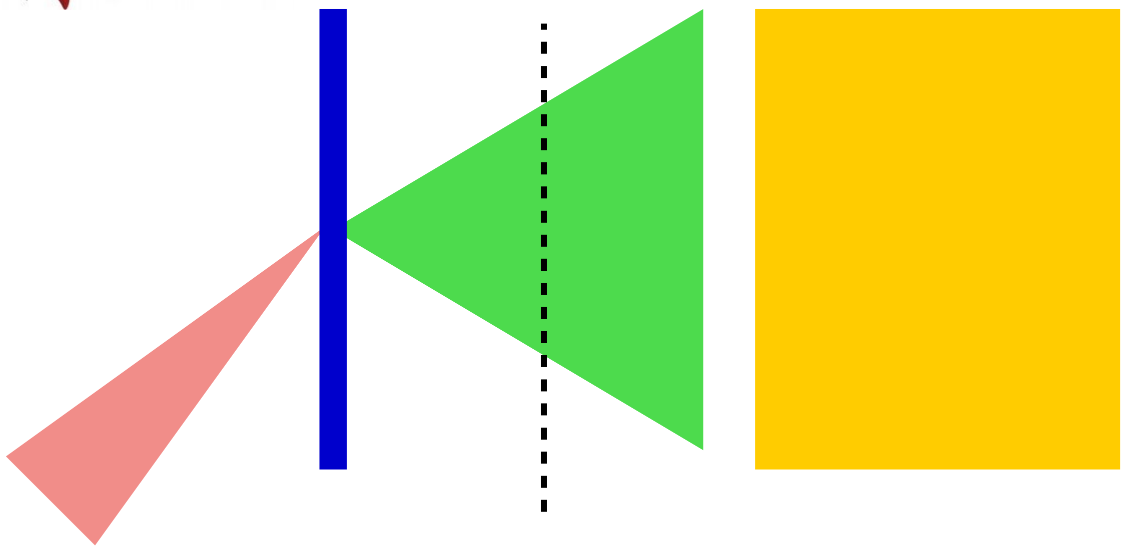


Coupling of PIC spectra with Geant4

piccante
Open Source PIC Code

Electrons and ions

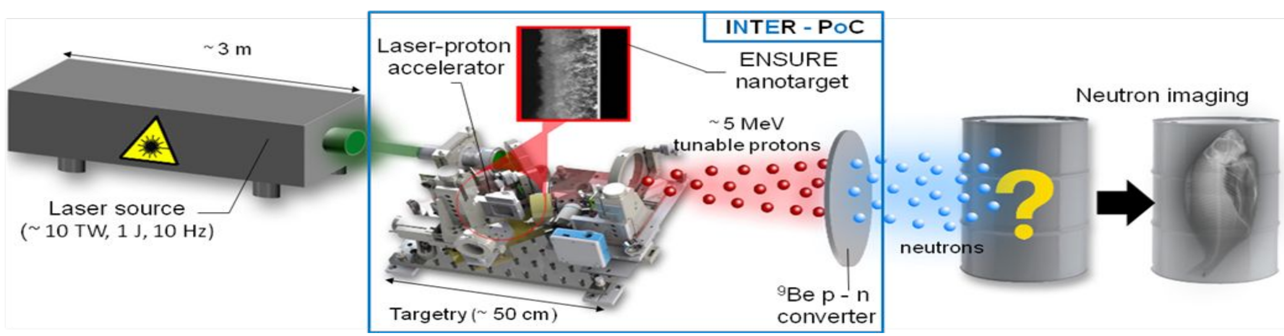
Geant4



Secondary target

SourceLAB

erc ERC-PoC: **INTER**



Conclusions

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- Nanostructured foams are one of the few ways to obtain a controlled near critical plasma
- With very high pulse contrast nanostructure might survive → simulations to understand what happens
- In numerical simulations the nanostructure is found to affect experimental observables

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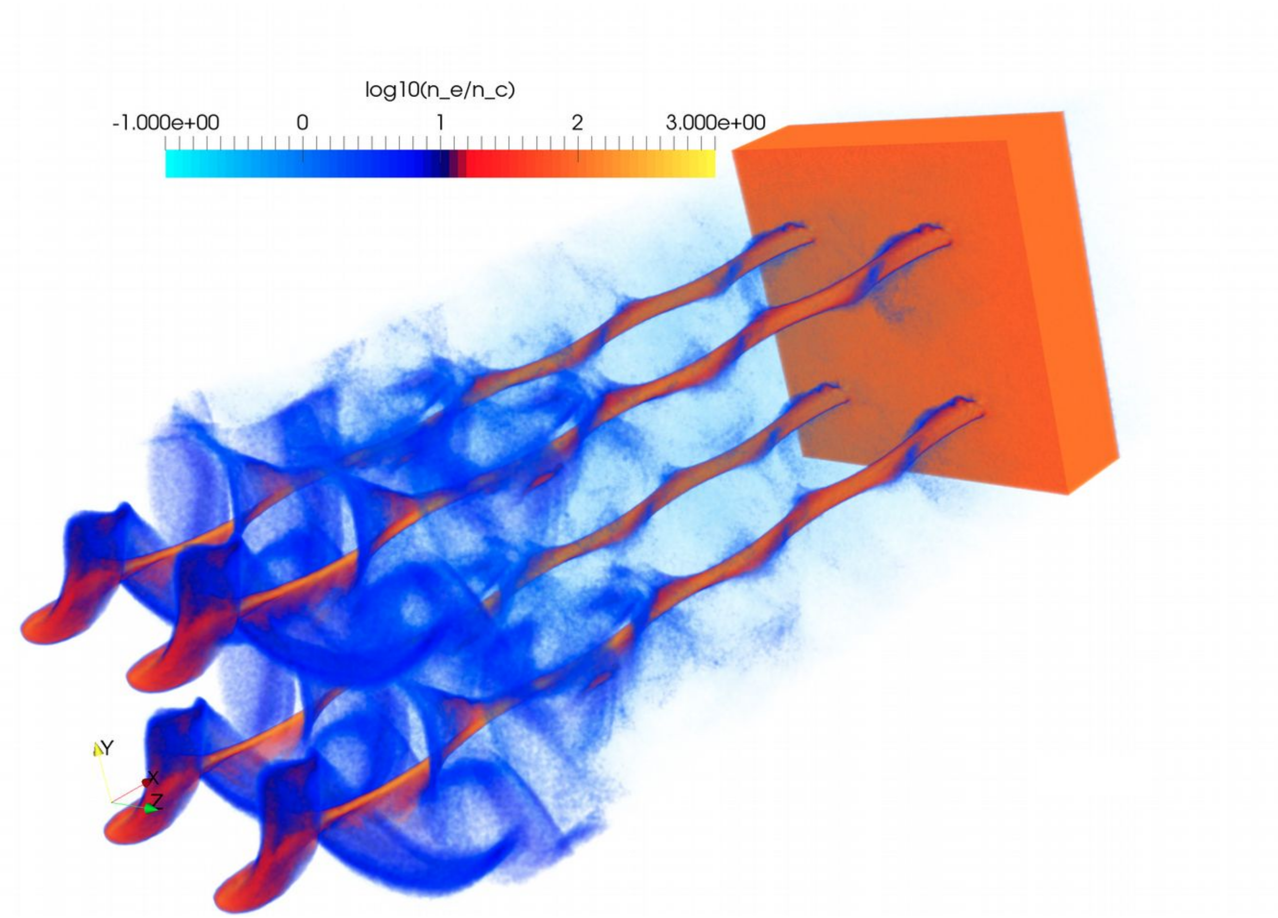
Thank you for your attention!



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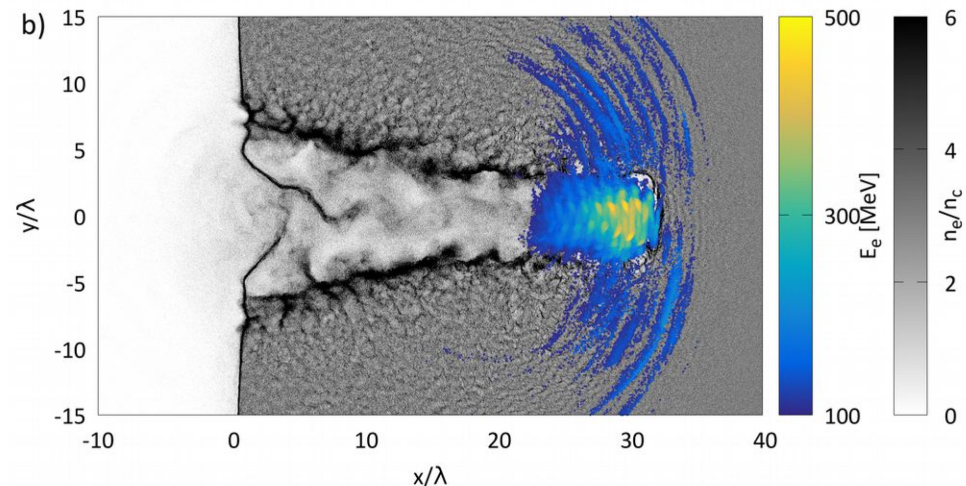
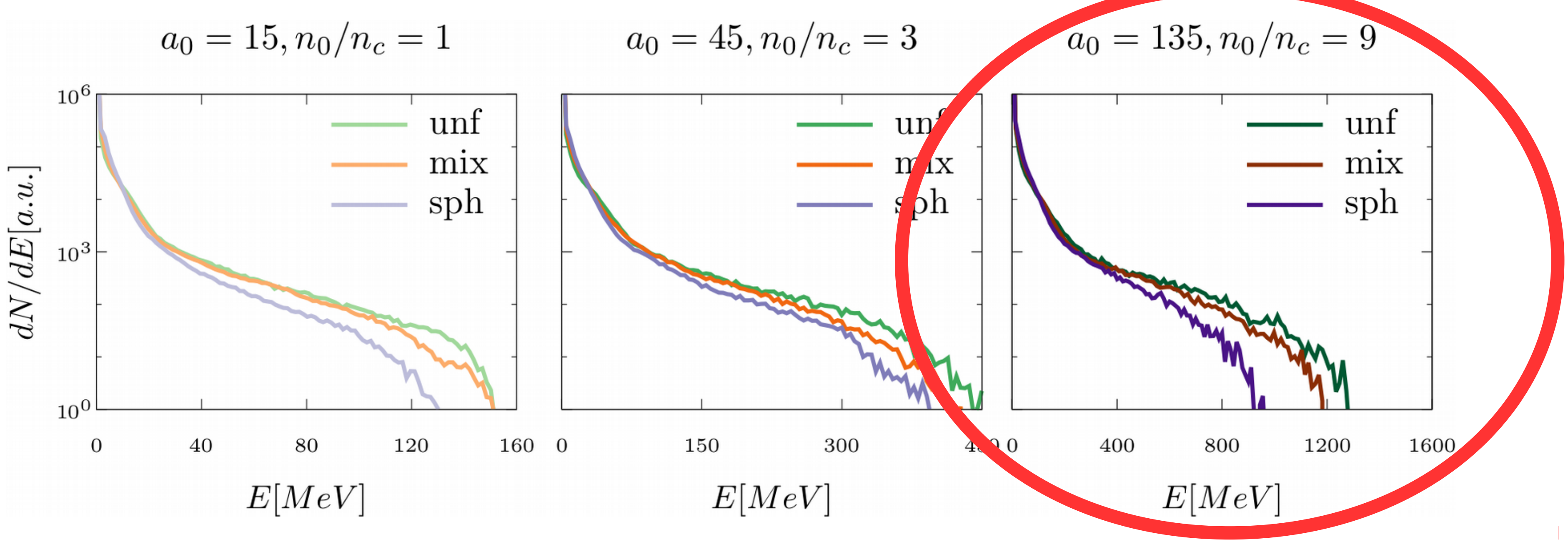
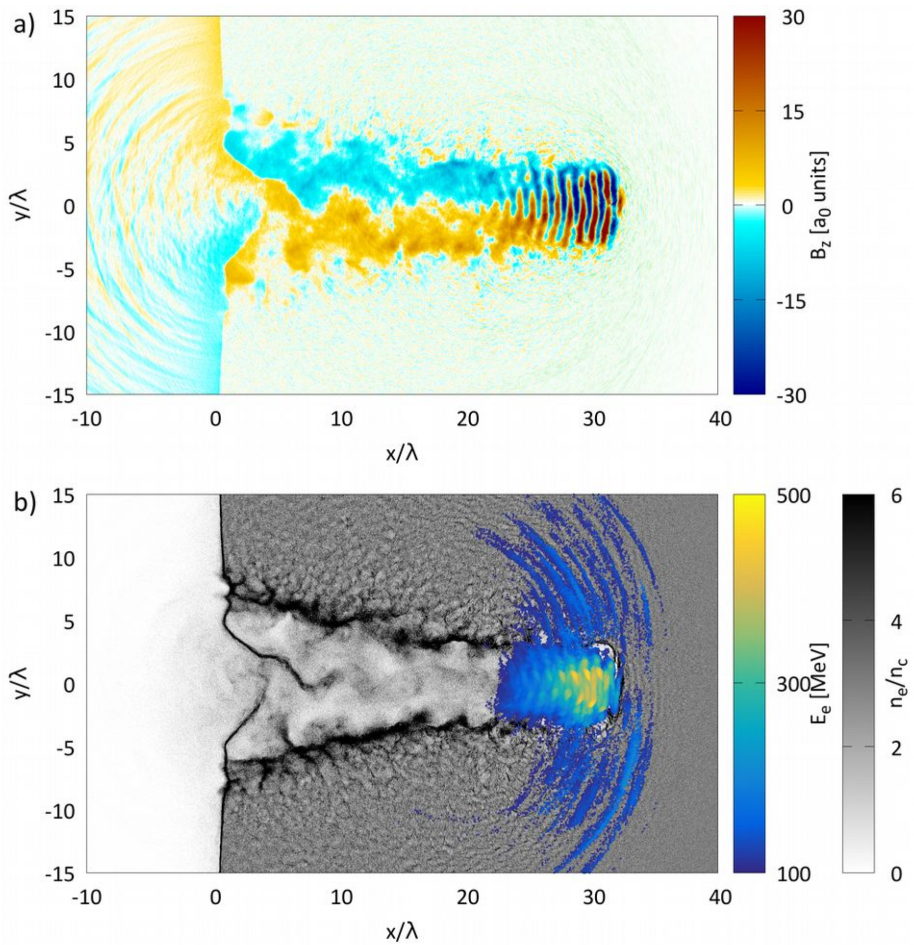
Backup slides

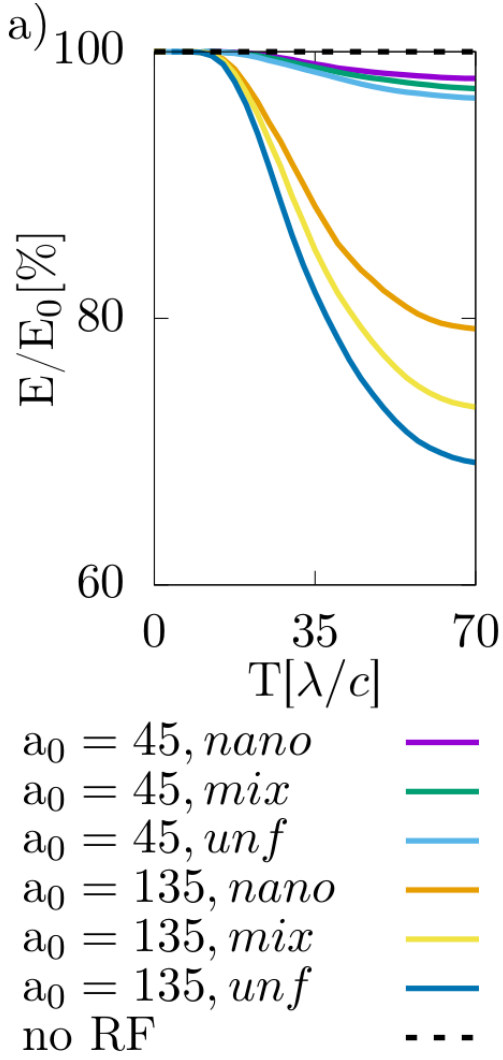
which can have consequences on radiative losses





If we turn on radiation reaction...





What we've learned

- Simple perturbations of the density **can** affect the interaction
- Nanostrcture leads to **higher energy into ion population** and **lower e^- energy distribution tails**
- For higher a_0 : nanostructure affects radiative losses

What we've learned

- Foam attached targets leads to higher electron temperature than simple flat targets

- Nanostructure affects the interaction