Highlights from PIC simulations of ultraintense laser-plasma interactions

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CSFI 2008 Conference, Rimini, May 29, 2008

Coworkers

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[1]*On leave from Institute for Computational Technologies, Novosibirsk, Russia*
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Collaboration with experimental partners –
Marco Borghesi et al.
School of Mathematics and Physics, Queen's University of Belfast, UK

The speaker acknowledges a visiting fellowship from QUB (presently running)

Outlook

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- Laser-plasma PIC simulations at CINECA

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- Highlight 1: “coherent” electromagnetic structures in laser plasmas

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- Highlight 1: “coherent” electromagnetic structures in laser plasmas
- Highlight 2: Radiation Pressure Acceleration with circularly polarized pulses

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- support to experimental activities
- “design and feasibility” for future projects (e.g. ELI, HiPER, PLASMONX, . . .)

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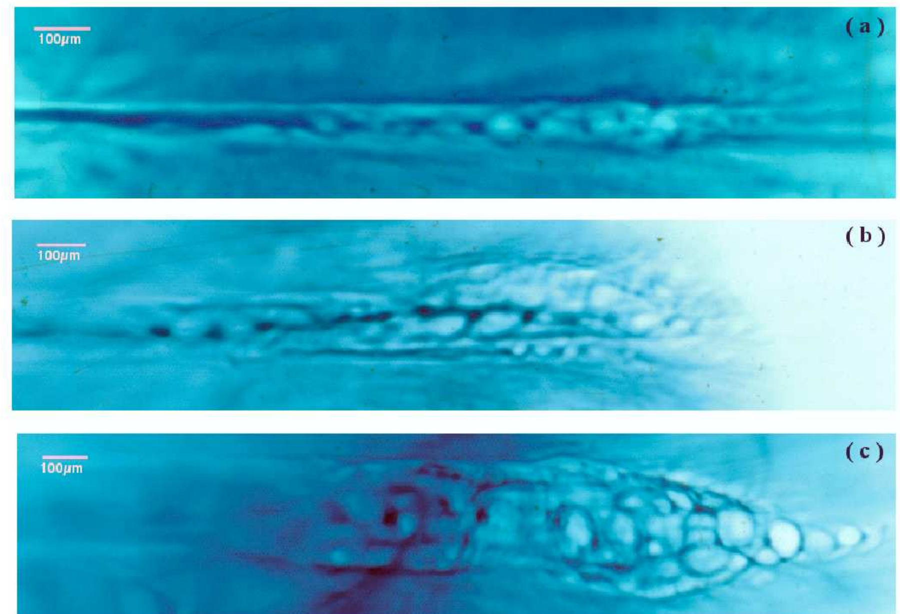

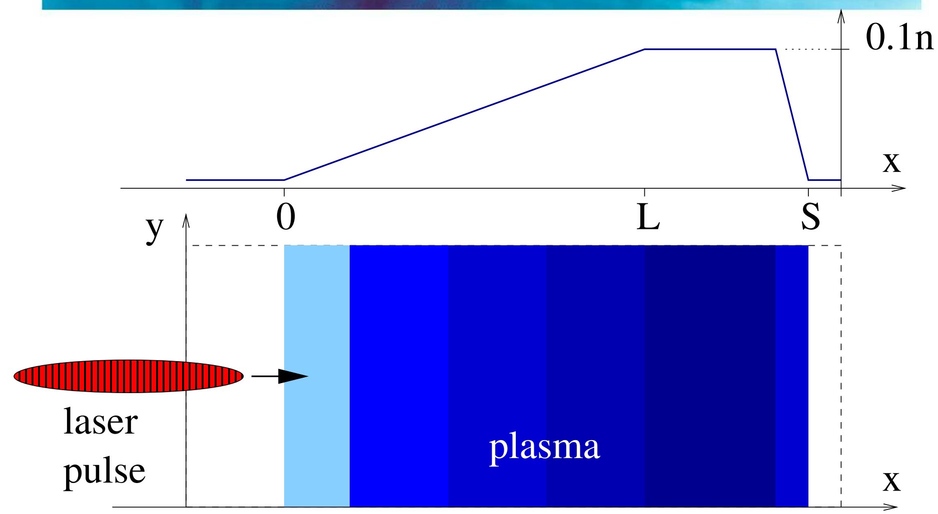

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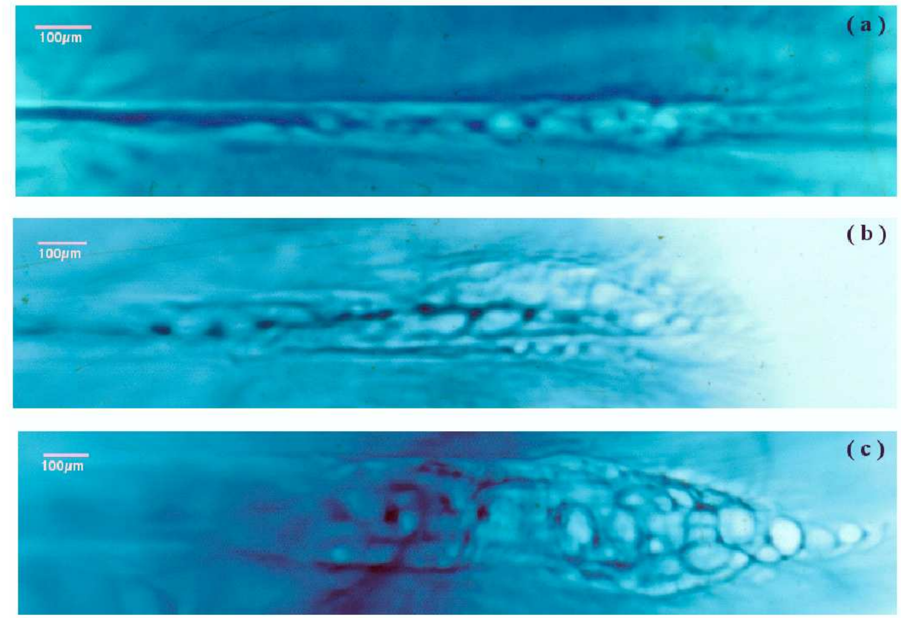

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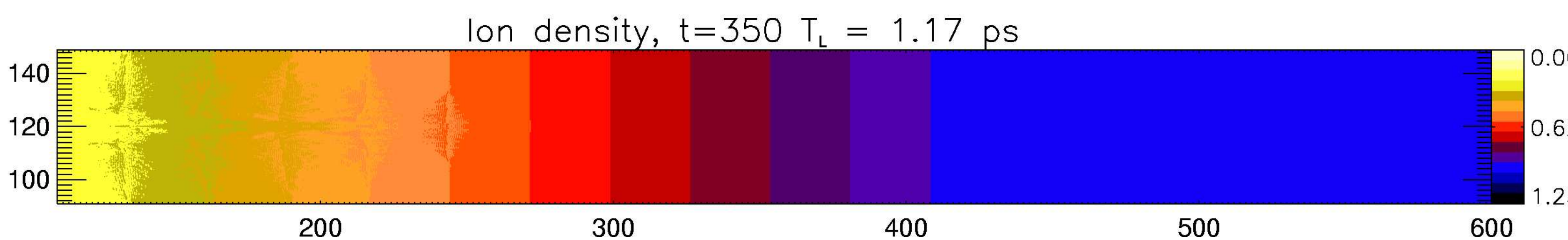

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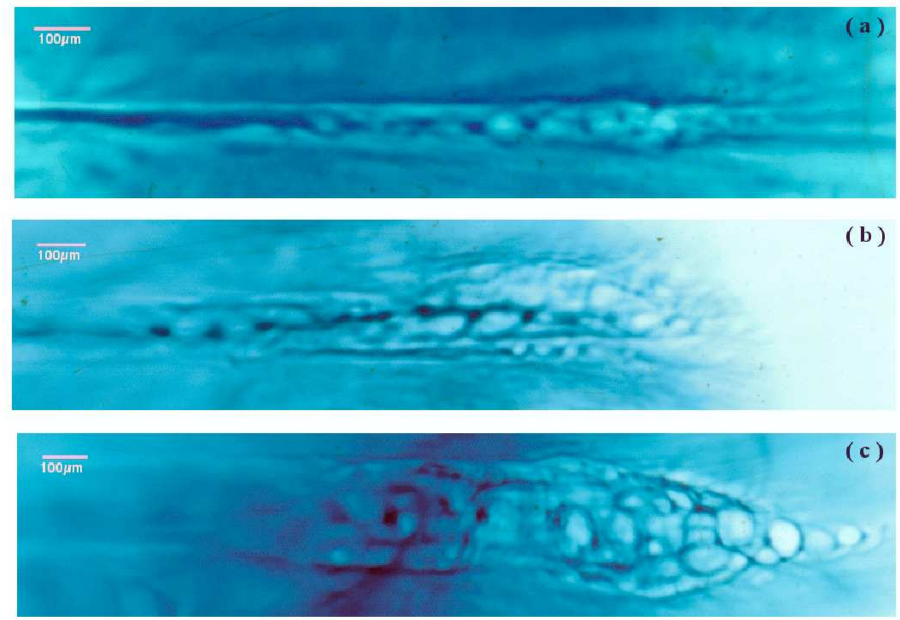

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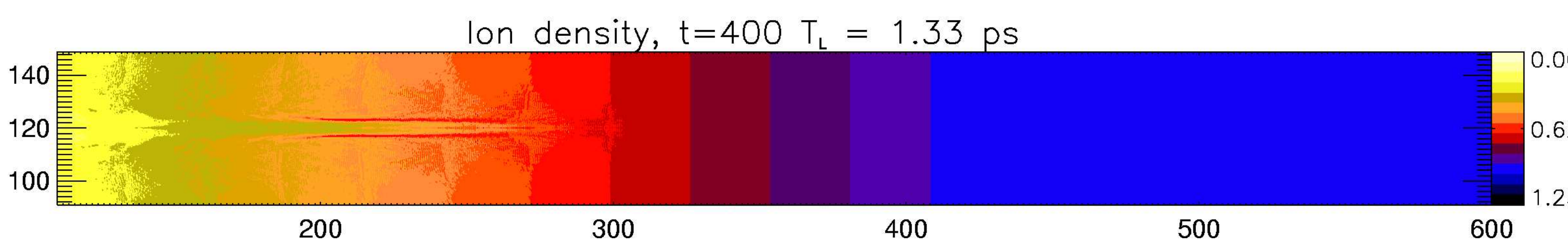

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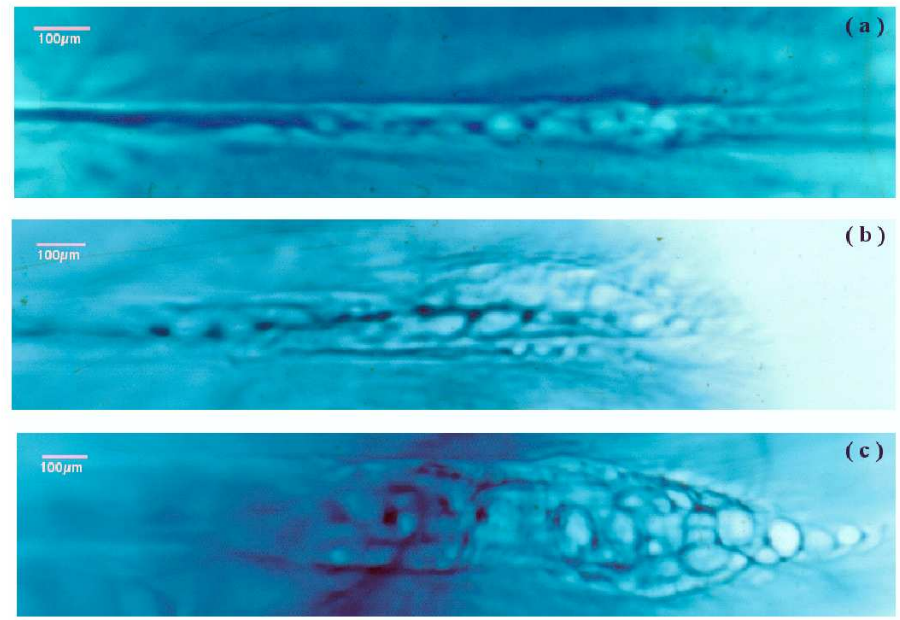

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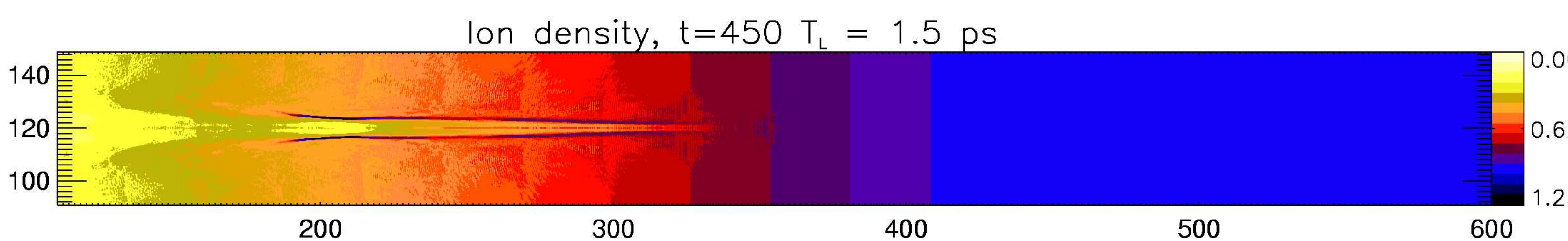

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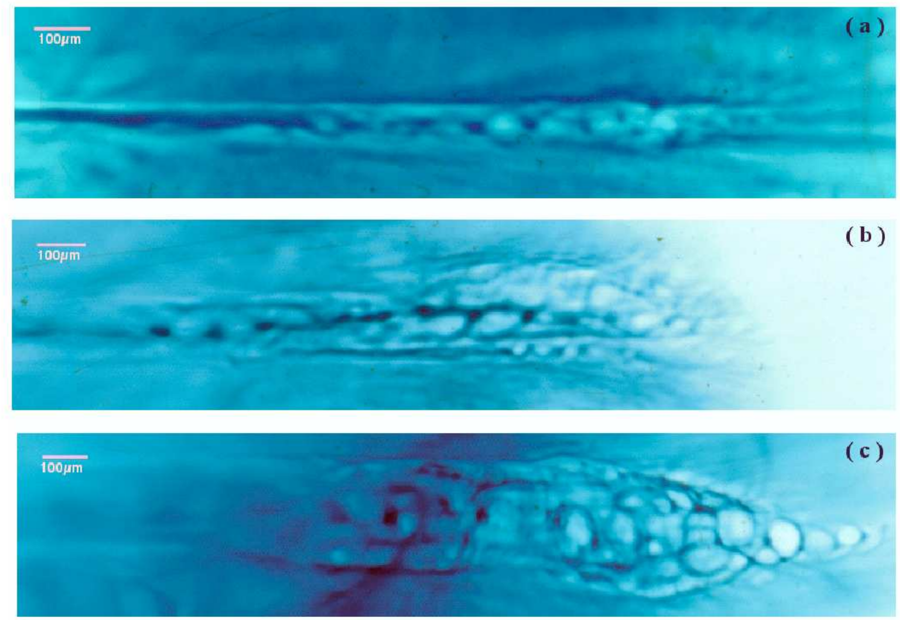

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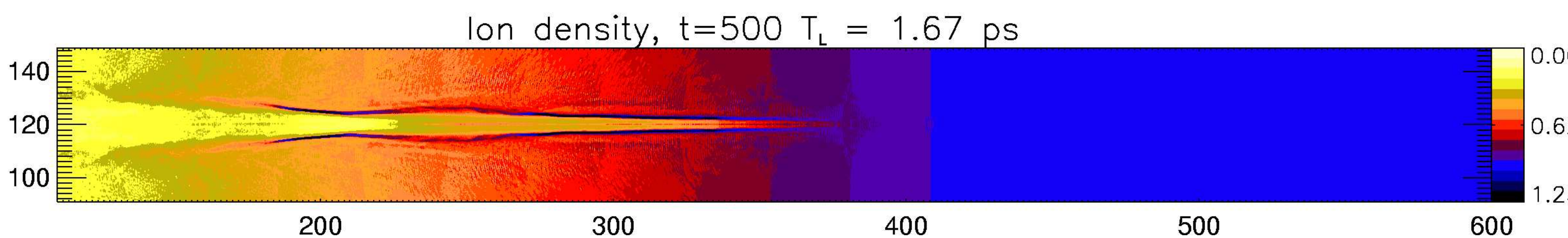

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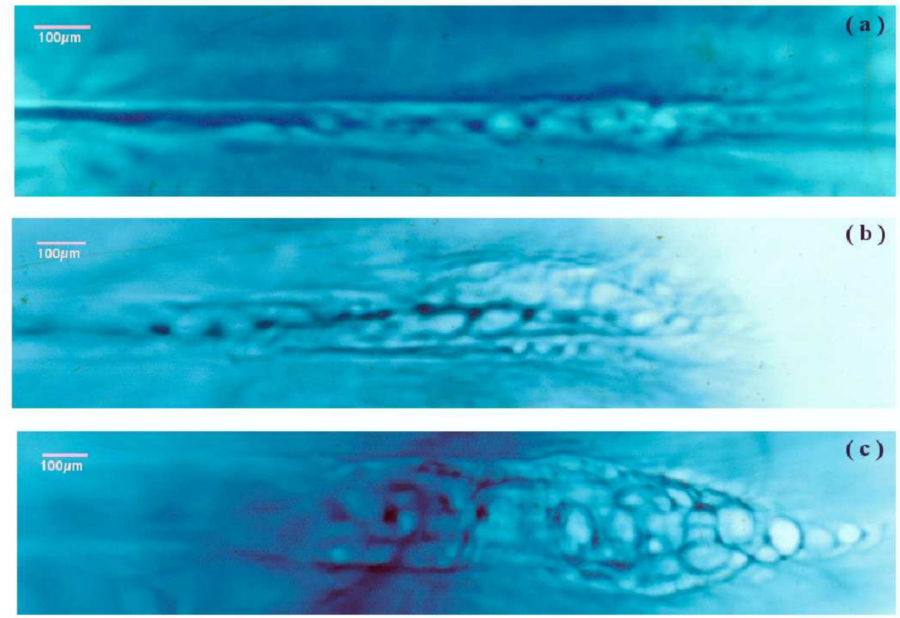

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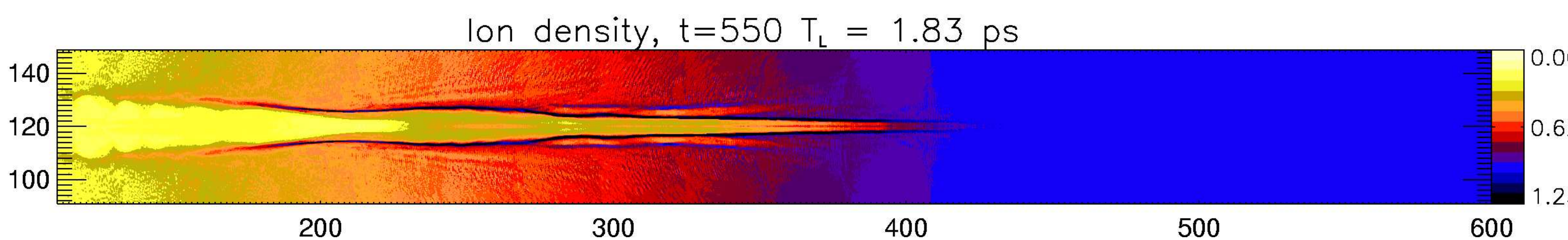

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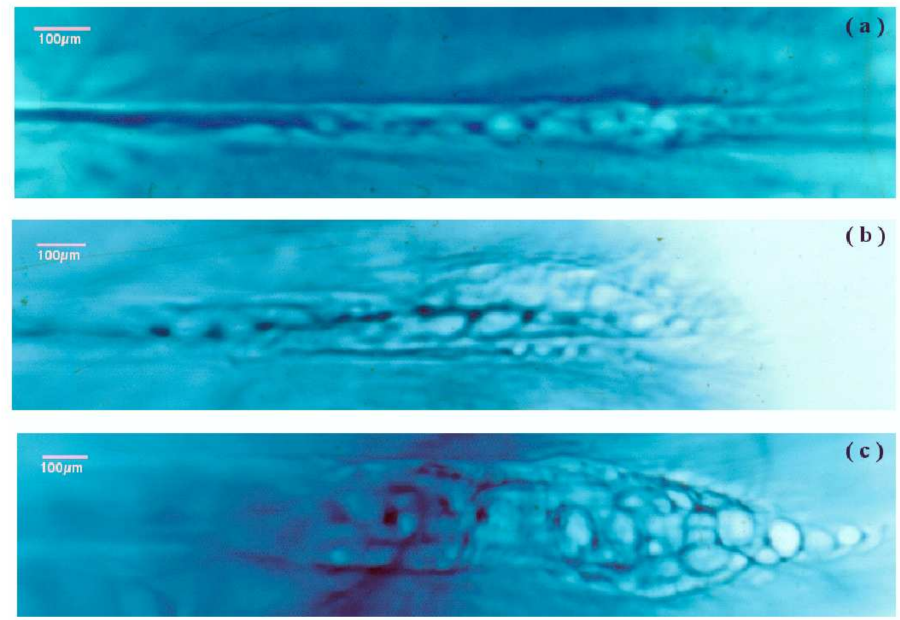

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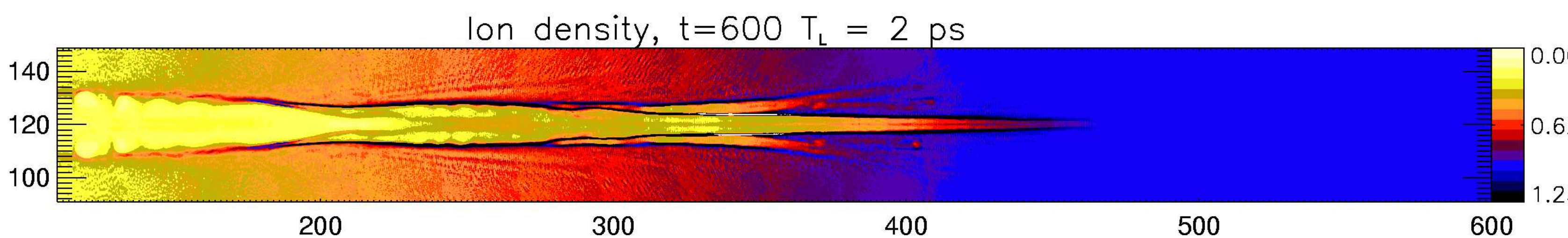

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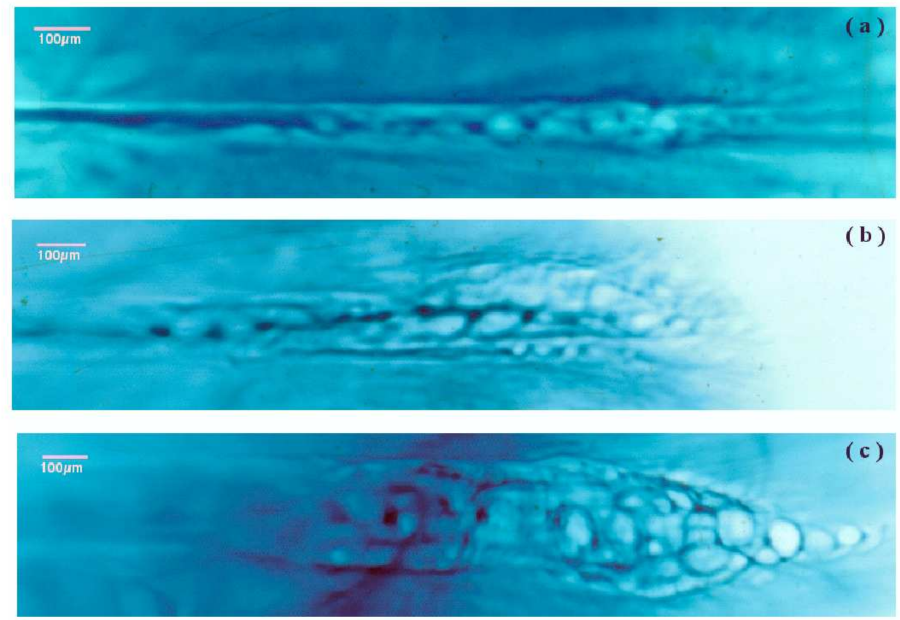

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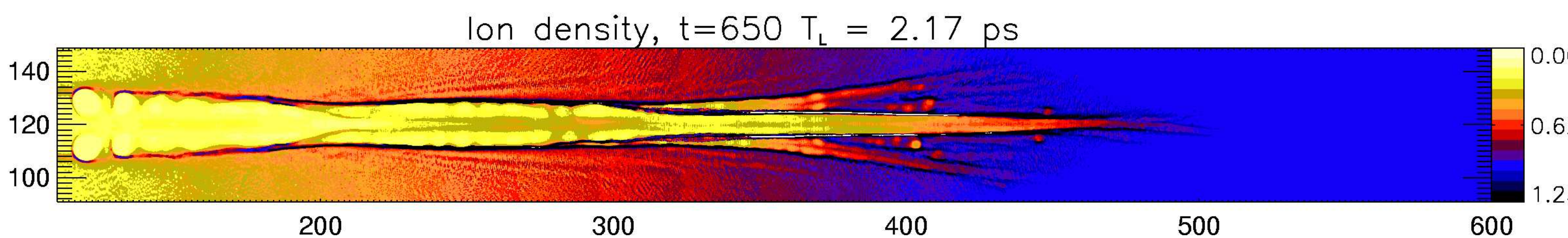

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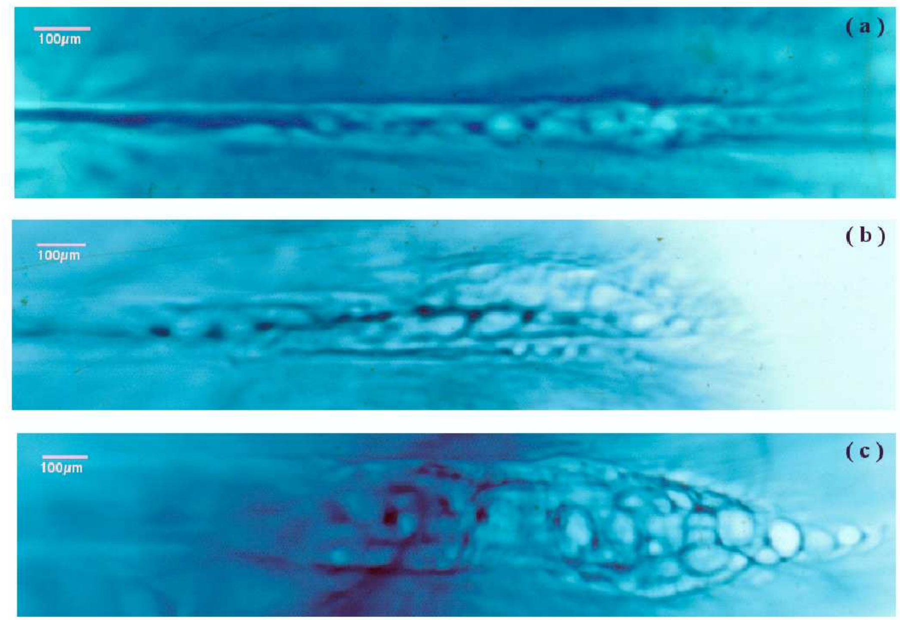

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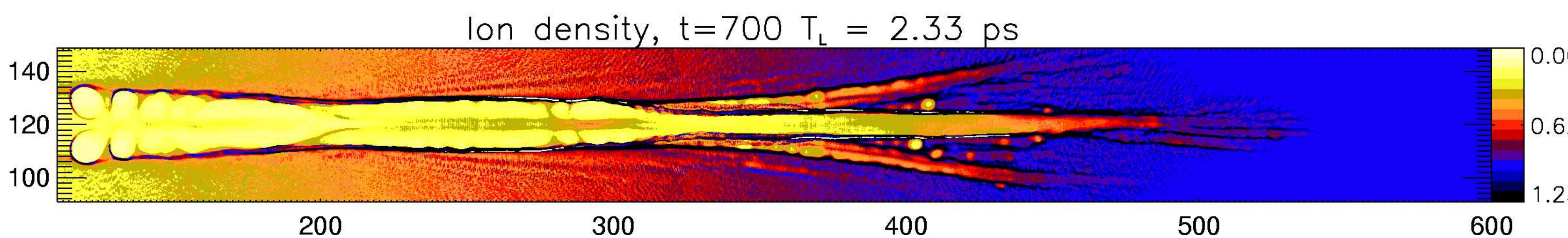

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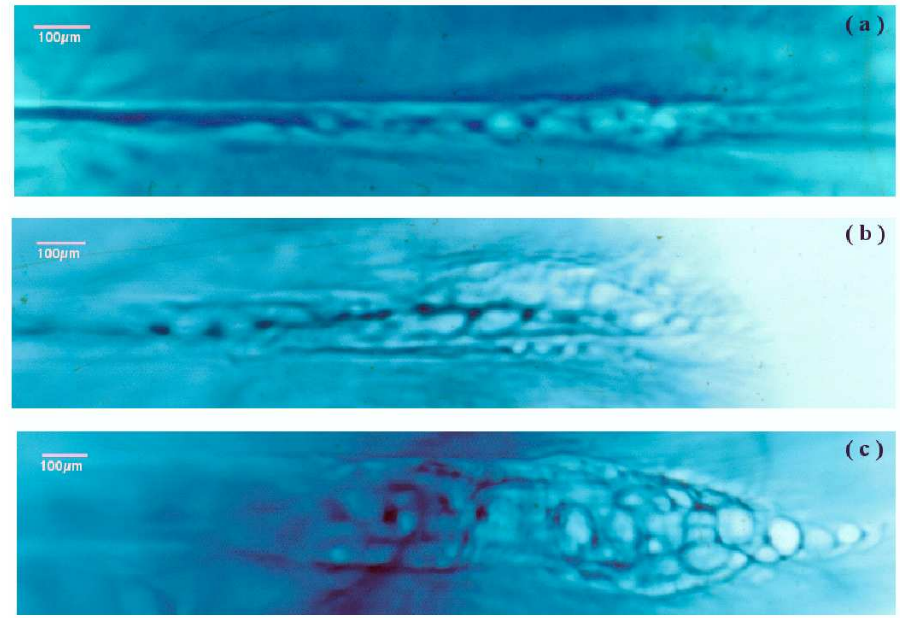

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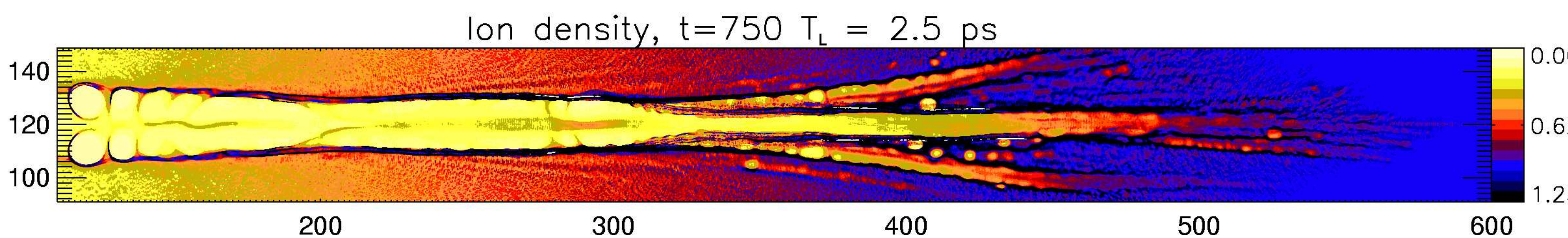

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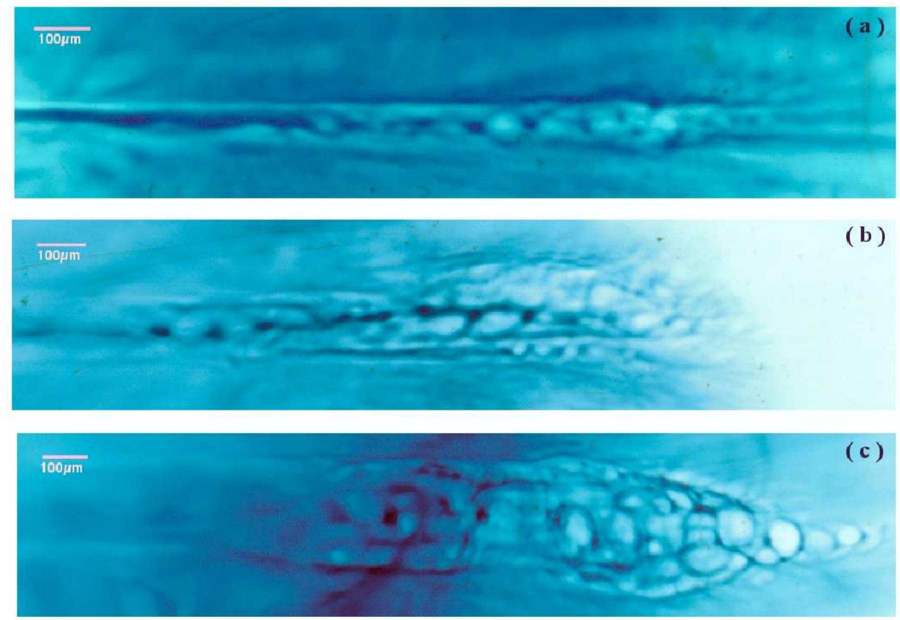

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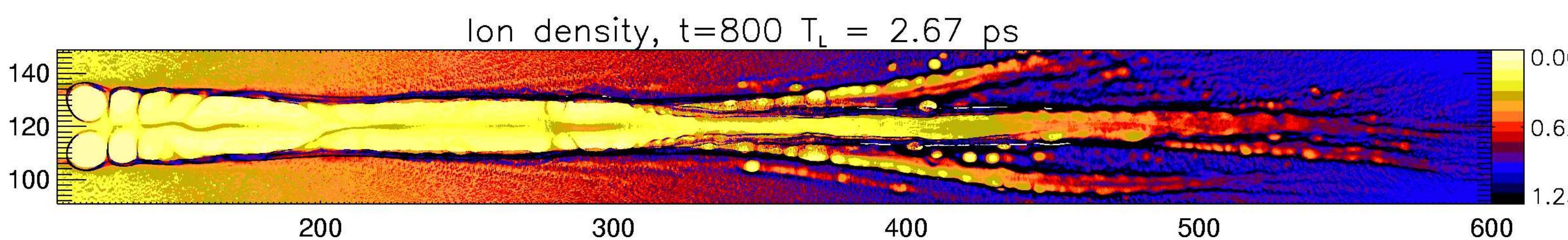

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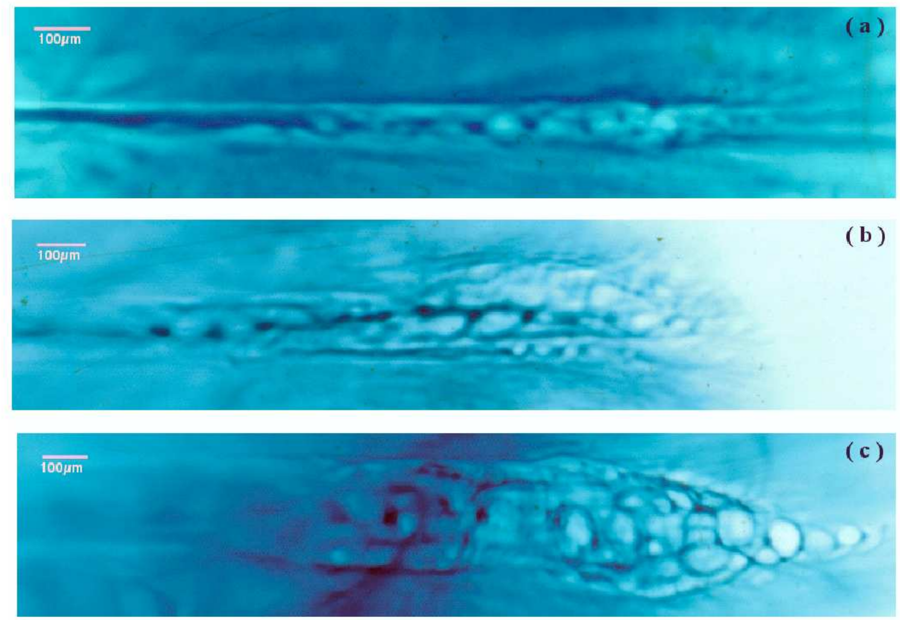

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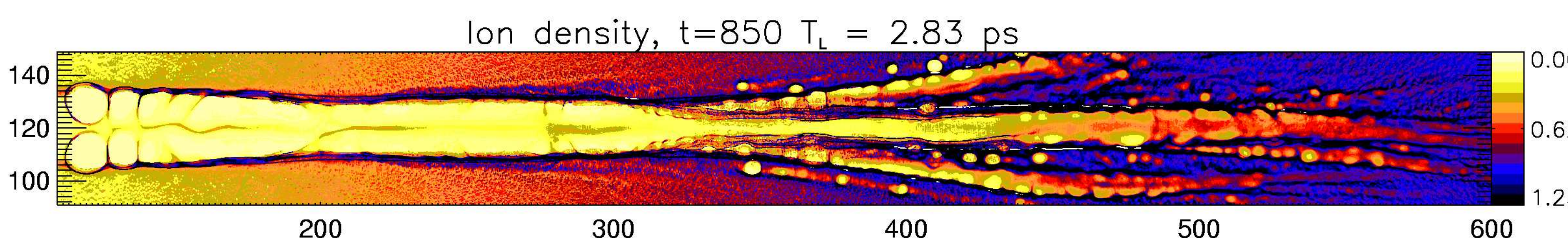

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$\sim 2 \times 10^8$ particles (16 per cell) ~ 13500 timesteps

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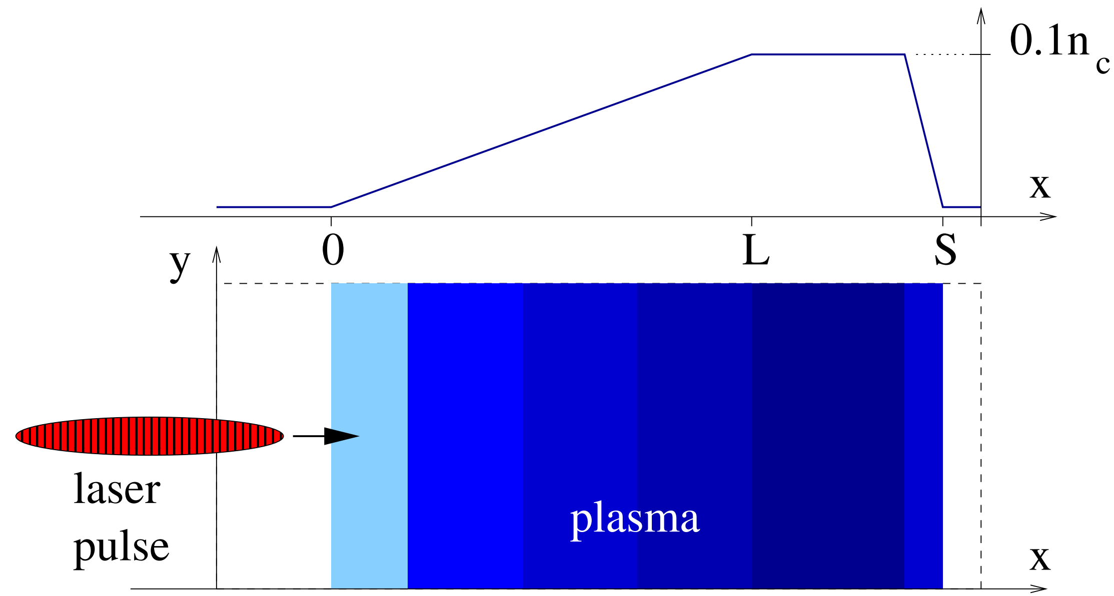

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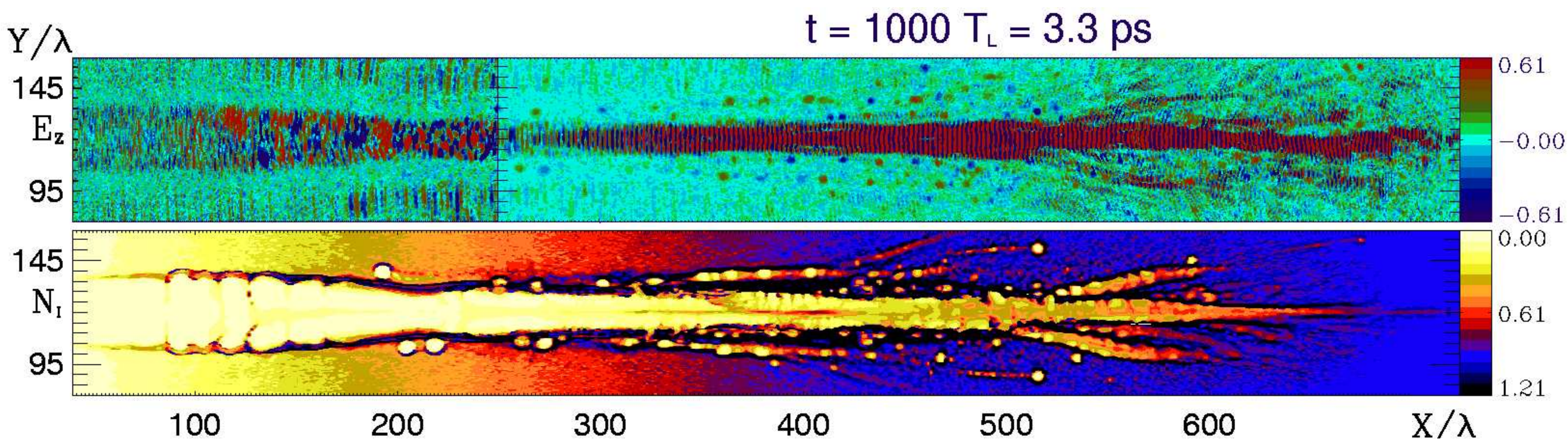
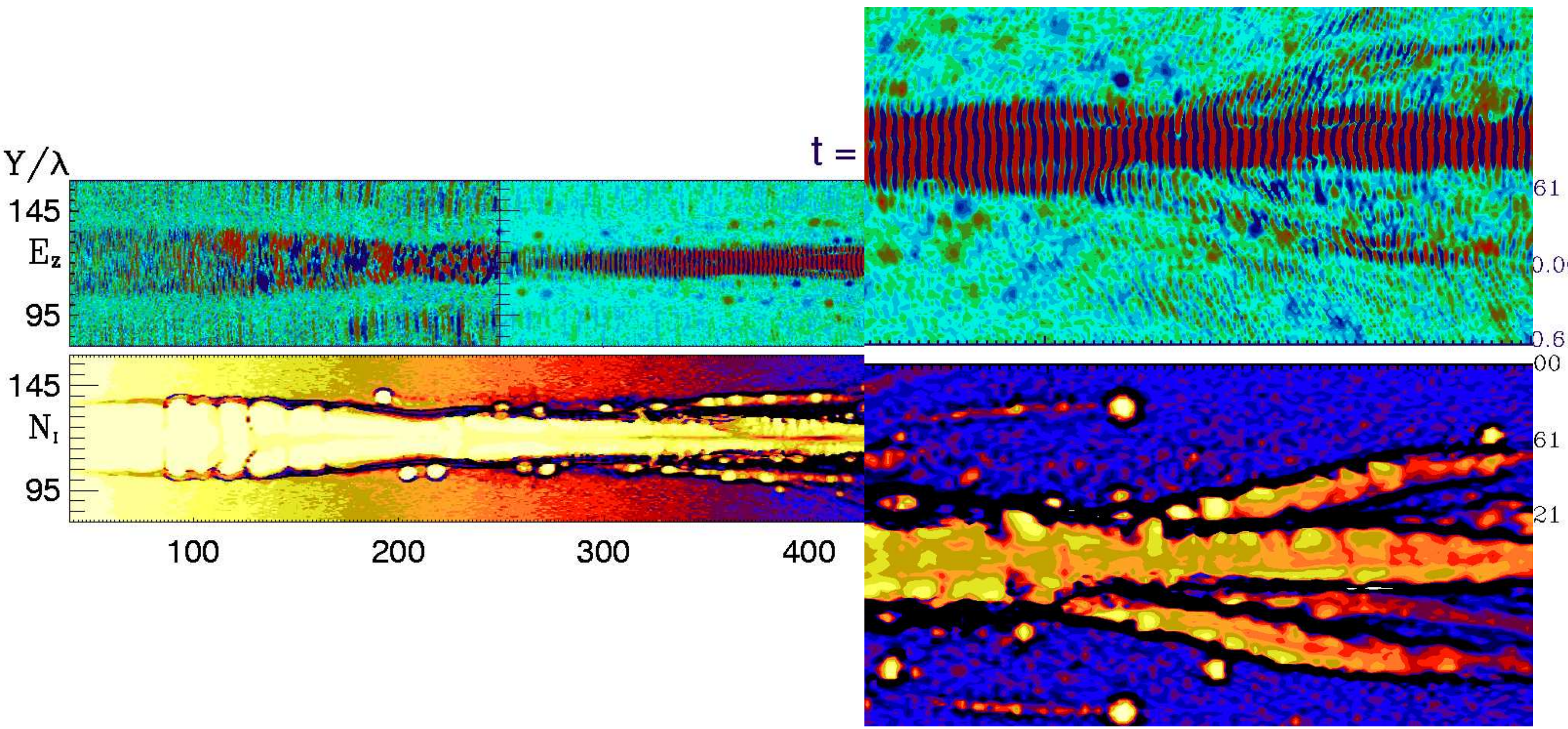


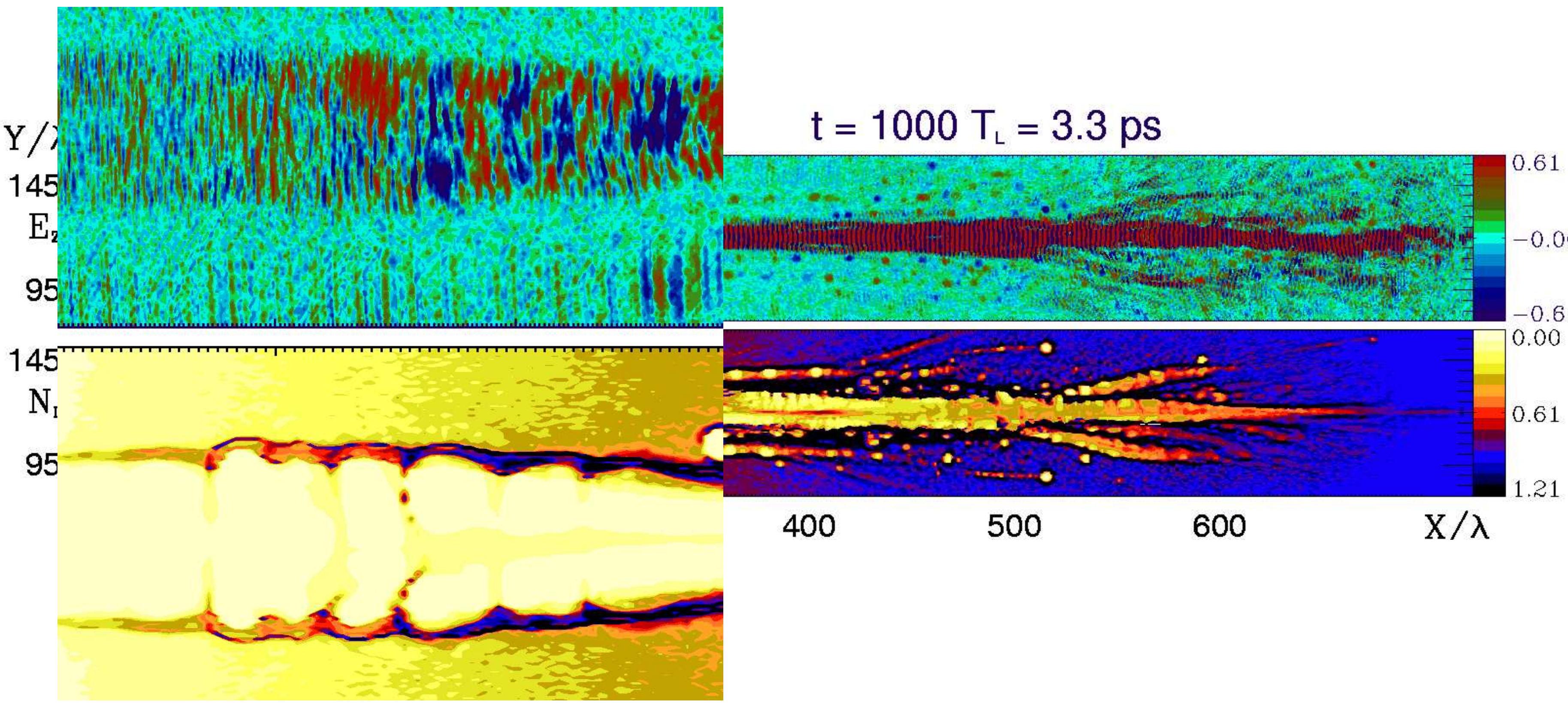
Slowly-varying EM structures

Both isolated “cavitons” or “post-solitons” and patterns inside density channels



Slowly-varying EM structures

Axially symmetrical pattern inside the main channel, in the low-density region



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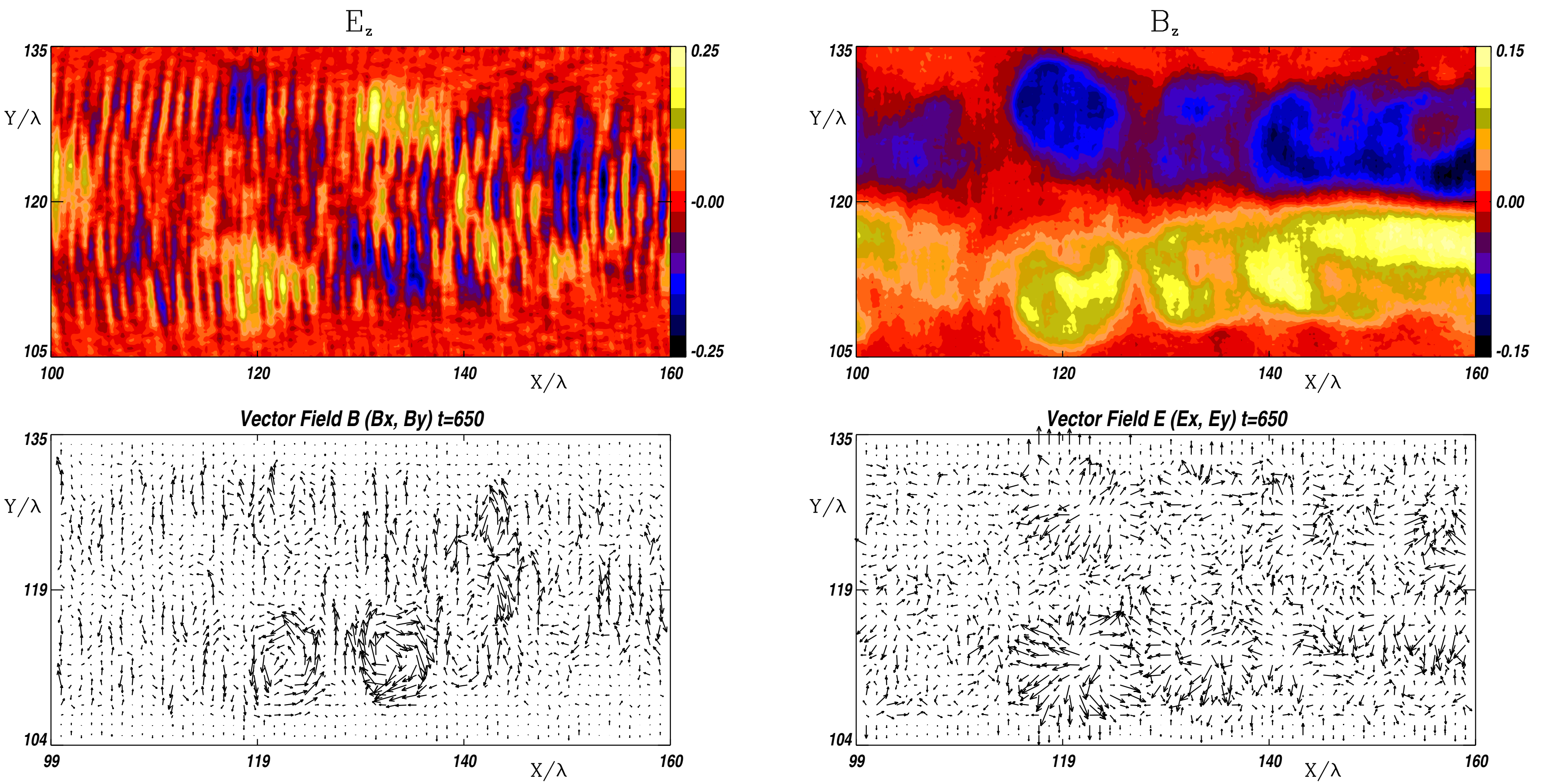

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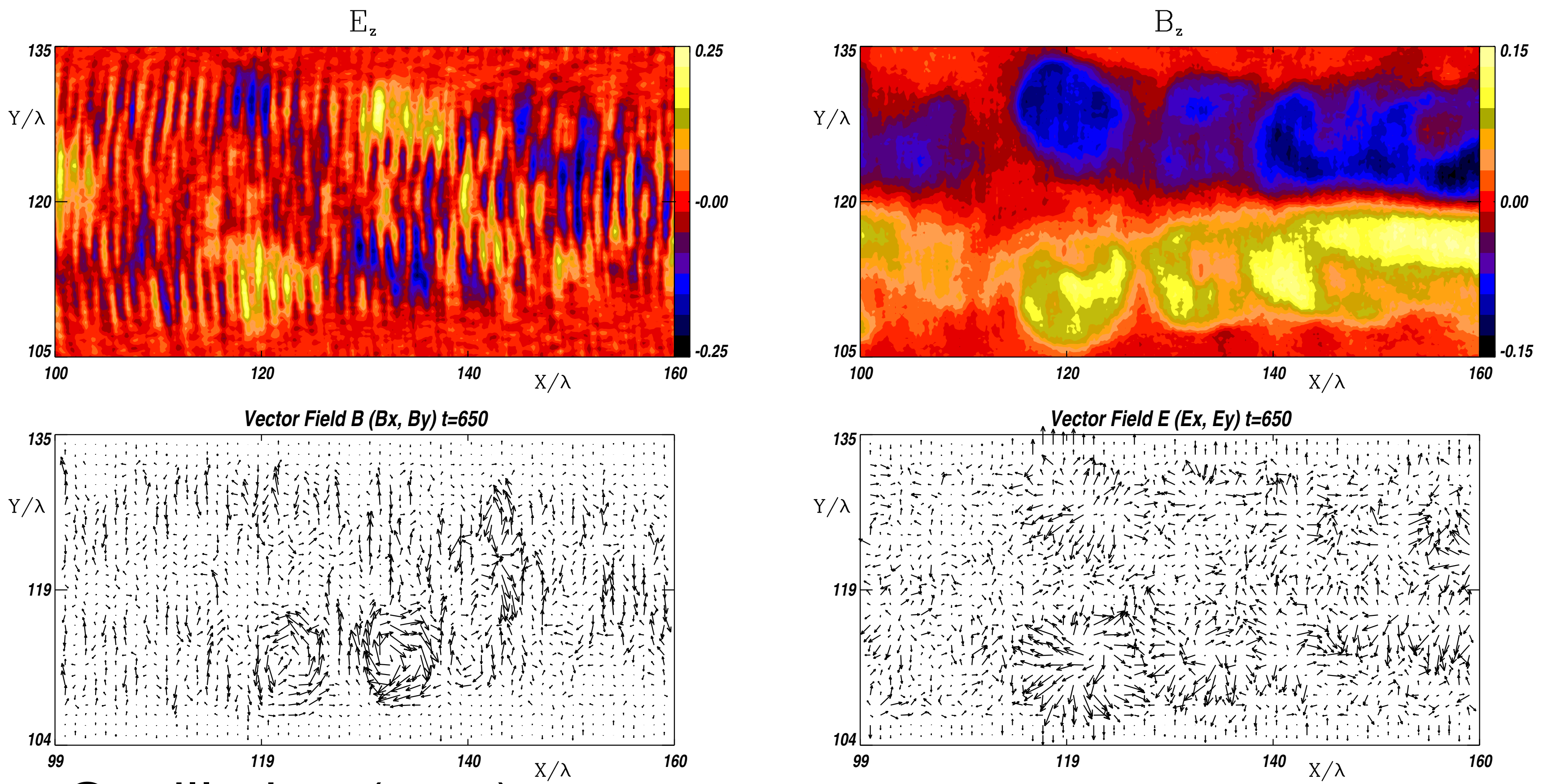

Oscillating (0.1ω) Quasi-static

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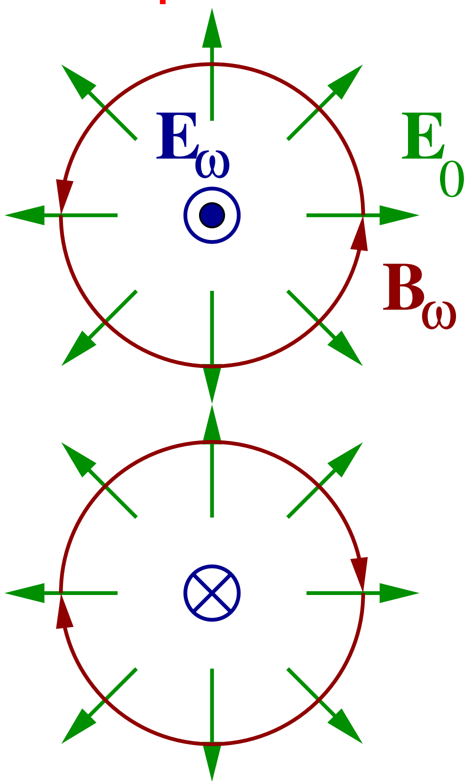

Antisymmetric “soliton” fields: oscillating E_z, B_x and B_y and electrostatic E_x, E_y

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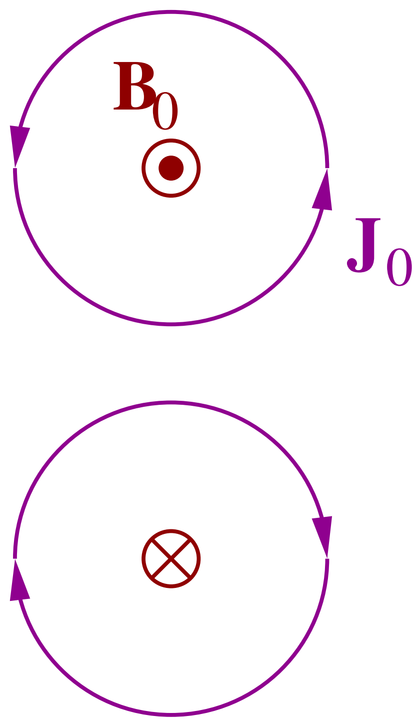

Antisymmetric “vortex” fields: static B_z, J_x and J_y

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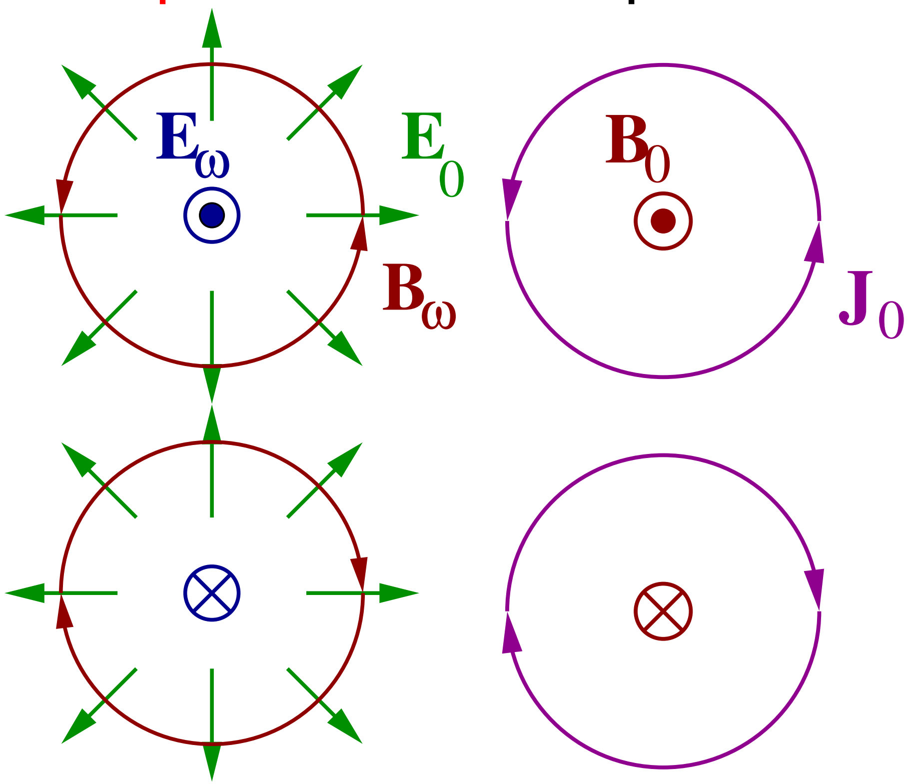

We may expect "toroidal" structures in 3D – related simulations are in progress ($3200 \times 320 \times 320$ grid, 8 points per λ, $\sim 5 \times 10^9$ particles – 8 per cell, 400 PEs, ~ 360 GBytes load)

Radiation Pressure Acceleration

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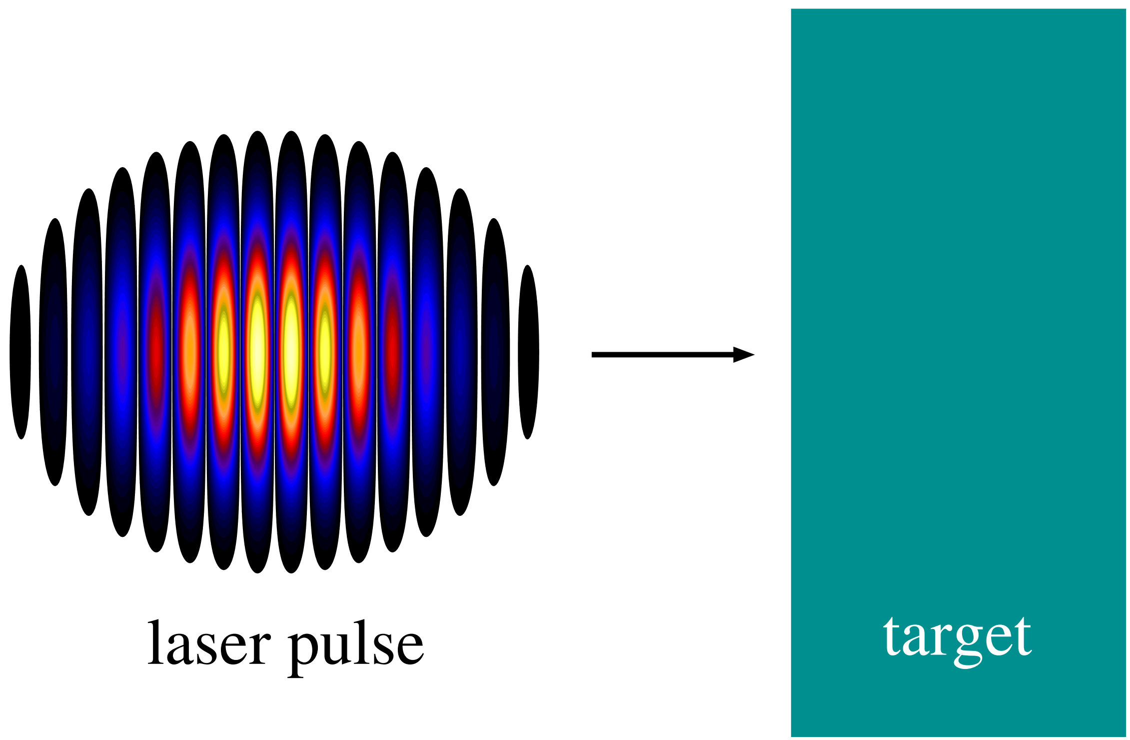
Goal: accelerate plasma ions to high energies using the radiation pressure of the laser pulse



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- Relevant to foreseeable applications (e.g. medical hadrontherapy)

- May be the dominant acceleration mechanism in the ELI experiment (www.eli-laser.eu)

- Use of Circularly Polarized pulses optimise RPA

Macchi et al, Phys. Rev. Lett **94**, 165003 (2005);
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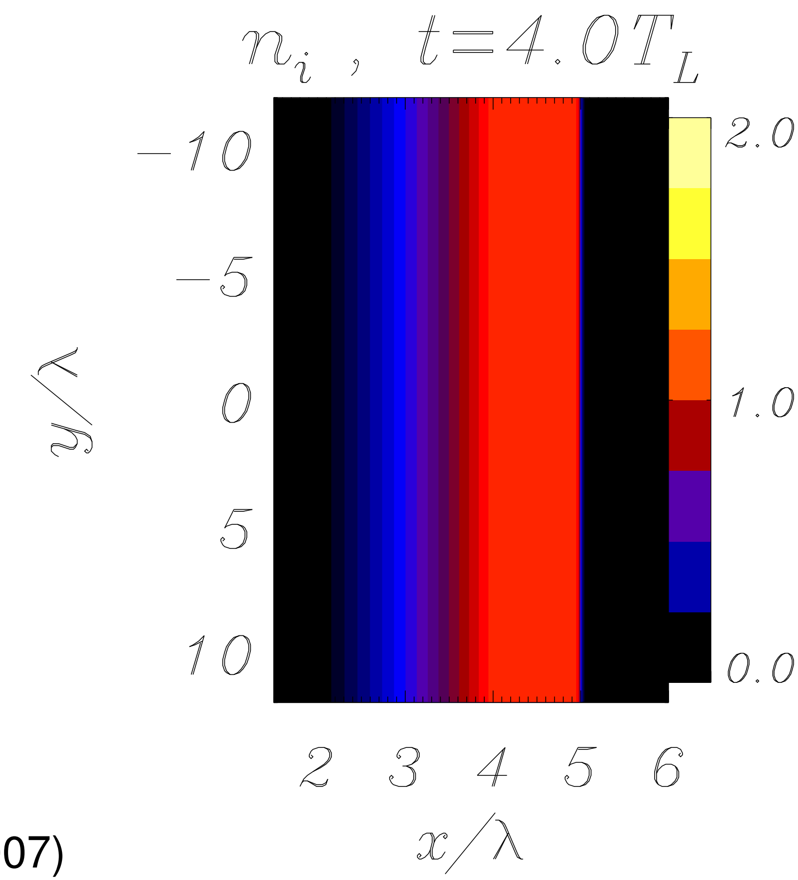

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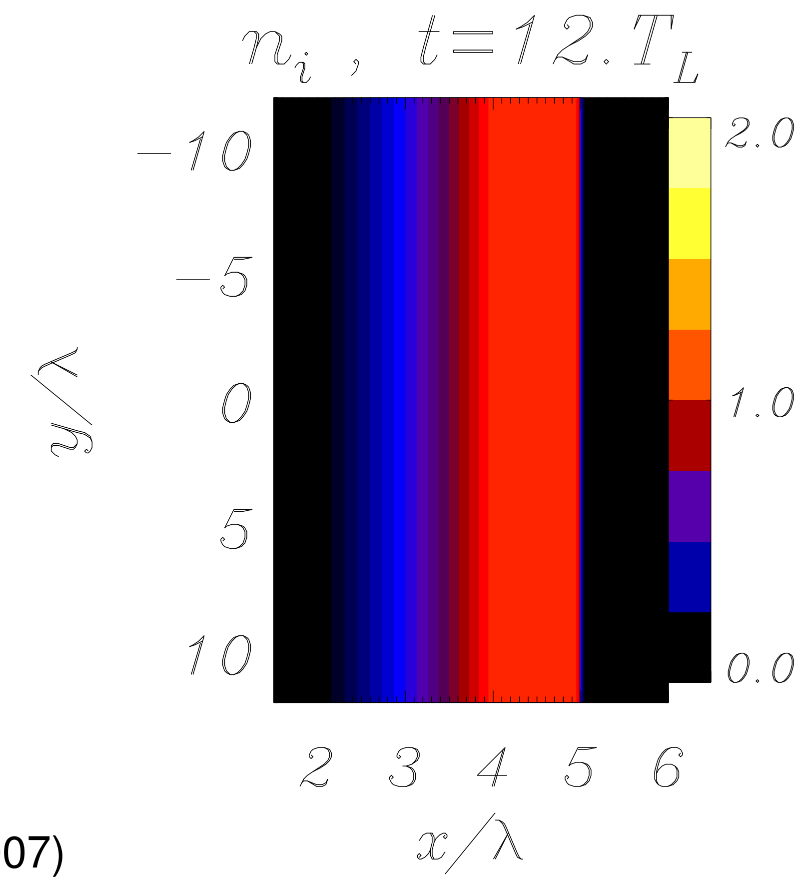

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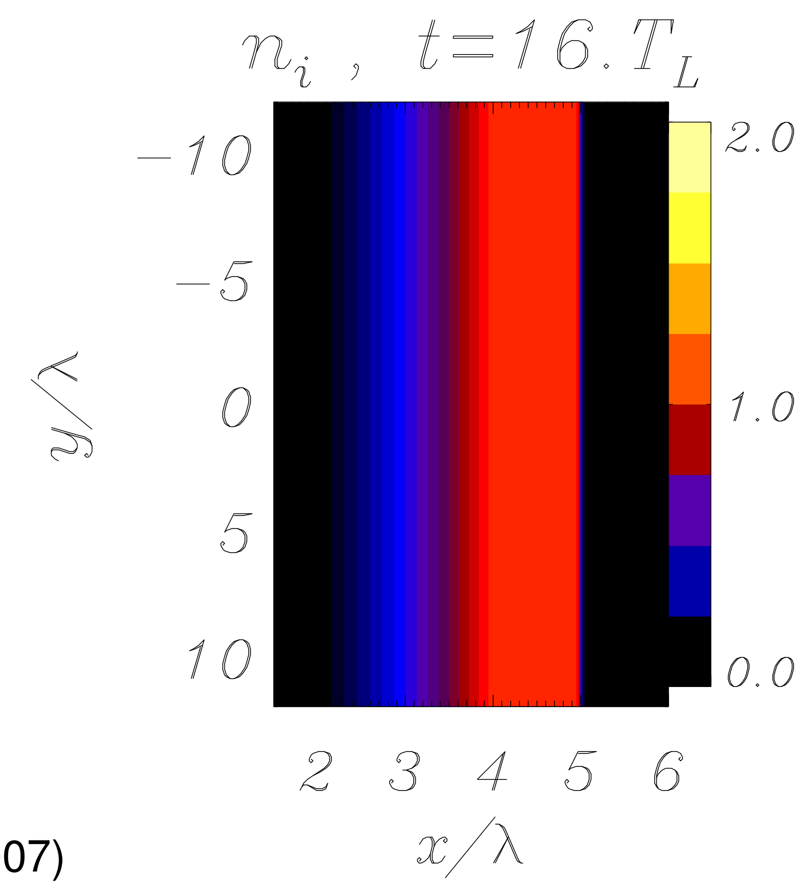

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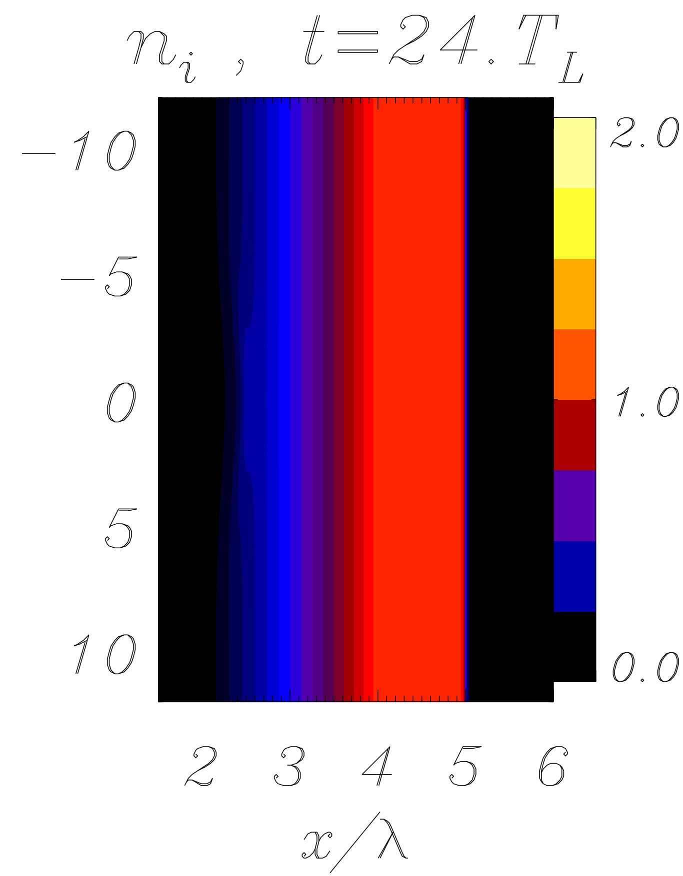

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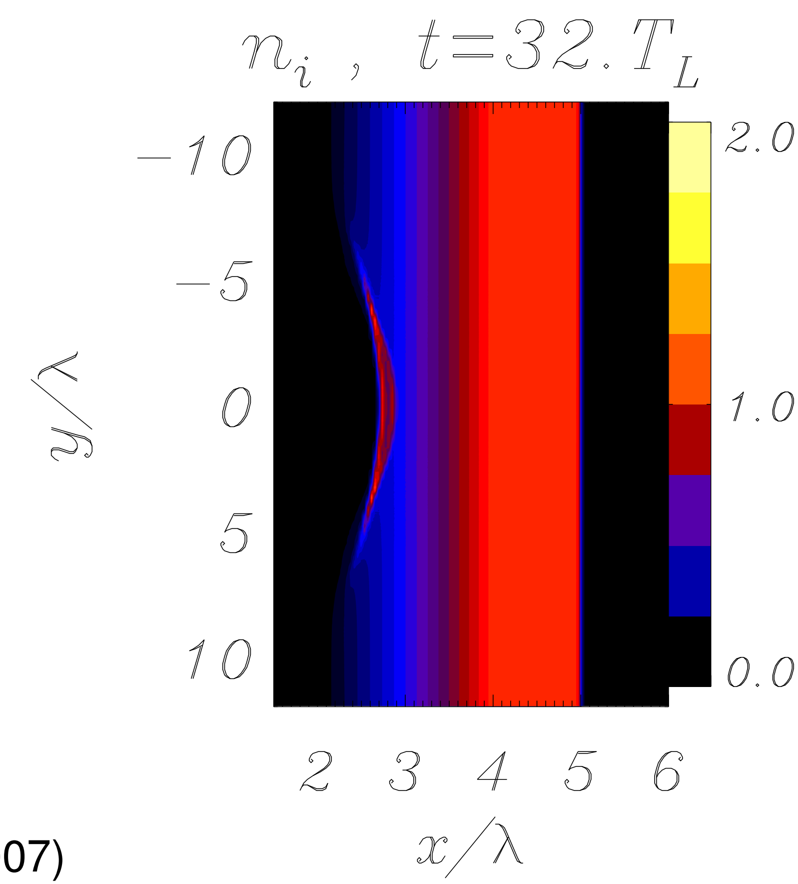

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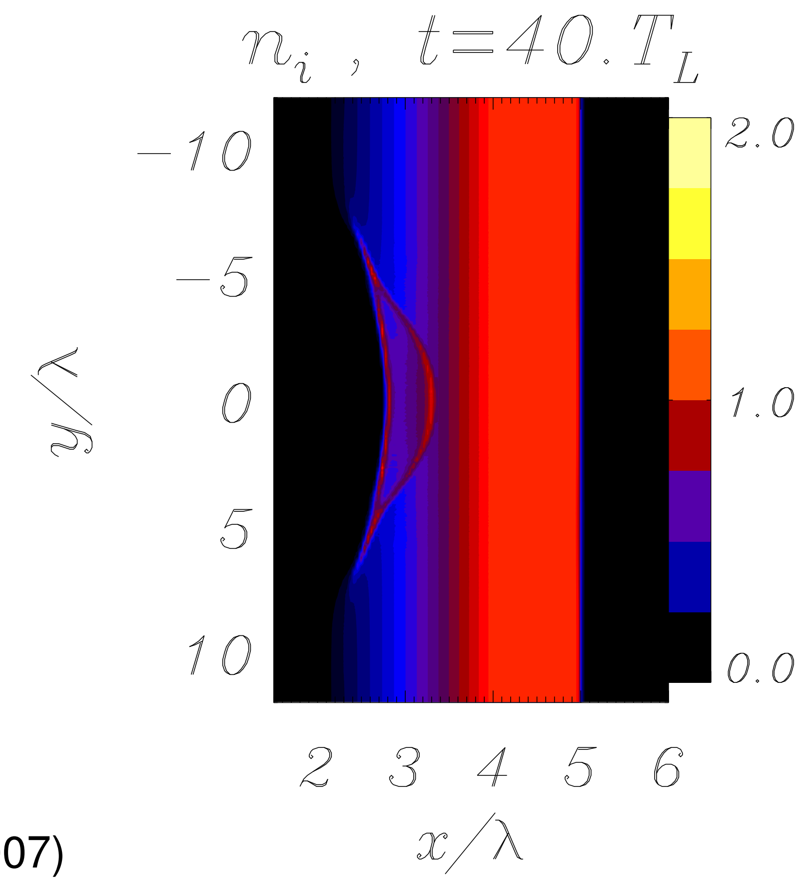

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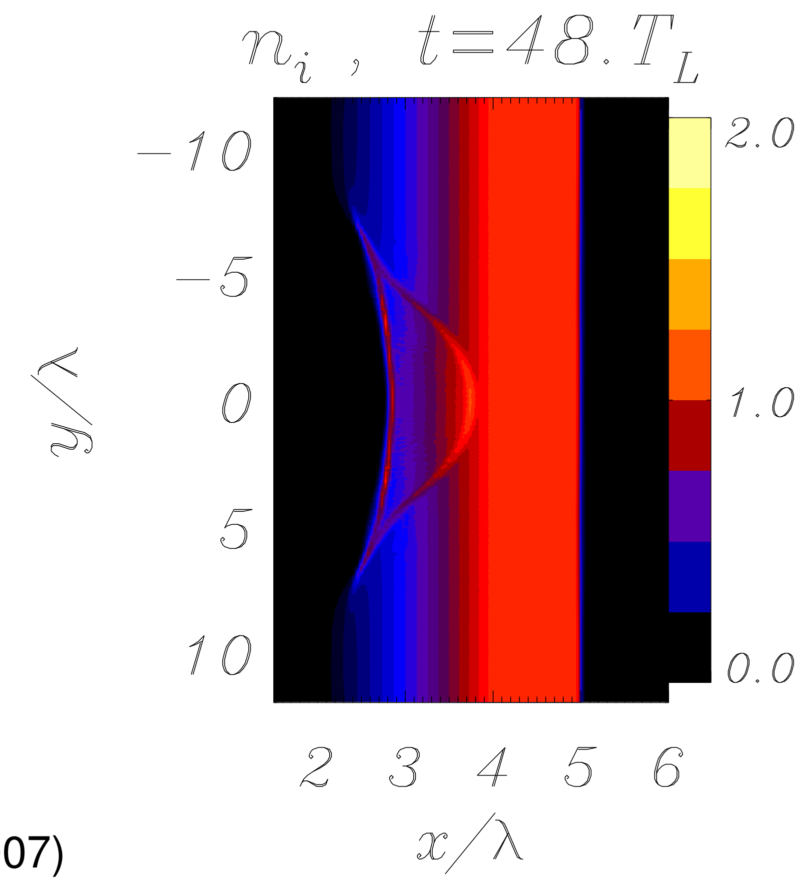

Radiation Pressure Acceleration

Goal: accelerate plasma ions to high energies using the radiation pressure of the laser pulse

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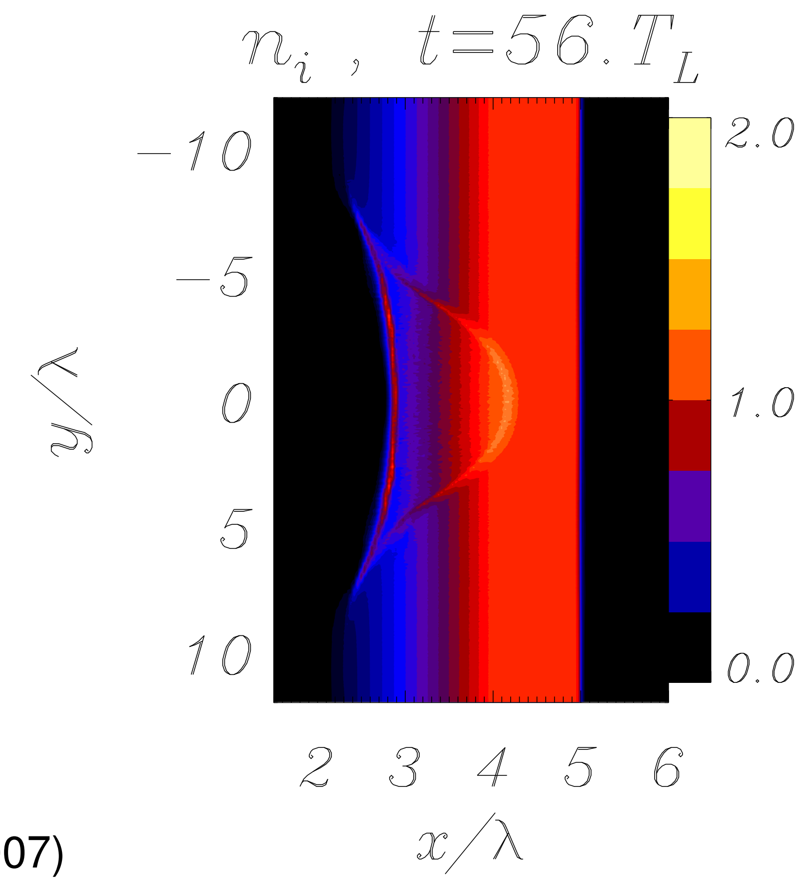

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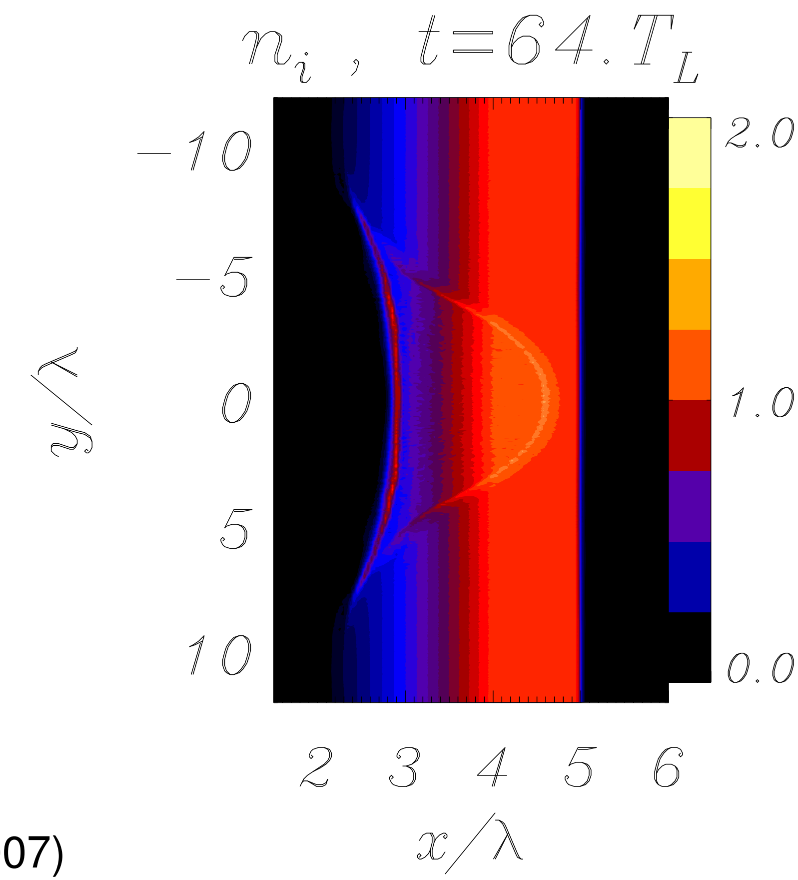

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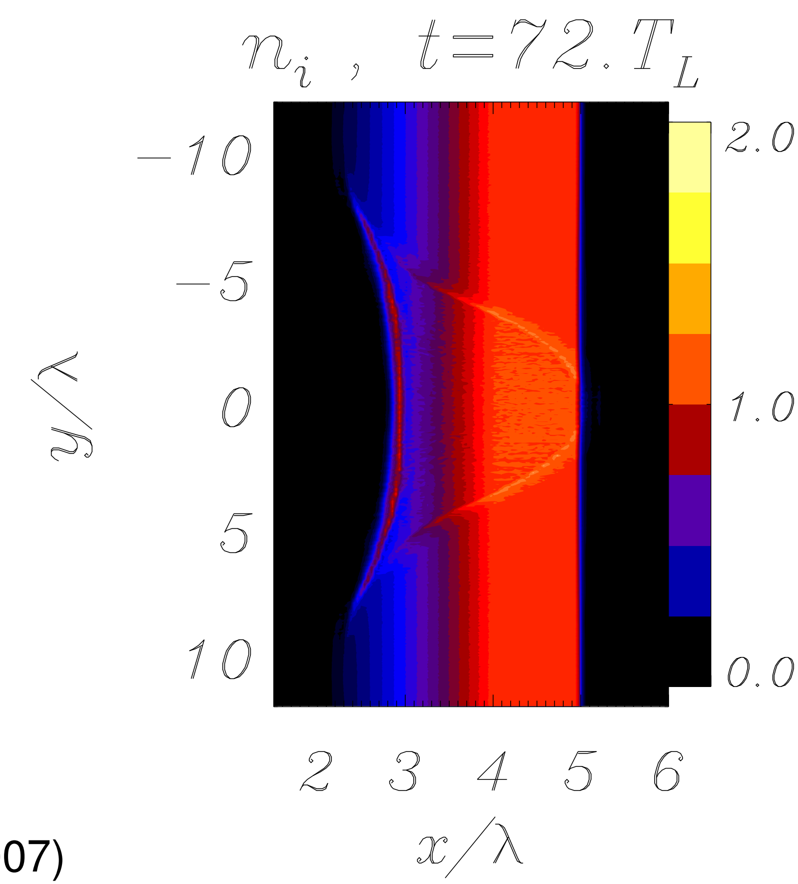

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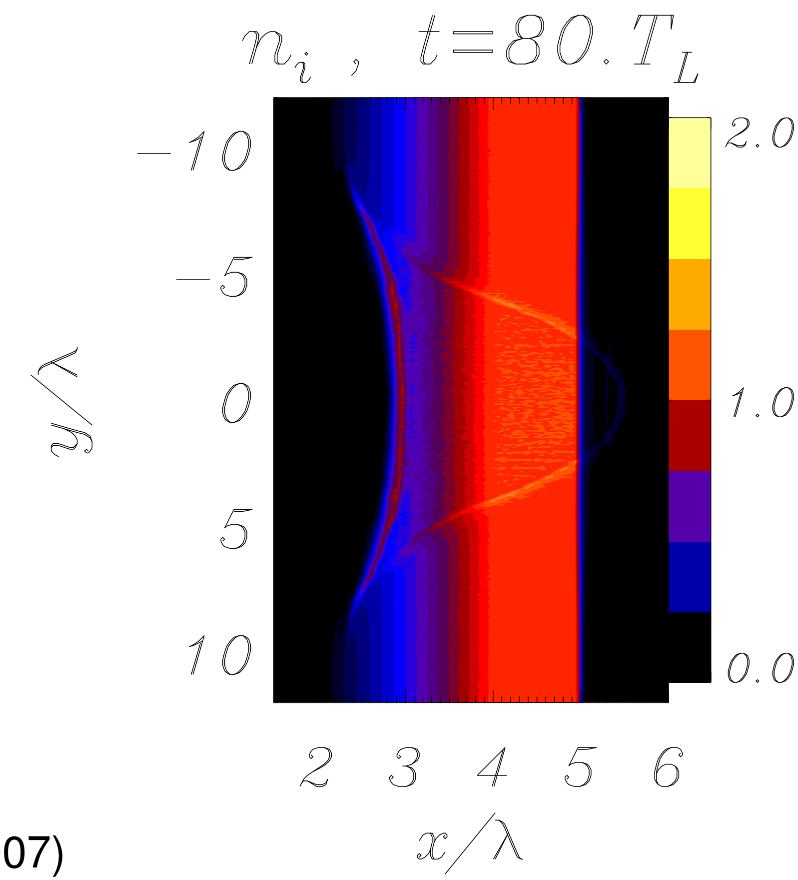

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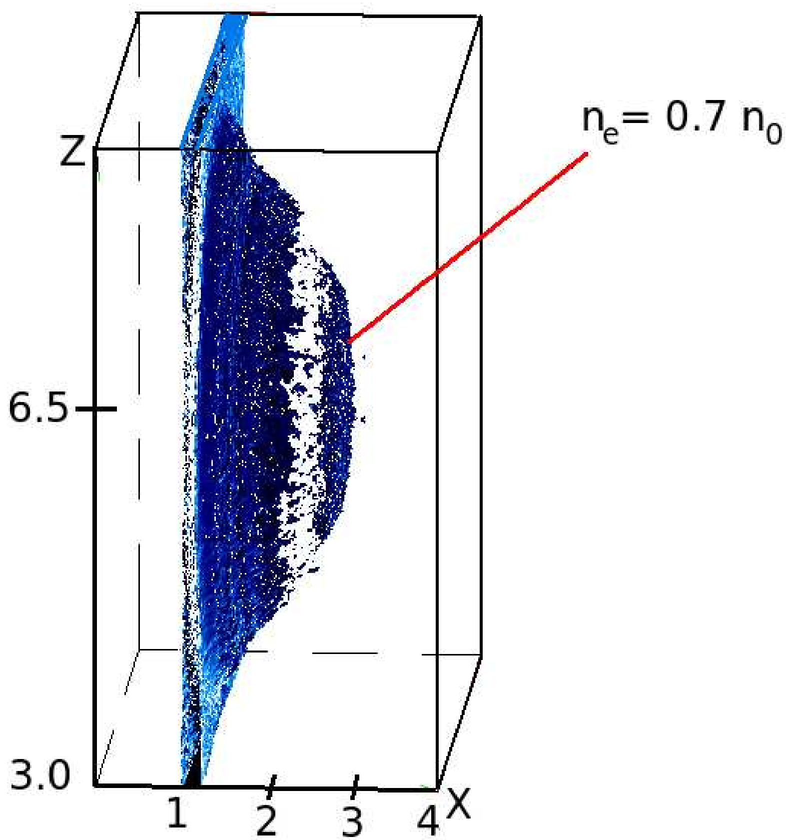
- a CP pulse carries electromagnetic angular momentum: its conservation gives an additional constraint in 3D
- theory shows that absorption of angular momentum does not occur for adiabatic acceleration of ions, thus it provides a diagnostic of the non-adiabatic or dissipative nature of energy transfer to ions (of possible interest for a collisionless system)

3D simulations of CP-RPA

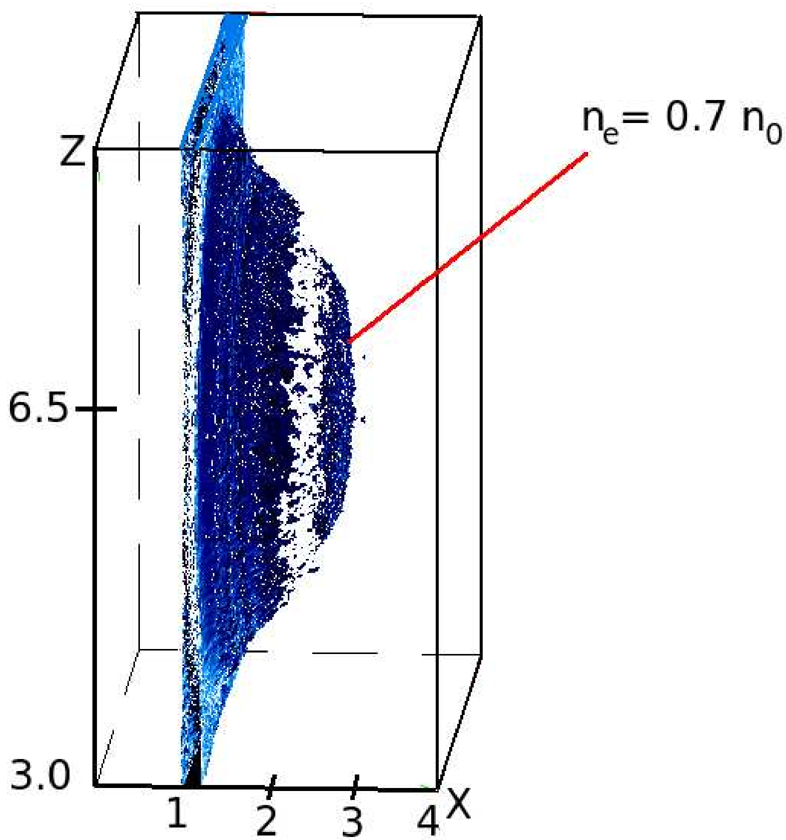
plasma: 0.3μm slab with $n_e = 16n_c = 1.8 \times 10^{22}$ cm^{-3}
pulse: $I = 3.4 \times 10^{19}$ W/cm^2, 6μm focal diameter, 50 fs duration.

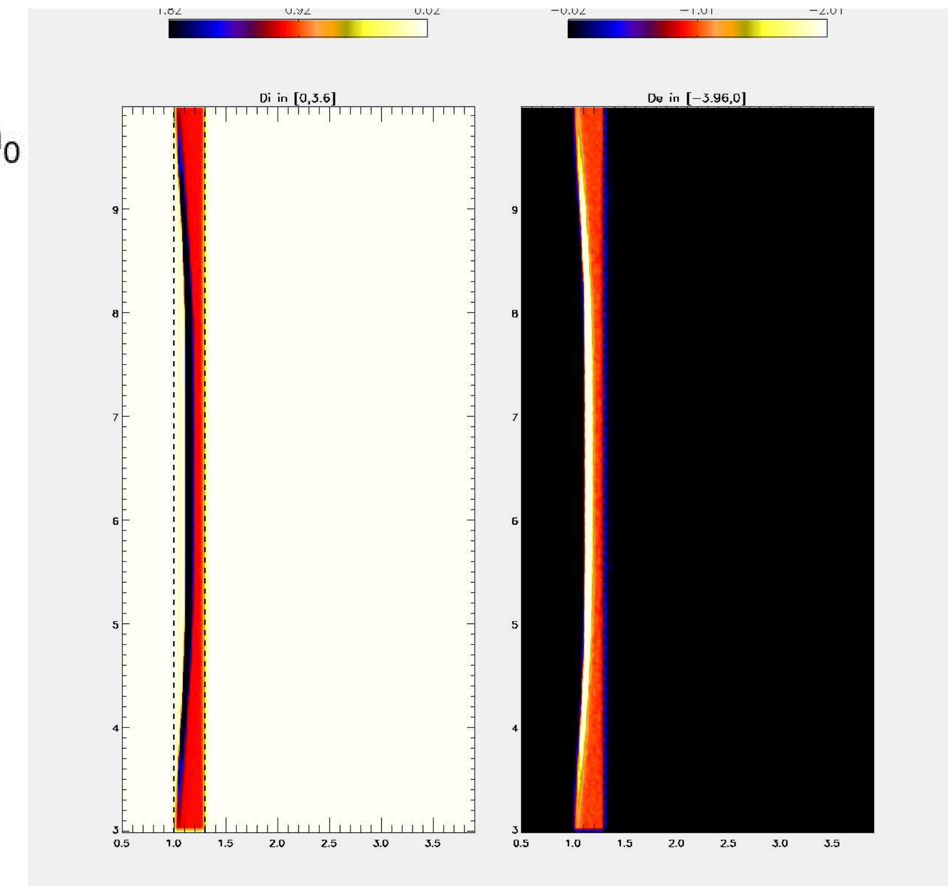


3D simulations of CP-RPA

182 PEs, $320 \times 1050 \times 1050$ grid, 80 points per λ
$\sim 1.5 \times 10^9$ particles (27 per cell), 360 GBytes load

Ion density (thin foil target)





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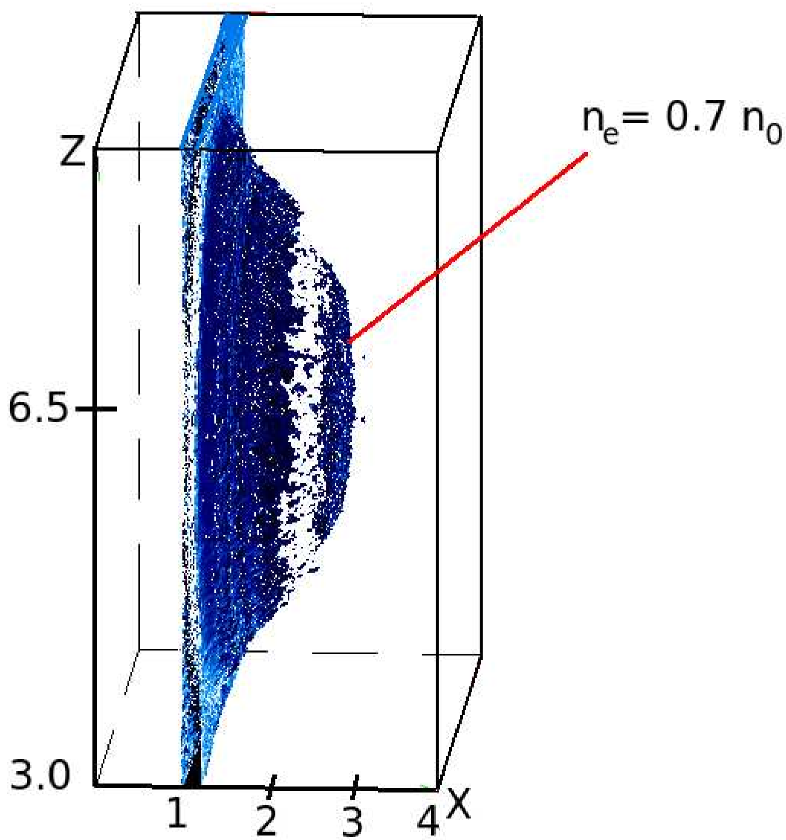

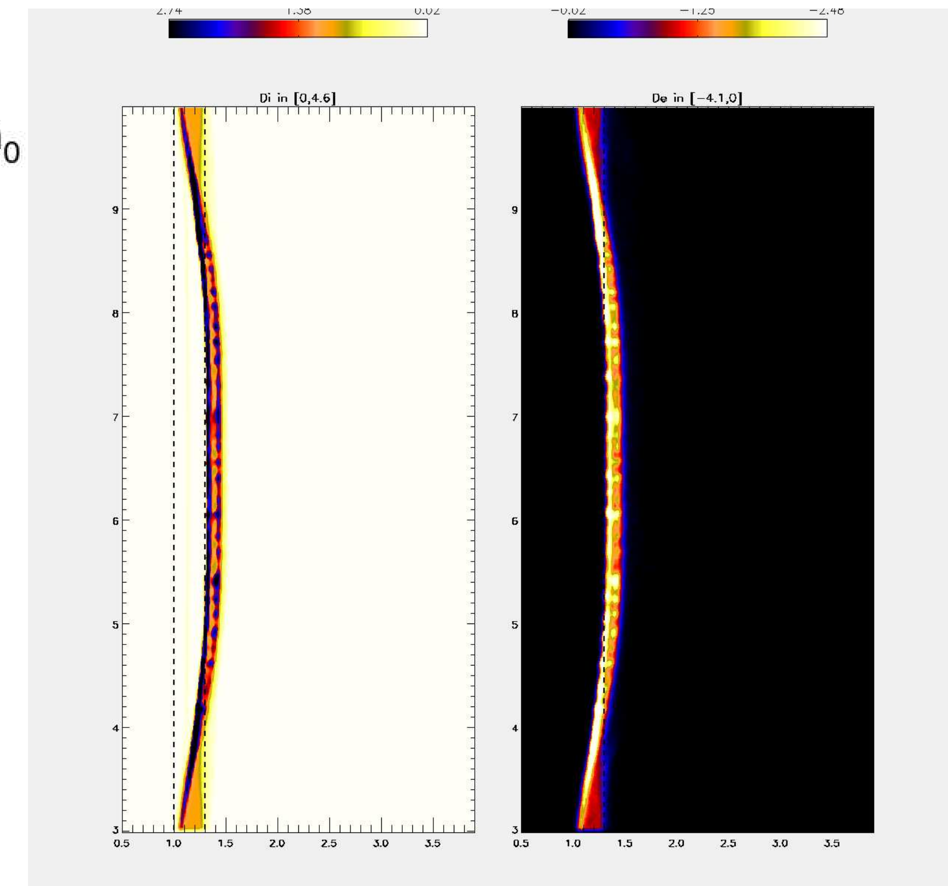

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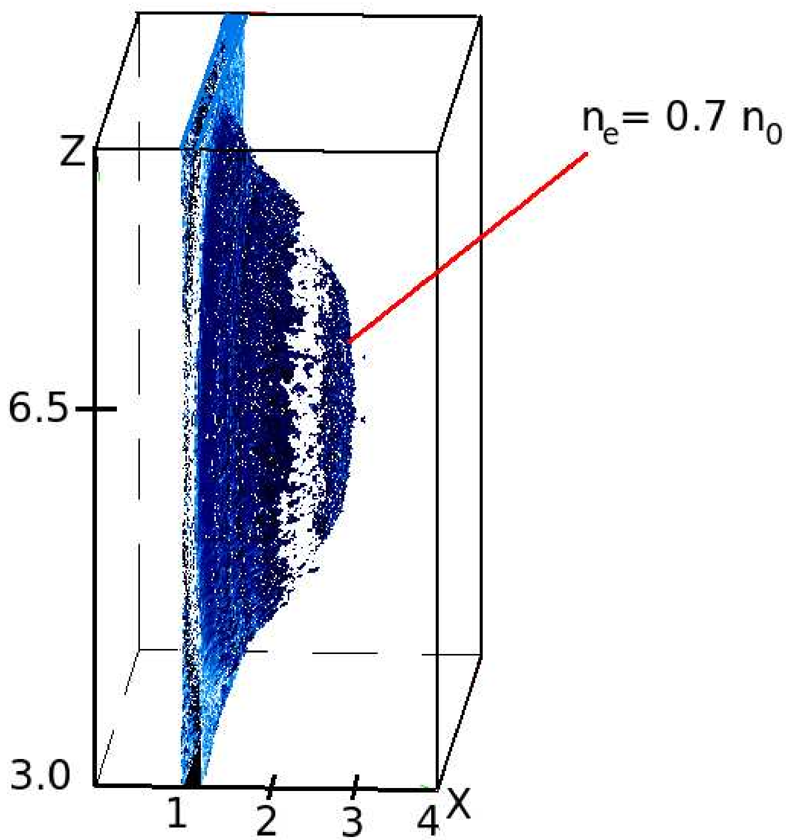

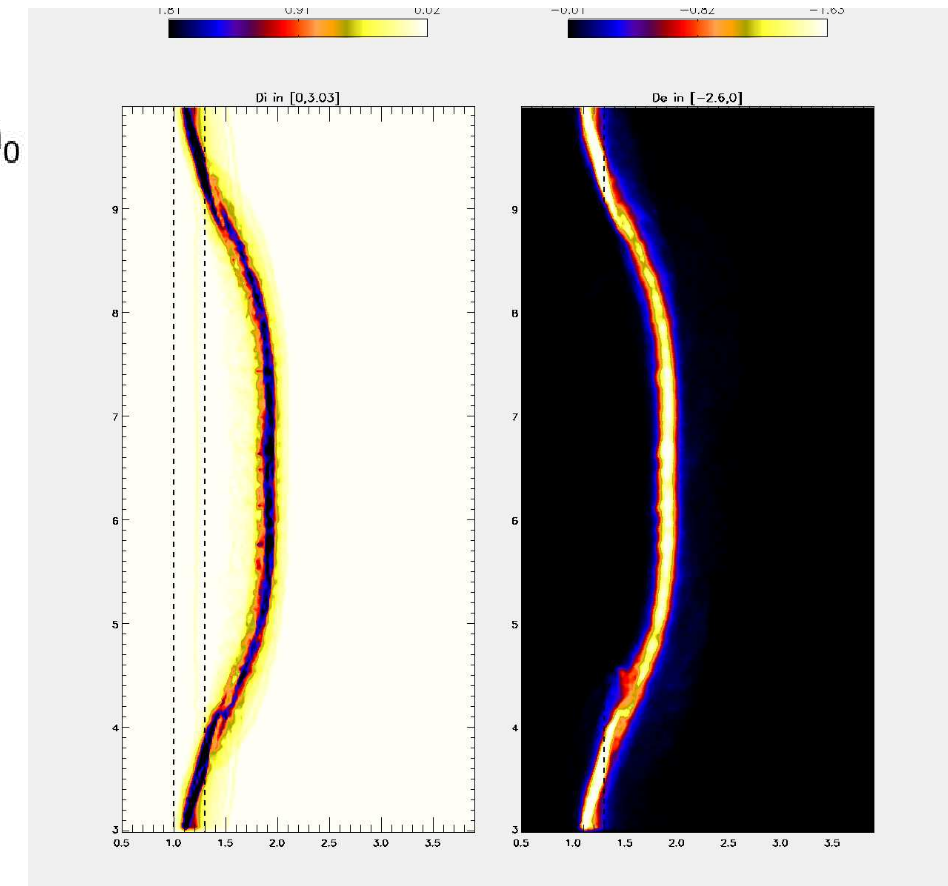

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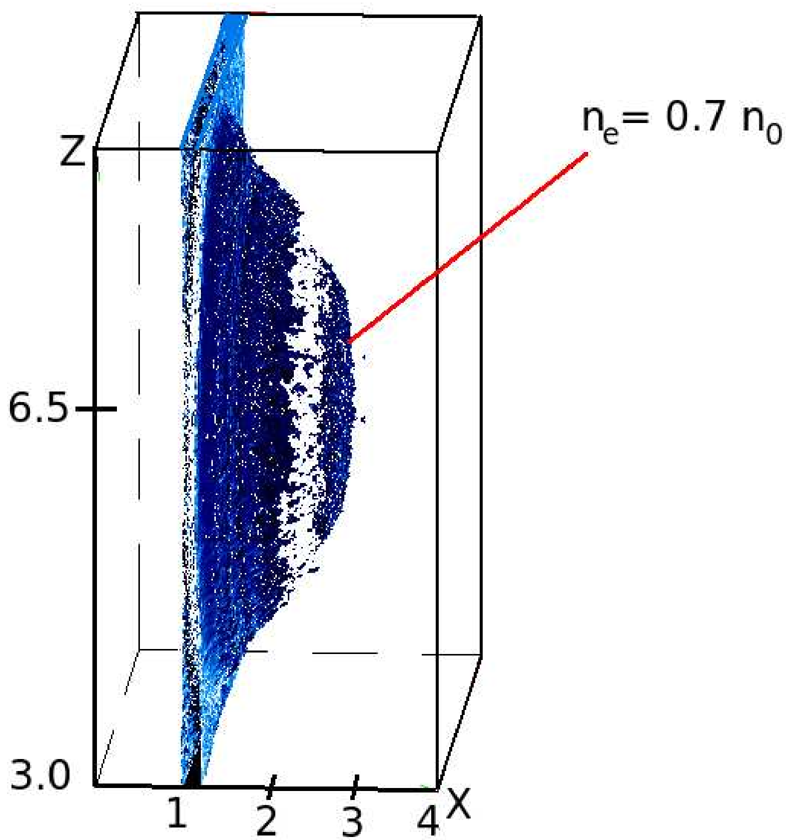

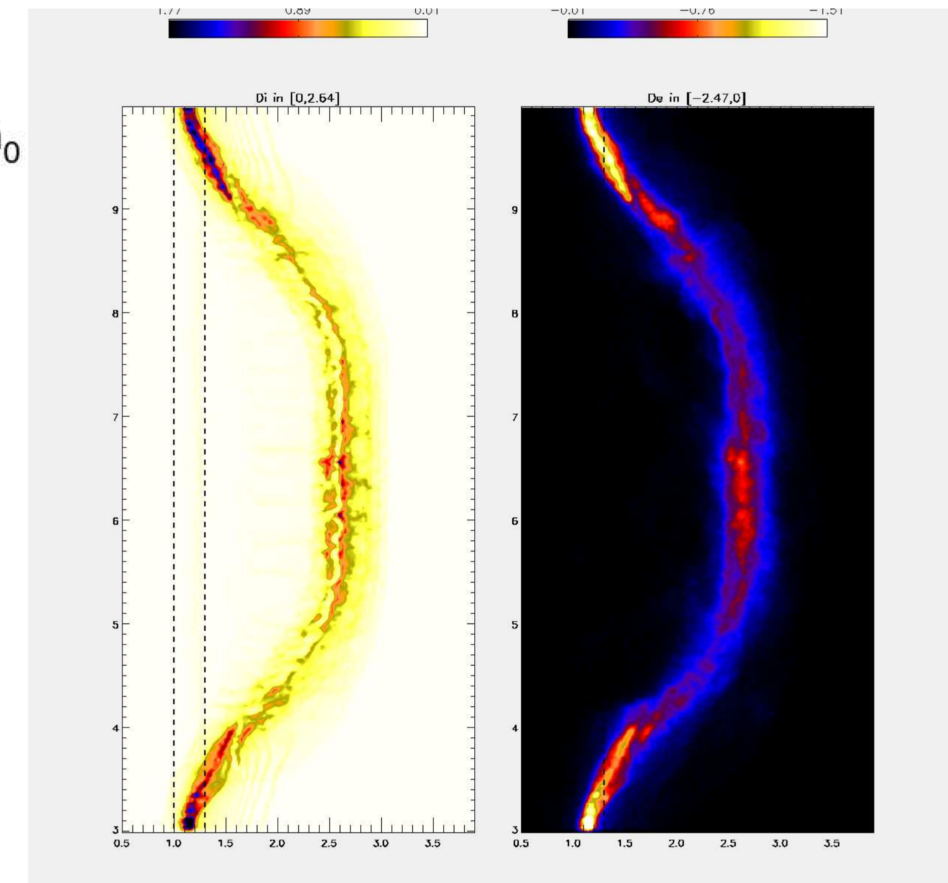

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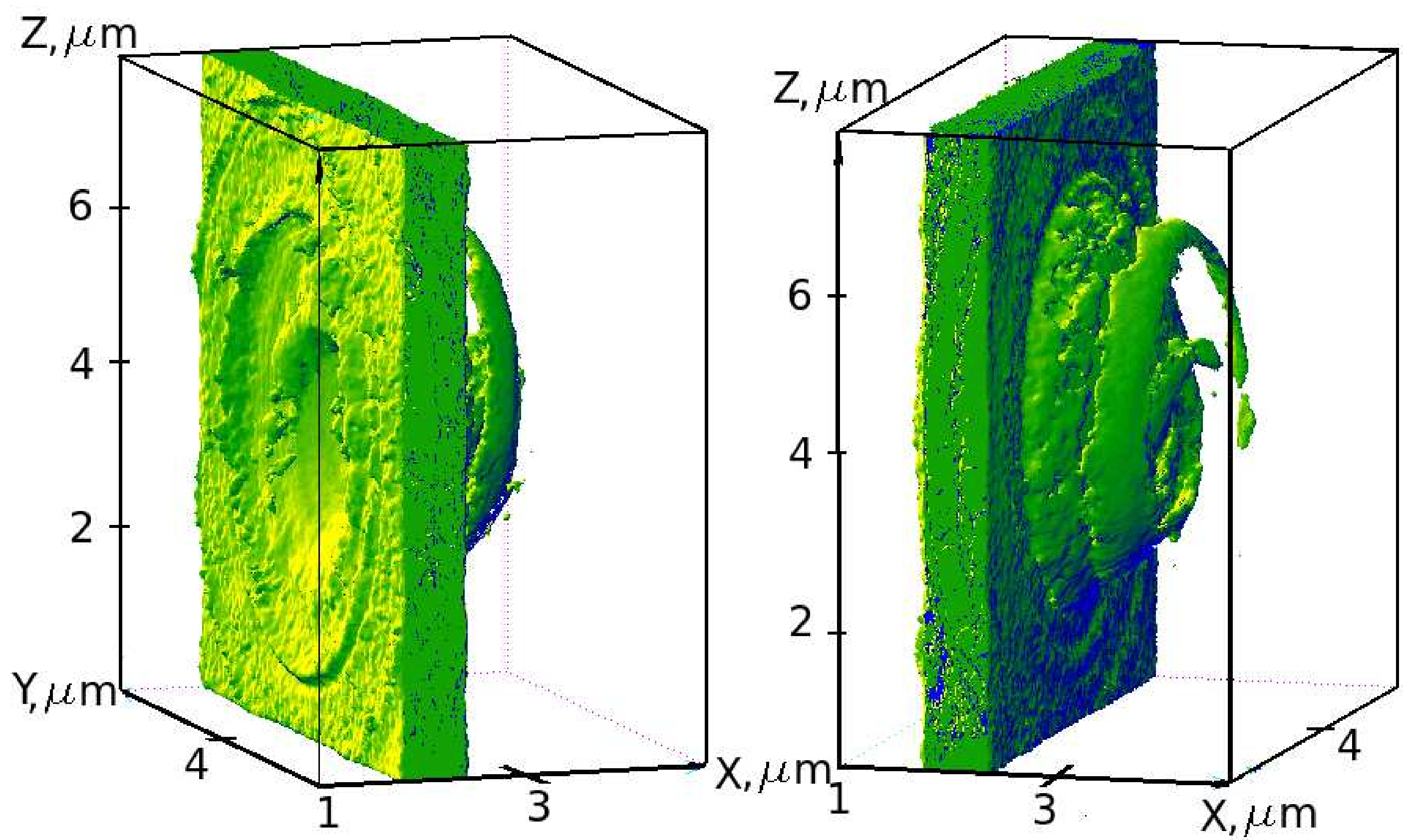
Electron density (rear and front views)



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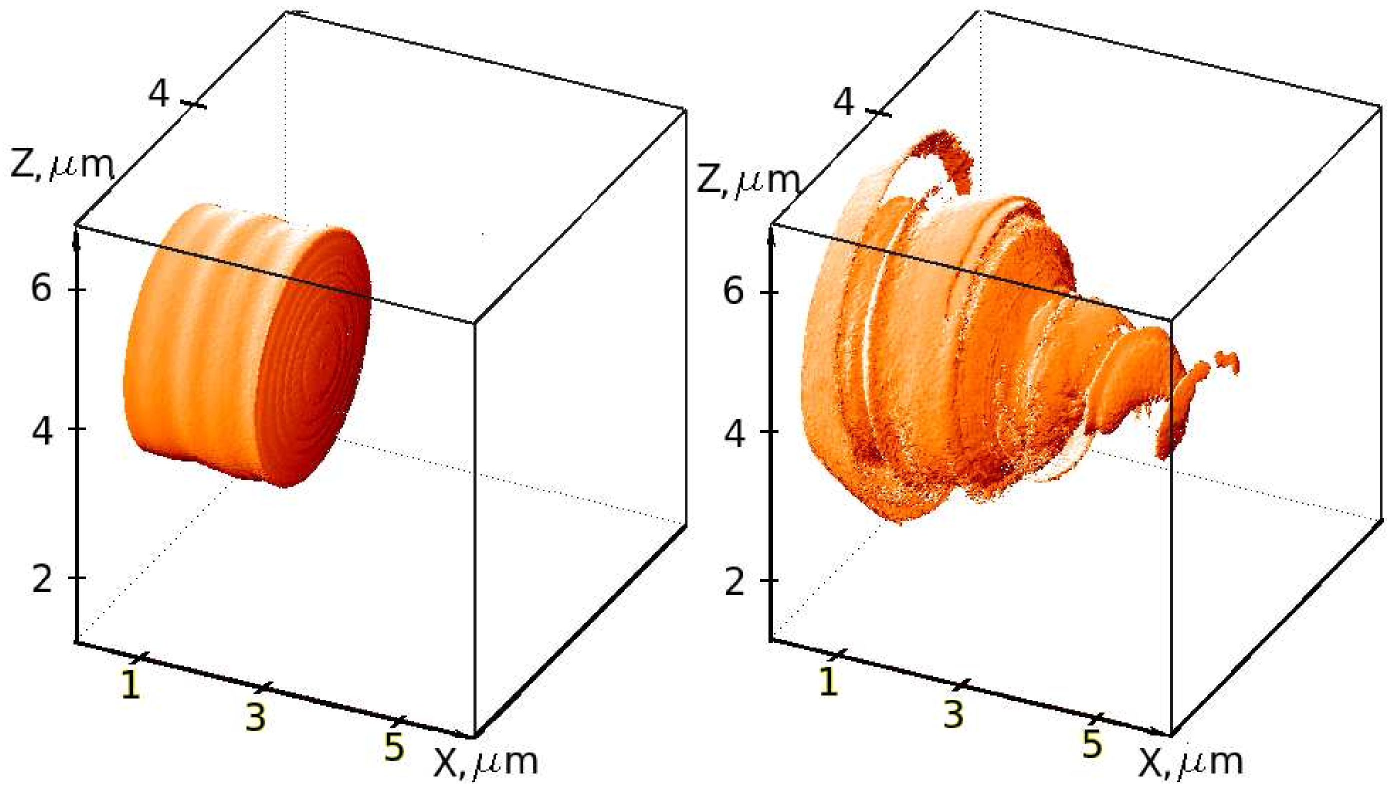
Electromagnetic energy density at two times



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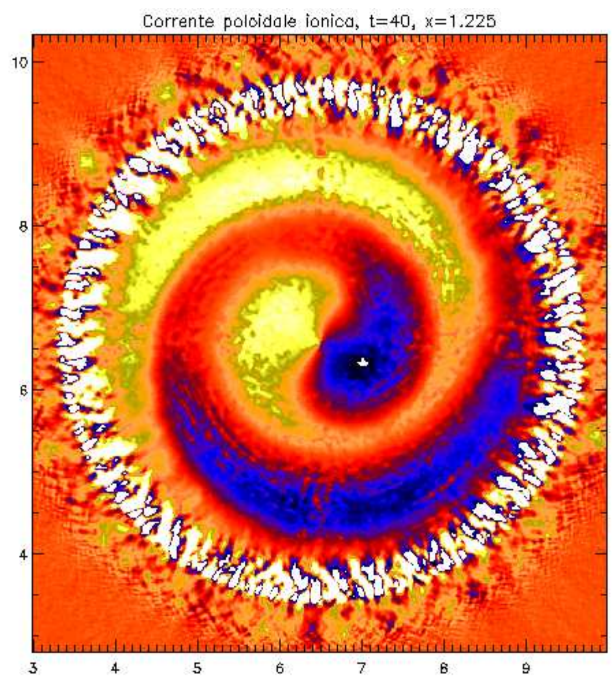
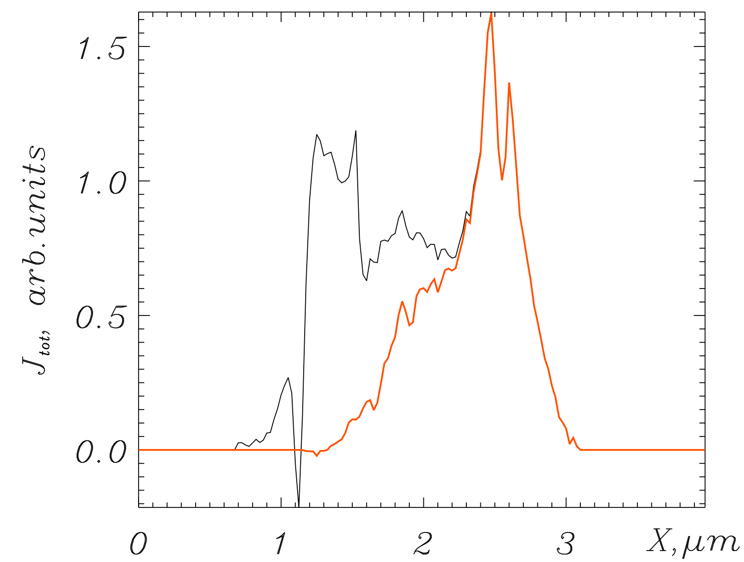
Angular momentum absorption is confirmed by integrating the azimuthal ion current ($J_{i,\phi}$) over the transverse plane (y, z)





Integrated ion current $J_{i,\phi}(x)$, black line: all r, red line: $r < 2.5\lambda$, $r = \sqrt{y^2 + z^2}$.

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- Would you like to see it again?
  www.df.unipi.it/∼macchi/talks.html

EXTRA SLIDES

Mathematical model

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- Vlasov + Maxwell equations

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$\vec{p} = m\gamma\vec{v}$ – particle momenta with $\gamma = \left(1 - v^2\right)^{-1/2}$

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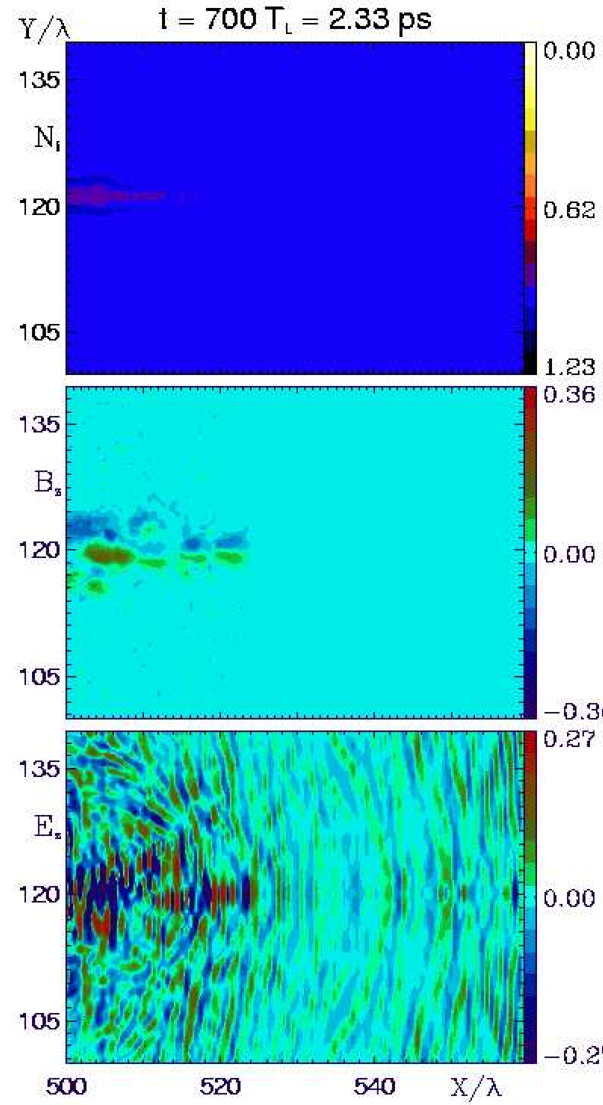

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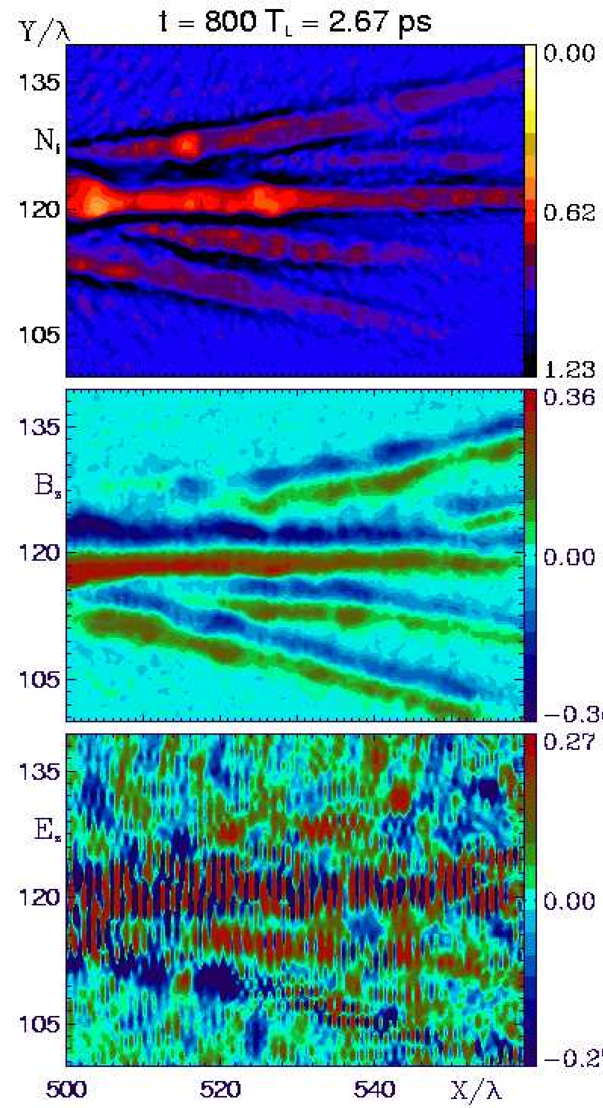

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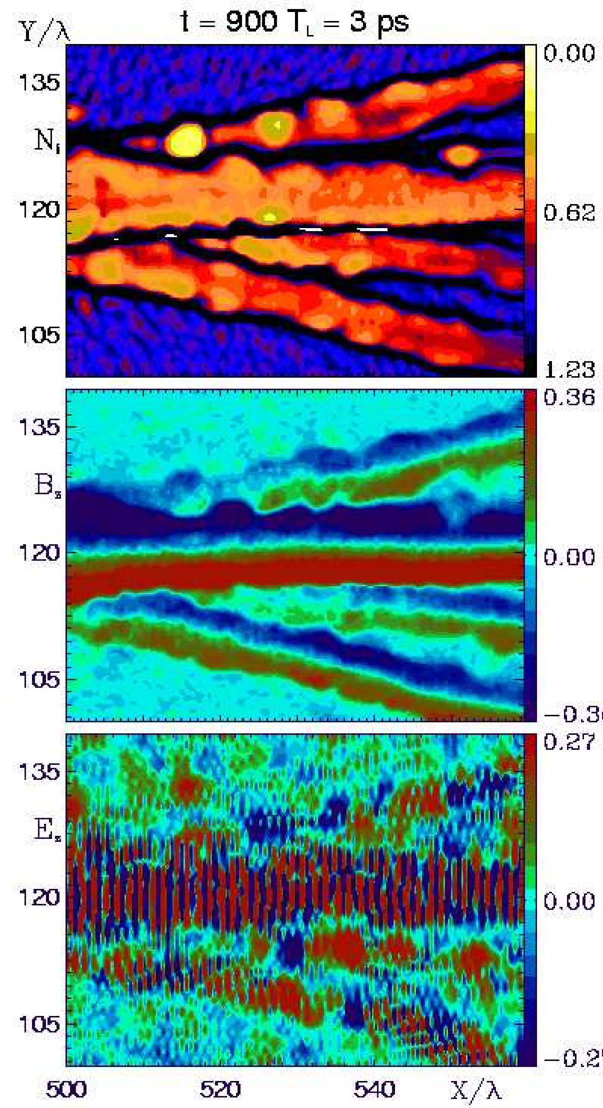

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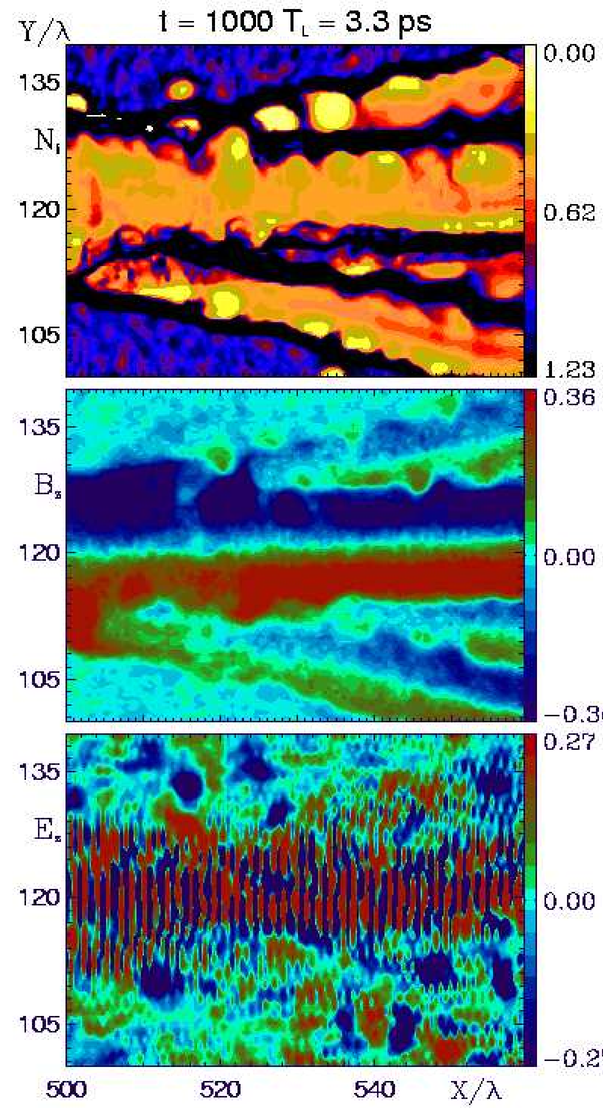

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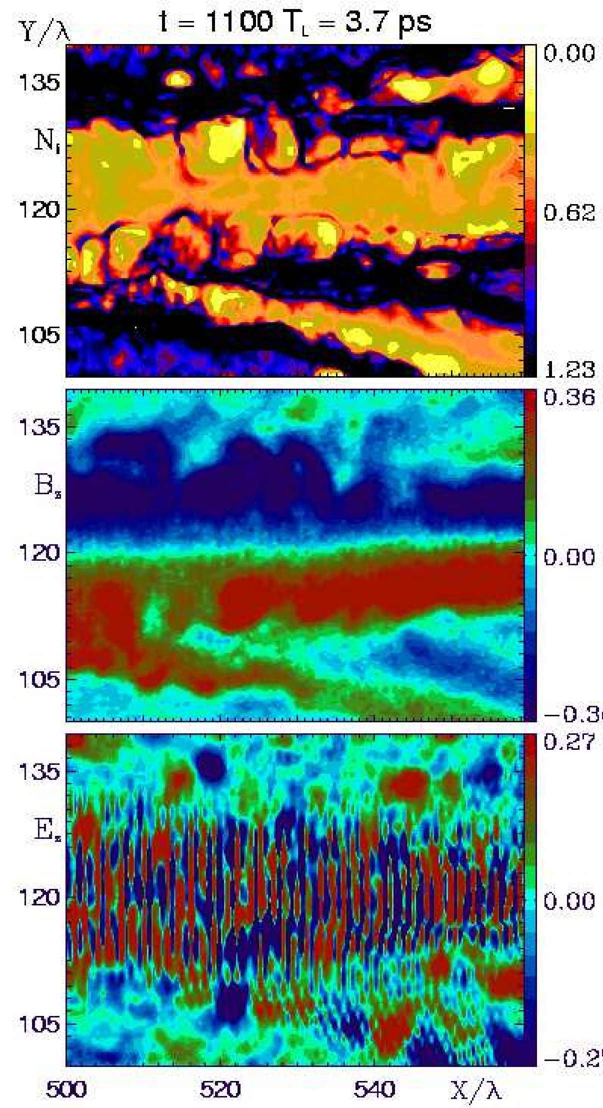

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Comparison with experiments, based on reconstruction of Proton Imaging data by computing probe particles deflection in the slowly varying field patterns, is very promising

[A.Bigongiari, Thesis, Pisa, 2008].