The Collapse of Solid-Density Plasma Shell Induced by Two Ultra-Intense Laser Pulses

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- The rate of fusion reaction per unit volume:

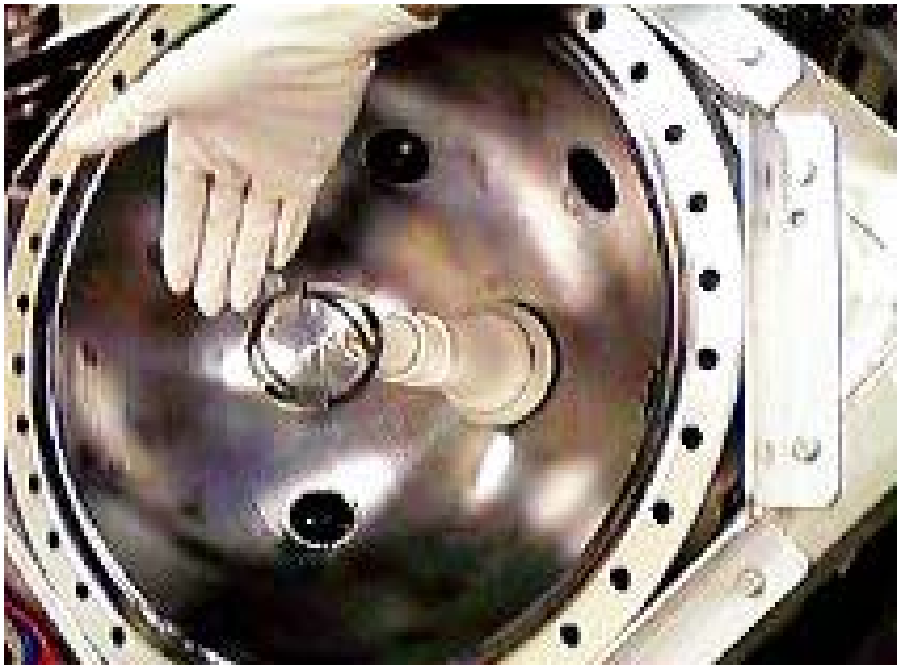
$$P = n_i^2 (\overline{\sigma v})$$

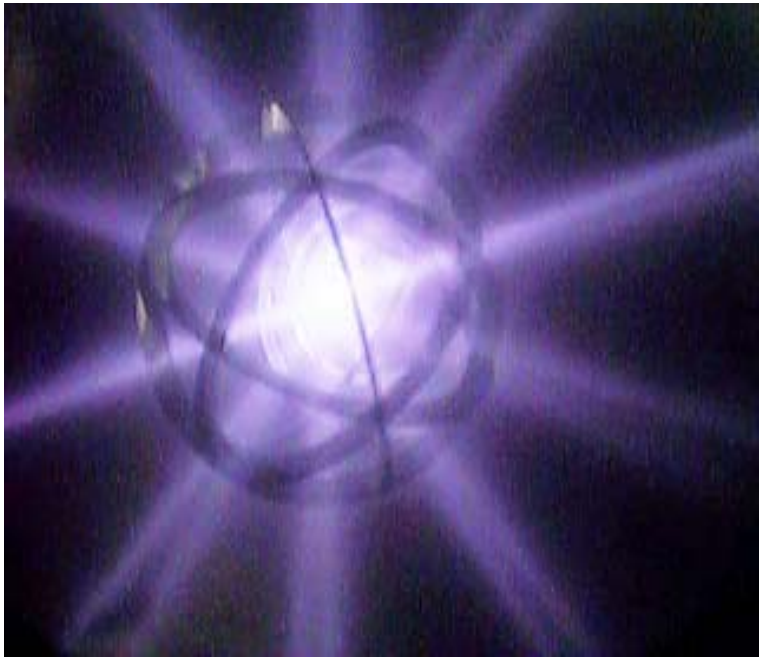
n_i : ion density, $(\overline{\sigma v})$: the reactivity which reaches maximum as ion temperature $T_i = 1.25\ \mathrm{MeV}$ for DD reaction and $T_i = 64\ \mathrm{KeV}$ for DT reaction.

The key issue for fusion reaction: high concentration of plasma ions at the appropriate temperature.

IEC (Inertial Electrostatic Confinement) fusion device

consists of a hollow cathode at the center of a spherical vacuum chamber (serves as anode) filled with a fuel gas, and glow discharge takes place between them, thereby, produced ions are accelerated toward the cathode, and most of them penetrating the hollow cathode wire undergo fusion reactions through beam-beam collisions.





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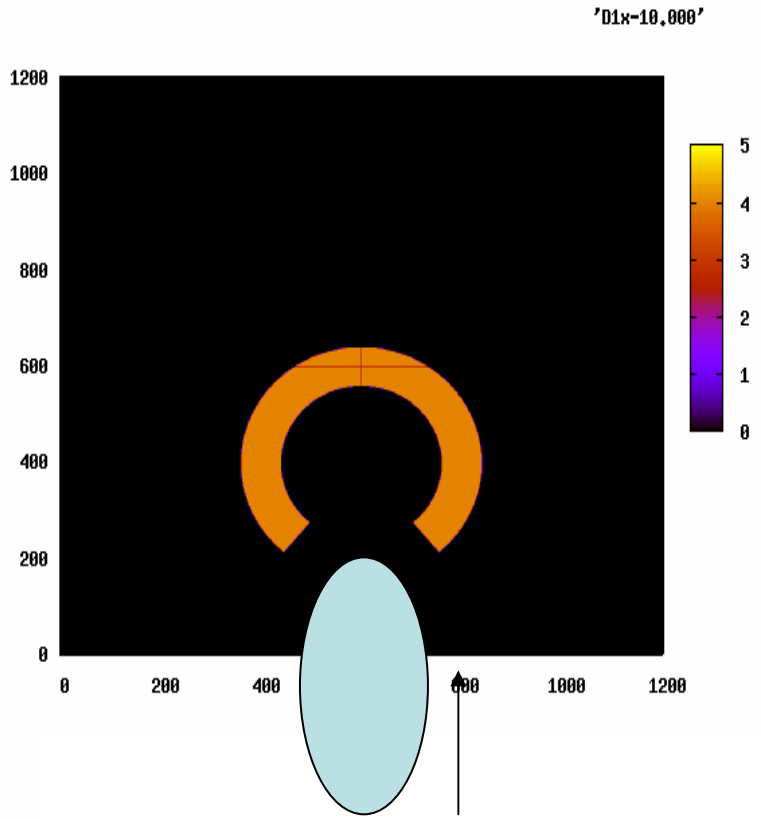
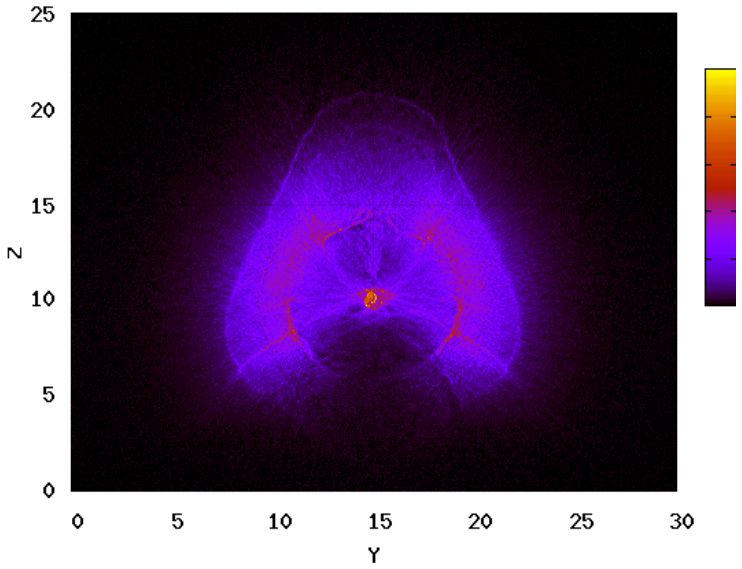
laser strength: a0=5,
duration: 20T,
spot size: 2 λ,

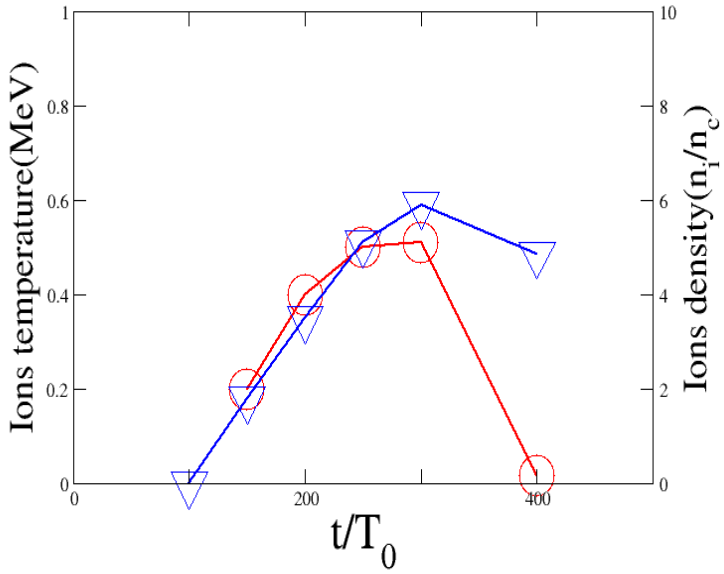
density: 4 nc,
inner radius: 4 λ
outer radius: 6 λ
40 degree opening.



The shell is heated by laser from inside,
leading to inward thermal expansion

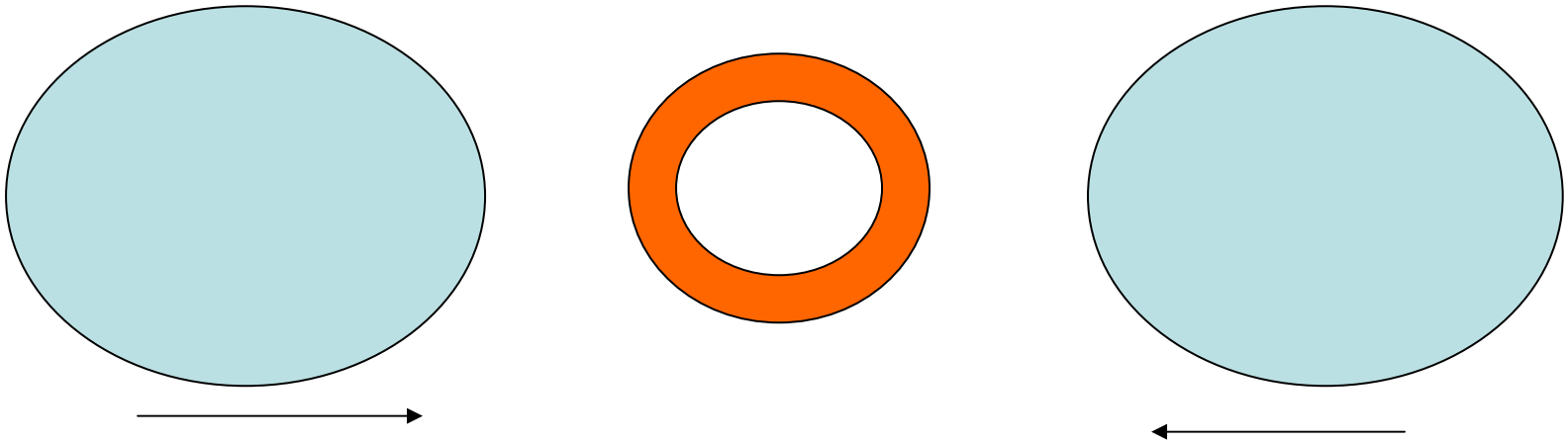
The inward expanding plasma slow down and pile up at shell center, where plasma motion becomes randomized with kinetic energy conversed into thermal energy.





Hot spot of 0.5MeV and 5 critical density.

3D PIC simulation:

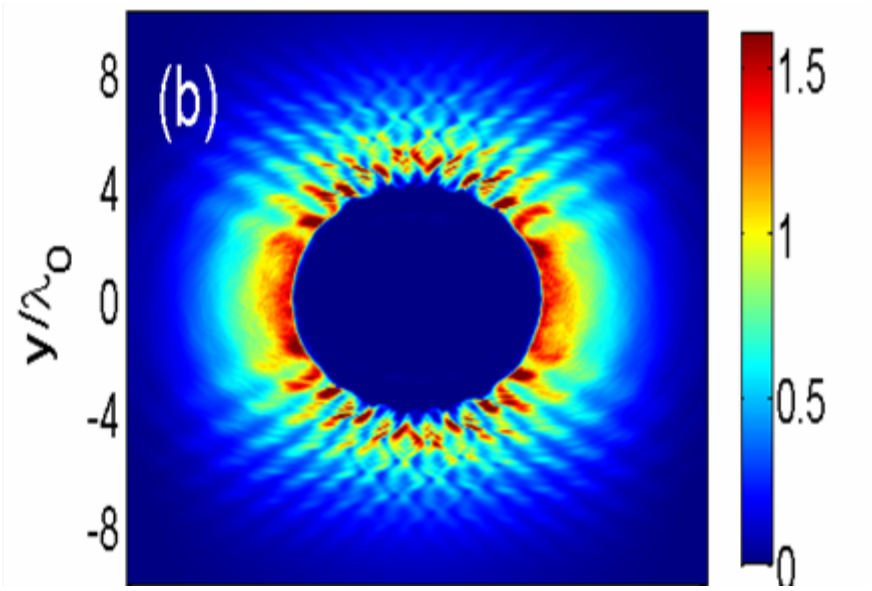


laser strength: a0=50
spot radius: 7 λ pulse width: 12 λ

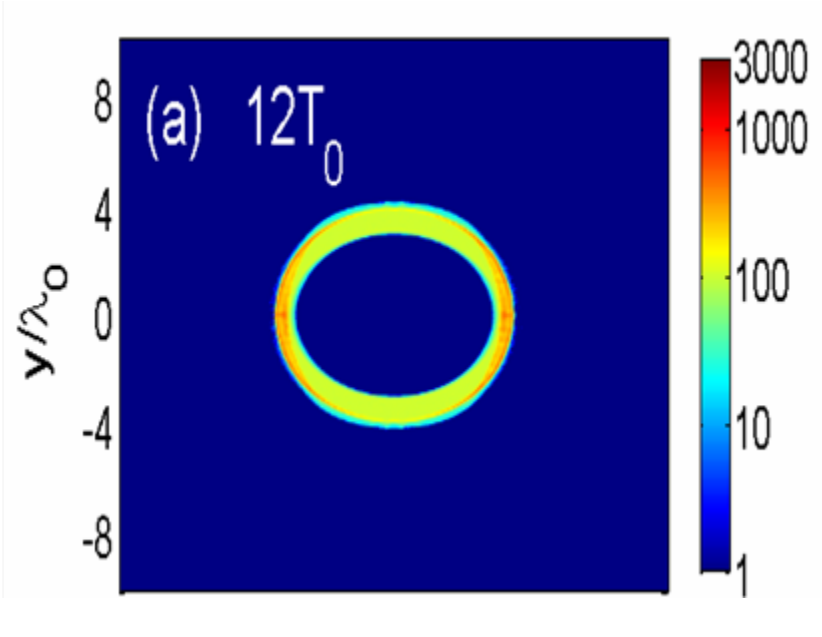
target density: 100nc
Inner radius: 3 λ. outer radius: 4 λ

(a), Laser pushing along the axis

When laser pulses just arrive the shell



Energy density of laser



Energy density of plasma ions

- The mighty light pressure pushes on the shell from left and right.

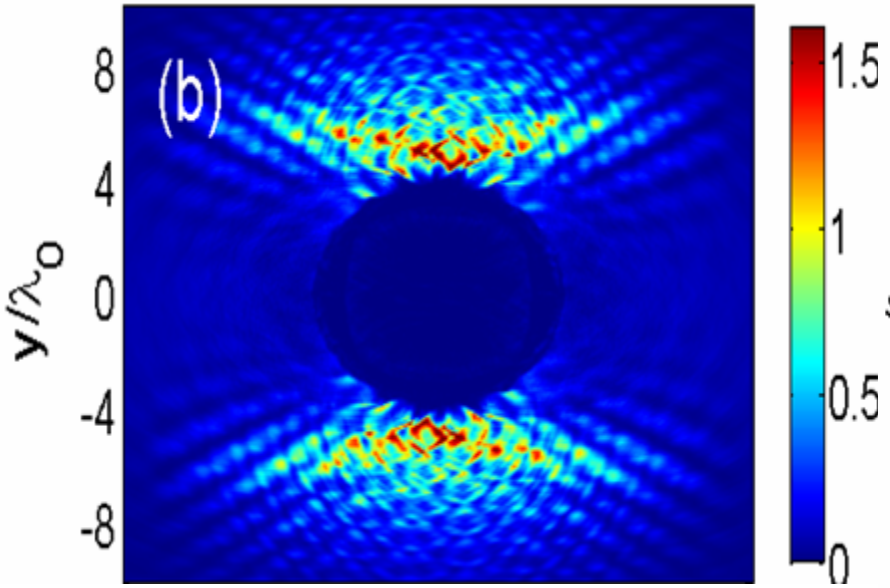
  However, the consequence of laser impact appears not at the moment, but at later times

- As forward propagation is blocked, the laser spreads and propagates along the outer shell surface.

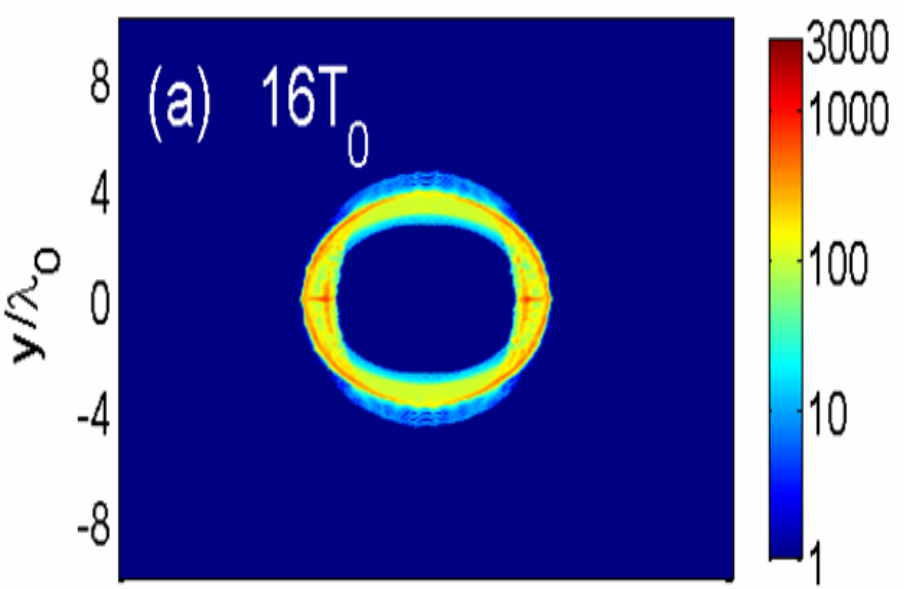
  Little reflection is found from the shell target, due to spherical geometry.

(b), Laser heating from outer shell surface

when two laser pulses meet at the middle.



Energy density of laser



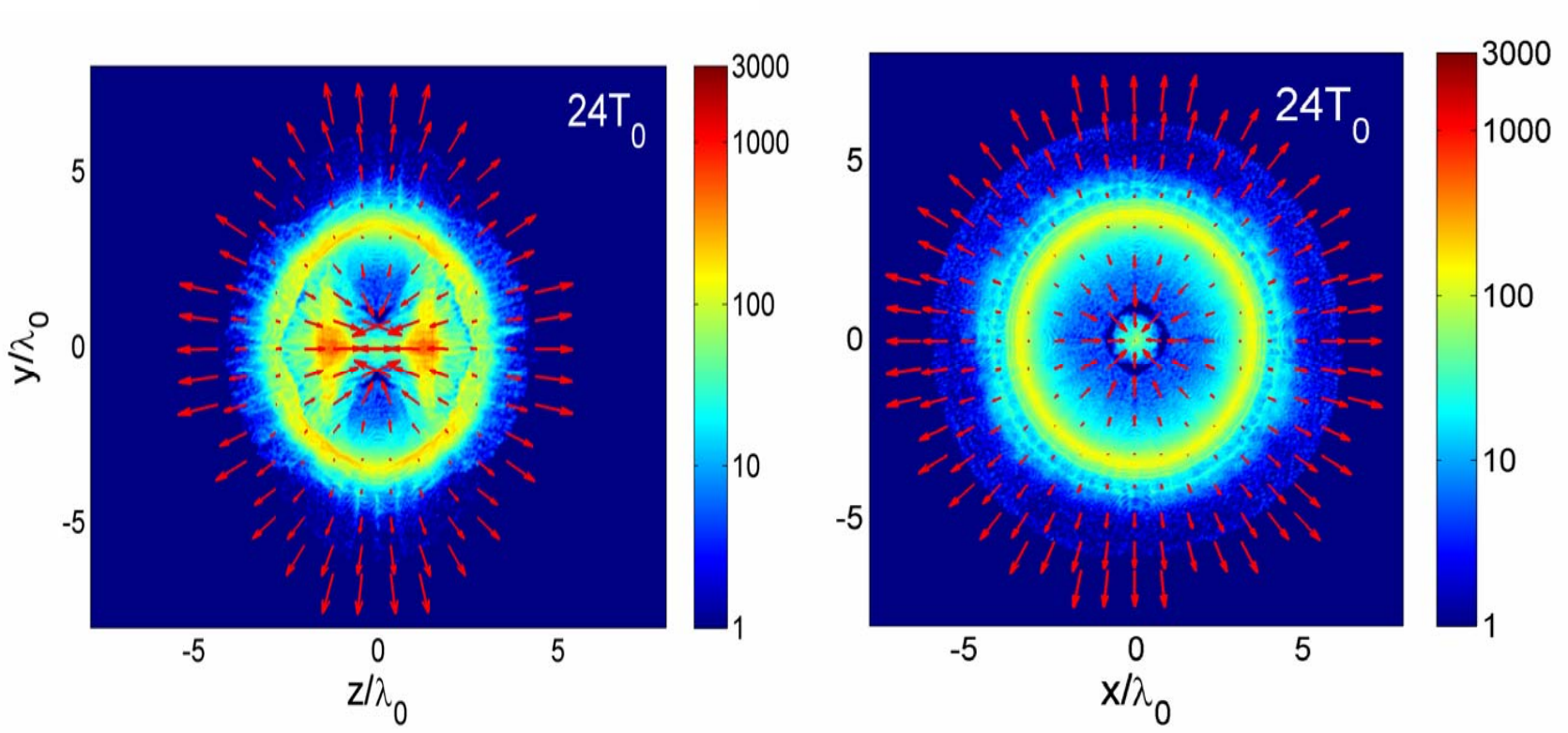
Energy density of ions

- As the laser pulses propagate along the outer shell surface, the plasma is effectively heated from outside.

- For t>20T, the laser pulses leave the shell target and propagate to the right and left, respectively.

  Although laser-target interaction is terminated, the dynamic motion of shell plasma just begins.

Ion density distribution in ZY (a) and XY (b) plane



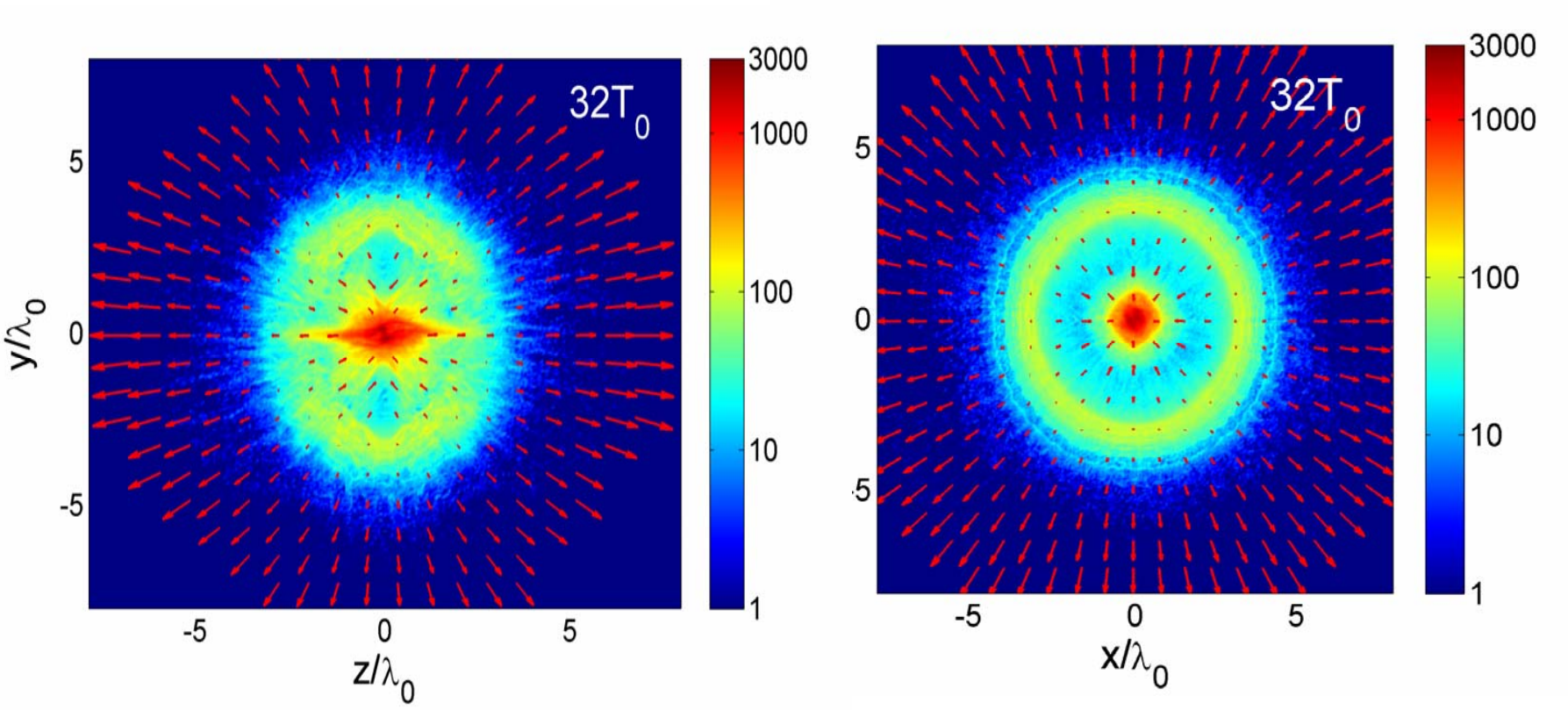
The arrows show the direction and magnitude of ion velocity

(a), Pushed by light pressure, two dense plasma blobs leave the shell and appear in the inner space,

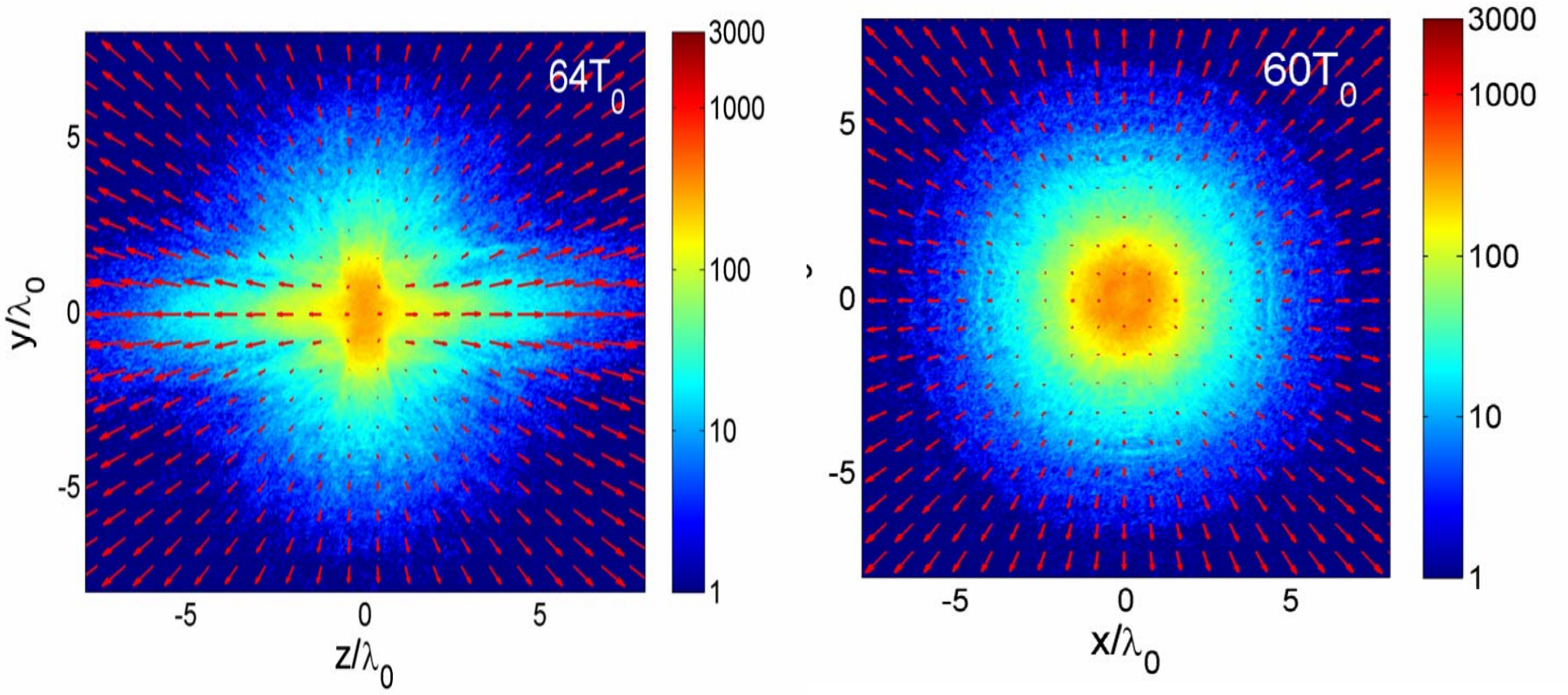
The two blobs are converging to shell center.

(b), The laser-headed shell plasma expands into vacuum. Outward thermal expansion is dominating since the shell was heated by laser from outside.

The reacting force of outward expanding plasma makes the shell converging to the center.

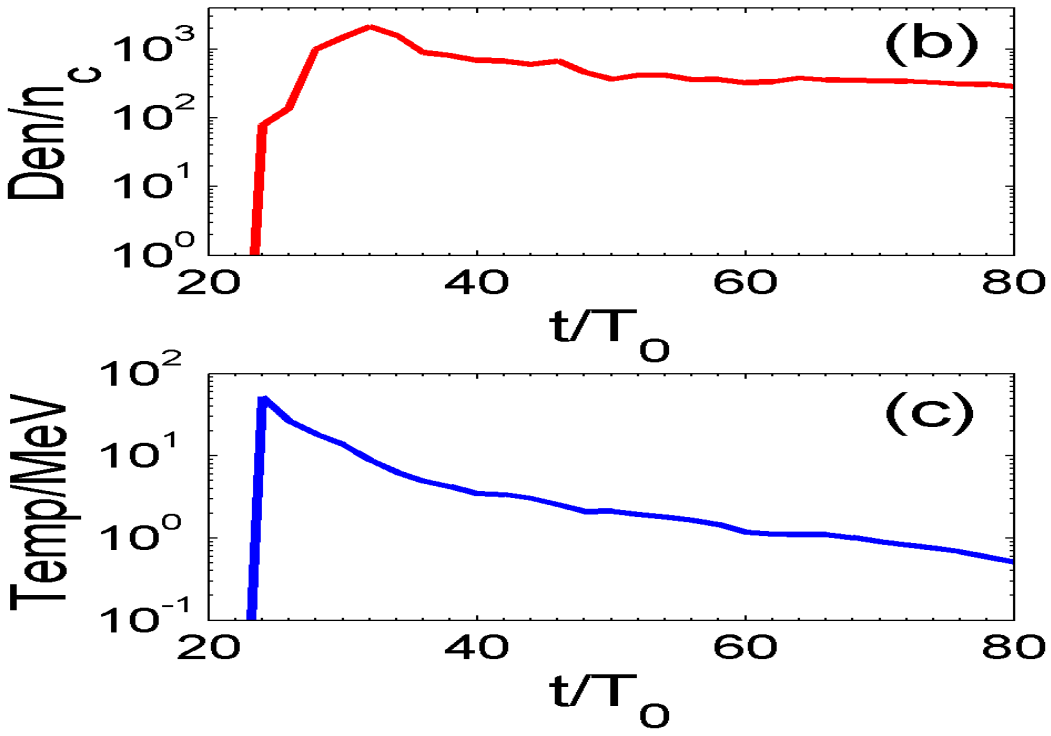


Two plasma blobs are merged at the shell center.
Shell plasma keeps expanding outwards and focusing inwards



The plasma shell disappears.
Instead, a dense hot spot appears at shell center.

Time evolution of plasma density and temperature in the center hot spot



- The ions slow down and pile up near the shell center, where plasma motion is randomized, and the kinetic energy of ion is conversed into thermal energy.

  The collapse of plasma shell leads to a MeV hotspot of thousands critical density.

- The center hotspot expands outward at later times.

Summary

3D PIC simulation is performed, in which two ultra-intense laser pulses impact on a solid-density plasma shell from opposite directions.

Due to laser pushing and outward thermal expansion, the plasma shell collapses after laser interaction, and the plasma converges into a small hotspot, with maximum density up to thousands critical density.

Thanks