DESY/XFEL - NSC KIPT meeting
15 July 2022

Simulation of the high-gradient wakefield excitation by an exawatt laser pulse in solid-density plasma

V.I.Maslov[1,2] (Head of Lab), D.S.Bondar[1,2],
R.T.Ovsiannikov[2], I.N.Onishchenko[1]

[1] Institute of Plasma Electronics and New Methods of Acceleration (Director I.N. Onishchenko)
[2] Karazin Kharkiv National University

Background

Along with plasma wakefield acceleration using particle beam driver (PWFA) (**KIPT, SLAC and others**) giving accelerating gradient of about **50 GeV/m and energy gain of 42 GeV,**
a lot of investigations are devoted to plasma wakefield acceleration using laser pulse driver (LWFA) (e.g. C. Benedetti, C.B. Schroeder, **E. Esarey, and W.P. Leemans. 2012 among others**) giving **energy gain of 8 GeV**.

The rapid development of laser technique has led to creation of Petawatt laser of mk wavelength and to possibility to produce **exawatt X-ray laser** based on thin foil compressor (G.Mourou et al).
T.Tajima (2014) proposed to use it for excitation intense wakefield in metallic-density plasma.

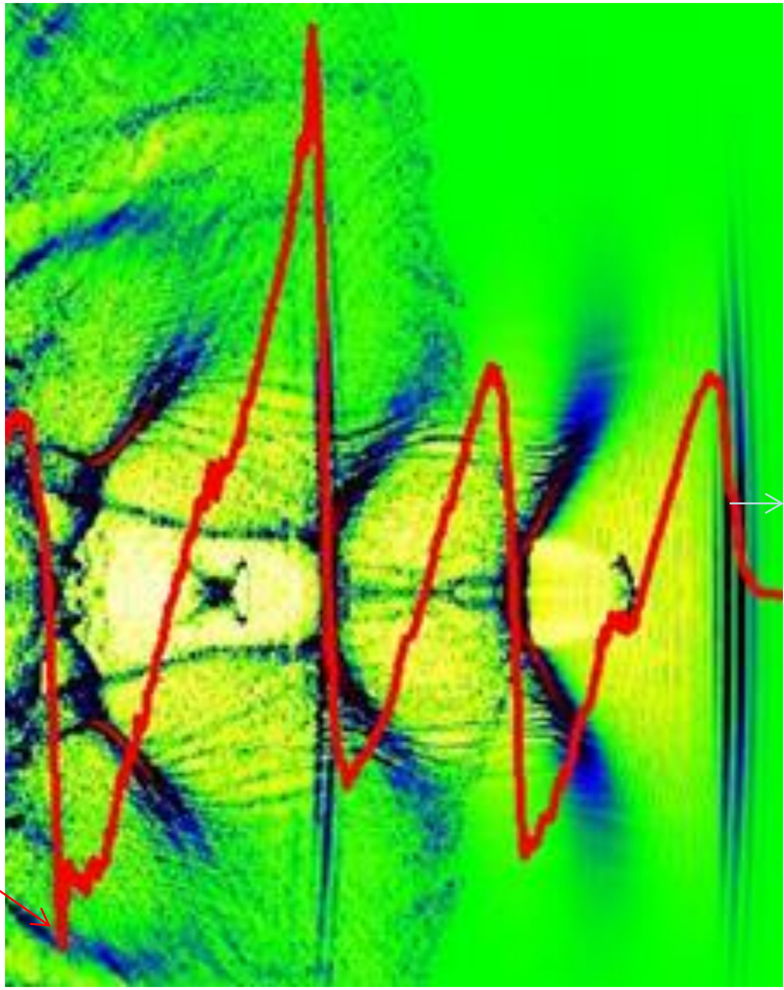
In this presentation the processes of the high-gradient wakefield excitation by a short exawatt laser pulse in metallic-density plasma is **simulated** with help of UMKA 2D3V code.

Electron Acceleration by Short Sequence of Two Laser Pulses in Plasma of Metallic Density

Since using modern, compact laser technology, it is possible to form laser pulses with a frequency much larger than the frequency of visible light,

Prof Toshiki Tajima

proposed using such a coherent short-wave pulse to accelerate the particles at injection this pulse into the crystal.



In our simulation accelerating field reaches the maximum value at $t=132t_0$ and this value is equal to

$E_x^{V/m} = 2.75\,TV/m$ **>>100 GV/m**

$$E_{max}\,[V/cm] \approx \sqrt{n_P}\,[cm^{-3}]$$

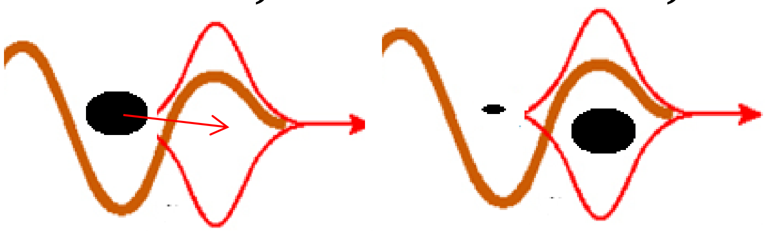
$$E_{max} \approx 10\ TV/m \quad \text{for } n_P = 10^{22}\ cm^{-3}$$

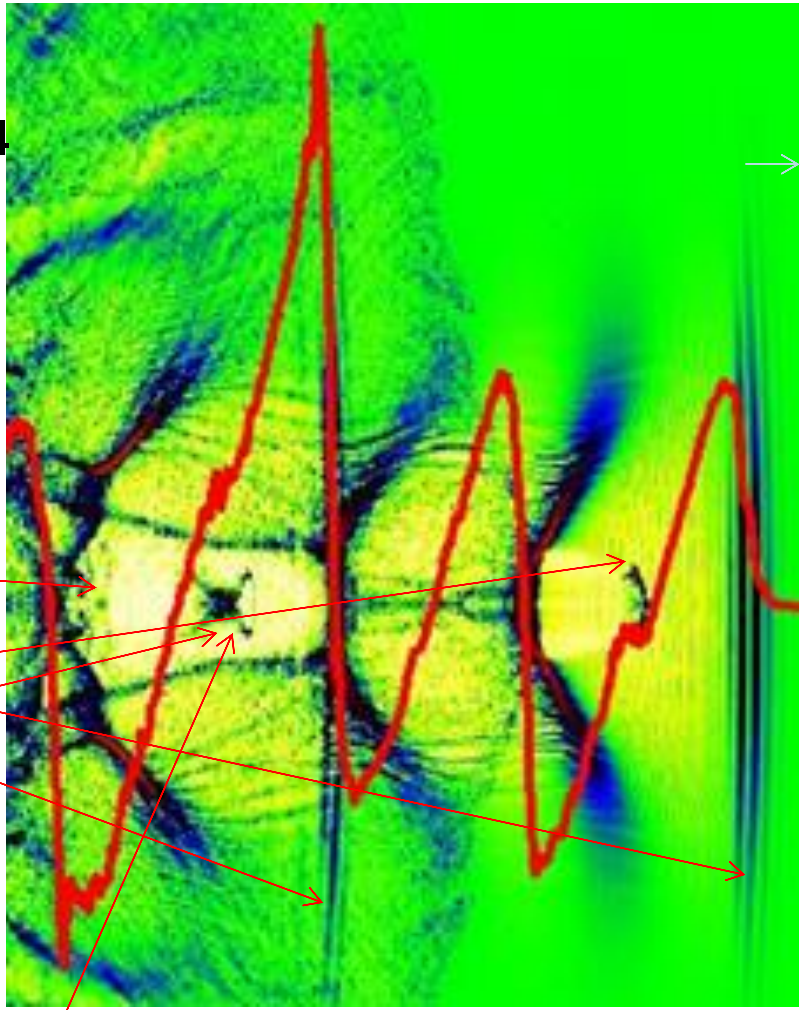
Transformation of Laser Wakefield Acceleration into Combined Laser Wakefield Acceleration and Plasma Wakefield Acceleration

B.Hidding et al. 2010

W. P. Leemans et al. 2014

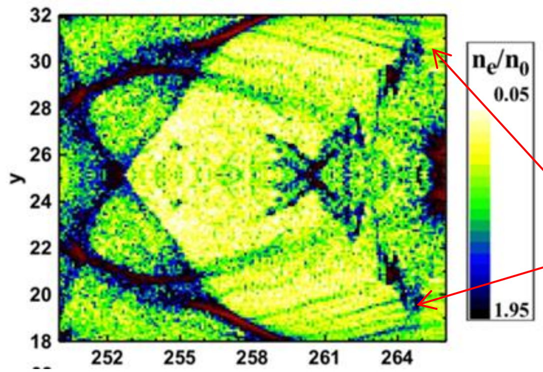
V.I.Maslov, I.N.Onishchenko, O.M.Svystun





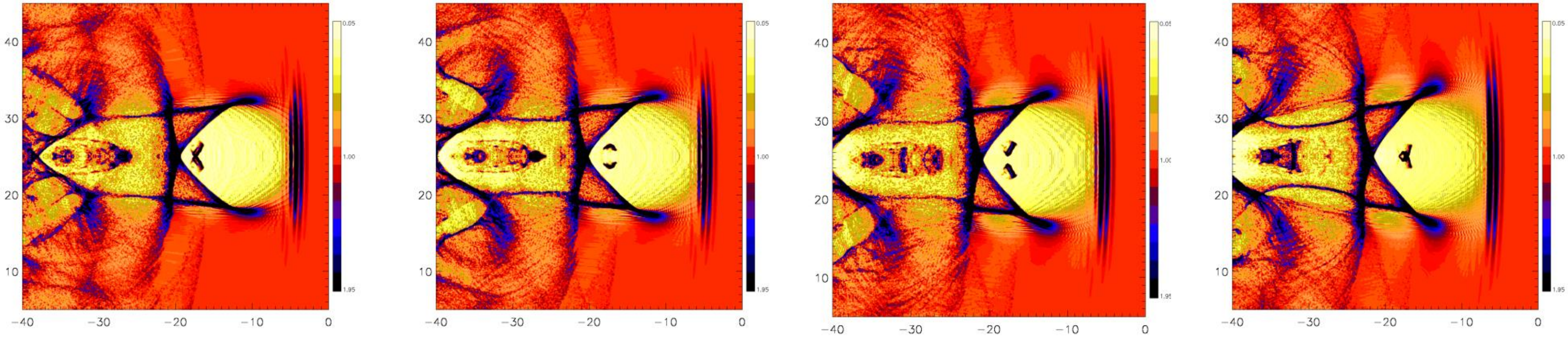
Self-injected bunch is initially accelerated by two drivers: two laser pulses and later by four drivers: two laser pulses, 1-st electron bunch in 1-st bubble and 1-st electron bunch in 3-rd bubble.

Self-cleaning V.I.Maslov, I.N.Onishchenko, O.M.Svystun



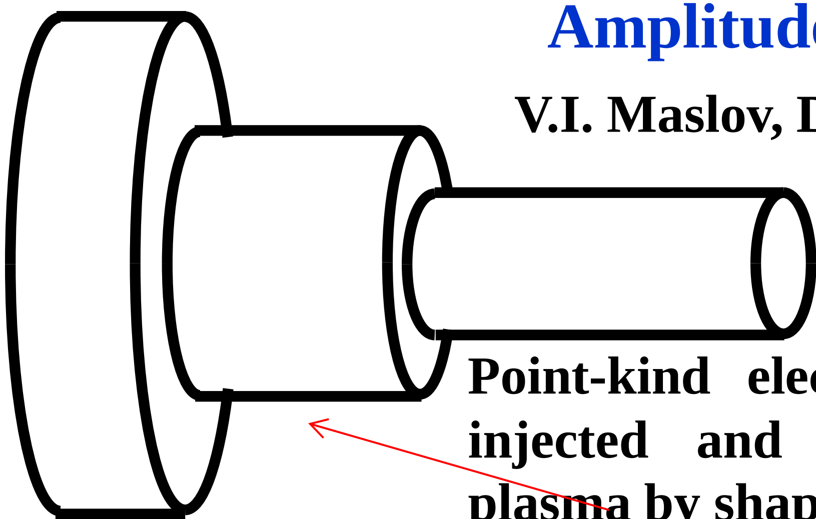
After deceleration 1-st electron bunch in 3-rd bubble is cleaned by defocusing in transversal direction.

Betatron oscillations (wake undulator)

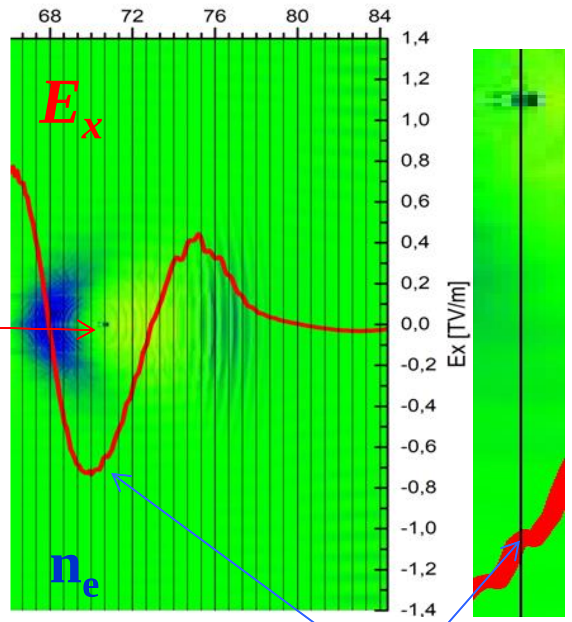


V.I.Maslov,
I.N.Onishchenko,
O.M.Svystun

Very Short Bunch Injection in Plasma by Laser Pulse Profiling by Amplitude, Radius and Shape

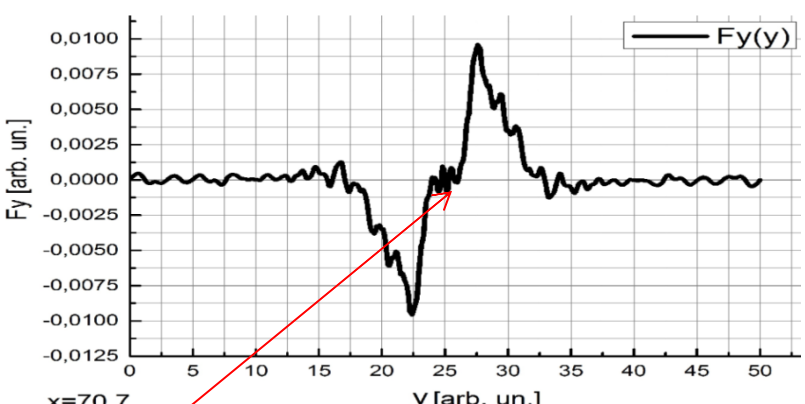


V.I. Maslov, D.S. Bondar et al. 2019



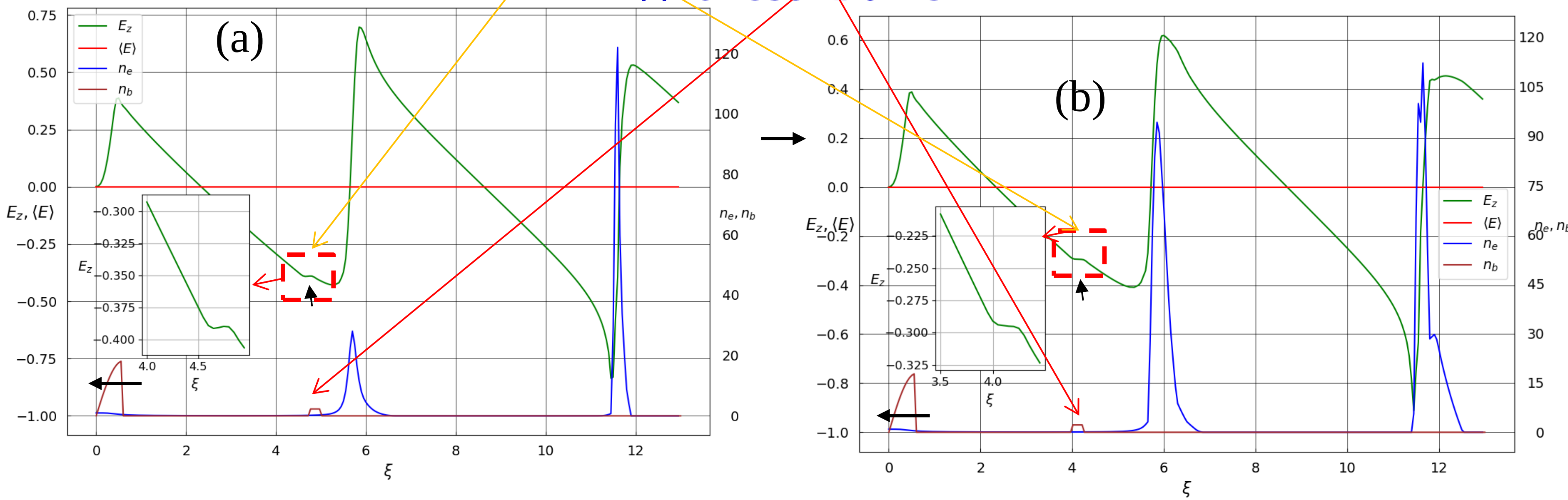
Point-kind electron bunch is injected and accelerated in plasma by shaped laser pulse.

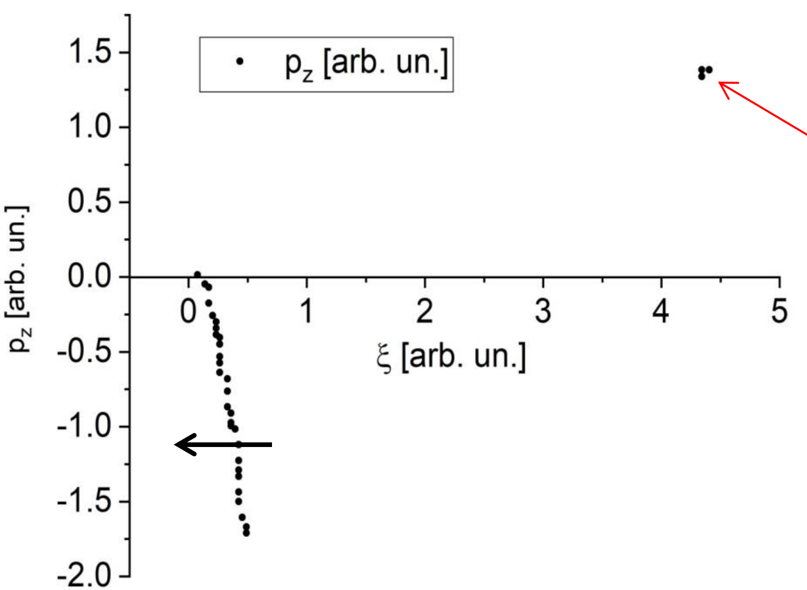
In the area of witness a plateau on accelerating wakefield $E_x(x)$ is formed.



Zero focusing/defocusing wake force $F_y(y)\approx0$ is in the area of the witness.

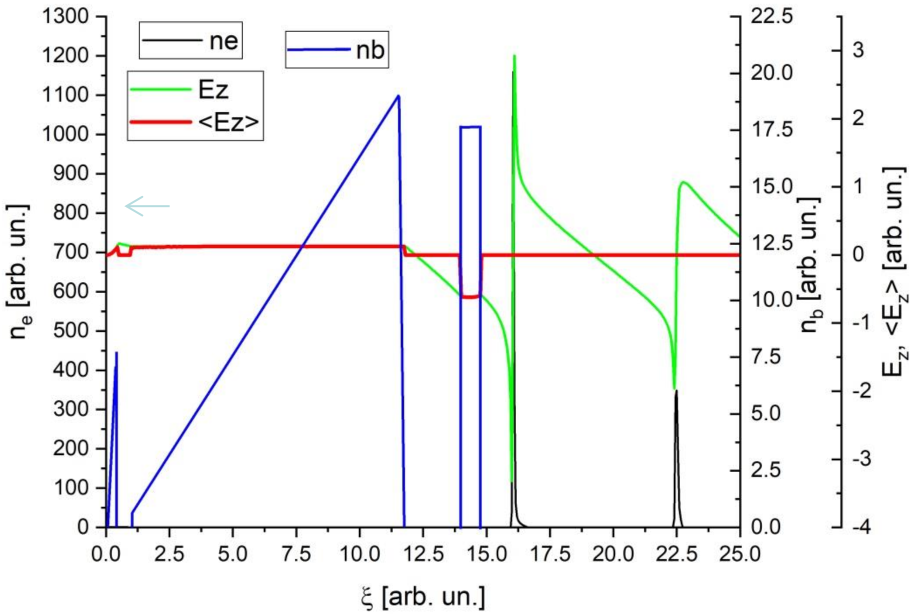
Shift of Supported Plateau into the Bubble at Acceleration of Witness-Bunch



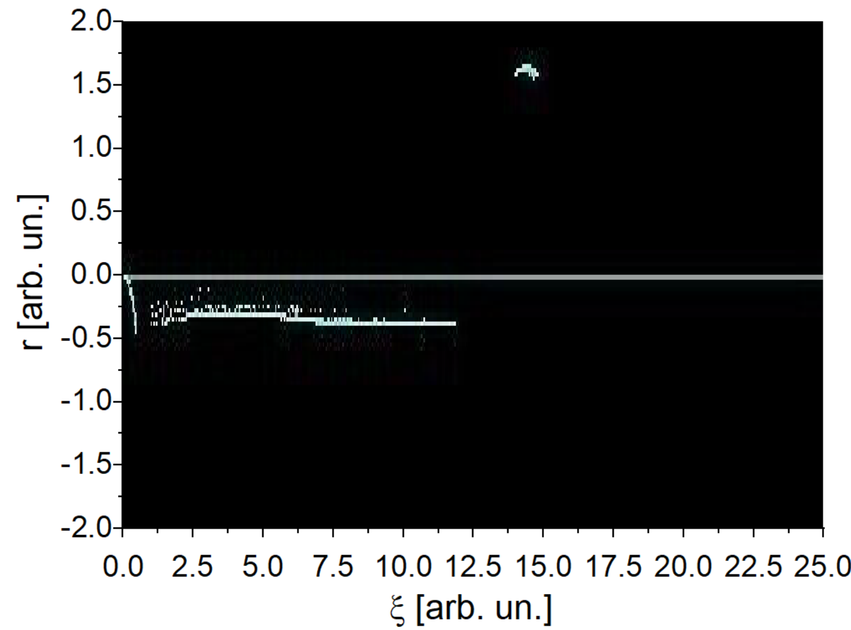


The plateau-kind wakefield accelerates a monoenergetic electron bunch.

Plateau Formation on Decelerating Wakefield for a Driver-Bunch and on Accelerating Wakefield for a Witness-Bunch by Driver and Witness Loading



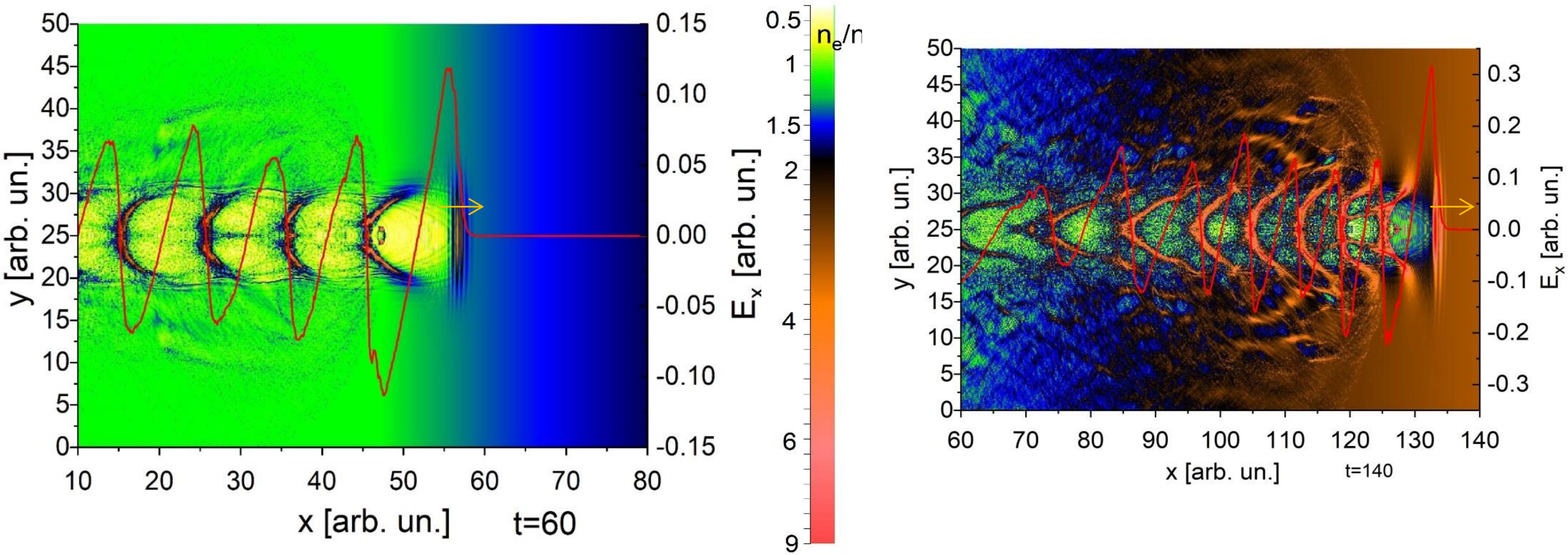
A wakefield that is almost independent on the longitudinal coordinate along the entire long profiled driver-bunch and along witness-bunch



Change of longitudinal momentum p_z of driver electrons and witness electrons in the wakefield, which is almost independent on the longitudinal coordinate

Optimal beam loading for the self-consistent distributions of a decelerating wakefield for a driver-bunch and an accelerating wakefield for a witness-bunch of plateau kind.

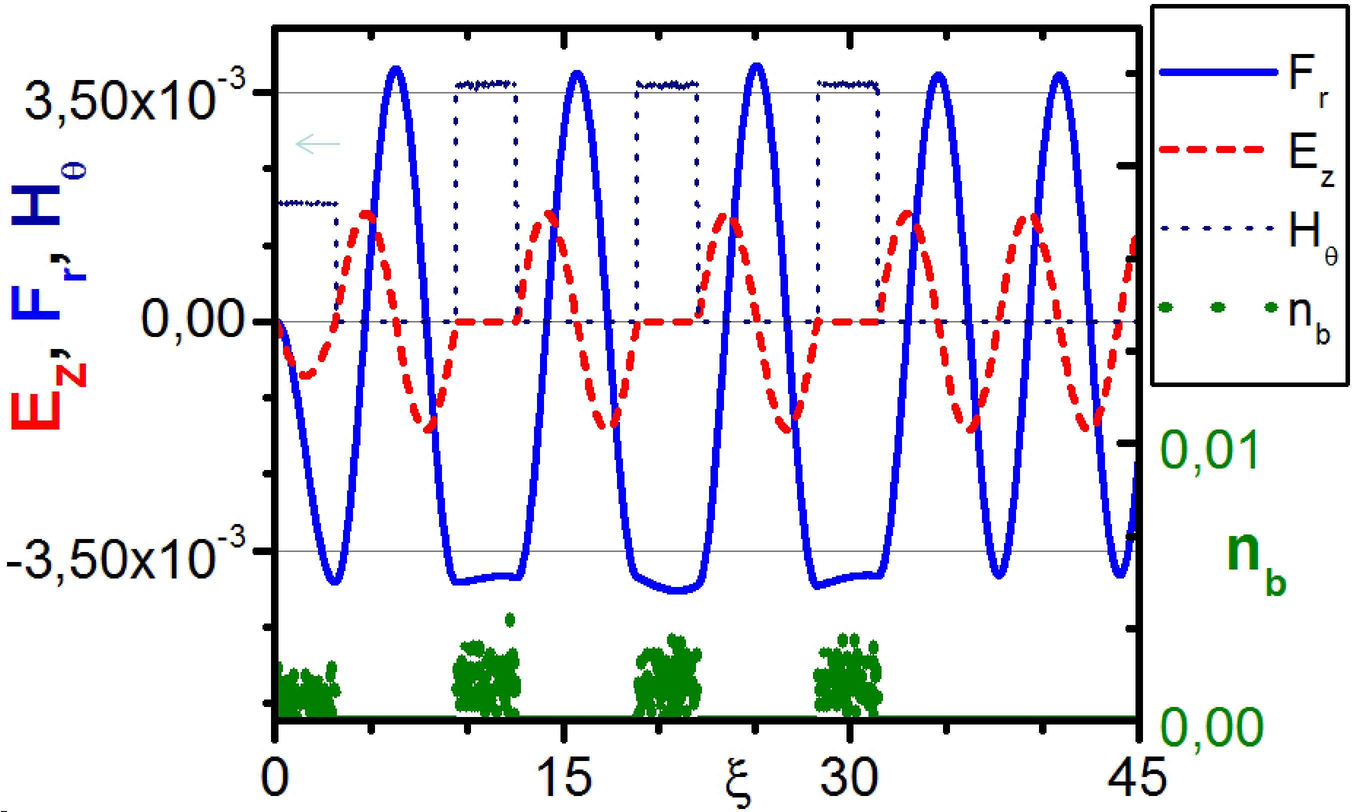
Witness and Wakefield Synchronization by Plasma Inhomogeneity



Excitation of a wakefield by a laser pulse in inhomogeneous plasma . The self-injected bunch is close to the area of maximum accelerating gradient. Plasma electron density and longitudinal accelerating field (red) distributions

V.I.Maslov, D.S.Bondar, I.N.Onishchenko. 2022

Homogeneous Focusing of Sequence of Positron Bunches in Plasma



Density of bunches n_b (green), longitudinal wakefield E_z (red), radial wake force F_r (blue) and manetic field H_θ (dark blue)

Focusing of sequence of positron bunches, length of each bunch equals half of wavelength $\xi_b=\lambda/2$, because in this case the wakefield has maximal value at increase of bunch length of the same density. We use the charge of first bunch, equal in two times smaller than charge of each next bunch

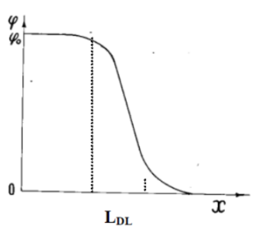
$$Q_1=Q/2,\ Q_i=Q,\ i=2, 3, 4 \ldots,\ \xi_{i+1}-\xi_i=1.5\lambda.$$

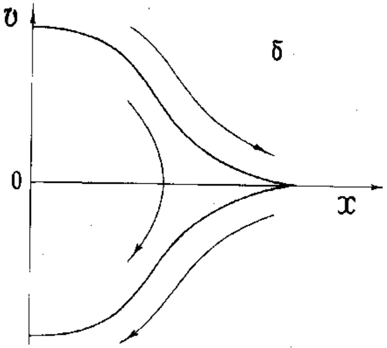
K.V.Lotov, V.I.Maslov, I.N.Onishchenko, O.M.Svystun. 2012,

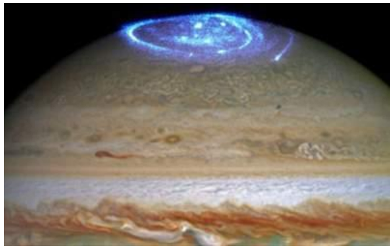
V.I. Maslov, D.S. Bondar et al. 2019

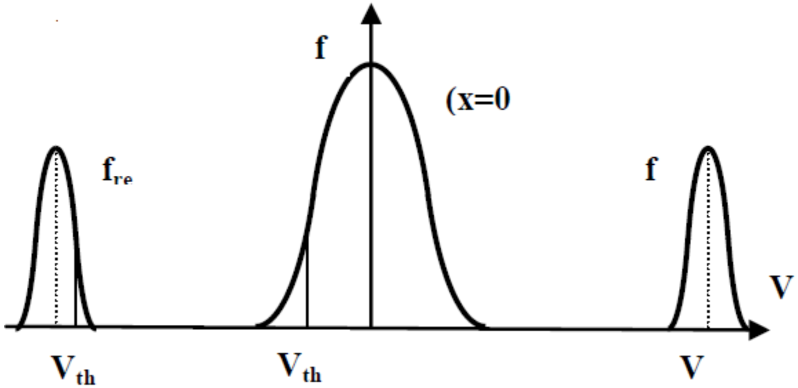
Radio-Emmision, Electron-Beam Formation and Dynamics, Strong Double Layer, Polar Lights, Vortex Structures near Jupiter

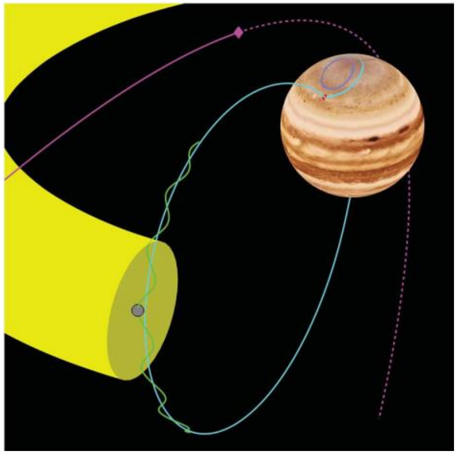
V.I.Maslov, A.P.Fomina, R.I.Kholodov, O.P.Novak et al. Accelerating Field Excitation, Occurrence and Evolution of Electron Beam near Jupiter. Probl of Atomic Science and Technology, 4, 106 (2018).

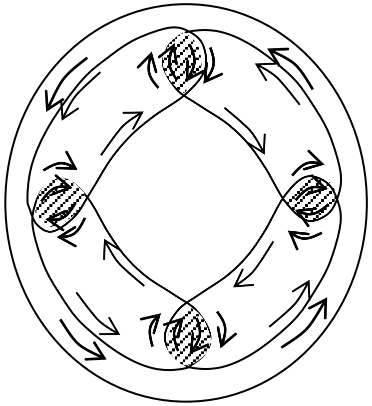


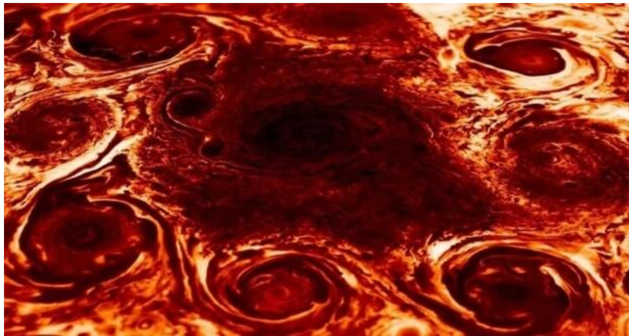












THANK YOU

National Scientific Center
"Kharkov Institute of Physics &
Technilogy"