Interaction of High Intensity Electromagnetic Waves with Plasmas: Final Report

G. Shvets – The University of Texas at Austin

Summary:

Our theoretical/computational group is based in the Physics Department of the University of Texas at Austin. The PI and his team are also affiliated (and physically located) at the Institute for Fusion Studies (IFS). The focus of our work during the duration of this grant was on the following areas: (a) the fundamental plasma physics of intense laser-plasma interactions, including the nonlinear excitation of plasma waves for accelerator applications, as well as the recently discovered by us phenomenon of the relativistic bi-stability of relativistic plasma waves driven by a laser beatwave; (b) interaction of high power microwave beams with magnetized plasma, including some of the recently discovered by us phenomena such as the Undulator Induced Transparency (UIT) as well as the new approaches to dynamic manipulation of microwave pulses; (c) investigations of the multi-color laser pulse interactions in the plasma, including the recently discovered by us phenomenon of Electromagnetic Cascading (EC) and the effect of the EC of three-dimensional dynamics of laser pulses (enhanced/suppressed self-focusing etc.); (d) interaction of high-current electron beams with the ambient plasma in the context of Fast Ignitor (FI) physics, with the emphasis on the nonlinear dynamics of the Weibel instability and beam filamentation.

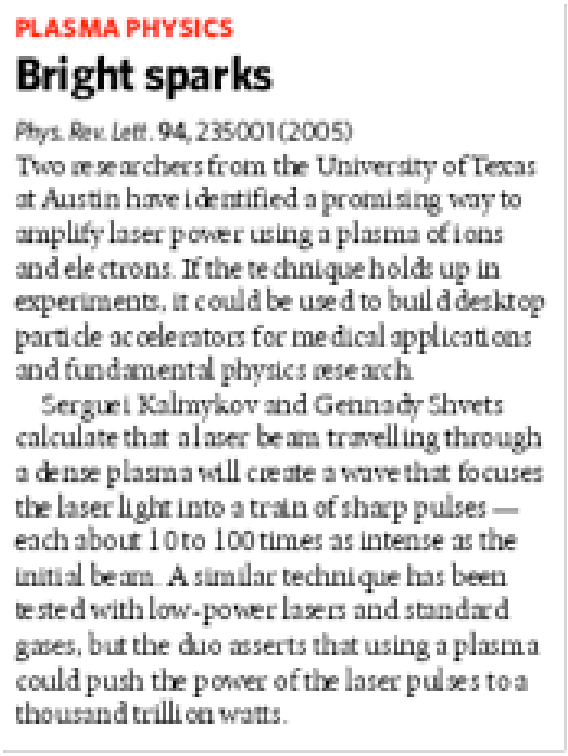
How did the Junior Investigator in Plasma Physics Grant Enhance My Carrer?

(a) Promotion to Associate Professor (with tenure) in September 2006
(b) Election to APS Fellowship through the Division of Plasma Physics (2008)
(c) Award of three additional grants in the field of plasma physics (2005-08: DOE-HEP grant titled "Theoretical Investigations of the plasma-based particle accelerators"; 2005-2007: DOE-FES grant titled "Research In Innovative approaches to high energy density physics in fusion sciences"; 2007-2010 DOE-FES grant titled "Collective high-current beam effects relevant to fast ignition of fusion targets".

Besides the PI, the group included (at various stages of this project) three postdoctoral fellows (Sergey Kalmykov, Oleg Polomarov, and Yoav Avitzour), graduate students (Michael Tushentsov, Austin Yi, Carl Siemon), and undergraduate students (Jakub Otwienowski and Jae Park). A short-term visitor, Professor Michael Tokman, from the Nizhny Novgorod Institute of Applied Physics, has also worked closely with our group. While pursuing basic research, we pay special attention to possible applications: plasma-based accelerators, laser energy compressors, microwave pulse compressors, etc. Most important advances have been made in the following areas: (i) theory of laser pulse compression in the plasma using Electromagnetic Cascading; (ii) electromagnetic wave propagation and manipulation in magnetized plasma in the presence of static magnetic fields, (iii) relativistic bi-stability of relativistic plasma waves driven by a laser pulse, (iv) Weibel instability of relativistic beams in the plasma. Members of our group have attended several plasma physics meetings and made a number of contributed and invited presentations. The meetings are: CLEO/QELS'05 in Baltimore, MD; Frontiers in Optics/Division of Laser Science Meeting in Tucson, AZ (FiO'05); Division of Plasma Physics APS meetings in Denver CO (2004-2007), Advanced Accelerator Concepts Workshops (in 2004

and 2006), and the Scientific Discussion Meeting of the Royal Society of London. Several invited talks by the group members were given at the annual APS/DPP meetings (Shvets in 2004, Kalmykov in 2005, Polomarov in 2006).

Our recent work on generation of a femtosecond pulse train was recently highlighted in the journal Nature (vol.436, 14 July 2005) under the Nature Research Highlights headline (see below). We have published the results of our work supported by this grant in the leading international journals, including Physical Review Letters, Nature Physics, Physics of Plasmas, and Physical Review E.



PLASMA PHYSICS

Bright sparks

Phys. Rev. Lett. **94**, 235001 (2005)

Two researchers from the University of Texas at Austin have identified a promising way to amplify laser power using a plasma of ions and electrons. If the technique holds up in experiments, it could be used to build desktop particle accelerators for medical applications and fundamental physics research.

Serguei Kalmykov and Gennady Shvets calculate that a laser beam travelling through a dense plasma will create a wave that focuses the laser light into a train of sharp pulses — each about 10 to 100 times as intense as the initial beam. A similar technique has been tested with low-power lasers and standard gases, but the duo asserts that using a plasma could push the power of the laser pulses to a thousand trillion watts.

Publications in 2004-2007:

Published Refereed Journal Articles:

1. S. Yu. Kalmykov and G. Shvets, "Stimulated Raman Backscattering of Laser Radiation in Deep Plasma Channels", Phys. Plasmas **11,** 4686 (2004).
2. I. Kaganovich, E. Startsev, G. Shvets, "Anomalous skin effect for anisotropic electron velocity distribution function", Phys. Plasmas **11,** 3328 (2004).
3. R. Zgadzaj, E. W. Gaul, N. H. Matlis, M. C. Downer, and G. Shvets, "Femtosecond pump-probe study of preformed plasma channels", JOSA B **21,** 1559 (2004).
4. M. Tushentsov, G. Shvets, A. Kryachko, and M. Tokman, "Undulator-Induced Transparency of Magnetized Plasma: New Approach to Electromagnetic Energy Compression", IEEE Trans. Plasma Science **33,** 23 (2005).
5. G. Shvets, “Beatwave Excitation of Plasma Waves Based on Relativistic Bi-Stability”,

Phys. Rev. Lett. **93,** 195004 (2004).
6. S. Yu. Kalmykov and G. Shvets, "Compression of Laser Radiation in Plasma Using Electromagnetic Cascade ", Phys. Rev. Lett. **94,** 235001 (2005).
7. S. Kalmykov, O. Polomarov, D. Korobkin, J. Otwinowski, J. Power, and G. Shvets, "Novel techniques of laser acceleration: from structures to plasmas ", Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences **364,** 725 (2006).
8. G. Shvets, M. Tushentsov, M. D. Tokman, and A. Kryachko, "Propagation of Electromagnetic Waves in the Plasma Near Electron Cyclotron Resonance: Undulator-Induced Transparency ", Phys. Plasmas **12,** 056701 (2005)..
9. M. Tushentsov, G. Shvets, A. Kryachko, and M. Tokman, "Undulator-Induced Transparency of Magnetized Plasma: New Approach to Electromagnetic Energy Compression", IEEE Trans. Plasma Science **33,** 23 (2005).
10. N. H. Matlis, S. Reed, S. S. Bulanov, V. Chvykov, G. Kalintchenko, T. Matsuoka, P. Rousseau, V. Yanovsky, A. Maksimchuk, S. Kalmykov, G. Shvets, and M. C. Downer, Snapshots of laser wakefields, Nature Physics **2**, pp. 749 – 753 (2006).
11. O. Polomarov and G. Shvets, "Relativistic dynamical bistability and adiabatic excitation of strong plasma waves", Phys. Plasmas **14**, 055908 (2007).
12. S. Kalmykov and G. Shvets, "Compression of laser radiation in plasmas via electromagnetic cascading", Phys. Plasmas **13,** 056707 (2006).
13. S. Kalmykov and G. Shvets, "Nonlinear evolution of the plasma beatwave: compressing the laser beatnotes via electromagnetic cascading", Phys. Rev. E **73,** 046403 (2006).
14. O. Polomarov and G. Shvets, "Adiabatic bi-stable evolution of dynamical systems governed by Hamiltonian with separatrix crossing", Phys. Plasmas **13,** 054502 (2006).
15. S. Yu. Kalmykov, L. M. Gorbunov, P. Mora, G. Shvets, "Injection, trapping, and acceleration of electrons in a three-dimensional nonlinear laser wakefield", Phys. Plasmas **13,** 113102 (2006).
16. G. Shvets and M. Tushentsov, "Nonlinear control of 'fast' light by 'slow' light", Journal of Modern Optics **53,** 2507 (2006).
17. O. Polomarov, A. Sefkow, I. Kaganovich, and G. Shvets, "Computationally efficient description of electron beam transport in collisionless plasma", Phys. Plasmas **14,** 043103 (2007).
18. Y. Avitzour and G. Shvets, "Manipulating Electromagnetic Waves in Magnetized Plasmas: Compression, Frequency Shifting, and Release", Phys. Rev. Lett. **100,** 065006 (2008).
19. A. Maksimchuk, S. Reed, S. S. Bulanov, V. Chvykov, G. Kalintchenko, T. Matsuoka, C. McGuffey, G. Mourou, N. Naumova, J. Nees, P. Rousseau, V. Yanovsky, K. Krushelnick, N. H. Matlis, S. Kalmykov, G. Shvets, M. C. Downer, C. R. Vane, J. R. Beene, D. Stracener, and D. R. Schultz, "Studies of laser wakefield structures and electron acceleration in underdense plasmas", Phys. Plasmas **15,** 056703 (2008).

Conference Proceedings:

1. S. Kalmykov and G. Shvets, "Application of detuned laser beatwave for generation of few-cycle electromagnetic pulses", AIP Conference Proceedings, **v. 737,** 552 (2004).
2. G. Shvets, "Relativistic Bi-Stability in a Plasma Beatwave Accelerator", AIP Conference Proceedings, **v. 737,** 818 (2004).

3. M. Tushentsov, G. Shvets, M. D. Tokman, and A. Kryachko, “A study of undulator induced transparency of magnetized plasma in the linear regime”, AIP Conference Proceedings, v. 737, 729 (2004).
4. R. Zgadzaj, E. M. Gaul, N. H. Matlis, G. Shvets, A. Debus, and M. C. Downer, "Femtosecond Pump-Probe Diagnostics of Preformed Plasma Channels", AIP Conference Proceedings, v. **737,** 736 (2004).
5. S. Reiche, C. Joshi, C. Pellegrini, J. B. Rosenzweig, S. Ya. Tochitsky, G. Shvets, "Feasibility Study of a Beat-wave Seeded THz FEL at the Neptune Laboratory", Proceedings of Particle Accelerator Conference, May 16-20, 2005, Knoxville, TN.
6. N. H. Matlis, S. Reed, S. S. Bulanov, V. Chvykov, G. Kalintchenko, T. Matsuoka, P. Rousseau, V. Yanovsky, A. Maksimchuk, S. Kalmykov, G. Shvets, and M. C. Downer, "Snapshots of Laser-Generated Wakefields", AIP Conference Proceedings, **v. 877,** 22 (2006).
7. Gennady Shvets and Paul Schoessow, "Summary Report of Working Group 3: High Energy Density Physics and Exotic Acceleration Schemes", AIP Conference Proceedings, **v. 877,** 147 (2006).
8. S. Kalmykov and G. Shvets, "Guiding of Laser Beams in Plasmas by Radiation Cascade Compression", AIP Conf. Proc., **v. 877,** 395 (2006).
9. O. Polomarov and G. Shvets, "Novel Computational Approach to Weibel Instability and Beam Transport in Overdense Plasma", AIP Conf. Proc., **v. 877,** 416 (2006).
10. O. Polomarov and G. Shvets, "Relativistic Dynamical Bi-Stability of Plasma Waves in a Plasma Wakefield Accelerator", AIP Conf. Proc., **v. 877,** 423 (2006).
11. S. Kalmykov and G. Shvets, "Relativistic Extension of the Accelerating-Focusing Phase in 3D Nonlinear Laser Wake", AIP Conf. Proc., **v. 877,** 735 (2006).

Invited Talks:

1. G. Shvets, "Exotic Acceleration Concepts", plenary talk, Advanced Accelerator Concepts Workshop, June 21-26, 2004, Stony Brook, NY
2. G. Shvets, "Undulator-Induced Transparency of Magnetized Plasma at the Cyclotron Frequency: a New Approach to EM Energy Compression", invited talk, ICOPS, June 28 - July 1, 2004, Baltimore, MD.
3. G. Shvets, "Electromagnetically Induced Transparency of Plasma: a New Approach to Electromagnetic Energy Compression and Particle Acceleration", invited talk, APS-DPP Meeting, November 15-19, 2004, Savannah, Georgia.
4. G. Shvets, "Novel techniques of laser-plasma acceleration: from structures to plasmas", Scientific discussion meeting of the Royal Society, June 7, 2005, London, United Kingdom.
5. G. Shvets, "Computationally Efficient Approach to Modeling Weibel Instability of Relativistic Beams in Plasma", Laboratory for Laser Energetics Colloquium, University of Rochester, October 9, 2006.
6. G. Shvets, "Electromagnetically Induced Transparency of Plasma: a New Approach to Electromagnetic Energy Compression and Particle Acceleration", University of Maryland at College Park, October 18, 2006.
7. G. Shvets, "Computationally Efficient Approach to Simulating Collective Stopping of Relativistic Beams in Dense Plasmas", 9th International Fast Ignitor Workshop, Nov.3-5, 2006, Cambridge, MA.

8. G. Shvets, "Accelerators of the future: from structures to plasmas", Electrical and Computer Engineering Colloquium, University of Maryland at College Park, April 2, 2007.
9. G. Shvets, "Surface wave accelerator based on silicon carbide", Center for Beams Physics, Lawrence Berkeley National Laboratory, Berkeley, CA, April 11, 2007.
10. G. Shvets, "Laser-driven accelerating structures: from photonic bandgap to surface waves", April APS Meeting, Jacksonville, FL, April 16, 2007.
11. G. Shvets, "Computationally efficient modelling of the Weibel instability of a relativistic beam in collisionless plasmas", Workshop on High Energy Density Plasma Astrophysics, Rice University, Houston, TX, May 15, 2007.
12. G. Shvets, "Negative index and super-lensing for optical frequencies", First year AFOSR MURI Review, Purdue University, West Lafayette, IN, May 21, 2007.
13. G. Shvets, "Collective instabilities of high-current electron beams in the context of Fast Ignition", Symposium on Recent Advances in Plasma Physics (in celebration of Ronald C. Davidson's 40 years of plasma physics research and graduate education), Princeton, NJ, June 11-12, 2007.
14. G. Shvets, "Filamentation of high-current electron beams in plasmas: applications to Fast Ignition and astrophysics", Theory Seminar, Princeton Plasma Physics Laboratory, March 13, 2008.
15. G. Shvets, "Dynamic manipulation of electromagnetic waves in magnetized plasmas: compression, frequency shifting, and release", Sandia National Laboratory, Albuquerque, NM, June 3, 2008.