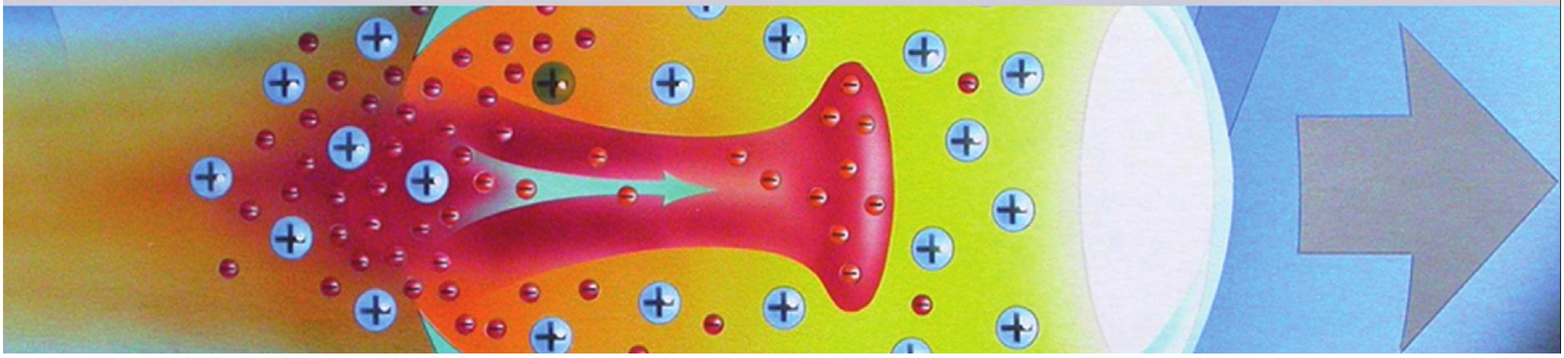

Frontiers in Intense Laser-Matter Interactions Theory

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Scientific report

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Summary

Sources of strong, short laser pulses, their use for ultrafast spectroscopy of atoms, molecules, and solids, and their application to construct high-brilliance photon and particle sources all develop extremely rapidly. At the extreme field end, the design field strength of ELI will take classical electronic motion into the self-field interaction regime and it may even approach vacuum breakup. Already at much lower intensities, present routine pulses can take atoms, molecules, and solids far from their ordinary field free state. Finally, the creation and strong-field control of plasma is the key to new brilliant particle and photon sources with a host of applications ranging from the creation of ever shorter X-ray pulses, over compact particle accelerators, all the way to medical diagnostics and therapy. Theory and simulation in some matters can anticipate new phenomena and identify their experimental signature, in other places we are caught in surprise and nearly empty-handed, when it comes to the interpretation of new experiments. This workshop was devoted to the challenges posed to theory and simulation by future intense laser sources and by current experiments.

There were a few selected topics in the center of discussion. In the area devoted to extreme fields expected for light sources currently under construction, these were among others the possibility of pair production directly by lasers sources, the need to face the breakdown of the equations of classical electrodynamics due to radiation back-reaction and to find workable solutions, or the possibility to detect QED effects. For strong laser-surface interactions, an overview of current approaches was given, ranging from intuitive models, over simulation of classical transport equations, to full blown quantum-chemistry type methods. Large part of the workshop was devoted to new laser based particle beams, were key ideas are well understood and the strive is for improving yields and quality of the beams by new injection schemes for bubble acceleration and new targets, like nano-foils. In addition, implementation of the new phenomena into known methods — mostly PIC simulations — was discussed and the prospect of dramatic improvements in simulation performance were presented.

The workshop was predominantly devoted to theory, but we scheduled several presentations by experimentalists — on the ELI project, on the state of the art of laser-surface experiments, on laser-based electron beams for FELs. In addition to formal conference participants, the workshop attracted at times large additional audiences of local researchers and students. Important in-kind and direct financial support from local sources for non-ESF participants reflected this additional benefit for local environment.

Abstracts of the majority of the presentations are available from the con-

ference web site www.mpq.mpg.de/APS/Frontiers/, in addition presentation slides are available to participants (password protected).

Details of the discussions

Ultra-intense fields

There was agreement that in principle laser-induced pair production may be expected well below the Schwinger limit. The key to this is that in real beams the field is not homogeneous, but, for example in a sharp focus, the strong field gradiants effectively can lower the threshold to peak intensities of $\sim 10^{27} W/cm^2$. As this is still out of reach for the new sources, a scheme for further inhancing local inhomogenuity by uniting several coliding beams was introduced. With this scheme, pair production may be achieved with pulse energies as "low" as $10kJ$ [Narozhny]. Alternatively, combining new γ sources with intense lasers will allow to overcome the pair-production threshold [Roepke]. In several presentations it was pointed out that, once a single pair is produced, a cascade of secondary pairs arises that may completely stop pulse propagation in vacuum already at comparativley low intensities[Narozhny,Bell], with one intensity quoted as low as $10^{24} W/cm^2$ [Fedotov].

It is a curious fact that classical electrodynamics with point charges is physically inconsistent, as a point charge can draw an infinite amount of energy from its self-field und "use" that energy to accelerate. The historical patchup of this problem are third order differential equations that undermine the foundations of classical physics. As in the new light sources particles will be accelerated to velocities where retardation of the self-field will come into play, we are in urgent need for a consistent, energy conserving, covariant formulation of equations of motion. This is not only of academic interest, as it is needed as input for simulations of the interaction of the new sources with matter. Different schemes were discussed and first implementations were presented [Sokolov,Gralla,DiPiazza,Naumova]. We learnt that this problem is approaching a solution that can carry us all the way to the range where QED effects become dominant. Some of the solutions suggest that one may use the back-action effects for highly efficient acceleration of free electrons [DiPiazza].

Intense laser-surface interactions

In this rather new field the participants learnt in an impressive presentation about new experiments on surfaces and thin adsorbates down to single-layers on surfaces [Ernstorfer]. Three approaches to understanding ultrafast photoemission processes from these systems were reviewed. Key problems are the correct modelling of electronic structure, the microscopic description of the laser field across the penetration skin depth, and dealing with few- and multi-electron effects.

Already simple single electron modelling using periodic potentials in the solid and a plausible model for the laser penetration can reproduce observed dynamical effects [Kazansky]. However, this explanation is not unique, as also simple classical transport description delivers similar observable effects [Lemell]. Both approaches have obvious shortcomings, either the absence of statistical and multi-electron effects, or problems with coherence of the ultra-fast electron motion in a classica model, which was intensly discussed.

Apart from pragmatic modelling, at the far end of ab-intio methods, two general quantum chemstry type of approaches to the field-surface problem were presented [Garcia, Klüner]. Impressiv results on ultrafst desorption processes were presented and it was made clear that standard many-particle structure methods are in adequate. For moderate fields and time scales, strongly correlated methods work. At intense fields, new method developments are needed. As one such possibility, hybridization of DFT with wave-packet methods was discussed.

On the application side, we learnt how intense, ultrashort pulses could be used to prepare nano-structured materials in exotic states [Berakdar].

Laser-based beams

Mostly two basic schemes to derive particle beams from intense laser beams were discussed: electron acceleration in plasma and charged particle emission from (thin) solid targets. The basic mechanisms are established, and there is enormous potential for applications. A key issue is the improvement of beam quality.

Intensity and monochromaticity of electrons on the slope of a plasma wave and more specifically inside the "bubble" formed behind an intense few-cycle pulse can be greatly improved by substituting the spontaneous trapping of electrons by controlled injection. Several new schemes were presented and discussed [Lundh, Lefebvre, Malka]. Among others, such schemes may allow to tune the final electron energies. On the same topic, new insight into the propagation of laser-plasma waves was provided by partially analytical solutions [Schroeder].

Particle acceleration schemes using thin foils are developing rapidly, and several new ideas were presented at the workshop. Sub-micrometer foils may allow a self-organizing scheme of proton acceleration with large improvement in beam quality [Yan]. We also learnt that reducing foil thickness to a few nanometers may deliver well-peaked, non-thermal electron distributions, as shown by PIC simulations and first experimental observations [Hegelich]. Yet another scheme suggests that quasi-monoenergetic proton beams can be generated by replacing the foil with a thin rapidly moving plasma sheath [Sheng]. Concerning laser ion acceleration and its application to tumor therapy, a most urgent problem is to discuss transport and collimation of the laser-generated ion bunches; a first study into this direction was presented by a specialist from the conventional accelerator community [Hofmann]. Another option for innovative medical diagnostics by means of VUV and X-ray phase-contrast imaging was discussed in the context of coherent Thomson scattering from laser-driven relativistic electron mirrors [Rykovanov,Hegelich,Wu].

Impact on the field

The workshop idea was to concentrate on topics in intense ultrafast fields where we felt that new theory questions are arising due to experimental developments and raise the awareness about this among theorists as well as experimentalists. We believe that we have delivered what we promised: in the three general areas of the workshop the pressing current topics were discussed and communicated to a broader audience. Theorists were brought up to date with promises and challenges of the upcoming new sources. Experimentalists had the opportunity to learn about the new physics to expect at the frontiers that they are heading for and about new ingenious acceleration schemes.

It has been made clearer to many that there is a realistic chance for testing QED effects and field back-action with the upcoming sources: with the schemes discussed the thresholds are much closer than what naive estimates suggest. Also, there was fruitful exchange about new possibilities of theory and simulation.

For laser-surface interactions it has become clear that, although approaches for different aspects of the laser-surface systems exists, the dominant aspects still need to be identified and integrated into a coherent theory. Efforts in this directions — uniting strong field and quantum chemistry methods — are under way.

The broad range of new ideas and progress reports on laser-based beams indicates the very rapid evolution of this field and its enormous application potential. For this particular community, the workshop served as one out of a string of meetings needed to keep track of the very dynamic developments.

Apart from the progress reports in the individual sub-fields, we believe that the mix of topics, several review-type talks [Korn,Quere,Habs,Ernstorfer], the moderate scale, and the relaxed workshop-type atmosphere have allowed official workshop participants and at times large local audiences to come up-to-date in several hot topics of strong field physics in general.

Workshop Program

Monday		
9:00-9:30	Joachain Meyer-ter-Vehn	Opening
9:30-10:00	Narozhny	New prospects for studying fundumental properties of vacuum with ELI *
10:00-10:30	Sokolov	QED effects in realistic laser fields *
10:30-11:00	COFFEE	
11:00-11:30	Bell	Pair production at high laser intensities *
11:30-12:00	Röpke	Sub-critical vacuum pair production with high power lasers*
12:00-12:30	Fedotov	Fundamental QED processes in ultra-intense laser fields*
12:30-14:30	LUNCH	
14:30-15:00	DiPiazza	Testing strong-field CED and QED with intense laser fields*
15:00-15:30	Naumova	Radiation back reaction on electrons and ion acceleration at super-high laser intensities
15:30-16:00	Rykovanov	Plasma dynamics and surface smoothing in the relativistic few cycle regime
16:00-16:30	COFFEE	
16:30-17:00	Sheng	Generation of tens of GeV quasi-monoenergetic proton bunches
17:00-17:30	Silva	Novel simulation approaches for laser-plasma accelerators and fast ignition
17:30-17:50	Psikal	Enhanced ion acceleration in thin foils of reduced surface*
17:50-18:20	Korn	Status report of the ELI project (preliminary title)
18:20-19:30	SNACKS & DRINKS	
	LAB TOUR	
Tuesday		
9:00-9:30	Ernstorfer	Attosecond electron dynamics in solids
9:30-10:00	Lemell	Attosecond streaking of photoelectrons emitted from surfaces
10:00-10:30	Garcia	Theoretical description of laser induced ultrafast structural changes in condensed matter*
10:30-11:00	COFFEE	
11:00-11:30	Klüner	Photoinduced dynamics at surfaces*
11:30-12:00	Kazansky	Theoretical studies of ultrafast processes at metal surfaces*
12:00-12:30	Gralla	A rigorous derivation of electromagnetic self-force*
12:30-14:30	LUNCH	
14:30-15:00	Quere	Intense laser-solid interactions : from ionization to plasma dynamics
15:00-15:30	Kabachnik	Time-dependent theory of laser-assisted Auger decay induced by ultra-short pulses*
15:30-16:00	Berakdar	Functionalization of intense laser-matter interaction for condensed matter applications*
16:00-16:30	COFFEE	
16:30-17:00	Keitel	Laser-induced high energy processes*
17:00-17:30	Zepf	Ultrabright laser driven attosecond sources
17:30-18:00	Wu	Coherent and bright x-ray source based on relativistic electron mirror

Wednesday		
9:00-9:30	Grüner	Overview of laser-driven X-ray sources
9:30-10:00	Reiche	Optimization and limitation of table-top free-electron lasers
10:00-10:30	Malka	On the control of e-beam parameters with laser plasma accelerators*
10:30-11:00	COFFEE	
11:00-11:30	Schroeder	Laser and plasma wave evolution in laser-plasma-based accelerators*
11:30-11:50	Lefebvre	Cold optical injection producing monoenergetic, multi-GeV electron bunches
11:50-12:10	Lundh	Few-femtosecond laser-accelerated electron bunches*
12:10-12:30	Kalmykov	Electron self-injection and trapping into an evolving plasma bubble*
12:30-14:30	LUNCH	
14:30-15:00	Hegelich	The little foil that can: ion-, electron- and photon beams from laser-nanofoil interactions
15:00-15:20	Geissler	Overview over Laser Plasma theory activities at QUB
15:20-15:40	Yan	GeV mono-energetic proton beam generation in laser foil-plasma interactions*
15:40-16:10	Hofmann	The physics of collimation of laser accelerated ions and their application to ion therapy
16:10-17:00	COFFEE	
17:00-17:40	Habs	High-power short-pulse lasers reach new frontier in nuclear physics

Closing evening event / dinner

Conclusions

POSTERS

Apostolova	Theoretical modeling of ultra-short pulse laser interaction with condensed matter *
Bamberg	Fast algorithms based on tree like structures for Adaptive-Mesh-Refinement Particle-In-Cell Code (AMR-PIC)
Elkina	Radiative properties of electrons at ultra-high fields
Iqbal	Numerical solution of Caldirola, Landau Lifshitz and LAD equations for a single electron in a plane wave*
Kirk	Pair production in counter-propagating laser pulses*
Klier	Couloub explosions plus inelastic processes
Klimo	Ion acceleration efficiency in laser-thin-foils interactions and the impact of structured surface*
Krüger	Processes of different nature in femtosecond-laser-induced electron emission from ultrasharp metal tips*
Schlegel	Ion fast ignition in inertial fusion
Macchi	Issues in radiation pressure acceleration*
Tamburini	A study of radiation reaction effects in superintense laser-plasma interaction*
Veisz	Relativistic electron acceleration with few-cycle laser pulses
Weng	Relativistic laser beam propagation and critical density increase*

Participants

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