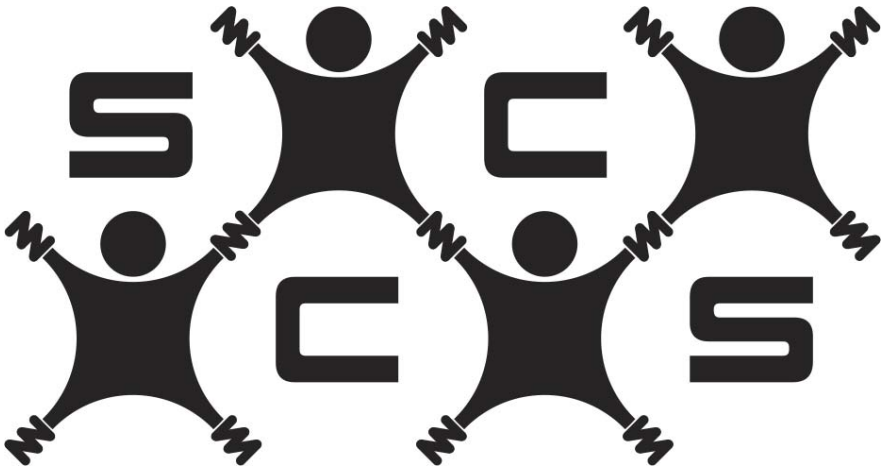
Budapest, July 24-29, 2011

Strongly Coupled Coulomb Systems

Final Programme

Book of Abstracts



STRONGLY COUPLED COULOMB SYSTEMS

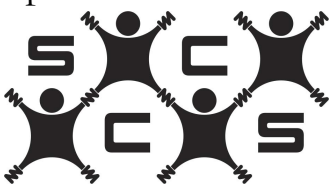
FINAL PROGRAMME
&
BOOK OF ABSTRACTS

24 - 29 JULY 2011, BUDAPEST, HUNGARY
DANUBIUS HOTEL FLAMENCO

TOPICS:

1 - Dense and astrophysical plasmas
2 - Plasmas in condensed matter
3 - Confined and mesoscopic Coulomb systems
4 - High energy density plasmas in the laboratory
5 - Classical charged systems
6 - Developments in theoretical methods and numerical techniques
7 - Thirty-five years with Strongly Coupled Coulomb Systems

Special thanks to G. Bánó for designing the logo of SCCS2011



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FINAL PROGRAMME

July 24 (Sunday):

15:30- **REGISTRATION**

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Meeting point: Main entrance of the Hotel Flamenco (Conference venue)

The first programme will be a Budapest sightseeing by bus with English speaking guide. Among several famous sights, the following places will be visited: Buda Castle, Fisherman's Bastion, Gellért Hill, Citadel, Heroes' Square, Basilica, etc.

After the sightseeing tour we will continue our trip by bus to the venue of the Conference Dinner to the so called "Szekér Csárda" Restaurant.

After the Dinner a 90 minutes long boat trip is organized. After the arrival bus transfer is provided back to the conference venue.

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SESSION 2

/Chair: Manfred Schlanges/

SESSION 3

/Chair: Zoltán Donkó/

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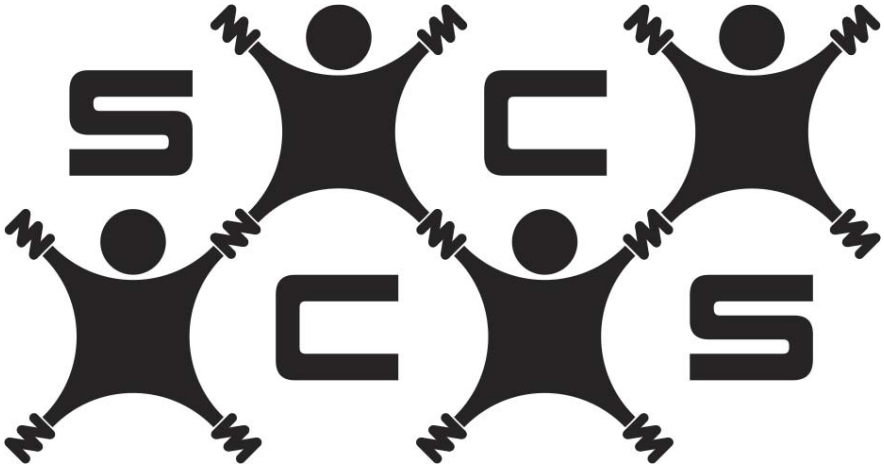
POSTER SESSION "A"

POSTER SESSION "B"



ORAL PRESENTATIONS

DENSE ASTROPHYSICAL PLASMAS

Gilles Chabrier

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In this talk, I will review our present knowledge of the properties of dense plasmas of astrophysical interest. I will first address the status of hydrogen, helium, and hydrogen/helium mixtures, and then consider heavier elements such as carbon, oxygen and water at high pressures. The properties of all these elements bear important consequences on the structure and the cooling properties of a wide range of astrophysical bodies, from solar and extrasolar giant planets to white dwarfs and neutron stars.

XUV ABSORPTION IN ALUMINUM: FIRST-PRINCIPLES OPACITY CALCULATIONS

Michael P. Desjarlais[1], Sam M. Vinko[2], Justin S. Wark[2], Gianluca Gregori[2]

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[2]*Department of Physics, Clarendon Laboratory, University of Oxford, UK*

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The development of intense XUV free-electron lasers, such as the FLASH FEL in Hamburg, has stimulated renewed interest in measurements and calculations of the XUV absorption of dense matter [1, 2]. Solid aluminum, with its plasmon energy at 15 eV and L edge at 73 eV provides a wide range of free-free dominated absorption that is well matched to XUV FELs and an excellent test of computational approaches to opacities in dense plasmas. Adding to the interest in aluminum is the systematic difference, on the order of a factor of two, between two widely referenced data sets for the absorption of aluminum in this energy range [3, 4].

We present first-principles density functional and *GW* calculations of the opacity of solid and liquid aluminum for photon energies from the near-optical to over 100 eV. These calculations require special attention to the higher energy scattering properties of the *ab initio* atomic aluminum potential and illustrate the importance of local field corrections above the plasma frequency. For FCC aluminum at 300 K, we find absorptions that are in good agreement with some of the existing data sets and reproduce very well the qualitative absorption behavior up to the L edge. We compare our results to the absorptions predicted using an *ad hoc* potential model [2], real-space Green's function methods [5], and new data from our experiments on the Artemis Facility at Rutherford Appleton Laboratory.

*MPD is supported by Sandia, a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under Contract No. DE-AC04-94AL85000.

[1] S.M. Vinko, G. Gregori, M.P. Desjarlais, B. Nagler, T.J. Whitcher, R.W. Lee, P. Audebert, J. S. Wark, High Energ. Dens. Phys. 5, 124 (2009).
[2] C. Iglesias, High Energ. Dens. Phys. 6, 311 (2010).
[3] B.L. Henke, E.M. Gullikson, J.C. Davis, Atom. Data Nucl. Data Tables 54, 181 (1993).
[4] E.M. Gullikson, P. Denham, S. Mrowka, J. Underwood, Phys. Rev. B 49, 16283 (1994).
[5] M.P. Prange, J. J. Rehr, G. Rivas, J. J. Kas, and J. W. Lawson, Phys. Rev. B 80, 155110 (2009).

NON-CONGRUENT PHASE TRANSITIONS IN COSMIC AND LABORATORY PLASMAS

Igor Iosilevskiy

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Non-congruent phase transitions (NCPT) in nonideal plasmas are under discussion as the most general form of phase coexistence in complex systems (chemically reacting plasma of chemical mixtures and/or high-*T*-high-*P* compounds). One widely finds NCPT in plasmas of terrestrial and astrophysical applications. The basic feature of NCPT is ability to vary chemical composition (stoichiometry) of coexisting phases without violation of total stoichiometry of two-phase system. Properties of NCPT i.e. parameters and even topology of phase boundaries, location and properties of critical point(s) and mutual end-points are significantly different from those of ordinary (VdW-like) phase transitions. Several examples of non-congruent fluid-fluid phase transitions are under discussion. The basic case is non-congruent evaporation in high-temperature chemically reacting uranium–oxygen system, which parameters up to the critical point have been studied thoroughly in frames of nuclear reactor safety problem [1, 2]. Numerous PT-s in giant planets, substellar objects and outer layers of compact stars are candidates for non-congruent type of phase transformations. In particular it is true for hypothetical plasma and dissociative phase transition(s) in H_2/He mixture in interiors of Jupiter, Saturn end extrasolar planets. One also meets NCPT in isentropically released plasmas of strongly shock-compressed lunar ground under natural or artificial huge impact. Hypothetical non-congruence of gas-liquid PT-s in ionic liquids and molten salts, as well as in other mixtures and compounds, are also discussed. Finally relevance of non-congruence is considered for phase transitions in exotic situations: quark-hadron and gas-liquid-like phase transitions in ultra-dense plasmas in deep interior of neutron and strange (hybrid) stars as well as for high-energy ion-ion collision products in super-colliders.

[1] I. Iosilevskiy, V. Gryaznov, E. Yakub, C Ronchi. and V. Fortov, Contrib. Plasma Phys. 43, 316 (2003)
[2] C. Ronchi, I. Iosilevskiy, E. Yakub, Equation of State of Uranium Dioxide, Springer, Berlin, 2004

PLASMA MODES AND COLLISION FREQUENCY – FROM BULK TO CLUSTER

H. Reinholz[1], T. Raitza[2], I. Morozov[3], I. Broda[1], G. Röpke[2]

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[2]*Institute of Physics, Rostock University, 18051 Rostock, Germany*
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Diagnostics of Coulomb systems in bulk as well as in clusters via transport and optical properties is investigated. Deduction of plasma parameters from line shapes and photoabsorption spectroscopy is discussed. Perturbative calculations as well as molecular dynamics (MD) simulations are applied in order to understand experiments, in particular, on shock-wave or laser induced warm dense matter. Systems of reduced dimensionality are considered with respect to the transition from bulk to cluster. While bulk plasmons cannot be excited via light waves, the more complex structure of longitudinal and transverse collective excitation modes in clusters should be observable via optical investigations.

Within a generalized linear response theory [1], optical properties in bulk are described consistently including collision effects relevant in correlated systems. Going beyond RPA for the dielectric function, the concept of the dynamical collision frequency, which is related to auto correlation functions, is applied. Collisions prove to be of relevance in strongly coupled plasmas. Exemplarily, results for line shifts and broadening in bulk systems are presented, in the optical [2] as well as in the X-ray regime, [3].

Plasma frequency and collision frequency are well defined quantities in bulk systems. We are interested in their generalization for finite systems, and the application to laser excited clusters. For the evaluation of equilibrium auto-correlation functions at arbitrary coupling strength we apply MD simulation techniques for classical systems [4, 5]. A restricted MD simulations scheme for finite systems [6, 7] has been developed and the spatially resolved momentum auto-correlation spectrum is interpreted in terms of collective electron excitation modes in [8]. Resonance frequencies are calculated and interpreted as rigid oscillation of all electrons and plane wave oscillations as well as so-called breathing modes.

Damping rates are discussed. The energy of collective excitations and spatial distribution of the eigenmodes has been analyzed within a hydrodynamical approach. Starting from the current-current ACF as the statistically better accessible quantitity, the relation to the density-density ACF is discussed, which will allow comparison with results for the dynamical structure factor obtained from DFT approaches.

[1] H. Reinholz, Ann. Phys. Fr. 30. N° 4-5 (2005)
[2] S. Lorenzen, A. Wierling, et al., AIP Conf. Proc. 1290, 99 (2010)
[3] U. Zastrau, A. Sengebusch, et al., High Energy Density Phys. 7, 47-53 (2011)
[4] I. Morozov, H. Reinholz, et al., Phys. Rev. E 71, 066408 (2005)
[5] H. Reinholz, T. Raitza, et al., Int. J. Mod. Phys. B 22 4627 (2008);
[6] T. Raitza, H. Reinholz, G. Röpke, I. Morozov; J. Phys. A 42, 214048 (2009).
[7] T. Raitza, H. Reinholz, G. Röpke, I. Morozov, E. Suraud, CPP 49, 498 (2009).
[8] T. Raitza, H. Reinholz, G. Röpke; J. Mod. Phys. B 24, 4961 (2011).

DYNAMIC COMPRESSION OF STRONGLY COUPLED PLASMAS AT MEGABARS

V. E. Fortov[1], R. I. Il'kayev[2], M. A. Mochalov[2], M. V. Zhernokletov[2], A. L. Mikhailov[2], A. N. Starostin[3], V. B. Mintsev[4], I. L. Iosilevskiy[5], V. Ya. Ternovoi[4]

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New experimental results on thermodynamics and electrical conductivity of shock and isoentropically compressed hydrogen and deuterium are presented. Strongly coupled plasmas at pressures achieved 18 Mbar, Coulomb coupling parameter exceeded 450, electron degeneracy parameter came up to 290 were obtained with semi-spherical explosive-driven generators. Theoretical models for description of thermodynamics of strongly coupled hydrogen are discussed, comparison of the experimental and theoretical data for strongly non-ideal hydrogen plasmas under high energy density are presented. Experimental and theoretical problems in studying of warm dense hydrogen are discussed. Problems of accurate description of weakly coupled solar plasma on basis of astrophysical observations are discussed as well.

Keywords: strongly coupled plasma, hydrogen, thermodynamics, high energy density, electrical conductivity, solar plasma, astrophysical observations, theory, experiment

CHARACTERIZATION OF ALPHA-QUARTZ FOR USE AS A HIGHLY ACCURATE STANDARD IN MULTI-MBAR HUGONIOT EXPERIMENTS*

M. D. Knudson, M.P. Dejsarlais

Sandia National Laboratories, Albuquerque, NM, USA

Quartz melts at roughly 100 GPa on the Hugoniot into a conductive fluid with appreciable reflectivity. This enables interferometric methods to be used to directly measure the shock velocity of quartz in the Mbar regime.

This property of quartz has resulted in prolific use of alpha-quartz as a standard for impedance matching experiments at high pressure. However, the accuracy of measurements in which quartz is used as a standard relies on knowledge of both the Hugoniot and off-Hugoniot response of quartz over a wide pressure range. To this end, the flyer plate capability at the Sandia Z machine was used to obtain both Hugoniot data and release data for quartz using a low density aerogel. Direct impact experiments provided a very precise determination of the Hugoniot for alpha-quartz and the low density aerogel. Measurements were then made for shock waves transmitted from quartz into aerogel, thereby enabling a measurement of the release adiabat. In this way measurements of the alpha-quartz Hugoniot from ~100-1600 GPa, and release measurements from ~300-800 GPa states on the quartz Hugoniot to ~50-125 GPa states on the aerogel Hugoniot have been obtained. Comparisons of the experimental measurements and Quantum Molecular Dynamics calculations of the quartz Hugoniot and release adiabats will also be presented.

* Sandia is a multiprogram laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Company, for the US Department of Energy's National Nuclear Security Administration under Contract No. DE-ACO4-94AL85000.

RECENT RESULTS ON STRONGLY INTERACTING QUARK-GLUON PLASMA AT LHC ENERGIES

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The data collected in Au+Au heavy ion collisions at RHIC indicated the formation of a strongly interacting quark-gluon matter with special properties, as close to be perfect fluidity and very small viscosity. Recent data from Pb+Pb collisions at LHC energies (at 10 times larger energy concentration) carry similar feature, the extracted physical parameters are comparable to the RHIC values. However, the intensity of the interaction inside the produced deconfined matter seems to be weaker. On the basis of the existing heavy ion data I summarize shortly the information supporting the formation of a liquid-like quark-gluon matter and explain the consequences of these measurements.

PROTON RADIOGRAPHY OF STRONGLY COUPLED PLASMA

V. B. Mintsev[1], S. A. Kolesnikov[1], S. V. Dudin[1], N. S. Shilkin[1], D. S. Yuriev[1], V. I. Turtikov[2], A. A. Golubev[2], B. Yu. Sharkov[2], V. E. Fortov[1]

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[2] SSC RF Institute for Theoretical and Experimental Physics, Bolshaya Cheremushkinskaya, 25, 117218 Moscow, Russia

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Experimental investigations of strongly coupled plasma produced by shock and detonation waves have been conducted at proton radiography facility developed at the ITEP Terawatt Accelerator (TWAC-ITEP). The 800 MeV proton beam intensity in these experiments is about 1010 particles per pulse. A single beam bunch consists of four consequent 70 ns long micro bunches with 250 ns intervals between them. The spatial resolution of the facility that was measured in static experiments is about 50 μm. For the generation of shock waves the energy of high explosives (HE) is used, therefore experimental targets are placed within the explosive containment chamber that is certified for the use of up to 100 g of HE in TNT equivalent. The results of latest experiments are presented, including results on propagation of the shock and detonation waves and measurements of the equation of state of strongly coupled shock-induced plasma of argon and xenon.

Detonation waves in condensed HE were studied as a dynamic test object at the facility. Series of radiographic images of areal density (i.e. density along the proton beam) of detonating HE charges were obtained in those experiments. On the basis of these images calculations of detonation wave velocities were performed and volume density profiles along the axes of charges were reconstructed. The analysis of these profiles shows that in the vicinity of Chapman – Jouget point, as well as in the following region of unloading, they give not only qualitative but also good quantitative agreement with the known experimental data obtained by other measurement techniques.

The experimental investigation of shock-induced strongly coupled plasma of argon and xenon is being conducted at the TWAC-ITEP proton radiography facility now. The shock pressure P in recent argon tests was from 100 to 1000 bars, temperature T was 8-20 kK with non-ideality parameter Γ of about 1. In similar tests with xenon the values of P=4-6.5 kbar, T= 20-25 kK and Γ=1-2.5 were reached. At several proton radiography images for argon the existence of shock waves propagating in it was registered. However, in present experimental setup the observed density gradient in these waves is of the same order as the sensitivity of the technique, so the accuracy of the experiment proved to be low ~20%. Considerably better situation is observed in xenon, where the formation and development of a shock wave and a plasma plug behind its front is firmly registered. Further processing of these proton radiography data on xenon allow to determine with sufficient accuracy the density of the developed strongly coupled plasma of xenon.

THEORETICAL MODELS FOR LIGHT SCATTERING FROM DENSE MATTER

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The scattering of photons has been demonstrated to be a robust and flexible tool for the diagnostics of plasmas. In dense matter one has to rely on UVU light or x-rays to counter the high absorption of low energy photons. Moreover, the strong correlations between the particles as well as partial ionization has to be taken into account. Thus theoretical models for the electron and ion structure in dense matter are needed to interpret the experimentally obtained spectra. Indeed, the basic plasma plasma parameters as well as collective and transport properties are typically obtained by a best fit to a given model [1].

In this contribution, we present recent extensions of the method that allow to describe mixtures (relevant for many applications) and systems that are not fully in thermodynamic equilibrium. For the description of systems with different elements, we generalize the theoretical model to account for *all* mutual correlations between the different ion species and also differences in the electron structure around the different ions [2]. Our structural analysis is mainly based on first principle (DFT-MD) simulations giving access to high quality data [3]. We demonstrate that x-ray scattering can clearly distinguish systems with different concentrations of elements. The elastic scattering signal also contains the information if a microscopically mixed or a phase separated fluid is probed. Thus, one can use this technique to study the process of demixing in dense hydrogen-helium systems important for planetary physics.

The second extension of the standard analysis concerns the possibility of nonequilibrium states to be probed. Here, we concentrate on the electrons. To this goal, one has to take into account both the nonequilibrium electron distribution *and* changes in the fluctuation-dissipation-theorem (connection between density response function and structure factor) [4]. We show how the new description results in a different dispersion relation for the collective electron modes and that these modifications in the inelastic electron feature of the scattering signal are significant enough to be probed. In particular, hot electrons might explain the strong blue wing in the spectrum obtained from heated beryllium [5]. A comparison with data for hydrogen [6] obtained at the FLASH facility shows very good agreement. As pump and probe are here the same, this is a continuously driven system. In this case, our nonequilibrium analysis reveals that the data are time-averaged and not equilibrium conditions averaged over sample conditions [4].

[1] S.H. Glenzer and R. Redmer, Rev. Mod. Phys. 81, 001625 (2009).
[2] K. Wunsch, J. Vorberger, G. Gregori, and D.O. Gericke, EPL 94, 25001 (2011).
[3] K. Wunsch, J. Vorberger, and D.O. Gericke, Phys. Rev. E 79, 010201(R) (2009).
[4] D.A. Chapman and D.O. Gericke, in preparation for Physical Review Letters.
[5] S.H. Glenzer et al., Phys. Rev. Lett. 98, 065002 (2007).
[6] R.R. Faustlin et al., Phys. Rev. Lett. 104, 125002 (2010).

STRONG-COUPLING THEORY OF COUNTER-IONS AT CHARGED PLATES

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Thermodynamic properties of charged mesoscopic bodies immersed in (classical) solution are of importance in colloid physics, biochemistry, structural biology, etc. A standard model for studying an effective interaction between charged bodies is the system of two parallel plates with the same surface charge density. There are mobile charges of opposite sign (counter-ions) between the plates, neutralizing their surface charge. A landmark in the field was the realization in the 1980s that similarly charged plates may attract each other under strong enough Coulombic couplings, which was accomplished in practice by increasing the valency of counter-ions. A theoretical explanation and a quantitative analysis of this "anomalous" phenomenon remained a puzzle for many years. Technically, the averaged density profile of counter-ions was calculated to derive the force between the plates by using the contact theorem.

In the high-temperature (weak-coupling) limit, described by the Poisson-Boltzmann mean-field approach, the plates always repel each other.

In the opposite low-temperature (strong-coupling, SC) limit, counter-ions form on each of the charged plates a two-dimensional Wigner crystal. In the field-theoretical method put forward in [1], the leading behavior stems from a single-particle theory in the electric potential induced by the charged plates. Next correction orders correspond to a virial or fugacity expansion in inverse powers of the coupling constant. The method requires a renormalization of infrared divergences via the electro-neutrality condition. A comparison with Monte Carlo (MC) simulations indicates the adequacy of the virial SC approach to capture the leading large-coupling order, but its failure for the first correction.

Recently [2], we proposed another SC method based on an exact low-temperature expansion in powers of spatial deviations of counter-ions around the ground state formed by the coupled pair of two-dimensional Wigner crystals on each of the plates. The leading large-coupling order coincides with the single-particle picture of the previous SC approach. Unlike the virial SC theory, the expansion is free of divergences and the obtained results for the first correction are in excellent agreement with available MC data under strong Coulombic couplings. Our results shed light on the like-charge attraction regime.

[1] A. G. Moreira and R. R. Netz, Europhys. Lett. 52, 705 (2000); Phys. Rev. Lett. 87, 078301 (2001); R. R. Netz, Eur. Phys. J. E 5, 557 (2001)
[2] L. Šamaj and E. Trizac, Phys. Rev. Lett. 106, 078301 (2011); Eur. Phys. J. E 34, 20 (2011)

35 YEARS OF STRONGLY COUPLED PLASMAS

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The SCCS series started as a NATO Summer Institute in 1977. I review how the series has developed since, morphing into the more general area of Strongly Coupled Coulomb Systems. It has paralleled the emergence of many novel areas, such as complex (dusty) plasmas, cryogenic traps, two-dimensional and layered condensed matter systems, highly compressed hydrogen, etc. where the concepts of strongly coupled Coulomb systems are relevant.

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BOUND STATES IN COULOMB SYSTEMS – OLD PROBLEMS AND NEW SOLUTIONS

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In May 1911, hundred years ago, Rutherford came forth with the model of matter as a Coulomb system, providing an understanding why electron scattering can deeply penetrate into matter. In Rutherford's model matter is nearly empty, made up of positive charges and electrons and the glue keeping the system together are the Coulomb forces. Soon after the development of the new model, a quantum-mechanical treatment by Bohr (1913) and a statistical treatment by Herzfeld (1913) were given. This is the begin of a long battle with the Coulomb singularities, which we plan to discuss here, in particular the problems connected with the Coulomb bound states. First we discuss the historical development of the problem solutions connected with the Rutherford-Bohr model of matter proposed by Herzfeld, Fermi, Becker, Planck and Brillouin to Larkin. Beyond this historical analysis, the main task of this lecture is the study of the solutions found by modern quantum statistics. We will show that the atomic partition function as well as the partition function of macroscopic systems are of course free of divergences and explain the role of compensation effects, screening effects and the Pauli exclusion principle. Next we discuss the problems connected with the ionization equilibrium and show that at high densities, the chemical species and the minimization of the free energy are not well defined. Further we discuss the problems of phase transitions predicted by the theory for dense partially ionized plasmas. The last part is entirely devoted to the discussion of available results for the so-called physical picture of Coulomb systems not operating with species like atoms and molecules which are difficult to define in strongly coupled Coulomb systems. We study the two typical transitions along isotherms, shown in Fig.1.

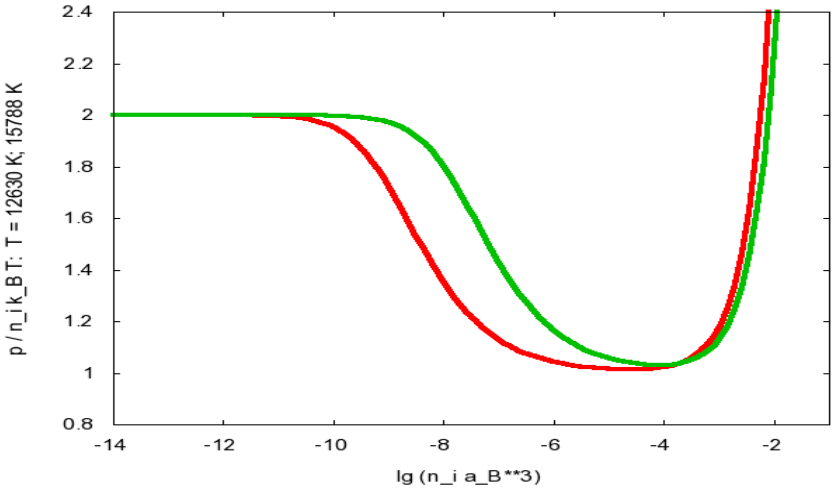

Figure 1: Two typical isotherms of hydrogen pressure on proton pressure demonstrating the valley of bound states as a function of density (in protons per Bohr cube).

[1] W. Ebeling, W.D. Kraeft, D. Kremp: Theory of bound states and ionization equilibrium, Akademie-Verlag, Berlin 1976

SPATIALLY SEPARATED, GATE VOLTAGE CONTROLLED ELECTRON-HOLE PLASMA IN SEMICONDUCTOR BILAYERS: RECENT PROGRESS AND CHALLANGES

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Recent developments in solid-state semiconductor devices have made it possible to prepare a layer of electrons and a layer of holes in close proximity (~ 10-20 nm), comparable to the excitonic Bohr radius of the host semiconductor (Gallium Arsenide)[1]. The physics of this system is driven by the attractive interlayer (electron-hole) Coulomb interaction and the in-plane repulsive interaction between the electrons (holes) themselves.

But the binding energy scales (few meV) and the mass ratio of the positive and negative charges (4-5) are very different from those in ionized Hydrogen plasmas. The electron and hole densities of this 2-component plasma can be individually controlled by gate voltages, set by the experimenter. Electrical current can be passed through each layer by independent ohmic contacts. The primary transport based tool for probing the interlayer scattering rate in these devices is the "Coulomb drag" method, in which a current is passed through one layer and Coulomb interaction mediated momentum transfer to the *other* layer is measured. The interesting physics in these bilayers can be observed at $T \approx 1\mathrm{K}$ or lower - readily accessible in liquid helium cooled cryostats. A rich phase diagram of the ground state of the electron-hole bilayer, consisting of excitonic phases[2], Charge density waves, Wigner crystals[4], excitonic condensates [3] has been anticipated for many years. Recent data from two experimental groups [1] have clearly shown that at low temperatures the interlayer scattering rate can no longer be correctly described by Fermi liquid theory. I will discuss the design concepts behind these devices, results of the ongoing experiments and several interesting open questions that have come up. Experimentally we have reached a strongly interacting regime, where the electron and hole densities can be tuned down to $\sim 5\ x\ 10^{10}\mathrm{cm}^{-2}$ ($r_s \approx 10$ for holes, $r_s \approx 2$ for electrons) at an interlayer separation of 10-20 nm. This is a regime where the finite thickness of the wavefunctions are comparable to their separation and the intra-layer separation between the similarly charge particles are larger than the inter-layer separation. The interlayer scattering and possible binding/density modulations must both be driven by the screened Coulomb interaction under these conditions. The behaviour of the dynamic bilayer dielectric screening $\epsilon(q;\ \omega)$ in presence of disorder would be crucial in understanding the results.

[1] A. F. Croxall et al. Phys. Rev. Lett., 101,246801, (2008) J. A. Seamons et al. Phys. Rev. Lett., 102, 026804, (2009)
[2] Yu.E. Lozovik and V. I. Yudson. Sov. Phys. J.E.T.P. 44, 389 (1976)
[3] G. Vignale and A.H. MacDonald. Phys. Rev. Lett., 76, 2786 (1996). A. V. Balatsky et al. Phys. Rev. Lett., 93, 266801 (2004)
[4] L. Liu et al. Phys. Rev. B, 53, 7923 (1996)

QMC SIMULATIONS OF 2D ELECTRONS WITH DISORDER AND DIVERGENCE OF THE SPIN SUSCEPTIBILITY AT THE MIT IN SI-MOSFETS

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We critically discuss the predictions made in [1] using the results of QMC simulations of electrons in 2D (2DEG), in the presence of a model disorder and with valley degeneracy, to mimick electron systems in high mobility Si-MOSFETs. [1] provides a fit of the spin polarization energy E_p of the 2DEG, as function of the density/coupling parameter r_s and the electronic mean free path l. To compare their predictions with experiments the authors of [1] employed a non-interacting formula $k_F l = \eta / r_s$, fixing η to the experimental mobility at high density; this formula becomes inappropriate at the large r_s values realized near the apparent metal-to-insulator transition (MIT) observed in these devices, because of electronic screening. We find that use of the experimental $k_F l$ in the above mentioned fit, as r_s varies, yields the vanishing of E_p at large r_s, in qualitative agreement with the apparent divergence of the experimental spin susceptibility and in contrast with the opposite conclusion drawn in [1].

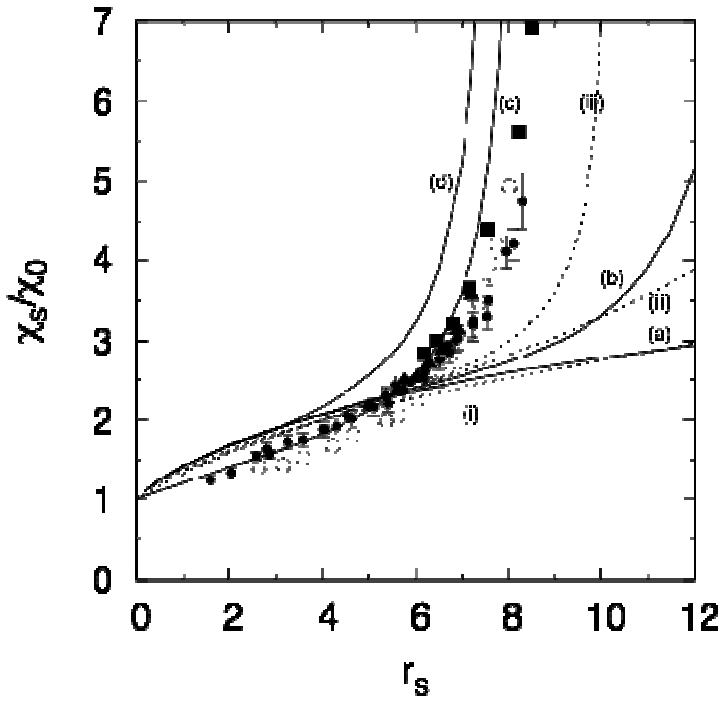

Figure 1: Spin susceptibilty enhancement in Si-MOSFETs: symbols (experimental results); (ii) original prediction of [1], (iii) prediction of [1] using the experimental $k_F l$.

[1] Geneviève Fleury and Xavier Waintal, Phys. Rev. B 81, 165117 (2010).

STRONGLY COUPLED COULOMB SYSTEMS IN GRAPHENE QUANTUM DOTS

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We review here our recent work on strongly coupled Coulomb systems in gated graphene quantum dots. The effect of Coulomb interactions, size, shape, edge and carrier density on the electronic, magnetic and optical properties of graphene quantum dots will be described. We will focus on a special class of triangular quantum dots (GTQD) with zig-zag edges. Such structures lead to a shell of degenerate zero-energy states at the Fermi level (Dirac point) [1-4]. The degeneracy is proportional to the edge size and can be made macroscopic[5]. Using a combination of tight-binding, density functional, Hartree-Fock and configuration interaction methods we will describe the strongly coupled Coulomb system, a degenerate shell, as a function of the fractional filling, drawing on analogy with the FQHE[4-9]. In particular, we will show that at half-filling the shell is fully spin polarised but polarization can be modulated by controlling the filling of the shell with the external gate. In particular, addition of a single electron leads to spin depolarisation due to electronic correlations and strong Coulomb interaction with the gate. The effect of shell filling and magnetic moment on transport [4] and optical properties of a single quantum dot will be described [6]. We will show that the magnetic moments of triangular quantum dots interact ferromagnetically in bi-layer quantum dots[9]. The tunability of this magnetic moment with vertical electric field and the possibility of isolating a single electron spin will be demonstrated[9]. These results show[4-9] that it is possible to combine electronic, photonic and magnetic functionalities in a single material system by engineering graphene quantum dot size, shape and character of the edge.

[1] Fernandez-Rossier J. and Palacios J.J. *Phys.Rev.Lett.* 99 177204 (2007).
[2] Ezawa M. *Phys.Rev.B* 77 155411 (2008).
[3] Wang W.L., Meng S. and Kaxiras E. *Nano Lett.* 8 241 (2008).
[4] Güçlü A D. Potasz P., Voznyy O., Korkusinski M, and Hawrylak P. - *Phys.Rev.Lett.* 103 246805 (2009).
[5] Potasz P., Güçlü A D, and Hawrylak P. Phys. Rev. B 81, 033403 (2010).
[6] A.D.Guclu, P.Potasz, and P. Hawrylak, Phys. Rev. B 82, 155445 (2010).
[7] Oleksandr Voznyy, Alev Devrim Güçlü, Pawel Potasz, Pawel Hawrylak, Phys.Rev.B83, 165417 (2011).
[8] P. Potasz, A. D. Güçlü , O. Voznyy, J.Folk and P. Hawrylak, Phys. Rev. B 83, 174441 (2011).
[9] A. D. Güçlü, P. Potasz and P. Hawrylak, submitted (arXiv:1104.3108).

COULOMB DRAG AND SPIN HALL DRAG: NEW COUPLING MECHANISMS FOR NANOELECTRONICS

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Double-layer structures consisting of two parallel quantum wells separated by a narrow potential barrier are an important class of nanoscale electronic devices. Each layer hosts a quasi-two dimensional electron gas and electrons interact across the barrier via the Coulomb interaction. When an electric current is driven in one of the layers, the Coulomb interaction causes a charge accumulation in the other layer. This phenomenon, known as Coulomb drag, is of fundamental interest as a probe of electronic correlations and phase transitions and provides a coupling mechanism between spatially separated elements of nano-electronic circuits. In this talk I review the extension of Coulomb drag theory to quantum plasmas with strong spin-orbit coupling.

Here the electron-electron interactions latches onto spin-orbit interactions to produce intriguing effects. In particular I describe the phenomenon of Spin Hall Drag - the generation of a transversal spin accumulation in one layer by an electric current in the other layer. This effect is controlled by the component of the Coulomb electric field parallel to the layers. Spin-current generation by the component of the Coulomb electric field perpendicular to the layers will also be discussed.

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TRANSPORT OF TWO-DIMENSIONAL ELECTRONS THROUGH NARROW CHANNELS WITH CONSTRICTION: "QUANTIZED" CONDUCTANCE IN CLASSICAL SYSTEM

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The two-dimensional system of electrons trapped on the surface of liquid helium enables us to perform clear experimental observations of various typical phenomena in the strongly coupled Coulomb systems. For example, the formation of the Wigner crystal was observed for the first time in this system. Recently, the transport properties of narrow channels with constrictions have been carefully measured and their nonlinear ("quantized") behavior has been found[1]: With the increase of the coupling $\Gamma=e^2(\pi n)^{1/2}/k_BT$, n and T being the density and the temperature, the conductance of the channel departs from a monotone function of the strength of the constriction and begins to have a tendency to follow stepwise changes as is shown in Fig.1. In this presentation, it will be shown that this nonlinearity is deeply related to the correlation between classical electrons on the basis the results of extensive numerical simulations and their visualization. It is well known that, in the quantum systems, the transport through the point contact is controlled by the nature of wave functions of electrons and we have the quantized conductance. Our results show that this kind of "quantized" behavior also occurs in the classical but strongly coupled systems. Preliminary results of simulations are shown in Fig.2. When electrons are strongly coupled, we have highly non-monotone conductance.

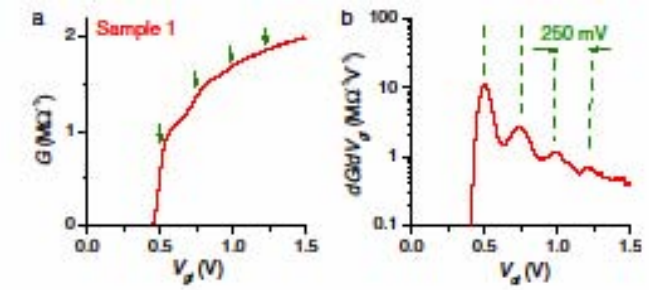

FIG. 3 (color online). Measurements with sample 1 for $V_{gs}^* - 0.62$ V, $V_r - 1$ V. (a) Conductance G measured while sweeping V_{gs}. The green arrows indicate the maxima in dG/dV_{gs}. (b) Corresponding derivative dG/dV_{gs}. The gradient at each point is calculated over a 50 mV sampling window. The dashed lines indicate the peak spacing of ~250 mV.

Figure 1: Conductance (experiments)[1].

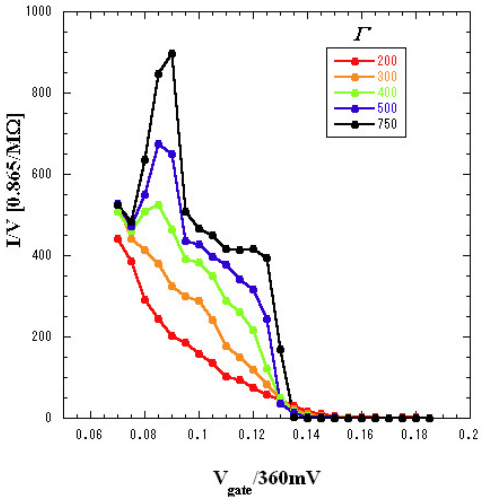

Figure 2: Conductance (simulations).

[1] D. Rees, et al., Phys. Rev. Lett. 106, 026803(2011)

ABNORMAL PRESSURE FLUCTUATIONS IN NONDEGENERATE NONIDEAL PLASMA

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An assumption about the plasma phase transition (PPT) is advanced in [1] by analogy with the Van der Waals equation where the phase transition origin is a result of the balance between long-range attraction and short-range repulsion. Coulomb interaction between charges is a long-range and effectively attractive one because of the plasma polarization. An effective repulsion at short distances even for an electron-proton pair is of the quantum nature. However contrary to real gases there are excited atoms in low temperature plasmas. The restriction of the discrete spectrum in the atomic partition function depends on the charge number density. Gryaznov and Iosilevskiy [2] noted that this dependence results in the appearance of a new term in the equation of state. The term is equivalent to the effective repulsion. Therefore this factor is able to suppress or influence the PPT. The chemical plasma model is used in [3]. It is more logical to apply the fluctuation approach [3] which provides the self-consistent joint description of free and weakly bound electron states without their separation. The molecular dynamics method is used. The electron-ion interaction is described by the density and temperature-independent cutoff Coulomb potential. Fluctuations of pressure of singly ionized nonideal plasma are studied. Two main abnormal features of pressure fluctuation distribution are observed. (a) The fully ionized plasma region is found where pressure fluctuation distribution dramatically differs from normal distribution and can be approximated by the superposition of two Gauss distribution functions. (b) There is also a region of plasma parameters where negative instantaneous values of pressure are observed. It should be noted that these regions of plasma parameters lay out of the area of the abovementioned stabilized factor action. The results could be considered as a precursor of the PPT.

[1] G.E. Norman, A.N. Starostin, High Temperature 6, 394 (1968)
[2] V.K. Gryaznov, I.L. Iosilevskiy, V.E. Fortov, J. Appl. Mech. and Tech. Phys. 3, 70 (1973)
[3] A.V. Lankin, G.E. Norman, J. Phys. A: Math. and Theor. 42, 214032 (2009)

DEVELOPMENT AND APPLICATIONS OF SIMULATIONS FOR DENSE HYDROGEN AND HELIUM

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We review some of the first principles simulation techniques for dense systems, in particular methods based on density functional theory and quantum Monte Carlo. We then discuss some recent applications for dense hydrogen and helium.

Although the properties of dense hydrogen and helium are important for understanding the giant planets, measurements or calculations in the relevant conditions are challenging. It has long been an open question how hydrogen makes a transition from a molecular insulating state to an atomic metallic state; current simulations now consistently find a weakly first-order liquid-liquid transition at temperatures lower than 1500K[1]. Simulations also show that helium at Mbar pressures and high temperatures (4000 to 10000 K) [2] is insoluble in dense metallic hydrogen; the temperatures for the demixing are sufficiently high to cross the planetary adiabat of Saturn as speculated 50 years ago. Since the first prediction of an atomic metallic phase of hydrogen by Wigner and Huntington, there have been many theoretical efforts aimed at determining crystal structures of atomic hydrogen. Using random structure searching new ground-state crystal structures are hydrogen have been predicted [3].

[1] M. A. Morales, C. Pierleoni, D. M. Ceperley "Evidence for first order liquid-liquid phase transition in high pressure hydrogen from ab-initio simulations" PNAS, 107, 12799-12803 (2010).

[2] M. A. Morales, E. Schwegler, D. Ceperley, C. Pierleoni, S. Hamel, and K. Caspersen, Phase separation in hydrogen–helium mixtures at Mbar pressures, PNAS, 106, 1324-1329 (2009).

[3] C. J. Pickard and R. J. Needs, Nature Phys. 3, 473 (2007); J. M. McMahon and D. M. Ceperley, Zero-Temperature Structures of Atomic Metallic Hydrogen, Phys. Rev. Letts. 106, 165302:1-4(2011); arXiv: 1011.5028.

LONG-RANGE CORRELATIONS OF THE SURFACE CHARGE BETWEEN TWO ELECTRICAL MEDIA

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We consider an interface between two semi-infinite media, characterized by different frequency-dependent dielectric functions, which are in thermal equilibrium. The distinct electric properties of the media give rise to a surface charge density on the interface which is associated with the discontinuity of the normal component of the electric field. The surface charge density fluctuates in time around its mean value. The correlation of the surface charge fluctuations at two points on the interface, with times different by t and distances different by r, is described by the structure function $S(t,r)$.

At large distances r, $S(t,r)$ exhibits a tail of type $h(t)/r^3$. This inverse-power law behavior is not a sign for a critical state of the system, but the result of the long-range character of electromagnetic forces combined with the asymmetry between the two media. In the sense of distributions, the 2D Fourier transform of $1/r^3$ is $-2\pi q$ (q is the wave vector). Thus the structure function $S(q,r)$ has a kink singularity at $q=0$, behaving like $-2\pi h(t)q$. This small-q behavior differs substantially from the standard q^2 dependence of short-ranged structure functions. The prefactor function $h(t)$ can be measured by scattering experiments.

The form of $h(t)$ depends on the considered "physical model" [1,2]: One can use either *classical* or *quantum* mechanics, the electromagnetic interactions can be treated in either *non-retarded* (the speed of light is infinite) or *retarded* regimes. First we evaluate $h(t)$ in the non-retarded regime. The classical universal form of the static $h(0)$ is obtained by simple macroscopic arguments based on a combination of the linear response theory and the electrostatic method of images. Rytov's phenomenological theory of fluctuations of electromagnetic fields [3] leads to a more complicated non-universal form of the quantum $h(t)$. The consideration of retardation effects puts back the quantum form of $h(t)$ to the classical one, in the region of very small values of the wave vector q. The obtained results are checked on the microscopic model of the jellium conductor in contact with vacuum.

[1] L. Šamaj and B. Jancovici, Phys. Rev. E 78, 051119 (2008)
[2] B. Jancovici and L. Šamaj, Phys. Rev. E 79, 021111 (2009); Phys. Rev. E 80, 031139 (2009)
[3] E. M. Lifshitz and L. P. Pitaevskii: Statistical Physics, Part 2 (Pergamon, Oxford, 1981)

MOMENTUM DISTRIBUTION AND EFFECTIVE MASS OF JELLIUM MOMENTUM DISTRIBUTION AND THE EFFECTIVE MASS OF THE ELECTRON GAS IN TWO AND THREE DIMENSIONS AT METALLIC DENSITIES

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In particular, I focus on the jump of the momentum distribution at the Fermi surface, the renormalization factor Z. Our QMC calculations allow us to compare Z with different perturbative RPA/GW methods and quantify their validity.

STRONGLY COUPLED COULOMB SYSTEMS OF DUST PARTICLES IN TRAPS AND PLASMAS

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After first experimental observations of ordered structures of dust particles in rf and dc gas discharges, similar dusty plasma structures are frequently considered as a macroscopic physical model of coupled Coulomb systems (SCCS), which can visually be observed. Using such structures of charged dust particles, one can investigate the processes of phase transitions, waves, and instabilities on kinetic levels.

One of the central problems associated with experimental studies of stable SCCS is that of ensuring the levitation of charged particles. The levitation of dust particles in gas discharges is provided by the interaction of the particle charge with electric field.

For confinement and investigation of SCCS of charged dust particles, we propose to use a trap based on the known possibility of the levitation of diamagnetic bodies in a nonuniform steady-state magnetic field. An experimental setup is described, which is capable of forming and confining clusters of charge graphite particles sized 100 to 300 μm in magnetic field B~1 T and $|\nabla B|$~10 T/cm. It is inferred that it will be possible to form stable 3d dust structures containing several thousand particles under terrestrial conditions by using more intensive magnetic fields B > 10 T. Less intensive magnetic fields (B ≈ 0.1 T, $|\nabla B| \approx 0.1$ T/cm) will be required for studying analogous structures under microgravity conditions.

The superhigh charging of dust particles under direct stimulation by an electron beam is experimentally investigated. The energy of beam electrons amounts to 25 keV, with the typical diameter of dust particles employed in the experiment of 100 μm. The charge acquired by a dust particle amounts to $5 \cdot 10^7$ electron charges, which is more than two orders of magnitude higher than the values of the charge of dust particles in gas discharges.

A technique for analyzing the pair interaction forces between particles in nonideal dissipative systems is presented. The technique is based on a solution of the inverse problem describing the movement of dust particles by a system of Langevin equations. The approbations of the proposed technique for analysis of interparticle's interactions in a plasma of rf discharge are presented.

The results of experimental and theoretical investigations of structural and dynamic properties of dusty plasma in dc glow discharge at the temperatures of 4.2-300 K were presented. The experiments were conducted in a gas-discharge tube cooled by cryogenic liquids (LN_2 and LHe) and their vapors. The kinetic processes of interaction of dust particles with the plasma component at cryogenic temperatures were analyzed with consideration for the ion-atom collisions. This analysis made possible to determine main mechanism responsible for the observed increase in the dusty plasma density. The experimental observations of the waves and vortices under cooling the discharge down to cryogenic temperatures were presented.

This work was supported by the Research Program of the Presidium of the Russian Academy of Sciences "Thermophysics and Mechanics of Extreme Power Actions and Physics of Highly Compressed Matter" and by the Russian Foundation for Basic Research, Project No. 10-02-90056 and Project No. 10-02-01428.

MELTING OF 2D PLASMA CRYSTALS: WAKE-MEDIATED MODE COUPLING INSTABILITY

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There are several mechanisms of melting of two-dimensional (2D) plasma crystals. These mechanisms can generally be divided into two categories – generic and plasma-specific. Generic mechanisms are those operating in any (classical) system with a given (conservative) pair interactions between particles (prominent examples are the KTHNY or grain-boundary melting scenarios). Plasma-specific melting mechanisms, which can only operate in complex plasmas, are associated with the energy exchange between charged microparticles and ambient plasma and can be considered as a result of the system openness.

The most universal among the plasma-specific mechanisms is that associated with the wake-mediated interaction between microparticles [1,2]: In the presence of strong plasma flow the screening cloud around each charged grain becomes highly asymmetric (along the flow, these clouds are usually referred to as plasma wakes) and starts playing the role of a "third body" in the interparticle interaction, making it nonreciprocal [3]. This provides effective conversion of the energy of flowing ions into the kinetic energy of microparticles.

The theory of mode-coupling instability provides comprehensive picture of a plasma-specific melting scenario [4,5]. It predicts a number of distinct fingerprints to be observed upon the instability onset, such as the emergence of a new hybrid mode, a critical angular dependence, a mixed polarization, and distinct thresholds. In this talk we summarize the key features of the instability and present their detailed discussion and comparison with experiments and numerical simulations.

[1] L. Couedel, V. Nosenko, A. V. Ivlev, S. K. Zhdanov, H. M. Thomas, and G. E. Morfill, Phys. Rev. Lett. 104, 195001 (2010).
[2] L. Couedel, S. K. Zhdanov, A. V. Ivlev, V. Nosenko, H. M. Thomas, and G. E. Morfill, to be published in Phys. Plasmas (arXiv:1105.6223).
[3] A. Melzer, V. A. Schweigert, and A. Piel, Phys. Rev. Lett. 83, 3194 (1999).
[4] A. V. Ivlev and G. Morfill, Phys. Rev. E 63, 016409 (2001).
[5] S. K. Zhdanov, A. V. Ivlev, and G. Morfill, Phys. Plasmas 16, 083706 (2009).

MAGNETIZED STRONGLY COUPLED PLASMAS – FIRST PRINCIPLE RESULTS

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Applying a strong uniform magnetic field onto a strongly coupled plasma gives rise to a number of interesting and peculiar effects. Here, we report on two of these: The effect of a magnetic field on the wave spectra of strongly coupled 2D systems and the influence of a magnetic field on field-parallel and cross-field diffusion in 3D systems.

The magnetized 2D one-component plasma sustains two modes, the magnetoplasmon and the magnetophonon, the frequencies of which are of the order of the Einstein or cyclotron frequency [1]. We report on the existence of additional high-frequency plasma oscillations in Coulomb and Yukawa systems at multiples of the magnetoplasmon, based on extensive molecular dynamics simulations. The emergent modes are reminiscent of the well-known Bernstein modes but are renormalized by the strong interparticle correlations. We present detailed numerical results and an analytical description of the observed features [2,3].

The diffusion coefficient of magnetized 3D plasma has been studied thorougly in the weak-coupling regime, both experimentally and theoretically. Much less is known about the strong-coupling regime, where the diffusion coefficient parallel to the magnetic field is also affected. Simulation results in this regime are presented and the scaling of the diffusion coefficient with the magnetic field are discussed.

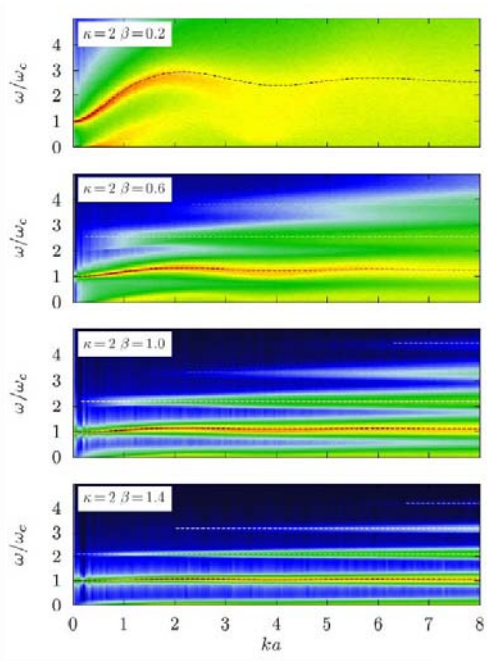

Figure 1: Additional high-frequency modes develop in the wave spectra of magnetized 2D systems as the magnetic field β increases (from top to bottom).

[1] Hou et al., Phys. Plas., 16, 73704 (2009)
[2] Bonitz et al., Phys. Rev. Lett., 105, 055002 (2010)
[3] Ott et al., Phys. Rev. E. 83, 046403 (2011)

MOLECULAR STATES OF CORRELATED ELECTRONS IN A QUANTUM DOT: THEORY AND INELASTIC LIGHT SCATTERING EXPERIMENTS

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The paradigm of few-electron complexes in semiconductor quantum dots relies on the "particle-in-a-box" idea that the lowest-energy orbitals are filled according to Pauli's exclusion principle. If Coulomb repulsion is sufficiently strong to overcome the kinetic energy cost of localization, a different scenario is predicted: a "Wigner" molecule forms, made of electrons frozen in space according to a geometrical pattern. In this talk I will provide evidence of correlated molecular behaviour in dots populated by two, three, and four electrons, which is based on inelastic light scattering measurements combined with configuration-interaction calculations [1].

Our spectroscopy measures the neutral few-body excitations of the electron molecule, which are either vibrations of the electrons around their relative equilibrium positions - fixed by Coulomb interaction - or rigid-body rotations. We find that spectra of low-lying excitations associated with changes of the relative-motion wave function - the analogues of the vibration modes of a conventional molecule - do not depend on the rotational state represented by the angular momentum [2]. In the case of a molecular dimer, we observe the fundamental breathing mode [3]. For three electrons, we see the emergence of a fully spin-polarized state [4], which is the simplest possible realization of Stoner ferromagnetism.

This work is done in collaboration with V. Pellegrini, A. Pinczuk, E. Molinari, G. Goldoni, L. N. Pfeiffer, B. S. Dennis, K. W. West, A. Gamucci, S. Kalliakos, C. P. Garcia, A. Singha, and it is supported by Projects MIUR-PRIN no. 2008H9ZAZR, CINECA-ISCRA-B FERMIFEW, and Fondazione Cassa di Risparmio di Modena COLDandFEW.

[1] C. P. Garcia, V. Pellegrini, A. Pinczuk, M. Rontani, G. Goldoni, E. Molinari, B. S. Dennis, L. N. Pfeiffer, and K. W. West, Phys. Rev. Lett. 95, 266806 (2005).

[2] S. Kalliakos, M. Rontani, V. Pellegrini, C. P. Garcia, A. Pinczuk, G. Goldoni, E. Molinari, L. N. Pfeiffer, and K. W. West, Nature Phys. 4, 467 (2008).

[3] A. Singha, V. Pellegrini, A. Pinczuk, L. N. Pfeiffer, K. W. West, and M. Rontani, Phys. Rev. Lett. 104, 246802 (2010).

[4] A. Gamucci et al., submitted (2011).

X-RAY SCATTERING DIAGNOSTICS OF SHOCK COMPRESSED COULOMB SYSTEMS

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Shock-compression of solid density targets produces matter under extreme conditions of density, pressure, and temperature for inertial confinement fusion research and laboratory astrophysics. Super high densities beyond the single-shock limit are reached through interaction of multiple strong shocks. Determining the space and time resolved physical parameters in the strongly coupled shock compressed matter is a challenge for both theoretical and experimental researchers. Spectrally resolved x-ray scattering of multi keV photons delivered from plasma X-ray sources and free electron lasers has become a standard diagnostic for plasma density, ionization, and temperature, as well as for the dielectric function and electric conductivity. We report on recent theoretical development and experimental applications of x-ray Thomson scattering to investigate the dynamic and static properties of shock-compressed matter. We present a first x-ray scattering experiment performed on counter-propagating shocks colliding in a beryllium target. This technique is shown to compress matter at low entropy increase. Using the Hugoniot relations for colliding shocks, we derive the heat capacity ratio $\gamma = c_p = c_v$ as a function of density and compare to equation of state models.

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COLLECTIVE MODES IN STRONGLY COUPLED BINARY LIQUIDS

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While a great deal of information - from experiments, simulations, as well as from theory - is available on the collective mode structure of a strongly coupled single component liquid (2D and 3D Yukawa systems in particular) [1], very little is known on the behavior of mixtures in this regard (Note, though, the existence of a large body of literature on the somewhat related subject of binary alloys). We have undertaken a systematic MD and theoretical study of 2D and 3D binary Yukawa liquids in order to map the collective mode structures of such systems over the parameter space of the 2 relevant mixing parameters c_2Z_2 / c_1Z_1 and m_1Z_2 / m_2Z_1, and over a wide range of Γ values, including the crystalline and disordered lattice phases.

Here we report on the first phase of the study, where we have concentrated on mixtures of components with different masses (m_1, m_2) and with different concentrations (c_1, c_2), but with identical charges. We observe the formation of acoustic and optic modes: the latter being the hallmark of the presence of more than one component. In the binary liquid there is one optic mode; in the binary crystal, however the number of optic modes also depends on the concentration ratios and on the crystal structure that can accommodate the chosen concentrations. We show that in all cases the mode frequencies satisfy a generalized Kohn sum rule.

The $k \to 0$ sound speeds (s_L, s_T) associated with the longitudinal and transverse acoustic modes exhibit a remarkable Γ-dependence. For weak coupling, the RPA predicted dominance of the lighter mass species should prevail: $s^2 \propto \left[(c_1 / m_1) + (c_2 / m_2)\right]$. For higher coupling however, the QLCA predicts the reversal of roles and the dominance of the heavy mass species: $s^2 \propto 1/\left[c_1 m_1 + c_2 m_2\right]$. MD simulations show clearly the transition from the intermediate coupling to the strong coupling regime both in the liquid and in the crystalline or disordered solid phase and fully corroborate the QLCA result.

[1] Z. Donkó, G. J. Kalman, and P. Hartmann, J. Phys. Condensed Matter **20**. 413101 (2008).

PRESSURE AND ELECTRICAL RESISTIVITY MEASUREMENTS ON HOT EXPANDED METALS: COMPARISONS WITH QUANTUM MOLECULAR DYNAMICS SIMULATIONS AND AVERAGE ATOM APPROACHES

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We present experimental results on pressures and resistivites of expanded metals such as nickel and titanium at low densities (0.1 g/cm3 and 0.5 g/cm3) and in a range of temperature of 1-3 eV) that corresponds to the warm dense matter (WDM) regime. These data are used to benchmark different theoretical approaches. A comparison is presented between fully 3-dimensional quantum molecular dynamics (QMD) methods, based on density functional theory, with average atom (AA) methods, that are essentially one dimensional.

AA methods are used to identify interband transitions and photoionization thresholds as shown in Fig. 1. In this regime the evaluation of the thermodynamic properties as well as electrical properties is difficult due to the concurrence of density and thermal effects which directly drive the metal-non-metal transition. QMD simulations are also helpful to give a precise estimation of the temperature of experiments which is not directly accessible.[1].

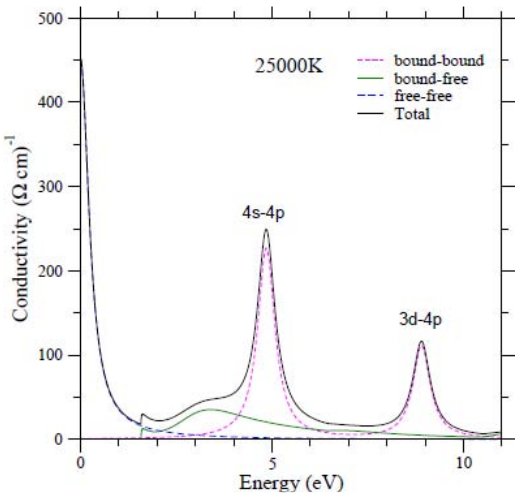

Figure 1: Optical conductivity of expanded nickel at 0.1 g/cc and 25000K computed with the average atom code SQAA.

[1] J. Clérouin, C. Starrett et al., Pressure and electrical resistivity measurements on hot expanded nickel: Comparisons with quantum molecular dynamics simulations and average atom approaches, Phys. Rev. E. 82, 046402 (2010).

SPIN-POLARIZED SYMMETRIC ELECTRON-HOLE QUANTUM BILAYERS SYSTEM: FINITE WIDTH EFFECT

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In this paper, we investigate the effect of finite width on ground-state properties of a spin-polarized symmetric electron-hole quantum bilayers (EHBL) system at zero temperature. We adopt the quantum self-consistent mean-field approximation of Singwi, Tosi, Land and Sjölander (qSTLS) to explore intra- and interlayer properties such as the pair-correlation function, the static density susceptibility, the local-field corrections and the ground-state energy. Interestingly, we noticed that due to the inclusion of finite width, the critical density for the onset of Wigner crystal (WC) phase is now lowered as compared to the recent spin-polarized EHBL system [1] without finite width and unpolarized EHBL system [2] with finite width. Further, spin-polarization effect is seen to introduce a marked change in the ground-state energy of EHBL system as compared to that of unpolarized system. Results of ground-state energy are also compared with the recent EHBL system [1, 3] without finite width.

[1] L. K. Saini, J. Low Temp. Phys. 158, 515-522 (2010)
[2] R. K. Moudgil, J. Phys. Condens. Matter 18, 1285-1301 (2006)
[3] R. K. Moudgil, G. Senatore, L.K. Saini, Phys. Rev. B 66, 205316-1-205316-10 (2002)

PLASMA POLARIZATION AROUND DUST PARTICLE IN AN EXTERNAL ELECTRIC FIELD

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There are a lot of works devoted to the description of plasma distribution around a single dust particle [1-5]. Dust particles immersed in a low-density plasma of a glow DC or RF discharge acquire a large negative charge, $Q_d = Z_d e_0 \sim 10^3$-$10^4 e_0$. A cloud of trapped ions with total number $N_{tr} \sim 0.5 Z_d$ can be formed around a dust particle [1,5]. All these models were made for the case of the absence of an external electric field. However, laboratory dusty plasma often exists in an external electric field, i.e., in cathode layers, striations in a DC glow discharge, etc. In the external electric field, the system of the negatively charged dust particle and the cloud of positive ions can be polarized, and the system acquires a dipole moment. In paper [5], it was shown that for a low-collision case the coefficient of polarizability of the dust particle – a cloud of trapped ions depends non-monotonously on the strength of the external electric field.

However, the external electric field breaks the spherical symmetry of plasma distribution around the dust particle and sufficiently complicates the semi-analytical approximations such as in [1,3,5]. In this paper, plasma polarization around a dust particle is studied by Monte Carlo simulation. Ion trajectories are calculated with the help of Newton motion equations with high precision. The cross section of charge exchange collisions of ions with neutral atoms was assumed to be independent of the ion energy. The ions free path lengths and new ions velocities after collisions with neutral atoms are simulated by Monte Carlo method. The times those ions spend passing through spatial cells around the dust particle are recalculated into ion density via normalization to the value of ion density in ambient plasma. The equilibrium dust particle charge was obtained from the equality of ion current (Monte Carlo calculations) and electron current (Boltzmann equation for EEDF) to the dust particle surface. It was assumed that the charge of the dust particle is equal to the total volume charge of the surrounding plasma in rather large volume.

Calculations were carried out for a wide range of mean free paths, ion Debye lengths, radii of dust particles, and values of the external electric field. It is shown that without the external electric field ion radial distributions agree with the results obtained in [1,2,4,5]. The external electric field leads to the disturbance of a spherical symmetry of plasma parameters around the dust particle. The density of ions, $n_i(\vec{r})$, becomes anisotropic, which leads to the formation of a dipole moment in the system of the dust particle and ion cloud. The dipole moment is equal to $P_z(E_z^0) = e\int d\vec{r}' z(n_i(\vec{r}') - n_e(\vec{r}'))$.

It is shown that not only trapped ions but also the redistribution of free ions in the external electric field influences the process of plasma polarisation around the dust particle. This dynamical process leads to a linear dependence of polarization on the external electric field in contrast to the non-monotonous dependence of polarization obtained for trapped ions only [5].

[1] M. Lampe et al., Phys. Plasmas 10, 1500–1513 (2003)
[2] A. V. Zobnin et al., Physics of Plasmas 15, 043705 (2008)
[3] D.Tskhakaya, P. Shukla. JETP 98, 53-61 (2004)
[4] I. H. Hutchinson and L. Patacchini, Physics of Plasmas 14, 013505 (2007)
[5] G. I. Sukhinin and A. V. Fedoseev, IEEE Trans. Plasma Sci. 38, 2345 – 2352 (2010)

EXTENT OF VALIDITY OF THE HYDRODYNAMIC DESCRIPTION OF THE ONE-COMPONENT PLASMA

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We have performed highly accurate large-scale Molecular Dynamics simulations for the equilibrium dynamics of a single component fluid with Yukawa interaction potential $v(r) = q^2 \exp(-r/\lambda_s)/r$. We use our numerical results to investigate the domain of validity of the hydrodynamic description, and determine how this depends on the coupling parameter Γ and screening parameter $\kappa = a/\lambda_s$ (a is the mean interparticle distance) that characterise the system. We find, remarkably, that the screening parameter completely determines the maximum wavenumber k_{max} at which the hydrodynamic description is applicable by $k_{max}\lambda_s \simeq 0.43$ (see Fig. 1). In the extreme case of the Coulomb interaction potential ($\lambda_s = \infty$, $\kappa = 0$), the very existence of a hydrodynamic description is a known but unsolved problem [1]. For this important special case, we show that the ordinary hydrodynamic description is never valid. Finally we investigate the system dynamics at wavevectors beyond the validity of conventional hydrodynamics (larger than k_{max}); we show that these are in striking agreement with a simple generalisation of the Navier-Stokes equations (see Fig. 2). Our results have significant applicability for both analyzing and interpreting the results of x-ray scattering experiments on dense plasmas.

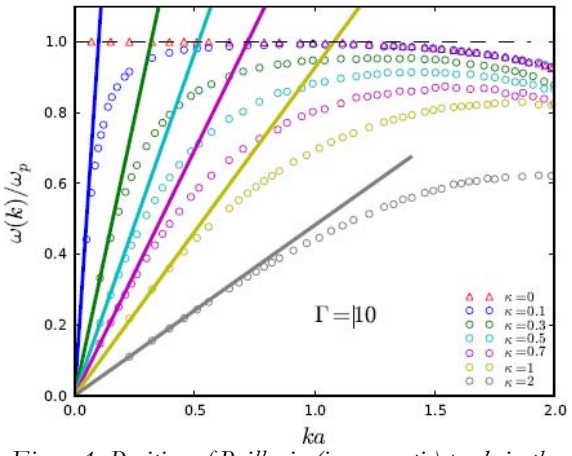

Figure 1: Position of Brillouin (ion-acoustic) peak in the dynamical structure factor as obtained from Molecular Dynamics simulations (open symbols) for potentials of various range and the linear predictions $\omega = c_s k$ (c_s is the sound speed) of the hydrodynamic description (solid lines).

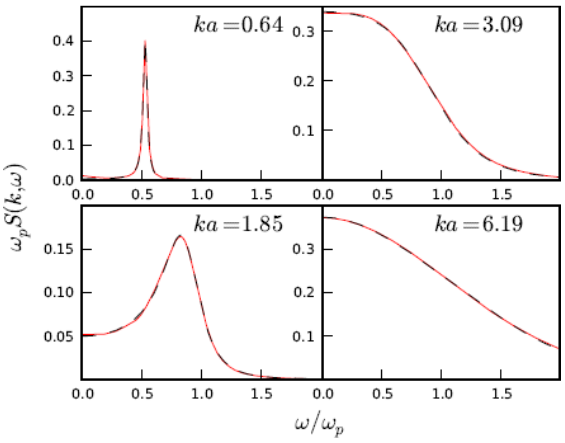

Figure 2: A simple generalisation of the Navier-Stokes equations (dashed line) yields excellent agreement with the Molecular Dynamics results for the dynamical structure factor $S(k, \omega)$ (solid red line - $\Gamma = 10$, $\kappa = 1$) for all reduced wavevectors ka. Here ω_p is the plasma frequency of the system.

[1] M. Baus and J.P. Hansen, Phys. Rep. 59, 1 (1980), in particular section 4.4.
[2] J.P. Mithen, J. Daligault and G. Gregori, Phys. Rev. E 83, 015401(R) (2011);
J.P. Mithen, J.Daligault and G. Gregori, arXiv:1008.1969

CRITICAL BEHAVIOR IN SOLUTIONS OF IONIC LIQUIDS

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The critical properties of phase transitions of fluids and fluid mixtures are known to agree with that of the 3D-Ising model because short-range r^{-6} interactions drive the phase transition. Because of the long- range nature of the Coulomb forces it was suspected that the universal validity of the 3D-Ising model may not apply for phase transitions of ionic systems; mean-field critical behavior was reported for the liquid-liquid phase transition discovered by Pitzer in the ionic solution of $N_{2226}B_{2226}$ (n-hexyl-triethylammonium n-hexyl-triethylborate) in biphenyl ether. However, later work [1] could not reproduce those results. Ising behavior was found instead. The investigations suggested experimental short comings in the earlier work [2].

However, it is very hard to draw firm conclusions from the work on Pitzer´s system because of the chemical instability of the salt. Thus experiments with solutions of new developed low-melting salts termed Ionic Liquids have been performed. These compounds are rather stable and in great variability in good quality commercially available. Some are hydrophobic and soluble in non-polar solvents like hydrocarbons, while others mix with water.

We discuss measurements of the viscosity, of the coexistence curve and the static and dynamic light scattering on solutions of various ionic liquids in different solvents involving non-polar hydrocarbons, simple polar liquids, water and alcohols. The critical data are compared with the simulation results of the model system charged hard spheres in a dielectric continuum [3].

The experiments reveal Ising criticality in all cases and all properties. All measurements indicate crossover to mean-field criticality described by the crossover theory, where the solution in water shows inhomogeneous crossover. The asymmetry of the coexistence curves, which for ionic solutions is much larger than that of non-ionic systems, is analysed applying the complete scaling approach.

[1] S.Wiegand, M.E. Briggs J.M.H. Levelt Sengers, M. Kleemeier, W.Schröer J. Chem. Phys. 109 9038-9051 (1998)
[2] W. Schröer, M. Wagner, O. Stanga, J. Mol.Liquids 127 2-9 (2006)
[3] W. Schröer, V.R.Vale VR J. Phys-Cond. Matter 21 424119 (2009)

MATTER UNDER EXTREME CONDITIONS AND THE INTERIOR OF SOLAR AND EXTRASOLAR GIANT PLANETS

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The behavior of warm dense matter (pressures of several megabar and temperatures of several eV) is of paramount importance for interior models of giant planets such as Jupiter and Saturn. Coulomb systems under those conditions are strongly correlated and quantum effects are important so that they can be used to check methods of manyparticle theory. Challenging problems in warm dense matter physics are, e.g., the highpressure phase diagram of the simplest and most abundant elements hydrogen and helium. Furthermore, novel phenomena such as proton conduction and demixing are expected in oxygen, carbon, nitrogen, their hydrides and mixtures at high pressures which are relevant for, e.g., Uranus and Neptune. Therefore, solar and extrasolar giant planets are perfect laboratories for the study of warm dense matter.

We apply ab initio molecular dynamics simulations based on finite-temperature density functional theory to calculate the thermophysical properties of H, He, their mixtures and of H_2O for a wide range of densities and temperatures. For instance, equation of state data for hydrogen indicate a first-order liquid-liquid phase transition which is closely connected with a nonmetal-to-metal transition [1,2]. Our results yield a critical point at 1400 K, 1.32 Mbar and 0.79 g/cm^3 [2] – i.e. at much lower temperatures than chemical models have predicted for the plasma phase transition. The behavior of the electrical and thermal conductivity, thermopower, and Lorenz number is analyzed along this transition, especially deviations from the Wiedemann-Franz relation [3]. We have identified the parameters for demixing of helium from hydrogen [4,5] which match the conditions in the interior of Saturn as long has been predicted. The high-pressure phase diagram of water has been calculated including the location of a superionic phase [6].

We have determined the interior structure and composition of Jupiter and Saturn based on this ab initio equation of state data within three-layer models [7,8]. We give results for the metallicity, the size of the core, and the cooling time. Corresponding interior models for Uranus and Neptune are in striking agreement with assumptions of dynamo simulations [9] that reproduce their unusual magnetic field structure [10]. Predictions for possible interior structures of extrasolar giant planets can be given as well, see e.g. [11].

[1] M.A. Morales et al., Proc. Nat. Acad. Sci. 107, 12799 (2010).
[2] W. Lorenzen, B. Holst, R. Redmer, Phys. Rev. B 82, 195107 (2010).
[3] B. Holst, M. French, R. Redmer, Phys. Rev. B (in print).
[4] W. Lorenzen, B. Holst, R. Redmer, Phys. Rev. Lett. 102, 115701 (2009).
[5] M.A. Morales et al., Proc. Nat. Acad. Sci. 106, 1324 (2009).
[6] M. French et al., Phys. Rev. B 79, 054107 (2009), ibid. 82, 174108 (2010).
[7] N. Nettelmann et al., Astrophys. J. 683, 1217 (2008).
[8] J.J. Fortney, N. Nettelmann, Space Sci. Rev. 152, 423 (2010).
[9] R. Redmer et al., Icarus 211, 798 (2011).
[10] S. Stanley and J. Bloxham, Nature 428, 151 (2004).
[11] N. Nettelmann et al., Astron. & Astrophys. 523, A26 (2010).

CRYSTALLIZATION OF HIGHLY CHARGED COLLOIDS UNDER STRONG CONFINEMENT

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It is well known from solid state studies that strongly confined (i.e., quasi two-dimensional or even one-dimensional) systems exhibit properties and a phase behavior that may drastically differ from those in the bulk Such features are also vivid in colloidal systems, and those materials represent ideal model systems to analyze (experimentally as well as theoretically) and understand confinement effects on a mesoscopic scale corresponding to the interparticle distance.

Strongly charged colloidal particles freeze into a periodic crystalline lattice and a high confinement leads to a very rich and fascinating crystal phase diagram [1, 2]. In this lecture, we shall summarize recent progress achieved in the understanding of freezing of (i) charged suspensions confined in a thin tube [3] and of (ii) two-dimensional ionic mixtures [4].

Using lattice sum minimization, the ground state of particles interacting via a Yukawa potential which are confined in a quasi-one-dimensional cylindrical tube is investigated [3]. Upon varying the screening strength and/or the particle density, the zero-temperature phase diagram exhibits a cascade of stable crystals with both helical and non-helical structures.

These quasi one-dimensional crystals can be confirmed in experiments on confined charged colloidal suspensions, trapped dusty plasmas or ions in nanotubes.

If the time allowed permits, results concerning the crystallization of ionic mixtures in two-dimensions will be presented as well [4]. Crystal structures are predicted for oppositely charged spheres. Upon varying the size ratio, the stable two-dimensional crystalline lattices consist of square, triangular and rhombic crystals as well as a dipolar pair gas and a gas of one-dimensional crystalline chains. Thereby, we confirm the square structure, found experimentally on charged granulates, and predict new phases detectable in experiments on granular and colloidal matter.

[1] R. Messina, J. Phys.: Condens. Matter 21, 113102 (2009).
[2] H. Löwen, L. Assoud, E. C. Oguz and R. Messina, Adv. Chem. Phys. (topical review to be published).
[3] E. C. Oguz, R. Messina and H. Löwen, Europhys. Lett. (in press).
[4] L. Assoud, R. Messina and H. Löwen, Europhys. Lett. 89, 36001 (2010).

MANY-BODY CORRELATIONS AND ELECTROSTATIC INTERACTIONS IN ELECTROLYTE SYSTEMS

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The proper inclusion of many-body correlation effects in the electrostatic interactions between particles in electrolyte solutions has been analyzed with statistical mechanical methods. The outcome is in some cases qualitatively similar to that predicted by simple mean field theories (but with renormalized interaction parameters). In other cases the results are quite different. Properties of the nonelectrostatic part of the interparticle interactions can in some cases make a difference for the qualitative behaviour of the electrostatic interactions. Some conceptual issues are raised for the description of the interactions in electrolyte systems.

WIDTH SPREADING AND TESTS OF WAVE PACKET MOLECULAR DYNAMICS

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We examine three aspects of wave packet molecular dynamics (WPMD): wave packet spreading, the versatility of the isotropic Gaussian basis, and the interpretation of WPMD data. It is commonly known in the WPMD community that at large temperatures isotropic Gaussian wave packets have divergent widths. We quantify the unphysicality of this behavior by calculating radial distribution functions at many temperatures and densities, and compare to quantum statistical potential and path integral Monte Carlo results. We also make direct comparisons with a numerically exact time-dependent Schrödinger equation solver to determine deficiencies in the basis by studying a single quantum electron traveling through a static classical dense plasma. Another aspect is the validity of standard calculation methods. Central to these quantum computations are the ensemble explored by WPMD and its ergodic properties.

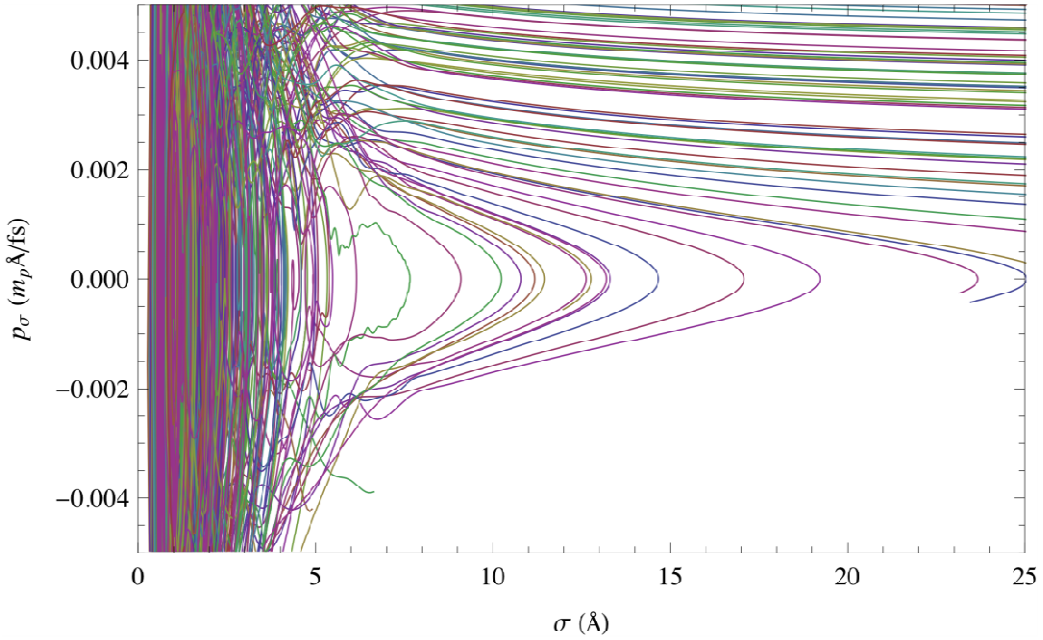

Figure 1: Generalized phase space of the wave packet widths and their conjugate momenta of a WPMD simulation at T = 46 eV and n = 10^{24} cm^{-3} during 17 fs of a 1000 particle simulation.

THE ATTOSECOND FACILITY OF THE EXTREME LIGHT INFRASTRUCTURE IN HUNGARY

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The Extreme Light Infrastructure (ELI) project is a joint European effort to form an integrated laser infrastructure comprised of three sites. The ELI Beamlines Facility (Czech Republic) will mainly focus on particle acceleration and X-ray generation, while the ELI Nuclear Physics Facility (Romania) will be dealing with laser-based nuclear physics and high-field physics [1]. Here, we report on the ELI Attosecond Light Pulse Source (ALPS) to be built in the city of Szeged, Hungary.

The frontiers of modern photonics are defined by the characteristics of available photon sources. Synchrotrons and X-ray free electron lasers offer Ångström wavelengths combined with high flux and brilliance, providing unique opportunities to explore the structure of matter with sub-atomic resolution. Laser-driven high harmonic sources, on the other hand, deliver flashes of extreme ultraviolet and soft X-ray light with durations below 100 asec, allowing direct time-domain insight into both structural and electronic motion, i.e. any dynamics taking place outside the atomic core [2]. ELI-ALPS will combine these characteristics of modern photon sources: the short-wavelength and high flux of third-generation synchrotron sources with the incomparable pulse duration of laser-driven harmonic sources. Thus, ALPS' energetic attosecond X-ray pulses will enable recording freeze-frame images of the dynamical electronic-structural behaviour of complex atomic, molecular and condensed matter systems, with attosecond-picometer resolution. In addition, these attosecond XUV/X-ray pulses will come in synchronism with waveform-controlled light pulses all the way from THz (far infrared) to PHz (ultraviolet) frequencies.

The main technological backbone of ELI-ALPS will be optical parametric chirped-pulse amplification (OPCPA). Pumped by dedicated all-solid-state short-pulse lasers and their (low-order) harmonics, this approach will be competitive with conventional (Ti:sapphire-laser-based) femtosecond technology. The laser architecture will consist of 3 main pillars, operating at different regimes of pulse repetition rates and peak powers: WB (wide-band): 10-100 kHz / 3-10 TW / 1.5-3 fs, SYLOS (single-cycle OPCPA system): 1kHz / >100TW / 3-5 fs, HF (high-field): 1-10Hz / 1-3PW / 3-5 fs. All 3 pillars will deliver pulses with unique parameters: unparalleled fluxes, bandwidths spanning octaves (by use of multi-channel amplification technology) and sub-cycle control of the generated fields. This will give way to a set of secondary sources with gas and solid-based high harmonic generation (HHG) being the two most important of them. The lasers will drive both user HHG and source development HHG units. With the unparalleled HHG photon flux offered by these schemes, several experimental applications will become within reach. The main application areas are attosecond valence and core electron science, sub-atomic 4D imaging (by combining attosecond and diffraction techniques), attosecond high-field science and laser plasma investigations as well as biomedical and industrial applications.

[1] G. A. Mourou, G. Korn, W. Sandner, J. L. Collier (Eds.), ELI – Extreme Light Infrastructure. Science and Technology with Ultra-Intense Lasers. Whitebook (THOSS Media GmbH, Berlin, Germany, 2011).

[2] F. Krausz and M. Ivanov, "Attosecond physics," Rev. Mod. Phys. 81, 163-234 (2009) and references therein.

UNIVERSAL PROPERTIES OF A STRONGLY INTERACTING FERMI GAS

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Universality is a remarkable property of strongly interacting systems of fermions. For sufficiently strong interactions, all dilute Fermi systems behave identically on a scale given by the average particle separation. With the discovery of universality in the Bose- Einstein condensate to Bardeen-Cooper-Schrieffer superfluid crossover, ultracold Fermi gases near Feshbach resonances have become a central topic in atomic physics. As a step towards a universal, scale-invariant state equation, we derive a virile expansion at high temperature based on exact solutions of few-body clusters. Together with experimental measurements, this is used to validate different types of analytic T-matrix theories of strongly-interacting Fermi gases

We also derive and experimentally verify a new exact property of universal Fermi gases. The static structure factor S(q), given by the Fourier transform of the density-density correlation function, displays a universal scaling proportional to the inverse of the momentum (1/q) at short-range (high q). We derive this result from Tan's relations - a set of exact results linking bulk thermodynamic properties to a single short-range coefficient known as the contact. Our prediction is experimentally verified using Bragg scattering of ultracold ^{6}Li atoms from a periodic optical potential, providing a new measure of Tan's contact and confirmation of this universal relation. We apply the f-sum rule to normalise our measured Bragg spectra which greatly improves the accuracy of the structure factor measurement. We also use Bragg spectroscopy to measure the temperature dependence of the contact at unitarity, over the temperature range. At high temperatures our results are compared to calculations based on the virial expansion.

SUPERFLUIDITY AND EXCITATION SPECTRUM IN 2D DIPOLE SYSTEMS

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We explore quantum coherent phenomena and phase transitions in 2D bosonic dipole systems. Relevant physical systems are ultra-cold dipolar atomic gases and polar molecules in strongly anisotropic (in one direction) traps, composite Coulomb systems, i.e. indirect excitons in semiconductor quantum wells [1, 2].

For quantitative analysis we perform the path integral Monte Carlo simulations and study the superfluid-normal fluid phase transition (Berezinskii-Kosterlitz-Thouless type). We observe a non-monotonic shape of the phase boundary (see Fig.1) with the maximum in the critical temperature T_c at the dipole coupling $D \approx 1$ ($D = p^2/a^3E_0$; $E_0 = \hbar^2/ma^2$), which is correlated with the formation in the excitation spectrum of the roton minimum, i.e. with the onset of the strong inter-particle correlations. We also obtain information about the equation of state, the momentum distribution and the isothermal compressibility.

The excitation spectrum, $\omega(q)$, of the longitudinal density oscillations is evaluated and analyzed in several approximations: classical QLCA, the Lindhard function (RPA), the sum-rules for the dynamical structure factor, the analytical continuation of the imaginary time density-density correlation function. The observed changes in the excitation spectra near the critical temperature (see Fig. 2) of the superfluid transition are discussed in terms of the quasiparticle and collective excitations.

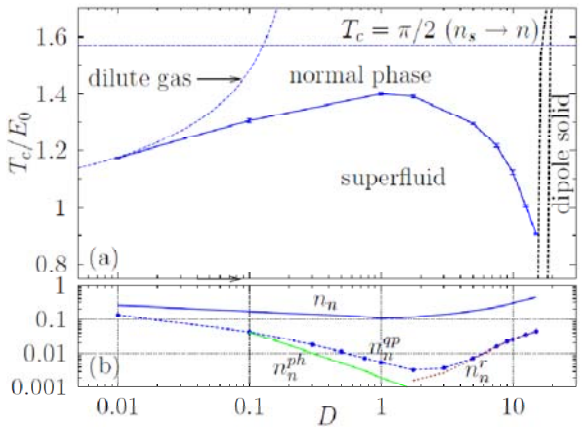

Figure 1: (a) Phase diagram in the plane temperature-dipole coupling parameter D [3]. (b) D-dependence of the normal density (PIMC result), the quasiparticle contribution n_n^{qp}, and the phonon (roton) contribution, n_n^{ph} (n_n^r).

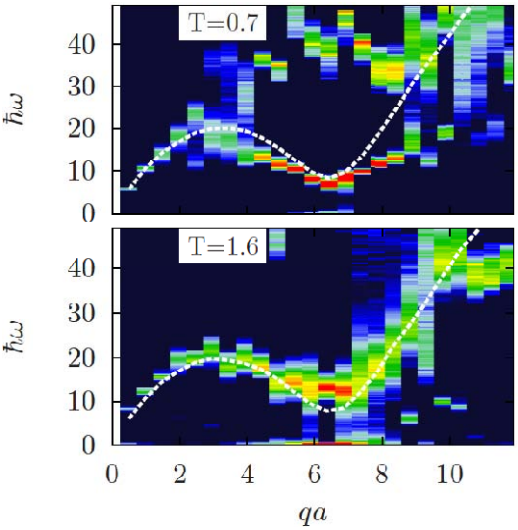

Figure 2: Dispersion relation $\hbar\,\omega\,(q)$ for temperatures below and above the BKT transition temperature $T_c = 1{:}2$ ($D = 7{:}5$). Reconstruction of the spectrum from the density-density correlation function. The dotted line is the upper bound for the spectrum assuming a single-quasiparticle mode.

[1] J. Böning, A. Filinov, and M. Bonitz, submitted for publication, arxiV: 1101.1757
[2] J. Böning, A. Filinov, and M. Bonitz, poster at SCCS 2011
[3] A. Filinov, N. Prokofev, and M. Bonitz, Phys. Rev. Lett. 105, 070401 (2010)

APPLICATION OF THE WAVE PACKET MOLECULAR DYNAMICS TO SIMULATION OF NONIDEAL PLASMAS AT MODERATE TEMPERATURES

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Atomistic simulation of matter at extreme conditions allows one to study equilibrium systems and relaxation processes at the microscopic level. The method of classical molecular dynamics is successfully applied to study nonideal (strongly coupled) plasmas at moderate densities (about 10^{21}cm^{-3} for H plasma) and relatively high temperatures (over 10^4K) [1, 2, 3, 4]. At lower temperatures and/or higher densities the use of the electron-ion and electron-electron pseudopotentials introduces considerable ambiguity in the plasma thermodynamics and relaxation rates.

Quantum methods such as DFT, applied to plasma simulations, are much more computationally demanding than the classical MD. Moreover, these methods are mostly not capable to handle the dynamics of electrons. Wave packet molecular dynamics method (WPMD) is the approach introducing quantum features in the classical electron dynamics.

The electron-ion interaction model resulting from WPMD may be regarded as a kind of ab-initio pseudopotential, free from empirical parameters.

The area of very high plasma densities (about 10^{23}cm^{-3} for H plasma) and low temperatures (less than 10^4K) is well described by the WPMD methods [5, 6] including the version with fully antisymmertized wave functions for electrons with the same spin [7].

These methods, however, are not directly applicable to higher temperatures due to the model breakdown caused by spreading of the wave packets for weakly bound electrons [8].

In this report we introduce an approach to simultaneous description of non-localized and bound electrons within the WPMD method. This approach is based on the numerical separation of the elastically and non-elastically colliding particles in course of the simulation. The elastic collisions are treated by the classical Coulomb model, whereas for non-elastic processes a version of the WPMD algorithm is applied. Application of the model to the case of hydrogen plasma is considered. Our approach allows one to consistently describe various bound states (at the accuracy level of a single Gaussian per electron) and the ionization balance within the plasma. A comparison of the results to other theoretical and experimental data is discussed.

[1] I.V. Morozov, G.E. Norman, JETP, 100, 370 (2005).
[2] T. Pschiwul, G. Zwicknagel, J. Phys. A, 36, 6251 (2003).
[3] L.X. Benedict, J.N. Glosli, D.F. Richards, F.H. Streitz, P. Hau-Riege, R.A. London, F.R. Graziani, M.S. Murillo, J.F. Benage, Phys. Rev. Lett. 102, 205004 (2009).
[4] Z. Donkó, J. Phys. A, 42, 214029 (2009).
[5] D. Klakow, C. Toepffer, P.-G. Reinhard, J. Chem. Phys., 101, 10766 (1994).
[6] J.T. Su, W.A. Goddard III, Phys. Rev. Lett., 99, 185003 (2007).
[7] B. Jakob, P.-G. Reinhard, C. Toepffer, G. Zwicknagel, J. Phys. A, 42, 214055 (2009).
[8] I.V. Morozov, I.A. Valuev, J. Phys. A, 42, 214044 (2009).

EFFECTIVE POTENTIALS AND SOME PHYSICAL PROPERTIES OF A STRONGLY COUPLED COMPLEX PLASMAS

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In this paper the interactions between macroparticles in complex plasmas are considered. To take into account screening effects in the interparticle interaction we use the method of dielectric response functions. According to this method the Fourier transform of the effective potential is defined by the dielectric response function and the Fourier transform of micropotential. The formalism of dielectric response function has been applied for determination of interaction potentials between particles in strongly coupled complex plasma (dusty and partially ionized plasma) [1,2]. The grains are considered as dipoles due to the nonequilibrium effects in dusty plasma. As a result, the dipole-dipole effective interaction potentials are obtained for several cases. Interaction between dust particles in a plasma is also investigated on the basis of experimental pair correlation functions of dust formation in a dc glow discharge and the Poisson equation [3].

The analytical expression for effective potential of dense semiclasssical plasma was derived on the basis of the Slater sum and the Boltzmann factor. The diffraction effect due to the uncertainty principle and the coupling between symmetry and diffraction effects in degenerate two-component plasma were taken into account.

The contributions of electron-atom interaction to the equation of state for partially ionized hydrogen plasma are studied using the cluster-virial expansion and the different pseudopotentials [4].

On the basis of the above mentioned effective potentials the thermodynamic and kinetic properties of a complex plasma were studied. The comparisons with theoretical and experimental data of another authors are made.

[1] T.S.Ramazanov, K.N.Dzhumagulova, Yu.A Omarbakiyeva, Phys. Plasmas, 12, 092702 (2005)
[2] T.S.Ramazanov, K.N.Dzhumagulova, M.T.Gabdullin, Phys. Plasmas, 17, 042703 (2010)
[3] T.S.Ramazanov e.a., J. Plasma Physics, 76, 57 (2010)
[4] Y.A.Omarbakiyeva, C.Fortmann, T.S.Ramazanov, G.Roepke, Phys.Rev.E, 82, 026407 (2010)

CLASSICAL REPRESENTATION OF A QUANTUM SYSTEM AT EQUILIBRIUM

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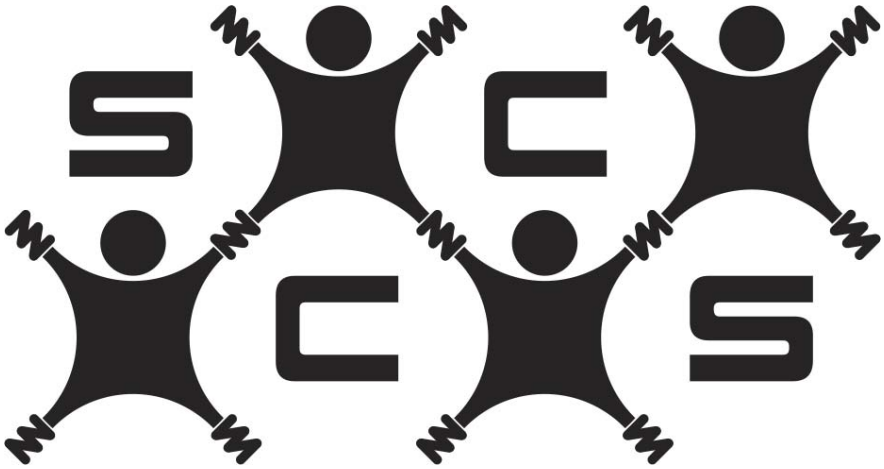
A quantum system at equilibrium is represented by a corresponding classical system, chosen to reproduce the thermodynamic and structural properties. The objective is to develop a means for exploiting strong coupling classical methods (e.g., MD, integral equations, DFT) to describe quantum systems. The classical system has an effective temperature, local chemical potential, and pair interaction that are defined by requiring equivalence of the grand potential and its functional derivatives with respect to the external and pair potentials for the classical and quantum systems. Practical inversion of this mapping for the classical properties is effected via the hypernetted chain approximation, leading to representations as functionals of the quantum pair correlation function (similar in spirit to the approach of Dharma-wardana and Perrot [1]). The parameters of the classical system are determined such that ideal gas, weak coupling RPA, and strong coupling pair limits are preserved. The potential advantages of this approach are discussed. Research supported by NSF/DOE Partnership in Basic Plasma Science Award DE-FG02-07ER54946, and by US DOE Grant DE-SC0002139.

[1] M. W. C. Dharma-wardana and F. Perrot, Phys. Rev. Lett. 84, 959 (2000).



POSTER SESSION

"A"

PA-01
CONTROL OF IONIZATION IN THE INTERACTION OF STRONG LASER FIELDS WITH DENSE SILVER NANOPLASMAS

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There are impressive developments in laser technology that make short-pulse lasers of high intensity available in the laboratory. Such experiments allow for the creation and diagnostics of dense plasmas relevant for astrophysics and inertial confinement fusion research.

Of special interest is the interaction of intense laser radiation with clusters. An important reason is that clusters present the advantage of high energy absorption leading to the creation of a high-density nanoplasma. Consequently, in laser-cluster experiments the emission of highly charged ions, very energetic electrons, higher-order harmonics and strong x-ray emission are observed. To have an adequate description of the different processes of laser-cluster interaction, theoretical investigations are of increasing importance.

Our theoretical investigations are motivated by recent laser experiments where pulse shaping is applied to affect specifically the dynamics of the system [1]. In particular, optimized pulses were found, which produce a maximum yield of highly charged ion species. For an understanding of the underlying physical processes in the corresponding dynamics of laser-cluster interaction, a theoretical description is required. For this purpose, we performed extensive numerical calculations using a genetic algorithm based on the nanoplasma model. With this model, the description of the different processes like ionization, heating, and expansion in the dynamics of laser-cluster interaction is possible using a coupled set of hydrodynamic and rate equations. We used a modified model accounting for quantum and correlation effects in the absorption and electron impact ionization rates [2].

In this contribution, recent results are presented concerning the control of the yield of highly charged ions in silver nanoplasmas irradiated by intense femtosecond laser pulses. A comparison is given with experimental investigations [1].

The work was supported by the Deutsche Forschungsgemeinschaft, SFB 652.

[1] N.X. Truong, P. Hilse, S. Göde, A. Przystawik, T. Döppner, Th. Fennel, Th. Bornath, J. Tiggesbäumker, M. Schlanges, G. Gerber, K.H. Meiwes-Broer, Phys. Rev. A81, 013201 (2010).
[2] P. Hilse, M. Moll, M. Schlanges, Th. Bornath, Laser Physics 19, 1 (2009).

PA-02
PHASE TRANSITIONS IN HYDROGEN AT MEGABAR PRESSURES

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The description of the state of hydrogen at megabar pressures is one of the unsolved problems in condensed matter physics, astrophysics, and an important issue in the physics of matter at extreme conditions. At low temperatures and pressures the hydrogen is either a molecular solid state or in a fluid phase. When external pressure is applied, it destabilizes molecular bounds in hydrogen and drives the system into a more disordered state with itinerant electrons. The new state, a disordered state with itinerate electrons is energetically favourable with lower free energy. The main reason for the transition is the reduction in the kinetic energy of electrons as a result of this delocalization from bound states to itinerant states in a denser phase.

Measurements of melting temperature at extremely high pressures (~ 300-400 GPa) obtained in diamond anvil cells [1], and discovery of dissociation in dense molecular gases under shock-wave action [2] will show a possible new picture to hydrogen phase state. Below 100 GPa a melting temperature is monotonically increasing with pressure. However, above 100 GPa the melting temperature reached a peak and began to decrease. Extrapolation of this line to even higher pressures and lower temperatures implies that at a pressure greater than 400 GPa hydrogen might be a liquid at T = 0 K. The presence of the noticeable dissociation under pressures 30-150 GPa and temperatures about (5–8) кK does not describe by ordinary thermal mechanism, because the molecular dissociation energies (5-7 eV) are large in comparison with temperature. The Wigner – Seitz cell model is used for description of these melting and dissociation peculiarities. Each ion is localized in such cell (its charge is completely screened) and surrounded by a cloud of quasi-localized and quasi-free electrons. The full electron energy together with contribution of degenerate protons is found for the calculation of the melting curve. The interaction between free atoms in dissociated atomic-molecular mixture is due to collective quantum cohesive energy, much as the bound energy of atom in liquid alkaline metals.

On the base of this model a domain of the transition in dissociated state was found and calculated the melting curve along which temperature decreases with pressure grows. The transition in the dissociated state is the first order phase transition – molecular fluid turns into atomic liquid with the critical temperature ~10 kK and density jump ~(0.7 –) g/cc for hydrogen at temperature 4kK. The obtained results are compared with data of physical and numerical experiments.

[1] P. Loubeyre, F. Oceeelll, and R. LEToullec, Nature 416, 613 (2002)
[2] W. Nellis, PRL 89,165502-1 (2002)

PA-03
QUANTUM MONTE CARLO SIMULATIONS OF STRONGLY COUPLED QUARK-GLUON PLASMA

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In recent years, there has been an increasing interest in dynamics and thermodynamics of non-Abelian plasmas at both very high temperature and density. It is expected that a specific state of matter with unconfined quarks and gluons - the so called quark - gluon plasma (QGP) - can exist. The most fundamental way to compute properties of the strongly interacting matter is provided by the lattice QCD. Interpretation of these very complicated computations requires application of various QCD motivated, albeit schematic, models simulating various aspects of the full theory. Moreover, such models are needed in cases when the lattice QCD fails, e.g. at large baryon chemical potentials and out of equilibrium. A semi-classical approximation, based on a point like quasi-particle picture has been recently introduced in literature. It is expected that it allows to treat soft processes in the QGP which are not accessible by the perturbative means and the main features of non-Abelian plasmas can be understood in simple semi-classical terms without the difficulties inherent to a full quantum field theoretical analysis.

Here we propose stochastic simulation of thermodynamics and kinetic properties for QGP in semi-classical approximation in the wide region of temperature, density and quasi-particles masses. We extend previous classical nonrelativistic simulations based on a color Coulomb interaction to the quantum regime and take into account the Fermi (Bose) statistics of quarks (gluons) and quantum degeneracy self-consistently.

In grand canonical ensemble for finite and zero baryon chemical potential we use the direct quantum path integral Monte Carlo method (PIMC) developed for finite temperature within Feynman formulation of quantum mechanics to do calculations of internal energy, pressure and pair correlation functions. The QGP quasi-particles representing dressed quarks, antiquarks and gluons interact via color quantum Kelbg pseudopotential rigorously derived in for Coulomb particles. This method has been successfully applied to strongly coupled electrodynamic plasmas (EMP) . A strongly correlated behavior of the QGP is expected to show up in long-ranged spatial correlations of quarks and gluons which, in fact, may give rise to liquid-like and, possibly, solid-like structures. This expectation is based on a very similar behavior observed in electrodynamic plasmas.

We have done already the first calculation of the QGP equation of state, spatial and color pair distribution functions, diffusion coefficients and shear viscosity.

PA-04
PROTON CRYSTALLIZATION IN A DENSE HYDROGEN PLASMA

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In a recent letter [1] we have predicted that in a dense hydrogen plasma at sufficiently low temperatures and high densities protons would spontaneously order into a lattice which is embedded into a highly degenerate electron gas. There the conditions for the stability of such an ion crystal in a neutral two-component plasma were derived. In particular, we found that there exists a minimal mass ratio of the heavy and light charges of about 80. Thus the effect should also be observable in various semiconductor materials [2].

Here we concentrate on the phase diagram of the proton crystal for which only a rough estimate of the phase diagram is known [1]. We present extensive new simulation results which allow to predict the temperature and density range for proton crystallization in dense laboratory experiments. We simulate a macroscopic spatially homogeneous fully ionized two-component electron-proton plasma in thermodynamic equilibrium from first principles using direct fermionic PIMC simulations, for an overview, see [3]. Our results for the phase diagram differ substantially from the previous predictions based on the one-component plasma (OCP) model: In the classical part of the phase diagram the crystal appears to be stabilized compared to the OCP predition. In contrast, in the quantum part of the phase diagram the crystal appears to be de-stabilized and vanishes at lower densities compared to the OCP prediction. Finally, the maximum temperature for the proton crystal is found to be around 40 000K, slightly below the previous prediction [1].

Our results indicate that the OCP treatment of the liquid-solid transition in a two-component plasma has to be questioned. The OCP-assumption of a homogeneous rigid neutralizing background gives rise to substantial deviations of the critical parameters. More simulations are underway to verify and generalize these predictions. The results are of relevance for a large variety of plasmas, including dwarf stars, laser-cooled expanding plasmas, warm dense matter, dusty plasmas, and semiconductors. We expect that the necessary parameters will be achievable in laser or ion beam compression experiments of hydrogen.

[1] M. Bonitz, V.S. Filinov, V.E. Fortov, P.R. Levashov, and H. Fehske, Phys. Rev. Lett. 95, 235006 (2005); Physical Review Focus 2 Dec. 2005.
[2] M. Bonitz, V.S. Filinov, V.E. Fortov. P.R. Levashov, and H. Fehske, J. Phys. A: Math. Gen. 39, 4717 (2006).
[3] "Introduction to computational methods for many-body physics", M. Bonitz and D. Semkat (eds.). Rinton Press, Princeton 2006, chapter 3.

PA-05
INDUCED INVERSE BREMSSTRAHLUNG FOR DENSE PLASMAS IN INTENSE LASER FIELDS

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During the interaction of intense laser fields with matter, plasmas with high density and high temperature are created. The heating of such plasmas is significantly determined by inverse bremsstrahlung when the electrons absorb energy from the electromagnetic field via electron-ion collisions.

If one studies the interaction of electromagnetic fields with plasmas composed of noble gases (Ar, Kr, Xe), one has to deal with complex ions containing a highly charged nucleus and bound core electrons. In the description of the scattering of electrons on noble gas ions in such plasmas, it is important to account for the inner structure of the ions and the screening due to the surrounding plasma medium which can be accomplished by the use of appropriate model potentials.

In calculations based on the first Born approximation, the consideration of the ionic structure on the scattering process had a huge effect on the heating rate [1,2]. However, in a wide parameter range met in experiments the applicability of the first Born approximation is questionable and, as was shown for low laser intensities in [3], the first Born approximation might overestimate the heating rate significantly. Hence, we analyze the electron-ion heating rate within a classical approach from the simulation of classical electron trajectories.

In this contribution, we investigate the dependence of the heating rate on relevant parameters such as the mean ion charge state, the laser field strength or the mean velocity of the electrons. Heating rates are calculated in the Born approximation as well as with classical methods, and the results from the different approximations are compared.

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[1] Z.B. Walters, R. Santra and C.H. Greene, Phys. Rev. A 74, 043204 (2006).
[2] F. Wang, E. Weckert and B. Ziaja, J. Plasma Physics 75, 289 (2009).
[3] M. Moll, P. Hilse, M. Schlanges, Th. Bornath and V.P. Krainov, J. Phys. B 43, 135103 (2010).

PA-06
THERMODYNAMICAL AND TRANSPORT PROPERTIES OF DENSE H-HE MIXTURES

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Hydrogen and helium are the main components of giant planets like Jupiter or Saturn. Although the properties of pure hydrogen and helium are reasonably well understood nowadays, the behavior of the mixture at high pressure remains poorly known. However, this is of fundamental importance to understand the structure and the evolution of these giant planets. For instance, the scenarios of cooling for Saturn are not compatible with its age, unless a demixing process of H-He occurs in the interior. But the existence of such a phase separation still needs to be confirmed by numerical simulations and/or laser-driven experiments.

We will present quantum molecular dynamics (QMD) simulation results of equimolar mixtures of hydrogen and helium, exploring densities from 0.24 to 3.5 g/cm^3 and temperatures from 1000 K to 17400 K (~ 0.1 to 1.5 eV). This is a range of parameters for which the mixture is a partially pressure-ionized plasma.

First, we will present thermodynamical properties as well as dynamical (diffusion) and structural (RDF and hydrogen dissociation fraction) analysis which characterize the behavior of the plasma. Secondly, we will present results on the transport properties (electrical and thermal conductivities and reflectivity) of the H-He mixture: these quantities are important observables for the laser-driven experiments dealing with hydrogen-helium mixtures. Finally, we will discuss the relevance of all these diagnostics for the detection of a phase separation in H-He mixtures experimentally as well as in simulations.

PA-07
THE ELECTRON TRANSPORT COEFFICIENTS OF AG AND AU PLASMA

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The electron transport coefficients of metals (conductivity, thermal conductivity and thermopower) play important role in fundamental tasks and applications. So there are many investigations of these coefficients for many metals in wide range of densities and temperatures [1-5]. The region for dense plasmas (i.e. T>5-10 kK and densities less than normal one) is the most problematic in these studies because of little measurement data and because the theoretical approaches developed in very dense (solid) and very rarefied (gas) phases are inapplicable directly to this area. Nevertheless it is possible whether to use ab initio simulation [2,3] or to combine more simple approaches [4,5] to describe the region of intermediate densities. A number of metals have already been studied this way. Besides there have been published new measurement data about transport coefficients of these metals in plasma region [6,7]. But among the noble metals only copper has obtained appropriate attention in theory and measurements. For Au there are calculations and of conductivity in Refs. [4,5], and to our knowledge for Ag there are no calculations as well as the measurements.

Consequently, the aim of present work is the calculation of the transport coefficients of Ag and Au plasmas. Usually, to do it, one needs to know the ionic composition or average ion charge (exclusion is only for ab initio MD [3]). To determine this charge we used several models like in [4, 5], namely the generalized chemical models [1,5], Tomas-Fermi model [2,5] and various "cell" models [8]. For Ag there no other data was found. But for Au it is possible to compare the results of present calculation with the data of [6, 7], where the conductivity was calculated and measured in the plasma region. This comparison shows that it is possible to use combination of several model, each working for own density region, to obtain sensible data on conductivity which are in agreement with calculations and measurements of [2, 3].

[1] S. Kuhlbrodt, and R. Redmer, Phys. Rev. E 62, 7191-7200 (2000)
[2] M. W. C. Dharma-Wardana, Phys. Rev. E 73, 036401 (2006)
[3] J. Clerouin, V. Recoules, S. Mazevet, P. Noiret, P. Renaudin, Phys. Rev. B 76, 064204 (2007)
[4] E. M. Apfelbaum, J. Phys. A 39, 4407-4410 (2006)
[5] E. M. Apfelbaum, High Temp. High Pressures 37, 253-260 (2008)
[6] A. W. DeSilva and G. B. Vunni, Phys. Rev. E 83, 037402 (2011)
[7] V. N. Korobenko ans A. D. Rakhel, JETP 139, 746-754 (2011) (in Russian)
[8] A. F Nikiforov., V. G. Novikov, Uvarov V., B., Quantum-statistical models of hot dense matter and methods for computation opacity and equation of state, Birkhauser Verlag. Boston-Basel. 442p. 2005.

PA-08
CONFIGURATION PATH INTEGRAL MONTE CARLO

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A novel path integral Monte Carlo (PIMC) approach for correlated many-particle systems with arbitrary pair interaction in continuous space at low temperatures is presented. It is based on a representation of the N-particle density operator in a basis of (anti-)symmetrized N-particle states ("configurations" of occupation numbers) [1].

The path integral is transformed into a sum over trajectories with the same topology and, finally, the limit of M to infinity, (M is the number of high-temperature factors), is analytically performed. This yields exact expressions for the thermodynamic quantities and allows to perform efficient simulations for fermions at low temperature and weak to moderate coupling. Our method is applicable to dense quantum plasmas in the regime of strong degeneracy where conventional PIMC, e.g. [2], fails due to the fermion sign problem.

[1] T. Schoof, M. Bonitz, A. Filinov, D. Hochstuhl, and J.W. Dufty, Contrib. Plasma Phys. (2011), DOI 10.1002/ctpp.201100012;.

[2] "Introduction to computational methods for many-body physics", M. Bonitz and D. Semkat (eds.). Rinton Press, Princeton 2006, chapter 4.

PA-09
COLLECTIVE EXCITATIONS OF A SPHERICALLY CONFINED DUSTY PLASMA

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Molecular dynamics (MD) simulations are performed to study the excitation properties of spherical Yukawa Balls [1,2]. Results are reported for the dependence of the normal modes on screening and the interaction strength [3]. While the low order modes are well explained by a cold fluid description [4] deviations occur for high order modes, in particular for strong screening of the interaction potential. At strong coupling the simulations reveal additional low frequency excitations which are not included in the theoretical fluid model. The breathing mode is studied in further detail and a comparison is made between the fluid model, MD simulations and the harmonic approximation for a crystallized system

[1] O. Arp, D. Block, A. Piel, and A. Melzer, Phys. Rev. Lett. 93, 165004 (2004)
[2] M. Bonitz et al., Phys. Rev. Lett. 96, 075001 (2006)
[3] H. Kählert and M. Bonitz, accepted for publication in Phys. Rev. E
[4] H. Kählert and M. Bonitz, Phys. Rev. E 82, 036407 (2010)

PA-10
GENERALIZED LINEAR MIXING RULE FOR COULOMB MIXTURES

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It is shown that the ionic contribution to the Helmholtz free energy F of fully ionized ionic mixture [1] can be written as a sum over partial contributions over ion species j: $F = k_{\rm B}T\sum_j N_j f(\Gamma_j,\kappa_j)$ (*generalized linear mixing rule*). Here $\Gamma_j = Z_j^2e^2/(a_jk_{\rm B}T)$, $a_j = (4\pi n_{\rm e}Z_j/3)^{1/3}$; N_j and Z_je are, respectively, the number of ions of type j and their charge. Finally, n_e is the number density of electrons. In contrast to the traditional linear mixing rule, applicable for strong coupling (see [2, 3], for example), the function f depends not only on Γ_j, but on an additional parameter $\kappa_j = a_j/r_{\rm D}$. This parameter does not depend on a specific composition of the mixture, but on the Debye radius $r_{\rm D}$ only, making the function $f(\Gamma_j,\kappa_j)$ universal. The generalized linear mixing rule can be applied at any coupling parameter, if ionic mixture is not crystalized. It reproduces the results of Debye-Hückel theory at weak coupling and traditional linear mixing rule at strong coupling. It can be easily applied to the complicated mixtures, composed of a large number of ion species. Since $\kappa_j \propto T^{-1/2}$, the Coulomb energy of the mixture can also be presented in a form of generalized linear mixing rule.

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[1] A. Y. Potekhin et al, Phys. Rev. E 80, 047401 (2009)
[2] J. P. Hansen and P. Villefosse, Phys. Rev. Lett 37, 391-394 (1976)
[3] H. DeWitt and W. Slattery, Contrib. Pasma Phys. 43, 279-281 (2003)

PA-11
DYNAMIC STRUCTURE FACTOR OF SINGLE HARMONIC OSCILLATOR AND LINEAR HARMONIC CHAIN

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The wave-number k dependent current-correlation function of a single harmonic oscillator is considered. Explicit analytic expressions for the Laplace transformed correlation functions are derived. They are compared with numerical solutions and results obtained by the recurrence relation method [1]. Several limiting cases such as the long-wavelength limit $k\to 0$ and the deep inelastic limit $k\to\infty$ are discussed in detail. In particular, it is shown that the deep inelastic limit allows for an explicit summation of the continued fraction. An approximation scheme for the recurrants at intermediate values of k is also considered. For details, see [2].

The approach is extended to the dynamic structure factor of the linear harmonic chain with periodic boundary conditions. Extensive semi-numeric results for the dynamic structure factor are presented. A detailed analysis of the moments of the dynamic structure factor is performed leading to simple expressions in long-wavelength as well as the deep inelastic limit. With the help of the recurrence relation method, approximations for the dynamic structure factor are established and compared to the (exact) numeric expressions.

[1] M. H. Lee, Phys. Rev. Lett. 49, 1072 (1982)
[2] A. Wierling and I. Sawada, Phys. Rev. E 82, 051107 (2010)

PA-12
DYNAMICAL SCREENING APPROACH TO STRONGLY CORRELATED MULTI-COMPONENT PLASMAS

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A key problem in the description of nonideal, multi-component plasmas are the dramatically different r,t-scales, which are caused by the different masses of the plasma constituents (electrons, ions, micron-sized "dust" particles etc.).[1,2]

In dusty plasma physics, this problem has been effectively tackled by the 'Dynamical Screening Approach' (DSA), which allows for an accurate description of essential plasma properties including screening, wakefield oscillations, ion and electron thermal effects as well as collisional and Landau damping.[3,4]

Here, the DSA is extended to non-equilibrium situations in partially ionized Warm Dense Matter, where a full dynamic treatment of the pair correlations of the heavy particles is crucial. Considering the strongly coupled ions as classical (or weakly degenerate) and the electrons as quantum degenerate but only weakly correlated, the ion dynamics will be studied on first principles by classical Langevin Dynamcis simulations, while the electrons are treated fully quantum-mechanically taking into account their dynamical screening of the ion-ion interaction in linear response on the basis of an extended Mermin formula.[5]

Like in streaming classical dusty plasmas, the effective wake-potential results in attractive (non-reciprocal) forces between equally charged plasma constituents, leading to remarkable structural and dynamical many-particle features.

[1] Introduction on Complex Plasmas, M. Bonitz, N. Horing, and P. Ludwig (eds.), Springer 2010
[2] P. Ludwig, H. Thomsen, K. Balzer, A. Filinov, and M. Bonitz, Plasma Phys. Control. Fusion 52, 124013 (2010)
[3] M. Lampe et al., IEEE Trans. Plasma Sci. 33, 57 (2005)
[4] P. Ludwig, W.J. Miloch, H. Kählert, and M. Bonitz, to be published (2011)
[5] P. Ludwig, M. Bonitz, H. Kählert, and J.W. Dufty, J. Phys. Conf. Series 220, 012003 (2010)

PA-13
DYNAMIC SCREENING IN SOLAR AND STELLAR NUCLEAR REACTIONS

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In the hot, dense plasma of solar and stellar interiors, Coulomb potentials are screened, resulting in increased nuclear reaction rates. Although Salpeter's approximation for static screening is widely accepted and used in stellar modeling, the question of screening in nuclear reactions has been revisited. In particular the issue of dynamic effects has been raised by Shaviv and Shaviv, who applied the techniques of molecular dynamics to the conditions in the Sun's core in order to numerically determine the effect of screening. By directly calculating the motion of ions and electrons due to Coulomb interactions, the simulations are used to compute the effect of screening without the mean-field assumption inherent in Salpeter's approximation. In 2009, the USC group has reproduced Shaviv and Shaviv's numerical analysis of the screening energy in the plasma of the solar core [1]. Very recently, we have computed the subsequent reaction-rate correction for such a dynamic screening. Rather surprisingly and contrary to static screening theory, we found that the dynamic screening does not significantly change the reaction rate from that of the bare Coulomb potential [2]. We therefore conclude that the effects of dynamic screening are relevant and should be included in stellar nuclear reaction rates. However, as in the case of the original Shaviv and Shaviv results, our findings are being considered controversial (see, e.g., [3]) and therefore more research is clearly warranted.

[1] Mao, D., Mussack, K. & Däppen, W., Astrophys. J. 701, 1204-1208 (2009)
[2] Mussack, K. & Däppen, W., Astrophys. J. 729, 96 (2011)
[3] Sawyer, R.F., arXiv:1103.3813 (2011)

PA-14
BREAKING STRESS OF NEUTRON STAR CRUST

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The breaking stress (the maximum of the stress-strain curve) of neutron star crust is important for neutron star physics including pulsar glitches, emission of gravitational waves from static mountains, and flares from star quakes. We perform many molecular dynamic simulations of the breaking stress at different coupling parameters (inverse temperatures), strain rates and composition of matter. We describe our results with the Zhurkov model of strength. We apply this model to estimate the breaking stress for timescales ~1 s – 1 year, which are most important for applications, but much longer than can be directly simulated. At these timescales the breaking stress depends strongly on the temperature. For coupling parameter $\Gamma<200$ matter breaks at very small stress, if it is applied for a few years. This viscoelastic creep can limit the lifetime of mountains on neutron stars. We also suggest an alternative model of timescale-independent breaking stress, which can be used to estimate an upper limit on the breaking stress.

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PA-15
WIDE-RANGE EQUATIONS OF STATE FOR METALS AT HIGH ENERGY DENSITIES

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A description of the thermodynamic properties of matter in a wide range of temperatures and pressures is of fundamental as well as practical interests. The equations of state for metals over the range from normal conditions to extremely high energy densities are necessary for hydrodynamic simulations of processes in strongly coupled plasmas under pulsed power influences [1]. In this report, a new semiempirical equations-of-state model, which takes into account melting, evaporation and ionization effects, is proposed. Wide-range equations of state for some metals (aluminum, copper, silver and others) are constructed on the basis of model developed. Calculation results are compared with available high-temperature, high-pressure experimental data. Most essential dynamic experiments are described. The equations of state can be used efficiently in numerical simulations of different physical processes in the metals at high energy densities.

[1] V. Fortov, I. Iakubov and A. Khrapak, Physics of Strongly Coupled Plasma (New York: Oxford University Press, 2006).

PA-16
PAIR INTERACTION POTENTIAL OF PARTICLES FOR TWO-COMPONENT PLASMA

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In this work the quantum pseudopotential for pair interaction of particles was considered, which takes into account the diffraction effects due to the uncertainty principle and the coupling between symmetry and diffraction effects in two-component plasma (the region of temperatures $10^4 K < T < 10^8 K$ and densities 10^{21} cm^{-3} < n ≤ 10^{24} cm^{-3}). Numerically the exact values of the Slater sum based on the method which was presented in work [1] were calculated.

Interpolation formula for the pseudopotential which takes into account the effect of diffraction and many particle quantum effects and is based on the exact numerical values of the Slater sum was founded. The interpolation formula at condition $\infty \to T$ has the following form:

$$\varphi\big|_{T\to\infty} = \frac{e_\alpha e_\beta}{r}\left(1 - \exp[-r/\lambda_{\alpha\beta}]\right),$$

that corresponds to the Deutsch potential [2].

For higher densities the pseudopotential which does not depend on density was considered. The results are in good agreement with similar data in [3], but diverge from data of the ion-electron pair's interaction given in [4]. This fact is explained by the different choices of the wave function. In works [5-7] quantum effects which effective potential takes into account were considered.

PA-17
COMPOSITION AND THERMODYNAMIC PROPERTIES OF DENSE ALKALI METAL PLASMAS

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In this work ionization equilibrium and thermodynamic properties of dense semiclassical nonideal alkali metal plasmas were investigated. The number density varies in the range $n_e = 10^{18} \div 10^{24}\ cm^{-3}$ and the temperature domain considered here is $T = 10^4 \div 10^6\ K$. To describe the electron-electron and electron-ion interactions, the effective potential was used. It takes into account the following effects: charge screening at long distances and short range quantum mechanical effects of diffraction and symmetry, which occurs in dense systems [1-2]. The electron-atomic interaction was described by polarization effective potential [3], which also takes into account the screening effects and quantum effects of diffraction. A similar effective potential has been used to describe ion–ion interactions [4].

Partially ionized plasma is multi-component system that contains electrons, ions, and atoms. The interactions between the particles causes a decrease of the ionization potential compared with isolated atoms and ions. The excess of chemical potential was calculated within the effective potential models. Obtained results were used for investigation of composition of dense semiclassical nonideal alkali metal plasmas by numerical solving the system of the Saha equations with corrections to nonideality (lowering of ionization potentials) [5]. The results are compared with results of other authors. The consideration of quantum mechanical effects of diffraction and symmetry in the interactions, at calculating of of dense semiclassical nonideal alkali metal plasmas composition leads to the deviations from the results of obtained for classical case.

[1] T.S. Ramazanov, et al., Phys. Plasmas 9, 3758 (2002).
[2] C.Deutsch, M.M.Combert, J. Math. Phys., 17, 1077-1090, (1976).
[3] T.S. Ramazanov, et al., Phys. Plasmas, 12, 092702 (2005).
[4] T.S. Ramazanov, et al., Phys. Plasmas, 17, 042702 (2010).
[5] R. Redmer, Physical Review E, 59, 1073 (1999).

PA-18
PLASMA DIAGNOSTICS APPLYING K-LINE EMISSION PROFILES OF MID-Z MATERIALS

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Narrow K-line emission of some keV is known as an appropriate light scource for Thomson scattering on warm dense matterwith solid and even over-solid electron density. However, as the K-spectra are emitted from a warm dense plasma themselves we are also able to infer plasma parameters by studying the line profiles [1, 2]. Our quantum-statistical approach to spectral line shifts is applied to various moderately ionized mid-Z materials. We focus on the opposing influence of ionization/excitation (blue shift) and plasma polarization effects (red shift).

The applied theoretical treatment of spectral line profiles is based on a self-consistent ion sphere model. We observe large contributions of satellite transitions due to M-shell ionization and excitation. To determine the composition, a mixture of various excited and ionized ionic states embedded in a plasma has to be considered. Plasma polarization effects that cause shifts of the emission and ionization energies are taken into account.

K-line profiles of titanium are calculated for bulk temperatures up to 100 eV and free electron densities up to 10^{24} cm^{-3} in order to analyze recent measurements with respect to the plasma parameters of electron heated target regions. Moreover, in high-intensity lasermatter interactions, inevitable prepulses are likely to create preplasma and shocks within the target before the main pulse arrives. We investigate the influence of density gradients due to prepulses on the spectral profiles. Further, radial bulk temperature distributions as well as the composition of the created warm dense matter can be inferred [3, 4]. Recent results on silicon (semi-conductor) are shown in comparison to titanium (metal) [5] and a polymere [3].

[1] E. Stambulchik, V. Bernshtam, L. Weingarten, et al., J. Phys. A: Math. Theor. **42**, 214056 (2009)
[2] U. Zastrau, P. Aubert, V. Bernshtam, et al., Phys. Rev. E **81**, 026406 (2010)
[3] A. Sengebusch, H. Reinholz, and G. Rpke, Contrib. Plasma Phys. **49**, 748 (2009)
[4] A. Sengebusch, H. Reinholz, G. Rpke, U. Zastrau, et al., J. Phys. A: Math. Theor. **42**, 214061 (2009)
[5] U. Zastrau, A. Sengebusch, et al., High Energy Density Phys. **7**, 47-53 (2011)

PA-19
EQUATION OF STATE FOR HIGH-DENSITY HYDROGEN

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The equation of state of fluid metallic hydrogen is of importance for the inner regions of solar and extrasolar planets. Furthermore, the equation of state in this parameter regime determines the behavior of the compressed deuterium-tritium shell of an ICF pellet. After compression, the heat capacity of the D-T shell material will determine how fast and how well the α-particles from the initial fusion seed can bring the bulk of the D-T fuel to fusion conditions. Of particular importance is the incorporation of quantum effects and strong ion-ion coupling in a consistent way which enables a correct description of the transition to $T = 0$ physics as well as to the nondegenerate case.

We present a two-fluid model for the equation of state of fluid metallic hydrogen. This model uses the thermodynamic Green's function method to describe the electron physics. The ionic subsystem is described by classical methods (like MC or HNC). This two-fluid model incorporates the correct high density limit and it is applicable for fully ionized plasmas of any degeneracy. We demonstrate agreement of this analytical method to first principle density-functional molecular dynamics (DFT-MD) for metallic fluids and to path integral Monte Carlo (PIMC) results in the low density limit. We furthermore compare PIMC and DFT-MD for the molecular fluid and metallic fluid phases. We find that the equation of state can be consistently described with these three methods in large part of the parameter space.

PA-20
TEMPERATURE RELAXATION IN DENSE TWO-TEMPERATURE PLASMAS

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We present a quantum kinetic approach for the energy and temperature relaxation in strongly coupled plasmas. Starting from the quantum version of the BBGKY-hierarchy, we derive a balance equation for the total energy [1]. With this approach, the problem of the division of the electron-ion part of the potential energy is solved. The right hand side of the balance equation includes a quite general expression for the energy transfer rate in terms of the correlation function of density fluctuations. By applying well-known approximation schemes for the density fluctuations, it is now possible to derive different expressions for the electron-ion energy transfer such as the Fermi Golden Rule (FGR) or Coupled Mode (CM) formulae [1]. Furthermore, it becomes possible to systematically improve the level of approximation for the energy transfer rates based on the real-time Green's function formalism.

For numerical evaluation, we apply here density response functions taken in random phase approximation and with static local field corrections. On this basis, the relaxation of the total energy in dense two-component plasmas is then investigated numerically. The heat capacity of the electron subsystem is derived using a perturbation expansion in the imaginary time Green's function formalism [2]. The ion heat capacity is calculated using techniques of classical statistics (HNC). It is shown that coupled collective modes can reduce the electron-ion energy transfer under certain conditions; typically in the beginning of the relaxation process [3].

We study the quantitative effects of ionic correlations, electron degeneracy and collective modes on the final temperature and on the relaxation time. The comparison of our results to recent computer simulations and to experiments shows agreement in certain limiting cases but differences in the relaxation process and relaxation time. Reasons for deviations from published results are discussed.

[1] J. Vorberger, D.O. Gericke, Th. Bornath, and M. Schlanges, Phys. Rev. E 81, 046404 (2010).
[2] J. Vorberger, M. Schlanges, andW.-D. Kraeft, Phys. Rev. E 69, 046407 (2004).
[3] J. Vorberger and D.O. Gericke, Physics of Plasmas 16, 082702 (2009).

PA-21
”HEATING” OF DUST PARTICLE MOTION IN PLASMA OF GAS DISCHARGE

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The phenomenon of acceleration of dust particles motion in plasma of gas discharge is studied. The dust particle kinetic energy exceeds own temperature of dust particle and also temperatures of electrons and ions. The mechanism of energy transfer from an external source to dusty particles in plasma is investigated and its influence on the spectrum of particles motion is discussed. The subsequent steps of the increase of the average kinetic energy of charged dust particles in gas discharge plasmas are suggested. Equations of 3D dust particles motion in gas discharge with account of charge fluctuations, features of near electrode layer and their influence on dust particle charge are formulated. The molecular dynamics simulations of dust particle system are performed. The combination of stochastic particle charge fluctuation and electric field gradient in near-electrode plasma results in the dust particle forced vertical oscillations. Resonance arises due to the intersection of a range of vertical oscillations natural frequencies with a range of charge fluctuation frequencies. The joint action of the parametric resonance and the forced oscillations explains the high kinetic temperature of dust particles. The mechanism of energy transfer from discharge to dust particles motion is divided into several parts. Warming up of dust particles vertical oscillations is considered separately from the heating of horizontal oscillation, as these processes are determined by several different phenomena due to near-electrode layer anisotropy. The energy transfer from vertical to horizontal oscillations is investigated separately. The outflow of energy from the dust particles oscillations due to friction on the neutral gas is also taken into account. The estimated frequency, amplitude and kinetic temperature are close to the experimental values. The question of the lawfulness of using the term ”temperature” to describe the kinetic energy of dust particles is considered. Some subsystems of plasma-dust systems are in partial equilibrium, which allows us to use the term ”kinetic temperature” for these subsystems. For various system parameters several modes are implemented. It is necessary to apply different types of kinetic temperatures for different modes. Consideration of dust particles horizontal and vertical oscillations separately reveals the possibility of two different average kinetic temperatures of dust particles motion. Molecular dynamics method was used to verify the theoretical calculations.

PA-22
THERMODYNAMIC PROPERTIES OF DENSE METALLIC PLASMA BY FIRST-PRINCIPLE CALCULATIONS

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Thermodynamics of electronic subsystem of metals substantially defines their properties in the vast region of phase diagram. Most often these properties are not required directly, but modern femtosecond laser facilities increase the importance of this knowledge.

Two-temperature hydrodynamic simulation requires equations of state both for ions and electrons. Traditionally the equations of state for electronic subsystem is calculated using the density functional theory. Currently pseudopotential approaches which take into account only valent electrons are very popular because of their robustness and speed. But the use of pseudopotentials can appreciably affect simulation results in comparison with the more reliable full-electron calculations.

In this work, we compare the contribution of electrons in thermodynamic functions of metals at different densities (higher than normal density) and electron temperatures up to 15 eV. One of the methods, FP-LMTO [1] (complex of programs LMTART modified similar to the way covered in [2]) describes all electrons in the framework of the density functional theory. The other approach, VASP [3] uses pseudopotentials also in the context of the density functional theory. We calculate specific energy, pressure, and thermal capacity of electrons in crystals of aluminum, sodium and tungsten by both approaches.

Also by quantum molecular dynamics method we compute the principal and porous shock Hugoniots as well as release isentropes of aluminum in the conditions of dense strongly coupled plasma in good agreement with experiment. We also compare our results with average atom models and popular semiempirical multiphase equation of state [4]. We state that in such equations of state it is important to take into account the properties of electronic subsystem from first-principle calculations instead of simple rough models.

[1] S. Y. Savrasov, Phys. Rev. B. 1996, 54, 16470.
[2] G. V. Sin'ko, N. A. Smirnov, Phys. Rev. B. 2006, 74, 134113.
[3] G. Kresse, J. Hafner, Phys. Rev. B. 1993, 47, 558; Ibid. 1994, 49, 14251.
[4] V. E. Fortov, K. V. Khishchenko, P. R. Levashov , I. V. Lomonosov, Nucl. Instr. Meth. Phys. Res. A, 1998, 415, 604.

PA-23
ISENTROPIC COMPRESSION OF DEUTERIUM BY QUANTUM MOLECULAR DYNAMICS

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In this work we present our calculations of the compression isentrope of deuterium. We use a pseudopotential density-functional-theory (DFT) code VASP [1] with the planeaugmented-wave pseudopotential and generalized-gradient-approximation exchange-correlation functional. The quantum molecular dynamics approach which is based upon the Born-Oppenheimer approximation is applied to calculate pressure and internal energy of dense deuterium plasma. The calculations were made in the range of temperatures 293–25000 K and densities 1–3 g/cm³. We use Zeldovich's approach to restore the isentrope and compare the results with experimental data and other theories [2]. The position of the calculated isentrope slightly depends on the initial point but agrees with the initial part of the experimental isentrope. However, we didn't find the density jump registered experimentally [2].

[1] G. Kresse, J. Hafner, Phys. Rev. B. 1993, 47, 558; Ibid. 1994, 49, 14251.
[2] V. E. Fortov et al., Phys. Rev. Lett., 2007, 99, 185001.

PA-24
SEMIEMPIRICAL EQUATIONS OF STATE FOR METALS BASED ON THE THOMAS-FERMI MODEL

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Equations of state (EOSs) over wide range of thermodynamic parameters are necessary to solve many physical tasks, such as simulation of a laser pulse interaction with different metals. Nowadays the semiempirical approach is one of the commonly used methods to construct wide-range EOSs for matter. In this work, we use the well-known adiabatic approximation, which allows us to treat contributions of ionic and electronic subsystems to the total Helmholtz free energy separately. The cold curve and the thermal contribution of ions is described by semiempirical expressions with coefficients determined from comparison with experimental data available, and the thermal contribution of electrons is considered in the framework of the finite-temperature Thomas–Fermi model [1]. Thus we can avoid the main drawback of the Thomas–Fermi model–incorrect behavior of thermodynamic quantities at low temperatures. Also there is no need to introduce additional fitting parameters into the thermal contribution of electrons. Similar technique was used in [2], however, agreement with experimental data was only demonstrated for the principal Hugoniot at high pressures.

We present several EOSs for metals, both one-phase and multi-phase. All of them are in agreement with shock-wave data in a wide range of temperatures and densities, including normal state and the region of strongly coupled plasma. These EOSs are included into EOS library and can be directly used for simulation.

[1] Feynman R. P., Metropolis N., Teller E. // Phys. Rev. 1949. V. 75. P. 1561–1573.
[2] Pain J. C. // High Energy Density Phys. 2007. V. 3. P. 204–210.

PA-25
MODELING OF INTERACTION OF INTENSE ULTRASHORT LASER PULSES WITH METALS

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A wide-range hydrodynamic model is used for a simulation of strongly coupled plasma response on ultrashort laser influence. The amplitude and phase of the complex reflection coefficient of Al and Ag plasmas were measured recently in pump-probe experiments [1–3]. The intense p-polarized pump pulse of 100 fs duration creates the plasma on the surface of a metal target. A weak s-polarized probe pulse is used for diagnostics of the plasma by means of femtosecond interference microscopy. In the present work, a theoretical model is developed for simulation of laser-mater interaction on the basis of two-temperature hydrodynamics with heat transport phenomenon, ionization, plasma expansion, electron-ion collisions and two-temperature equation of state for an irradiated substance. A comparison of the results of modeling with the experimental data for Al and Ag targets shows that the model is suitable up to the pump laser pulse intensities of 10^{15} W/cm^2 as well as up to the electron temperatures of 100 eV.

[1] M. B. Agranat, N. E. Andreev, S. I. Ashitkov, M. E. Veisman, P. R. Levashov, A. V. Ovchinnikov, D. S. Sitnikov, V. E. Fortov and K. V. Khishchenko, JETP Lett. 85, 271–276 (2007).
[2] M. E. Veysman, M. B. Agranat, N. E. Andreev, S. I. Ashitkov, V. E. Fortov, K. V. Khishchenko, O. F. Kostenko, P. R. Levashov, A. V. Ovchinnikov and D. S. Sitnikov, J. Phys. B: At. Mol. Opt. Phys. 41, 125704 (2008).
[3] P. S. Komarov, S. I. Ashitkov, A. V. Ovchinnikov, D. S. Sitnikov, M. E. Veysman, P. R. Levashov, M. E. Povarnitsyn, M. B. Agranat, N. E. Andreev, K. V. Khishchenko and V. E. Fortov, J. Phys. A: Math. Theor. 42, 214057 (2009).

PA-26
STREAMING INSTABILITIES IN YUKAWA LIQUIDS

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A Yukawa liquid is a system of charged particles which interact via a screened Coulomb interaction and in which the electrostatic energy between neighboring particles is larger than their thermal (kinetic) energy but not large enough for crystallization. Various plasma systems including complex (dusty) plasmas or ultracold neutral plasmas can exist in this strongly coupled liquid phase. Since strong coupling affects the dispersion of collective modes in these plasmas, the behavior of instabilities should be similarly affected [1-3]. Here, we investigate instabilities driven by the relative streaming of various plasma components in Yukawa liquids. In a complex plasma such instabilities could be excited (i) as a dust-dust instability that may occur when strongly coupled dust grains counter-stream, and (ii) as a dust acoustic instability driven by weakly coupled streaming ions. Compared to the Vlasov behavior, we find a modification of the unstable k-spectrum induced by strong coupling effects.

[1] G. J. Kalman and M. Rosenberg, J. Phys. A: Math. Gen. 36, 5963-5969 (2003)
[2] M. Rosenberg and P.K. Shukla, Phys. Scripta 83, 015503 (2011)
[3] S. Kyrkos, G. J. Kalman and M. Rosenberg, Phys. Rev. Lett. 102, 225006 (2009)

PA-27
THE ORIGIN OF THE ROTON MINIMUM

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The roton minimum, first postulated by Landau [1] and then identified by clear observational evidence in superfluid liquid Helium [2], is a deep minimum in the collective excitation spectrum of the liquid, forming around fairly high k-values.

We have discovered, through a series of MD simulations, that this phenomenon appears to be a general feature of strongly coupled liquids and is ubiquitous in 2D and 3D Yukawa liquids. We also have been able to match the predicted roton minimum in a 2D bosonic dipole superfluid with classically simulated results [3].

We suggest that the physical origin of the roton minimum has to be sought in the quasi-localization of particles in a strongly correlated liquid and in the ensuing formation of local microcrystals whose averaged frequency dispersion would show roton minimum- like feature. Focusing on the formation of the phonon dispersion relation in a 2D crystal lattice, one observes that the position of the roton minimum is coincident with that of the closest point on the Brillouin zone boundary. To show how this feature leads to the development of the roton minimum we have constructed a model for the dynamical structure function $S(\mathbf{k}, \ )$ of a 2D lattice system. By using the classical fluctuation dissipation theorem (FDT) we obtain $S(\mathbf{k}, \ ) = -(1/\ )\mathrm{Im}\ (k, \ )$ through a lattice model for the density response function $(\mathbf{k}, \ )$, where the liquid behavior is emulated by a phenomenological collision frequency. Corresponding to the randomly distributed microcrystal picture, the liquid dispersion relation is calculated through angular averaging. We examine its behavior in the vicinity of the Brillouin zone boundaries, and compare the results with those provided by MD simulations.

[1] Landau L., J. Phys. USSR 5, 71 (1941); 11, 91 (1947); Phys. Rev. 75, 884 (1949).
[2] Woods A. D. B., Phys. Rev. Lett. 14, 355 (1965); Cowley R. A. and Woods A. D. B., Can. J. Phys. 49, 117 (1971).
[3] G. J. Kalman, P. Hartmann, K. I. Golden, A. Filinov and Z. Donkó, EPL 90, 55002 (2010).

PA-28
SHEAR MODULUS OF THE NEUTRON STAR CRUST

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The shear modulus of the solid neutron star crust is calculated by the thermodynamic perturbation theory, taking into account ion motion. At given density, the crust is modelled as a body-centred cubic Coulomb crystal of fully ionized atomic nuclei of one type with the uniform charge-compensating electron background. Classic and quantum regimes of ion motion are considered. The calculations in the classic temperature range agree well with previous Monte Carlo simulations. At these temperatures, the shear modulus is given by the sum of a positive contribution due to the static lattice and a negative $/T$ contribution due to the ion motion. The quantum calculations are performed for the first time. The main result is that at low temperatures the contribution to the shear modulus due to the ion motion saturates at a constant value, associated with zero-point ion vibrations.

Such behaviour is qualitatively similar to the zero-point ion motion contribution to the crystal energy. The quantum effects may be important for lighter elements at higher densities, where the ion plasma temperature is not entirely negligible compared to the typical Coulomb ion interaction energy.

Additionally, the correction to the static lattice shear modulus due to the electron gas polarizability is evaluated. This effect is taken into account in the formalism of the dielectric function. Static zero-temperature dielectric function of degenerate relativistic electron gas obtained in the Random Phase Approximation is used.

The results of numerical calculations are approximated by convenient fitting formulae.

They should be used for precise neutron star oscillation modelling, a rapidly developing branch of stellar seismology.

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PA-29
X-RAY THOMSON SCATTERING IN WARM DENSE MATTER AT LOW FREQUENCIES

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The low-frequency portion of the x-ray Thomson scattering spectrum is determined by electrons that follow the slow ion motion. This ion motion is characterized by the ion-ion dynamic structure factor, which contains a wealth of information about the ions, including structure and collective modes. The frequency-integrated (diffraction) contribution is considered first. An effective dressed-particle description of warm dense matter is derived from the quantum Ornstein-Zernike equations, and this is used to identify a Yukawa model for warm dense matter. The efficacy of this approach is validated by comparing a predicted structure factor with data for the extreme case of a liquid metal. A Thomas-Fermi model is then introduced to allow the separation of bound and free states at finite temperatures, and issues with the definition of the ionization state in warm dense matter are discussed. For applications, analytic structure factors are given on either side of the Kirkwood line. Finally, several models are constructed for describing the slow dynamics of warm dense matter. Two classes of models are introduced that both satisfy the basic sum rules. One class of models is the ``plasmon-pole"-like class, which yields the dispersion of ion-acoustic waves. Damping is then included via generalized hydrodynamics models that incorporate viscous contributions. This suggests a method by which viscous transport properties can be measured.

PA-30
BOUNDARIES OF THERMODYNAMIC STABILITY FOR WIDE-RANGE ANALYTIC EOS OF FULLY IONIZED ELECTRON-IONIC PLASMAS

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Boundaries for thermodynamic instability are studied for well-known wide-range analytic equations of state (EOS) of non-ideal fully ionized electron-ionic plasmas (Potekhin & Chabrier [1]), which is widely used in astrophysical applications. It was found that for one-element electron-ionic plasmas (Z:e) this thermodynamic instability region looks as 1st-order phase transition of gas-liquid type with upper critical point, which is well described by simple relation: $T_c(Z) \approx T_c(1)Z^{\gamma}$ (here $\gamma \approx 3/2$ and $kT_c(1) \approx 1.49$ eV). Structure and parameters of discussed phase transition proved to be very close to those for similar phase transition(s), which were studied previously by Iosilevskiy and Chigvintsev for so-called Double-OCP model [2,3] i.e. for superposition of two OCP-models for ions and electrons without electron-ionic screening effects. In particular both phase transitions predict highly asymmetric phase diagrams with remarkably low values of critical compressibility factor for all values of Z. Parameters of mentioned above thermodynamic instability have been calculated for global and local instability conditions (i.e. binodals and spinodals). Calculations were provided for plasmas of single elements and for mixtures in Linier Mixing Rule approximation, recommended in [1]. Validity of several well-known semi-empirical rules for phase diagram is discussed. In particular new variant for the rule of "rectilinear diameter" was discovered for compressibility factor. This new variant appends standard variant of the rule for density-temperature phase diagram. Perspectives for calculation of simplest variant for non-congruent phase transition are discussed for the model of "binary ionic mixture" with the use of present and previous approximate equations of state.

[1] A.Y. Potekhin and G. Chabrier, Phys. Rev. E 62, 8554 (2000); Phys. Rev. E 58, 4941 (1998)
[2] I.L. Iosilevskiy, High Temperature, 23, 807 (1985) arXiv:0901.3535
[3] I. Iosilevskiy and A. Chigvintsev, in "Physics of Strongly Coupled Plasmas" Eds. W. Kraeft and M. Schlanges, (World Scientific, Singapore-London, 1996) pp.145. / arXiv:0902.2353

PA-31
EQUATION OF STATE OF STRONGLY SHOCK COMPRESSED GASES AT MEGABAR PRESSURE RANGE

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Model for equation of state of dense strongly coupled plasmas of strongly shock-compressed gases is developed in frames of "chemical picture". Shock compressed matter is considered as a multi-component strongly interacting mixture of atoms, molecules, ions and electrons. Non-ideality due to Coulomb interaction of charged particles, short-range repulsion and attraction of heavy particles in combination with electrons partial degeneracy are taken into account. Modified pseudopotential model is used for description of charged particles non-ideality effects. Contribution for short-range repulsion of heavy particles to thermodynamic functions is taken into account in frames of modified model for soft-spheres mixture. Repulsion parameters were chosen in accordance with recommendations of non-empirical atom-atomic approximation (E. Yakub). Results for calculation of principal and reflected Hugoniots for hydrogen (deuterium), helium and nitrogen are presented. Calculation results are compared with available experimental data and results of direct numerical simulation.

PA-32
FRACTIONAL QUANTUM HALL EFFECT IN GRAPHENE

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The emergence of fractional quantum Hall states in two-dimensional electron systems in a strong magnetic field is one of the most spectracular consequences of the Coulomb interaction. We know several systems which allow the experimental observation of the fractional quantum Hall effect (FQHE): semiconductor heterostructures, quantum wells, graphene mono- and multilayers and, possibly, surface states of topological insulators.

We discuss the FQHE in monolayer graphene, where electrons have a massless Dirac dispersion, and the existence of two inequivalent Fermi points introduce a pseudospin degree of freedom. Unlike regular electron spin, the pseudospin degeneracy of Fermi points does not couple directly to the magnetic field. Therefore, graphene provides a natural vehicle to observe quantum Hall physics in an elusive limit analogous to zero Zeeman splitting in GaAs systems. This limit can exhibit new integral plateaus arising from interactions, large pseudoskyrmions, fractional sequences, even/odd numerator effects, composite-fermion pseudoskyrmions, and a pseudospin-singlet composite-fermion Fermi sea. The Dirac nature of the B=0 spectrum, which induces qualitative changes in the overall spectrum, has no bearing on the FQHE in the n=0 Landau level of graphene. The second Landau level of graphene is predicted to show more robust FQHE than the second Landau level of GaAs.

Further, we consider FQHE for SU(4) symmetry, as appropriate for the situation when all four spin and valley Landau bands are degenerate, and predict new FQHE states that have no analog in GaAs. These result from an interplay between the two-fold spin and valley degeneracies at fractions of the form $\nu=n/(2pn\pm1)$, for $n\geq3$. We describe the structure of these states and their excitations. In the SU(4) limit, predicting that new low-energy Goldstone modes determine the stability of the fractional quantum Hall states at 2/5, 3/7 etc.

While graphene allows in principle the observation of one, two or four component FQHE in different parameter regions, we argue that some, though not all, apparently puzzling features observed in recent experiments are consistent with a two-component fractional quantum Hall effect, with the electron spin frozen but the Dirac-valley symmetry approximately intact.

PA-33
A PRACTICAL EQUATION OF STATE FOR THE SUN AND SOLAR-LIKE STARS

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For models of the Sun and Sun-like stars, a high-quality equation of state is crucial. Conversely, helio- and asteroseismological observations put constraints on the physical formalisms and they effectively turn the Sun and stars into laboratories for dense plasmas. For models of the Sun and Sun-like stars, the most accurate equation of state so far is the one developed as part of OPAL opacity project of Livermore. However, the OPAL equation of state is limited in two important respects. First, it is only available in the form of pre-computed tables that are provided from Lawrence Livermore National Laboratory. Applications to stellar modeling require therefore interpolation, with unavoidable loss of accuracy. Second, the OPAL equation of state is proprietary and not freely available. Varying its underlying physical parameters is therefore no option for the community. We report on progress with the development of an emulation of the OPAL equation of state as an "in-line" tool (that is, a set of subroutines) suited for modelers. Our approach starts out from the widely used Eggleton-Faulkner-Flannery [1] (EFF) formalism, more precisely its offspring CEFF [2]. Then it implements the USC group's prior work, based on a modification of the so-called MHD equation of state [3]. While this is a successful OPAL emulation, it is still relying on pre-computed tables [4]. Implementation as an in-line formalism, such as CEFF, would remove that limitation. However, as we showed in a recent paper [5], for the required precision, the thermodynamic quantities of CEFF and MHD do not sufficiently agree. Therefore, the prior MHD-based emulation cannot be transported directly into CEFF. Rather, it has to be tweaked to account for the difference between MHD and CEFF. We present the results of this effort.

[1] Eggleton, P.P., Faulkner, J. & Flannery, B.P. 1973, Astron. Astrophys. 23, 325
[2] Christensen-Dalsgaard, J. & Däppen, W. 1992, Astron. Astrophys Reviews. 4, 267
[3] Däppen, W., Mihalas, D. & Hummer, D.G. 1988, Astrophys. J., 332, 261
[4] Lin, H.-H. & Däppen, W. 2010, Astrophysics and Space Science, 328, 175-178
[5] Lin, H.-H. & Däppen, W. 2011, Astrophysics and Space Science, (in press)

PA-34
LOW-TEMPERATURE EXTENSIONS OF THE VIRIAL EQUATION-OF-STATE FOR SOLAR MODELING

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Among competing formalisms for solar modeling, virial expansions of the equation of state have the potential to become the most accurate of them. So far, the best equation of state has been OPAL, an activity expansion developed at Livermore [1]. Exact virial expansions for Coulomb plasmas were obtained on the one hand by path-integral methods in the framework of the so-called Feynman-Kac (FK) representation [2], and on the other hand by Green-function techniques [3]. To the 5/2-th power of density, both of these expansions agree perfectly. However, in contrast to activity expansions, any such low-order virial expansion cannot describe recombination at low temperatures. For solar modeling, their domain of applicability has to be restricted to conditions of nearly full ionization [4]. Therefore, the application of FK is limited to the deeper interior of the Sun (and similar stars). However, for full-fledged solar modeling, it is at least formally necessary to extend the domain of applicability of FK to the entire Sun. While such an extension cannot retain the entire rigor of the FK formalism in the low-temperature part of the Sun, it should at least result in a good computational tool for solar modeling. Here, we present a low-temperature extension based on the ideal Saha equation. This approach has the advantage that, in principle, it can be upgraded with the help of the systematic non-ideal corrections derived by Alastuey & Ballenegger [5].

[1] Rogers, F.J. & Nayfonov, A. 2002, Astrophys. J., 576, 1064
[2] Alastuey, A. & Perez, A. 1992, Europhys.Lett., 20, 19
[3] Kremp D., Schlanges, M. & Kraeft, W.-D., 2005, Quantum Statistics of Nonideal Plasmas (Springer)
[4] Perez, A., Mussack, K., Däppen, W & Mao, D. 2009, Astron. Astrophys., 505, 735
[5] Alastuey, A. & Ballenegger, V. 2009, J. Phys. A: Math. Theor. 42, 214031

PA-35
RAMAN SPECTRA OF $INAS_XP_{1-X}$ ALLOY FILMS UNDER HYDROSTATIC PRESSURE

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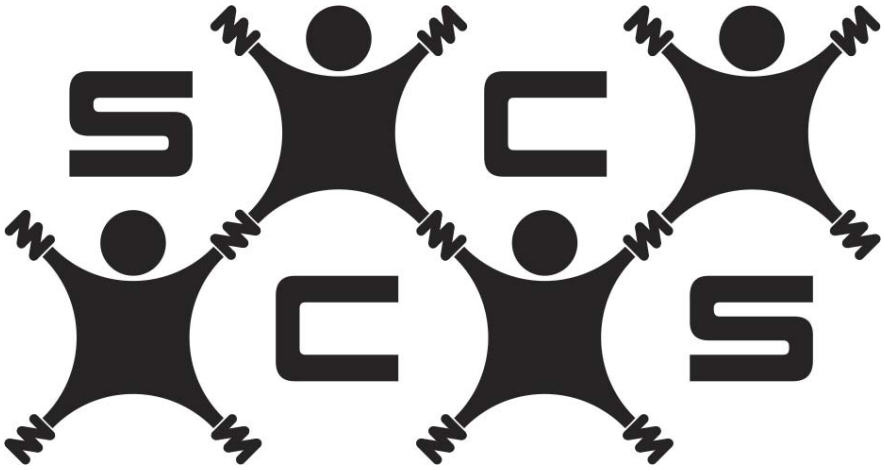
We have measured the Raman shift of $InAs_xP_{1-x}$ (x=0.0, 0.4, 0.6, 0.8, 1.0) alloy films grown on InP substrates under hydrostatic pressures up to ~90 kbar. Pressure blueshifts the phonon frequencies of InP-like and InAs-like modes for all the As compositions we tried. The shift rate of the LO phonon frequency of the InP-like mode increases with increasing x, which looks consistent with the known elastic properties of binary InP and InAs. Resonance effect is observed from x=0.7, x=0.75, and x=0.8 alloys when excited by 457.9 nm laser, which allows the measurement of shift rates of E_1 band gap with pressure.



POSTER SESSION

"B"

PB-01
GROUND STATE CONFIGURATIONS AND MELTING CHARACTERISTICS OF A TWO-DIMENSIONAL DUST CLUSTERS

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Numerical simulation is performed for a two-dimensional dust clusters in an elliptical electrostatic confinement potential. The case of parabolic confinement is also investigated. The interaction between dust particles is modeled by three different potentials namely Coulomb, Yukawa and logarithmic. The effect of charge fluctuation, due to the discrete nature of particles flowing onto the dust surface, is investigated for a finite number of particles. Structural arrangement and phase transition are found to be dependent on the potential interaction and the charge fluctuation. The charge fluctuation corresponds to an additional heating of the system giving rise to a change on the ground state configurations as well as on the melting characteristics. The eccentricity of the confinement potential leads, for a critical number, to a zigzag transition from a two-dimensional (2D) to a one-dimensional (1D) configuration.

[1] O.S. Vaulina, S.A. Khrapak, A.P. Nefedov, O.F. Petrov, Phys. Rev. E. 60, 5959-5964 (1999).
[2] S. A. Khrapak, B. A. Klumov, and G. E. Morfill, Phys. Rev. Lett.100. 225003 (2008).
[3] L. Rouaiguia, M. Djebli and F. Peeters, Phys. Lett.A 372, 4487-4492 (2008).
[4] A. Piel, Plasma Physics, Springer-Verlag Berlin Heidelberg (2010).
[5] M. Djebli, M. Issaad, and L. Rouaiguia , Phys. Plasmas 17, 033704 (2010).

PB-02
NUMERICAL ALGORITHMS FOR MODELING MHD FLOWS AT LOW AND HIGH MAGNETIC FIELD

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We develop new numerical algorithms for low and high magnetic field to be applied on magnetohydrodynamics (MHD), magnetoconvection and plasma turbulence problems.

We assess the validity of our numerical approaches and methods via previously proven concepts on simpler cases. We also validate such methods using some theoretical approaches; the global asymptotic analysis methods. The numerical algorithms employ variational and quasi variational inequality methods. We hence apply and discuss our approaches for the nonlinear turbulent flows.

[1] Chebotarev, A. Yu., and Savenkova, A. S., Variational Inequalities in Magneto-Hydrodynamics, Mat. Zametki, 82, No. 1, pp. 135–149 (2007)
[2] Glatzmaier, G. A., and Roberts, P. H., A three-dimensional convective dynamo solution with rotating and finitely conducting inner core and mantle, Phys. Earth Planet. Inter., 91, pp. 63-75 (1995)
[3] Jones, C. A., Mussa, A. I. and Worland, S. J., Magnetoconvection in a Rapidly Rotating Sphere: the weak field case, Proc. R. Soc. Lond. A, 459, No. 2031, pp. 773-797 (2003)
[4] Jones, C. A., Soward, A. M, and Mussa, A. I., The Onset of Thermal Convection in a Rapidly Rotating Sphere, J. Fluid Mech., 405, pp. 157-179 (2000)
[5] Laurence, P., Some rigorous results concerning spectral theory for ideal MHD, Courant Institute of Mathematical Sciences, New York University (1985)
[6] Lineberry, J. T., Chapman, J. N., Litchford, R. J., and Jones, J., MHD Augmentation of Rocket Engines Using Beamed Energy, AIP Conf. Proc., May 14, 664, pp. 280-291 (2003)
[7] Mussa, A. I., MHD Plasma: Spherical Region Model-Analytical and Numerical Investigation, Forshungszentrum Junze in der Helmholtz-Gemeinschaft, 34, pp. 279-282 (2004)
[8] Mussa, A. I., Auxiliary Variational Inequality Principle and Projection Methods for MHD Propulsion System, Proc. of NumAn2010, Greece, pp. 195-201 (2010)
[9] Mussa, A. I., MHD variational inequality theory and approximation, (in preparation) (2011)
[10] Noor, A. M., Iterative Schemes for Nonconvex Variational Inequalities, Journal of optimization theory and applications, 121, No. 2, pp. 385–395 (2004)
[11] Takezawa, S., Tamama, H., Sugawawa, K., Sakai, H., ChiakiMatsuyama, HiroakiMorita, Suzuki, H., and Ueyama, Y. Operation of the Thruster for Superconducting Electromagnetohydrodynamic Propulsion Ship "YAMATO 1", bulletin of the M.E.S.J 29, No.6 (1993)

PB-03
MAGNETIC TRAP FOR COULOMB CLUSTERS OF DIAMAGNETIC PARTICLES

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Ordered structures of dust particles in rf and dc discharge plasmas are frequently considered as a macroscopic physical model of strongly coupled Coulomb systems (SCCS) [1,2], which can visually be observed, and using them, one can study the properties of SCCS on kinetic level. However, the dust particle charge in plasma is screened, not fixed depending on the local conditions, and responsible both for interaction with other particles (and consequently for the formation of a Coulomb system) and for its levitation in electrical fields. In order to fix the particle charge and separate the particle interaction and levitation, one should place the particles into nonionized medium and create a trap confining the particles by non-electrostatic forces. For this aim, we have proposed [3] to use a trap based on the known possibility of the levitation of diamagnetic bodies in a nonuniform steady-state magnetic field, that was earlier applied for levitation of single macroscopic bodies [4]. In a nonuniform magnetic field $\mathbf{B}$, any particle is acted upon by the effective force $\mathbf{F}_m = (\chi m/2)\nabla(\mathbf{B}^2)$, where χ is the specific magnetic susceptibility of matter, and m is the mass of particle. For diamagnets, $\chi < 0$, and diamagnetic particles are forced out to the region with lower magnetic field. Under conditions of gravitation, we use magnetic fields which decrease upward, and the potential well is created by the superposition of the magnetic and gravity fields. Confinement of the particles and their stable levitation are provided by the special configuration of the magnetic field. We have derived a theoretical model of magnetic-gravity trap based on a general assumption about the symmetry properties of the magnetic field. In the framework of the model we have obtain the conditions for the location and orientation of a simplest two-particle cluster in the trap. Using the model we have calculated the trap in the applied experimental setup [3]. The height of the potential barriers for different directions is found. It is shown that the trap exists in a certain region of the magnetic field values. For lower fields the potential well disappears and the particles fall down. For higher fields the potential well transforms to a saddle. Increasing the geometrical size of the trap, one should increase the magnetic field. Calculation of the two-particle cluster in the trap was performed. We have found the position, size, energy, and oscillation frequencies of the cluster. The possible values of the particle charge have been estimated. However, our main aim is the formation and study of large-sized 3D structures containing thousands charged particles. For this aim, we need magnetic fields $B > 10$ T with $\nabla B \approx 10$ T/cm under terrestrial conditions. Under microgravity conditions, fields $B \approx 0.1$ T with $\nabla B \approx 0.1$ T/cm are sufficient. At present we begin microgravity experiments aboard space vehicles with the magnetic trap containing 2000 particles and obtain first results.

This study was supported by the program of the Presidium of RAS on Thermophysics and Mechanics of Extreme Energy Actions and RFBR grant 11-02-01051.

[1] V.E. Fortov, I.T. Iakubov and A.G. Khrapak, Physics of Strongly Coupled Plasma (Oxford University Press, Oxford) 2006
[2] P.K. Shukla and B. Eliasson, Rev. Mod. Phys. 81, 25-44 (2009)
[3] S.F. Savin, L.G. D'yachkov, M.M. Vasiliev, O.F. Petrov and V.E. Fortov, EPL 88, 64002 (2009)
[4] A. Geim, Phys. Today 51, N 9, 36-39 (1998)

PB-04
EQUATION OF STATE OF DENSE PLASMAS OF MIXTURE: APPLICATION TO THE CENTER OF THE SUN

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We present a quantum-statistical model for the calculation of atomic structure and equation of state of mixture plasmas (i.e. plasmas containing different elements). An ion of charge q+ is defined as the ensemble of configurations having (Z-q) bound electrons. When the number of configurations becomes too large, they can be gathered into super-configurations. In each (super-) configuration, the nucleus is totally screened by the electrons (spherical symmetry of the central-field model). Bound and free electrons are described within a quantum-mechanical self-consistent procedure and relativistic effects are taken into account in the Pauli approximation. The assumption that all the ionic species of all the elements should have the same electronic environment leads to the equality of electronic pressure for all ions having therefore different volumes [1, 2].

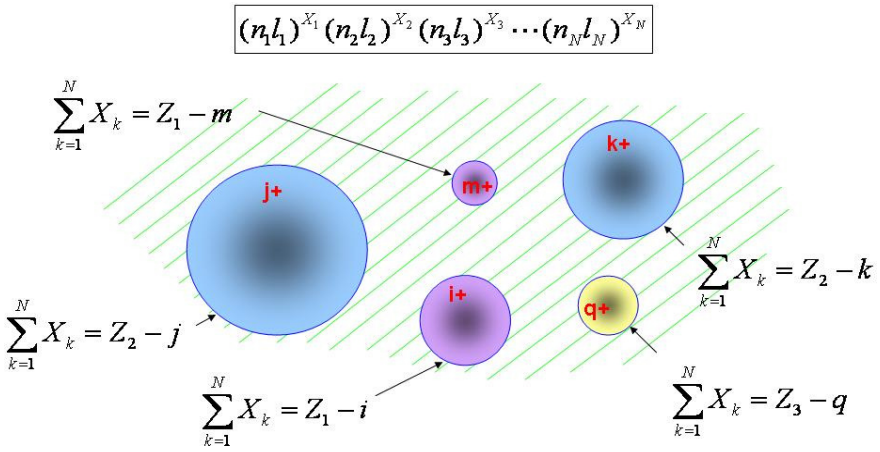

Figure : Ions of a ternary plasma (atomic numbers Z_1, Z_2, and Z_3) as ensembles of configurations.

The partial volumes are therefore obtained from the equality of the electronic pressure, evaluated by the stress-tensor formula, for all the (super-) configurations. The thermodynamic consistency resulting from this "redefinition" of ions is the most important feature of the method. The numerical procedure is particularly robust, and can handle plasmas where light and heavy nuclei co-exist. The present study shows that the atomic radius of a particular element in the mixture is modified by the atomic shell structure of the other elements (*i.e.* by the fact that the ionization potentials differ from an element to another). With such a proper treatment of the interactions between electrons and between electron and nucleus, this model can produce reliable stellar opacities and equations of state. Calculations of the pressure in the center of the Sun will be presented, and compared with other models [3].

[1] J. C. Pain and T. Blenski, Laser Part. Beams 20, 211 (2002).
[2] J. C. Pain, G. Dejonghe and T. Blenski, J. Quant. Spectrosc. Radiat. Transfer 99, 451 (2006).
[3] J. Dai, Y. Hou and J. Yuan, Astrophys. J. 721, 1158 (2010).

PB-05
DINAMIC DUST PARTICLE CONFINEMENT IN CORONA DISCHARGE PLASMA

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Experimental research of argon-xenon dusty plasma and numerical simulation [1,2] shows the possibility of forming of the ordered dust structures and dust crystals from charged micron uranium and uranium oxide particles. Such dust structures allow to increase efficiency of the direct conversion of nuclear energy into the optical radiation. We are using numerical simulations to investigate the possibility of the forming of the dust structures in dynamic electrical traps such as the Paul trap or quadrupole trap. Numerical simulations of dust particles behaviour for potential forces acting on dust particles is considered, the influence of buffer gas medium is taken into account by viscosity and random forces. In considered model the dust particle motion is described by the Langevin equation:

$$m_d \frac{d^2 r_i}{d^2 t} = F_{tr}(t, r_i) + F_{\text{int}}(r_i) - 6 \quad R_d \frac{dr_i}{dt} + F_i^{Br} + F_{mg}$$

where i = 1,…,N_d, N_d – number of dust particles, R_d – dust particle radius, - dynamic viscosity, $F_{tr}(t,r_i)$=-grad(U_i ,t) – force of external electric field that compensate the gravity force, F_{Br} – stochastic delta correlated forces that describe dust and plasma particles collisions, F_{mg} – dust particle weight, $F_{int}(r_i)$=- grad(U_i) – forces acting between dust particles, U – potential energy of dust particle interaction accounting for the shielding. Detailed description of numerical method is given in [3]. All test of calculations were carried out for one dust particle in harmonic trap $V(x)=\omega x^2/2$. Test results agree very well with analytical solutions.

Obtained results for Paul trap showed the appearance of standing waves of the dust particle density arising due to the dynamic effects of periodic external low frequency electric field. The dependences of electric field amplitude and frequency needed for levitation of dust particles in a quadrupole trap have been studied. The dependence of the equilibrium position of dust structures in a quadrupole trap versus the frequency of the alternating electric field is investigated.

[1] Rykov V.A., Khudyakov A.S., Filinov V.S. and others, Plasma Physics. V.28, No.5, P.1-11. (2002)
[2] Filinov V.S., Naumkin V.N., Vladimirov V.I., Meshakin V.I., Rykov V.A., Influence of Potential and Non Potential Forces of Interparticle Interaction on Stability of Nuclear Excited Dusty Plasma, Contrib. Plasma Phys. V.49, No.7-8, P.446-450 (2009)
[3] Skeel R.D., Izaguirre J.A. An impulse integrator for Langevin dynamics, Molecular Physics. V.100, No.24, P.3885-3891. (2002)

PB-06
NONLINEAR RESPONSE THEORY OF NON-IDEAL CHARGED AND NEUTRAL MATTER

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The nonlinear response theory approaches are developed to study the nonlinear phenomena and nonlinear transport in non-ideal Coulomb systems. The nonlinear phenomena: plasma wave echo and waves transformation have been investigated under non-ideal Coulomb system conditions based on a variant of the nonlinear response theory. Some general restrictions on the values of nonlinear response functions are considered. The model for the determination of quadratic response functions is presented. The conditions for experimental realization of the mentioned phenomena in non-ideal plasma are examined. It is shown that ultra-short field pulses can induce the phenomena. Other nonlinear phenomena in non-ideal charged matter can be considered in the offered way. In these cases the studying of frequency moments and corresponding explicit approximations of response functions, described nonlinear phenomena, would be performed.

The theory of non-linear transport is elaborated to determine the Burnett transport properties of non-ideal multi-element matter. The procedure of the comparison of the phenomenological conservation equations of a continuous charged and neutral medium and the microscopic equations for dynamical variables is used for the definition of these properties. The Mori's algorithm is developed to derive the equations of motion of dynamical value operators of a non-ideal system in the form of the generalized nonlinear Langevin equations. In consequence, the correlation function expressions of kinetic coefficients corresponding to second order thermal disturbances (temperature, mass velocity, etc) have been found in the long-wavelength and low frequency limits. To establish a link between the results of the performed investigations and hydrodynamic problems the properties are discussed of the matrix of coefficients at highest derivatives in the set of conservation equations in the linearized Burnett approximation.

The method for calculation of Burnett kinetic coefficients is developed. This method is based on the investigations of long-wavelength limits of correlation functions which determine the coefficients. For the determinations of long-wavelength limits of correlation functions corresponding kinetic equations are used. The calculations are provided for a model system.

The approach for non-linear transport properties definitions can be used for different dense matter: one and two-component Coulomb systems, electrolytes, liquid metals, nuclear matter etc and for dense neutral isotropic matter. It is important also to provide the calculation of Burnett kinetic coefficients of non-ideal matter by computer modeling.

The report shows the difference and similarity between the variants of non-linear response theory: the description of nonlinear phenomena and nonlinear transport in non-ideal charged matter. Other nonlinear phenomena in non-ideal charged matter can be considered in the offered way. In these cases the studying of frequency moments and corresponding explicit approximations of response functions, described nonlinear phenomena, would be performed.

[1] G.A. Pavlov NONLINEAR TRANSPORT PROPERTIES OF NON-IDEAL SYSTEMS J. Phys.A, V.42, N 21, 214046, 2009
[2] G.A. Pavlov NONLINEAR RESPONSE THEORY IN DENSE PLASMA Mexico, Cancun, 11-17.07, 2009 r. (ICPIG 2009)
[3] G.A. Pavlov BURNETT COEFFICIENTS IN DENSE CHARGED AND NEUTRAL SYSTEMS Mexico, Cancun, 11-17.07, 2009 r. (ICPIG 2009)

PB-07
CHARGE CORRELATIONS IN A HARMONIC TRAP

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A system of N classical Coulomb charges trapped in a harmonic potential displays shell structure and orientational ordering. The shell structure can be accurately reproduced by using correlations from the bulk three dimensional one component plasma (3D OCP)[1]. In addition there are other relationships between the correlations of the trap system and the bulk OCP: the location free pair correlation function for the trap and the OCP are in agreement, and the orientational pair correlations within a shell agree with the bulk OCP when a specific length transformation is used (Euclidean distance replaced by arc length). This transformation leads to qualitative agreement with the 3D OCP and quantitative agreement with the 2D OCP, and is studied here with respect to the geometry and also the form of the Hamiltonians of the two systems. At stronger coupling the orientational correlations due to the ordering are in agreement with the single sphere Thomson problem, i.e. the Thomson sites represent a spherical "lattice" for the individual shells of the trap system. A simple model of the charges at the Thomson sites predicts the behavior of the finite temperature orientational correlations of the trap system as determined by molecular dynamics simulation. Research supported by DOE award DE-FG02-07ER54946, and by the Deutsche Forschungsgemeinschaft via SFB-TRR24.

[1] J. Wrighton, J. Dufty, H. Kählert, and M. Bonitz, Phys. Rev. E **80**, 038912 (2009); Contrib. Plasma Phys. **50**, 26-30 (2010).

PB-08
STRONGLY-COUPLED-COUNTERIONS MEDIATED INTERACTION REGIMES FOR TWO OPPOSITELY CHARGED PLATES

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A system of two oppositely charged plates constitutes a model of choice to get physical insights about ion mediated interactions between two bodies in electrolyte solutions. This is of interest for various fields ranging from colloidal science to cellular and sub-cellular biology [1]. In absence of salt reservoir the mean field treatment of the ions - when relevant - provides a very simple physical picture of what is happening in the system. In particular, a long range attraction is expected while a short range repulsion arises when the condensed counterions layers completely overlaps [2]. This mean field understanding however breaks down in principle if one has to deal with multivalent counterions or highly charged surfaces [3, 4]. In this work, we propose simple physical ideas applicable for two plates with strongly coupled condensed counterions to capture the physics at play for different short distances regimes. We then rely on the exact contact value theorem [5] to determine analytically the equation of state for each regime. To complete the picture we consider the large distance limit, from which one can retrieve a mean field picture for the interaction [6].

A schematic phase diagram displaying a reentrant behaviour finally summarizes plausible interaction paths when the plate to plate distance is decreased from infinity.

[1] V. Dahirel, F. Paillusson, M. Jardat, M. Barbi, and J.-M. Victor, Phys. Rev. Lett. 102, 228101 (2009).
[2] F. Paillusson, M. Barbi, and J.-M. Victor, Mol. Phys. 107, 1379 (2009).
[3] R. Netz, Eur. Phys. J. E 5, 557 (2001).
[4] L. _Samaj and E. Trizac, Phys. Rev. Lett. 106, 078301 (2011).
[5] H. Wennerström, B. Jönsson, and P. Linse, J. Chem. Phys. 76, 4665 (1982).
[6] A. dos Santos, A. Diehl, and Y. Levin, J. Chem. Phys. 130, 124110 (2009).

PB-09
VELOCITY AUTOCORRELATION FUNCTIONS AND DIFFUSION COEFFICIENT OF DUSTY COMPONENT IN COMPLEX PLASMAS

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Such a complex system as a dusty plasma is characterized by many parameters, which may influence in various ways to the investigated characteristics. One of these parameters is the charge of dust particles. Theoretically, it can be determined by different methods, the simplest method is a method based on the condition of the equilibrium of electron thermal energy and its electrostatic energy of interaction with dust particle. More adequate method is to calculate the charge basing on the theory of OML, in this theory the balance equation of flows of electrons and ions on the surface of the macroparticle is used. Included in the balance equation the electron velocity distribution function (VDF) is usually taken as Maxwellian, however, it is known that in gas discharges VDF differs from Maxwellian. In [1,2] were calculated VDF and the charges of dust particles in dusty plasmas of dc glow discharge.

In the present work, the velocity autocorrelation function of dust particles and their diffusion coefficient for different parameters of dusty plasma, based on computer simulation method of Langevin dynamics (see [3]) were obtained. Particular attention is paid to depending on the investigated variables on the charge of dust particles.

[1] G.I. Sukhinin, A.V. Fedoseev, T.S. Ramazanov, K.N. Dzhumagulova, R. Amangaliyeva, J. Phys.D, 40, 7761 (2007)

[2] G.I. Sukhinin, A.V. Fedoseev, T.S. Ramazanov, K.N. Dzhumagulova, R. Amangaliyeva, Abstr. XXVIII Int. Conf. On Phenomena in Ionized Gases. 2007, Prague, Czech Republic, P.252.

[3] F.B. Baimbetov, T.S. Ramazanov, K.N. Dzhumagulova, E.R. Kadyrsizov, O.F. Petrov and A.V. Gavrikov, J.Phys.A: Math. And Gen., 39, 4521–4525 (2006).

PB-10
THERMODYNAMICAL FUNCTIONS OF HYDROGEN AT LOW DENSITIES, FROM PLASMA TO MOLECULAR PHASES

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A precise knowledge of the thermodynamical properties of hydrogen is needed by astrophysicts over a wide range of pressures and temperatures. The low-density regime, where a finite fraction of the charges may recombine into atoms H or molecules H_2, is of strong interest for both theoretical reasons and for astrophysical applications. A highly accurate equation of state in that regime is necessary for instance to interpret helioseismology measurements.

The sought-after accuracy in that regime can only be obtained by using the physical picture, in which hydrogen is described in terms of a quantum plasma made up of protons and electrons interacting via the Coulomb $1=r$ potential. The screened cluster representation [1] of the quantum electron-proton plasma is well suited to study hydrogen in the low density regime, since it allows to treat all screening, interaction and recombination phenomena at work in a fully consistent and more tractable way than in other many-body methods. That representation is obtained from a systematic reorganization of the activity series to take into account screening and recombination into arbitrary complexes (characterized by well-defined partition functions in the vacuum). The screened cluster representation has been used recently to derive an exact asymptotic expansion for the equation of state of a dilute partially-ionized atomic hydrogen gas [2, 3, 4] in some scaling low temperature and low density limit. Here, we turn to a more phenomenological approach, still based on the screened cluster representation. Now, we keep a few suitable diagrams, which account for the phenomena which are expected, on physical grounds, to provide the most important contributions at low densities. Within that approximation, and using also familiar phenomenological values for rotational and vibrational energies, we compute the resulting pressure and thermal equations of state of hydrogen. The newly calculated values coincide with those of the exact asymptotic expansion in the dilute plasma and atomic phases, while still remaining reliable in the molecular phase, provided the density is not too high. Our thermodynamical values are compared with those of path integral Monte Carlo simulations [5] and of the OPAL tables [6], which have been calculated using the ACTEX method [7] in the physical picture.

[1] A. Alastuey, V. Ballenegger, F. Cornu and Ph.A. Martin, J. Stat. Phys. 113:455-503 (2003)
[2] A. Alastuey, V. Ballenegger, F. Cornu and Ph.A. Martin, J. Stat. Phys. 130:1119-1176 (2008)
[3] A. Alastuey and V. Ballenegger, J. Phys. A: Math. Theor. 42, 214031 (2009)
[4] A. Alastuey and V. Ballenegger, Contrib. Plasma Phys. 50, 46 (2010)
[5] B. Militzer and D. Ceperley, Rev. Rev. E 63, 066404 (2001)
[6] F. J. Rogers, F. J. Swenson, and C. A. Iglesias, Astro phys. J. 456, 902 (1996)
[7] F.J. Rogers, Phys. Review A 10: 2441 (1974)

PB-11
ON THE EFFECT OF ELECTRON'S RUNAWAY IN PARTIALLY IONIZED HYDROGEN SEMICLASSICAL NONIDEAL PLASMA

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The effect of runaway electrons occurs frequently in tokamak plasmas. The majority of experiments in tokamak research have been devoted to the study of confinement properties of runaway electrons. Runaway electrons are reason of various destroying untolarance in tokamak plasmas [1,2]. At high plasma density, when the critical energy is comparable with the rest energy the multiplication of runaway electrons accelerate at the sacrifice of increase of plasma density. The plasma conductivity is determined by electrons with energy several times higher than the thermal one and does not practically depend on slower electrons distribution [3]. It is important to analyze the probability of runaway electrons at investigation of physical properties of nonideal plasmas under external electric field and running numerical simulations of their [4,5].

The present paper is devoted to the investigation of effect of runaway electrons in partially ionized hydrogen dense plasma using the effective potentials of particle's interaction [6-8]. At the investigation of composition of plasma we used the Saha equation with corrections to nonideality (lowering of ionization potentials). The Saha equation was solved for obtaining of plasma ionization stages at the different number density and temperature.

As well, when take into account quantum-mechanical diffraction and screening effects, whereas free path of electrons increases with increase of plasma coupling parameter. The condition for appearance of runaway electrons in semiclassical partially ionized plasma is more favorable in regime of dense plasma. In summary it means that the probability of runaway electron in dense plasma is more than the same in rarified plasma that is possibly connected with formation of some ordered structures in dense plasma [9].

[1] J. R. Martнn-Solнs, B. Esposito, R. Sõnchez, F. M. Poli, and L. Panaccione. Phys. Rev. Lett. 97, 165002 (2006)
[2] M. Bakhtiari, D.G. Whyte. Phys. Plasmas 13, 112511 (2006);
[3] Kozlov N.P., Protasov Yu.S., Norman G.E. Phys. Lett. - 1980. - Vol. 77A, № 6. - P. 445.
[4] P.B. Parks, Cowan T.E. Phys. Plasmas 14, 013102 (2007);
[5] T.S. Ramazanov, K.M. Turekhanova. Phys. Plasmas. 12, 102502 (2005)
[6] T.S. Ramazanov, K.N. Dzhumagulova Phys. Plasmas. 9. 3758 (2002)
[7] R. Redmer Phys. Rev. E. 59, 1073 (1999)
[8] T.S. Ramazanov, K.N. Dzhumagulova, Yu.A. Omarbakiyeva, G. Roepke. J.Phys.A: Math. And Gen. 39. 4369 (2006)
[9] T.S. Ramazanov, K.M. Turekhanova. Phys. Plasmas. 12, 102502 (2005)

PB-12
THE BEHAVIOR OF DUST PARTICLES NEAR LANGMUIR PROBE

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The dynamics of dust particles near negative Langmuir cylindrical probe was numerically analyzed in [1,2]. In this work the dynamics of dust particles near electric probe depending on the pressure in the discharge tube was studied. Trajectories of dust particles at different pressure values with taking into account of the ion drag force and neutral friction force were calculated numerically. Ion drag force was observed in the layer at the surface of the probe with a large negative potential when the ions moved along radial direction. Numerical calculations showed that with increasing of pressure the ion drag force effects more significantly than the neutral friction force due to the high velocities of dust particles and increase the attraction of dust particles to the probe. The experimental results indicated the same result that with increasing of gas pressure the influence of the probe on the trajectories of dust particles has been increased. The calculated results were compared with experimental results and showed the good agreement.

[1] T.S. Ramazanov, et al., J. Phys. A: Math. Theor., 42, 214026(2009)
[2] T.S. Ramazanov, et al., Physics of Plasmas 15, 053704(2008)

PB-13
CRYSTALLIZATION OF AN EXCITON SUPERFLUID

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Indirect excitons pairs of electrons and holes spatially separated in semiconductor bilayers or quantum wells are known to undergo Bose-Einstein condensation and to form a quantum fluid. Here we show that this superfluid may crystallize upon compression. However, further compression results in quantum melting back to a superfluid. This unusual behavior is explained by the effective interaction potential between indirect excitons which strongly deviates from a dipole potential at small distances due to many-particle and quantum effects [1]. The effective inter-exciton interaction potential is obtained by a full two-exciton calculation including particle spins and finite electron/hole effective masses.

Based on first principle path integral Monte Carlo simulations, we compute the complete phase diagram (see Fig.1) of this system and predict the relevant parameters necessary to experimentally observe exciton crystallization in semiconductor quantum wells [2].

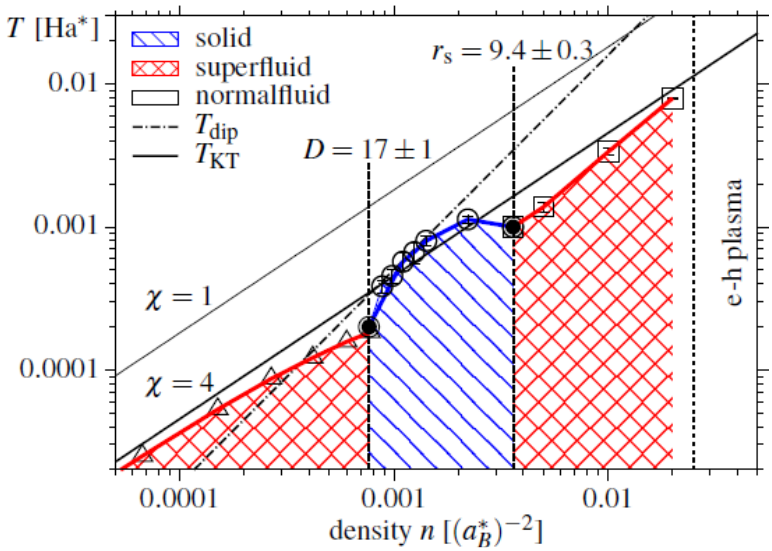

Figure 1: Phase diagram of 2D indirect excitons with the dipole moment $d = 13{:}3\ a_B^*$. *Vertical dashed lines (*$D = 17 \pm 1$ *and* $r_s = 9{:}4 \pm 0.3$*) indicate the two density induced quantum freezing (melting) transitions. The normal fluid–superfluid phase boundary is marked by the red line. Line* T_{dip} *marks the freezing transition of a classical 2D dipole system*

[1] A Filinov, P Ludwig, M Bonitz, and Y E Lozovik, J. Phys. A 42, 214016 (2009).
[2] J. Böning, A. Filinov, and M. Bonitz, submitted for publication, arxiV: 1101.1757

PB-14
STRONGLY COUPLED FINE PARTICLES PLASMAS AS SOLUTIONS

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Fine particles in fine particle (dusty, complex) plasmas easily become strongly coupled due to large negative charges accumulating on their surfaces. When the density of fine particles is low enough, they can be regarded as a solute in the solvent of ambient plasma composed of ions and electrons. Even in this case, the coupling between fine particles can still be kept in the state of strong coupling. When we analyze the thermodynamics of this solution, we find a possibility of phase separation and related critical point[1]. Some examples of parameters are shown in Figs.1, 2, and 2. In this presentation, we further search for the physical parameters of fine particle plasmas which are appropriate to observe the above predictions in experiments. Our aim is at finding the relation of this property of the solution to sharp boundaries often observed in fine particle plasma experiments. The behaviour of the solution near the critical point will also be investigated especially from the point of view of application to chemical reactions.

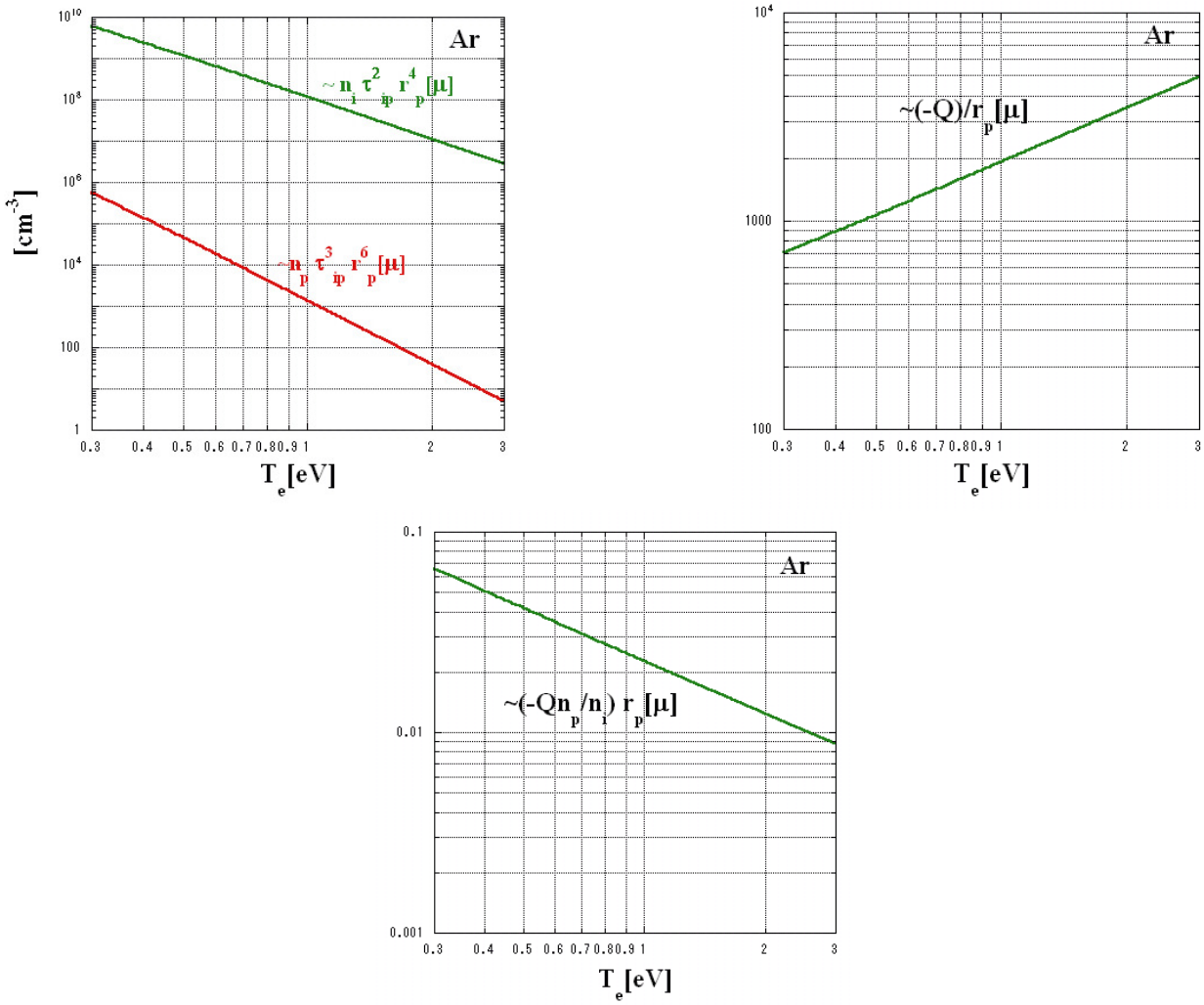

Figure 1: Examples of parameters at critical point of fine particle solutions

[1] H. Totsuji, Microgravity Science and Technology, **23**, 159(2011).

PB-15
CONFIGURATIONAL ENTROPY OF CONFINEDWIGNER CLUSTERS

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Competition between the strong repulsion between charged particles and their external confinement results in formation of ordered structures –Wigner clusters. A number of informative experiments have been performed on charged particles in a plasma environment [1], however, the phenomenon is a general one as analogous situations exist in diverse systems such as semiconductor quantum dots or vortex matter in superconductors. In most cases, a number of competing stable configurations (the ground state plus numerous metastable states) are observed [1, 2].

It is often argued that the total number of metastable states grows exponentially with the the number of particles in the trap. However, the total number of metastable states is not a well-defined and representative quantity as different states have very different realization probabilities, and not all metastable states are found during the finite time of an experiment or a simulation.

Therefore we propose to rely on an alternative concept of configurational entropy [3] akin to the Shannon entropy defined in the context of information theory: $S = -\Sigma_k p_k \log p_k$.

Here, the index k numbers various stable configurations and p_k stands for their respective realization probabilities. This entropy may be understood as the logarithm of the effective number of states.

We apply the concept of configurational entropy to confined 2D and 3D systems interacting through both long-range (Coulomb) and short-range (Yukawa, logarithmic) forces.

The results indicate that: (i) the entropy is indeed a robust quantity as it can be determined quickly and reliably, (ii) the entropy is larger in systems with short interparticle interaction range, and (iii) the effective number of states grows faster than the exponential function of the number of constituent particles.

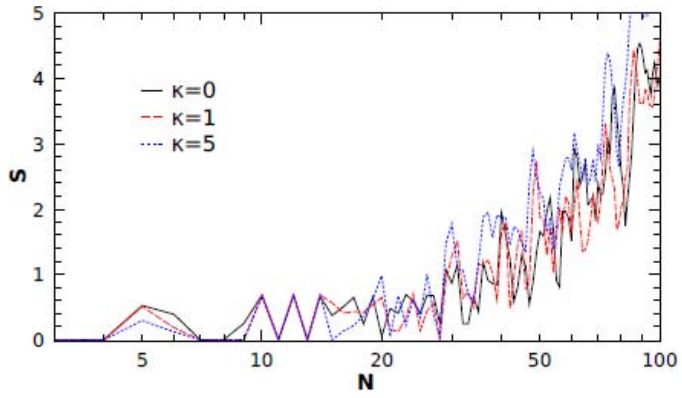

Figure 1: Configurational entropy of a 2D Wigner cluster plotted as a function of the number of particles N. Three curves corresponding to different values of the dimensionless screening strength κ are shown.

[1] M. Bonitz, C. Henning and D. Block, Rep. Prog. Phys. 73, 066501 (2010).
[2] H. Kählert et al., Phys. Rev. E 78, 036408 (2008).
[3] A. Radzvilavičius and E. Anisimovas, J. Phys.: Condens. Matter 23, 075302 (2011).

PB-16
THE TRIPLE CORRELATION FUNCTION AS A TOOL FOR ANGLE RESOLVED STRUCTURAL ANALYSIS OF SPHERICAL CLUSTERS

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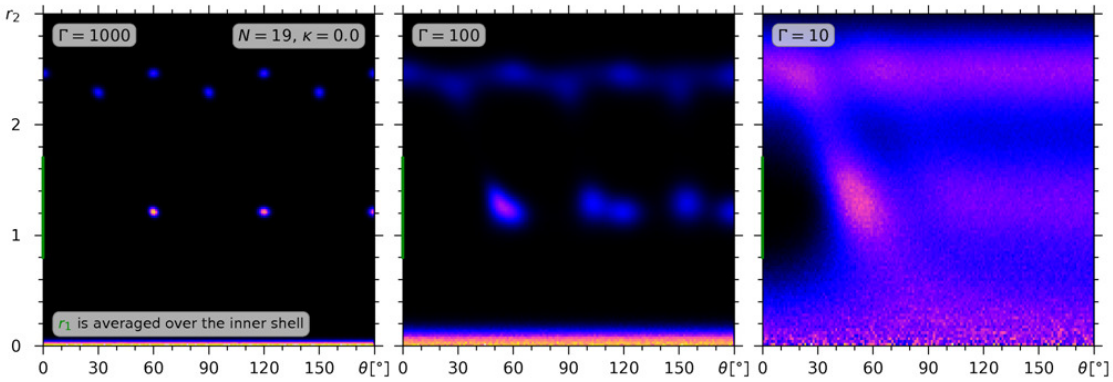
Finite charged particle ensembles in externally controlled confinement geometries allow for a systematic investigation of correlation effects over broad ranges of plasma parameters. Additionally, the formation of distinct shells emerges as a governing finite-size effect in systems of trapped ions and dusty plasma as well [1].

As a sensitve tool to study the internal cluster structure, we introduce the "Triple Correlation Function" (TCF), which allows for an angle resolved structure analysis.[2] The TCF can not only resolve the transition probability of particles between shells, but also structural modifications within the shells during dynamic processes, e.g. melting or excitation. In particular this quantity is not affected by rotational invariance (i.e. rotation of the entire cluster).

Using the TCF we study the effect of Coulomb screening, temperature, and special symmetries of different ground and metastable states with respect to the exact particle number as well as the limiting case of large N.



TCF for a 2D Coulomb cluster with N=19 particles during the melting process

[1] M. Bonitz, C. Henning, and D. Block, Reports on Progress in Physics 73, 066501 (2010)
[2] P. Ludwig, H. Thomsen, K. Balzer, A. Filinov, and M. Bonitz, Plasma Phys. Control. Fusion 52, 124013 (2010)

PB-17
STRUCTURES AND DYNAMICS OF YUKAWA AND COULOMB PARTICLES IN CYLINDRICAL SYSTEMS

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Low temperature structures of Yukawa particles in systems with cylindrical symmetry are analyzed by numerical simulations. As is shown in Fig.1, particles are organized into well-defined thin concentric shells forming triangular lattices with defects on each shell and structural parameters are expressed by simple interpolation formulas including the limiting case of Coulomb particles. In outer shells, the local structure can be regarded as three-dimensional closest packing as in the case the background of uniformly filled spheres. These formulas can be directly compared with fine particle experiments in long cylindrical chambers under microgravity or colloidal suspensions in cylinders and may be useful as a basis of structural analyses in cylindrical systems.

When we have two species of particle with different charge, they form shells separately. As is shown in Fig.2, the shell of larger charges seems to be located inside of the one of smaller charges. However, the parameter space even in the case of two species is wide and it is difficult to survey completely. In this case, dynamical properties are of interest: One may have relative translational motion between two species which can be compared with experiments under the electric field parallel to the axis.

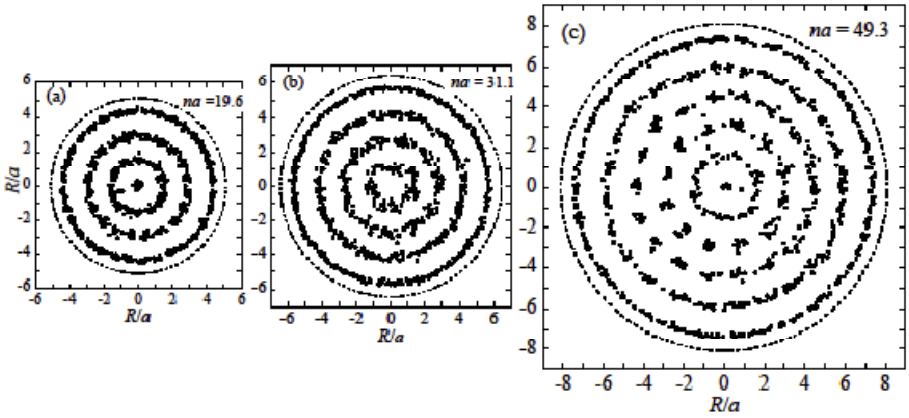

Figure 1: Examples of structures

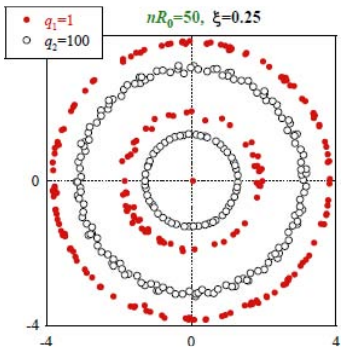

Figure 2: Example of structures in two-component system

PB-18
HOW TO CONVERT SPME INTO P3M: LATTICE GREEN FUNCTIONS AND ERROR ESTIMATES

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Particle-Mesh methods, such as Particle-Particle Particle-Mesh (P3M) [1] and Smooth Particle Mesh Ewald (SPME) [2], are efficient methods to compute long-range Coulomb (or gravitational) forces in simulations of many-particle systems. These methods reduce the complexity of computing $O(N^2)$ pairwise interactions into an $O(N \log N)$ problem by discretizing the charge density onto a mesh and by using Fast-Fourier-Transforms to calculate the electrostatic potential.

Several variants of particle-mesh methods exist, characterized by different choices for some ingredients, in particular the charge assignment function used to map the particles onto the mesh, the lattice Green function used in the computation of the electrostatic potential, and the differentiation scheme used to calculate forces from the mesh-based potential. The accuracy of particle-mesh methods can also be enhanced by using mesh interlacing (or staggering). In the SPME method, forces are computed for example by using the analytical differentiation (AD) scheme, which uses the exact gradient of the charge assignment function, while forces are usually computed in a P3M algorithm by using finite differences, or by differentiating the potential in reciprocal space (multiplication by $i\sim k$).

The accuracy of the P3M method has been studied in depths using Fourier and signal analysis methods. That analysis allowed to optimize the accuracy of the P3M method via the use of an error-minimizing lattice Green function, and also to have full control over the accuracy of the method thanks to an a priori error estimate [1, 3].

In this work, we show that a similar analysis can also be applied to the commonly used SPME method. This enables to convert straightforwardly an SPME method into the corresponding P3M method, which allows to improve slightly the accuracy of the algorithm by using the optimized P3M lattice Green function [4]. As a by-product, that analysis yields also an a priori error estimate for the SPME method. Thanks for that error estimate, the various parameters of the method (mesh size, charge interpolation order, Ewald splitting parameter, real-space cutoff) can be tuned automatically in a simulation program to reach a given target accuracy of the forces at a minimal computational cost.

When using the AD scheme, particles are subjected to self-forces that depend on the position of the particle relative to a mesh cell. A formula allowing to substract completely these spurious self-forces within the particle-mesh calculation is also provided [5].

[1] R.W. Hockney and J.W. Eastwood, Computer Simulation Using Particles (IOP, Bristol, 1988)
[2] U. Essmann, L. Perera et al., A Smooth Particle Mesh Ewald Method, J. Chem. Phys. 103, 8577 (1995)
[3] M. Deserno and C. Holm, How to mesh up Ewald sums II: an accurate error estimate for the P3M method, J. Chem. Phys. 109, 7694 (1998)
[4] V. Ballenegger, J.J. Cerdà and C. Holm, How to convert SPME into P3M: lattice Green functions and error estimates, submitted for publication.
[5] V. Ballenegger, J.J. Cerdà and C. Holm, Removal of spurious self-interactions in particle-mesh methods, Computer Physics Communications (2011), doi:10.1016/j.cpc.2011.01.026

PB-19

ON THE NATURE OF DD SYNTHESIS AT INITIAL AND FURTHER STAGES OF VACUUM DISCHARGE WITH DEUTERIUM-LOADED PD ANODE

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The generation of energetic ions and DD neutrons from microfusion at the interelectrode space of a low energy nanosecond vacuum discharge with deuterium-loaded Pd anode has been demonstrated recently [1]. To understand better the physics of fusion processes the detailed particle-in-cell (PIC) simulation of the discharge experimental conditions have been developed [2] using a fully electrodynamic code KARAT [3]. At this work the review of experimental data and modelling results related is presented. The dynamics of all charge particles was reconstructed in time and anode-cathode (A-C) space. The principal role of a *virtual cathode* (VC) and the corresponding single and double potential well formed in the interelectrode space are recognised. The calculated depth of the *quasistationary potential well* (PW) of the VC is about 50-60 kV, and the D^+ ions being trapped by this well accelerate up to energy of few tens keV that provides DD nuclear synthesis under head-on D^+ collisions. In particular, ions in the potential well undergo high frequency (~80 MHz) harmonic oscillations accompanied by a corresponding regime of oscillatory DD neutron yield. The value of high frequency ion oscillations observed coincides with extrapolation of expressions obtained for inertial electrostatic confinement fusion (IECF) scheme with periodic oscillating plasma spheres (POPS) [4] (for A-C geometry of experiment [1] and PW depth calculated [2]). In fact, the miniature size of VC (r_{VC} ~ 0.1 см) and rather deep PW (like ≈ 50 кV) correspond to favourable *scaling of the fusion power density* (~ $^2/r^4_{VC}$) as well as for frequency of ions oscillations (~ $^{1/2}$ $/r_{VC}$) which have been demonstrated at the present moment by IECF scheme based on table-top vacuum discharge [1,2]. (Underline, that expanded ion cloud is *strongly coupled* meanwhile collapse phase corresponds to fusion temperatures). The anode erosion may provide the partial fulfillment of PW by deuterium clusters (dense interelectrode ensembles).The total trapping of fast ions by clusters observed would increase the neutron yield essentially (up to ~ $10^7/4$) [1,2]. Besides of small-scale discharge geometry itself, the limiting case $r_{VC} \rightarrow 0$ might be realized at very initial stage of discharge probably also, when the voltage is applied and electron beam extracting from cathode starts to interact with the surface of deuterium-loaded Pd anode. In fact, at this early stage of discharge sometime the neutron peaks registered by time-of-flight do appear also. We may conclude preliminary that micropores, microcracks, dislocations (fulfilled by dense deuterium) and so on, at deuterium-loaded Pd anode represent potential natural array of microchannels for certain number of microfusions near the surface at initial stage of discharge (integrated multichannel chip –sized microreactor).

[1] Yu.K. Kurilenkov, M. Skowronek and J.Dufty. J.Phys.A:Math&Gen 39 4375 (2006).
[2] Yu.K. Kurilenkov, V.P.Tarakahov, S.Yu.Gus'kov et al. J.Phys.A: Math &Theor 42 214041 (2009); Yu. K. Kurilenkov et al. Plasma Physics Reports 36 (2010) 1227 (2010).
[3] V.P.Tarakanov. User's Manual for Code KARAT (BRA Inc., Va, USA, 1992).
[4] J. Park, R.Nebel et al. Physics of Pasmas 12 (2005) 05631.

PB-20
THE KINETIC THEORY MOLECULAR DYNAMICS METHOD

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We are interested in simulating plasmas under conditions relevant to the National Ignition Facility and thermonuclear burn. Under these conditions, the plasma electrons are generally moderately degenerate, weakly coupled, and quantum mechanical, whereas the ions are known to be fully classical and are moderately to strongly coupled. As such, we have recently developed the Kinetic Theory Molecular Dynamics (KTMD) method, which attempts to take advantage of these properties under with the observations that: (1) molecular dynamics is very good at propagating classical particles and computes their correlations exactly and (2) kinetic theory is well developed for weakly coupled plasmas. Hence, the basic approach of KTMD is to describe the non-equilibrium electron dynamics fully with a kinetic equation while leaving the ion dynamics to MD.

The current version of KTMD self-consistently follows the time evolution of an initial Fermi-Dirac electron distribution via the Vlasov-Poisson system. Our method utilizes smoothed particle shapes within the KT framework to avoid the "Coulomb catastrophe" common to point electrons within the standard MD framework. An optimized Ewald method has been developed for the calculation of Coulombic forces.

We present several initial results obtained using the WPMD method and discuss future improvements to the code. These include a binary collision model within the Vlasov framework as well as the extension of the method to the quantum Vlasov (Wigner) equation.

PB-21
COLLECTIVE MODES IN CLASSICAL MASS-ASYMMETRIC BILAYERS

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In order to better understand the collective mode behavior of electronic bilayers actually realized in laboratory quantum well structures, there is a need to take into account the mass asymmetry. For example, in electron-hole bilayers (EHBs), one can hardly ignore the marked disparity in the electron and hole masses. So, with the aid of the quasilocalized charge approximation (QLCA), we have calculated the longitudinal sound speeds and long-wavelength finite-frequency (energy) gaps for closely spaced massasymmetric EHB and electron bilayer (EBL) systems. The present study generalizes our earlier QLCA collective mode studies in symmetric EBLs [1, 2] and EHBs [3].

Concentrating here on the closely spaced equal-density EHB in its dipole liquid phase, we find that for $d/a < 1$ (d is the layer spacing and a is the 2D Wigner-Seitz radius), the small-k behavior of the "in-phase" mode is acoustic with slope $s_+ \propto \omega_0 d$, where $\sqrt{\omega_0 = 4e^2/(m_1 + m_2)a^3}$. This is in marked contrast to the $\sqrt{d}$ dependence exhibited by the RPA acoustic speed $s_+ = \omega_0\sqrt{ad}$; this latter is entirely suppressed in the strongly coupled dipole liquid. Note the decidedly different in-phase dispersion of the strongly coupled EBL liquid, $\omega_+(k\to 0) \approx \omega_0\sqrt{2ka}$. The "out of phase" collective mode spectrum of the EHB dipole liquid features the $k = 0$ finite-frequency energy gap formula [3] which is dominated by the prominent Gaussian-like peak in the interlayer pair distribution function at $r = 0$ [4]; thus the emergence of the Kepler frequency $\Omega_K(d) = \sqrt{(e^2/\pi d^3)(1/m_1 + 1/m_2)}$. Here, in contrast to the in-phase acoustic speed, it is the lighter particles (the electrons) that play the dominant role. Our calculated sound speed for the closely spaced asymmetric EHB is in perfect agreement with the sound speed reported for the strongly coupled 2D dipole liquid with repulsive interaction potential $\varphi(r) = e^2d^2/r^3$ [5, 6].

[1] G. J. Kalman, V. Valtchinov, and K. I. Golden, Phys. Rev. Lett. 82, 3124 (1999).
[2] Z. Donkó, G. J. Kalman, P. Hartmann, K. I. Golden, and K. Kutasi, Phys. Rev. Lett.90, 226804 (2003).
[3] G. J. Kalman, P. Hartmann, Z. Donkó, and K. I. Golden, Phys. Rev. Lett.98, 236801 (2007).
[4] P. Hartmann, Z. Donkó, and G. J. Kalman, Europhys. Lett. 72, 396 (2005).
[5] K. I. Golden, G. J. Kalman, Z. Donkó, and P. Hartmann, Phys. Rev. B 78, 045304 (2008); 78, 239905(E) (2008).
[6] K. I. Golden, G. J. Kalman, P. Hartmann, and Z. Donkó, Phys. Rev. E 82036402 (2010).

PB-22
DIFFUSION IN A QUASI-ONE-DIMENSIONAL SYSTEM WITH A PERIODIC SUBSTRATE

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The diffusion of charged particles confined in a quasi-one dimensional (Q1D) system and subjected to a periodic substrate is investigated. The particles interact through a repulsive Yukawa potential, are confined by a parabolic potential in the y-direction and subjected to a periodic substrate potential in the x-direction. Brownian dynamic simulations are used to investigate the effect of the particle density, substrate strength, and the range of the interparticle interaction potential on the diffusive behavior of the particles. We found that the diffusion can be suppressed and remarkably even enhanced in certain cases when increasing the strength of the substrate potential. In addition, we found a strong dependence of the diffusion on the specific arrangement of the particles, e.g. single-chain versus multi-chain configuration. For certain particle configurations, a reentrant behavior of the diffusion is found as function of the substrate strength due to structural transitions in the ordering of the particles.

PB-23
NON-IDEAL DUST STRUCTURES IN CRYOGENIC COMPLEX PLASMAS

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In the previous research [1] of cryogenic complex (dusty) plasma we observed experimentally the possibility of the formation of dust structures in cryogenic environment at 4.2-77 K. It was revealed from the experiments, among others, that the dust structures with high concentration of dust particles can be formed, in which interparticle distance is comparable with particle size – so-called superdense dusty plasma structures. Such structures had exotic properties such as globular (spherical) form, free boundaries, etc. In the present work new results on the experimental investigations of *spheroidizing* – phenomenon of the transition of dust structures to compact globular shape at cryogenic temperatures – were presented. The experiments were made by means of recently developed techniques and new cryogenic facilities (optical helium cryostat). Possible nature of such phenomenon is discussed.

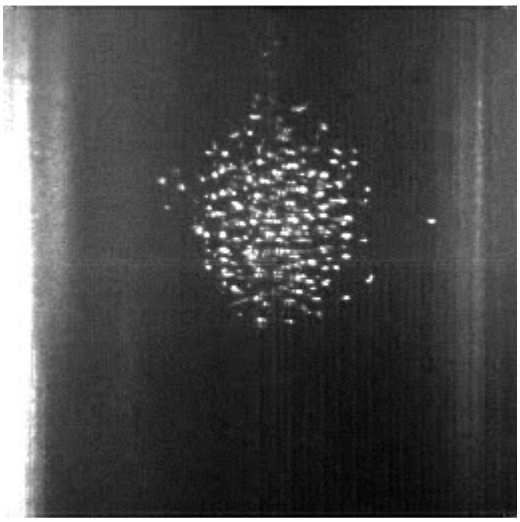

Figure 1: Compact globular dust structure in DC glow discharge at 77K

[1] S. N. Antipov, et al., Phys. Plasmas. 14, 090701 (2007)

PB-24
GROUND STATE STRUCTURES OF SUPERPARAMAGNETIC DUSTY PLASMA CRYSTALS

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In colloidal suspensions sub-micron sized (~100 nm) polyacrylate-capped superparamagnetic magnetite (Fe_3O_4) particles were successfully used to produce highly tunable photonic crystals [1,2]. We investigate the possibility of using similar superparamagnetic particles in the micrometer size range in planar dusty plasma experiments with the aim of producing a tunable lattice structure for possible application in the THz technology [3].

We present numerical results based on lattice summation and molecular dynamic (MD) methods for 2D Yukawa systems of charged particles with magnetic moment. Ground state configuration is identified by computing and minimizing the total (magnetic + electrostatic) interaction potential energy of the rhombic crystalline system, keeping the screening length ($_D$), the particle charge (Q) and the total pressure (p) constant, while varying the density (n), the rhombic angle ( ) and the aspect ratio. In the MD simulations the time evolution of the system (consisting of about 10.000 particles at high Γ) is simulated using a flexible simulation cell with varying rhombic angle ( ) and aspect ratio. Periodic boundary conditions are applied. The stress matrix is evaluated and the simulation box is slowly deformed to fulfill the prescribed equilibrium conditions: $_{xy} = _{yx} = 0$ (shear-stress), $_{xx} = _{yy} = p_0$ (pressure).

Our preliminary results for the case of the magnetic moments oriented perpendicular to the particle layer show that the hexagonal lattice structure is preserved even with a significant variation of the particle density. Our previous studies of in-plane magnetization [4] have shown a changing lattice structure as a result of varying the direction of the in-plane magnetic moment. Allowing an arbitrary direction and amplitude for the magnetization we expect a rich variety of crystalline structures and a significant variation of the particle density (up to a factor of about 2).

Work partially supported by Grants OTKA-T-77653, OTKA-PD-75113, MTA NSF/102 and NSF-PHYS 0715227, DOE grant DE-FG02-04ER54804.

[1] Jianping Ge, Yongxing Hu, and Yadong Yin, Angew. Chem. Int. Ed. 46, 7428 (2007)
[2] Jianping Ge, Yongxing Hu, Tierui Zhang, Tuan Huynh, and Yadong Yin, Langmuir 24, 3671 (2008)
[3] M. Rosenberg, D. P. Sheehan, P. K. Shukla, IEEE Trans. Plasma Sci. 34, 490 (2006)
[4] J. D. Feldmann, G. J. Kalman, P. Hartmann, and M. Rosenberg, Phys. Rev. Lett. 100, 085001 (2008)

PB-25
DENSITY-DENSITY CORRELATIONS WITHIN A NANOSAMPLE IRRADIATED BY AN XFEL PULSE

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Single molecule imaging at atomic (0.1nm) resolution is a major goal for the present and forthcoming X-ray Free Electron Lasers (LCLS, European XFEL, SCSS) [1-3]. The high intensity (10^{20} W/cm^2) and the extremely short pulselength (<100fs) of the XFEL beam are needed to get a sufficiently strong scattering signal from the sample and to reduce the effect of radiation damage at the same time. However, the measured diffraction patterns are still influenced by the deterioration of the sample during pulse, so modelling and understanding of the dynamics of radiation damage is needed.

Continuum approach [4,5] is an effective way of modelling dynamics of 10-100 nm size samples, that can be used to investigate the changes of the diffraction pattern. However, continuum models deliver information on average quantities (e.g. average electron and ion densities), so scattering intensities derived this way may differ from the scattering intensities obtained by averaging over individual diffraction patterns. The difference depends on density-density correlation functions.

Here we report on the theoretical and numerical investigation of the electron density-density correlation function in irradiated systems during single biomolecule imaging process. The suitability of applying the continuum model for image degradation studies will be discussed.

[1] P. Emma, R. Akre, J. Arthur, R. Bionta, C. Bostedt, J. Bozek, A. Brachmann, P. Bucksbaum, R. Coffee, F.-J. Decker, Y. Ding, D. Dowell, S. Edstrom, A. Fisher, J. Frisch, S. Gilevich, J. Hastings, G. Hays, P. Hering, Z. Huang, R. Iverson, H. Loos, M. Messerschmidt, A. Miahnahri, S. Moeller, H.-D. Nuhn, G. Pile, D. Ratner, J. Rzepiela, D. Schultz, T. Smith, P. Stefan, H. Tompkins, J. Turner, J. Welch, W. White, J. Wu, G. Yocky, and J. Galayda, Nature Photon. 4, 641-647 (2010)
[2] M. Altarelli, R. Brinkmann, M. Chergui, W. Decking, B. Dobson, S. Düsterer, G. Grübel, W. Graeff, H. Graafsma, J. Hajdu, J. Marangos, J. Pflüger, H. Redlin, D. Riley, I. Robinson, J. Rossbach, A. Schwarz, K. Tiedtke, T. Tschentscher, I. Vartaniants, H. Wabnitz, H. Weise, R. Wichmann, K. Witte, A. Wolf, M. Wulff, and M. Yurkov, eds., The European X-Ray Free–Electron Laser Technical Design Report (DESY, Germany, 2007)
[3] T. Tanaka and T. Shintake, eds., SCSS X-FEL Conceptual Design Report (RIKEN, Japan, 2005)
[4] B. Ziaja, A. R. B. de Castro, E. Weckert, and T. Möller, Eur. Phys. J. D 40, 465-480 (2006)
[5] S. P. Hau-Riege, R. A. London, and A. Szoke, Phys. Rev. E 69, 051906 (2004)

PB-26
STRUCTURAL AND TERMODYNAMICAL PROPERTIES OF DUSTY PLASMA PARTICLES

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In the present work structural and thermodynamic properties of fully ionized hydrogen plasmas with conductive grains are investigated from the viewpoint of a new pseudopotential model of dusty plasma particles interactions [1]. The pseudopotential model itself, taking into account correlation effects, is derived with the help of the so-called generalized Boltzmann-Poisson equation [1]. The static structure factors as long as corresponding thermodynamic characteristics (the equation of state, correlation and internal energies) are calculated on the basis of the proposed interaction model. The results obtained adequately describe the possibility of short- and long-range order formations.

[1] Yu. V. Arkhipov, F. B. Baimbetov, A. E. Davletov, Phys. Rev. E 83, 2011, 016405.

PB-27
LASER FOCUSING AND MULTIPLE IONIZATION OF ARGON IN A HYDROGEN PLASMA CHANNEL CREATED BY A PRE-PULSE

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A model for plasma channel formation by a laser pre-pulse in a low z gas (Hydrogen) embedded with high z atoms (Argon) is developed. The laser of intensity $I \cong 10^{14} W / cm^2$ ionizes hydrogen atoms fully whereas Argon atoms are ionized only singly. After the first pulse is gone, plasma expands on the time scale of a nanosecond to produce a hydrogen plasma channel [1,2] with minimum density on the axis. A second intense short pulse laser of intensity $I \geq 10^{16} W / cm^2$ gets focused. It tunnel ionizes the remaining Argon. The Argon acquires Ar^{8+} charge state after loosing 8 ions and acquires Neon like configuration and could emit X-rays[3,4].

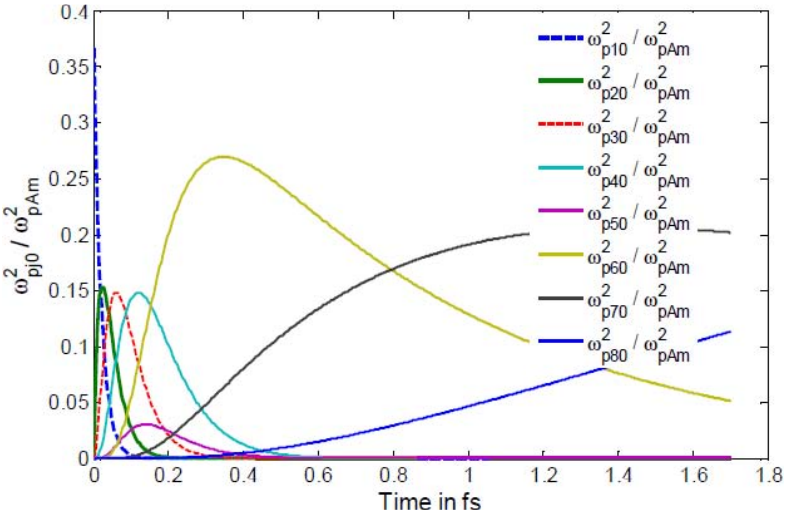

Figure 1. Variation of axial density of different charge states of argon ions with time.
For parameters $a_0 = 0.2$, $I_H/I_A = 0.8630$, $w^2_{pmH} / w^2 = 0.05$ and $w^2_{pmA} / w^2 = 0.005$

[1] C. G. Durfee III and H. M. Milchberg, Phys. Rev. Lett., 71, 2409 (1993).
[2] U. Verma and A. K. Sharma, Laser and Particle beams, 27, 33-39 (2009).
[3] Y. P. Zhao, Y. Xie, Q. Wang and T. Liu, Eur. Phys. J. D. 49, 379 (2008).
[4] J. J. Rocca, V. Shlyaptsev, F. G. Tomasel, O. D. Cortazar, D. Hartshorn, and J. L. A. Chilla, Phys. Rev. Lett. 73, 2192 (1994).

PB-28
SIMULATION OF LASER MANIPULATION EXPERIMENTS WITH FINITE SIZE DUST CLUSTERS

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The ability to influence the spatial structure and the velocity distribution of two-dimensional trapped Yukawa clusters by lasers has been exploited in different experiments in order to analyze melting effects [1,2]. We present results of Langevin Molecular Dynamic simulations which allow to model these processes in detail [3].

The goal is to get a better understanding of how the additional time dependent force affects on the particles dynamics.

The focus lies on the question how different parameters influence the heating effect. Depending on the scanning parameters the laser can either cause heating or provide a quasi-static force field. Often, even small changes in the simulation parameters result in major changes in the clusters' behavior.

[1] M. Wolter and A. Melzer, Phys. Rev. E 71, 036414 (2005)
[2] J. Schablinski, Kontrolle von Struktur und Dynamik finiter Plasmakristalle mittels Lasermanipulation, Diplomarbeit, CAU Kiel (2010)
[3] H. Thomsen, Excitation and Melting of Yukawa Balls, Diploma thesis, CAU Kiel (2011)

PB-29
STRUCTURAL PHASE TRANSITIONS IN CRYOGENIC DUST PLASMA OF GLOW DISCHARGE

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Cooling of dust plasma to cryogenic temperatures leads to diminishing of distances between dust particles [1, 2] and to formation of non regular chain clusters in glow discharge. In this work the phase diagram "pressure-current" for dust structures from 4.14 m MF dust particles in cryogenic neon plasma at temperature of liquid nitrogen and pressure 0.14 – 1.4 torr is represented for the first time. The regions of transition from chain-ordered clusters (a) to homogeneous structures (b) and regions of clusters melting are registered (Figure 1). The distance D between dust particles and shapes of dust clouds are observed to have complicate dependence versus temperature of ion component, gas pressure and discharge parameters. At diminishing of temperature down to 200 K, in the center of dust structure the formation of dense core similar to the "center of crystallization" was observed. The vertical oscillations of dust particles were observed with amplitude depending on gas pressure. Further diminishing of temperature resulted in the formation of dense homogeneous structures with distance of 25-40 m between dust particles, or in the formation of chain clusters with the distance of 125-150 m between clusters. In contrast to observations in air, here clusters were observed to form regular structures similar to points of hexagonal lattice. With increase of discharge current, clusters were observed to melt, the distance between particles and amplitude of longitudinal oscillations of particles increased. The border of clusters melting versus current and pressure approximately coincides with the border of transition from sub-normal to normal glow discharge. The increase of gas pressure leads to the coagulation of clusters into dense homogeneous structures, while the increase of discharge current results in diminishing of longitudinal size of dust structure and increase of its diameter.

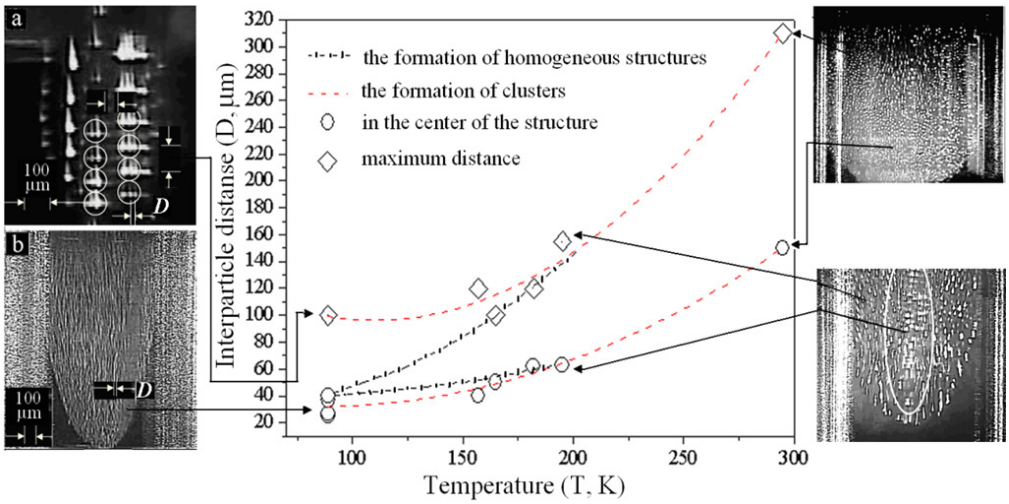

Figure 1: Reduction of interparticle distance by the reduction of gas temperature at current 0.61 mA.

[1] V.E. Fortov et al., Doklady Physics, 47(1), 21 (2002)
[2] L. M. Vasilyak et al., JETP 96(3), 436 (2003)

PB-30
INFLUENCE OF DUST PARTICLES ON CRYOGENIC PLASMA OF GLOW DISCHARGE IN NEON

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The experimental study of influence of dust particles on parameters of positive column of glow discharge in neon at cryogenic temperature is presented. Melamine formaldehyde particles of 4.14 m diameter were introduced in discharge maintained near liquid nitrogen temperature in the discharge tube of 16.5 mm i. d. cooled in optical cryostat. The neon pressure range was 0.14-1.4 torr, measured at room temperature. The optical images of dust structures, current-voltage characteristics of positive column of discharge and temperature of discharge tube wall were registered. Dust cloud seated in a single stratum between the short cylindrical electrodes designed to measure the voltage in the positive column of glow discharge. The character of dust particles influence on plasma parameters and on changes of dust cloud shape versus discharge current are similar to those at room temperature [1]. Nevertheless, unlike experiments at room temperature, the dust structures with central zone free of particles were not registered in cryogenic plasma at the same currents. The dependence of distance between particles versus discharge current at cryogenic temperatures was absent. Cooling of gas was followed by initiation of longitudinal oscillations of dust particles and increase of particles density in dust structure. The current-voltage characteristic of positive column with dust particles at 0.57 torr and 89 K is represented in figure 1. The discharge with dust particles was ignited at current of 2 mA, after that current was increased up to 3 mA and then diminished back (see arrows). As a result, some part of dust particles precipitated from dust cloud. Finally, the lower voltage of the positive column was observed, which was due to the lower losses of plasma electrons on dust particles. The number of particles confined in discharge decreased with current due to the thermophoretic force action, which push particles out of the electrostatic trap formed by strata, towards the wall of the discharge tube.

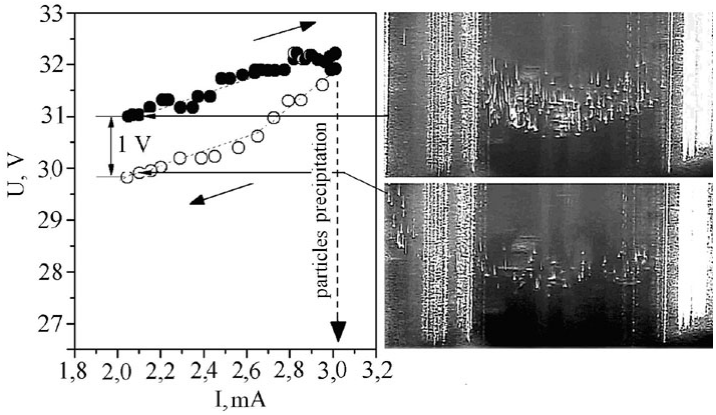

Figure 1: Current-voltage characteristics for the discharge of 40 mm long with variable number of dust particles. Images of initial and final states of dust structure are represented

[1] Vasilyak, S. Vetchinin, D. Polyakov and V. Fortov, JETP 100, 1029 (2005)

PB-31
STUDY OF GLOW DISCHARGE POSITIVE COLUMN IN AIR WITH DUST STRUCTURES

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Experimental and numerical study of positive column of glow discharge with dust particles was motivated by the need to simulate plasma parameters and electric field configuration changes induced by cloud of particles. Dust structures of micron size particles were developed in the positive column of a glow discharge in air at pressure of 0.1 - 0.6 torr and discharge current of 0.1 - 3 mA. The numerical model of positive column with dust cloud with the specified geometric parameters, represented in [1], is developed. Plasma of positive column is described in terms of diffusion model and OML approximation is applied for description of dust particle charging. The numerical task was solved at discharge parameters where the most stable dust structures were observed. The radial distributions of plasma components reflect the change of electric field in presence of dust particles. When concentration of particles attains sufficient value, the efficiency of particle surface absorption becomes comparable with diffusive losses of electrons on walls of discharge tube leading to the situation when the electron concentration on outer face of dust cloud becomes even higher than in the center of discharge tube. At some critical concentration of dust particles, the radial electric field changes its direction towards the axis of the tube in certain region inside the dust cloud. Experimentally measured and simulated current-voltage characteristics of discharge with and without dust component show the increase of the positive column electric field strength in the presence of dust particles and the higher stability of discharge against disturbing action of dust particles at high currents.

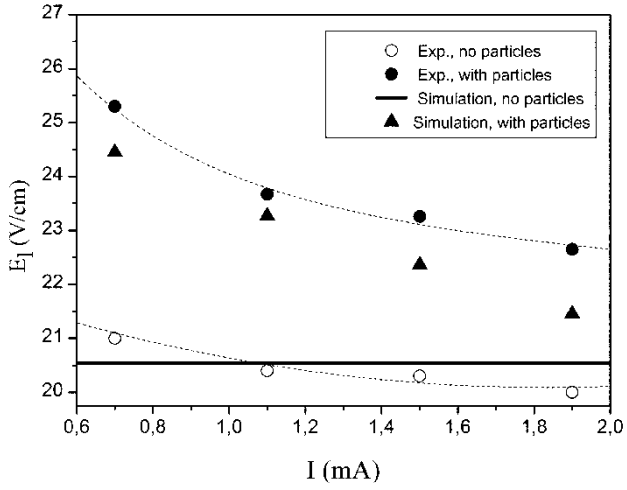

Figure 1: Current-voltage characteristics of positive column of discharge in air at concentrations of dust particles (0.2 – 3) 10^5 cm^{-3}

[1] D.N. Polyakov, V.V. Shumova, L.M. Vasilyak and V.E. Fortov, Phys. Scr. **82**(10), 055501 (2010)

PB-32
INFLUENCE OF DUST PARTICLES ON POSITIVE COLUMN OF GLOW DISCHARGE IN NEON

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Dust structures arising in gas discharge plasmas cause additional electron losses on the dust particle surface, changing plasma ionization balance. This is followed by increase of ionization frequency and electron temperature and result in increase of electric field strength that was confirmed in experimental [1] and theoretical [2] studies. These processes take place in plasma in order to conserve the total discharge current, necessary for the self-maintained discharge and result in increase of electron drift and positive column voltage. In this work, the experimental data on the influence of dust particles and their dynamical stability in dust structures, on the voltage of positive column of glow discharge in neon are represented for the first time. Experiments were carried out at pressure of 0.35 and 0.6 torr. The discharge glowed in a cylindrical discharge tube of 16.5 mm i.d. with two ring electrodes, glued into the tube walls with distance of 4 cm between them for measuring the voltage drop in the positive column. Electrodes were situated in front of the region of formation of dust structure. Dust structures were formed from mono dispersed 2.55 m MF dust particles. Registered were images of dust structures, corresponding current-voltage characteristics of discharge and the same characteristics of discharge without dust particles. The highest difference between current-voltage characteristics of free discharge and discharge with particles was registered for large-scale dust structures containing a large number of dust particles and also for spatially stable structures. Such structures were observed in the region of non-monotonous behavior of current-voltage characteristics at currents of 0.5 – 1 mA. This region corresponds to values of current of sub-normal glow discharge. When instabilities in the form of dust acoustic waves were developed, the difference between current-voltage characteristics of free discharge and discharge with dust particles wasn't registered even at a very high total number of particles in dust structures, increasing that in spatially stable structures.

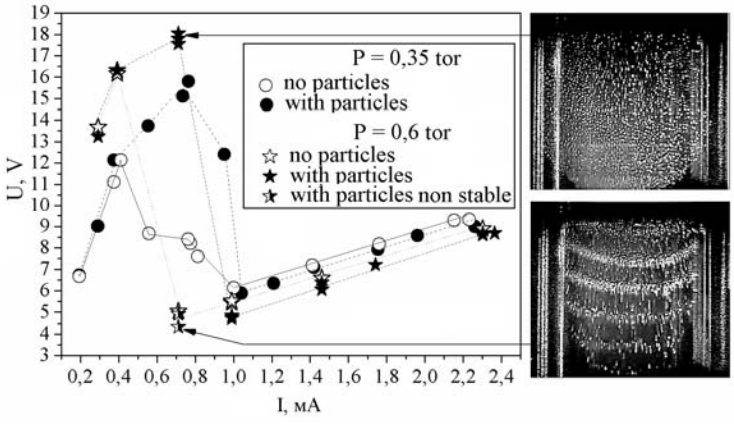

Figure 1: Current-voltage characteristics of positive column of glow discharge in neon and longitudinal cross-sections of dust structures

[1] L.M.Vasilyak, S.P. Vetchinin, D.N. Polyakov and V.E. Fortov, JETP 94(3), 521 (2002)
[2] D N. Polyakov, V.V. Shumova, L.M. Vasilyak and V.E. Fortov, Phys. Scr. 82, 055501 (2010)

PB-33
RESONANCE EFFECTS AT ACTION OF NANOSECOND PULSES ON DUSTY PLASMA STRUCTURES

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Within researching processes of an appearance of ordered structures and phase transitions in non-ideal dusty plasma the behavior of dust structures under the action of nanosecond electric pulses in the DC glow discharge has been studied. The search of resonance effects, stabilization, precipitation and destruction of dust structures is carried out. We performed experiments to study the action of nanosecond electric pulses with pulse repetition frequencies from 4 to 300 Hz. The analysis of a particle fluctuation amplitude has revealed the resonant frequency of 7.1 Hz (Fig. 1). The investigation of a mechanism of particle fluctuations was of great interest. It was revealed that nanosecond pulses change the background plasma near the particle and do not get an impact on the displacement of particles. In the previous experiments with the RF discharge a stabilization of particles was observed at the pulse repetition frequency of 16 Hz [1]. The similar experiment has been made in the DC glow discharge. The stabilization effect of self-excited fluctuations and waves was observed at a pulse repetition frequency of 200 Hz. Such behavior of particles is due to that an application of the capacitor nanosecond discharge forms an additional local ionization of plasma and artificial striation in which the dust cloud is stabilized. The further increase of nanosecond pulses frequency caused the effect of the dusty crystal melting and subsequently a precipitation of particles. We found experimentally that when a dusty cloud contains particles of two sizes it is possible to separate a heavier fraction by the partial trap destruction.

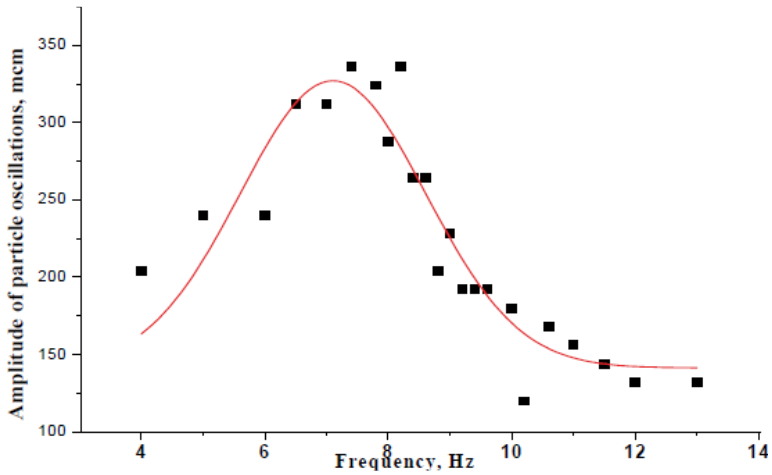

Figure 1: Amplitude dependence of particle oscillations on frequency. Nitrogen pressure is p= 0.067 Pa, I= 0.4 mA, U=1890 V. Diameter of dust particles d_p= 2.55 μm

[1] M.Y. Pustylnik, A.V. Ivlev, H.M. Thomas, G.E. Morfill, L.M. Vasilyak, S.R. Vetchinin, D.N. Polyakov and V.E. Fortov, Physics of Plasmas 16, 113705 (2009)

PB-34
SELF-CONSISTENT RADIAL DISTRIBUTIONS OF DUSTY PLASMA PARAMETERS IN A DC GLOW DISCHARGE

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There are many papers devoted to the influence of dust particles on gas discharge plasma parameters [1-5]. For the conditions of RF discharge used for thin films preparation, the influence of dust particles on discharge properties was investigated with the help of Particle-in-Cell Monte Carlo simulations by J.P. Boeuf [1] and later with the help of Boltzmann equation for EEDF by I. Denysenko et al. [2]. It should be stressed that even without dusty particles, a DC glow discharge in a cylindrical tube is a very complex open non-equilibrium system of ions, electrons, and neutral atoms in different electronic states. The quasi two-dimensional simulation of a DC gas discharge with dust particles was presented in [3], where 2D distributions of dusty plasma parameters were obtained in different approximations. In paper [4], with the help of a homogeneous self-consistent kinetic model it was shown that the increase of dust particles density leads to the increase of an averaged electric field and ion density, and to the decrease of a dust particle charge in a dusty cloud. The influence of dust particles on radial distributions of plasma parameters was studied by Vasilyak et al. with the help of local ambipolar diffusion approximation [5].

We present a non-stationary non-local kinetic model for self-consistent radial distribution of dusty plasma parameters. The model is based on the solution of Boltzmann equation for the electron energy distribution function (EEDF). For the case of a non-monotonous electric potential spatial distribution, the solution of Boltzmann equation written in "total electron energy – radial position" coordinates [6] becomes inapplicable. For this case we developed a non-stationary iterative method of solving Boltzmann equation in "kinetic electron energy – radial position" coordinates. Electrons and ions production in ionizing collisions and their recombination on dust particle surface were taken into account. The drift-diffusion approximation for ions was used. To obtain the self-consistent radial distribution of electric potential the Poisson equation was used. The dust particles radial distribution was taken as a step-like function with a given height and radial width.

The results of calculations show that with the increase of dust particle density the double layer in bulk charge distribution is formed on the boundary of the dusty cloud. It is shown that at high dust particle density the recombination of electrons and ions can exceed their production in ionization collisions at some distances from the axis of the discharge tube. In this case a non-monotonous radial distribution of the electric filed takes place, the radial electric field is reversed and the radial electron and ion fluxes change their direction toward the centre of the tube.

[1] J.P. Boeuf, Phys. Rev. A, 46, 7910 (1992)
[2] I. Denysenko et al., Phys. Rev. E, 70, 046403 (2004)
[3] G.I. Sukhinin, A.V. Fedoseev, Plasma Physics Reports, 33, 1023-1031 (2007)
[4] G.I. Sukhinin, A.V. Fedoseev, Phys. Rev. E, 81, 016402 (2010)
[5] D. N. Polyakov, V.V. Shumova, L.M. Vasilyak, V.E. Fortov, Phys. Scr., 82, 055501 (2010)
[6] D. Uhrland, M. Schmidt, J.F. Behnke, T. Bindemann, J. Phys. D., 33, 2475-2482 (2000)

PB-35
MOLECULAR DYNAMICS SIMULATION OF MODERATELY COUPLED YUKAWA LIQUIDS ON GRAPHICS PROCESSING UNITS

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During the past decade Graphics Processing Unit (GPU) architectures have seen not only continuous performance increase, but a completely new horizon through general purpose computing as well. Thus, being integrated inside personal computers (PC), besides high-performance graphics applications, they provide a new platform for scientific computing, too, at moderate cost. Single instruction multiple data (SIMD) parallelism of GPUs is attractive for molecular simulations, as particle methods can largely be parallelized. We have developed a molecular dynamics (MD) simulation code for the NVIDIA Compute Unified Device Architecture (CUDA) GPU architecture [1] that allows massive parallel computing, thereby permitting relatively big systems to be simulated on PC class computers, compared to the traditional Central Processing Unit (CPU) computations.

We have carried out simulations of moderately coupled ($0.1 \leq \Gamma \leq 10$) 3-dimensional Yukawa liquids [2], using particle numbers in the 10^5-10^6 range. Besides the MD simulations we have as well obtained pair correlation functions using the Hypernetted Chain (HNC) Approximation, and have compared the results with the GPU-MD data. The analysis of the asymptotic long-range behaviour of the pair correlation functions (transition between monotonic vs. oscillating decay) confirmed the results of [3].

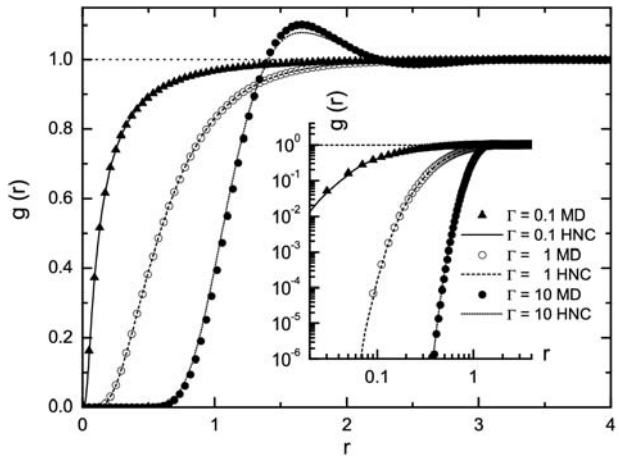

Figure 1: Pair correlation functions of 3D Yukawa liquids at Γ=0.1, 1 and 10 (at =1), obtained from the GPU-MD simulations (of 125,000 particles) and the HNC calculations. The inset shows the decay of the correlation functions for small r. (r is given in units of the Wigner-Seitz radius.)

Figure 1 shows pair correlation functions obtained from the numerical simulations and the theoretical HNC method, in which the bridge function was set to zero. We find a very good agreement between the curves at Γ=0.1 and 1, over several orders of magnitude. The only difference seen at Γ=10 is the (expected) slightly higher correlation peak amplitude obtained from the MD simulation, compared to the HNC result.

We thank OTKA for supporting this work (grant K77653) and Dr A. Archer for useful discussions.

[1] http://www.nvidia.com/object/cuda_home_new.html
[2] Z. Donkó, G. J. Kalman, and P. Hartmann, J. Phys. Condensed Matter 20, 413101 (2008).
[3] P. Hopkins, A. J. Archer, and R. Evans, Phys. Rev. E 71, 027401 (2005).

PB-36
ANOMALOUS SCENARIO FOR SPINODAL DECOMPOSITION OF METASTABLE MELTING IN THE ZERO-TEMPERAURE LIMIT

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Hypothetical scenarios for termination of deep metastable melting in Coulomb model at zero-temperature limit ($T \to 0$) are under discussion. Present analysis based on study of topology for combination of melting, boiling and sublimation boundaries in non-standard version of one-component plasma model on uniformly compressible background: OCP(~) [1][2]. In contrast to the widely accepted scenario of metastable melting termination in rare gases [3] and metals [4], when metastable melting curve reaches actually isotherm $T = 0$ ("cold curve") of a matter, present work devoted to more plausible scenario of deep metastable melting, titled as "spinodal decomposition". Its basic point [5] is unavoidable intersection at finite temperature of metastable liquid melting boundary (liquidus) with spinodal curve of metastable liquid-gas phase transition. Metastable melting at lower temperature is impossible in this case since absolute instability of liquid phase, so that metastable crystal has no where to melt.

Two non-standard and more exotic scenarios for metastable melting termination (MMT) are under discussion in addition to two mentioned above MMT scenarios. In the first one (***A***) hypothetical unique crystal-fluid global phase coexistence is realized as smooth superposition of boiling and sublimation curves (without gas-liquid phase transition and corresponding critical point). In second scenario (***B***) anomalous non-standard type of "spinodal decomposition" is realized, when metastable solid binodal (solidus) intersects gaseous spinodal of metastable gas-liquid phase transition. Features of all mentioned above variants of MMT are under discussion as well as hypothetical possibility of direct numerical simulations for such new, exotic MMT-s.

[1] I. Iosilevskiy, A. Chigvintsev, Phase Transition in Simplest Plasma Models, in "Physics of Strongly Coupled Plasmas" Eds. W. Kraeft and M. Schlanges, (World Scientific, Singapore-London, 1996) P.145, <arXiv:0902.2353>.

[2] I. Iosilevskiy, Thermodynamics of non-ideal plasmas, in "Encyclopedia of Low-T. Plasma Physics" (Suppl. III-1), Eds. A. Starostin & I. Iosilevskiy, M.: Fizmatlit, 2004, PP.349-428.

[3] V. Skripov, M. Fizullinn, High Temp. 37, 814 (1999).

[4] K. Khishenko, V. Fortov, in "Physics of Matter under Extreme Conditions", ed. V. Fortov, IPCP RAS, Chernogolovka, P. 68 (2002).

[5] I. Iosilevskiy, A. Chigvintsev, Spinodal decomposition of metastable melting in the zero-temperature limit, in "Equation-of-State and Phase Transition in Models of Astrophysical Matter" / Eds. W. Däppen, D. Gough, V. Čelebonovič, Am. Institute of Physics, New York, 2004, PP. 255-260,<arXiv:0609059>

PB-37
GLOBAL COLD CURVE. THERMODYNAMICS OF ZERO-TEMPERATURE PLASMA FROM ULTRA-LOW TO ULTRA-HIGH DENSITIES

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Non-standard representation for Global Cold Curve /GCC/ (i.e. isotherm $T = 0$) is under discussion. The main point is that chemical potential of substance, μ, plays role of ruling parameter in basic GCC-dependence of internal energy on density, $U = U(\mu)$, in contrast to the standard form $U = U(\ )$. This substitution changes radically low-density ("gaseous") part of GCC. Namely: (*i*) - physically meaningless part of standard cold curve ($U(\ )$ at $\to 0$) disappears totally from new version of GCC. This deleted part corresponded to absolutely thermodynamically unstable states in standard representation $U(\ )$; (*ii*) - new branch of cold curve comes in GCC $U = U(\mu)$. It corresponds to thermodynamically stable (and metastable) states only and describes in simple, schematic way thermodynamics of gas-like plasma at $T \to 0$ [1-4] as combination of all ionization and dissociation processes available for equilibrium plasma system at finite temperature. Binding energies of all complexes (atomic, molecular and ionic) in their ground states, added by sublimation energy of the gas-crystal phase transition, are the only quantities that display themselves as meaningful details of this new gaseous zero-temperature isotherm ("energy scale" [1-4]). Gaseous portion of the zero-temperature isotherm can be naturally conjugated with corresponding zero-temperature isotherm ("cold curve") of condensed phase. This united (global) zero-temperature isotherm (GCC) no more contains artificial and meaningless part between gaseous and crystalline spinodals. The limiting zero-temperature form of plasma thermodynamics for Coulomb systems could be used as a natural basis for rigorous development of quasi-chemical approach (the "chemical picture") in frames of the asymptotic *temperature* (not density) expansion around the zero-temperature isotherm as a reference system.

The simple, schematic structure, which is typical for new form of cold curve in ultra-low densities, appears again in ultra-high densities, which is typical for interiors of compact stars (neutron star crust). It looks as if low-temperature thermodynamics in ultra-low and in ultra-high densities have the same remarkably primitive structure by the same physical reason.

[1] I. Iosilevskiy and V. Gryaznov, High Temperature, 19, 1121 (1980).
[2] I. Iosilevskiy, Thermodynamics of gaseous plasma in zero-temperature limit, X-Int.Conference "Physics of Nonideal Plasmas" (PNP-10), Greifswald, 2000.
[3] I. Iosilevskiy, in: "Encyclopedia of Low-Temperature Plasma Physics" (Supplement III-1), Eds. A.Starostin and I.Iosilevskiy, Moscow: FIZMATLIT, 2004, PP.349-428 (in Russian).
[4] I. Iosilevskiy, Contrib. Plasma Phys. 49, 713 (2009); arXiv:0902.3708v1

PB-38
DYNAMIC SHEAR VISCOSITY IN A 2D YUKAWA SYSTEM

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We present non-equilibrium molecular dynamics simulation studies on the dynamic (complex) shear viscosity of a 2D Yukawa system. We make use of the homogeneous shear algorithm with an applied oscillatory shear, based on the Gaussian thermostated SLLOD equations of motion in planar Couette flow, in conjunction with Lees-Edwards boundary conditions [1]. We perform the calculation for N = 11400 particles, in a wide range of shear rates (1), for a series of perturbation frequencies (2) and Coulomb coupling parameters (3), with a Yukawa screening parameter = 1:

$$\Gamma = (\partial v_x / \partial y)(a / v_{therm}) = 0.04 - 4.00 \quad (1)$$

$$\bar{\omega} = \omega / \omega_p = 0.1 - 1.00, \text{ where } \omega_p^2 = n Q^2/(2 \varepsilon_0 m a) \quad (2)$$

$$\Gamma = \frac{Q^2}{4 \pi \varepsilon_0} \frac{1}{a k_B T} = 100, 200, 500 \quad (3)$$

The principal investigated quantities are the real (viscous dissipative) and imaginary (elastic) parts of the complex viscosity, the energy absorbed by the thermostat (equivalent to the energy absorbed by the particle ensemble from the external perturbation), the density and current fluctuation spectra, and the pair correlation function.

In the small shear limit our 2D simulation results are in good qualitative agreement with 3D simulation results [2]. We obtain good agreement with 2D dusty plasma experiments [3] (i) for the shear rate dependence of the viscosity at small excitation frequencies and (ii) frequency dependence of the viscosity at intermediate shear rates. At high shear rates and frequencies we observe a qualitatively new, non-monotonic behavior of shear viscosity.

Our simulations show a peak in the absorbed energy near the Einstein frequency at intermediate shear rates ($\Gamma \approx 1$). An enhanced collective wave activity is observed, when the excitation is near the plateau frequency of the longitudinal wave dispersion. Significant configurational anisotropy develops at small frequencies and high shear rates resulting in the change of structural properties.

[1] D. J. Evans and G. Morriss, Statistical Mechanics of Nonequilibrium Liquids (Academic Press, New York, 1990)
[2] Z. Donkó, J. Goree, and P. Hartmann, Phys. Rev. E 81, 056404 (2010)
[3] P. Hartmann, M.Cs. Sándor. A. Kovács, Z. Donkó, Phys. Rev. E (accepted), arXiv:1103.0124v2 [physics.plasm-ph]

PB-39
DUSTY PLASMA STRUCTURES IN HE–KR DC GLOW DISCHARGE

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Ion drift in gas mixtures has certain properties that can be used to generate ion flows with desired characteristics. For example, when the field is strong, ion heating is significant, and there is a large difference in atomic weight between ions and atoms, the ion velocity distribution can be highly anisotropic [1]. Ion distribution anisotropy can cause a substantial change in properties of dust structures in plasmas [2, 3].

Experiments on dusty plasma structures in glow discharge in mixtures of light and heavy gases [2] (helium and argon), [3] (helium and krypton) are performed, and results of numerical simulations of ion and electron drift in the mixture are presented.

The model of electron-atom collisions is considered taking into account non-elastic collisions in electron energy balance.

On the basis of numerical simulation the characteristics of electron velocity distribution function, the energy characteristics of electron drift in constant electric field in ***He-Kr*** discharge were tabulated. Values of drift velocity, average electron energy, Townsend characteristic energy, and average electron energy leading to excitation and ionization of atoms, ratio between energy losses in elastic and non-elastic collisions, Townsend ionization coefficient were obtained.

For the experiment conditions calculations of dust particle charging characteristics are also conducted – values of an average dust charge, charge fluctuation, and number of the bounded ions are calculated. These calculations have shown that dust charging in a mix of a "light" gas with a small additive of a "heavy" gas and ions has a number of features which lead, in particular, to considerable (up to thousand times) increase of dust kinetic energy – this effect was observed in the experiments [3]:

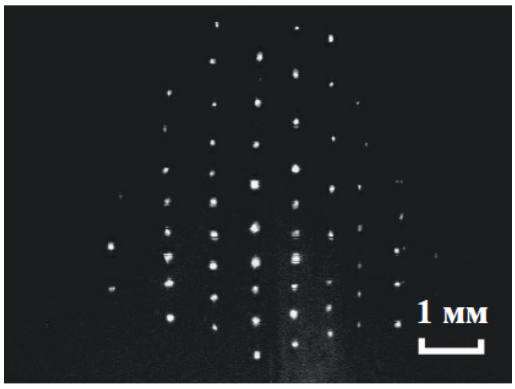


Fig. 1. Image of an axial vertical cross section of a dust structure in a helium–krypton mixture at a pressure p = 0.35 Torr, a current i = 0.5 mA, and a krypton concentration of 1%

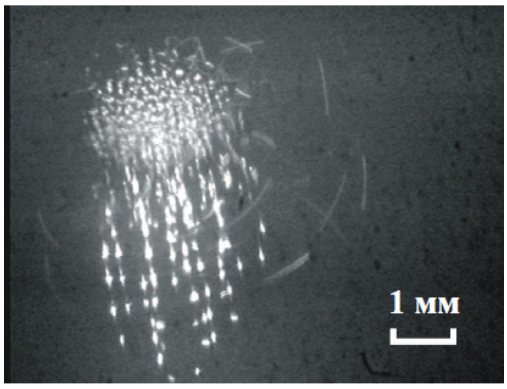
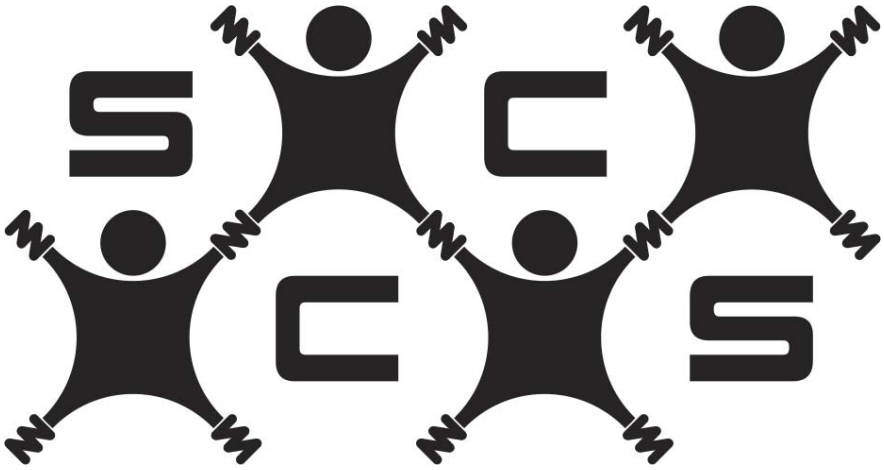


Fig. 2. Typical dust structure involving fast_moving grains in discharge plasma (p = 0.3 Torr, i = 1.2 mA) in He + 10% Kr mixture illuminated by a wide laser beam, viewed from above at an angle of 40° to 50° to the vertical axis

[1] S.A. Maiorov// Plasma Phys Reports 35 (9), 869-880 (2009).
[2] S.A. Maiorov, T.S. Ramazanov, K.N. Dzhumagulova, A.N. Jumabekov and A.N. Dosbolaev// Phys. Plasmas 15, 093701 (2008).
[3] S.N. Antipov, M.M. Vasiliev, S.A. Maiorov, O.F. Petrov, V.E. Fortov// JETP 112(3), 482-493 (2011).



AUTHORS' INDEX

NOTES:

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Timetable

	Sunday 24	Monday 25	Tuesday 26	Wednesday 27	Thursday 28	Friday 29
09:00-09:30		Chabrier (1)	Das Gupta (2)	Ceperley (6)	Rontani (6)	Schröer (5)
09:30-10:00					Fortmann (4)	Redmer (1)
10:00-10:30		Desjarlais (1)	Poster Session A Oral Summaries	Samaj (6)	Poster Session B Oral Summaries	Messina (5)
10:30-11:00		Iosilevski (1)		Holzmann (2)		Kjellander (5)
11:00-11:30		Reinholz (1)		Petrov (5)		Grabowski (6)
11:30-12:00		Morning			Coffee	
12:00-12:30		Fortov (4)	Senatore (2)	Ivlev (5)	Hartmann (5)	Dombi (4)
12:30-13:00		Knudson (4)	Hawrylak (3)	Bonitz (5)	Clérouin (1)	Drummond (6)
13:00-14:00		Lunch				
14:00-14:30		Time devoted to informal discussions	Time devoted to informal discussions*		Time devoted to informal discussions	A. Filinov (3)
14:30-15:00						Morozov (6)
15:00-15:30						Ramazanov (1)
15:30-16:00		Levai (4)	Vignale (3)	**14:30-21:30**	Nayak (3)	Dufty (6)
16:00-16:30	Registration	Mintsev (4)	Totsuji (5)		Sukhinin (5)	Closing
16:30-17:00		Gericke (4)	Saitov (1)	**Conference Excursion & Dinner**	Mithen (5)	
17:00-17:30		Trizac (6)	Poster Session A		Poster Session B	
17:30-18:00		Coffee				
18:00-18:30	Welcome	Kalman (7)				
18:30-19:00		Fisher (7)				
19:00-19:30	Reception	Ebeling (7)				

*** A meeting of the SCCS International Advisory Board will take place between 13:00-15:30 on 26 July, Tuesday.**

Topics:

1 – Dense and astrophysical plasmas
2 – Plasmas in condensed matter
3 – Confined and mesoscopic Coulomb systems
4 – High energy density plasmas in the laboratory
5 – Classical charged systems
6 – Developments in theoretical methods and numerical techniques
7 – Thirty-five years with Strongly Coupled Coulomb Systems

Colour codes:

Invited talk
Contributed talk
Poster session

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