The nature and scope of research at the Centre of Theoretical Physics (CTP)

Amr ElZant

A tantalising trait of our universe lies in the apparent congruence of the natural laws inferred and applied in earthly contexts with those governing the cosmos as a whole. As a consequence, advances in our basic understanding of the forces that hold subatomic particles and galaxies together, and how they conspire to produce the cosmological large scale structure observed via giant telescopes, have developed historically in tandem with technological progress.

There is a positive 'feedback loop' coupling basic and applied sciences that is hard to overlook: the discipline of thermodynamics, essential to the understanding of the evolution of the early universe, had developed originally in the context of applied research aiming at advancing heat engine designs; electronic devices and computers would have been impossible without the advent of quantum mechanics—an abstract and perplexing, yet stunningly successful response to a theoretical crisis in classical physics; and quantum field theory, with its system of involved rules so essential to understanding nature's fundamental forces, is also indispensable in understanding phenomena such as superconductivity, as well as the Casimir effect figuring in nanotechnology research.

The list goes on, so I will focus herein on illustrating a few aspects of this interaction while outlining the nature, scope, and aims of our activities at the Centre of Theoretical Physics (CTP). One of these is our ongoing collaboration in the Compact Muon Solenoid (CMS) experiment at the Large Hadrons Collider (LHC) at the *Centre European pour la Recherche Nucleare* (CERN). I have mentioned quantum mechanics having developed in the context of a crisis in theoretical classical physics, but that 'theoretical crisis' has actually transpired as a result of technical advances, especially in spectroscopy, which revealed the shortcomings of classical physics. In a similar vein, the LHC near Geneva is a state-of-the-art technological tool testing fundamental physics. This giant particle accelerator—with its 1600+ superconducting magnets, each weighting over 27 tonnes and arrayed in an underground tunnel spanning a circle of 27 km in circumference—may help us select, among present models, those fittest in fitting the data; alternatively, in another turn of the century about-turn, it may throw our fundamental frameworks for apprehending the cosmos into chaos.

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In 2008, the Egyptian Network of High Energy Physics (ENHEP) was established by the Ministry of Higher Education and Scientific Research and the Academy for Scientific Research and Technology (ASRT) to 'act as a nucleus for the scientific cooperation between the Egyptian experts in the areas of high energy physics and CERN in the LHC project'. It is our aim to make the BUE a central node in that nucleus in the coming period; and we are exceptionally well placed towards achieving that goal. The current director of the ENHEP is a member of the CTP; through the past couple of years Professor Amr Radi has been active in the training of graduate students at the BUE and the organisation of several workshops and collaborative visits by international scientists associated with the LHC experiments. These activities normally involve training sessions and lectures for Egyptian students. Throughout this period, he has been a regular visitor to CERN.

Dr. Sherif ElGammal, who is a BUE lecturer and full-time CTP member, is actively involved in the CMS experiment at CERN, where he had previously spent time as a postdoctoral scholar. He has a significant track record of internal research notes and associated CMS publications in international journals, presenting work in which he was actively involved and made central contributions. Dr. ElGammal's main line of work involves the analyses of terabytes of data produced at the LHC: the output of a sustained effort at tracking elusive subatomic particles and their properties. However, he is also interested in aspects of particle detector design and development (see his article on page page 57). Moreover, the statistical and optimisation methods involved are widely used in engineering and technological research, and the CERN Grid computing network he employs for his research is one of the most advanced in the world. Egypt, as yet, is not effectively connected to that vast computing structure of advanced hardware and software, and most of Dr. ElGammal's work has hitherto been conducted in collaboration with the *Ecole Polytechnique* in Paris. This may be about to change, however, as the equipment required to connect Egypt to the Grid, recently donated to ENHEP by CERN, is installed. We will endeavour to ensure that the BUE is part of this development.

The LHC is designed to probe the interactions of matter at velocities reaching 99.999% that of light: recreating the conditions of the early universe a fraction of a second after its expansion began. This is one aspect of the ever widening interface between particle physics, cosmology, and galaxy formation, which also includes the nature of dark matter dominating the large scale structure of the universe, currently thought to consist of hitherto undiscovered elementary particles. This interface is also a source for collaborative projects for different members of the CTP—particularly between other members and myself. My research is largely concerned with the dynamics of galaxies, their formation, and their evolution in the context of current cosmological models.

Physical cosmology, no longer the domain of speculative theoretical models, is now, in its 'precision era', an empirical science, driven by an avalanche of data incoming from ground- and space-based observations and vast advances in computer hardware and software. The analyses and computations often involve optimisation methods originally developed in engineering research, such as techniques dealing with large constrained linear and nonlinear programming problems. Current research tackling the problem of galaxy formation and evolution also employs large scale fluid dynamics computations. This topic, also evidently relevant to applied research, is very well developed in astrophysics, with methods such as the Lagrangian Smooth Particle Hydrodynamics having been originally devised therein. State-of-the-art astrophysical codes also currently involve advanced mesh refinement and moving mesh techniques.

The largest scales in cosmological simulations are beyond the computational power currently available at the BUE, but their analysis is not; and in this regard I have an ongoing collaboration with the Paris Observatory and the *Intitut D'astrophysique* in Paris to analyse some of the largest calculations made to date. Nevertheless, smaller scale controlled simulations of the gas dynamics of galaxy formation and of the dissipationless dark component thought to dominate the gravitational field are within the capabilities of the BUE's High Performance Computing (HPC) system. This HPC system comprises Sun workstations and a Blade server, originally acquired through a proposal made by Mark Everitt and myself and funded in part by the CTP. In collaboration with Dr. Adham Naji, we plan to optimise the performance of the present system—including putting the file server to proper use, installing software and renewing our licence for the Red Hat Enterprise Linux operating system—for more efficient use. Once done, we plan to initiate an application procedure, organising time allocation on the system to the benefit of the BUE community. It is hoped that the quality and the quantity of research produced will encourage the enlargement of the system, rendering it one of the largest HPC facilities in Egypt.

The discovery of the Higgs Boson in the summer of 2012 was a triumph of contemporary fundamental physics. The Higgs explains how the universe acquired mass; the last piece of the jigsaw puzzle known as the standard model (SM) of particle physics. However, no other, additional particles were found, practically ruling out many of the simplest extensions of the SM. Yet we know that the SM cannot be complete, since it hosts only massless neutrinos, while these particles are now known to have non-vanishing masses. More fundamentally, perhaps it lacks in satisfying the quest of unifying the forces of the physical world, a quest that dates back to the contributions of Newton, Maxwell, and Einstein. Gravity, in particular, has proven hard to incorporate into the theories of fundamental physics. However, a possibly promising pathway to unification may be found in the context of String theories (whereby, as the name suggests, elementary particles are represented by tiny strings rather than point masses). This is a field where Dr. Adel Awad has been active.

Dr. Awad has also investigated modifications of Einstein's general relativity. In a recent paper (discussed in the following article, on page page 56), he studied the consequences of a theory known as 'Rainbow Gravity', in a context where the propagation speed of light depends on its frequency. It was shown that, in a 'rainbow universe', time may have no beginning, thus sidestepping the 'singularity' at the Big Bang. This research was highlighted in *Nature Middle East* and, most notably, *Scientific American*, in what probably is a first in terms of public propagation of Egyptian scientific activity in the international science media.

Another formidable problem facing fundamental physics involves the nature of the dark energy driving the acceleration of our expanding universe. Despite intense research delving into its possible origin, the issue remains wide open. Dr. Awad has recently contributed to this domain, exploring various scenarios for the evolution and fate of our universe, in different dark energy models. Professor Gamal Nashed, whose main interest is geometric theories of gravity beyond general relativity, has also prolifically explored dark energy models, in particular through modifications of Einstein's theory based on the 'f(T) model' (see page page 60). Also interested in extensions of general relativity that may be helpful in explaining recent cosmological data is Walid ElHanafy, who is particularly concerned with alternative theories of gravity in the context of Riemann-Cartan geometry (see page page 59).

The presence of dark energy was first inferred via observations of distant exploding stars (supernovae), acting as 'standard candles' through which cosmic distances can be inferred. The observations were made using large ground-based telescopes employing advanced adaptive optics, a technique largely developed in astronomical research but which now has many (including military) applications. This interplay between technical progress and basic research is expected to continue; several ground- and space-based astronomical surveys, probing the supernovae population and the large scale structure of the universe, are planned for the next decade, with the goal of placing strict constraints on the cosmic evolution theory of dark energy. Once again we see, as in the case of the era of quantum mechanics, technological progress enabling the harvesting of novel empirical data that drive the fundamental questions about the universe, perhaps to the limit of possible scientific knowledge.

Universe's fate under causal models and a dubious Big Bang singularity using Rainbow Gravity theory

Adel Awad

More than a decade ago, we started to have a series of cosmological observations: among them was the Supernova project and the Wilkinson Microwave Anisotropy Probe (WMAP), which provided us with a strong evidence of the accelerating expansion of our universe, i.e. the expansion rate increases with time. The material component that causes this acceleration is not known yet—this is why it is called 'Dark Energy'. What is known about dark energy is that it can be described as a cosmological constant: a constant cosmic force that accelerates the expansion of the universe. Unfortunately, this model does not provide any physical picture for dark energy. To describe dark energy in the realm of general relativity, we need to consider some exotic fluid with an unusual equation of state that has a negative pressure! The existence of this exotic fluid not only opens the door for re-examining the constituents of our universe but also to have a possible violent end of the universe, which is called the 'Big Rip singularity'. A special class of these exotic fluids is called 'phantom matter', which may, or may not, evolve into Big Rip singularities.

In a recent work[1], I studied a general class of models with pressure that does not violate causality; no matter disturbances can propagate faster than light. I found two interesting conclusions. First, it is impossible for our universe to evolve into any type of singularity in the future, including a Big Rip, as long as causality is not violated and dark energy is not clumped (i.e. it does not become stable). Second, it is impossible for our universe to evolve from hosting regular matters to hosting phantom matters in a finite time. This last statement has been argued by other authors in long proofs, but in this work I was able to prove it in a simple and transparent manner, using a mathematical technique called the Phase Space Method. In the same study, I also discussed possible scenarios for the fate of the universe. These scenarios are: the universe continues expanding with a constant acceleration (de Sitter Universe); the universe

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continues expanding, then it starts decelerating, ending up as an empty universe (extremely dilute density); or the universe continues expanding to a maximum size before it re-collapses (an oscillating universe).

In another research[2], we tried to address the issue of Big Bang singularity: that the universe has started from a state of infinite density and pressure. We used a new extension of general relativity, which is called 'Rainbow Gravity'. Rainbow Gravity has been proposed ten years ago to extend Einstein's theory of gravity as to describe systems with very high energies and densities, which mimic our universe in its early times. Unlike in Einstein's theory, in Rainbow Gravity particles with different energies 'feel' the same gravitational field differently. By applying Rainbow Gravity into cosmology to describe the evolution of our universe, we found that it gives a very similar behavior to the Big Bang model in late times, which is in good agreement with the known cosmological observations. We found that the behavior of the Rainbow universe in the very early times is quite different from the Big Bang model and the high energy/high density corrections are always strong enough to resolve (i.e. smooth out) the Big Bang initial singularity. As a result, the density and pressure are always finite and we do not have any special point in time. Therefore, time is stretched out infinitely in the past.

This research has been highlighted and discussed in the Nature Middle East and the Scientific American magazines[3–4]. It has also made some public news headlines[5].

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Physical analysis and detection simulations for the Compact Muon Solenoid (CMS) detector at CERN

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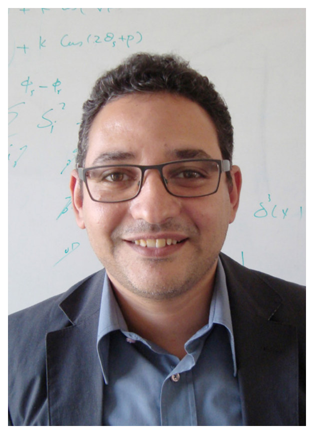
The Large Hadron Collider (LHC) is a gigantic scientific instrument near Geneva, where it spans the border between Switzerland and France, at about 100 m underground. It is a particle accelerator used by physicists to study the smallest known particles—the fundamental building blocks of all things. It will revolutionise our understanding, from the minuscular world deep within atoms to the vastness of the universe.

Two beams of subatomic particles called 'hadrons' (either protons or lead ions) travel in opposite directions inside the circular accelerator, gaining energy with every lap. Six detectors have been constructed at the LHC, located underground in large caverns excavated at the LHC's intersection points.

Two of them, the ATLAS experiment and the Compact Muon Solenoid (CMS), are large general-purpose particle detectors. The general purpose of the CMS detector is to hunt for the Higgs boson and look for evidence to the nature of dark matter.

My interest is in the areas of physical analysis and detector simulation. To be able to operate CMS and, moreover, to address the highest priority goals associated with higher luminosities, as foreseen for instance in the framework of the HL-LHC, some of the existing systems need to be upgraded or replaced. I wish to participate in the upgrading of the CMS muon software/trigger developments. The work towards the 'phase 2 upgrade' will cover the following aspects: (1) quantitative studies of the radiation damage of current detector subsystems and precise evaluations of their expected lifetimes; (2) simulation studies demonstrating the performance of upgrade options under the challenging conditions at high luminosity, with a nominal average pile-up of 140 interactions per bunch crossing; (3) an ongoing programme of R&D for detector technologies for systems that must be replaced or upgraded; and (4) exercises to estimate the costs of the present conceptual



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designs, putting emphasis on finding the most cost effective solutions for the upgrades that address the challenges of high pile-up, dose rate, and cumulative dose/fluence associated with the phase 2 programme.

1. Physical analysis

The analyses of the 2011 and 2012 data collected by CMS experiment show a very unique result with the discovery of the Higgs boson. This discovery lead to the 2013 Nobel Prize in physics, which was awarded to Professors Francois Englert and Peter Higgs for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles.

Many other models beyond the standard model exist, which opens a window for the search for new physics beyond the standard model. These new models predict the existence of new unknown particles, like the heavy neutral gauge boson (Z') and the heavy graviton (G). The search for these particles is taking place at CMS experiment as well. The existence of heavy neutral bosons is a future of many extension of the standard model. They arise in extended gauge theories, including Grand Unified Theories (GUTs), and other models like Left-Right symmetric Models (LRM).

Z' → l– l+

Grand unified theories (GUTs) suppose that strong and electroweak interactions can be described by a simple gauge group, at very high energies E > EGUT, where EGUT is defined as the energy where the three gauge coupling constants of the SM gauge groups become equal. In 1974, H. Georgi and S. L. Glashow showed that minimal simple group which can contain the SM gauge groups is SU(5) → SU(3)c × SU(2)L × U(1)Y , where SU(3)c is the gauge group of the strong interaction. The precision measurements at LEP and SLC experiments prove that the three gauge coupling constants do not meet at one point if they are predicted in the SU(5) GUT. Therefore, it was needed to search for other theories if one wants to describe all SM interactions by one simple group, and avoiding the problem arising from the SU(5) GUT. All the GUTs with gauge groups larger than SU(5) can solve this problem, predicting at least one extra gauge boson (Z'). It was seen by H. Fritzsch and P. Minkowski in 1975 that the next gauge group larger than SU(5) is SO(10). SO(10) predicts the existence of one extra neutral gauge boson Z'c. GUTs with larger gauge groups than SO(10) predict the existence of more than one extra neutral gauge boson and many 'exotic' fermions, which must be heavy to make the theory consistent with present experiments. The heavy bosons can decay to di-leptons in the final state as: Z' → l– l+ (l = e, μ).

The existence or nonexistence of this kind of models was investigated using the data gathered by CMS experiment[1, 2]. The analysis is based on the study of High Energy Electron-Positron Pairs (HEEP)[3, 4] or high energy muon pairs, which can lead to the discovery of new physics, emanating particularly from new gauge groups from Grand Unified Theories (GUTs), or extra spatial dimensions (which could show up through modifications to the Standard Model Drell-Yan pair production and through heavy resonance production). The main background processes to Z' and G' signals are tŧ (t-tbar) production, tW production, WW pair production and SM Z → tt → ll, with the topology of two electrons or muons in the final state. The second background topology includes processes for which at least one jet is misidentified as an electron. The relevant processes are QCD dijet, W+ jets and photon+ jets production. In order to discriminate our signal from backgrounds, a special selection of electrons or muons with highest possible efficiency is used for the signal events, with acceptable rejection power for the backgrounds.

I have been involved in this study since 2006. The update of this study with 2015 data can be performed to investigate a higher invariant mass spectrum, which could lead to the discovery of new particles (like Z' or RS KK excitation graviton) or putting an exclusion limit on the existence of these particles. This discovery should be observed first as a deviation in the invariant mass plot of the main irreducible background, which is a Drell-Yan distribution. The spin determination of this new heavy boson is important to know the nature and then the model which predicts this particle. The main quantity that determined directly the particle spin is the angular distribution. The angular distributions, based on the Collins Soper frame, have been studied in the framework of high energy electron pairs (HEEP)[5]. Several signal MC samples of new heavy bosons (Mee = 2 TeV/c2) originated from different models (Randall Sundrum and ADD models for spin 2 graviton, grand unified theories as spin 1 Z'y, and the Contact Interaction model), in addition to MC productions of high mass Drell-Yan (above 2 TeV/c2), have been used for this study. The study done at high mass for Drell-Yan background and different signal samples has shown that the angular distribution based on cos(qCS) is a very useful variable to discriminate between Drell-Yan background and spin 2 particle (RS KK or ADD KK excitation) and spin 1 particle as Z'y with high mass.

Finally, the discrimination power of the cos(qCS) variable between different signals and the main background (Drell-Yan events) was quantified using the likelihood ratio, in case a signal of 10 or 20 events is observed. In all cases and for all the models a 1 s expected separation is achieved. It was shown that the discrimination can be sensitively improved by using the rapidity of the pair as a second variable in the likelihood ratio, which allows us to reach a separation close to 2 s with 20 events for some models[5].

Although this study was performed at 8 TeV, where no signal was seen, it gives insight of the sensitivity that could be reached. The foreseen increase of LHC center of mass energy will help in the possible observation of a new high mass signal, which could show up only in a couple of months after the LHC resumes operation in 2015. For this reason the study will be repeated with the foreseen MC production suitable for 13 TeV center of mass energy to match the condition of data taking in 2015.

2. Upgrade simulation studies for the CMS high eta forward region

The CMS electromagnetic (EM) Calorimeter ECAL has been designed to measure the energy of electrons or photons produced in the pp collisions. Its energy resolution is expected to be at its best when the energy of the electromagnetic shower is the highest. Its calibration was performed by a test beam with single electrons of up to 250 GeV. However, at high energies one has to rely on Monte Carlo simulations which assume linearity response of the ECAL crystal. A method has been designed to check the ECAL linearity at high energy, and it was developed in a previous report based on simulation.

The method[6] relies on the fact that EM showers initiated by high energy electrons or photons, including most of Bremsstrahlung emission effects, are essentially contained in matrices of 5x5 PbW0_4 crystals, both in the ECAL Barrel (EB) and Endcaps (EE).

Due to this containment, the energy deposit E_1 in the central crystal of a 5x5 matrix can be measured with good precision from the energy deposit distribution in the surrounding crystals. This is used to check the energy calibration.

The data with high statistics collected by CMS experiment will be used in order to perform the ECAL calibration validation to cover both the ECAL barrel and endcaps.

The Very Front End (VFE) electronics will saturate for energy deposits E > 2000 GeV in a single crystal in matrices of 5x5 PbW0_4 crystals of the electromagnetic calorimeter ECAL in Barrel part, and E > 2820 GeV for the endcap parts. It was proposed that the parameterisation of electromagnetic showers to reconstruct the energy deposits in the saturated crystal [6].

The same method which has been described for the study of ECAL calibration will be used to recover the saturated crystals. The problem of saturated crystals will arise up with the foreseen run of the LHC with 13 TeV center of mass energy in 2015. The data collected by CMS detector in 2015 will be dedicated for solving this problem. A new machine learning techniques, based on the Multivariate Data Analysis (MVA), will be used.

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Torsion and its effect on cosmological and astrophysical applications of field theories

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It is well known that the most acceptable theory, so far, for gravitational interaction is the General theory of Relativity (GR). The theory is constructed in the context of Riemannian geometry, a geometry with vanishing torsion but non-vanishing curvature. Some recent results of cosmological and astrophysical observations can perhaps more naturally be explained in the context of alternative theories of gravity. In our research work, we have attempted to construct such alternative theories using wider geometries than Riemann's. Particularly, geometries with simultaneously non-vanishing curvature and torsion (Riemann-Cartan geometry type) have been investigated. Next, we test the suggested field theory by comparing its predictions with cosmological and astrophysical observations.

Accounting for the universe's accelerating expansion using *f(T)* gravity theory

Gamal Nashed

Astrophysical data from different sources, such as cosmic microwave background fluctuations, Supernovae Ia (SNIa) experiments, X-ray experiments, and large-scale structure, indicate that our universe is currently expanding with an accelerated rate. Higher dimensional theories like M-theory or String theory may explain this accelerated expansion. Another explanation comes from the modification of Einstein's theory.

An alternative modification of Einstein's theory of general relativity (GR), known as f(T) gravity, has been examined recently as a possible way of describing the current acceleration of the universe. The origin of f(T) gravity theory goes back to 1928 with Einstein's attempt to unify gravity and electromagnetism through the introduction of a tetrad field along with the concept of absolute parallelism. The gravitational field equation of teleparallel gravity is then described in terms of the torsion instead of the curvature. In comparison with f(R) gravity in the metric formalism, whose field equations are of the fourth order, f(T) gravity has the advantage that the dynamics are governed by second-order field equations. The fact that f(T) theories can potentially be used to explain the observed accelerating expansion of the universe with the relative simplicity of their field equations has given birth to a number of publications on these gravity theories[1–3]. Several features of f(T) gravity have been discussed, including observational cosmological constraints, solar system constraints, cosmological perturbations, dynamical behavior, spherically symmetric solutions, the existence of relativistic stars, the possibility of quantum divide crossing, cosmographic constraints, and the lack of local Lorentz invariance.

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Quantum effects in electron beam pumped GaAs

Mohamed Yahia

Quantum hydrodynamics of electron-hole (e–h) semiconductor plasma is essential to our understanding of the properties of several types of nano-sized semiconductor devices[1–4] and semiconductor lasers[5–7]. For example, electron beam pumped semiconductor lasers[8–11], nanophotonics and nanowires[12–14], resonant tunneling diodes[15–17], high-gain photoconductive semiconductor switches[18], current filament semiconductor lasers[19], and picosecond super-luminescence[20–22].

Since the pioneering work of Bohm and Pines[23–28] in the field of quantum plasma physics, around sixty years ago, the theoretical and practical interest in the field has not stopped, especially at the end of the last century, where a clear tendency towards nano-structured systems appears in physical advanced materials, including semiconductor devices. There is no doubt that some understanding of solid state properties is achieved by considering non-interacting electrons (free electron gas), but a more accurate description can be achieved by treating the electron population as a plasma neutralised by the lattice ions. The physical models must reach beyond single particle interactions and include collective, many-body, hydrodynamic, and quantum effects to obtain a reasonable agreement with measurements. The quantum effects play the role when the average distance between particles is equal to or smaller than the de Broglie (thermal) wave length. The tiny size of today's electronic components has become actually comparable with the de Broglie wave length, so the quantum effects are explicitly involved and therefore the classical description is rendered insufficient[1,2,18,30,33].

Semiconductors are considered as one of the candidates which provide a compact and less expensive medium to model and optimise phenomena encountered in recent developments in quantum solid state plasma. Propagation of the perturbation (energy) into the semiconductor plasma could be done by electron beam pumping, which drives the instability. The electron beam interaction generates electrons and holes, which creates our plasma system. During this process, plasma oscillations are excited due to e–h displacements. The population inversion in the semiconductor's band system is a resultant lag process of such pumping. This excitation could be instable, in which the energy is deposited and the plasma oscillation could be grown in time. Investigation of these plasma waves and their instability in quantum plasma has attracted considerable attention, since it could introduce a new unstable branch of the dispersion relation without analogy in classical plasmas.

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Electron beam can be used directly to pump bulk samples, and it does not require matching to the semiconductor's band gap energy as does optical pumping[34]. It can also be an effective probe of internal plasma fields. Picosecond or femtosecond electron beams, synchronised to a femtosecond light pulse, are just beginning to be used as probe pulses solid-state physics[35,36].

The literature exhibits many studies of electron beam pumped semiconductor quantum plasmas (for example, see refs. 37–41). However, no reported studies have attempted to investigate these different quantum effects together, such as electron-exchange and elec-

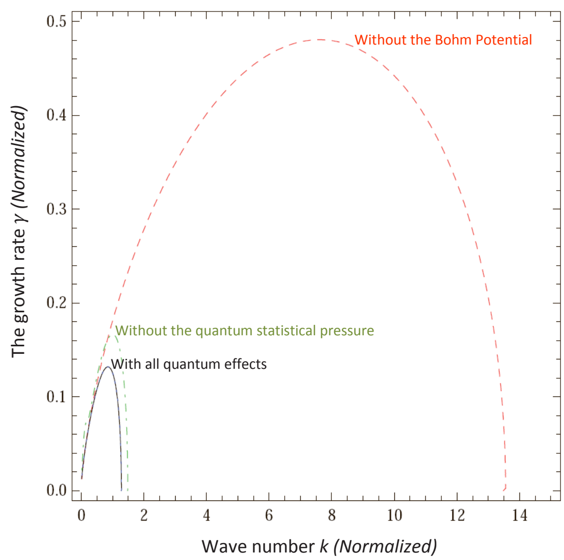

Figure 1. The normalised growth rate, γ, versus the normalised wavenumber, k, for GaAs with all quantum effects (solid curve); without the Bohm Potential term (dashed curve); without the electron exchange-correlation term (dotted curve, overlapping with the solid curve); and without the quantum statistical pressure term (dash-dotted curve).

tron correlation effects due to electron spin; quantum recoil force associated with the Bohm potential due to the electrons/holes tunneling through a potential barrier; degenerate pressure due to the high number density of the electrons and holes; as well as the electron beam velocity and number density. In recent investigation[42], we examine the behavior and instability of the electrostatic perturbations in the e–h semiconductor quantum plasma pumped by an energetic electron beam. The physical interpretation of the beam parameters on the quantum e–h plasma provides us with a deep understanding of the possible excitations, which can be used to enhance the efficiency of the semiconductors. Our research combines the advanced fields of research like probing plasma dynamics by electron beam, semiconductor wave length converters, and super-fluorescent bursts from a semiconductor.

The evolution of Langmuir and acoustic modes are investigated in an electron-hole-electron beam pumped GaAs nano-sized semiconductor, taking into account the above mentioned effects. For this purpose, the linear dispersion relation is derived which admits growing instability of the system. The instability is strongly dependent on the electron beam parameters, quantum recoil effects, and degenerate pressures. Furthermore, it is found that the instability region shrinks with the increase of the semiconductor number density. The instability arises because of the electron beam's production of e-h pairs which do not keep in phase with the electrostatic potential arising from the pair's plasma. The quantum recoil effect is the leading term to reduce the wave instability, while the exchange-correlation spin effect does not play a significant role (see Figure 1).

For full details of this study, refer to our recent work in reference 42.

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Electron–hole two-stream instability in quantum semiconductor plasma with exchange-correlation effects

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Researches in Plasma Physics span a vast array of intellectually exciting areas, from deep mathematical structures to state of the art technology. Physically, all matter under physical conditions with energies exceeding one electron volt (temperature ≈ 10^4 Kelvin) per atom above the ground state will involve plasma-physics phenomena. Semiconductors provide a compact and less expensive medium to model phenomena encountered in solid state plasma. When a semiconductor is excited by a short laser pulse, electrons absorb the photon energy and transit from the valence to the conduction band via single and/or multi-photon absorption, depending on the photon energy and the band-gap energy. This inter-band transition of the electrons creates holes in the valence band, and this state may satisfy the plasma conditions.

The great degree of miniaturization of today's semiconductor components is such that the de Broglie wave length of the charge carriers is frequently comparable to the dimensions of the system. Hence, the quantum mechanical effects (tunneling of degenerate electrons and holes through the Bohm potential barrier, exchange/correlation effects, effects due to spin, effects of degenerate plasma species, and phonon collision frequencies) are expected to play a role in the behavior of electronic components to be constructed. In a recent work[1], we present an investigation of the quantum two-stream instability in electron-hole plasmas, including all the aforementioned quantum effects. With the help of our quantum hydrodynamics model, we obtained an accurate description of what's going on inside GaAs and GaSb bulk semiconductors. It is interesting to see the limits between classical and quantum description of our cases as seen in Figure 1.

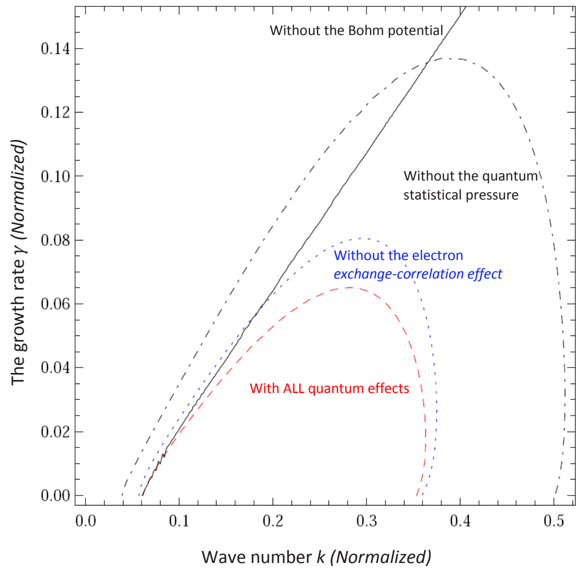

Figure 1. The normalised growth rate, γ, versus the normalised wavenumber, k, for GaAs with all quantum effects (dashed curve); without the Bohm Potential term (solid curve); without the electron exchange-correlation term (dotted curve); and without the quantum statistical pressure term (dash-dotted curve).

References and further reading

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