MIT\_Department of Physics.\_267

Controlled transport of energy and information is of paramount importance. It remains challenging, however, partially from the difficulty in controlling their physical carriers. Steering electrons and photons is now routine, yet atomic vibrations (quantized as phonons) are hard to control. This is partly due to the centrality of phonons in the disordered transport of energy as heat, but even in ordered sound waves problems persist. Phonons can readily couple to each other or to other degrees of freedom, degrading their energy or information content. Reversing these couplings, thereby regulating atomic motion, only recently became plausible. This increased control would reduce parasitic losses and turn phonons into information carriers. Dynamical effects are a crucial and under-examined aspect of this control as static devices are insufficient for changing external conditions. Dynamical control adds flexibility and versatility to phononic systems. Essentially, dynamical control requires tunable materials, materials whose physical properties depend on an external signal. Dynamical tuning is sensitive to the relative frequencies of the tuning signal and the controlled phonons. We develop an intuitive framework of the temporal modulation regimes. In low frequency tuning, phonons can adapt adiabatically to the material's changes. A variety of signals can be temporally and spatially modulated to tune phonon transport in this regime. We apply this adiabatic perspective to analyze dynamical effects in thermal cloaks. Tuning signals near the frequency of some phonon mode can produce resonant couplings. This hybridization can produce large changes in phonon properties. We apply this hybridization to develop a rigorously nonreciprocal phononic computer using magneto-acoustic materials that can outperform conventional computers in some tasks.

At high frequencies, phonons can only respond perturbatively to the tuning signal's changes. This regime is generally limited to optical control but it opens up new avenues for control. Employing an alternative approach to optical coupling, we develop a model of inverse acousto-optics (tuning the speed of sound with optical intensity) and dynamical phonon localization.

MIT\_Department of Physics.\_722

Lead sulfide colloidal quantum dots (PbS QDs) possess a uniquely tunable set of electronic properties that has generated considerable interest in their use as active materials in lightweight, flexible, solution-processed photovoltaics. The bandgap of PbS QDs can be tuned across the entire range relevant for solar cells through modification of the QD size, and a range of other QD electronic properties can be modified through control of the chemical ligands bound to the QD surface.

In this thesis we demonstrate how control of the energy level profile within PbS QD solar cells can be used to understand and improve their operation. First, we demonstrate that improvements in power conversion efficiency may be attained for ZnO / PbS QD heterojunction photovoltaics through the incorporation of a MoO3 interlayer between the PbS QD film and the top-contact anode.The deep-work-function MoO3 layer mitigates a Schottky junction that would otherwise form at the PbS / anode interface, resulting in performance improvements for devices employing a range of different anode materials. Then, we demonstrate how the tunable bandgap of PbS QDs can be used to elucidate charge- and exciton-transfer processes within hybrid organic /QD photovoltaic devices that demonstrate singlet exciton fission. We find that PbS QDs can accept electrons from triplets generated by singlet fission in pentacene and act as low-bandgap light absorbers complementary to the singlet fission material, and we explore the dependence of the triplet dissociation process on the energy levels of the QDs. Finally, we show that the energy levels of lead sulfide QDs, measured by ultraviolet photoelectron spectroscopy, shift by up to 0.9 eV between different chemical ligand treatments. The directions of these energy shifts match the results of density functional theory calculations and scale with the ligand dipole moment, and trends in the performance of photovoltaic devices employing ligand-modified QD films are consistent with the measured energy level shifts. These studies identify energy level shifts resulting from interface modification, QD bandgap modification through size control, and ligand-induced surface dipoles as means of predictably controlling the electronic properties of colloidal QD films and as versatile adjustable parameters in the performance optimization of QD optoelectronic devices.

MIT\_Department of Physics.\_723

Friction is the basic, ubiquitous mechanical interaction between two surfaces that results in resistance to motion and energy dissipation.

To test long-standing atomistic models of friction processes at the nanoscale, we implemented a synthetic nanofriction interface between a laser-cooled Coulomb crystal of individually addressable ions as the moving object and a periodic light-field potential as the substrate.

Through a variety of experiments presented in this thesis, we show atom-by-atom and with high spatial resolution that friction at the nanoscale can substantially differ from the simple phenomenological laws observed at the macroscale. Namely, we show that atomic-scale stick-slip friction can be tuned from maximal to nearly frictionless via arrangement of the ions relative to the periodic potential, and study the associated transition in transport dynamics as manifested by the propagation of kinks. We show that friction depends on velocity and temperature, in excellent agreement with simple analytical models, and that in the appropriate velocity regime, the dynamics can be observed in a way that is effectively at zero-temperature. We also establish a direct link between Aubry's structural transition for an infinite chain in an incommensurate periodic potential, and the vanishing of friction in nanocontacts. Our model system enables a microscopic and systematic investigation of friction, potentially even into the quantum many-body regime.

MIT\_Department of Physics.\_724

In order to gain a deeper understanding of the Standard Model of particle physics and test its limitations, it is necessary to carry out accurate calculations to compare with experimental results. Event shapes provide a convenient way for compressing the extremely complicated data from each collider event into one number. Using eective theories and studying the appropriate limits, it is possible to probe the underlying physics to a high enough precision to extract interesting information from the experimental results. In the initial sections of this work, we use a particular event shape, C-parameter, in order to make a precise measurement of the strong coupling constant, s. First, we compute the e+e- C-parameter distribution using the Soft-Collinear Eective Theory (SCET) with a resummation to N3LL' accuracy of the most singular partonic terms. Our result holds for C in the peak, tail, and far-tail regions. We treat hadronization effects using a field theoretic nonperturbative soft function, with moments [omega]n, and perform a renormalon subtraction while simultaneously including hadron mass effects. We then present a global fit for [alpha]s(mZ), analyzing the available C-parameter data in the resummation region, including center-of-mass energies between Q = 35 and 207 GeV. We simultaneously also fit for the dominant hadronic parameter, [omega]1. The experimental data is compared to our theoretical prediction, which has a perturbative uncertainty for the cross section of ~/= 2:5% at Q = mZ in the relevant t region for [alpha]s(mZ) and [omega]1. We find [alpha]s(mZ) = 0:1123 +/- 0:0015 and [omega]1 = 0:421 +/- 0:063 GeV with X2 / =dof = 0:988 for 404 bins of data. These results agree with the prediction of universality for [omega]? between thrust and C-parameter within 1-[sigma]. The latter parts of this study are dedicated to taking SCET beyond leading power in order to further increase the possible precision of calculations. On-shell helicity methods provide powerful tools for determining scattering amplitudes, which have a one-to-one correspondence with leading power helicity operators in SCET away from singular regions of phase space. We show that helicity based operators are also useful for enumerating power suppressed SCET operators, which encode subleading amplitude information about singular limits. In particular, we present a complete set of scalar helicity building blocks that are valid for constructing operators at any order in the SCET power expansion. We also describe an interesting angular momentum selection rule that restricts how these building blocks can be assembled.

MIT\_Department of Physics.\_733

Many astronomical sources produce transient phenomena at radio frequencies, but the transient sky at low frequencies (&lt; 300 MHz) remain relatively unexplored. Blind surveys with new widefield radio instruments are filling this gap. Although many of these instruments are limited by the classical confusion noise, one can in principle detect transients below the classical confusion limit.This thesis develops a technique for detecting radio transients that is based on temporal matched filters applied directly to time series of images. This technique has well-defined statistical properties and is applicable to variable and transient searches for any instrument. Using the Murchison Widefield Array as an example, we demonstrate that the technique works well on real data despite the presence of classical confusion noise, sidelobe confusion noise, and other systematic errors. We search for transients lasting between 2 minutes and 3 months and improve the upper limits on the transient surface density at 182 MHz for fluxes between ~ 20-200 mJy. We use this technique to characterize detectability of radio afterglows from compact binary coalescence, which are predicted electromagnetic counterparts of gravitational wave (GW) sources and the most promising progenitor of short gamma-ray bursts.While the next generation of GW detectors have come online and detected the first GW event, their ability to localize these events will remain poor during the early days of their operation. Many new widefield radio instruments will be able to cover large areas of the sky in a short amount of time. We use simulated afterglow light curves to estimate the rates of detection for different radio instruments under ideal conditions. We find that some widefield radio instruments might be able to detect radio afterglows and constrain their properties.

MIT\_Department of Physics.\_734

This thesis reports on progress in understanding the set of 6D F-theory vacua.F-theory provides a strikingly clean correspondence between physics and physical quantities and mathematics and geometrical quantities, which allows us to make precise mathematical statements using well defined and understood methods.We present two related results that both serve the following principal goal: to understand the set of 6D F-theory vacua using geometrical methods, and then to compare these to low-energy supergravities. In doing so, we find a near-perfect correspondence between low-energy supergravities that can be obtained from F-theory and field theories that satisfy known low-energy consistency conditions, e.g. anomaly cancellation. However, we will also isolate several cases that we prove can never arise in F-theory yet have no visible lowenergy inconsistencies. The results are presented in two chapters. First, we describe a complete, systematic enumeration of all elliptically fibered Calabi-Yau threefolds (EF CY3s) with Hodge number h2,1 &gt;/= 350; physically, this classifies all F-theory models that lead to low-energy supergravities with &gt;/= 351 neutral hypermultiplets. This result is obtained using global geometric calculations in finitely many, specific geometries.Second, we classify which local geometrical structures, corresponding to combinations of gauge algebras and (potentially shared) matter, can arise in F-theory. This classification is performed using local geometric calculations. This investigation reveals an exceedingly tight correspondence between F-theory models and consistent low-energy supergravities. Indeed, this near-perfect agreement provides a backdrop against which discrepancies between F-theory and low-energy supergravities stand out in sharp contrast. We describe in detail these discrepancies, in which seemingly consistent field theories cannot be described in F-theory.This work has several implications. First, it further refines the understanding of 6D supergravity models in F-theory, which has implications for string universality in 6D. It adds a level of mathematical precision to the study of 6D superconformal field theories (SCFTs) begun in [4, 3], which is a conjecturally complete classification of all 6D SCFTs. Our analysis confirms many of their results, but also explicitly shows that some of their proposed models cannot in fact be realized through their construction. Since our results can be phrased in terms of geometry, they also have implications for the study of EF CY3s. Finally, we discuss the subset of our results that hold in 4D F-theory as well, where they provide additional structure in a still difficult-to-constrain landscape.

MIT\_Department of Physics.\_735

In this thesis I study applications of effective field theories to understand aspects of QCD jets and their substructure at the Large Hadron Collider. In particular, I introduce an observable, D2 , which can be used for distinguishing boosted W/Z/H bosons from the QCD background using information about the radiation pattern within the jet, and perform a precision calculation of this observable. To simplify calculations in the soft collinear effective theory, I also develop a helicity operator basis, which facilitates matching calculations to fixed order computations performed using spinor-helicity techniques, and demonstrate its utility by computing an observable relevant for studying the properties of the newly discovered Higgs boson.

MIT\_Department of Physics.\_736

The optical properties of the spin-1/2 kagome lattice antiferromagnetic Herbertsmithite, ZnCu?(OH)?Cl?, are studied by means of Terahertz Time-Domain Spectroscopy. Herbertsmithite is proposed to exhibit Quantum Spin Liquid behavior, in which electron spins have strong antiferromagnetic interactions, but quantum fluctuations inhibit magnetic order even at 0 K, instead giving way to a Resonating Valence Bond state. Quantum Spin Liquids host exotic fractionalized excitations called spinons, which carry spin 1/2 but no charge. The low-energy behavior of these excitations are proposed to be governed by emergent gauge fields that depend on the quantum order of the macroscopically entangled ground state wavefunction. The nature of the quantum order of the ground state in Herbertsmithite has been the subject of great debate in the past decade. While computational work has suggested that a gapped Z 2 spin liquid is realized in Herbertsmithite, experimental work has seen no evidence of a spin gap, suggesting that a U(1) Dirac spin liquid might be realized instead. Recent theory work has proposed that a signature of the quantum order of the ground state of Herbertsmithite is manifested in its low-frequency optical conductivity as a result of the coupling of the charge and spin degrees of freedom through an emergent gauge field. In this dissertation, Terahertz Time-Domain Spectroscopy measurements on single crystals of Herbertsmithite will be used to test these theories, and provide evidence for the existence of a U(1) Dirac spin liquid state in Herbertsmithite.

MIT\_Department of Physics.\_942

Fluid dynamics is the universal theory of low-energy excitations around equilibrium states, governing the physics of long-lived modes associated with conserved charges. Historically, fluid dynamics has been formulated at the level of equations of motion, in terms of a local fluid velocity and thermodynamic quantities.In this thesis, we describe a new formulation of fluid dynamics in terms of a path integral, which systematically encodes the effects of thermal and quantum fluctuations. In our formulation, the dynamical degrees of freedom are Stuckelberg-type fields associated to the conserved quantities, which are subject to natural symmetry considerations, and the time evolution of the path integral is along the closed-time contour. Our formulation recovers the standard hydrodynamics, including the expected constraints from thermodynamics and the fluctuation-dissipation theorem, as well as an additional non-linear generalization of the Onsager relations. We demonstrate an emergent supersymmetry in the "classical statistical" limit of our theory. For the non-linear fluid, the formalism is encoded in a non-trivial differential geometric structure, with a non vanishing torsion tensor required to recover the correct physics of the most general fluid. Finally, we discuss progress in obtaining a holographic derivation of the action formulation at the ideal level, in which the low energy degrees of freedom emerge naturally as the relative embedding of the boundary and horizon hypersurfaces.

MIT\_Department of Physics.\_2654

This thesis focuses on the relationship between black holes in holography, chaos in strongly-coupled quantum systems, and the computational complexity of holographic states.By directly considering the time evolution of local operators, I am led to a simple diagnostic of many-body chaos: a commutator of such operators separated in time and space. Using this diagnostic, I study the growth of operators-a manifestation of the butterfly effect-in a variety of quantum systems. By considering the butterfly effect in holography, I find evidence for a detailed correspondence between the tensor network (or quantum circuit) that builds the holographic state and the interior geometry (or Einstein-Rosen bridge) of the black hole.Ultimately, I try to understand these connections by considering entanglement across time: the entanglement between an output system following time evolution and a record or memory perfectly correlated with the initial system.

MIT\_Department of Physics.\_3723

Flow of microparticles through geometrically confined spaces is a core element of most microfluidic technologies. Flowing particles are typically ordered and manipulated with external forces or coflowing streams, but these methods can be limited in generality and scalability. New techniques to control particle trajectories would enable new applications in such areas as materials assembly, optofluidics, and miniaturized "on-chip" bioassays and cytometry. Recently, researchers have sought to understand the conditions under which particles can organize themselves through interactions generic to the flow of suspensions through microchannels. In particular, a particle moving through a viscous fluid will create a disturbance flow, affecting the motion of distant particles. These hydrodynamic interactions (HI) are sensitive to particle shape and the presence of confining boundaries. This sensitivity presents a powerful opportunity: particle trajectories could be "programmed" into particle morphology and channel design. These could chosen so that many-body hydrodynamic interactions drive self-organization of the desired particle motions. Even a single particle could be designed to "self-steer" to a desired position in the channel cross-section through its hydrodynamic self-interaction. In this thesis, we present a series of studies exploring new possibilities for achieving selforganization, self-steering, and other flow-driven collective phenomena via design of particle shape and channel geometry. We focus on a particular setting: quasi-two-dimensional (q2D) confinement, in which particles are tightly "sandwiched" between parallel plates, free to move in only two dimensions. In this confinement regime, hydrodynamic interactions take a unique dipolar form. This form had been shown to sustain novel collective phenomena with much greater spatiotemporal coherence than can be achieved in unconfined or weakly confined suspensions. However, self-organization of q2D suspensions had not been demonstrated prior to our studies. Starting from a two-body problem, we progressively consider larger numbers of particles and more complex particle shapes. In our first study, we develop model equations for the coupled motion of two discs in a quasi-two-dimensional channel. Numerically, we find that a pair can form a hydrodynamic bound state with complex oscillatory motion. We demonstrate that this "quasiparticle" can be manipulated via patterning of confining boundaries. In the following study, we consider larger clusters of discs. We provide symmetry principles for the a priori construction of "flowing crystals": configurations of particles that maintain their relative positions as they are carried by the flow. The crystalline states generalize the two-body bound state to more complex configurations and collective modes. We also consider the wider dynamical landscape, finding metastable states with new, exquisitely coordinated particle motions. However, neither flowing crystals nor metastable states spontaneously form from a disordered configuration of discs. In pursuit of self-steering and self-organization, we turn to particle shape, and study the dynamics of a single "dumbbell" comprising two connected discs.We find that a fore-aft asymmetric dumbbell will reliably align with the flow and focus to the channel centerline. In contrast, a symmetric particle will oscillate between the channel side walls indefinitely. Through theoretical arguments, we isolate three viscous hydrodynamic mechanisms that together produce self-steering, and which generically occur for asymmetric particles in q2D. We carry out experiments with Continuous Flow Lithography (CFL), finding qualitative and semi-quantitative agreement with our theoretical predictions. Obtaining statistics from hundreds of particle trajectories, we provide a convincing experimental demonstration of self-steering for device applications.To our knowledge, this study provides the first demonstration that rigid particles can focus to the centerline in a channel flow. This progression culminates in our final study.

Inspired by the mobility formalism of polymer dynamics, we develop a theoretical and numerical framework that can recover the collective dynamics of many particles with complex shape. We find that small clusters of dumbbells can self-organize from disorder into one-dimensional flowing crystals. However, dumbbells can also pair as undesirable "defects." This two-body effect frustrates self-organization in large suspensions of dumbbells, driving formation of particle aggregates. To tame this aggregation, we rationally redesign particle shape, tailoring hydrodynamic interactions to promote chaining of particles in the flow direction. The redesigned "trumbbell" particles self-organize into large, two-dimensional flowing crystals. We reveal how crystal self-organization occurs through a multistage process. One, two, several, and finally many-body interactions become implicated in successive stages. This study is the first to demonstrate that flowing lattices can be stabilized purely by viscous hydrodynamic interactions.

MIT\_Department of Physics.\_3724

Results are presented on 5.1 fb- 1 of proton-proton collisions at a center of mass energy of 7 TeV and 19.7 fb- 1 at 8 TeV in a search for decays of the Standard Model (SM) Higgs boson to two Z bosons to four charged leptons. We observe a single excess above background expectation with a significance of 7.4 standard deviations at a mass of 125.6 ±0.4(stat) ±0.2(syst) GeV. This excess has a signal strength parameter ... We examine the transverse momentum spectrum of the new particle and find it to be consistent with the SM expectation, and also determine that the Standard Model JPC = 0++ is favored over the plausible alternative hypotheses.

MIT\_Department of Physics.\_3726

Astronomical and cosmological evidence suggests that 27% of the energy content of the universe is in the form of non-baryonic matter referred to as "dark matter." Weakly interacting massive particles have long been considered attractive candidates for this dark matter and can be found in a wide variety of models of physics beyond the Standard Model. The Dark Matter Time Projection Chamber experiment uses low-pressure gas time projection chambers to search for nuclear recoils caused by interactions between nuclei inside a detector and weakly interacting massive particles in the dark matter halo of the Milky Way galaxy. These detectors are also able to reconstruct the directions of these nuclear recoils, allowing for better rejection of possible background events. This thesis describes the design of a small prototype detector and the strategies used by the DMTPC collaboration to reconstruct events, reject backgrounds, and identify nuclear recoil candidate events. It presents the results of several studies aimed at understanding background events in DMTPC detectors. Finally, this work will present the first results from a nuclear recoil search taken with this detector in a surface laboratory at MIT.

MIT\_Department of Physics.\_3727

In this thesis, I describe the search for a Higgs boson through its decay to a pair of tan leptons with the tau-pair subsequently decaying to ail electron, a muon, and neutrinos.The search is performed using data collected from proton-proton collisions by the Compact Muon Solenoid experiment at the Large Hadron Collider, corresponding to 5.0 fb-1 of integrated luminosity recorded at a center-of-mass energy of 7 TeV and 19.7 fb-1 at 8 TeV. The expected significance for a Standard Model Higgs boson signal with a mass of 125 GeV is at the level of 1.2 standard deviations for the electron muon tau-pair decay mode. A mild excess of events is seen above the SM background expectation in this decay mode, consistent with a SM Higgs boson of mass 125 GeV. In combination with results using other tau-pair decay modes, an excess of events above the background expectation is seen at the level of 3.4 standard deviations. This constitutes the first evidence for a Higgs boson to decay to leptons.

This thesis also describes an analysis of the data in the context of physics beyond the Standard Model, particularly in the framework of its Minimal Supersymnnetric extension.

MIT\_Department of Physics.\_3728

Electronic transport in atomically thin layered materials has been a burgeoning field of study since the discovery of isolated single layer graphene in 2004. Graphene, a semi-metal, has a unique gapless Dirac-like band structure at low electronic energies, giving rise to novel physical phenomena and applications based on them. Graphene is also light, strong, transparent, highly conductive, and flexible, making it a promising candidate for next-generation electronics. Graphene's success has led to a rapid expansion of the world of 2D electronics, as researchers search for corollary materials that will also support stable, atomically thin, crystalline structures. The family of transition metal diclialcogenides represent some of the most exciting advances in that effort. Crucially, transition metal dichalcogenides add semiconducting elements to the world of 2D materials, enabling digital electronics and optoelectronics. Moreover, the single layer variants of these materials can posses a direct band gap, which greatly enhances their optical properties.This thesis is comprised of work performed on graphene and the dichalcogenides MoS 2 and WSe2. Initially, we expand on the family of exciting graphene devices with new work in the fabrication and characterization of suspended graphene nanoelectromnechanical resonators. Here we will demonstrate novel suspension techniques for graphene devices, the ion beam etching of nanoscale patterns into suspended graphene systems, and characterization studies of high frequency graphene nanoelectromechanical resonators that approach the GHz regime. We will then describe pioneering work on the characterization of atomically thin transition metal dichalcogenides and the development of electronics and optoelectronics based on those materials. We will describe the intrinsic electronic transport properties of high quality monolayer and bilayer MoS 2 , performing Hall measurements and demonstrating the temperature dependence of the material's resistivity, mobility, and contact resistance. And we will present data on optoelectronic devices based on electrically tunable p-n diodes in monolayer WSe2 , demonstrating a photodiode, solar cell, and light emitting diode.

MIT\_Department of Physics.\_4294

Charge exchange, the semi-resonant transfer of an electron from a neutral atom to an excited state in an energetic ion, can occur in plasmas where energetic ions are incident on a cold, at least partially neutral gas. Supernova remnants, especially in the immediate shock region, provide conditions conducive to charge exchange. The emission from post charge-exchange ions as the captured electron cascades down to the ground state, can shed light on the physical conditions of the shock and the immediate post-shock material, providing an important tool for understanding supernova explosions and their aftermath. In the first half of this thesis, I study charge exchange in the galactic supernova remnant G296.1-0.5 in two energy bands: the optical and the X-ray. The optical study, performed using both imaging and high resolution spectroscopy from the IMACS instrument on the Magellan Baade Telescope at Las Campanas Observatory, seeks to identify 'Balmer-dominated shocks' in the remnant, which signal the occurrence of charge exchange between hot, postshock protons and colder neutral hydrogen in the environment. The X-ray study probes line ratios in dispersed spectral data obtained with XMM-Newton RGS from an X-ray lobe in the NW of the remnant to hunt for signatures of charge exchange. The dispersed data are degraded by the extended nature of the source, blurring emission lines and making precise measurements difficult.The focus of the second half of this thesis is Micro-X : a sounding rocket-borne X-ray telescope, utilizing an array of microcalorimeters to achieve high energy resolution for even extended sources. I describe the design and commissioning of the payload and the steps toward launch, which is anticipated in the spring of 2015.

MIT\_Department of Physics.\_4445

An overwhelming proportion of the universe (83% by mass) is composed of particles we know next to nothing about. Detecting these dark matter particles directly, through hypothesized weak-force-mediated recoils with nuclear targets here on earth, could shed light on what these particles are, how they relate to the standard model, and how the standard model fits within a more fundamental understanding. This thesis describes two such experimental efforts: CDMS 11 (2007-2009) and SuperCDMS Soudan (ongoing). The general abilities and sensitivities of both experiments are laid out, placing a special emphasis on the detector technology, and how this technology has evolved from the first to the second experiment. Some topics on which I spent significant efforts are described here only in overview (in particular the details of the CDMS II analysis, which has been laid out many times before), and some topics which are not described elsewhere are given a somewhat deeper treatment. In particular, this thesis is hopefully a good reference for those interested in the annual modulation limits placed on the low-energy portion of the CDMS II exposure, the design of the detectors for SuperCDMS Soudan, and an overview of the extremely informative data these detectors produce. It is an exciting time. The technology I've had the honor to work on the past few years provides a wealth of information about each event, more so than any other direct detection experiment, and we are still learning how to optimally use all this information. Initial tests from the surface and now underground suggest this technology has the background rejection abilities necessary for a planned 200kg experiment or even ton-scale experiment, putting us on the threshold of probing parameter space orders of magnitude from where the field currently stands.

MIT\_Department of Physics.\_4446

This thesis benchmarks the deterministic lattice code, DRAGON, against data, and then applies this code to make a prediction for the antineutrino flux from the Chooz BI and B2 reactors. Data from the destructive assay of rods from the Takahama-3 reactor and from the SONGS antineutrino detector are used for comparisons. The resulting prediction from the tuned DRAGON code is then compared to the first antineutrino event spectra from Double Chooz. Use of this simulation in nuclear nonproliferation studies is discussed.

MIT\_Department of Physics.\_4447

We present results from the first systematic survey for Mg ii absorption lines at z &gt; 2.5. Using 46 infrared QSO spectra we discovered 111 Mg II systems, including five with z &gt; 5- the most distant systems now known. The comoving line density for weaker systems is statistically consistent with no evolution from z = 0.4 to z = 5.5. The density for stronger systems increases three-fold until z ~ 3 before declining towards higher redshifts, suggesting a connection to star formation. The weaker systems' lack of evolution does not fit within this interpretation, but may be reproduced by extrapolating low redshift scaling relations between host galaxy luminosity and absorbing halo radius to earlier epochs. Using new measurements from optical spectra of the same targets and low redshift control samples we study evolutionary trends in the chemical composition of Mg ii systems from z = 0 --&gt; 5.33. We observe a significant strengthening in the characteristic N(H I) for fixed Mg 11 strength as one moves toward higher redshift. We set lower limits on the metallicity where we can measure H 1, and find that systems with W? [delta]2796 = 0.3 - i.OA are quite metal rich at ~ 0.1 Solar. We speculate that if weaker Mg ii systems represent accreting gas, then their high metal abundance suggests re-accretion of recently ejected material rather than first-time infall from the metal-poor IGM, even at early times. We present a new technique for simultaneously fitting bright point sources in ungridded visibility data called the side lobe matrix technique. We provide computational speedups which allow for real time implementation. We derive analytic approximations for the error distributions of fit intensities in the presence of thermal noise, imperfect calibration, and ionospheric errors. We find that the intensity errors of the brightest sources with imperfect calibration and ionospheric errors are dominated by 'self errors' that exist independent of side-lobe contamination. We demonstrate that to lowest order, the dynamic range obtained with calibration/ionospheric errors is the same as when the source intensities are perfectly known.

MIT\_Department of Physics.\_4448

Discriminating between quantum states is an indispensable part of quantum information theory.This thesis investigates state discrimination of continuous quantum variables, focusing on bosonic communication channels and Gaussian states. The specific state discrimination problems studied are (a) quantum illumination and (b) optimal measurements for decoding bosonic channels.Quantum illumination is a technique for detection and imaging which uses entanglement between a probe and an ancilla to enhance sensitivity. I shall show how entanglement can help with the discrimination between two noisy and lossy bosonic channels, one in which a target reflects back a small part of the probe light, and the other in which all probe light is lost. This enhancement is obtained even though the channels are entanglement-breaking.The main result of this study is that, under optimum detection in the asymptotic limit of many detection trials, 6 dB of improvement in the error exponent can be achieved by using an entangled state as compared to a classical state. In the study of optimal measurements for decoding bosonic channels, I shall present an alternative measurement to the pretty-good measurement for attaining the classical capacity of the lossy bosonic channel given product coherent-state inputs. This new measurement has the feature that, at each step of the measurement, only projective measurements are needed. The measurement is a sequential one: the number of steps required is exponential in the code length, and the error rate of this measurement goes to zero in the limit of large code length. Although not physically practical in itself, this new measurement has a simple physical interpretation in terms of collective energy measurements, and may give rise to an implementation of an optimal measurement for lossy bosonic channels.The two problems studied in my thesis are examples of how state discrimination can be useful in solving problems by using quantum mechanical properties such as entanglement and entangling measurements.

MIT\_Department of Physics.\_4449

Understanding the structure of the proton is an ongoing effort in the particle physics community. Existing in the region of nonperturbative QCD, the various models for proton structure must be informed and constrained by experimental data. In 2009, the STAR experiment at Brookhaven National Lab recorded over 12 pb-1 of data from polarized p+p collisions at 500 GeV center-of-mass energy provided by the RHIC accelerator. This has offered a first look at the spin-dependent production of W+(-) bosons, and hence at the spin-flavor structure of the proton, where the main production mode is through d+u (u+d) annihilation. Using STAR's large Time Projection Chamber and its wide-acceptance electromagnetic calorimeters, it is possible to identify the e+ + v (e- + v) decay mode of the W bosons produced. This thesis presents the first STAR measurement of charge-separated W production, both the pseudorapidity-dependent ratio and the longitudinal single-spin asymmetry.These results show good agreement with theoretical expectations, validating the methods used and paving the way for the analysis of larger datasets that will be available soon. In the near future the range of this measurement will be augmented with the Forward GEM Tracker. A discussion of the design and implementation of this upgrade is also included, along with projections for its impact.

MIT\_Department of Physics.\_4452

DNA conformation within cells has many important biological implications, but there are challenges both in modeling DNA due to the need for specialized techniques, and experimentally since tracing out in vivo conformations is currently impossible.This thesis contributes two computational projects to these efforts.The first project is a set of online and offline calculators of conformational statistics using a variety of published and unpublished methods, addressing the current lack of DNA model-building tools intended for general use. The second project is a reconstructive analysis that could enable in vivo mapping of DNA conformation at high resolution with current experimental technology.

MIT\_Department of Physics.\_4484

The Standard Model (SM) of particle physics is a quantum field theory of the strong, weak, and electromagnetic interactions. It successfully describes a large majority of observed phenomena at microscopic scales. The key issue that remains to be addressed is the mechanism for electroweak symmetry breaking (EWSB). Without EWSB in the theory, the massive weak force mediators - the W and Z bosons, are required to be massless to satisfy gauge symmetry. To incorporate EWSB into the SM, the Higgs mechanism is invoked and introduces a scalar field, the Higgs field, that couples to the W and Z bosons and gives them mass. Additionally, the SM postulates that the fundamental fermions acquire mass through interactions with the Higgs field. Observation of the field quantum, the Higgs boson, would greatly validate our ideas on electroweak symmetry breaking and complete the table of fundamental particles predicted by the Standard Model. If it exists, the Higgs boson has eluded detection for decades. A primary objective of the Large Hadron Collider (LHC) project is to make a definitive statement about the existence of the Higgs boson. The LHC provided proton-proton collisions at [square root of]s = 7 TeV for the 2011 run. The search for the SM Higgs with the 2011 dataset represented the first major foray into the search effort by the LHC project. This thesis presents a search for the SM Higgs boson in the ZZ --&gt;2?2v channel from the analysis of 4.9 fb-1 of data collected with the Compact Muon Solenoid (CMS) detector at the LHC. Overviews of electroweak theory and of Higgs production at the LHC are given, followed by descriptions of the CMS detector and the algorithms for event reconstruction. A measurement of the inclusive cross section for Z boson production is presented as a validation on the measured efficiencies of the electron and muon reconstruction and selection requirements. Lastly, the Higgs search analysis and results are presented.

MIT\_Department of Physics.\_4486

Experiments using ultracold atomic gases address fundamental problems in many-body physics.This thesis describes experiments on strongly-interacting gases of fermionic atoms, with a focus on non-equilibrium physics and dimensionality. One of the fundamental dissipative processes in two-component gases is the transport of spin due to relative motion between the two spin components. We generate spin transport in strongly-interacting Fermi gases using a spin dipole excitation and measure the transport coefficients describing spin drag and spin diffusion. For resonant interactions, we observe strong suppression of spin transport, with the spin transport coefficients reaching quantum-mechanical limits. Dimensionality plays an important role in the formation of bound states between pairs of particles. We tune the dimensionality of a Fermi gas from three to two dimensions (2D) using an optical lattice potential and observe the evolution of the pair binding energy using radio-frequency spectroscopy. The binding energy increases as the lattice depth increases, approaching the 2D limit. Gases with resonant interactions, which have no two-body bound state in three dimensions, show a large binding energy determined by the confinement energy of the lattice wells. The themes of non-equilibrium dynamics and dimensionality come together in the study of soliton excitations in superfluid Fermi gases. We create a planar defect in the superfluid order parameter of an elongated Fermi gas using detuned laser light. This defect moves through the gas as a solitary wave, or soliton, without dispersing. We measure the oscillation period of the soliton and find it to exceed the predictions of mean-field theory by an order of magnitude.

MIT\_Department of Physics.\_4487

In this thesis we present a data-driven neuromuscular model of human walking and its application to prosthesis control. The model is novel in that it leverages tendon elasticity to more accurately predict the metabolic consumption of walking than conventional models. Paired with a reflex-based neural drive the model has been applied in the control of a robotic ankle-foot prosthesis, producing speed adaptive behavior.

Current neuromuscular models significantly overestimate the metabolic demands of walking. We believe this is because they do not adequately consider the role of elasticity; specifically the parameters that govern the force-length relations of tendons in these models are typically taken from published values determined from cadaver studies. To investigate this issue we first collected kinematic, kinetic, electromyographic (EMG), and metabolic data from five subjects walking at six different speeds. The kinematic and kinetic data were used to estimate muscle lengths, muscle moment arms, and joint moments while the EMG data were used to estimate muscle activations. For each subject we performed a kinematically clamped optimization, varying the parameters that govern the force-length curve of each tendon while simultaneously seeking to minimize metabolic cost and maximize agreement with the observed joint moments. We found a family of parameter sets that excel at both objectives, providing agreement with both the collected kinetic and metabolic data. This identification allows us to accurately predict the metabolic cost of walking as well as the force and state of individual muscles, lending insight into the roles and control objectives of different muscles throughout the gait cycle. This optimized muscle-tendon morphology was then applied with an optimized linear reflex architecture in the control of a powered ankle-foot prosthesis. Specifically, the model was fed the robot's angle and state and used to command output torque. Clinical trials were conducted that demonstrated speed adaptive behavior; commanded net work was seen to increase with walking speed. This result supports both the efficacy of the modeling approach and its potential utility in controlling life-like prosthetic limbs.

MIT\_Department of Physics.\_4488

In this thesis the jet fragmentation function of inclusive jets with transverse momentum PT &gt; 100 GeV/c in PbPb collisions is measured for reconstructed charged particles with PT &gt; 1 GeV/c within the jet cone. A data sample of PbPb collisions collected in 2011 at a center-of-mass energy of [square root of]sNN = 2.76 TeV corresponding to an integrated luminosity of 150 [mu]b-1 is used. The results for PbPb collisions as a function of collision centrality are compared to reference distributions based on pp data collected at the same collision energy. A centrality-dependent modification of the fragmentation function is revealed. For the most central collisions a significant enhancement is observed in the PbPb/pp fragmentation function ratio for the charged particles with PT less than 3 GeV/c.

MIT\_Department of Physics.\_4521

In this thesis, we investigate the implications of fluctuations in systems away, possibly even far, from equilibrium due to their motion either in or out of thermal equilibrium. This subject encompasses several topics in physics including the dynamical Casimir effect in the presence of moving boundaries, and non-contact friction between objects in relative motion. In both cases, photons are created due to the coupling of the motion and zero-point fluctuations in the vacuum, resulting in dissipation and radiative loss. We introduce a general formalism, equally applicable to lossy and ideal objects, to compute the quantum radiation and dissipation effects solely in terms of the classical scattering matrices. We obtain trace formulas which are general and independent of any approximation scheme where numerous examples, many novel, are discussed in great detail. Specifically, we give an exact treatment of quantum fluctuations in the context of a neutral rotating object, and show that it spontaneously emits photons and drags objects nearby, and compute the associated photon statistics and entropy generation. In the context of non-contact friction, we find a quantum analog of the classical Cherenkov effect for two neutral plates in relative motion, purely due to quantum fluctuations. We present a number of arguments and exact proofs, including a method introduced in the context of quantum field theory in curved space, as well as the scattering approach, to show that a friction force between two plates appears at a threshold velocity set by the speed of light in their medium.

MIT\_Department of Physics.\_4522

Interactions between charge and lattice degrees of freedom play a critical role in determining the properties of canonical BCS superconductors where integration out of the phonon subsystem results in an effective pairing interaction between electrons. In the study of high temperature superconductors the importance of phonons is less well understood and charge ordering properties vary between the families of high-Tc cuperates. While superconductivity in these materials is not believed to originate from phonon excitations, there is evidence for strong electron-phonon coupling from significant electron dispersion renormalization and the observation of increased breadth in optical Cu-O bond modulating phonons. Here we present measurements of acoustic phonons in single and double layer BSCCO which show several effects: broadening of the longitudinal acoustic in correspondence to approximately period-four ordering tendencies and signatures of time-reversal and inversion symmetry breaking. Measurement of these anomalous properties is feasible due to renormalization of the lattice propagator by strong interactions with underlying symmetry-breaking electronic states.These symmetries are broken at room temperature for all materials in the 'strange metal' state above the pseudogap, but are enhanced, particularly around the period four intercell ordering wavevector, as the system is cooled into the pseudogap state. In-plane acoustic phonons are a probe of the electron physics localized on the Cu-O plane due to the residual eigenvector components in this plane. 4.These phonon measurements then present a picture of BSCCO in which charge correlations stay dynamic with a pronounced tendency toward ordering at a specific wave-vector and an underlying symmetry-breaking ground state.

MIT\_Department of Physics.\_4604

A new generation of interferometric gravitational wave detectors, currently under construction, will closely approach the fundamental quantum limits of measurement, serving as a prominent example of quantum mechanics at the macroscale. Simultaneously, numerous experiments involving micro-mechanical oscillators are beginning to explore the quantum regime, with the help of optical cooling techniques. We discuss the approach to the quantum regime in a gram-scale opto-mechanical experiment, and in large-scale gravitational wave detectors. The gram-scale experiment is designed so that radiation pressure forces completely dominate the dynamics of the mechanical mirror suspensions. We review a series of optical trapping and cooling techniques that we have demonstrated using this apparatus. A variant of these techniques is applied to a gravitational wave interferometer -- yielding an effective temperature of 1.4 microkelvin and a phonon occupation number of 234 in a kilogram-scale oscillator. Then we analyze the displacement noise spectrum in the gram-scale system, which is currently limited by thermally driven fluctuations of the mirror suspensions. We identify methods for improving the suspension, in order to reveal the quantum fluctuations attributable to back-action of a displacement measurement. Finally, we propose a scheme for exploiting the opto-mechanical coupling in this system to generate optical entanglement.

MIT\_Department of Physics.\_4605

High spectral resolution observations of X-ray phenomena have the potential to uncover new physics. Currently, only point sources can be probed with high resolution spectra, using gratings. Extended objects like supernova remnants cannot be dispersed, leaving the dense forest of emission lines blended by the moderate resolution of modern instruments. In the first half of this thesis, I undertake two investigations of the supernova remnant Cassiopeia A using the flagship X-ray observatory, Chandra. The first study combines the spatial resolution of the ACIS instrument with the spectral resolution of the dispersive HETG to investigate the evolution of ejecta knots. The second improves on statistical limits of radioactive ejecta, and simulates what higher resolution instruments may observe. Micro-X, a new high resolution X-ray telescope, is the focus of the second half. I detail the commissioning of this novel sounding rocket payload, which uses a focal plane of micro-calorimeters to achieve high spectral resolution in each pixel. The flight hardware is in a final state of testing and integration before the launch, which is anticipated in 2014.

MIT\_Department of Physics.\_4606

Lattice QCD allows us to study the structure of hadrons from first-principles calculations of quantum chromodynamics.We present calculations that shed light on the behavior of quarks inside hadrons in both qualitative and quantitative ways. The first is a study of diquarks.We bind two quarks in a baryon with a static quark and compute the simultaneous two-quark density, including corrections for periodic boundary conditions. Defining a correlation function to isolate the intrinsic correlations of the diquark, we find that away from the immediate vicinity of the static quark, the diquark has a consistent shape, with much stronger correlations seen in the scalar diquark than in the axial-vector diquark. We present results at pion masses 293 and 940 MeV and discuss the dependence on the pion mass. The second set of calculations is a more quantitative study that covers a wide range of (mainly isovector) nucleon observables, including the Dirac and Pauli radii, the magnetic moment, the axial charge, and the average quark momentum fraction. Two major advances over previous calculations are the use of a near-physical pion mass, which nearly eliminates the uncertainty associated with extrapolation to the physical point, and the control over systematic errors caused by excited states, which is a significant focus of this thesis. Using pion masses as low as 149 MeV and spatial box sizes as large as5.6 fm, we show the importance of good control over excited states for obtaining successful postdictions -- which we achieve for several quantities -- and we identify a remaining source of systematic error that is likely responsible for disagreement with experiment in the axial sector. We then use this understanding of systematics to make predictions for observables that have not been measured experimentally.

MIT\_Dept. of Physics.\_5

The nucleon elastic electromagnetic form factors are fundamental quantities needed for an understanding of nucleon and nuclear electromagnetic structure. The evolution of the Sachs electric and magnetic form factors with Q2, the square of the four-momentum transfer, is related to the distribution of charge and magnetization within the nucleon. High precision measurements of the nucleon form factors are essential for stringent tests of our current theoretical understanding of confinement within the nucleon. Measurements of the neutron form factors, in particular, those of the neutron electric form factor, have been notoriously difficult due to the lack of a free neutron target and the vanishing integral charge of the neutron. Indeed, a precise measurement of the neutron electric form factor has eluded experimentalists for decades; however, with the advent of high duty-factor polarized electron beam facilities, experiments employing polarization degrees of freedom have finally yielded the first precise measurements of this fundamental quantity. Following a general overview of the experimental and theoretical status of the nucleon form factors, a detailed description of an experiment designed to extract the neutron electric form factor from measurements of the neutron's recoil polarization in quasielastic 2H(e, e')1H scattering is presented. The experiment described here employed the Thomas Jefferson National Accelerator Facility's longitudinally polarized electron beam, a magnetic spectrometer for detection of the scattered electron, and a neutron polarimeter designed specifically for this experiment. Measurements were conducted at three Q2 values of 0.45, 1.13, and 1.45 (GeV/c)2, and the final results extracted from an analysis of the data acquired in this experiment are reported and compared with recent theoretical predictions for the nucleon form factors.

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The Relativistic Heavy Ion Collider (RHIC) has provided its experiments with the most energetic nucleus-nucleus collisions ever achieved in a laboratory. These collisions allow for the study of the properties of nuclear matter at very high temperature and energy density, and may uncover new forms of matter created under such conditions. This thesis presents measurements of the elliptic flow amplitude, v?, in Au+Au collisions at RHIC's top center of mass energy of 200 GeV per nucleon pair. Elliptic flow is interesting as a probe of the dynamical evolution of the system formed in the collision. The elliptic flow dependences on transverse momentum, centrality, and pseudorapidity were measured using data collected by the PHOBOS detector during the 2001 RHIC run. The reaction plane of the collision was determined using the multiplicity detector, and the azimuthal angles of tracks reconstructed in the spectrometer were then correlated with the found reaction plane. The v? values grow almost linearly with transverse momentum, up to P[sub]T of approximately 1.5 GeV, saturating at about 14%. As a function of centrality, v? is minimum for central events, as expected from geometry, and increases up to near 7% (for 0 &lt; [eta] &lt; 1) at (N[sub]part) =83. The v2 dependence on pseudorapidity was measured over the range 0 &lt; [eta] &lt; 1.8 for three centrality rangess: 3-15%, 15-25% and 25-50%. 4.For all but the most central of the three centrality ranges, v? is seen to decrease with increasing starting already near mid-rapidity. The results, their comparison to models and interpretation are discussed.

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This thesis describes recent single-ion Penning trap mass spectrometry measurements of the mass of atomic Cesium with a relative uncertainty of 2 x 10-10. This measurement reduces the uncertainty on the mass of Cesium by a factor of 100, and removes this uncertainty as a limitation on the accuracy of a determination of the fine-structure constant alpha via a Cesium photon recoil experiment. Removal of this limit should ultimately allow this value of alpha to have a relative accuracy ~1 ppb, which would be comparable to or even better than the most accurate measurement of alpha currently available. This value of alpha will help shed light on the current ~50 ppb discrepancies between values of alpha measured via different routes. In addition to the mass measurement of Cesium, this thesis also describes related mass measurements of atomic Rubidium and Sodium which reduce the uncertainties on these masses by factors - 100, with a view to possible future photon recoil measurements using these species. The measurements were taken using a new Penning trap mass spectrometer constructed by the author and his colleagues. This new spectrometer followed the general design principles of previous MIT ICR Lab Penning trap mass spectrometers, and incorporated a DC SQUID as an ion detector for the first time. This thesis concludes with a discussion of a passive two-coil system designed for shielding magnetic field gradients. These may prove to be the key enabling technology for a future double Penning trap mass spectrometer.

MIT\_Dept. of Physics.\_86

In Part I of the thesis, a general physical framework describing the kinetics of protein- DNA interaction is developed. Recognition and binding of specific sites on DNA by proteins is central for many cellular functions such as transcription, replication, and recombination. In the process of recognition, a protein rapidly searches for its specific site on a long DNA molecule and then strongly binds this site. Earlier studies have suggested that rapid search involves sliding of the protein along the DNA. I treat sliding as a one-dimensional diffusion in a sequence-dependent rough energy landscape. I demonstrate that, despite the landscape's roughness, rapid search can. be achieved if one-dimensional sliding is accompanied by three-dimensional diffusion. I estimate the range of the specific and nonspecific DNA-binding energy required for rapid search and suggest experiments that can test the proposed mechanism. It appears that realistic energy functions cannot provide both rapid search and strong binding of a rigid protein. To reconcile these two fundamental requirements, a search-and-fold mechanism is proposed that involves the coupling of protein binding and partial protein folding. In this regard, I propose an effective energy landscape that incorporates longitudinal (sliding) and transversal (folding) dynamics. I also study the influence of finite correlation length in the binding potential profile on the one-dimensional diffusion. The proposed mechanism has several important biological implications for search in the presence of other proteins and nucleosomes, simultaneous search by several proteins, etc. In Part II, I analyze the behavior of random walks in presence of smooth manifolds. First, I treat a random walk (or gaussian polymer) confined to a half-space using a field-theoretic approach. Using path integrals, I derive basic scaling relations and the probability distribution function for arbitrary coupling strength between the polymer and the manifold. Next, I consider self-avoiding polymers attached to the tip of an impenetrable probe. The scaling exponents [gamma] ? and [gamma]?, characterizing the number of configurations for the attachment of the polymer by one end, or at its midpoint, are shown to vary continuously with the tip's angle. These apex exponents are calculated analytically by [epsilon]-expansion and compared to numerical simulations in three dimensions. I find that when the polymer can move through the attachment point, it typically slides to one end; the apex exponents quantify the entropic barrier to threading the eye of the probe.

MIT\_Dept. of Physics.\_87

We present a parallel implementation of the particle-particle/particle-mesh (P3M) algorithm for distributed memory clusters. The llp3m-hc code uses a hybrid method for both computation and domain decomposition. Long-range forces are computed using a Fourier transform gravity solver on a regular mesh; the mesh is distributed across parallel processes using a static one-dimensional slab domain decomposition. Short-range forces are computed by direct summation of close pairs; particles are distributed using a dynamic domain decomposition based on a space-filling Hilbert curve. A nearly-optimal method was devised to dynamically repartition the particle distribution so as to maintain load balance even for extremely inhomogeneous mass distributions. Tests using 8003 simulations on a 40-processor Beowulf cluster showed good load balance and scalability up to 80 processes. We discuss the limits on scalability imposed by communication and extreme clustering and suggest how they may be removed by extending our algorithm to include a new adaptive P3M technique, which we then introduce and present as a new llap3m-hc code. We optimize free parameters of adaptive P3M to minimize force errors and the timing required to compute short range forces. We apply our codes to simulate small scale structure of the universe at redshift z &gt; 50. We observe and analyze the formation of caustics in the structure and compare it with the predictions of semi-analytic models of structure formation. The current limits on neutralino detection experiments assume a Maxwell-Boltzmann velocity distribution and smooth spatial distribution of dark matter. It is shown in this thesis that inhomogeneous distribution of dark matter on small scales significantly changes the predicted event rates in direct detection dark matter experiments. The effect of spatial inhomogeneity weakens the upper limits on neutralino cross section produced in the Cryogenic Dark Matter Search Experiment.

MIT\_Dept. of Physics.\_88

Nanoscale structures present both unique physics and unique theoretical challenges. Atomic-scale simulations can find novel nanostructures with desirable properties, but the search can be difficult if the wide range of possible structures is not well understood. Electrical response and other non-equilibrium transport phenomena are measured experimentally, but not always simulated accurately. This thesis presents four diverse applications that demonstrate how first-principles calculations can address these challenges. Novel boron nanotube structures with unusual elastic properties are presented. Internal degrees of freedom are identified that allow longitudinal stress to be dissipated without changing the tube's diameter, leading to high lateral stiffness. Self-trapped hole structures in amorphous silicon dioxide are investigated in order to connect the behavior of hole currents to atomic-scale structures. Calculations on a paired-oxygen analogue to the ... center show that such a configuration does not result in a metastable trapped-hole state. A novel method to enable first-principles mobility calculations in ultrathin silicon-on-insulator (UTSOI) structures is presented and applied to interface roughness scattering in transistor channels. Self-consistent potentials and accurate wavefunctions and band structures allow for a direct link between measured electrical response and atomic structure. Atomic-scale interface roughness is shown to be an important limit on mobility at high carrier densities. At low carrier densities, such short-wavelength roughness results in qualitatively different mobility behavior than gradual UTSOI channel thickness fluctuations. An effective Hamiltonian technique to calculate short-time, non-equilibrium fluctuations in quantum devices is developed. Applications to quantum dots and resonant tunneling diodes show that temporal fluctuations are reproduced well.

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In this thesis, we present some results that strongly support Sen's conjectures on tachyon condensation on a bosonic D-brane. Our main tool of analysis is level truncated open bosonic string field theory We use level truncation to check that the energy difference between the local maximum and the local minimum of the open bosonic tachyon effective potential is equal to the tension of a space-filling D-brane (Sen's first conjecture). Our results prove this equality within a precision of about 0.1%. We then construct lump solutions of open bosonic string field theory, which are conjectured by Sen (third conjecture) to be D-branes of lower dimensions. We check that indeed the tensions of lumps of codimension one and two, coincide with the tensions of the respective D-branes within a precision of a few percent. We also give evidence for Sen's second conjecture; that in the nonperturbative tachyon vacuum all open string degrees of freedom must disappear. We show that this is guaranteed if we can write the identity string field I in the form I = QA, where A is some string field and Q is the BRST operator in the true vacuum. We show evidence that the identity can indeed be written in this form. We also analyze the dynamics of tachyon condensation by studying time-dependent solutions of p-adic string theory and level truncated string field theory. Although our rolling solutions conserve energy, their pressure oscillates with diverging amplitudes. These results therefore don't support Sen's proposal of a pressureless tachyon matter.

MIT\_Dept. of Physics.\_98

This Thesis describes the basic framework of a relativistic ray-tracing code for analyzing accretion processes around Kerr black holes. We begin in Chapter 1 with a brief historical summary of the major advances in black hole astrophysics over the past few decades. In Chapter 2 we present a detailed description of the ray-tracing code, which can be used to calculate the transfer function between the plane of the accretion disk and the detector plane, an important tool for modeling relativistically broadened emission lines. Observations from the Rossi X-Ray Timing Explorer have shown the existence of high frequency quasi-periodic oscillations (HFQPOs) in a number of black hole binary systems. In Chapter 3, we employ a simple \hot spot" model to explain the position and amplitude of these HFQPO peaks. The power spectrum of the periodic X-ray light curve consists of multiple peaks located at integral combinations of the black hole coordinate frequencies, with the relative amplitude of each peak determined by the orbital inclination, eccentricity, and hot spot arc length. In Chapter 4, we introduce additional features to the model to explain the broadening of the QPO peaks as well as the damping of higher frequency harmonics in the power spectrum. The complete model is used to fit the power spectra observed in XTE J1550-564, giving confidence limits on each of the model parameters. In Chapter 5 we present a description of the structure of a relativistic alpha-disk around a Kerr black hole. Given the surface temperature of the disk, the observed spectrum is calculated using the transfer function mentioned above. The features of this modified thermal spectrum may be used to infer the physical properties of the accretion disk and the central black hole. In Chapter 6 we develop a Monte Carlo code to calculate the detailed propagation of photons from a hot spot emitter scattering through a corona surrounding the black hole. The coronal scattering has two major observable effects: the inverse-Compton process alters the photon spectrum by adding a high energy power-law tail, and the random scattering of each photon effectively damps out the highest frequency modulations in the X-ray light curve.

MIT\_Dept. of Physics.\_169

The Neutralized Transport Experiment (NTX) has been built at the Heavy Ion Fusion Virtual National Laboratory. NTX is the first successful integrated beam system experiment that explores various physical phenomena, and determines the final spot size of a high intensity ion beam on a scaled version of a Heavy Ion Fusion driver. The final spot size is determined by the conditions of the beam produced in the injector, the beam dynamics in the focusing lattice, and the plasma neutralization dynamics in the final transport. A high brightness ion source using an aperturing technique delivers 25 mA of single charged potassium ion beam at 300 keV and a normalized edge emittance of 0.05 r-mm-mr. The ion beam is injected into a large bore magnetic quadrupole lattice, which produces a 20 mm radius beam converging at 20 mr. The converging ion beam is further injected into a plasma neutralization drift section where it is compressed ballistically down to a 1 mm spot size. NTX provides the first experimental proof of plasma neutralized ballistic transport of a space-charge dominated ion beam, the information about higher order aberration effects on the spot size, the validation of numerical tools based on excellent agreement between measurements and numerical simulations over a broad parameter regime, and the development of new diagnostics to study the ion beam dynamics. The theoretical and experimental results are presented on the beam dynamics in the ion diode, downstream quadrupole lattice, and final neutralized transport.

MIT\_Dept. of Physics.\_170

The first excited state of the proton, the Delta, can be reached through a magnetic dipole spin flip of one of the quarks (M1) or through electric and Coulomb quadrupole terms (E2 and C2) which indicate a deviation from spherical symmetry. The quark models using the color hyperfine interaction underestimate the size of the quadrupole terms by more than an order of magnitude. Models using the pion cloud do a much better job of describing the data. This is expected due to the spontaneous breaking of chiral symmetry which leads to a cloud of virtual p wave pions which introduce the non-spherical amplitudes. The data presented in this work fill gaps in the low Q2, long distance region where the pion cloud is expected to dominate and to produce significant Q2 variation. The p(e, e'p)7r0 reaction was measured in the A region at Q2 = 0.060 (GeV/c)2, the lowest Q2 to date for pion electroproduction, utilizing out-of-plane magnetic spectrometers at the Mainz Microtron in Germany. This work reports results for the dominant transition magnetic dipole amplitude and the quadrupole to dipole ratios obtained from fitting the new data with models using a three parameter, resonant multipole fit: M3/2 = (40.33 i 0.63stat+syst ± 0.61model) (10-3/m,r+), E2/M1 = Re(E3/2/M3/2) = (-2.28 i 0.29stat+syst ± 0.20modeI)%, and C2/M1 = Re(S3/M+3/2) = (-4.81 ± 0.27stat+syst i 0.26model)%. These new results for the transition multi-poles disagree with predictions of the quark models but are in reasonable agreement with a chiral extrapolation of lattice QCD, chiral effective field theory and dynamical model results confirming the dominance and general Q2 variation of the long range pionic contribution. While there is qualitative agreement with the models, there is no quantitative agreement thus indicating the need for further improvement of the models.

MIT\_Dept. of Physics.\_187

Both high index-contrast (HIC) photonic crystals and HIC microphotonic circuits are presented in this thesis. Studies of macro-scale 2D photonic crystal meta-materials are first described. Through comparison of experimental and theoretical beam evolution about the super-collimation frequencies, the effects of disorder on beam evolution are pinpointed. Despite the effects of disorder, super-collimation is found to be robust, producing stationary beam-widths over 600 isotropic diffraction-lengths. In addition, nano-scale photonic crystal defect modes are studied over large optical bandwidths through newly developed supercontinuum based techniques.Novel all-fiber supercontinuum sources facilitate the generation of unpolarized supercontinuum light over 1.2-2.0 micron wavelengths. Broadband experimental methods make possible the application of these sources to the study of 1D and 3D photonic crystals with defect states. Studies of both static and dynamic microring resonator based HIC filters are described. Numerous microring based studies are reported which lead to frequency-compensated multi-ring filters, permitting the first high-fidelity microring filters in HIC microphotonics. Though telecom-grade performance achieved via frequency compensation, the aforementioned filters exhibit severe polarization sensitivities, making them incompatible for real-world applications. Through integration of identical sets of these filters in a generalized polarization diversity scheme, polarization insensitive HIC filters are demonstrated for the first time, yielding a maximum polarization dependant loss of 2.2 dB over broad bandwidths. Finally, evanescent field-perturbation is investigated as a means of tuning microcavities over ultrawide wavelength ranges. Through nano-metric control of a silica perturbing body in the near-field of a microring waveguide, a 27 nm (or 1.7%) reversible tuning of its cavity mode is achieved.

MIT\_Dept. of Physics.\_324

Accreting x-ray binaries are sometimes observed to emit compact, relativistic jets of cool plasma; these objects are called "microquasars". It is possible that these jets are responsible for a large flux of galactic cosmic ray protons and nuclei. The energy spectrum from these sources will be very different from the featureless power-law expected from ordinary cosmic-ray acceleration in supernova shocks. The AMS-01 instrument measured cosmic ray protons and helium during 10 days on the Space Shuttle Discovery in 1998; we analyze this data searching for spectral distortions due to nearby microquasar activity. We show that the microquasar contribution to the CR proton flux can be no more than [approximately] 2% in the range 2-50 GeV.

MIT\_Dept. of Physics.\_404

The thesis applies position-space renormalization-group theory to a variety of correlated electron systems, determining finite-temperature phase diagrams and thermodynamic properties for electron densities both at and away from half-filling. We begin by assessing the effectiveness of the Suzuki-Takano quantum decimation method on a d = 1 Hubbard model in an external magnetic field, where exact results for the specific heat, magnetic and charge susceptibilities are available at various electron densities. We find that our approach converges to the exact values at high temperature, and agrees well even at moderate-to-low temperatures. We then extend the decimation through the Migdal-Kadanoff procedure to a Hubbard model in d = 3. Phase diagrams are calculated for a range of Coulomb couplings, and two new "" phases are found for hole-dopings of 10 - 18% and 30 - 35%. The electron hopping strength renormalizes to infinity at the T phase sinks, possibly indicating superconductivity, an interpretation further supported by features of the specific heat. The next part turns to the tJ model in d = 3, where the phase was originally observed.In the vicinity of this phase we see a sharp peak in the superfluid weight, and a suppressed low temperature specific heat indicating gap formation. The doping dependence of the free carrier density is similar to that found experimentally in cuprate superconductors. Since strong anisotropy is a key aspect of high-T, materials, we also consider a d = 3 tJ model with distinct in-plane and out-of-plane couplings. We examine the evolution of the phase diagram as the interplane coupling is weakened, and find that the T phase persists even in the quasi-two-dimensional regime. The complex lamellar structure of antiferromagnetic and disordered phases that develops between the T phase and half-filling could be a sign of incommensurate spin ordering. While the pure d = 2 tJ model does not exhibit a phase, we see pre-signatures of it in the renormalization-group flows, and the phase becomes stabilized with a finite transition temperature upon the addition of even the smallest interplane coupling. The last part of the thesis looks at renormalization-group techniques for quenched random systems. As a preliminary step to dealing with disorder in the tJ model, we start with a simpler, yet currently important, classical system, testing a conjecture relating the locations of multicritical points on dual pairs of hierarchical lattice Ising spin glasses. Finally, we incorporate nonmagnetic impurities into the d = 3 tJ model. Small oncentrations of these impurities rapidly destroy the r phase and enhance antiferromagnetism, observations that have parallels in Zn-doped cuprates.

MIT\_Dept. of Physics.\_405

This thesis describes the first observations in trapped hydrogen of optical transitions starting from the metastable 2S state. It covers in detail the design and construction of two stabilized diode laser systems for performing spectroscopy of the 2S-3P and 2S-8S transitions. Spectroscopy of the one photon 2S-3P transition in hydrogen is demonstrated both by the depletion of the metastable 2S atom state and the absorption of the 2S-3P laser light. A model for absorption spectroscopy as a probe for metastable number is developed and absorption is shown to offer a major improvement over current detection methods. In the course of these experiments, techniques with diode lasers were developed that will be used later in the proposed precision measurements of 2S-nS transitions. The design, construction and characterization of the diode laser system for performing spectroscopy of the two photon 2S-8S transition is explained and recommended parameters for a proposed signal search are outlined.

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This thesis describes the design, construction, and testing of a new source of entanglement. The goal is to produce pairs of photons which are not only polarization-entangled, but also have a high brightness within a narrow bandwidth. This novel source is more suitable than previous SPDC sources for transferring entanglement to future qubit storage such as a trapped rubidium memory. The narrow bandwidth is imposed by modifying the spectrum of the photon pairs by performing the down-conversion inside a cavity. The collinear downconversion geometry inside the linear cavity is achieved by using a quasi-phased-matched periodically-poled potassium titanyl phosphate (PPKTP) crystal. The single-pass free-space photon-pairs produced were demonstrated to be polarization-entangled by measuring the Hong-Ou-Mandel interference dip and measuring a violation of Bell's inequality of 2.711 ± 0.010 (which was greater than the classical limit of 2). The cavity-enhanced downconversion was observed with a brightness of 0.7 pairs/s per mW of pump per MHz of bandwidth in the Gaussian mode collected (a generation rate of 110 pairs/s/mW/MHz is inferred). The interference dip from the pairs was measured to have a visibility of 75% when near the ideal equal-FSR operating point, where the pairs are in the biphoton triplet state. When detuned to have unequal FSR the output pairs show the an interference dip behavior consisting of a combination of triplet and singlet states that depends on the time separation of the pair as it leaves the cavity. The observed results corroborate detailed predictions of a Gaussian-state model of cavity-enhanced downconversion.

MIT\_Dept. of Physics.\_446

This thesis presents experiments in which a strongly interacting gas of fermions was brought into the superfluid regime. The strong interactions are induced by a Feshbach scattering resonance that allows to tune the interfermion scattering length via an external magnetic field. When a Fermi mixture was cooled on the molecular side of such a Feshbach resonance, Bose-Einstein condensation of up to 107 molecules was observed. Subsequently, the crossover region interpolating between such a Bose-Einstein condensate (BEC) of molecules and a Bardeen-Cooper-Schrieffer superfluid of long-range Cooper pairs was studied.Condensates of fermion pairs were detected in a regime where pairing is purely a many-body effect, the pairs being stabilized by the presence of the surrounding particles. Superfluidity and phase coherence in these systems was directly demonstrated throughout the crossover via the observation of long-lived, ordered vortex lattices in a rotating Fermi mixture.Finally, superfluidity in imbalanced Fermi mixtures was established, and its Clogston limit was observed for high imbalance. The gas was found to separate into a region of equal densities, surrounded by a shell at unequal densities.

MIT\_Dept. of Physics.\_447

Analysis of HETE-II data is discussed with the aim of understanding the intrinsic properties of gamma-ray bursts (GRBs). A technique is developed that allows the simultaneous estimation of source and background counts during a burst with coded aperture instruments such as the Wide-field X-ray Monitor (WXM) on HETE-II. A closely related photon-by-photon statistical bootstrap analysis is then described that can be used to compute the non-Gaussian error distribution of GRB temporal statistics. This is applied to the T90 and To.45 duration measures. The distribution of T90 has been extensively studied since the availability of the BATSE gamma-ray burst catalogs and is widely believed to be log-normally distributed. It is shown that intrinsically, GRBs may in fact have a much narrower distribution, and the wide log-normal may primarily be due to measurement artifacts. Computation of the TO.45 parameter enables the inference of redshifts through the recently discovered Liso-Epk-TO.45 relation. This in turn allows the compilation of a flux-limited sample of bursts with redshifts that is free of the observational selection effects inherent in spectroscopic catalogs. This analysis is performed for 31 WXM bursts and redshift-corrected distributions of T90 and T0.45 are computed. It is shown for the first time that the distribution of T0.45 can be modeled by an exponential distribution. The redshifts calculated through the Liso-Epk-TO.45 relation are also used to calculate the implied isotropic luminosities. The normalized luminosity function and redshift distribution of gamma-ray bursts are derived using the non-parametric methods of Lynden-Bell and Efron &amp; Petrosian. The results imply strong evidence for luminosity evolution with redshift and are consistent with prior studies based on BATSE bursts. Concordance cosmology (QA = 0.7, QM = 0.3, Ho=70 km s-1 Mpc-1) is assumed throughout the analysis. Effects of log-normal errors in the redshifts are estimated using Monte-Carlo methods. Results indicate that a fraction close to 10% of GRBs are to be expected at high redshifts (&gt; 5) in consonance with theoretical predictions of high-redshift Swift detections.

MIT\_Dept. of Physics.\_448

Bose-Einstein condensates in optical lattices have proven to be a powerful tool for studying a wide variety of physics. In this thesis a series of experiments using optical lattices to manipulate 87Rb Bose-Einstein condensates are described. A systematic shift of the photon recoil momentum due to the index of refraction of a dilute gas of atoms has been observed. The recoil frequency was measured interferometrically using a two-pulse Ramsey interferometer. The two pulses were created using a one dimensional optical lattice. By measuring the resulting frequency as a function of the lattice detuning from the atomic resonance, we found a distinctive dispersive shape for the recoil frequency that fit the recoil momentum as n,.hk. A one-dimensional optical lattice was used to modify the dispersion relation of the condensate in order to demonstrate the matter-wave analogue of Optical Parametric Generation (OPG) and Amplification (OPA) of photons. A condensate was loaded into a moving optical lattice with adjustable quasimomentum k0. As the value for k0o was varied, we observed elastic scattering into two distinct final momentum states k1 and k2. When a small fraction of atoms was first transferred to k1 before ramping on the lattice, we observed the amplification of scattered atoms into k1 and k2. The superfluid-Mott Insulator transition was studied using microwave spectroscopy in a deep three-dimensional optical lattice. Using the density dependent clock shift we were able to spectroscopically distinguish sites with different occupation numbers, and to directly image sites with occupation number from 1 to 5, revealing the shell structure of the Mott Insulator phase.

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A combination of radio frequency radiation and magnetic field gradients was used to trap atoms in dressed states. In a magnetic field with a quadrupole minimum. RF fields resonant with the (I F. m)) 11. -1) -- 1, 0) transition trapped the atoms on the surface of a sphere, and gravity caused the atoms to pool at the bottom of the sphere. BECs were transferred into this dressed Zeeman trap with 100% efficiency, with lifetimes of up to 30 s, and trapping frequencies of up to 250 Hz were measured. A hard disk platter with a specially written magnetic pattern was used to generate magnetic fields to confine atoms tightly. Detrimental interactions with the surface were avoided by using an extremely thin film with a large magnetic remnant. BECs of up to 5 x 10" atoms were produced in cigar shaped traps -40 pin above the surface, and trap frequencies up to 5 kHz were measured. After evaporation, condensed clouds moved(] closer to the surface to probe imperfections in the magnetic potential, revealing defects at distances closer than 35 prn. Finally, BECs were dropped from a height of 350 pm in an attempt to achieve specular reflection. but a large amount of dispersion was observed. Finally, BECs were loaded into a three-dimensional optical lattice, and a quantum phase transition from a superfluid to a Mott insulator was observed. Using microwave spectroscopy. the density dependent "clock shift" was was found to depend on the occupation number of the wells. The singly occupied lattice sites were then investigated as an atomic clock system with no density shift. Linewidths as small as 1 Hz FWHMI out of 6.8 GHz are comparable to current atomic frequency standards.

MIT\_Dept. of Physics.\_650

The LIGO-Virgo network of kilometer-scale laser interferometric gravitational-wave detectors reached a major milestone with the successful operation of LIGO's fifth (S5) and Virgo's first (VSR1) science runs during 2005-2007. This thesis presents several issues related to gravitational-wave transient detection from the perspective of the joint all-sky, un-triggered burst search over S5/VSR1 data. Existing searches for gravitational-wave bursts must deal with the presence of non-Gaussian noise transients which populate the data over the majority of sensitive signal space. These events may be confused with true signals, and are the current limiting factor in search sensitivity and detection confidence for any real event. The first part of this thesis focuses on the development of tools to identify, monitor and characterize these instrumental disturbances in LIGO and Virgo data. An automated procedure is developed and applied to the S5/VSR1 search in order to safely remove noise transients from the analysis without sacrificing sensitivity by making use of the wealth of auxiliary information recorded by the detectors. The second part of this thesis focuses on the interpretation of outlier events in the context of a non-Gaussian, non-stationary background. An extensive follow-up procedure for candidate gravitational-wave events is developed and applied to a single burst outlier from the S5/VSR1 search, later revealed to be a blind simulation injected into the instruments. While the follow-up procedure correctly finds no reason to reject the candidate as a possible gravitational wave, it highlights the difficulty in making a confident detection for signals with similar waveform morphology to common instrumental disturbances. The follow-up also deals with the problem of objectively defining the significance of a single outlier event in the context of many semi-disjoint individual searches. To address this, a likelihood-ratio based unified ranking is developed and tested against the original procedures of the S5/VSR1 burst search. The new ranking shows a factor of four improvement in the statistical significance of the outlier event, and a 12% reduction using fixed thresholds and 38% reduction using a loudest event statistic for a rate upper limit on a mock signal population.

MIT\_Dept. of Physics.\_662

The MiniBooNE experiment was designed to perform a search for Vu --&gt; Ve oscillations in a region of A[delta]sin 2 20very different from that allowed by standard, three neutrino oscillations, as determined by solar and atmospheric neutrino experiments. This search was motivated by the LSND experimental observation of an excess of F/e events in a 1,1 beam which was found compatible with two-neutrino oscillations at [delta]m 2 ~ 1 eV2 and sin2 20 &lt; 1%. If confirmed, such oscillation signature could be attributed to the existence of a light, mostly-sterile neutrino, containing small admixtures of weak neutrino eigenstates. In addition to a search for Vu --&gt; Ve oscillations, MiniBooNE has also performed a search for Vu --&gt;Ve oscillations, which provides a test of the LSND two-neutrino oscillation interpretation that is independent of CP or CPT violation assumptions. This dissertation presents the MiniBooNE Vu --&gt;Ve and Vu --&gt; Ve analyses and results, with emphasis on the latter. While the neutrino search excludes the two-neutrino oscillation interpretation of LSND at 98% C.L., the antineutrino search shows an excess of events which is in agreement with the two neutrino Vu --&gt;Ve oscillation interpretation of LSND, and excludes the no oscillations hypothesis at 96% C.L. Even though the neutrino and antineutrino oscillation results from MiniBooNE disagree under the single sterile neutrino oscillation hypothesis, a simple extension to the model to include additional sterile neutrino states and the possibility of CP violation allows for differences between neutrino and antineutrino oscillation signatures. In view of that, the viability of oscillation models with one or two sterile neutrinos is investigated in global fits to MiniBooNE and LSND data, with and without constraints from other oscillation experiments with similar sensitivities to those models. A general search for new physics scenarios which would lead to effective non-unitarity of the standard 3 x 3 neutrino mixing matrix, or mixing freedom, is also performed using neutrino and antineutrino data available from MiniBooNE.

MIT\_Dept. of Physics.\_664

Measuring galaxy cluster total masses and the amount of dark matter substructure within galaxy cluster haloes is a fundamental probe of the ACDM model of structure formation, as well as the interactions between baryonic and non-baryonic matter. In this thesis I approach the topic of cluster mass structure in two ways. With a combination of optical imaging, spectroscopy, and X-ray observations I determine that the cluster RCS043938-2904.7, while apparently anomalous initially due to its high optical richness and low X-ray surface brightness, is in fact an association of structures along the line of sight. Accounting for this structure brings the observed cluster properties into agreement with known scaling relations. I also present a novel method for measuring weak gravitational lensing flexion to inform mass measurements on small scales. While previously published methods for measuring flexion focus on measuring derived properties of the lensed images, such as shapelet coefficients or surface brightness moments, my method fits a fully mass-sheet-invariant parametrized Analytic Image Model (AIM) to the each galaxy image. This simple parametric model traces the distortion of lensed image isophotes. I tested the AIM method using simulated data images with realistic noise and a variety of input image properties, and I show that it successfully reproduces the input lensing fields. I also apply the AIM method for flexion measurement to Hubble Space Telescope observations of Abell 1689, and detect mass structure in that cluster using only flexion measured with the AIM method.

MIT\_Dept. of Physics.\_665

In this thesis, I present results from two Paul-trap based ion traps carried out in the Vuleti? laboratory: the Atom-Ion trap for collision studies between cold atoms and cold ions, and the Cavity-Array trap for studying the interaction between ionic ensembles and photons. The Atom-Ion trap overlaps a surface-planar ion trap with a magneto-optical trap (MOT) for neutral atoms. The initial results of this system were loading of a shallow surface-planar ion trap at an unprecedented high rate of 4. 105 s-1 and isotopic purity by photoionization from the MOT. We demonstrate the first collisions between trapped atoms and trapped ions in the Langevin collision regime between Yb+ and Yb. A measurement of the Langevin rate constant through charge-exchange collisions between [alpha]Yb+ and [beta]Yb over three orders of magnitude in collision energy down to 3 yueV follows. The measured rate coefficient of 6 - 10-10 cm 3 s-1 is in good agreement with the Langevin model based on theoretical predictions of the polarizability of Yb. The theory and limits of sympathetic cooling of ions by localized cold atoms at low temperature is outlined. Measurements of momentum-transfer collisions between Yb+ and Rb are presented indicating that momentum-transfer collisions affect the ion energy at the Langevin rate. Finally, the fabrication and assembly of the Cavity-Array trap are presented. The Cavity-Array trap overlaps a high-finesse optical cavity with a linear array of Paul traps in order to reach the high co-operativity limit with trapped ions. Initial results from loading of the Cavity- Array trap are shown, indicating successful overlap of the optical cavity mode with the ion trapping region and the ability to load individual sites of the array ion trap.

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The products of interactions between galaxies with a high mass ratio and low orbital angular momentum are studied. The interactions scatter the material from the smaller galaxy into structures with distinctive dynamics and morphology, including high local densities and a simple density profile related to properties of the participating galaxies. The role of the larger galaxy's tides in creating these structures and their relation to a well-studied class of mathematical objects motivates us to name them "tidal caustics". We study the densities achievable in tidal caustics for a typical merger of this type using an example from the Andromeda galaxy to determine whether they are sufficient to produce a detectable gamma-ray signal from self-interactions in the dark matter component, for likely particle models of dark matter. We find that the expected signal is an order of magnitude too low to be detected with current instruments. We also study the constraints that can be placed on the properties of the participating galaxies by observing the surface brightness profiles of the tidal caustics. We find that the local gravity and gravity gradient of the larger galaxy, and the energy spread and initial phase space density of the smaller galaxy, can be jointly constrained by fitting this profile. The constraints are degenerate but model-independent. We find that measurements of multiple caustics and the velocity of the material in each caustic along the line of sight give information about the orbital angular momentum and the deviations from spherical symmetry in the larger galaxy, though this information is somewhat model-dependent. We discuss the main technical difficulty in fitting the surface brightness profile: determining the inclination angle of the caustic. We demonstrate that a simple model can successfully recover the necessary parameters for some cases, and that a simple modification to this model will improve its success rate.

MIT\_Dept. of Physics.\_667

For most of its 60 year history, the Casimir effect was an obscure theoretical backwater, but technological advances over the past decade have promoted this curious manifestation of quantum and thermal fluctuations to a position of central importance in modern experimental physics. Dramatic progress in the measurement of Casimir forces since 1997 has created a demand for theoretical tools that can predict Casimir interactions in realistic experimental geometries and in materials with realistic frequency-dependent electrical properties. This work presents a new paradigm for efficient numerical computation of Casimir interactions. Our new technique, which we term the fluctuating-surface-current (FSC) approach to computational Casimir physics, borrows ideas from the boundary-element method of computational electromagnetism to express Casimir energies, forces, and torques between bodies of arbitrary shapes and materials in terms of interactions among effective electric and magnetic surface currents flowing on the surfaces of the objects. We demonstrate that the master equations of the FSC approach arise as logical consequences of either of two seemingly disparate Casimir paradigms-the stress-tensor approach and the path-integral (or scattering) approach-and this work thus achieves an unexpected unification of these two otherwise quite distinct theoretical frameworks. But a theoretical technique is only as relevant as its practical implementations are useful, and for this reason we present three distinct numerical implementations of the FSC formulae, each of which poses a series of unique technical challenges. Finally, using our new theoretical paradigm and our practical implementations of it, we obtain new predictions of Casimir interactions in a number of experimentally relevant geometric and material configurations that would be difficult or impossible to treat with any other existing Casimir method.

MIT\_Dept. of Physics.\_772

Two experiments are presented which measure atomic properties using an atom interferometer. The interferometer splits the sodium de Broglie wave into two paths, one of which travels through an interaction region. The paths are recombined, and the interference pattern exhibits a phase shift depending on the strength of the interaction. In the first experiment, the interaction involves a gas. De Broglie waves traveling through the gas experience a phase shift represented by an index of refraction. By measuring the index of refraction at various wavelengths, the predicted phenomenon of glory oscillations in the phase shift has been observed for the first time. The index of refraction has been measured for sodium atoms in gases of argon, krypton, xenon, and nitrogen over a wide range of wavelength. These measurements offer detailed insight into the interatomic potential between sodium atoms and the gases. Theoretical predictions of the interatomic potentials are challenged by these results, which should encourage a renewed effort to better understand these potentials. The second experiment measures atomic polarizability with an atom interferometer. Here, the interaction is with an electric field; the atom experiences a phase shift proportional to its energy inside the field. Previously, this method was used to perform the most accurate (&lt; 1%) measurement of sodium polarizability. The precision was limited, however, by the spread of velocities in the atomic beam-the phase shift is different depending on velocity, and the -interference pattern is washed out. This thesis presents a new technique to "rephase" the interference pattern at large applied fields, and demonstrates a measurement that is free of this limitation. In addition, most of the systematic errors that plagued the previous polarizability measurement are eliminated by the new technique, and an order of magnitude improvement in precision now appears quite feasible. The remaining systematic errors can be eliminated by measuring the ratio of polarizabilities between two different atoms, a comparison whose precision is better by another order of magnitude.

MIT\_Dept. of Physics.\_773

16 years and counting ... In 1986 Bednorz and Muller discovered the layered perovskite structure (La - Ba)2Cu04 which showed the phenomenon of superconductivity at the unprecedented high temperature of Tc = 33 K. In the ensuing months and years it became more and more apparent that the cuprates, as the materials came to be known, show very peculiar correlations in their "normal" state at temperatures T &gt; Tc. The majority of this thesis is concerned with this abnormal "normal" state, attempting to extract a coherent picture for the strange phenomenology. The underlying theoretical framework is a slave particle description of the tJ model proposed by Wen and Lee. The conceptual background is rooted in Anderson's proposal of spin charge separation as the key emergent phenomenon in cuprate physics. After a brief motivation we look at single particle tunneling into the cuprate's superconducting state from the perspective of both d-wave BCS and the SU(2) slave boson theory of Wen and Lee. Both approaches work well close to zero tunneling bias. The slave particle formulation however also naturally incorporates the particle/hole asymmetric background that is seen in experiments. The question of single particle correlations studied experimentally via angle resolved photo emission experiments motivates the analysis of the next chapter. The broad spectral line-shapes seen experimentally imply the absence of well defined quasi-particles in the Fermi liquid sense. We study how gauge fluctuations arising from our use of slave particle coordinates affect the physical hole spectral function. The primary influence of gauge fluctuations turns out to be through their confining tendency on the vertex rather than as a scattering field for the slave particles. The last chapter discusses the effect of gauge fluctuations on the spin susceptibility and shows that they play a vital role in restoring Neel correlations. This allows us to give a natural explanation for the spin related phenomenology of underdoped cuprates.

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Experiments have now established that the order parameter (gap) in the high-Tc cuprate superconductors exhibits d-wave symmetry, vanishing at four nodal points on the Fermi surface. Near each of these four gap nodes, quasiparticles are easily excited and behave more like massless relativistic particles than electrons in a metal. In this thesis, we study the transport properties of these nodal quasiparticles, providing theoretical interpretations for the results of low temperature thermal and (microwave) electrical transport experiments in the cuprates. We begin by considering the very low temperature regime in which transport is dominated by quasiparticles induced by the very presence of impurities. This is known as the universal limit because prior calculations indicate that the transport coefficients obtain universal (scattering-independent) values. We improve upon prior results by including the contribution of vertex corrections and find that while the electrical conductivity obtains a scattering-dependent correction, the thermal and spin conductivity maintain their universal values. We then focus on the microwave electrical conductivity and consider the slightly higher temperature regime where quasiparticles are excited thermally. Since measurements in detwinned samples yield results that are inconsistent with simple models of impurity scattering, we hypothesize that line defects, remnant from the process of removing twin boundaries, may provide an additional scattering mechanism. We calculate the self-energy and microwave conductivity due to line defect scattering and obtain results that agree well with experiment. Finally, we turn on a magnetic field and consider thermal transport in the mixed (vortex) state. In the weak-field regime, the thermal conductivity tensor can be expressed in terms of the cross section for quasiparticle scattering from a single vortex. We calculate this cross section and thereby obtain both the longitudinal thermal conductivity and the thermal Hall conductivity in surprisingly good qualitative agreement with the measured data. The transparent nature of our calculation allows us to obtain a physical understanding of the features seen in experiments.

MIT\_Dept. of Physics.\_809

We calculate moments of the generalized parton distributions of the nucleon using lattice QCD. The generalized parton distributions determine the angular momentum decomposition of the nucleon and the transverse distributions of partons within the nucleon. Additionally, the generalized parton distributions reduce to the elastic form factors and ordinary parton distributions in particular kinematic limits. Thus by calculating moments of the generalized parton distributions in lattice QCD we can explore many facets of the structure of the nucleon. In this effort, we have developed the building block method to determine all the lattice correlation functions which con- tribute to the off forward matrix elements of the twist two operators. These matrix elements determine the generalized form factors of the nucleon which in turn give the moments of the generalized parton distributions. Thus we use our building block method to calculate all the matrix elements of the lowest twist two operators. Fur- thermore, we use our method to construct an overdetermined set of matrix elements allowing a more accurate calculation of the generalized form factors.

MIT\_Dept. of Physics.\_810

Chapter 1 introduces the subject of photonic crystals and reviews the basic physical principles underlying the formation of a band gap and the creation of localized defect modes. Proposed applications, fabrication techniques, and numerical simulation methods are surveyed. Chapter 2 demonstrates the construction of 2D-like defect modes in a 3D photonic crystal with a complete gap. The modes are similar to those in 2D photonic crystals in terms of polarization, field profile, and projected band structures. The results should facilitate the implementation of 2D photonic-crystal devices in realistic 3D systems. Chapter 3 explores the possibility of using photonic-crystal defect modes to design magnetic metamaterials: structures that exhibit magnetic properties despite the non- magnetic character of their constituents. 4.A synthetic magnetic moment is provided by a point-defect mode studied in Chapter 2. Quantitative analysis of the far-field radiation pattern proves that the mode has a primarily magnetic character: over 98% of the emitted power goes into magnetic multipole radiation. Chapter 4 calculates the radiation pressure on the surface of a waveguide formed by ornnidirectionally reflecting mirrors. In the absence of losses, the pressure goes to infinity as the distance between the mirrors is reduced to the cutoff separation of the waveguide mode. The divergence results from the reduction of the modal group velocity to zero, which causes slow-light magnification of the field intensity at constant power input. Chapter 5 analyzes slow-light, band-edge waveguides for compact, integrated, tun- able optical time delays. Slow group velocities at the photonic band edge give rise to large changes in time delay for small changes in refractive index, shrinking device size. Figures of merit are defined for tuning sensitivity and signal dispersion. Exact calculations for a realistic, three-dimensional grating structure are shown to be well predicted by a simple quadratic-band model, simplifying device design. Chapter 6 derives a general, coupled-mode theory for disorder-induced scattering in strongly periodic systems.

The analytical results allow the comparison of photonic- crystal waveguides to similar index-guided waveguides. In the realistic limit of weak disorder, reflections are identical while transmission is higher for the photonic-crystal waveguide. The general results, verified by direct numerical simulations in an example system, suggest a new mechanism for the design of low-loss waveguides.

MIT\_Dept. of Physics.\_811

The research presented in this thesis comprises a theoretical study of several aspects relating to the dynamics and evolution of dense stellar systems such as globular clusters. First, I present the results of a study of mass segregation in two-component star clusters, based on a large number of numerical N-body simulations using our Monte-Carlo code. Heavy objects, which could represent stellar remnants such as neutron stars or black holes, exhibit behavior that is in quantitative agreement with simple analytical arguments. Light objects, which could represent free-floating planets or brown dwarfs, are predominantly lost from the cluster, as expected from simple analytical arguments, but may remain in the halo in larger numbers than expected. Using a recent null detection of planetary-mass microlensing events in M22, I find an upper limit of 25% at the 63% confidence level for the current mass fraction of M22 in the form of very low-mass objects. Turning to more realistic clusters, I present a study of the evolution of clusters containing primordial binaries, based on an enhanced version of the Monte-Carlo code that treats binary interactions via cross sections and analytical prescriptions. All models exhibit a long-lived "binary burning" phase lasting many tens of relaxation times. The structural parameters of the models during this phase match well those of most observed Galactic globular clusters. At the end of this phase, clusters that have survived tidal disruption undergo deep core collapse, followed by gravothermal oscillations. The results clearly show that the presence of even a small fraction of binaries in a cluster is sufficient to support the core against collapse significantly beyond the normal core collapse time predicted without the presence of binaries. For tidally truncated systems, collapse is delayed sufficiently that the cluster will undergo complete tidal disruption before core collapse. Moving a step beyond analytical prescriptions, I incorporate into the Monte-Carlo code an exact treatment of binary-single interactions, and show that the results are in good agreement with those using analytical prescriptions. The direct integration of binary interactions in the Monte-Carlo code requires a reason- ably sophisticated N-body code geared toward small-N dynamics. I present and describe in detail Fewbody, a new, freely available numerical toolkit for simulating small-N gravitational dynamics. Fewbody is a general N-body dynamics code, though it was written for the purpose of performing scattering experiments, and therefore has several features that make it well-suited for this purpose. To validate the method, I compare with several previous binary scattering experiments in the literature and find excellent agreement. As a simple example of the use of Fewbody, I calculate the destruction cross sections and characteristic lifetimes of black hole-pulsar binaries in globular clusters. At present, there should be observable ...

MIT\_Dept. of Physics.\_812

In this thesis I discuss various aspects of Witten's cubic string field theory. After a brief review of the basics of string field theory we begin by showing how string field theory can be used to check certain conjectures about the tachyon vacuum. We then discuss the problem of trying to globally gauge fix string field theory. We end with a discussion of various results in the quantization of the theory.

MIT\_Dept. of Physics.\_813

The measurement of B?s mixing is one of the flagship analyses for the Run II B physics program. The sensitivity of the measurement to the frequency of B?s oscillations strongly depends on the number of reconstructed B? mesons. We present the measurement of the ratio of branching fractions Br ... , which directly influences the number of B?s events available for the measurement of B?s mixing at CDF-II. We analyze 115 pb-l of data collected with the CDF-II detector in pp collisions at ... TeV using a novel displaced track trigger ...

MIT\_Dept. of Physics.\_877

In this thesis, we study dynamical pairing of fermions caused by the time-dependent interaction.

Fermionic pairing develops on time scales short compared to the quasiparticle relaxation time where existing approaches to the problem including the Boltzmann kinetic equation and time-dependent Ginzburg-Landau theory are not applicable. 'The nonequilibrium dynamics can be explored in cold Fermi gas at a Feshbach resonance, a system with magnetically tunable interaction. Motivated by recent experiments, in Chapters 2 and 3 we study the pairing of fermions when a sudden switch of interaction induces the Bardeen-Cooper-Schrieffer (BCS) instability of the system. In this case, the pairing amplitude is found to be an oscillatory function of time with predictable characteristics. Another dynamical regime corresponding to a linear magnetic field sweep from atomic to molecular side at a Feshbach resonance is explored in Chapter4.

We find that pairing correlations of fermions in the initial state are encoded in the momentum distribution of molecules after the sweep. Finally, in Chapter 5, we consider pair excitations caused by the harmonic modulation of the interaction, and compare our results to experimental observations.

MIT\_Dept. of Physics.\_878

If dark matter consists of Weakly Interacting Massive Particles (WIMPs), such as the supersymmetric neutralino, various theories predict that their annihilation in the galaxy can give rise to anomalous features in the otherwise smooth spectra of charged cosmic rays. Up to now searches for these spectral anomalies have focused largely on antiparticles (p, e+) due to their lower astrophysical backgrounds. In this thesis we present results of a search for dark matter annihilation in the charge Z = -1 spectrum of AMS-01 (essentially electrons and antiprotons). To avoid model dependent complications we assume that the primary annihilation channel is through W+W- production. We use the galactic propagation software GALPROP to determine the dark matter spectra at Earth from a smooth isothermal source. Fits to the data did not reveal any contribution from dark matter and limits were placed on the rate of W+W- production in the galaxy and on the corresponding cross-section for WIMP annihilation through the W+W- channel (given a smooth isothermal distribution).

MIT\_Dept. of Physics.\_996

We carry out various investigations regarding gauge theories on the worldvolume of D-branes probing toric singularities. We first study the connection that arises in Toric Duality between different dual gauge theory phases and the multiplicity of fields in the gauged linear sigma models associated with the probed geometries. We introduce a straightforward procedure for the determination of toric dual theories and partial resolutions based on the (p, q) web description of toric singularities. We study the non-conformal theories that arise in the presence of fractional branes. We introduce a systematic procedure to study the resulting cascading RG flows, including the effect of anomalous dimensions on beta functions. Supergravity solutions dual to logarithmic RG flows are constructed, validating the field theory analysis of the cascades. We systematically study the IR dynamics of cascading gauge theories. We show how the deformation in the dual geometries is encoded in a quantum modification of the moduli space. We construct an infinite family of superconformal quiver gauge theories which are AdS/CFT dual to Sasaki-Einstein horizons with explicit metrics. The gauge theory and geometric computations of R-charges and central charges are shown to agree. We introduce new Type IIB brane constructions denoted brane tilings which are dual to D3-branes probing arbitrary toric singularities. Brane tilings encode both the quiver and superpotential of the gauge theories on the D-brane probes. They give a connection with the statistical model of dimers. They provide the simplest known method for computing toric moduli spaces of gauge theories, which reduces to finding the determinant of the Kasteleyn matrix of a bipartite graph.

MIT\_Dept. of Physics.\_1011

In this thesis, we explore aspects of fermionic superfluidity through a mean-field approximation. Our framework is extremely general, includes both pairing and Hartree-Fock contributions, and is derived rigorously from a variational principle. This framework allows us to analyze a wide range of fermionic systems. In this thesis, we shall consider two-species nonrelativistic atomic systems with various types of interactions, and relativistic QCD systems with 3 x 3 x 4 = 36 different quark degrees of freedom (3 colours, 3 flavours, and 4 relativistic degrees of freedom). We discuss properties of a new state of matter: gapless (Breached Pair) superfluidity, and include a summary of potential experimental realizations. We also present numerical results for a completely self-consistent approximation to the NJL model of high-density QCD and use these results to demonstrate a microscopic realization of kaon condensation. We describe how to match the mean-field approximation to the low-energy chiral effective theory of pseudo-Goldstone bosons, and we extract the numerical coefficients of the lowest order effective potential.

MIT\_Dept. of Physics.\_1084

We report on a search for an annual variation of a daily sidereal modulation of the frequency difference between co-located 12?Xe and 3He Zeeman masers that sets a stringent limit on boost-dependent Lorentz and CPT violation involving the neutron, consistent with no effect at the level of 150 nHz. In the framework of the general Standard-Model Extension, our result provides the first clean test for the fermion sector of the symmetry of spacetime under boost transformations at a level of 10-27 GeV [1]. We also report progress on the optimization and operation of the Harvard-Smithsonian 12?Xe/3He dual noble gas maser. The 12?Xe/3He maser is the first device to sustain simultaneous active maser oscillations on distinct transitions in two intermingled atomic species, and it allows sensitive differential measurement of the 12?Xe and 3He nuclear spin-1/2 Zeeman transition frequencies [2, 3, 4]. The optimized 12?Xe /3He maser will be used for highly sensitive tests of Lorentz and CPT symmetry.

MIT\_Dept. of Physics.\_1138

Transport properties are reported for Bi nanowires, which have been prepared by the filling of an alumina template with molten Bi. Lithographic processes are devised to pattern 4-point electrodes on single Bi nanowires that have been removed from the alumina template. High resistance non-ohmic contacts are attributed to a thick oxide layer formed on the surface of the nanowires. The non-linear 2-point i(V) response of these contacts is understood on the basis of a tunneling model. Techniques are developed for making ohmic contacts to single bismuth nanowires through the thick oxide coating using a focused ion beam (FIB) to sputter away the oxide and then deposit contacts. By combining the FIB techniques with electron beam lithography we achieve contacts stable from 300K to 2K for nanowires less than 100nm in diameter. Annealing in H2 and also NH3 environments is found to reduce the oxide completely. However, the high tempertures required for this annealing are not compatible with the lithographic techniques. A method for preventing the burnout of nanowires by electrostatic discharge is developed. A lithographic scheme for measuring the Seebeck coefficient of a single Bi nanowire is devised. Techniques are also developed for measuring a single Bi nanowire inside the template. The electronic band structure of Bi nanowires is modeled theoretically based on the quantum confinement of electrons. 4-point resistivity data on single Bi nanowires are reported and understood on the basis of the theoretical model of the quantized electronic band structure and considering the wire boundary and grain boundary scattering not present in bulk bismuth.

MIT\_Dept. of Physics.\_1159

We have improved the ability to compare the masses of single ions by an order of magnitude to a fractional accuracy of [approx.] 7 x 10-12. This is done by simultaneously confining two ions in a Penning trap, and simultaneously comparing their cyclotron frequencies which are inversely proportional to the masses. The precision of the previous technique of alternately trapping the two ions was completely limited by magnetic field noise. Our new technique reduces the impact of both magnetic field and trap voltage noise by more than three orders of magnitude. We can measure and control the relative motion of the two ions in the Penning trap. We have developed a new mode coupling technique to park the ions on a shared magnetron orbit of diameter 1 mm but on opposite sides of the trap. We superpose on top of this magnetron motion the small cyclotron orbits of 150 [mu] diameter needed to simultaneously compare the cyclotron frequencies. The Coulomb interaction keeps the separation of the cyclotron guiding centers constant, thus minimizing cyclotron frequency perturbations due to ion-ion interactions. The ions spatially average magnetic field inhomogeneities and electrostatic imperfections at the magnetron frequency of 5 kHz. We have developed techniques to precisely measure and systematically vary the ion-ion separation. The control techniques are critical for exploring systematic errors. We discovered that we are sensitive to induced charge distributions within our molecular ions. As an ion moves on its cyclotron motion, it experiences a motional electric field which can polarize the ion. The induced charge distribution then leads to a systematic cyclotron frequency shift. Since the polarizability of the ion depends on its quantum state, we can monitor the quantum rotational state of a single CO+ molecule by measuring its cyclotron frequency. From the size of the observed cyclotron frequency shifts between rotational states, we determine the electric dipole moment of the CO+ to be 1.025(15) eao. This novel example of a polarization force has not been observed previously.

MIT\_Dept. of Physics.\_1161

Transition metal oxides with low dimensional geometry have displayed fascinating new phenomena such as high temperature superconductivity and unconventional magnetism. The first part of this thesis is related to this rich and diverse subject, where TiOCl is studied as an example of an S = 1/2 layered Mott insulator. Earlier experiments on this material indicating two-dimensional spin-liquid behavior are reviewed critically and are compared to new susceptibility data. The latter suggest a new picture, where band structure effects produce quasi-one-dimensional spin chains formed by t2g orbitals. Based on these findings, TiOC1 is proposed to be a new example of Heisenberg-chains which undergo a spin-Peierls transition. Within this picture, the effect of doping with non-magnetic Sc impurities can be explained in good agreement with the experiment. The magnetic energy scale of J - 660K and the frustration of the interchain geometry render TiOC1 unique among materials with a spin-Peierls transition. This unusual geometry is interpreted as the main reason for the failure of conventional mean-field theory to describe the details of the transition such as its first order character. It will be shown that a simple Ginzburg-Landau theory which takes proper account of interchain-frustration is capable of explaining this unconventional behavior. In the second part of the thesis, the problem of a doped dimerized spin chain is studied in the context of the tJJ'-model one dimension. The focus is on the regime J'/J - .5 where a spin gap is present at small doping and the undoped spin chain is strongly dimerized, and on the limit of small hole doping x as well as small J/t, J'/t. In this regime, earlier numerical calculations have not been able to yield conclusive results. Using a perturbative approach and Luttinger liquid arguments, it will be demonstrated for this non-integrable class of models that the charge degrees of freedom behave as non-interacting spinless solitons in the dilute hole limit. These results are verified up to third order in perturbation theory. The same approach is also used to evaluate the energy and mass renormalization of a single hole, where non-analytic corrections in powers of [the square root of] J/t are obtained. At J'/J = .5 a variational spin-polaron wave function for the hole is constructed and good agreement with the perturbative results is found.

MIT\_Dept. of Physics.\_1162

The HETE satellite became operational on the 2nd of February, 2001. In the first 2.5 years of the mission prior to July 1 of 2003, 42 Gamma-ray bursts (GRBs) were promptly localized and publicized over the GRB Coordinates Network (GCN). The first part of this thesis deals with the detection of GRBs in data down-linked from the HETE satellite using a suite of automated routines. This "ground triggering" was designed to supplement the HETE on-board triggering systems. To date, it has facilitated the broadcast of six HETE GRBs to the GCN. A novel trigger search routine using wavelets, which is included in the suite, is discussed. Near real time searches for very long duration (&gt; 300s) GRBs using this and other methods are presented. The second part of the thesis focuses on imaging observations with Chandra of two GRB X-ray afterglows and high-resolution spectroscopic observations of five GRB X-ray afterglows. The imaging observations explore the nature of the class of short/hard GRBs and the class of "optically dark" GRBs, while the spectroscopic observations probe the relation of the long/soft class of GRBs to supernovae. Our observations suggest that no long/soft GRBs are optically dark. Rather, many appear to be "optically faint." In one case, a short/hard GRB may have been optically dark, because it lacked entirely an afterglow in the optical, radio, and X-ray bands. Finally, If the emission lines we detect in a Chandra spectrum of the X-ray afterglow to GRB 020813 are real, then a supernova likely occurred 2 2 months prior to the GRB. The statistical significance of the discrete spectral features reported to date in high resolution spectra taken with Chandra are discussed in detail, as the believability of the features is critical to moving forward in the field.

MIT\_Dept. of Physics.\_1163

A novel covariant formalism for the treatment of the transfer and Compton scattering of partially polarized light is presented. In this approach, the polarization state of a light beam is described by a tensor constructed from the time average of quadratic products of the electric field components in a local observer frame. This leads naturally to a covariant description which is ideal for calculations involving the boosting of polarized light beams between Lorentz frames, and is more flexible than the traditional Stokes parameter approach in which a separate set of polarization basis vectors is required for each photon. The covariant kinetic equation for Compton scattering of partially polarized light by relativistic electrons is obtained in the tensor formalism by a heuristic semi-classical line of reasoning. The kinetic equation is derived first in the electron rest frame in the Thomson limit, and then is generalized to account for electron recoil and allow for scattering from an arbitrary distribution of electrons. This formalism is applied to a calculation of the relativistic corrections to the spectral distortions imprinted in the intensity and polarization of the cosmic microwave background radiation (CMB) by inverse Compton scattering in clusters of galaxies (the Sunyaev-Zeldovich effects). We develop a Monte Carlo method for simulating these effects, based on the tensor formalism and kinetic equation. We also consider the use of the polarization signal generated by scattering of the CMB from distant clusters as a probe of cosmological perturbations. Such observations allow an indirect measure of the CMB quadrupole as seen on the last scattering surfaces of observers at nonzero redshift. The statistical properties of this signal in a simple cosmological model are derived.We demonstrate that measurements of this signal would yield more information than is available from observations of the CMB anisotropies on our sky, and would potentially allow more precise measurement of cosmological parameters and the primordial power spectrum of density fluctuations.

MIT\_Dept. of Physics.\_1183

We investigate color superconducting phases of cold quark matter at densities relevant for the interiors of compact stars. At these densities, electrically neutral and weak-equilibrated quark matter can have unequal numbers of up, down, and strange quarks. The QCD interaction favors Cooper pairs that are antisymmetric in color and in flavor, and a crystalline color superconducting phase can occur which accommodates pairing between flavors with unequal number densities. In the crystalline color superconductor, quarks of different flavor form Cooper pairs with nonzero total momentum, yielding a condensate that varies in space like a sum of plane waves. Rotational and translational symmetry are spontaneously broken. We use a Ginzburg-Landau method to evaluate candidate crystal structures and predict that the favored structure is face-centered-cubic. We predict a robust crystalline phase with gaps comparable in magnitude to those of the color-flavor-locked phase that occurs when the flavor number densities are equal. Crystalline color superconductivity will be a generic feature of the QCD phase diagram, occurring wherever quark matter that is not color-flavor locked is to be found. If a very large flavor asymmetry forbids even the crystalline state, single-flavor pairing will occur; we investigate this and other spin-one color superconductors in a survey of generic color, flavor, and spin pairing channels. Our predictions for the crystalline phase may be tested in an ultracold gas of fermionic atoms, where a similar crystalline superfluid state can occur. If a layer of crystalline quark matter occurs inside of a compact star, it could pin rotational vortices, leading to observable pulsar glitches.

MIT\_Dept. of Physics.\_1245

The kinetic properties of ions in the solar wind plasma are studied. Observations of solar wind +H and +2He by the Faraday Cup instrument component of the Solar Wind Experiment on the Wind spacecraft show that these ions have magnetic field-aligned, convected, bi-Maxwellian velocity distribution functions. The analysis yields the best-fit values of the bulk velocity, U, number density n, and parallel T and perpendicular T temperatures of each of the ion species. The accuracy of each of these measurements is studied and an absolute calibration of the Faraday Cup is performed, demonstrating the accuracy of the densities to =/&lt; 2%. The range of the proton temperature anisotropy Rp= - Tp/Tp is explored, and it is demonstrated that thermodynamic concepts such as the double adiabatic equations of state are insufficient approximations for a kinetic description of the solar wind plasma. It is shown that Rp is constrained on macroscopic timescales by Coulomb relaxation and the expansion of the solar wind, and on kinetic timescales by the mirror, cyclotron, and firehose plasma micro-instabilities. Electromagnetic fluctuations generated by growing mirror and cyclotron modes are detected in the solar wind. The first detailed observations of the firehose instability are presented. The limiting bounds to Rp imposed by each of these instabilities are measured and compared with the theoretical predictions of fluid magnetohydrodynamics, linear kinetic Vlasov theory, and numerical simulations. It is shown that the predictions of linear theory and the simulations are in agreement with the observations. A new proton temperature anisotropy driven instability in the regieme Rp &lt; 1, βP &lt; 1 is discovered. The kinetic properties of +H and +2He are compared.

For the first time a cyclotron resonant instability driven by the proton temperature anisotropy is demonstrated to limit the differential flow U=Uα-Up attainable in the solar wind, in confirmation of recent theoretical predictions. It is shown that the +2He temperature anisotropy Rα=Tα/Tα is also constrained by micro-instabilities, and the first observations of the+2He cyclotron and firehose instabilities are presented. The parallel and perpendicular temperatures of +H and +2He are compared, and evidence of cyclotron-resonant heating of +2He preferrentially to +H in the interplanetary medium is presented.

MIT\_Dept. of Physics.\_1321

We have studied the transport of magnetization and energy in systems of spins 1/2 on a lattice at high temperature. This work was motivated by recent experiments which observed "spin diffusion" among the dipolar coupled nuclear spins of the insulator calcium fluoride, under conditions where it was appropriate to neglect the coupling to any heat reservoir. The dynamics under these conditions is coherent and reversible, yet signatures of irreversibility (i.e. diffusion) are typically observed. This state of affairs poses a formidable conceptual puzzle. In this thesis we present both phenomenological and microscopic models of spin diffusion, retaining the important aspects of statistical approaches to transport while incorporating relevant quantum effects. These methods allow an efficient calculation of energy diffusion for a long- range interaction, which has largely been an intractable problem. We study transport in two different limits, that where the XY term of the spin Hamiltonian is dominant, and that where it can be treated as a perturbation compared to the Ising term. In the case of dipolar couping, both limits are found to show slightly more rapid diffusion of inter spin energy than magnetization, in qualitative agreement with experiments.

MIT\_Dept. of Physics.\_1322

We present theoretical and experimental results from a Smith-Purcell radiation experiment using the electron beam from a 17 GHz high gradient accelerator. Smith- Purcell radiation occurs when a charged particle travels above a periodic grating structure. The electron beam consists of a train of 15 MeV, 9 pC bunches of bunch lengths varying from 600 fs to 1 ps. The radiated energy for one electron travelling above a periodic grating is solved. The effects of multiple electrons in a bunch and multiple bunches in a train are introduced. The Smith-Purcell resonance condition and the dependence of the radiated energy upon beam current and beam height above the grating are presented. Measurement of the angular distribution of the Smith- Purcell radiation resulted in bunch length measurements of 0.60 ± 0.1 ps and 1 ± 0.1 ps under different accelerator operating conditions. This demonstrates the use of Smith-Purcell radiation as a non-destructive bunch length diagnostic with 100 fs resolution. Smith-Purcell radiation is comparable to other sources of radiation, such as transistion radiation, synchrotron radiation, etc. except that it has an inherent enhancement by a factor of Ng, the number of grating periods. Additional enhancement occurs when the electron bunch length is short compared with the radiation wavelength, resulting in coherent emission with an enhancement by a factor of Ne the number of electrons in the bunch. Finally, the electron beam consists of a regular train of Nb bunches, resulting in an energy density spectrum that is restricted in frequency space to harmonics of the bunch train frequency, with an increase in the energy density at these frequencies by a factor of Nb. We report the first observation of Smith-Purcell radiation displaying all three of these enhancements, that is, with a total enhancement of Ng.Ne.Nb. This total enhancement provides a simple method of generating powerful THz radiation at specific frequencies, which can be detected with a high signal to noise ratio by a heterodyne receiver.

MIT\_Dept. of Physics.\_1323

Magnetic monopoles are highly ionizing and curve in the direction of the magnetic field. A new dedicated magnetic monopole trigger at CDF, which requires large light pulses in the scintillators of the time-of-flight system, remains highly efficient to monopoles while consuming a tiny fraction of the available trigger bandwidth. A specialized offline reconstruction checks the central drift chamber for large dE/dx tracks which do not curve in the plane perpendicular to the magnetic field. We observed zero monopole candidate events in 35.7 pb?1 of proton-antiproton collisions at ... = 1.96 TeV. This implies a monopole production cross section limit [sigma] &lt; 0.2 pb for monopoles with mass between 100 and 700 GeV, and, for a Drell-Yan like pair production mechanism, a mass limit m &gt; 360 GeV.

MIT\_Dept. of Physics.\_1451

Hydrogen is considered a good energy carrier candidate for future automotive applications because of its high abundance and its potential role in a carbon-free cycle. The high gravimetric and volumetric storage capacities of metal hydrides make them ideal hydrogen carriers if the limitations associated with their slow hydrogen release kinetics, their high hydrogen release temperatures, and their poor thermal properties can be resolved. In this thesis, the thermodynamic and kinetic improvements on the hydrogen release properties of nanostructured metal hydrides are investigated both theoretically and experimentally. Four main results are presented in this work. The excess volume present in deformed regions is identified as the key factor in explaining the reduction in the enthalpy of formation observed experimentally in nanostructured materials. The impact of excess volume on the enthalpy of formation at OK is quantified using three equations of state, and it is found to be as important as the combined impact of surfaces, grain boundaries and the presence of metastable crystalline phases. Then, the findings on the properties of excess volume are generalized to high temperatures. It is demonstrated that the impact of temperature will be more favorable to a reduction of the enthalpy of formation if a large fraction of the metal hydride is in a state of small excess volume compared to a small fraction of the hydride in a state of high excess volume. The impact of a temperature increase on the enthalpy of formation of metal hydrides is found to offset the effect of the excess volume as calculated at OK. The stability of the regions containing excess volume over multiple hydriding/dehydriding cycles is also calculated. At high temperatures and large excess volumes, the free energy barrier created by the excess entropy reduces the recrystallization rate of the deformed regions by several orders of magnitude. A regime where the benefits of the excess volume on the enthalpy of formation can be maintained is thus identified.

Finally, an experiment to study the cycling properties of metal hydrides was designed using Raman spectroscopy. It is demonstrated that the release temperature of hydrogen could be accurately measured using Raman spectroscopy.

MIT\_Dept. of Physics.\_1452

A 4-channel microwave interferometer (center frequency: 60 GHz) has been constructed to measure the density profiles of plasmas confined within the Levitated Dipole Experiment (LDX). LDX is the first and only experiment built to study plasmas confined by the field of a levitating, dipole magnet in a geometry that exploits plasma compressibility to achieve stability. Theoretical predictions--based partly on observations of planetary magnetospheres-suggest that dipole-confined plasmas will be driven by fluctuations into pressure and density profiles that are "stationary" to MHD interchange modes. The stationary pressure profile is characterized by an equal amount of entropy per flux-tube while the stationary density profile is characterized by an equal number of particles per flux-tube. These predictions are of interest to nuclear fusion research since they imply that the pressure and density profiles of dipole-confined plasmas can be simultaneously peaked and stable. Measurements with the interferometer show that the total density of LDX plasmas is strongly affected by the following parameters: levitated vs. mechanical support of the central dipole coil; input ECRH frequency and power; background pressure of neutral particles; plasma species. The gradients of the density profiles are, however, largely independent of the experimental conditions and approximate the value predicted for the stationary profile. Non-linear analyses suggest that dipole-confined plasmas are maintained in their stationary pressure and density profiles by a process of self-organized convection. We present measurements indicating that this self-organization process is observed in LDX.

MIT\_Dept. of Physics.\_1614

We begin by presenting some results of studying certain axially symmetric super- gravity geometries corresponding to a distribution of BPS D6-branes wrapped on K3, obtained as extremal limits of a rotating solution.

The geometry's unphysical regions resulting from the wrapping can be repaired by the enhancon mechanism, with the result that there are two nested enhancon shells. For a range of parameters, the two shells merge into a single toroidal surface. Given the quite intricate nature of the geometry, it is an interesting system in which to test previous techniques that have been brought to bear in spherically symmetric situations. We are able to check the consistency of the construction using supergravity surgery techniques, and probe brane results. Implications for the Coulomb branch of (2+1)-dimensional pure SU(N) gauge theory are extracted from the geometry. Related results for wrapped D4-- and D5-brane distributions are also discussed. Next, we turn to the issue of time travel.

Many solutions of General Relativity appear to allow the possibility of time travel. This was initially a fascinating discovery, but geometries of this type violate causality, a basic physical law which is believed to be fundamental. Although string theory is a proposed fundamental theory of quantum gravity, geometries with closed timelike curves have resurfaced as solutions to its low energy equations of motion. In chapter 3, we will study the class of solutions to low energy effective supergravity theories related to the BMPV black hole and the D1--D5-brane-SSW system. Time travel appears to be possible in these geometries. We will attempt to build the causality violating regions and propose that stringy effects prohibit their construction. We will show how the geometry is corrected and that, once corrected, causality is preserved. We will track our chronology protection proposal in the dual conformal field theory. The absence of closed timelike curves in the geometry coincides with the preservation of unitarity ill the conformal field theory. Our mechanism will also have the pleasing result of being an enforcer of the second law of thermodynamics. We will generalize our results to a broader class of geometries. Finally we discuss physics associated with horizons. A de Sitter Space version of Black Hole Complementarity is formulated which states that an observer in de Sitter Space describes the surrounding space as a sealed finite temperature cavity bounded by a horizon which allows no loss of information. We then discuss the implications of this for the existence of boundary correlators in the hypothesized dS/CFT correspondence. We find that dS complementarity precludes the existence of the appropriate limits. We find that the limits exist only in approximations in which the entropy of the de Sitter Space is infinite. The reason that the correlators exist in quantum field theory in the de Sitter Space background is traced to the fact that horizon entropy is infinite in QFT.We will consider the implications of a cosmological constant for the evolution of the universe, under a set of assumptions motivated by the holographic and horizon complementarity principles. We discuss the "causal patch" description of spacetime required by this framework, and present some simple examples of cosmologies ...

MIT\_Dept. of Physics.\_1696

Fitting the X-ray spectra of thermal radiation from neutron stars with realistic atmosphere models provides a way to place constraints on their radii, surface gravities and compositions, and to test general relativity in the strong field limit. Such determinations allow us to constrain the the equation of state of nuclear matter. I present fits which constrain the radii and surface compositions of two neutron stars, using high quality Chandra X-ray Observatory observations of the point source in the Cassiopeia A supernova remnant (Cas A XPS), and the isolated neutron star RX J1856.5-3754. I apply models calculated with advanced versions of the ATM model atmosphere code developed by Madej and Joss for neutron-star atmospheres composed of hydrogen, hydrogen-helium, iron, or a silicon to iron mixture. The results, taken assuming a typical value of 1.4 solar masses, show that the X-ray emission is generated from hot spot regions of scale size - 3-4 km, on stars of intrinsic radius 9 and 12.5 km. This implies a relatively stiff equation of state. For the Cas A XPS, I fit the most source photons to date with spectra extracted from three Chandra Advanced CCD Imaging Spectrometer observations (ObsIds 114, 1952, 1046), with a total effective exposure of approximately 110,000 seconds. With these data, I am able to show that atmosphere models fit significantly better than blackbody models, although a wide range of radii are permitted. I also present evidence of an absorption feature in the XPS spectrum caused by silicon present in the supernova remnant, and discuss efforts to to fit CCD pileup of the spectrum. For the RX J1856.5-3754, I fit a 450,000 second Chandra Low Energy Transmission Grating/High Resolution Camera observation. My findings agree with previous results that a blackbody model provides the best fit, and reject hydrogen and iron atmospheres. While previous attempts to fit the spectrum with rotationally-blurred iron or solar abundance atmospheres have failed, I successfully fit the spectrum to a rotationally Doppler blurred silicon-ash model, a surface composition which might exist following a supernova. The fit implies a rotational period of approximately 2 ms.

MIT\_Dept. of Physics.\_1697

Helical ribbons with pitch angles of either 11? or 54? self-assemble in a wide variety of quaternary surfactant-phospholipid/fatty acid-sterol-water systems. In all of the systems studied, the thermodynamically stable state for the sterol is plate like mono-hydrate crystals. However, the sterol is typically found to pass through a serious of metastable intermediates from filaments to helical ribbons to tubules before reaching the stable crystalline state. In the present work, we chose to focus on helical ribbons formed in the Chemically Defined Lipid Concentrate (CDLC) system. These helices typically have radii on the order of a few to a few tens of microns and lengths on the order of hundreds of microns. By tethering to these mesoscopic helical ribbons using Devcon 5-Minute Epoxy?, we have been able to elastically deform them, and thus examine their response to uniaxial tension. For small deformations, the low pitch helices behave like linear elastic springs with a spring constant for a typical example measured to be (4.80 +/- 0.77) x 10-6 N/m. From the observed spread in helix dimension, our theory predicts a corresponding range of spring constants for the structures of 10-7 to 10-4 N/m allowing, in principle, a great range of forces to be examined. Under larger tensions, both low and high pitch helices have been observed to reversibly separate into a straight domain with a pitch angle of 90ê? and a helical domain with a pitch angle of (16.5 +/1 1.3)? for the low pitch or (59.6 +/- 1.7)? for the high pitch. Using a newly developed continuum elastic free energy model, we have shown that this phenomena can be understood as a mechanical phase transition of first order. From this analysis, we have also been able to determine all of the parameters within our model, and to show that it is capable of self-consistently and quantitatively explaining all of the observed properties of these self-assembled helices.

MIT\_Dept. of Physics.\_1698

This thesis describes research to theoretically model and experimentally measure electronic systems which employ ballistic electron emission. First, a Monte-Carlo framework for simulating electron injection from a tunnel junction emitter into a semiconductor collector is presented in detail and a few applications of this theory are described. Second, a method of treating ballistic electron transport through nano-scale heterostructures by considering realistic, atomic-scale periodic potentials is examined. Third, experimental results toward development of a novel scanning-probe microscopy for the local study of buried luminescent heterostructure layers is presented. Finally, a number of future research directions suggested by these results are described.

MIT\_Dept. of Physics.\_1736

During the last decade the three interferometers of the Laser Interferometer Gravitational Wave Observatory (LIGO) were built and commissioned. In fall 2005 design sensitivity was achieved, corresponding to a strain sensitivity of 2.5 x 10-23 Hz-1/2 at 150 Hz. All three interferometers are now in an extended science run. One of the most critical steps to reach this goal was increasing the power in the interferometer to more than 200 Watt at the beam splitter. This required the commissioning of both a thermal compensation system and shot noise limited sensing electronics capable of detecting all the light. Additionally, a series of unexpected noise sources had to be mitigated. This work is described in the first part of this thesis. In a second part I introduce a radiometer analysis that is capable of spatially resolving anisotropies in a stochastic gravitational wave background. The analysis is optimized for identifying point sources of stochastic gravitational radiation. Finally, data from the fourth LIGO science run is used to set both isotropic and directional upper limits on the stochastic background of gravitational waves. The bound set on the normalized gravitational wave energy density is h2 gw(f) &lt; 6.25 x 10-5 and the limit set on a broadband and flat strain power spectrum coming from a point source varies between 8.5 x 10-49Hz-1 and 6.1 x 10-48Hz-1, depending on the source position. Additionally a limit on gravitational radiation coming from the direction of Sco-X1, the brightest X-ray source short of the sun, is set for each frequency bin.

MIT\_Dept. of Physics.\_1737

In this thesis we investigate building models of family symmetry that give the Higgs fields family structure. We construct several models, starting with 2 generation models then moving onto 3 generation models. These models are described sequentially in chapters 2 through 6. All of these models are supersymmetric and they did not previously exists in the literature. In these models, quark (and lepton) masses and mixings are determined the vacuum expectation values of the family sector. These vacuum expectation values (VEV) can have a hierarchal structure because they correspond to flat directions of a superpotential. At low energies these models contain just one light pair of Higgs fields. Experimentally, the most interesting feature of these models are couplings between the low energy Higgs and moduli of the family sector. These couplings should be observable at the Large Hadron Collider.

MIT\_Dept. of Physics.\_1738

We conducted an experiment to load a shallow planar ion trap from a cold atom source of Ytterbium using photoionization. The surface trap consisted of a three-rod radio frequency Paul trap fabricated using standard printed circuit board techniques. The cold atom source was an isotope-selective magneto-optical trap of naturally-occurring Yb isotopes. The confining beams were provided by commercially-available ultra-violet diode lasers locked to an atomic reference using the Dichroic Atomic Vapor Laser Lock technique. We used photoionization from the Yb magneto-optical trap located within the region of the ion trapping potential.

MIT\_Dept. of Physics.\_1741

In this thesis, we study inclusive decays of the B meson. These allow one to determine CKM elements precisely and to search for physics beyond the Standard Model. We use the framework of effective field theories, in particular the Soft-Collinear Effective Theory, which is a suitable method when the decay products include a jet-like set of hadronic states. We derive factorization theorems for ... corrections (including all orders in a,) to ... in the shape function region, where ... A complete enumeration of ... contributions is provided. We also point out the presence of new shape functions that arise from four-quark operators. These induce an additional uncertainty in certain inclusive determinations of ... Next, we derive the triply differential spectrum for ... in the shape function region, consideration of which is necessitated by experimentally required cuts. It is shown that the same universal jet and shape functions appear as in the decays ... We also show that one can treat the perturbative power counting above and below the scale ... independently, using a procedure we call "split matching". This resolves the conflict between what is suitable in each of these regions. Finally, we use these results to calculate the fraction of the total rate that is measured in the presence of a cut on the hadronic invariant mass, mx. We find that the effect of this cut depends strongly on the value of mt and is approximately universal for all short-distance contributions. This feature can be exploited to minimize hadronic uncertainties and thereby maintain sensitivity to new physics.

MIT\_Dept. of Physics.\_1742

For many years, it was thought that Landau's theory of symmetry breaking could describe essentially all phases and phase transitions. However, in the last twenty years, it has become clear that at zero temperature, quantum mechanics allows for the possibility of new phases of matter beyond the Landau paradigm. In this thesis, we develop a general theoretical framework for these "exotic phases" analogous to Landau's framework for symmetry breaking phases. We focus on a particular type of exotic phase, known as "topological phases", and a particular physical realization of topological phases - namely frustrated quantum magnets. Our approach is based on a new physical picture for topological phases. We argue that, just as symmetry breaking phases originate from the condensation of particles, topological phases originate from the condensation of extended objects called "string-nets." Using this picture we show that, just as symmetry breaking phases can be classified using symmetry groups, topological phases can be classified using objects known as "tensor categories." In addition, just as symmetry breaking order manifests itself in local correlations in a ground state wave function, topological order manifests itself in nonlocal correlations or quantum entanglement. We introduce a new quantity - called "topological entropy" - which measures precisely this nonlocal entanglement. Many of our results are applicable to other (non-topological) exotic phases.

MIT\_Dept. of Physics.\_1743

In this thesis, I show some of the results of my research work in the field at the crossing between Cosmology and Particle Physics. The Cosmology of several models of the Physics Beyond the Standard Model is studied. These range from an inflationary model based on the condensation of a ghost-like scalar field, to several models motivated by the possibility that our theory is described by a landscape of vacua, as probably implied by String Theory, which have influence on the theory of Baryogenesis, of Dark Matter, and of Big Bang Nucleosynthesis. The analysis of the data of the experiment WMAP on the CMB for the search of a non-Gaussian signal is also presented and it results in an upper limit on the amount on non-Gaussianities which is at present the most precise and extended available.

MIT\_Dept. of Physics.\_1744

In this thesis we will explore three approaches to aspects of the fundamental structure of string theory. We first provide a brief review of perturbative string theory, and briefly discuss how each of the three topics to be discussed in the body of this thesis depart from this starting point. We then study the open string one-loop tadpole diagram in Witten cubic open string field theory. We compute this diagram both analytically and numerically and study the divergences arising from the collective behavior of open string fields in the short-distance region of the diagram. We demonstrate that this region of the diagram encodes information about the linearized Einstein equation describing the shift in the closed string fields in reaction to the D-brane supporting the open strings. We also show that the manner in which this information is encoded is somewhat singular, and comment on the implications for the quantum consistency of open bosonic string field theory. We next compute the closed string radiation from a decaying D-brane in type II string theory. The calculation is made possible by noting that the integrals involved in the requisite disk one-point functions reduce to integrals over the group manifold of a product of unitary groups. We find that the total number and energy of strings radiated during the decay process diverges for D-branes of small enough dimension, in precise analogy to the bosonic case. Finally, we investigate a simple class of type II string compactifications which incorporate nongeometric "fluxes" in addition to "geometric flux" and the usual H-field and R-R fluxes. We develop T-duality rules for NS-NS geometric and nongeometric fluxes, which we use to construct a superpotential for the dimensionally reduced four-dimensional theory.

The resulting structure is invariant under T-duality, so that the distribution of vacua in the IIA and IIB theories is identical when nongeometric fluxes are included.

MIT\_Dept. of Physics.\_1838

A new physical mechanism for positron accumulation is explained and demonstrated. Strongly magnetized Rydberg positronium is formed and then ionized, allowing us to trap equal numbers of either positrons or electrons over a wide range of conditions. Antiprotons are trapped, cooled, and stacked from the new Antiproton Decelerator facility for the first time. Combining positrons and antiprotons, we have demonstrated the first positron cooling of antiprotons. The cooling takes place in a 4.2 K, nested Penning trap where conditions are ideal for the eventual goal of the formation of antihydrogen.

MIT\_Dept. of Physics.\_1885

Quantum mechanical computers can solve certain problems asymptotically faster than any classical computing device. Several fast quantum algorithms are known, but the nature of quantum speedup is not well understood, and inventing new quantum algorithms seems to be difficult. In this thesis, we explore two approaches to designing quantum algorithms based on continuous-time Hamiltonian dynamics.In quantum computation by adiabatic evolution, the computer is prepared in the known ground state of a simple Hamiltonian, which is slowly modified so that its ground state encodes the solution to a problem. We argue that this approach should be inherently robust against low-temperature thermal noise and certain control errors, and we support this claim using simulations. We then show that any adiabatic algorithm can be implemented in a different way, using only a sequence of measurements of the Hamiltonian. We illustrate how this approach can achieve quadratic speedup for the unstructured search problem. We also demonstrate two examples of quantum speedup by quantum walk, a quantum mechanical analog of random walk. First, we consider the problem of searching a region of space for a marked item. 4.Whereas a classical algorithm for this problem requires time proportional to the number of items regardless of the geometry, we show that a simple quantum walk algorithm can find the marked item quadratically faster for a lattice of dimension greater than four, and almost quadratically faster for a four-dimensional lattice. We also show that by endowing the walk with spin degrees of freedom, the critical dimension can be lowered to two. Second, we construct an oracular problem that a quantum walk can solve exponentially faster than any classical algorithm. This constitutes the only known example of exponential quantum speedup not based on the quantum Fourier transform. Finally, we consider bipartite Hamiltonians as a model of quantum channels and study their ability to process information given perfect local control. We show that any interaction can simulate any other at a nonzero rate, and that tensor product Hamiltonians can simulate each other reversibly. We also calculate the optimal asymptotic rate at which certain Hamiltonians can generate entanglement.

MIT\_Dept. of Physics.\_1889

This thesis describes the demonstration of a new technique that allows masses to be compared with fractional uncertainty at or below 1 x 10-11, an order of magnitude improvement over our previous results. By confining two different ions in a Penning trap we can now simultaneously measure the ratio of their two cyclotron frequencies, making our mass comparisons insensitive to many sources of fluctuations (e.g. of the magnetic field). To minimize the systematic error associated with the Coulomb interaction between the two ions, we keep them about 1 mm apart from each other, on a common magnetron orbit. We have developed novel techniques to measure and control all three normal modes of motion of each ion, including the two strongly coupled magnetron modes. With the help of a new computer control system we have characterized the electric field anharmonicities and magnetic field inhomogeneities to an unprecedented level of precision. This allows us to optimize the trap so that our measurement of the cyclotron frequency ratio is to first order insensitive to the field imperfections. Using the ions 13C2H2+ and 14N2+, we performed many tests of our understanding of the ions dynamics and of the various sources of errors in this technique.From these we conclude that there should be no systematic error in our measurements at the level of 5 x 10-12. Thus we feel confident reporting a value for the mass ratio of these ions with an uncertainty of 10-11. In this thesis, we also report measurements of the two mass ratios m[33S+]/m[32SH+] and m[29Si+]/m[28SiH+] with a relative uncertainty of less than 10-1l, which makes them the best known mass ratios to date. These can be combined with precise measurements of high-energy gamma-rays to provide a direct test of the relation E = mc2. This is a test of special relativity which does not rely on the assumption of a preferred reference frame. The uncertainty on the atomic mass of 29Si is also reduced by about an order of magnitude.

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Despite the study of shock wave compression of condensed matter for over 100 years, scant progress has been made in understanding the microscopic details. This thesis explores microscopic phenomena in shock compression of condensed matter including electronic excitations at the shock front, a new dynamical formulation of shock waves that links the microscopic scale to the macroscopic scale, and basic questions regarding the role of crystallinity in the propagation of electromagnetic radiation in a shocked material. In Chapter 2, the nature of electronic excitations in crystalline solid nitromethane are examined under conditions of shock compression. Density functional theory calculations are used to determine the crystal bandgap under hydrostatic stress, uniaxial strain, and shear strain for pure and defective materials. In all cases, the bandgap is not lowered enough to produce a significant population of excited states. In Chapter 3, a new multi-scale simulation method is formulated for the study of shocked materials. The method allows the molecular dynamics simulation of the system under dynamical shock conditions for orders of magnitude longer time periods than is possible using the popular non-equilibrium molecular dynamics (NEMD) approach. An example calculation is given for a model potential for silicon in which a computational speedup of 10? is demonstrated. Results of these simulations are consistent with some recent experimental observations. Chapters 4 and 5 present unexpected new physical phenomena that result when light interacts with a shock wave propagating through a photonic crystal. These new phenomena include the capture of light at the shock wave front and re-emission at a tunable pulse rate and carrier frequency across the bandgap, and bandwidth narrowing of an arbitrary signal as opposed to the ubiquitous bandwidth broadening. Reversed and anomalous Doppler shifts are also predicted in light reflected from the shock front.

MIT\_Dept. of Physics.\_1894

This thesis applies principles of statistical physics and non-equilibrium dynamics to problems of scale, randomness, and growth in plant communities. It includes three projects related by their methodology and distinct in the nature of their applications. In the first project, we analyze the relationship between resource availability and species richness in community and regional level models of plant/tree communities. At local scales, vegetative communities tend to follow a unimodal relationship between resources and species richness. However, as per the results of species-energy theory, they tend to obey a monotonically increasing relationship at large scales. We use a multi-species neutral contact process coupled to a heterogeneous resource landscape to explain the scale-dependent transition. We find that the unimodal curve at the community scale may be understood as a tradeoff between colonization of and competition for limited resources. We then construct statistical aggregates of community level ecosystems and find two necessary conditions for a scale-dependent transition: (i) the spatial distribution of resources is highly correlated and (ii) the extent of species pools increases in regions with higher overall resources. The second project integrates the analysis of size-structured populations into the study of the contact process. We introduce the contact process with ontogeny to describe the growth and spread of organisms with size-structured juvenile and adult stages. We derive a mean field theory of the contact process with ontogeny, which we solve yielding an additional oscillatory phase. The mean field phase diagram is found in terms of A, the dimensionless reproductive rate, and 0, the dimensionless growth rate. However, the oscillatory phase is not borne out in explicitly spatial Monte Carlo simulations, in contrast to the regularity with which oscillations are observed for well-stirred models of size-structured populations. Instead we find a "corralled" phase where the growth of new seeds interfere with one another, limiting basal area and number of adults, and leading to a unimodal relationship between density p and reproductive rate A. We analyze the onset of the corralled phase by analyzing spatial correlations and find that this self-limiting phase is characterized by distinct peaks in the radial distribution function. We also determine the universality class of the transition between life and death and point out where generalizations of the model may be applied to plant/tree communities. The final project addresses the size distributions of systems where growth is limited by geometric constraints. We develop a model termed packing limited growth (PLG) which describes the interaction and growth of sessile organisms. We show that a class of models previously introduced in the context of growth and nucleation kinetics may be mapped onto PLG. We develop a scaling theory which connects the fractal dimension of packings to the approach to the fully packed state. The equilibrium size distribution of PLG models is shown to depend on dimensionality, anisotropy, and geometric shape. Numerical estimates of fractal dimensions are calculated in d = 2, 3, and 4.

MIT\_Dept. of Physics.\_1907

This thesis describes four new optical surveys for gravitationally lensed quasars. The goal of this work has been to (1) explore new strategies for conducting optical surveys, especially in the southern hemisphere, in the hopes of "fine-tuning" the survey techniques toward finding systems of particular scientific interest; and (2) to increase the number of optically-selected lenses, and by extension, to improve future statistical analyses of lens surveys by enlarging the sample size of quasars that have been surveyed for lensing. Optical surveys for strong lenses have the potential to discover an order of magnitude more systems than radio surveys, to produce optically-bright lenses that are well-suited for long-term monitoring and followup observations, and to yield statistical constraints on the overall geometry and dynamics of the Universe. Three of these surveys take the form of traditional "targeted" searches. These include: 1) a ground-based survey targeting 173 radio-loud quasars using the 2.4 m telescope at Michigan-Dartmouth-MIT Observatory (MDM), producing one certain lens and one binary quasar; 2) a ground-based survey targeting 377 quasars in the southern hemisphere using the 1.5 m telescope at Cerro-Tololo Interamerican Observatory (CTIO), producing two certain lenses and one binary quasar; 3) a space-based snapshot survey for close separation lenses targeting 320 quasars using the Hubble Space Telescope (HST), producing three certain lenses and maybe a fourth. The MDM survey has been designed to combine the high discovery efficiency of optical surveys with the rich image morphology often found in radio-loud lenses. The CTIO survey makes use of two new catalogs of bright quasars to provide a high discovery efficiency of 0.7%. The HST snapshot survey has searched for close separation lenses - spirals in particular - that are difficult to resolve from ground-based surveys. Of the eight systems discovered form these surveys, five are described in detail in this thesis. The first object, FBQ 1633+3134, is a 0"f7 double discovered from the MDM survey. Discrepant optical and radio flux ratios for this system means that it is most likely a physical binary quasar. The second, third and fourth objects -CTQ 414, HE 0230-2130, and CTQ 839 - were all discovered from the CTIO survey. The former two systems are confirmed gravitational lenses, while the latter is a binary quasar. CTQ 414 is a 12 double quasar that is well suited for future optical monitoring and a possible time-delay measurement, HE 0230-2130 is a complex four-image gravitational lens formed by two lensing galaxies, and CTQ 839 is almost certainly a binary quasar after repeated attempts to detect the hypothesized lensing galaxy have failed. The fifth system, the lensed quasar CTQ 327, is a 1"/2 double discovered from the HST survey which is also well suited for optical monitoring and a possible time-delay measurement. The superior angular resolution afforded by the HST snapshot survey is also used to constrain the matter density of any hypothetical population of dark, compact objects at high redshift to be less than 2.2% of the closure density for objects of mass 109 6M0, and rules out a closure density of any compact object in the mass range 1075 &lt; M/M &lt; 1011.5 at the 99.7% confidence level ...

MIT\_Dept. of Physics.\_1908

In this thesis properties of various condensed matter systems are studied, whose dependency on electronic behavior is incorporated through coarse-grained interactions. Three specific systems are considered. In the first system of study, high momentum, plane wave states of the electronic wave function are coarse-grained, while the low momentum states are fully resolved. Moreover, the coarse-graining procedure incorporates the response of the high momentum states to environmental changes and its couplings to changes in the low momentum states. Within density functional theory this allows the representation of the electronic wave function, when using a plane wave basis, to be computationally feasible without having to make the pseudopotential approximation. This coarse-graining procedure is beneficial for the study of high pressure systems, where the response of the core region is important. With this method we study a number of solid phases of boron and reveal a number of important structural and electronic properties on its high pressure and superconducting phase. The second system of study focuses on a slightly coarser scale, where a theory for the elasticity of nanometer sized objects is developed. This theory provides a powerful way of understanding nanoscale elasticity in terms of local group contributions and acts as a bridge between the atomic and the continuum regimes. This theory properly describes elastic fluctuations on length scales on the order of the decay length of the force constant matrix; allowing for straightforward development of new relations between the bending and stretching properties of nanomechanical resonators, which prove to be much more accurate than the continuum-based relations currently employed in experimental analysis. This theory is then used to link features of the underlining electronic structure to the local elastic response in silicon nanoresonators, emphasizing the importance of electronic structure on the local and overall elastic response. Our final system of study focuses on the longest length scales, the continuum. It is shown that the inclusion of electronic structure is crucial in the study of the role of dislocations on the macroscopic property of slip. This thesis explores the discrepancy between experimental data and theoretical calculations of the lattice resistance in bcc metals. This thesis presents results for the temperature dependence of the Peierls stress and the first ab initio calculation of the zero-temperature Peierls stress which employ periodic boundary conditions. The ab initio value for the Peierls stress is over five times larger than current extrapolations of experimental lattice resistance to zero-temperature. Although it is found that the common techniques for such extrapolation indeed tend to underestimate the zero-temperature limit, in this work it is shown that other mechanisms other than the simple Peierls mechanism are important in controlling the process of low temperature slip.

MIT\_Dept. of Physics.\_1909

As the first generation of laser interferometric gravitational wave detectors near operation, research and development has begun on increasing the instrument's sensitivity while utilizing existing infrastructure. In the Laser Interferometer Gravitational Wave Observatory (LIGO), significant improvements are being planned for installation in 2007 to increase the sensitivity to test mass displacement, hence sensitivity to gravitational wave strain, by improved suspensions and test mass substrates, active seismic isolation, and higher input laser power. Even with the highest quality optics available today, however, finite absorption of laser power within transmissive optics, coupled with the tremendous amount of optical power circulating in various parts of the interferometer, result in critical wavefront deformations which will cripple the performance of the instrument. Discussed is a method of active wavefront correction via direct thermal actuation on optical elements of the interferometer; or, "thermally adaptive optics". A simple nichrome heating element suspended off the face of an affected optic will, through radiative heating, remove the gross axisymmetric part of the original thermal distortion. A scanning heating laser- will then be used to remove any remaining non-axisymmetric wavefront distortion, generated by inhomogeneities in the substrate's absorption, thermal conductivity, etc. This work includes a quantitative analysis of both techniques of thermal compensation, as well as the results of a proof-of-principle experiment which verified the technical feasibility of each technique.

MIT\_Dept. of Physics.\_1911

Neutron scattering, magnetization and transport measurements were performed on single crystals of Bi2Sr2CoO6+[delta] to study the evolution of the magnetic properties as a function of the oxygen content . The oxygen content was varied by annealing single crystals in either a reducing or oxidizing environment to obtain an experimental range of 0.25 =/&lt; [delta] =/&lt; 0.5 and a corresponding average Co valence between +2.5 and +3. We show that the as-grown samples, which are oxygen rich ([delta approximately] 0.5) and therefore contain mostly Co3+ ions, enter an antiferromagnetic (AF) phase with a Neel temperature - 250 K. On the other hand, annealing as-grown crystals in vacuum to reach [delta approx.] 0.25 destroys the AF phase; these samples exhibit predominantly ferromagnetic (FM) behavior with Tc [approx.] 100 K. At intermediate doping, 0.25 &lt; [delta] &lt; 0.5, we find evidence for co-existence of FM and AF domains, which are characteristic of the [delta] = 0.25 and [delta] = 0.5 phases, respectively. The signature of the co-existence is the presence of simultaneous FM and AF magnetic Bragg peaks in the neutron diffraction pattern. Polarized neutron scattering measurements confirm that the FM and AF peaks do not arise from different components of a canted antiferromagnet. The FM regions give rise to a ferromagnetic-like peak in the susceptibility at the same temperature as the spins in the AF phase order. In addition, the FM regions exert a random field in the AF phase, above a critical field Hc. We explain the field dependence of the two-phase samples with a microscopic model. We propose that the FM clusters within the AF phase are the result of regions which are rich in Co2+. Furthermore, we suggest that oxygen facilitates the formation of electronically inhomogeneous regions.

MIT\_Dept. of Physics.\_1941

We describe results obtained by a novel scanning technique, called Subsurface Charge Accumulation (SCA) Imaging, that enables the direct imaging of electronic systems buried inside semiconductor materials. Using SCA Imaging, we image and measure properties of a two-dimensional electron system (2DES) in a GaAs/AlGaAs heterostructure, in the regime of the integer quantum Hall effect. We observe general charging features in a plain 2DES near quantum Hall integer filling factors. We proceed by imaging low compressibility strips in the presence of an artificially created density gradient in the 2DES. We study them in detail at Landau level filling factors v = 2, 4. The strips appear significantly wider than predicted by theory and we account for the discrepancy by presenting a model that considers the disorder-induced nonzero density of states in the cyclotron gap. We also measure the charging properties of incompressible strips that form parallel to the edges of a metal gate deposited on the surface of our sample. An RC model considering charging of the 2DES across the strip, closely fits the data. This allows us to determine the longitudinal resistivity of the incompressible part of the edge state that runs parallel to the gate, for a range of filling factors. Surprisingly, the strip becomes more resistive in regions of high electronic density gradient, where its width is expected to decrease. By sensing charge from the motion of single electrons inside the 2DES we produce a topographic map of the random potential inside the integer quantum Hall liquid. We achieve this by creating a mobile quantum dot inside the 2DES. By scanning the dot, single electrons enter or leave it, in response to the local potential. Detection of this motion leads to the creation of a potential contour map. We find that the 2D electron screening of the random potential induced by external impurities, changes little between quantum Hall plateaus and within each plateau. We finally present preliminary results from a 2DES sample with a built-in backgate. The backgate enables us to deplete the 2DES and perform measurements in the regime of low electronic densities.

MIT\_Dept. of Physics.\_1942

I discuss the significance of the antiferromagnetic Heisenberg model (AFHM) in both high-energy and condensed-matter physics, and proceed to describe an efficient cluster algorithm used to simulate the AFHM. This is one of two algorithms with which my collaborators and I were able to obtain numerical results that definitively confirm that chiral perturbation theory, corrected for cutoff effects in the AFHM, leads to a correct field-theoretical description of the low-temperature behavior of the spin correlation length in various spin representations S. Using a finite-size-scaling technique, we explored correlation lengths of up to 105 lattice spacings for spins S=1 and 5/2. We show how the recent prediction of cutoff effects by P. Hasenfratz is approached for moderate correlation lengths, and smoothly connects with other approaches to modeling the AFHM at smaller correlation lengths. I also simulate and discuss classical antiferromagnetic systems with simultaneous SO(M) and SO(N) symmetries, which have been proposed as models for magnets in external fields and for electronic and color superconductors. After detailing the algorithms which were employed, I present results for the various observables which confirm the existence of the expected ordered and disordered phases. I obtain a preliminary phase diagram from these systems, from which the location of an expected bicritical point may be estimated. This is a necessary first step in determining whether the point exhibits a dynamically-generated enhanced symmetry, a possibility first suggested by Wiese and Chandrasekharan but not fully resolved in three dimensions.

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