Transient Recovery Method using Zernike PSF Decomposition for joint GW-EM analysis

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Advanced Gravitational-Wave (GW) detectors such as Advanced LIGO and Advanced Virgo are expected to become operational for observation runs in 2015. At the same time, joint searches for electromagnetic (EM) counterparts to GW events, aimed at confirming any potential GW detection, will also begin. There are many potential EM counterparts to GWs including short and long gamma-ray bursts (GRBs) and kilonovae. These three types of sources are expectedto have detectable traces in the optical band, albeit requiring very sensitive optical telescopes. In order to aid in the optimization of GW trigger follow-up procedures, we perform a method of transient recovery simulating a theoretical EM counterpart injected into archival optical images from Palomar Transient Factory (PTF) based on observed lightcurves of short GRBs, long GRBs, and kilonovae. The use of Zernike PSF decomposition on candidate objects offers a fast way to identify point sources, speeding up the automated identification of transient sources in the images. Here we present the latest results of our transient recovery method.

Post-Newtonian Corrections to Dynamical Friction

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Dynamical friction causes spinning supermassive black holes to experience an acceleration perpendicular to their translational motion. Using a post-Newtonian expansion up to the order of 1.5, will uncover gravitational effects which lead to nonzero perpendicular components of the coefficient of dynamical friction. These effects are caused by stars on hyperbolic orbits around the black hole, and the change in velocity of each of these stars (and hence, the change in velocity of the black hole) can be expressed as changes in their orbital elements (inclination, argument of periapsis, and longitude of ascending node). The talk will summarize the post-Newtonian equations used for this calculation. Additionally, the perturbative solutions obtained for the changes in the orbital elements of these stars will be covered.

LISA technology development using the UF precision torsion pendulum

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LISA, the laser interferometer space antenna, will be a space-based gravitational wave detector consisting of three satellites flying in an approximately equilateral triangle formation. LISA will accurately measure gravitational waves from astronomical sources such as supermassive black holes and give insight into the cosmological origins of the universe. This gravitational wave detector will measure gravitational-wave induced strains in space time. This will be accomplished with the use of laser interferometry to measure picometer changes in distance between free falling test masses that are millions of kilometers apart. A GRS, gravitational reference sensor, will consist of a test mass and corresponding actuation, sensing, charge control, and housing components. In order to test LISA technology and adhere to the acceleration noise requirement of LISA rigorous ground testing must be conducted. As a result the University of Florida has developed a torsion pendulum to test and improve LISA GRS technology. This facility is largely based off the design of the torsion pendulum facility at the University of Trento. The UF torsion pendulum facility consists of a torsion pendulum with suspended mockups of the LISA test masses surrounded by electrode housings all enclosed in a vacuum chamber. This presentation will discuss the design of the UF torsion pendulum facility and the current acceleration noise performance.

Study of vortices in Axion BEC dark matter

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We present an analytic study of the vortices in the Axion BEC dark matter and their effects on the galactic angular momentum distribution of baryons and dark matter in disk galaxies.

A cosmological sector of loop quantum gravity: Overview and symmetry conditions

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Loop quantum cosmology develops models of homogeneous, isotropic spacetimes in a familiar way. One imposes symmetries that eliminate gravitational degrees of freedom at the classical level before quantizing the resulting mechanical model. The particular quantization used shares important features with the loop quantization of the full theory, however, and so captures its general flavor. But the detour through the classical realm to impose symmetries nonetheless obscures the precise relation between the full and reduced quantum theories. Thus, although loop quantum cosmology makes concrete predictions that in principle can be compared with observation, it is unclear what exactly this reveals about loop quantum gravity proper. In this talk, I present an overview of a scheme to impose the same classical symmetry conditions in a gauge- and diffeomorphism-invariant way, which moreover can be carried over to the full quantum theory in a manner reminiscent of the Gupta--Bleuler quantization of the electromagnetic field. This selects a sector of homogeneous, isotropic states (albeit distributional ones) of loop quantum gravity that can serve as the foundation for a direct comparison of the quantum theories.

Precision Predictions for the Primordial Power Spectra in Arbitrary Histories

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We propose a new numerical technique for connecting the observed primordial power spectra to fundamental theory. I explain the new technique in the context of the tensor power spectrum for single-scalar inflation. I then show how the same technique can be applied to the scalar power spectrum and to other models of inflation. In addition to its numerical efficiency, the new technique also allows one to derive good approximate analytical predictions.

Effects of Dynamical Friction on Spinning Supermassive Black Holes

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Ever since they were predicted by Einstein's field equations, black holes have been fantastic sources of inspiration for cosmologists and astrophysicists. These incredibly massive objects represent regimes within our universe in which the gravitational force “beats out” all other fundamental forces of nature, and they’re able to offer us an amazing amount of insight into the structure of the cosmos, and the nature of reality on a vast range of scales. Within our research project we explore how the velocity of a supermassive Kerr black hole changes due to the dynamical friction force acting on it from the background stars of a galaxy. We will aim to show, through the use of a post-Newtonian expansion up to 1.5 order, that spinning supermassive black holes will experience a nonzero acceleration along axes perpendicular to their translational velocity. This change in velocity has not, previously, been investigated, and can be expressed in terms of changes to the orbital elements of stars on unbound orbits around the black hole, such as the inclination, argument of periapsis, and longitude of ascending node. We will show that this acceleration arises from the 1.5 PN spin term within our expansion and illustrate our method to approximate this qualitatively new effect.

"Proper" graviton propagator in spin foam formalism

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The gravitational two-point function is calculated using the "proper" spin foam vertex . The proper vertex amplitude was obtained from the EPRL vertex by projecting to a single gravitational sector in order to obtain correct semi-classical behavior. This calculation is done using boundary amplitude formalism.

Gravitational Self-Force Techniques and Second Order Prospects

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One of the promising sources for gravitational waves to be analyzed by detectors such as LISA and LIGO are Extreme Mass Ratio Inspirals (EMRIs), systems where a small mass orbits a much larger black hole. Energy carried away by gravitational waves will give rise to a "self-force" causing the object to deviate from geodesic motion. We analyze the case of a small compact object spiraling into a large black hole in the context of perturbation theory. Modeling the small object as a point mass allows us to bypass difficulties in numerical simulations but presents new challenges due to the object's singular nature. We explain several techniques developed to deal with these issues and discuss the future prospects and problems faced in moving to second order perturbations.

A New Optical Bench Concept for Space-Based Laser Interferometric Gravitational Wave Missions

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Space-based interferometric gravitational wave detectors such as LISA have been proposed to detect low-frequency gravitational wave sources such as the inspirals of compact objects into massive black holes or two massive black holes into each other. The optical components used to perform the high-precision interferometry required to make these measurements have historically been bonded to Zerodur optical benches, which are thermally ultrastable but difficult and time-consuming to manufacture. More modern implementations of LISA-like interferometry have reduced the length stability requirement on these benches from 30 fm/√Hz to a few pm/√Hz. We therefore propose to alter the design of the optical bench in such a way as to no longer require the use of Zerodur; instead, we plan to replace it with more easily-used materials such as titanium or molybdenum. In this presentation, we discuss the current status of and future plans for the construction and testing of such an optical bench.

Newtonian perturbation theory from the Schroedinger-Poisson equations

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Dark matter is a crucial ingredient of the standard cosmological model, making up over 80% of the total matter in the Universe. Although observational evidence strongly favours the existence of dark matter, we are yet to physically detect a particle, despite many attempts to do so. In order to model the dynamics of structure formation with dark matter one uses Newtonian physics, where we are able to understand much in the linear regime. While this is reliable for WIMPs, it is not necessarily the case for other candidates. In particular, for the axion, one might expect that this description as a classical, pressureless fluid is incomplete, since the axion is really a quantum field. In this talk I will describe work done here at UF on the first step towards the goal of describing structure formation with axions. Namely, I will show that the wavefunction approach reproduces the usual evolution equation for the density perturbation, albeit with an additional term dubbed the 'quantum pressure' term. I will close with a discussion of limitations of the approach, and plans for future work.

A New Cosmology Theory: An Integrated Theory of Everything

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The prevailing cosmology theory "The Ultimate Free Lunch" satisfies only the third of three laws of physics and should be replaced by a new cosmology theory which satisfies all three. The laws are: Conservation of Energy/Mass, Einstein's Theory of General Relativity (GR), and the Second Law of Thermodynamics. The solution requires amplifications of the following 5 existing theories.

1. String: Each of 129 fundamental matter/force particles resides in a Planck cube as a string; any object in the Super Universe (multiverse) can be defined by a volume of contiguous Planck cubes containing these fundamental strings; super force string doughnut singularities existed at the center of Planck cubes at the start of all universes.

2. Higgs: Each of 32 matter/force and their 32 anti-particles has an associated supersymmetric Higgs particle; matter particles and their associated Higgs forces are one and inseparable; spontaneous symmetry breaking is bidirectional; dark energy is the sum of 8 Higgs force energies associated with 8 permanent matter particles.

3. Super Universe: Our universe is nested in our precursor universe which is nested in the Super Universe.

4. Stellar black hole: Includes quark stars (matter) and black holes (energy); a quark star (matter) has mass, volume, near zero temperature, permanence, and maximum entropy; a black hole (energy) has super force energy, a Planck cube singularity with minimal volume, near infinite temperature, transientness, and minimal entropy; in our precursor universe, a quark star (matter) instantaneously evaporated, deflated, and collapsed to its associated black hole (energy) which created our universe's "big bang" (white hole); latter was Friedmann's second of 3 GR scenarios (big crunch); a symmetrical black hole/white hole satisfied both Conservation of Energy/Mass and Einstein's GR.

5. Arrow of time: Entropy increased in our precursor universe whereas entropy decreased in a subset volume where a quark star (matter) evaporated, deflated, and collapsed to a black hole (energy) and reset entropy to a minimum; entropy reset reconciled apparent contradiction between Einstein's symmetrical Theory of GR and Second Law of Thermodynamics.

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Extrinsic Curvature in Regge Calculus

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Regge calculus uses discrete geometry to model General Relativity, approximating smooth manifolds by joining simplicial blocks of flat space. Though the extrinsic curvature vanishes on each block, existing purely on the hinges between neighbouring blocks, a distributed curvature is required for many constructions. The integral of the curvature over a hinge has been well understood, but a particularly natural distribution of this integrated curvature is demonstrated here, with a new intuitive interpretation. This distributed curvature is constructed using the circumcentric dual lattices.

Conservative Transformation Group: Dark Matter Halos and Solar System Dynamics

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Previously a theory has been presented which extends the geometrical structure of a real four dimensional space-time via an enlarged transformation group. This new transformation group, called the conservation group, contains the group of diffeomorphisms as a proper subgroup and we hypothesize that it is the foundational group for quantum geometry. The fundamental geometric object of the new geometry is the curvature vector, C_\mu. Using the scalar Lagrangian density g^\mu\nu C_\mu C_\nu \sqrt{-g} , field equations for the free field have been obtained which are invariant under the conservation group. Spherically symmetric external, free-field models are developed. The theory implies that the external stress-energy tensor has non-compact support that may be interpreted as halos of dark matter. The resulting model is compared to the external Schwarzschild model. Results for the Pioneer anomaly and the corona heating problem are discussed.

Studying the Perturbed Einstein Equation

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The Regge, Wheeler, and Zerilli metric perturbation equation for the Schwarzschild space-time has been the basis of much progress in the study of black holes. For the Kerr space-time, a master perturbation equation was derived for the curvature perturbations. Using metric reconstruction one can obtain an expression for the perturbed metric from these curvature solutions. However, during this process, radiation gauge conditions are implicitly imposed. This leads to a discussion of gauge condition implications and possible limitations. Therefore, we are motivated to explore the possibilities of a metric perturbation equation for Kerr directly. Facilitated by use of GHP-NP/Tetrad formalism (which will be briefly reviewed) we plan to re-derive an analogous set of metric perturbation equations for Schwarzschild in an effort to gain insights into a Kerr derivation.

Dynamical cosmological sector in loop quantum gravity

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We introduce a set of diffeomorphism and gauge-covariant constraint functions on the gravitational phase space whose vanishing imposes homogeneity and isotropy, and which form a first class system. We furthermore define a quantization of these constraint functions on diffeomorphism invariant states in full loop quantum gravity. The kernel of the resulting operators then defines a diffeomorphism-invariant homogeneous isotropic sector of full loop quantum gravity - that is, a sector in which the Gauss constraint, the diffeomorphism constraint, and homogeneity and isotropy hold. The kinematical Hilbert space of loop quantum cosmology LQC also represents states in which these same conditions hold. A strategy for constructing an embedding of LQC states into this full theory sector, and using this embedding to compare dynamics in the full and reduced theories, is presented.

Effective potentials and morphological transitions for binary black-hole spin precession

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We derive an effective potential for binary black-hole (BBH) spin precession at second post- Newtonian order. This effective potential allows us to solve the orbit-averaged spin-precession equa- tions analytically for arbitrary mass ratios and spins. These solutions are quasiperiodic functions of time: after a fixed period the BBH spins return to their initial relative orientations and jointly precess about the total angular momentum by a fixed angle. Using these solutions, we classify BBH spin precession into three distinct morphologies between which BBHs can transition during their inspiral. We also derive a precession-averaged evolution equation for the total angular momentum that can be integrated on the radiation-reaction time and identify a new class of spin-orbit reso- nances that can tilt the direction of the total angular momentum during the inspiral. Our new results will help efforts to model and interpret gravitational waves from generic BBH mergers and predict the distributions of final spins and gravitational recoils.

Use of Symmetry Constraints to Embed FLRW Cosmology into Bianchi I

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I will present an application of the methods described by Chris Beetle and Matt Hogan to the embedding of FLRW cosmology into Bianchi I.

A post-TOV formalism for relativistic stars

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Despite being in agreement with observations and widely accepted, the strong field regime of the now centennial general relativity remains fairly unexplored. Motivations coming from cosmology and high-energy physics suggest that general relativity might not be final theory of the gravitational interaction. In this context, various modified gravity theories have been proposed. Compact objects, such as neutrons stars and black holes, are ideal laboratories to study gravity in the strong-field regime. Consequently, a large amount of work has been done studying these objects for each particular alternative theory. These works show a degeneracy between different theories, in the sense that, for a set of particular realistic equation of state, the mass-radius relation of neutron stars deviates from general relativity in a similar manner for different theories. Instead of committing ourselves to one particular theory, we propose a unified approach to study modifications on neutron star structure due to modified gravity theories, in the spirit of the parametrized post-Newtonian formalism.

UV-LED-based charge control for LISA

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UV-LED-based charge control for LISA

Taiwo Olatunde, Stephen Apple, Ryan Shelley, Andrew Chilton, Giacomo Ciani, Guido Mueller, John Conklin

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Test masses inside the LISA gravitational reference sensor (GRS) must maintain almost pure geodesic motion for gravitational waves to be successfully detected. The residual accelerations have to stay below 3 fm/s^2/rtHz at all frequencies between 0.1 and 3 mHz. One of the well-known noise sources is associated with the charges on the test masses which couple to stray electrical potentials and external electro-magnetic fields. The LISA Pathfinder (LPF) will use Hg-discharge lamps emitting mostly around 254 nm to discharge the test masses via photoemission in its 2015/16 flight. A future LISA mission launched around 2030 will likely replace the lamps with newer UV-LEDs. Their lower mass, better power efficiency and small size make them an ideal replacement for Hg lamps. Without contamination, which generally causes a reduction in the work function of Au, UV photons with energy below 5.1eV would not have sufficient energy to liberate electrons from pure Au. Presented here is a preliminary design for effective charge control through photoelectric effect by using latest generation UV-LEDs which produce light at 240 nm with work function above that of pure Au.

Cas A and friends: directed searches for continuous gravitational waves from isolated neutron stars

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We present the results of searches for continuous gravitational waves from the central compact object in supernova remnant Cassiopeia A and eight other young suspected neutron stars whose positions are known well enough to use a single barycentric correction per object. All objects have age estimates less than a few thousand years, young enough that r-modes could still be active. The searches coherently integrate from five to twenty-five days of the LIGO S6 data run and cover gravitational wave frequency bands of varying widths from 140 Hz to 2 kHz so that each requires a similar computational cost, which is about 1/3 that of the published LIGO search for Cassiopeia A due to the use of SSE2 floating point extensions. The objects are chosen so that each search can detect a neutron star in the band if its (unknown) spin-down has been dominated by gravitational-wave emission since birth.

Electrovacuum solutions to the Einstein-Maxwell system via the Ernst potentials

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I review briefly the methods proposed by Geroch and Ernst to generate solutions to the Einstein's field equations. This review outlines the main ideas of the projection formalism by Geroch, as a technique to produce one-parameter solutions to the source-free Einstein's field equations, given a solution (M,g_{ab}) and a Killing vector ξ^{a}. The main feature of this method, is that there exists a mapping from the 4-manifold M into a 3-manifold of trajectories of ξ^{a}. In the Ernst formalism, the problem of finding axially symmetric solutions to the source-free field equations is reformulated in terms of a complex scalar potential. By using this method in terms of prolate spheroidal coordinates, the Kerr spacetime can be derived. The generalization to the electrovacuum situation is also discussed. The coupled Einstein-Maxwell system is described in terms of two complex potentials ε and Φ. By using this formalism, I will show some examples of the technique to generate solutions. The derivation of the Reissner-Nordstr\"om metric (electrostatic solution) and the Kerr-Newmann solution (axially symmetric with electric charge) are discussed. I also show the procedure to produce the mapping from the Reissner-Nordstr\"om metric to the axially symmetric solution.

Simplicial Ricci flow and guided optimization for isometric embeddings of 2-surfaces in Euclidean 3-space

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Solutions to Einstein's equations can be sliced to produce a variety of 2-surfaces. Some notable 2-surfaces include the event horizon and ergosphere of rotating and non-rotating black holes. To visualize these surfaces, it is necessary to isometrically embed them in Euclidean 3-space. The isometric embedding of 2-surfaces is also pivotal for calculating the Brown-York and Wang-Yau quasi-local energies. I will present an algorithm that uses simplicial Ricci flow (SRF) and guided optimization to isometrically embed triangulated 2-surface in Euclidean 3-space. I will show examples of these embeddings that include non-axial symmetric surfaces with regions of negative Gaussian curvature. One example is the embedding of the ergosphere of a Kerr blackhole

How replacing points with edges addresses locality problems in a causal set

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Causal set is a theory of discrete spactime which consists of events (points) and their causal relations (two points are causally related if and only if you can go from earlier one to later one without going faster than the speed of light). Normally, in order to preserve Lawrentz covariance, it is assumed that causal set is generated by Poisson distribution. This, however, creates a problem: since the Lorentzian neighborhood fills in the vicinity of light cone, any given point will have infinitely many neighbors, most of which are arbitrary far away coordinate-wise. This is one of the open questions in causal set theory that has not been resolved.

Nevertheless, if we are to replace points with edges, the situation is slightly better. If we have an edge p<q, then the edge q<r is only considered a "neighborhood" of the edge p<q if the Lorentzian distance between p and r is below a certain upper bound. Geometrically, this means that we can't "tilt" the edge q<r with respect to the edge p<r too much, thus limiting the number of such edges.

However, in light of discreteness, things are not as simple. In particular, the way we define the Lorentzian distance between p and r is by the number of points of a longest possible chain p<s_1< ... < s_{n-1} < r. While it has been shown that there is a close correlation between the two numbers, there are very rare cases where such is not the case. In other words, it is possible to find r whose continuum distance to p is large, yet discretized one is small. And, as rare as that r is, the fact that there is an infinite poll of points, we will find infinitely many copies of such r, thus again obtaining non-locality.

The way I propose to address it is to put by hand the Lorentzian distance between points. Thus, contrary to how it is done in causal set theory, the distance will no longer be defined in terms of chains of points but, instead, it would be real valued two-point function put by hand. With this definition of a distance, coupled with focusing on links instead of points, we will, in fact, obtain locality.

Finally, we will re-define scalar field as a function of links rather than points, and then define Lagrangian density (again function of links) of such a scalar field.

Effective Source Methods for Second-Order Perturbations

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Accurate modeling of an extreme mass-ratio inspiral necessitates the development of second-order perturbative solution schemes, as the second-order self-force plays a substantial role in the dynamical evolution of the system. Solution techniques are being developed to mediate the increased difficulty of such calculations, including the non-linearities that arise at higher perturbative order; one such technique is an adaptation of the \textit{effective source} method, wherein an approximate local representation of the compact object's self-field is used to replace the object itself, yielding field equations that remain regular across the object's worldline.

Proper vertex asymptotics and its use in the graviton propagator

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The EPRL vertex amplitude provides a consistent formulation of dynamics of loop quantum gravity states. However, its semi-classical limit does not exactly match classical Regge calculus. We present a modification of the EPRL amplitude - the proper vertex amplitude - that has the correct semi-classical limit. We use the proper vertex amplitude to calculate graviton propagator and find that in semi-classical limit it agrees with the result from Lorentzian Regge calculus.

Geometry from probability: a possible origin of dark energy or the inflaton

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In this paper I propose a simple variational principle involving nonlinear differential operators, such as probability distributions on manifolds, that leads to a geometric interpretation of

the universal covering algebra of tensors and a generalization of general relativity. Using a subalgebra, the theory resembles Kaluza-Klein theory with the distinction that there are only four physical

dimensions and tensor multinomials are involved rather than tensors. The equivalent Ricci tensor of this geometry yields vacuum general relativity and electromagnetism, as well as a Klein-Gordon-like

quantum scalar field. With a generalization of the stress-energy tensor, an exact solution for a plane-symmetric dust can be found where the scalar portion of the field drives early universe inflation,

levels off for a period, then causes a later continued universal acceleration. That suggests that some version of this theory may be of utility in modeling the effects of the inflaton or dark energy.

Characterization of the Instrumental Background of Advanced LIGO's Gravitational Wave Burst Search

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In preparation for Advanced LIGO's first observing run (scheduled for Fall 2015), I am analyzing the instrumental background noise that limits the gravitational wave burst search, characterizing major populations of instrumental artifacts to diagnose their causes in order to develop vetoes that will reduce the background. Using results from the burst search performed on Livingston full interferometer data combined with a simulated second detector in December 2014, I have investigated the major sources of false alarms in the Livingston detector. Several of these instrumental problems have since been identified and mitigated, but others require further exploration or veto development. This work will lead us to a better understanding of the instrumental background and ways that it can be reduced, thereby increasing our sensitivity to gravitational waves.

Quantum Gravitational Corrections to Electromagnetism during Inflation

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First part is a brief review of inflation driven particle production mechanism. Then I discuss a recent work about using the result of the graviton contribution to the one loop vacuum polarization to solve the effective field equations for dynamical photons on de Sitter background. Our results show that the electric field experiences a secular enhancement proportional to the number of inflationary e-foldings. I will also discuss the minimum this establishes for primordial inflation to seed cosmic magnetic fields.

Parity in canonical loop quantum gravity

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In this presentation we extend the parity reversal operation from Newtonian Physics on flat space to general covariance theory on curved manifold. Then the parity symmetry of loop quantum gravity is examined and we conclude that the theory of LQG requires a background orientation.

The Centennial of Einstein's Three Crucial Tests

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This year marks the 100th anniversary of general relativity. In Einstein's papers of November 1915, he described three crucial tests of the theory, the bending of light, the gravitational redshift, and the perihelion advance of Mercury. We describe the history and current status of these tests.

Nonrelativistic Gravity in the Standard-Model Extension

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General Relativity has built-in local Lorentz symmetry and describes gravity phenomena at macroscopic scales. However, many symmetries in nature are broken at small scales, and some attempts to unify General Relativity with quantum theory suggest tiny violations of Lorentz symmetry could appear in nature. A framework for studying these effects is the general effective field theory describing possible Lorentz violation within existing physics, known as the gravitational Standard-Model Extension. This theory predicts many interesting potential corrections to existing physical results. The talk will focus on possible corrections to Newtonian gravity, including recent experimental developments.