APS April Meeting 2010
Washington, DC
http://www.aps.org/meetings/april/index.cfm
The holographic correspondence provides, among other things, a framework for studying certain strongly interacting field theories using a 'dual' classical theory of gravity in one higher dimension. The last couple of years has seen an explosion of interest in applying the techniques of this correspondence to strongly correlated electron systems in condensed matter physics. The hope of this research program is that specific behaviors of exotic electronic states that defy conventional treatment, can be usefully tackled via this holographic approach. In this talk I will briefly outline the holographic methodology and emphasize the ease with which finite temperature and finite density response functions may be computed from black hole physics. I will discuss the onset of superconductivity within this framework as well as the appearance of theoretically controlled 'non-Fermi' liquids. A short introduction to this material can be found at http://arXiv.org/abs/0909.3553 while a longer and slightly older discussion is http://arXiv.org/abs/0903.3246.

The authors acknowledge support from the Foundational Questions Institute (FQXi).
9:18AM A11.00005 Solutions to a Modified Newtonian Dynamics Force Law , RONALD MICKENS, Clark Atlanta University — We consider a specific relation for a modified Newtonian force law in one space dimension:
\[ m\ddot{a} = F(a) = \frac{m a^2}{(a_0 + |a|)} \]
where \( a = \frac{d^2x}{dt^2} \) and \( a_0 \) is a very small "cosmic" related acceleration. Exact solutions are calculated for zero, constant, and linear damping forces. However, the linear harmonic oscillator force situation could not be solved exactly and, as a consequence, an approximation to the periodic solutions was determined. To check the consistency of the calculations, we took the \( a_0 \rightarrow 0 \) limits and found that the prior known results were obtained for all four systems.


9:30AM A11.00006 Mitigation of Laser Frequency Noise in LISA Interferometry , JAMES IRA THORPE, NASA/GSFC — The Laser Interferometer Space Antenna (LISA) is a proposed detector of gravitational waves in the 0.1 mHz – 1 Hz band. LISA will measure gravitational wave strain at the \( 10^{-22} \) level by monitoring the distance between freely-falling test masses separated by baselines of \( 5 \times 10^9 \) m with a precision of roughly \( 10^{-14} \) m. These distance measurements will be made using heterodyne interferometry with multiple light sources on moving spacecraft with changing baselines, all of which cause frequency noise to couple into the displacement measurement. I will describe how LISA interferometry mitigates the effects of laser frequency noise through active suppression and common mode rejection. Recent laboratory developments will also be discussed.

9:42AM A11.00007 Laser Communications for LISA and the University of Florida LISA Interferometry Simulator , DYLAN SWEENEY, JUSTIN COHEN, SIMON BARKE, SHAWN MITRYK, VINZENZ WAND, GUIDO MUELLER — The LISA mission uses laser interferometry to measure fluctuations in the path length between the spacecraft caused by gravitational waves. For LISA to be successful the spacecraft must be able to communicate with each other in order to transfer clock signals, measure the range between the spacecraft, and to share recorded data. All of these functions will be accomplished using the laser links between the spacecraft. The University of Florida LISA Interferometry Simulator (UFLIS) is capable of simulating LISA interferometry with realistic delay times between the spacecraft by utilizing an electronic phase delay technique. We plan to upgrade the UFLIS to include the laser communication systems, and present the work towards this goal that has already been accomplished.

9:54AM A11.00008 Time-Delay Interferometry Simulations and Gravitational Wave Extraction at the University of Florida Interferometric Simulator1, SHAWN MITRYK, University of Florida, VINZENZ WAND, EADS Astrium, ALIX PRESTON, GUIDO MUELLER, DAVID TANNER, University of Florida — The Laser Interferometer Space Antenna (LISA) is a NASA/ESA space mission with the goal of measuring gravitational waves (GW) at frequencies of 30 uHz - 1 Hz. Going to space avoids seismic and gravity-gradient noise which limit all ground-based detectors. LISA will measure the spatial changes between drag-free proof masses separated by a distance of 5 Gm using heterodyne interferometry. The laser noise must be recorded and removed from the measurement through time-delay interferometry (TDI) to extract gravitational wave signals. The University of Florida LISA Interferometry Simulator (UFLIS) performs hardware-in-the-loop simulations of LISA by reproducing the expected pre-stabilized laser noise, delaying the laser frequency noise by the light-travel time along the LISA arms, injecting mock gravitational wave signals, and forming the required TDI combinations to extract the injected GW signals. Using the UFLIS, we present the extraction of mock GW signals buried under 9 orders of magnitude of laser frequency noise.

1Supported by NASA through grants BEFS 04-0019-0019 and 07 ATFP 07-0116.

10:06AM A11.00009 Arm locking experiments on UFLIS , YINAN YU, GUIDO MUELLER, University of Florida — The Laser Interferometer Space Antenna (LISA) will detect gravitational waves in the frequency region of \( 3 \times 10^{-5} \) Hz to 1 Hz by means of laser interferometry. At the University of Florida we developed the University of Florida LISA Interferometer Simulator (UFLIS) in order to study and verify laser frequency noise reduction and suppression techniques under realistic LISA-like conditions. These conditions include the Doppler shifts between the spacecraft, LISA-like signal travel times, and realistic laser frequency and timing noise. One of the proposed laser frequency stabilization techniques in LISA is arm locking, which synthesizes an adequately filtered linear combination of the LISA interferometer signals as a frequency reference. The arm locking experiments on UFLIS have already demonstrated the capability of single arm locking integrated with tunable cavity pre-stabilization as well as the presence of a Doppler knowledge error. In this presentation we will report about experiments on advanced arm locking schemes such as dual arm locking and modified dual arm locking. We will demonstrate the noise suppression performance of dual arm locking and the capability of modified dual arm locking sensor to alleviate the frequency pulling effect due to the Doppler error. Furthermore, the limits of different noise sources such as digitization noise and clock noise in our experiments will also be discussed. This work is supported by NASA grant 07-ATFP07-0116.

10:18AM A11.00010 Testbed for LISA photodetectors , FELIPE GUZMAN, JEFFREY LIVAS, ROBERT SILVERBERG, NASA Goddard Space Flight Center — The Laser Interferometer Space Antenna (LISA) is a gravitational wave observatory consisting of three spacecraft separated by 5 million km in an equilateral triangle whose center follows the Earth in orbit around the Sun but offset in orbital phase by 20 degrees. LISA is designed to observe sources in the frequency range of 0.1 mHz–100 mHz by measuring fluctuations of the inter-spacecraft separation with laser interferometry. Quadrant photodetectors are used to measure both separation and angular orientation. Noise level, phase and amplitude inhomogeneities of the semiconductor response, and channel cross-talk between quadrant cells need to be assessed in order to ensure the \( 10 \) \( \mu \)m/\( \sqrt{Hz} \) sensitivity required for the interferometric length measurement in LISA. To this end, we are currently developing a testbed that allows us to evaluate photodetectors to the sensitivity levels required for LISA. A detailed description of the testbed and preliminary results will be presented.

Saturday, February 13, 2010 8:30AM - 10:18AM –
Session A14 GGR: Gravitational Collapse and Numerical Relativity  Washington 4
8:30AM A14.00001 Gravitational Waves from Core-Collapse Supernova using CHIMERA: Models and Numerical Methods\textsuperscript{1}, PEDRO MARRONETTI, Florida Atlantic University, JOHN BLONDIN, North Carolina State University, AUSTIN CHERTKOW, University of Tennessee - Knoxville, CHARLOTTE DICK, Florida Atlantic University, WILLIAM R. HIX, Oak Ridge National Laboratory, ERIC LENTZ, University of Tennessee - Knoxville, O.E. BRONSON MESSER, ANTHONY MEZZACAPPA, Oak Ridge National Laboratory — CHIMERA is a multi-dimensional code composed of three tightly coupled physics modules: VH1 used to evolve stellar gas hydrodynamics, MGFLD-TRANS which handles the neutrino transport, and XNET that describes the thermonuclear reactions. These are complemented with a sophisticated equation of state for nuclear matter (Lattimer-Swesty) and a self-gravity solver capable of an approximation to general-relativistic gravity. We will present the latest simulations of core-collapse supernova for different-mass progenitors. These models are evolved for up to one thousand seconds in all cases, making them some of longest term simulations of their kind.

\textsuperscript{1}ORNL is managed by UT-Battelle, LLC, for the U.S. Department of Energy under contract DE-AC05-00OR22725.

8:42AM A14.00002 A new open-source spherically-symmetric general-relativistic hydrodynamics code for the study of stellar collapse and black hole formation, EVAN O’CONNOR, CHRISTIAN OTT, California Institute of Technology — We present a new open-source general-relativistic (GR) code based on the formulation of Romero-Ibanez and employing radial-gauge, polar-slicing coordinates in which the 3+1 equations simplify substantially. We discretize the GRHD equations with a finite-volume scheme, employing piecewise-parabolic reconstruction of state variables at cell interfaces and approximate Riemann solvers. The GRHD part of the code is coupled to various finite-temperature microphysical equations of state and an approximate deleptonization scheme for the collapse phase and a neutrino-leakage/heating scheme for the postbounce epoch are included and described. An array of test calculations is presented.

8:54AM A14.00003 Numerical experiments testing the Kerr Limit, Naked Singularities and Surface Gravity\textsuperscript{1}, PABLO LAGUNA, TANJA BODE, Georgia Tech, RICHARD MATZNER, University of Texas at Austin — We present results from numerical relativity simulations of accretion onto a black hole puncture. The simulations are aimed at investigating the possibility of violating the Kerr limit of rotating black holes. In particular, we focus our attention on the evolution of apparent horizons and the corresponding measure of mass, angular momentum and surface gravity. We address the challenges associated with identifying naked singularities in numerical simulations.

\textsuperscript{1}Work supported by NSF grants PHY-0914553, 0941417, 0855892.

9:06AM A14.00004 Variational Integrators for Numerical Relativity, WILL FARR, Northwestern University — I present a new method for numerical simulations of general relativistic systems that eliminates constraint violating modes without the need for constraint damping. The method is a type of variational integrator. It is based on a discretization of an action for gravity (the Plebański action) on an unstructured mesh that preserves the local Lorentz transformation and diffeomorphism symmetries of the continuous action. Applying Hamilton’s principle of stationary action gives discrete field equations on the mesh. For each gauge degree of freedom there is a corresponding discrete constraint; the remaining discrete evolution equations exactly preserve these constraints under time-evolution. I validate the method using simulations of several analytically soluble spacetimes: a weak gravitational wave spacetime, the Schwarzschild spacetime, and the Kerr spacetime.

9:18AM A14.00005 Error Reduction in Numerical Relativity Calculations Using Local Coordinates, WILLIAM DARIAN BOGGS, University of Maryland, College Park, JOHN G. BAKER, JAMES R. VAN METER, JOAN CENTRELLA, NASA GSFC, NASA GODDARD NUMERICAL RELATIVITY TEAM — In simulations of binary black hole systems, errors in the local calculations are determined in part by the coordinate system in which they are performed. Calculating the field quantities in coordinate systems matched to the local dynamics of each portion of the simulation grid promises to reduce this local error. I will talk about my implementation of this technique in our numerical relativity code, HAHNDOL, and its potential to improve the accuracy and efficiency of our simulations and allow us to perform more ambitious simulations.

9:30AM A14.00006 Studying competitive critical behavior in problems of gravitational collapse, using numerical relativity, THEODOR BRASOVEANU, Princeton University — Einstein equations, with or without coupling to matter, admit special strong-field, non-trivially dynamic solutions which sit at the threshold of black hole formation. These solutions, initially discovered by M. Choptuik, are minimally unstable and can be obtained by studying parametrized families of initial data, where the family parameter can be tuned to control the amount of non-linearity in the generated spacetime. Following the recent introduction of “competitive critical behavior” by the same author, we study the interaction between two different matter models in spherical symmetry that exhibit the same type of threshold solution. Specifically, we look at a boson star vs. an SU(2)2(2) Mills-perturbing field, to investigate if competitive critical behavior occurs and find out whichever solution becomes unstable in the presence of the other. We use finite-difference approximations of PDEs to solve Einstein equations coupled to matter, find the (type I) threshold of black hole formation for each individual matter system and study the relative stability of the two critical solutions.

9:42AM A14.00007 Petrov Classification in Numerical Relativity, ROBERT OWEN, Cornell University — The algebraic classification system of Petrov, Pirani, and Penrose provides a method to unambiguously characterize the gravitational degrees of freedom point-by-point throughout a spacetime. It is tempting to apply this system to the numerically-generated spacetimes that have recently proliferated, and some work has already gone in this direction. However, the array of current physical interest — such as binary black hole mergers — raise subtleties in that they are generically, strictly speaking, Type I, but approximately, in some sense, Type D. To make any such claims about “approximate Petrov class” meaningful, one must introduce a ‘degeneracy measure’ on the space of null rays. In this talk, I will describe some of the difficulties in this undertaking, and present results applying such degeneracy measures to binary black hole simulations from the Caltech/Cornell/CITA group.

9:54AM A14.00008 Late time Kerr tails, GAURAV KHANNA, University of Massachusetts Dartmouth, LIOR M. BURKO, University of Alabama in Huntsville — We revisit the question of the decay rate of the late time tails of Kerr black holes. We focus on three interrelated phenomena: (a) Excited “up” modes (i.e., the decay rate of modes of a higher multipole moment than the initial mode), (b) the apparent breakdown of linear superposition, and (c) the differences in the evolutions of pure mode initial data sets and those of generic initial data sets. Specifically, letting $\ell$ be the multipole moment of the initial data, and $\ell'$ being the moment of an excited mode (so that $\ell' > \ell$), we find for the case of scalar field perturbations that the late time decay rate behaves like $t^{-n}$, where $n = \ell + \ell' + 3$. This result has been verified numerically for $\ell' - \ell = 2, 4$. Pure- and generic–mode evolutions are found to be different because the former involve non-generic, specially fine-tuned evolutions.
10:06AM A14.00009 Exact Solutions to Einstein’s Field Equations for Static Spherically Symmetric Perfect Fluids, THOMAS KIESS, self — In classical general relativity, exact solutions to Einstein’s Field Equations are useful, but for static spherically symmetric perfect fluids, only a handful of their exact closed form metrics satisfy the physical boundary conditions. We derive exact solutions to Einstein’s Field Equations for a static spherically symmetric perfect fluid (in 3+1 dimensions), including a physical solution. This physical metric can be cast as the line element \( ds^2 = -c^2 \left( 1 - \frac{x^2}{7} (1 + x^3)^{2/3} - \frac{\beta}{192c^2} (11 + 2x - x^2) \right)^2 dt^2 + \frac{(1+x^3)}{(1-x^7)} dr^2 + r^2 d\Omega^2 \), where \( c \) is the speed of light, \( c_1 \) is a constant, and \( x = c_1 r^2 \), for \( c_1 \) > 0 and \( \beta \) satisfying \(-0.0616 < \frac{\beta}{192c^2} < 1\). This physical solution used as a stellar model provides relatively large redshifts \( z \) – as large as 0.87 at the stellar surface, and as large as 4.05 in the interior. Modeling large redshift objects is of interest because their populations constrain cosmological models of dark energy. Another exact solution we derive is an unphysical one for zero mass, which can be cast as the line element \( ds^2 = \left[ a + br^2 \right] c^2 dt^2 + dr^2 + r^2 d\Omega^2 \) for constants \( a \) and \( b \). Although values of \( b \neq 0 \) are unphysical, this metric is potentially interesting because it provides another classical way (apart from the introduction of a cosmological constant) to generate finite pressure everywhere in space, in a system of zero net mass.

Saturday, February 13, 2010 10:45AM - 12:21PM – Session B13 DAP GGR: Observational Implications of Gravitational Waves

10:45AM B13.00001 Detecting Gravitational Waves with Pulsar Timing Arrays, LARRY PRICE, XAVIER SIEMENS, JOLIEN CREIGHTON, PENG YU, University of Wisconsin – Milwaukee — Long-term high-precision astronomical timing observations of a network of pulsars, a pulsar timing array, open a portal over local frequency gravitational waves. In this talk I’ll discuss progress on efforts to detect both a stochastic background of gravitational radiation and gravitational waves from un-modeled bursts of gravitational waves using a pulsar timing array. I’ll also address prospects for stochastic backgrounds of gravitational waves from cosmological sources in the pulsar timing band.

10:57AM B13.00002 First search for gravitational waves from the youngest known neutron star, BENJAMIN OWEN, Penn State, LIGO SCIENTIFIC COLLABORATION — We present preliminary results of a search for continuous gravitational waves from the central compact object in supernova remnant Cassiopeia A. The object is the youngest suspected neutron star in the Galaxy. Its position and binarity can be determined with high precision using LISA at high frequencies (\( \log f \) > 2) due to the presence of gravitational waves. This system is one of the closest, oldest, and most massive compact binaries in the Milky Way. We present results from the searches for gravitational waves from the coalescence of binary systems of neutron stars and black holes in LIGO and Virgo data. These searches are done with a variety of methods, all using optimal filtering of waveform templates. We present results on data from the Fifth Science Run LIGO run S5 from November 2005 to October 2007, which was joint with Virgo’s first science run VIRGO run VIRGO from May to October 2007. We also show how these methods are being applied in the current LIGO S6/Virgo VIRGO data-taking run started in July 2009.

11:09AM B13.00003 Gravitational Waves and SGR Bursts, LEO SINGER, California Institute of Technology, LIGO SCIENTIFIC COLLABORATION, VIRGO COLLABORATION — Soft gamma repeaters (SGRs) are nearby, they burst repeatedly and sometimes spectacularly, and their burst emission mechanism may involve neutron star crust fractures and excitation of non-radial modes which could emit gravitational waves (GW). We present recent searches for GW associated with SGR bursts, including a new individual burst search of SGR events which occurred between 2006 November and 2009 June. The search examines burst events from six magnetar sources, including one (SGR 0501+4516) which is likely less than 1 kpc from Earth, and uses data from five GW detectors. Due to the proximity of SGR 0501+4516 we are able to probe GW energies more than an order of magnitude lower than previous SGR GW searches. We present results from SGR GW searches and discuss the emerging astrophysical context.

11:21AM B13.00004 Searches for coalescence of binary systems in LIGO and Virgo data, GABRIELA GONZALEZ, Louisiana State University, LIGO SCIENTIFIC COLLABORATION AND THE VIRGO COLLABORATION — We present the latest results from the searches for gravitational waves from the coalescence of binary systems of neutron stars and black holes in LIGO and Virgo data. These searches are done with a variety of methods, all using optimal filtering of waveform templates. We present results on data from the Fifth Science Run LIGO run S5 from November 2005 to October 2007, which was joint with Virgo’s first science run VIRGO run VIRGO from May to October 2007. We also show how these methods are being applied in the current LIGO S6/Virgo VIRGO data-taking run started in July 2009.

11:33AM B13.00005 Distinguishing Compact White-dwarf Binary Systems - An application of GW color magnitude diagram for LISA, RAVI KUMAR KOPPARAPU, Pennsylvania State University — The population of Double white dwarf (DWD) and neutron star-white dwarf (NSWD) binaries in our Galaxy are considered to be a few of the most promising gravitational-wave (GW) sources for LISA. Electromagnetic observations have already discovered several of these white-dwarf binary systems in various phases of their evolution, in LISA’s band of detection. Here we illustrate a GW equivalent of a color-magnitude diagram (CMD), assuming non-zero temperature white-dwarf donors, and propose boundaries for both inspiralling and mass-transferring systems in the CMD. Depending upon the precision with which LISA can measure the frequency evolution \( f \) of a white-dwarf binary system we show that one can distinguish between a DWD and a NSWD system, and possibly the composition of the donor white dwarf, using CMD. We assess the limits and applicability of our theoretical boundaries with respect to observations and find that a measurement of \( f \) by LISA at high frequencies (\( \log f \) > 2) would likely distinguish between DWD/NSWD binary. For low-frequency sources, GW observations alone would unlikely tell us about the binary components, without the help of electromagnetic observations.

11:45AM B13.00006 ABSTRACT WITHDRAWN –

11:57AM B13.00007 Extracting accretion disk radii from LISA observations of accreting binary star systems, SHANE LARSON, Utah State University — LISA will be sensitive to a wide range of ultra-compact binary star systems in the Milky Way. A handful of these binaries will be verification binaries – systems which can be seen electromagnetically, and individually resolved and characterized in the LISA data stream. This multi-messenger characterization of these systems provides a useful synergy of observing capabilities that can be exploited to recover detailed information about the underlying astrophysical processes in the binary. This poster discusses how simultaneous photon and EM observations can be used to study mass transferring system and characterize parameters such as the mass transfer rate and radius of accretion disks around the primary.
orbital evolution, and compare with the counterpart evolution obtained by monitoring fluxes and updating the orbit based on global conservation laws. We also use previous results for the self force to drive the instability near the black hole's event horizon that comes about because of the inadequacy of Boyer–Lindquist coordinates, and (b) uncontrolled growth of effects due to the finite but small size of the body. Also, by including all particle-field interactions consistent with the symmetries of the theory we use the EFT approach to study non-linear effects in the ringdown of Schwarzschild black holes due to mode-mode coupling and the dependence of these effects on the type and shape of initial perturbation. Finally we will compare results with numerical simulations of colliding binary black holes in their late stage (ringdown) phase.

We use the effective field theory (EFT) approach to perturbatively calculate the self-forced motion of the body and the wave generation through second order in the expansion parameter. Also, by including all particle-field interactions consistent with the symmetries of the theory we use the EFT approach to study the impact and role of higher order self-force corrections on physically relevant quantities in extreme mass ratio inspirals. As an example, we exploit the analogy between gravitation and electromagnetism to gain some insight into the origin and nature of "bobbing motion" and momentum "kicks" that occur in the merger of black hole binaries with spin. Specifically, we consider two charged magnetic dipoles in slow-motion approximation, and examine the role that field momentum plays in their motion. As expected, there is significant exchange of momentum between field and bodies during bobbing. However, the bodies store this momentum as "hidden mechanical momentum" rather than center-of-mass velocity. In fact, the center-of-mass bobbing is entirely caused by a "purely kinematical" spin-acceleration effect that has nothing to do with electromagnetism (or gravity). A spinning binary will bob regardless of the source of acceleration, whereas the presence of a kick requires a release of field momentum. We conclude that the kick is not an inertial continuation of the bobbing.

Gravitational self-force for a particle in circular orbit around the Schwarzschild black hole , ABHAY SHAH, UNIVERSITY OF WISCONSIN-MILWAUKEE, LARRY PRICE, University of Wisconsin-Milwaukee — This talk reports recent progress on computing the self-force in a radiation gauge. The Weyl scalars determine the perturbed metric only up to a type D perturbation, and Carter's theorem is not sufficient to rule out a local perturbed Kerr-NUT or C-metric contribution to the singular field. Nevertheless, we show that only infinitesimal changes in mass and angular momentum arise and present alternative methods for obtaining the renormalized field for these contributions in a Schwarzschild and Kerr background. We present a corrected computation of the conservative part of the self-force in a radiation gauge for a particle circling a Schwarzschild black hole. The Weyl scalar and its derivatives are renormalized by subtracting the singular field to leading and sub-leading order from the retarded solution to the Bardeen-Press (Teukolsky) equation. Higher powers of \( l \) are subtracted by matching the retarded field with a series in \( l \) at high \( l \). From the renormalized Weyl scalar (and its derivatives), one computes the renormalized Hertz potential (and its derivatives) by an algebraic inversion. From the renormalized Hertz potential and a renormalization of the \( l=0 \) and \( l=1 \) parts of the metric, we obtain the self-force.

Higher order self-force effects , CHAD GALLEY, University of Maryland — We present recent progress towards understanding the impact and role of higher order self-force corrections on physically relevant quantities in extreme mass ratio inspirals. As an example, we study the motion of a scalar charge interacting with a nonlinear scalar field (that is motivated from general relativity) in a background black hole spacetime. We use the effective field theory (EFT) approach to perturbatively calculate the self-forced motion of the body and the wave generation through second order in the expansion parameter. Also, by including all particle-field interactions consistent with the symmetries of the theory we use the EFT approach to study the effects due to the finite but small size of the body.

Gravitational Self-force in a Radiation Gauge: Circular Orbits in the Schwarzschild Spacetime , TOBIAS KEIDL, University of Wisconsin–Washington, JOHN FRIEDMAN, LARRY PRICE, ABHAY SHAH, University of Wisconsin–Milwaukee — In this talk, I discuss current progress in computing the self-force of a perturbation caused by a particle in circular orbit in Schwarzschild. This talk will focus on the developing the formalism necessary. Using only a single Weyl component of the perturbation, we generate a Hertz potential and use this to calculate the perturbed metric and self-force. The Weyl scalar and its derivatives are renormalized by subtracting the singular field to leading and sub-leading order from the retarded solution to the Bardeen-Press (Teukolsky) equation. Higher powers of \( l \) are subtracted by matching the retarded field with a series in \( l \) at high \( l \). From the renormalized Weyl scalar (and its derivatives), one computes the renormalized Hertz potential (and its derivatives) by an algebraic inversion. From the renormalized Hertz potential and a renormalization of the \( l=0 \) and \( l=1 \) parts of the metric, we obtain the self-force.

Time-domain 2+1D Lorenz gauge self force and orbital evolution for EMRI’s progress report , KRISTEN A. LACKEOS, University of Alabama in Huntsville, LEGR BARACK, University of Southampton, GAURAV KHANNA, University of Massachusetts Dartmouth, LIOR M. BURKHO, University of Alabama in Huntsville — We report on progress made in the calculation of the self force taking the approach of time-domain evolutions in 2+1D in the Lorenz gauge. We encounter several kinds of numerical instabilities: (a) dynamical instability near the black hole’s event horizon that comes about because of the inadequacy of Boyer–Lindquist coordinates, and (b) uncontrolled growth of Lorenz gauge violating modes. We address type (a) instabilities with a transformation to a different coordinate system that cures the dynamical problem, and type (b) instability by the introduction of Lorenz gauge damping terms in the evolution equations. We also use previous results for the self force to drive the orbital evolution, and compare with the counterpart evolution obtained by monitoring fluxes and updating the orbit based on global conservation laws.
understanding of gas dynamics near black holes, and what we've learned about the fundamental nature of Sgr A* already.

When combined with existing observations at other wavelengths, it is possible to place extraordinary constraints upon the existence of a horizon in Sgr A*, subject only to the assumption that gravity is a metric theory admitting stationary solutions. I will describe what we expect to see, how this will inform our understanding conditions under which coinciding EM and GW signatures are expected to arise and outflow processes at the edge of a black hole, the existence of event horizons, and fundamental black hole physics (e.g., spin). Steady long-term progress in improving the capability of Very Long Baseline Interferometry (VLBI) at short wavelengths has now made it extremely likely that this goal will be achieved within the next decade. The most compelling evidence for this is the recent observation, using 1.3mm wavelength VLBI, of Schwarzschild radius scale structure in SgrA*, the compact source of radio, submm, NIR and xrays at the center of the Milky Way. There is now very strong evidence that SgrA* marks the position of a ∼ 4 million solar mass black hole, which, due to its proximity and estimated mass, presents us with the largest apparent event horizon size of any black hole candidate in the Universe. By extending the observing wavelength of VLBI to the sub-mm bands, we will achieve angular resolution sufficient to detect strong field GR effects on the appearance of the plasma surrounding the black hole. Short wavelength VLBI can also be used to directly detect signatures of matter spiraling into the black hole with the potential to estimate the periods of orbits close to the event horizon. I will discuss what current VLBI observations of SgrA* tell us about this closest super–massive black hole, describe the exciting potential of future work, and outline plans to assemble a Global submm-VLBI “Event Horizon Telescope”.

This was supported by grants from NASA and the NSF.

Recent, mm-VLBI observations capable of resolving sub-horizon structure in the emission from Sgr A*, the supermassive black hole at the center of the Milky Way, have become possible. These promise to open a new window upon the physics of black hole accretion, jet formation and gravity itself. Already, when combined with existing observations at other wavelengths, it is possible to place extraordinary constraints upon the existence of a horizon in Sgr A*, subject only to the assumption that gravity is a metric theory admitting stationary solutions. I will describe what we expect to see, how this will inform our understanding of gas dynamics near black holes, and what we’ve learned about the fundamental nature Sgr A* already.

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2:42PM D4.00003 Nature of the black hole in the center of the Milky Way, AVERY BRODERICK, CITA — Recently, mm-VLBI observations capable of resolving sub-horizon structure in the emission from Sgr A*, the supermassive black hole at the center of the Milky Way, have become possible. These promise to open a new window upon the physics of black hole accretion, jet formation and gravity itself. Already, when combined with existing observations at other wavelengths, it is possible to place extraordinary constraints upon the existence of a horizon in Sgr A*, subject only to the assumption that gravity is a metric theory admitting stationary solutions. I will describe what we expect to see, how this will inform our understanding of gas dynamics near black holes, and what we’ve learned about the fundamental nature Sgr A* already.

2:42PM D4.00003 Nature of the black hole in the center of the Milky Way, AVERY BRODERICK, CITA — Recently, mm-VLBI observations capable of resolving sub-horizon structure in the emission from Sgr A*, the supermassive black hole at the center of the Milky Way, have become possible. These promise to open a new window upon the physics of black hole accretion, jet formation and gravity itself. Already, when combined with existing observations at other wavelengths, it is possible to place extraordinary constraints upon the existence of a horizon in Sgr A*, subject only to the assumption that gravity is a metric theory admitting stationary solutions. I will describe what we expect to see, how this will inform our understanding of gas dynamics near black holes, and what we’ve learned about the fundamental nature Sgr A* already.

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1Short Wavelength VLBI work at MIT Haystack Observatory is funded through grants from the National Science Foundation.

1This work was supported by grants from NASA and the NSF.

12:21PM D14.00009 Harmonic (Lorenz) Gauge Perturbations of the Schwarzschild Metric, MARK BERNDTSON, University of Colorado-Boulder — The satellite observatory LISA will be capable of detecting gravitational waves from extreme mass ratio inspirals (EMRIs), such as a small black hole orbiting a supermassive black hole. The gravitational effects of the much smaller mass can be treated as the perturbation of a known background metric, here the Schwarzschild metric. The perturbed Einstein field equations form a system of ten coupled partial differential equations. We solve the equations in the harmonic gauge, usually called the Lorenz gauge or Lorentz gauge. Using separation of variables and Fourier transforms, we write the solutions in terms of six radial functions which satisfy decoupled ordinary differential equations. The six functions are the Zerilli and five generalized Regge-Wheeler functions of spin s = 2, 1 or 0. We then use the solutions to calculate the gravitational self-force for circular orbits. The self-force gives the first order perturbative corrections to the equations of motion. This talk is based mainly on unpublished thesis work, which is online at arxiv.org (gr-qc 0904.0033).

Saturday, February 13, 2010 1:30PM - 3:18PM – Session D4 GGR: Probing Strong-Field Gravity with Observations of the Galactic Center Black Hole

1:30PM D4.00001 Probing strong-field gravity at the galactic center using stellar motions1, DAVID MERRITT, Rochester Institute of Technology — The center of our galaxy contains the nearest supermassive black hole, with a mass four million times that of the Sun. The black hole’s location and mass have been accurately determined by tracing the motions of a handful of bright young stars that move in tight orbits about the Galactic center, some with periods as short as 15 years. Until now, the measured orbits have been found to be consistent with Keplerian ellipses about a Newtonian point mass. But the stellar orbits potentially contain much more information: about the distributed mass in the inner parsec (consisting of faint stars, dark stellar remnants, and possibly particle dark matter); and also about the non-Newtonian contributions to the gravitational potential from the supermassive black hole. For stars nearer than about one milli-parsec from the singularity, frame-dragging torques should induce precession of orbital planes at a rate that is potentially observable after a few years’ monitoring using the next generation of optical astrometric instruments, allowing a direct determination of the black hole’s spin. Even more challenging would be a test of ‘no hair’ theorems by comparing the frame dragging precession with that induced by the black hole’s quadrupole moment. Results of detailed numerical simulations of the nuclear star cluster that include relativistic terms will be presented, which demonstrate the feasibility of testing theories of gravity using stellar orbits, given the inevitable noise from star-star perturbations and perturbations due to the unseen stellar remnants.

This work was supported by grants from NASA and the NSF.

1:30PM D14.00001 Simulations of Binary Black Hole Mergers in Gaseous Environments, BRIAN FARRIS, YUK TUNG LIU, STUART SHAPIRO, University of Illinois Urbana-Champaign — Massive black hole mergers in the presence of gaseous accretion flows are prime candidates for simultaneous observations of both gravitational waves and electromagnetic signals. We study such systems using our fully general relativistic hydrodynamical study of the late inspiral and merger of equal-mass SMBHs with spin a/Mb ≤ 0.6 in a gas cloud.

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1:54PM D14.00003 Binary black hole initial data with tidal deformations and outgoing radiation
NATHAN JOHNSON-MCDANIEL, Penn State, NICOLAS YUNES, Princeton, WOLFGANG TICHY, FAU, BENJAMIN OWEN, Penn State — We present initial data for the quasicircular inspiral of a nonspinning black hole binary, including tidal deformations and outgoing radiation. We construct these data by asymptotically matching two perturbed Schwarzschild metrics to a post-Newtonian (PN) metric. We carry out this matching through \( O(\epsilon^4) \) (\( \epsilon \) is the binary’s orbital velocity) so the data are conformally curved. The PN metric includes both near and radiation zone contributions and uses the 3.5PN results for the binary’s past history. Asymptotic matching produces piecewise continuous global data; we smooth the joins using transition functions. The inclusion of tidal deformations and outgoing radiation might ameliorate the initial burst of spurious radiation observed with conformally flat data. Such an improvement might be essential for simulations to provide sufficiently accurate templates for parameter estimation with advanced gravitational wave detectors.

2:06PM D14.00004 Numerical simulations of binary black holes with nearly extremal spins
GEOFFREY LOVELLACE, Cornell University — There is a significant possibility that astrophysically realistic black holes may have nearly extremal spins (i.e., spins close to 1 in dimensionless units). The prospect of observing the gravitational waves from a binary-black-hole merger with nearly extremal spins motivates the goal of simulating these systems numerically. These simulations must begin with initial data that satisfy the Einstein constraint equations; however, the commonly used methods of generating constraint-satisfying initial data cannot yield data with nearly extremal spins. In this talk, I will describe evolutions of conformally curved binary-black-hole initial data with nearly extremal spins using the Caltech-Cornell-CITA Spectral Einstein Code (SpEC).

2:18PM D14.00005 Extracting physics from numerical spacetimes with constant-expansion surfaces
ELOISA BENTIVEGNA, ERIK SCHNETTER, Louisiana State University, BADRI KRISHNAN, Albert Einstein Institute — Extracting unambiguous physical information from a spacetime has long been one of the central issues in General Relativity. Defining unique expressions that are generally covariant and have recognizable physical properties (e.g., obey conservation laws when the appropriate symmetries apply) has proven to be impossible without the introduction of further structure, such as coordinate conditions at null infinity or restrictions on the 2-surfaces to be used for gravitational wave extraction. Inspired by the successes of the Isolated and Dynamical Horizon framework, along with its practical effectiveness in numerical contexts, we discuss the use of general constant-expansion surfaces in the resolution of the ambiguities, and illustrate the results in a few cases of physical interest.

2:30PM D14.00006 Comparing binary black hole evolutions using finite difference and spectral methods
ENRIQUE PAZOS, University of Maryland, LARRY KIDDER, Cornell University, ABDUL MROUE, Canadian Institute for Theoretical Astrophysics, MANUEL TIGLIO, University of Maryland — We compare waveforms for binary black hole simulations using finite difference with adaptive mesh refinement and spectral methods with multiple domains. In both cases we use the exact same initial data, extracting waves at a fixed location and extrapolating them to infinity.

2:42PM D14.00007 Binary Black Hole Mergers in SpEC
BELA SZILAGYI, Caltech — The Caltech-Cornell spectral Einstein Code (SpEC) is now able to robustly and accurately evolve binary black hole systems through the inspiral, merger and ringdown phases. This is attributed to new gauge conditions as well as a robustly stable numerical algorithm. The talk will highlight the key new elements of our algorithm.

2:54PM D14.00008 Modelling multiple modes of spinning merger waveforms
BERNARD KELLY, JOHN BAKER, WILLIAM D. BOGGS, JAMES VAN METER, NASA Goddard Space Flight Center — The Implicit Rotating Source (IRS) ansatz provides a coherent model of the dominant modes of gravitational radiation from a merging black-hole binary. Building on work with unequal-mass nonspinning binaries [Baker et al. Phys. Rev. D vol. 78, 044046 (2008)], we have applied the IRS to mergers of aligned and anti-aligned spinning binaries to form useful multi-mode waveform templates. We also discuss issues of parameter selection and spin and mass measurement with the Goddard Hahndol code.

Sunday, February 14, 2010 8:30AM - 10:18AM
Session G4 GGR DCOMP: Numerical Relativity and Astrophysics
Thurgood Marshall North

8:30AM G4.00001 Statistical studies of Spinning Black-Hole Binaries
CARLOS LOUSTO, Rochester Institute of Technology-CRCG — We study the statistical distribution of the spins of generic black-hole binaries during the inspiral and merger, as well as the distribution of the remnant mass, spin, and recoil velocity. For the inspiral regime, we start with a random uniform distribution of spin directions \( S_1 \) and \( S_2 \) over the sphere and magnitudes \( |S_i/m|^2 = 0.97 \) for different mass ratios. Starting from a fiducial initial separation of \( r_i = 50m \), we perform 3.5 post-Newtonian evolutions down to a separation of \( r_f = 5m \), where \( m = m_1 + m_2 \). At this final separation, we compute the angular distribution of the spins with respect to the final orbital angular momentum. We perform \( 10^4 \) simulations for mass ratios between \( q = 1 \) and \( q = 1/16 \) and compute the distribution of the angles \( \Delta \cdot \tilde{L} \) and \( \Delta \cdot \tilde{S} \), directly related to recoil velocities. We find a small but statistically significant bias of the distribution towards counter-alignment of both scalar products. To study the merger of black-hole binaries, we introduce empirical formulae to describe the final remnant black-hole mass, spin, and recoil velocity for merging black-hole binaries with arbitrary mass ratios and spins. Our formulae are based on the post-Newtonian scaling with amplitude parameters chosen to fit recently available fully nonlinear numerical simulations. We then evaluate these formulae for randomly chosen directions of the individual spins and magnitudes, and the binary’s mass ratio. We found that the magnitude of the recoil velocity has a decaying e-folding distribution with a mean value of \( 2500 \text{ km/s} \) and a highly peaked angular distribution along the final orbital axis. The distribution of the final black-hole spin magnitude show an universal distribution highly peaked at \( S_f/m_r^2 = 0.73 \) and with a nearly 25\(^\circ\) degree misalignment with respect to the final orbital angular momentum, just prior to full merger of the holes.

9:06AM G4.00002 What happens when black holes and neutron stars merge?
MATTHEW DUEZ, Cornell University — Neutron star-neutron star mergers and black hole-neutron star (BHNS) mergers are fascinating and violent events which combine strongly curved spacetimes, relativistic speeds, and super-density-mass states. They are also promising sources of gravitational waves and potential causes of short-duration gamma-ray bursts. The gravitational waveform and the characteristics of the post-merger accretion disk are strongly affected by the the mass ratio, the neutron star equation of state, and (for BHNS binaries) the pre-merger black hole spin. In the past few years, numerical simulations in full general relativity have made significant progress both in incorporating more realistic NS microphysics and in sampling the astrophysically relevant binary parameter space. In this talk, I review this progress, focusing particularly on studies of BHNS binaries that look at the effects of black hole spin and nuclear equation of state on the gravitational wave signal and the post-merger disk.
9:42AM G4.00003 Seeing Spacetime by Proxy: Binary Black Holes in Gaseous Environments
SCOTT C. NOBLE, Rochester Institute of Technology — Even though binary black hole (BBH) systems are expected to come in a wide range of masses, only the mergers of supermassive black holes—at the centers of galaxies—are expected to live in gas-rich environments. The presence of matter opens up the possibility that gravitational aspects of the binary’s interaction can be transmitted—to distant observers—electromagnetically via dissipation of gas motion. Matching theoretical predictions to observations of systems before and after merger has the potential to improve our estimates of merger rates, and tell us about the spin and mass distribution of supermassive black holes. Seeing the light from the precise moment of merger—if such a robust signature exists—presents us with additional information such as more evidence that black holes merge, how material behaves in the strong-field dynamical regime of gravity, and a new and independent class of redshift-distance measurements if found with accompanying gravitational radiation (as with LISA). All of these exciting possibilities require realistic predictions for how gas—which will likely be magnetized—responds to a BBH evolution. In this talk, we will provide a brief survey of past and current work on theoretical models of BBH systems with gas. The consequences of recent numerical relativity simulations on these electromagnetic signature models will be emphasized. Knowledge gleaned from simulations of single black hole accretion disks will be presented to explain the likely importance of initial conditions on the circumbinary disk. We will also describe our efforts towards accurately simulating magnetized BBH disks just prior to merger, and a disk’s response to the binary’s coalescence and recoil of the nascent black hole.

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8:30AM G14.00001 Use and Abuse of the Model Waveform Accuracy Standards
LEE LINDBLOM, California Institute of Technology — Accuracy standards have been developed to ensure that the waveforms used for gravitational-wave data analysis are good enough to serve their intended purposes. These standards place constraints on certain norms of the frequency-domain representations of the waveform errors. Examples will be presented of possible misinterpretations and misapplications of these standards, whose effect could be to vitiate the quality control they were intended to enforce. Suggestions will be given for ways to avoid these problems.

8:42AM G14.00002 Fundamental bias and the Parameterized Post-Einsteinian Framework
NICOLAS YUNES, FRANS PRETORIUS, Princeton University — With the imminent detection of gravitational waves, we must ask ourselves: how much do we trust general relativity? Experimental tests have confirmed the validity of general relativity in the weak-field, but no such tests exist in the strong, dynamical regime. Because of their inherent weakness, the extraction of gravitational waves relies on matched filtering, where templates are used to filter data. Currently, such templates are constructed assuming general relativity is correct and this assumption constitutes a fundamental bias, which could introduce a systematic error in the detection and parameter estimation of signals. In this talk, I define this bias, explain its possible consequences and propose a remedy: the parameterized post-Einsteinian framework. This framework enhances waveforms via the inclusion of post-Einsteinian parameters that allow for well-motivated deviations from general relativity. Matched filtering with these waveforms allows the data to select the theory that describes gravitational wave emission and propagation, without a priori assuming the validity of general relativity.

3We acknowledge support from NSF grant PHY-0745779.

8:54AM G14.00003 Gravitational-Wave Recoil from the Ringdown Phase of Coalescing Black Hole Binaries
CLIFFORD WILL, Washington University, St. Louis, ALEXANDRE LE TIEC, LUC BLANCHET, Institut d’Astrophysique de Paris — The gravitational recoil or “kick” of a black hole formed from the merger of two orbiting black holes, and caused by the anisotropic emission of gravitational radiation, is an astrophysically important phenomenon. We combine (i) an earlier calculation, using post-Newtonian theory, of the kick velocity accumulated up to the merger of two non-spinning black holes, (ii) a “close-limit approximation” calculation of the radiation emitted during the ringdown phase, and based on a solution of the Regge-Wheeler and Zerilli equations using initial data accurate to second post-Newtonian order. We prove that ringdown radiation produces a significant “anti-kick”. Adding the contributions due to inspiral, merger and ringdown phases, our results for the net kick velocity agree with those from numerical relativity to 10 to 15 percent over a wide range of mass ratios, with a maximum velocity of 180 km/s at a mass ratio of 0.38.

3Supported by NSF grant No. PHY06-52448, NASA grant No. NNG-06GI60G, and CNRS PICS grant No. 4396.

SEAN MCWILLIAMS, JAMES IRA THORPE, JOHN G. BAKER, BERNARD J. KELLY, NASA Goddard Space Flight Center, 8800 Greenbelt Rd., Greenbelt, MD 20771 — Until recently, only the inspiral and ringdown phases of black hole binary (BHB) coalescences had been modeled. The merger signals, which were expected to be the most luminous portion of the total signal, were unavailable due to the technical difficulty of calculating the behavior of a BHB in this highly dynamical and non-linear regime. Advancements in the field of numerical relativity make it possible to include the merger segment of BHB coalescences in the search for and characterization of gravitational wave signals. The implications for LISA include an increase in the event rate due to the increase in achievable signal-to-noise ratio, as well as potentially improved accuracy regarding the extraction of the source parameters. We investigate the degree to which mergers improve parameter estimation, by studying the impact of including mergers on achievable parameter accuracy over a significant range of masses and mass ratios for nonspinning systems, and its impact on LISA science. We find that nonspinning waveforms that include mergers provide competitive constraints on extrinsic parameters such as the sky position, as compared to results from rapidly spinning and precessing systems where the merger was not included.

9:18AM G14.00005 Selection biases of nonspinning searches for spinning binaries
ANDREW LUNDGREN, DUNCAN BROWN, Syracuse University, RICHARD O’SHAUGHNESSY, Penn State — Current searches for compact binary mergers by ground-based detectors assume for simplicity that the two bodies are not spinning. If black holes (BHs) are rapidly spinning, this limitation significantly biases searches for realistic BH-BH and particularly BH-NS binaries. We present accurate fits for the range to which a binary can be seen by a single detector, accounting for both (i) its band-limited loudness along the line of sight, as a function of all combinations of masses and spins, and (ii) the best match between the real signal and nonspinning model waveform. We discuss the biases caused by these effects as well as physical and mathematical intuitions for the behavior of the signals.

9:30AM G14.00006 How well do harmonics and merger and ringdown signals improve parameter estimation?
EVAN OCHSNER, ALESSANDRA BUONANNO, YI PAN, University of Maryland, B.S. SATHYAPRAKASH, Cardiff University — It is now well-known that the inclusion of higher harmonics of the orbital phase in gravitational waveforms greatly improves the parameter estimation and distance reach of compact binaries for which the inspiral takes place in the sensitive band of interferometric gravitational-wave detectors. This is also true when the merger and ringdown portions of the waveform are included. In this work we use effective-one-body inspiral-merger-ringdown waveforms with higher harmonics to study the improvement in the estimation of source parameters over simpler inspiral waveforms which contain only the dominant harmonic. The implications for second and third generation ground-based gravitational-wave detectors will also be discussed.
9:42AM G14.00007 Detectability of Numerical Relativity Waveforms for Black Hole Binaries with Rotating Spins and Templateless Analyses1, DEIRDRE SHOEMAKER, Georgia Tech, LAURA CADONATI, SEBASTIAN FISCHETTI, UMass Amherst, JAMES HEALY, Penn State, SATYANARAYAN MOHAPTRA, UMass Amherst, DUSTIN BURNS, Georgia Tech — Recent years have seen tremendous progress in numerical relativity and an ever improving performance of ground-based interferometric gravitational wave detectors. The numerical relativity and gravitational wave data analysis communities are collaborating to ascertain the most useful role for NR waveforms in the detection and characterization of binary black hole coalescences. We explore the particular case of detectability with algorithms designed for unmodeled (“burst”) waveforms for merging black hole binaries with rotating spins using NR waveforms. In this study, we present the detection systematics using waveforms produced by the MayaKranc code that are added to colored, Gaussian noise and analyzed with the Omega burst search algorithm (also used in LIGO-Virgo burst searches). Detection efficiency and parameter accuracy are systematically weighted against the rotation of one of the black-hole’s spin axis as well as numerical details such as waveform accuracy, the number of gravitational wave cycles, the number of included modes and extraction radius.

1NSF PHY-0925345, NSF PHY-0653303, TG-PHY060013N.

9:54AM G14.00008 Characterizing Black Hole Mergers, JOHN BAKER, WILLIAM DARIAN BOOGS, BERNARD KELLY, NASA-Goddard Space Flight Center — Binary black hole mergers are a promising source of gravitational waves for interferometric gravitational wave detectors. Recent advances in numerical relativity have revealed the predictions of General Relativity for the strong burst of radiation generated in the final moments of binary coalescence. We explore features in the merger radiation which characterize the final moments of merger and ringdown. Interpreting the waveforms in terms of an rotating implicit radiation source allows a unified phenomenological description of the system from inspiral through ringdown. Common features in the waveforms allow quantitative description of the merger signal which may provide insights for observations large-mass black hole binaries.

Sunday, February 14, 2010 10:45AM - 12:33PM — Session H14 GGR: Black Holes Washington 4

10:45AM H14.00001 Simulating the emission from shocked disks and black hole–neutron star mergers, MATTHEW ANDERSON, Louisiana State University, LUIS LEHNER, Perimeter Institute, DAVID NEILSEN, Brigham Young University, MIGUEL MEGEVAND, Louisiana State University — Astrophysical systems that radiate strongly in both electromagnetic and gravitational wave bands are of particular interest for study since the combined information can provide access to a number of rich phenomena. We simulate the possible electromagnetic emission from two scenarios: a disk perturbed by a recoiling super-massive black hole and the post-merger remnant disk from a black hole–neutron star merger. We present radiation transfer results from several configurations of these systems using different radiation models.

10:57AM H14.00002 A Numerical Study of Skyrmion Collisions, BENJAMIN GUTIERREZ, Department of Physics and Astronomy, University of British Columbia — We present results on numerical experiments on the relativistic scattering of skyrmions and domain walls in 2 + 1 and 3 + 1 dimensions. Parallel adaptive mesh refinement is implemented to study the collisions of spherically symmetric (hedgehog) skyrmion configurations. We investigate reported numerical instabilities and the hyperbolic nature of the system in the relativistic limit.

11:09AM H14.00003 Over-spinning a black hole with a test body1, TED JACOBSON, University of Maryland, THOMAS SOTIRIOU, University of Cambridge — A black hole of a given mass has a maximum possible spin. For greater spin, the corresponding solution to the Einstein equation has a naked singularity. Thus the question: can one spin up a black hole and expose a naked singularity? It has long been known that a maximally spinning black hole can not be over-spun by tossing in a test body. However, we find that if instead the black hole starts out with below maximal spin, then over-spinning can be achieved. We find that the requirements on the size and internal structure of the test body can be met if the body carries in either orbital or spin angular momentum. Our analysis neglects radiative and self-force effects, which may of course prevent the over-spinning.

1Research supported by NSF grants PHY-0601800 and PHY-0903572, and by STFC.

11:21AM H14.00004 Gravitational and Electromagnetic Signatures from the Tidal Disruption of a White Dwarf by an Intermediate Mass Black Hole, ROLAND HAAS, Georgia Institute of Technology, TANJA BODE, PABLO LAGUNA, Georgia Institute of Technology — Observations of the gravitational and electromagnetic radiation from the tidal disruption of a white dwarf by an intermediate mass black hole (IMBH) could provide evidence for the existence of IMBHs. During the inspiral and violent disruption of the star, the system will emit both gravitational waves and possibly X-ray radiation from the remnant accretion disk around the IMBH, which together will allow both the system’s location and internal parameters to be measured. We present results for the first fully general relativistic hydrodynamics simulations of these encounters focusing not only on the gravitational wave emission but also the electromagnetic signatures during the disruption and subsequent accretion. Our code uses the successful puncture recipe as implemented in an enhanced version our vacuum MayaKranc code coupled to the hydrodynamics code Whisky.

11:33AM H14.00005 Using Strong Field Images near Sgr A* to Probe Extra Dimensions, AMITAI BIN-NUN, University of Pennsylvania — In recent years, theories of uncompactified extra dimensions have been the subject of much study. As of now, there are few observational tests of extra dimensions. Now, building on recent work in calculating the magnitudes of images in the strong-field of gravity, I use metrics for black holes in the Randall-Sundrum (RS) braneworld and apply them to the class of S-stars near Sgr A*. Using a modified lens equation to account for the strong field nature of the lensing and using data from surveys of the Galactic Center, I calculate differences in magnification between a black hole in a 3+1 model and in a RS-braneworld scenario. In ideal cases, this difference in magnification can be detected in next generation surveys and serve as an experimental verification of extra dimensions.

11:45AM H14.00006 Is the central object in the galaxy a black hole?1, LALEH SADEGHIAN, CLIFFORD WILL, Washington University, St. Louis — The spin and quadrupole moment of the supermassive black hole at the Galactic center can in principle be measured by studying the precessions of the orbital planes of stars in high-eccentricity orbits within milliparsec distance of the black hole [1]. Measuring these precessions could yield a test of the black hole no-hair theorem, and thus verify if the central object in the Galaxy is really a black hole. Other factors that might perturb these orbits include a population of other stars orbiting the black hole, a distribution of dark matter near the black hole and tidal distortions of the stars as they pass near the black hole at perihelion. We calculate the effects of these perturbing factors analytically using standard orbital perturbation theory, and compare them with the relativistic precessions.


1Supported in part by the NSF, grant no. PHY06-52448.
11:57AM H14.00007 A simple non-singular black hole model. MANASSE MBONYE, Rochester Institute of Technology — We present a new and simple model of a non-singular black hole (NSBH) as an end result of gravitational collapse. The matter density grows from \( \rho_\text{in} \approx 0 \), at the matter boundary surface \( R \) inside the Schwarzschild horizon, to a maximum \( \rho = \rho_{\text{max}} \) at a well defined position \( 0 < r < r_{\text{max}} < R \). For \( 0 < r < r_{\text{max}} \) the matter fluid progressively transitions into a de Sitter-like fluid with a density \( \rho_\text{in} \approx 0 \) that monotonically grows to maximize at \( \rho_{\text{max}} \) at \( r=0 \). In the process the matter fluid density \( \rho_\text{in} \) falls, toward \( \rho = 0 \). The resulting picture resembles that of a first order phase transition in which a well defined mixed-phase system is set up in the inner core, \( 0 < r < r_{\text{max}} \), of the black hole. In this mixed-phase region the net 2-fluid density is constrained to be both constant and maximum. The net fluid pressure is initially matter-like positive in the outer region but eventually assumes negative enough values to offset singularity formation at the center. The model predicts the de Sitter-like fluid constitutes about 5.5% of the total mass. We show however that only about 24% of this fluid provides the needed anchoring against singularity formation. At all the fluid interfaces the fields are well behaved, and satisfy the required junction conditions. We feel that the model offers a simple but yet logical working picture, in line with a complete quantum gravity theory, of how matter at high densities might coexist in a mixed-phase with singularly avoiding fields.

12:09PM H14.00008 Kerr-Schild Method and the Geodesic Structure in a Codimension-2 Brane Black Holes. NELSON ZAMORANO, SUSANA AGUILAR, Universidad de Chile, BERTHA CUADROS MELGAR, Universidad Nacional Andres Bello — In this work we consider black hole solutions in a five-dimensional gravity. We include a Gauss-Bonnet term in the bulk and an induced gravity term on a 2-brane of codimension-2. Applying the Kerr-Schild method we have been able to generate additional solutions which include charge, angular momentum and a scalar field. In an effort to understand the geometric structure of these new spacetimes, we display a set of relevant geodesic families generated in these geometries.


12:21PM H14.00009 A Practical Foundation for Mapping Black Hole Spacetimes. SARAH VIGELAND, SCOTT HUGHES, MIT — Observations have shown that the universe contains many compact and massive objects that are believed to be black holes. Precise observations of orbital motion near candidate black holes have the potential to determine if they have the spacetime structure predicted by general relativity. We propose to compare strong-field observations of compact objects with the spacetime of bumpy black holes: objects whose multipolar structure is almost, but not quite, equal to that of the Kerr spacetime. We build bumpy black hole spacetimes by adding a perturbation onto a Kerr black hole, and we show how to map the perturbation onto changes in the multipole moments. The perturbation results in changes to the orbital frequencies which we calculate using Hamilton-Jacobi techniques.


3:30PM K4.00001 Laboratory Tests of the Inverse Square Law of Gravity. STEPHAN SCHLAMMINGER, University of Washington — Newton’s inverse square force law of gravity follows directly from the fact that we live in a 3-dimensional world. For sub-millimeter length scales there may be undiscovered, extra dimensions. Such extra dimensions can be detected with inverse square law tests accessible to torsion balances. I will present an overview of two experiments that are being conducted at the University of Washington to search for gravitational-strength deviations from the inverse square law for extra dimension length scales smaller than 50 micrometers. One experiment is designed to measure the distance dependent force between closely spaced masses, whereas the second experiment is a null experiment and is only sensitive to a deviation from the inverse square law of gravity. The first experiment consists of a torsion pendulum that is suspended above a continuously rotating attractor. The attractor and the pendulum are disks with azimuthal sectors of alternating high and a low density. The torque on the pendulum disk varies as a function of the attractor angle with a 3 degree period. The amplitude of the torque signal is analyzed as a function of the separation between the pendulum and the attractor. The second experiment consists of a plate pendulum that is suspended parallel to a larger vertical plate attractor. The pendulum plate has an internal density asymmetry with a dense inlay on one half facing the other. The torque on the pendulum disk varies as a function of the separation between the pendulum and the attractor. The second experiment consists of a null experiment and is only sensitive to a deviation from the inverse square law of gravity. The first experiment measures the distance dependent force between closely spaced parallel to a larger vertical plate attractor. The pendulum plate has an internal density asymmetry with a dense inlay on one half facing the other. The torque on the pendulum disk varies as a function of the separation between the pendulum and the attractor. The second experiment measures the distance dependent force between closely spaced masses, whereas the second experiment is a null experiment and is only sensitive to a deviation from the inverse square law of gravity. The first experiment consists of a torsion pendulum that is suspended above a continuously rotating attractor. The attractor and the pendulum are disks with azimuthal sectors of alternating high and a low density. The torque on the pendulum disk varies as a function of the attractor angle with a 3 degree period. The amplitude of the torque signal is analyzed as a function of the separation between the pendulum and the attractor. The second experiment consists of a plate pendulum that is suspended parallel to a larger vertical plate attractor. The pendulum plate has an internal density asymmetry with a dense inlay on one half facing the other. The torque on the pendulum disk varies as a function of the separation between the pendulum and the attractor. The second experiment consists of a null experiment and is only sensitive to a deviation from the inverse square law of gravity.

4:06PM K4.00002 ESA's GOCE gravity gradiometer mission. PIERRE TOUBOUL, ONERA — In the present decade, three space gravity missions, CHAMP, GRACE and GOCE provide unique information about mass and mass redistribution in the Earth system with a wide range of scientific returns like global ocean circulation, ice mass balance, glacial isostatic adjustment, continental ground water storage. On board the four satellites of these missions, similar electrostatic space inertial sensors deliver continuously, during quite nine years for the older, the accurate acceleration data needed for the missions. The sensor operation remains on the six axes electrostatic suspension of one solid metallic mass, which is servo-controlled motionless at the centre of the highly stable set of gold coated silica electrode plates. All degrees of freedom are measured with very sensitive capacitive sensors down to a few pic-o-m and the applied electrostatic forces to pico-N. With similar sensor design and technologies, full scale range and resolution can be adjusted according to the satellite environment and the mission requirements. The CHAMP and GRACE accelerometer have demonstrated their orbit performance. They provides measurements of the satellite non gravitational surface forces like the atmospheric drag and radiation pressures in order to extract from the satellite measured orbital position and velocity fluctuations, the effects of gravity anomalies. The six GOCE accelerometers compose the three axes gradiometer, combined to the SST-high-low GPS tracking to provide higher precision and resolution of the Earth static field. They contribute also to the satellite attitude control and drag compensation system, allowing the heliosynchronous orbit at the very low 260 km altitude. So, the accelerometers are designed to exhibit a full range of 6.5 \( \times 10^{-6} \) ms\(^{-2}\) and a resolution of 2 \( \times 10^{-14} \) ms\(^{-2}\) Hz\(^{-1/2}\). Since the gradiometer switch on in April 09, they deliver data leading to the components of the gravity gradient tensor. The main characteristics of the GOCE accelerometers and the mission are depicted in comparison to the previous ones, exhibiting the increase of performance and the limits. First in orbit results are mentioned like in particular the satellite drag free fly. The future gravity mission configuration is envisaged as well as other fundamental physics applications of such sensors.

1Acknowledgements to the ESA and Industrial Core Team of the GOCE mission.
2Physics Department

4:42PM K4.00003 Advancing Tests of Relativity via Lunar Laser Ranging. TOM MURPHY, University of California, San Diego — Laser range measurements between the earth and the moon have provided some of our best tests to date of general relativity and gravitational phenomenology—including the equivalence principle, the time-rate-of-change of the gravitational constant, the inverse square law, and gravitomagnetism. APOLLO (the Apollo Point Observator Lunar Laser-ranging Operation) is now collecting measurements at the unprecedented precision of one millimeter, which will produce order-of-magnitude improvements in a variety of gravitational tests. Experimental performance, evidence for degradation of the reflectors, project status and science outlook will be discussed.
moves. The expansion begins at order $R$ coupling. The expansion parameter is the inverse length scale of Guelph — The metric of a nonrotating black hole deformed by a tidal interaction is calculated and expressed as an expansion in the strength of the tidal

To show that the effect of passing through the transition regime amounts to small shifts in the constants of motion, whose magnitudes can be computed, together with a time adjustment. These results give insight into how the information about the initial conditions from the beginning of the inspiral is passed through the separatrix to give the initial conditions for the plunge. Since the timescale for the plunge is much shorter than the radiation reaction timescale, the plunging orbit will closely track the corresponding unperturbed separatrix trajectory. A detailed theoretical model of the near-separatrix dynamics for generic orbits is important for understanding features such as zoom-whirl behavior.

Hamiltonian of a spinning test-particle in curved spacetime, ENRICO BARAUSS, ETIENNE RACINE, ALESSANDRA BUONANNO, University of Maryland — Using a Legendre transformation, we compute the unconstrained Hamiltonian of a spinning test-particle in a curved spacetime at linear order in the particle spin. The equations of motion of this unconstrained Hamiltonian coincide with the Mathisson-Papapetrou-Pirani equations. We then use the formalism of Dirac brackets to derive the constrained Hamiltonian and the corresponding phase-space algebra in the Newton-Wigner spin supplementary condition (SSC), suitably generalized to curved spacetime, and find that the phase-space algebra ($q, p, S$) is canonical at linear order in the particle spin. We provide explicit expressions for this Hamiltonian in a spherically symmetric spacetime, both in isotropic and spherical coordinates, and in the Kerr spacetime in Boyer-Lindquist coordinates. Furthermore, we find that our Hamiltonian, when expanded in Post-Newtonian (PN) orders, agrees with the Arnowitt-Deser-Misner (ADM) canonical Hamiltonian computed in PN theory in the test-particle limit. Notably, we recover the known spin-orbit couplings through 2.5PN order and the spin-spin couplings of type $S_{Gerr} S$ (and $S_{Gerr}^2$) through 3PN order, $S_{Gerr}$ being the spin of the Kerr spacetime. Our method allows one to compute the PN Hamiltonian at any order, in the test-particle limit and at linear order in the particle spin. As an application we compute it at 3.5PN order.

Hamiltonian of a spinning test-particle in curved spacetime

4:18PM K14.00008 A Hybrid Approximation Technique for Head-on Black-Hole-Binary Mergers, DAVID NICHOLS, YANBEI CHEN, DREW KEPPEL, California Institute of Technology, GEORFFREY LOVELACE, Cornell University, ULRICH SPER-HAKE, California Institute of Technology — Black-hole-binary coalescence is often divided into three stages, inspiral, merger and ringdown; the post-Newtonian (PN) approximation treats the inspiral phase, black-hole perturbation (BHP) theory describes the ringdown, and the strongly nonlinear dynamics of spacetime characterize the merger. In this paper, we introduce a hybrid method that incorporates elements of PN and BHP theories, and we apply it to the head-on collision of black holes with transverse, anti-parallel spins. We compare our approximation technique with a full numerical-relativity simulation by G. Lovelace et al., and we find surprisingly good agreement between the gravitational waveforms and the radiated energy and momentum. We also apply this model to understand the flow of gravitational field momentum in the simulation, quantified by the Landau-Lifshitz pseudotensor. Our results indicate that while PN and BHP theories do not capture all the strongly nonlinear physics of the merger, they do suffice to explain the outgoing gravitational radiation for head-on mergers.

4:42PM K14.00007 Searching for a Carter-like constant of motion in the Bach-Weyl solution, SAEED MIRSHEKARI, CLIFFORD WILL, Washington University, St. Louis — It was recently shown that the Newtonian gravitational field of two fixed point masses in a circular orbit around a Schwarzschild black hole can be approximated as a geodesic plunge. A systematic local analysis of the orbital dynamics near the separatrix together with matched asymptotic expansions shows that the effect of passing through the transition regime amounts to small shifts in the constants of motion, whose magnitudes can be computed, together with a time adjustment. These results give insight into how the information about the initial conditions from the beginning of the inspiral is passed through the separatrix to give the initial conditions for the plunge. Since the timescale for the plunge is much shorter than the radiation reaction timescale, the plunging orbit will closely track the corresponding unperturbed separatrix trajectory. A detailed theoretical model of the near-separatrix dynamics for generic orbits is important for understanding features such as zoom-whirl behavior.

Geometry and dynamics of a tidally deformed black hole

1:30PM K14.00001 A solution to the Fourth order Killing Equations, JEANDREW BRINK, CALTECH — I present a closed form analytic solution to the fourth order Killing equations in stationary axisymmetric vacuum spacetimes. Properties of the solution as well as implications for gravitational wave observations are discussed.

3:42PM K14.00002 Self-force with numerical relativity tools, IAN VEGA, University of Guelph, PETER DIENER, Louisiana State University, WOLFGANG TICHY, Florida Atlantic University, STEVE DETWEILER, University of Florida — We review recent progress towards developing an approach to self-force problems that take advantage of extensive infrastructure within numerical relativity. We shall describe our prescription and its application to the case of a scalar charge in a circular orbit around a Schwarzschild black hole with the use of two evolution codes originally written for numerical relativity applications. Within this framework, the self-force on the charge and the corresponding energy fluxes are computed to within 1% of the known correct answer. This constitutes the first successful calculation of a self-force in a (3+1) setting.

3:54PM K14.00003 Hamiltonian of a spinning test-particle in curved spacetime

4:06PM K14.00004 Analysis of extreme mass ratio inspirals in Kerr: Transition from inspiral to plunge, TANJA HINDERER, Caltech — The gravitational radiation reaction driven inspiral of a compact object into a much more massive Kerr black hole proceeds through three different regimes: (i) An adiabatic inspiral, where the inspiral time scale is much larger than the orbital period and which can be modeled theoretically using two-timescale expansions. (ii) a transition regime near the separatrix where the orbit becomes unstable, and (iii) the infall which can be approximated as a geodesic plunge. A systematic local analysis of the orbital dynamics near the separatrix together with matched asymptotic expansions shows that the effect of passing through the transition regime amounts to small shifts in the constants of motion, whose magnitudes can be computed, together with a time adjustment. These results give insight into how the information about the initial conditions from the beginning of the inspiral is passed through the separatrix to give the initial conditions for the plunge. Since the timescale for the plunge is much shorter than the radiation reaction timescale, the plunging orbit will closely track the corresponding unperturbed separatrix trajectory. A detailed theoretical model of the near-separatrix dynamics for generic orbits is important for understanding features such as zoom-whirl behavior.

4:18PM K14.00005 Geometry and dynamics of a tidally deformed black hole, ERIC POISSON, University of Guelph — The metric of a nonrotating black hole deformed by a tidal interaction is calculated and expressed as an expansion in the strength of the tidal coupling. The expansion parameter is the inverse length scale $R^{-1}$, where $R$ is the radius of curvature of the external spacetime in which the black hole moves. The expansion begins at order $R^{-3}$, and it is carried out through order $R^{-4}$. The metric is parameterized by a number of tidal multipole moments, which specify the black hole’s tidal environment. The tidal moments are freely-specifiable functions of time that are related to the Weyl tensor of the external spacetime. The metric is presented in a light-cone coordinate system that possesses a clear geometrical meaning. At the order of accuracy maintained in this work, the horizon is a stationary null hypersurface foliated by apparent horizons; it is an isolated horizon in the sense of Ashtekar and Krishnan. As an application of our results we examine the induced geometry and dynamics of the horizon, and calculate the rate at which the black-hole surface area increases as a result of the tidal interaction.

4:30PM K14.00006 Accurate analytical waveforms of coalescing binary black holes, YI PAN, University of Maryland — I will present analytical waveforms of gravitational-wave radiation from coalescing binary black holes generated within the analytical effective-one-body approach. These waveforms agree, within numerical errors, with waveforms generated by highly accurate numerical relativity simulations. Furthermore, in the test-particle limit, these waveforms agree with the extreme mass ratio inspiral waveforms generated by numerically solving the Teukolsky equations. I will show how this analytical approach extracts non-perturbative information contained in the numerical simulations, models the full coalescence phase, and provides a sufficiently accurate bank of waveforms to be used in matched-filtering based searches of coalescing binary black holes with ground-based gravitational-wave detectors.

4:42PM K14.00007 Searching for a Carter-like constant of motion in the Bach-Weyl solution, SAEED MIRSHEKARI, CLIFFORD WILL, Washington University, St. Louis — It was recently shown that the Newtonian gravitational field of two fixed point masses has multipole moments linked by the same relation as those for Kerr black holes, and that there is a Carter-like constant of the motion for this system. In this work, we study whether the general relativistic analogue, the Bach-Weyl solution, also has a Carter-like constant. We carry this out by (1) searching for a symmetric Killing tensor for the Bach-Weyl spacetime, and (2) trying to construct a Carter-like constant in its post-Newtonian limit. Preliminary results will be reported.

3Supported in part by the NSF, grant No. PHY06-52448.

4:54PM K14.00008 A Hybrid Approximation Technique for Head-on Black-Hole-Binary Mergers, DAVID NICHOLS, YANBEI CHEN, DREW KEPPEL, California Institute of Technology, GEORFFREY LOVELACE, Cornell University, ULRICH SPER-HAKE, California Institute of Technology — Black-hole-binary coalescence is often divided into three stages, inspiral, merger and ringdown; the post-Newtonian (PN) approximation treats the inspiral phase, black-hole perturbation (BHP) theory describes the ringdown, and the strongly nonlinear dynamics of spacetime characterize the merger. In this paper, we introduce a hybrid method that incorporates elements of PN and BHP theories, and we apply it to the head-on collision of black holes with transverse, anti-parallel spins. We compare our approximation technique with a full numerical-relativity simulation by G. Lovelace et al., and we find surprisingly good agreement between the gravitational waveforms and the radiated energy and momentum. We also apply this model to understand the flow of gravitational field momentum in the simulation, quantified by the Landau-Lifshitz pseudotensor. Our results indicate that while PN and BHP theories do not capture all the strongly nonlinear physics of the merger, they do suffice to explain the outgoing gravitational radiation for head-on mergers.
Gravitational self-force meets the post-Newtonian approximation in extreme-mass ratio inspiral of binary black holes. STEVEN DETWELDER, University of Florida — Post-Newtonian analysis, numerical relativity and, now, perturbation-based gravitational self-force analysis are all being used to describe key aspects of black hole binary systems. Recent comparisons between self-force analysis, with $m_1 \ll m_2$, and post-Newtonian analysis, with $v/c \ll 1$ show excellent agreement in their common domain of validity. This lends credence to the two very different regularization procedures which are invoked in these approximations. When self-force analysis is able to create gravitational waveforms from extreme-mass-ratio inspiral, then unprecedented cross cultural comparisons of these three distinct approaches to understanding gravitational waves will reveal the strengths and weaknesses of each.

Monday, February 15, 2010 10:45AM - 12:45PM — Session P14 GGR: Numerical Simulations of Black Holes and Neutron Stars Washington 4

10:45AM P14.00001 The Magnetic field and Black Hole Spin in Black Hole–Neutron star mergers. SARVARPUR CHAWLA, MATTHEW ANDERSON, Louisiana State University, LUIS LEHNER, Perimeter Institute, STEVEN LIEBLING, Long Island University, MIGUEL MEVEVAND, Louisiana State University, PATRICK MÖTL, Indiana University Kokomo, DAVID NEILLS, Brigham Young University, CARLOS PALENZUELA, Canadian Institute for Theoretical Astrophysics — A sizable magnetic field in neutron star-black hole binaries can have a strong influence on the merger dynamics of the fluid by redistributing angular momentum through different mechanisms. The magnetic field can also be responsible for collimating jets. BH spin can increase the number of orbits before merger as compared to a binary with a non-spinning BH. The corresponding decrease in ISCO can alter the tidal disruption suffered by the NS. We present results of fully relativistic black hole–neutron star simulations proceeding from quasi-circular initial data generated with the Lorene libraries. We explore the effect of magnetic field and spin by evolving four sets of nearly identical initial data which differ in their magnetic field and spin values. We examine the gravitational wave signature through direct simulation. Finally, we compare the fluid structure and explore the magnetic field configuration in the post-merger remnant disk.

10:57AM P14.00002 Merger of white dwarf-neutron star binaries: Prelude to hydrodynamic simulations in general relativity. VASILEIOS PASCHALIDIS, University of Illinois at Urbana-Champaign, MORGAN MACLEOD, THOMAS W. BAUMGARTE, Bowdoin College, Brunswick, ME, STUART L. SHAPIRO, University of Illinois at Urbana-Champaign — White dwarf-neutron star binaries generate detectable gravitational radiation. We construct Newtonian equilibrium models of corotational white dwarf-neutron star (WDNS) binaries in circular orbit and find that these models terminate at the Roche limit. At this point the binary will undergo either stable mass transfer (SMT) and evolve on a secular time scale, or unstable mass transfer (UMT), which results in the tidal disruption of the WD. The path a given binary will follow depends primarily on its mass ratio. We analyze the fate of known WDNS binaries and use population synthesis results to estimate the number of LISA-resolved galactic binaries that will undergo either SMT or UMT. We then model the quasistationary SMT epoch by solving a set of simple ordinary differential equations and compute the corresponding gravitational waveforms. Finally, we discuss in general terms the possible fate of binaries that undergo UMT. If sufficient WD debris lands on the NS, the remnant may collapse, whereby the gravitational waves from the inspiral, merger, and collapse phases will sweep from LISA through LIGO frequency bands. If the debris forms a disk about the NS, it may fragment and form planets.

11:09AM P14.00003 Gravitational Waves from Magnetized Binary Neutron Star Mergers. BRUNO GIACOMAZZO, University of Maryland, LUCIANO REZZOLLA, Albert Einstein Institute, LUCA BAIOTTI, Yukawa Institute for Theoretical Physics — Binary neutron stars are among the most important sources of gravitational waves which are expected to be detected by the current or next generation of gravitational wave detectors, such as LIGO and Virgo, and they are also thought to be at the origin of very important astrophysical phenomena, such as short gamma-ray bursts. In order to describe the dynamics of these events one needs to solve the full set of general relativistic magnetohydrodynamics equations through the use of parallel numerical codes. I will report on some recent results obtained with the use of the fully general relativistic magnetohydrodynamics code Whisky in simulating binary neutron stars which inspiral and merge forming an hypermassive neutron star which eventually collapses to form a black hole surrounded by a torus. I will in particular describe how the magnetic fields can affect the dynamics and consequently the gravitational waves emitted by these systems and discuss about their detectability by current and future gravitational-wave detectors.

11:21AM P14.00004 Simulations of Black Hole–Neutron Star Binaries. FRANCOIS FOUCART, MATTHEW DUEZ, LAWRENCE KIDDER, SAUL TEUKOLSKY, Cornell University — We present simulations of black hole-neutron star binaries aimed at the determination of the relative importance of different initial parameters. Keeping a constant mass ratio of 1:3, we vary the radius of the star, the stiffness of the equation of state, and the magnitude and orientation of the black hole spin. We discuss differences in the tidal interactions and the characteristics of the long-lived accretion disk which eventually forms, and we describe how these differences influence the gravitational waves emitted by the system. Using eccentricity removal techniques, we also assess the effect of small deviations from circular orbits due to imperfections in the initial data.

11:33AM P14.00005 Simulations of Neutron-Star Binaries using the Spectral Einstein Code (SpEC). JEFFREY KAPLAN, CHRISTIAN OTT, California Institute of Technology, CURRAN MULHBERGER, MATTHEW DUEZ, FRANCOIS FOUCART, Cornell University, MARK SCHEEL, California Institute of Technology — Since the first successful fully general-relativistic simulations of coalescing neutron-star binaries, researchers have steadily improved the quality of their neutron-star binary evolutions with the goal of drawing connections between neutron-star physics (such as the NS equation of state, magnetic fields, etc.) and astrophysical observables (in the form of gravitational waves and the electromagnetic signature of short gamma-ray bursts). We present the progress of the Caltech-Cornell numerical relativity collaboration in simulating the merger of neutron star binaries. Our simulations employ a two-grid approach: on one grid we evolve the Einstein equations in the generalized harmonic formulation using pseudospectral methods, and on the other we solve the hydrodynamics using a piecewise parabolic method. We focus on results of long-term simulations of the coalescence, merger, and post-merger evolution of equal mass neutron-star binaries using a simple gamma law equation of state and discuss preliminary results from work towards including a microphysical finite-temperature nuclear equation of state and neutrino cooling.

11:45AM P14.00006 Simulations of Binary Star-Stripping Black Hole Binary Mergers: Simulations in Full General Relativity. ZACHARIAH ETIENNE, YUK TUNG LIU, STUART SHAPORO, University of Illinois, THOMAS BAUMGARTE, Bowdoin College — Binary black hole-neutron star (BHNS) binary mergers are candidate engines for both short-hard gamma-ray bursts and detectable gravitational radiation. Using our most recent conformal thin-sandwich BHNS initial data and our fully GR hydrodynamics code, which is now AMR-capable, we are able to simulate these binaries accurately through inspiral, merger, and ringdown. We explore the effects of BH spin (aligned and anti-aligned with the orbital angular momentum) by evolving binaries with BH:NS mass ratio $q = 5$ that are nearly identical, except the BH spin is varied between $a/M_{BH} = -0.5$ (anti-aligned) to 0.75. The number of orbits before merger increases with $a/M_{BH}$. We also study the nonspinning BH case in depth, varying $q$ between 1, 3, and 5. Gravitational waveforms are calculated and compared to binary BH waveforms. Only a small disk ($\lesssim 0.01 M_{\odot}$) forms for the anti-aligned spin case ($a/M_{BH} = -0.5$) and for the largest mass ratio case ($q = 5$). By contrast, a massive ($M_{disk} \approx 0.2 M_{\odot}$) hot disk forms in the rapidly spinning $a/M_{BH} = 0.75$ aligned BH case. Such a disk could drive a SGRB, possibly by, e.g., producing a copious flux of $\nu - \bar{\nu}$ pairs.
I will compare the computed results with recent observations of Sgr A* performed by Doeleman et al. in the early 1970s. Next I will present a mathematical generalization of this formula, and apply it to slightly perturbed Kerr metrics. If time permits, I will discuss the ways in which this effort is currently being extended to include more types of astrophysical events observed with different “messengers” and the era of gravitational waves. The LIGO-Virgo gravitational-wave detectors have achieved phenomenal sensitivities and recently completed a search for the stochastic background of gravitational waves, which could be cosmological or astrophysical in origin. I will give sensitivity projections for the next generation gravitational-wave detectors. In this talk I will discuss the latest results of searches for periodic gravitational waves from spinning neutron stars. I will also review the results of searches for the stochastic background of gravitational waves, which could be cosmological or astrophysical in origin. I will give sensitivity projections for the current run and next generation gravitational-wave detectors, and assess their impact on astronomy and cosmology.

1:30PM Q4.00001 The LIGO and Virgo Gravitational Wave Detectors, RANA ADHIKARI, Caltech — Since 2008, the LIGO and Virgo interferometers have been undergoing substantial upgrades. These include increases of the laser power, improvements in the signal readout hardware, upgrades of the thermal adaptive optics, and improved seismic isolation. I will describe each of these upgrades and how they contribute to the overall sensitivity improvement of the interferometers.

2:06PM Q4.00002 Multi-Messenger Astronomy and Astrophysics with Gravitational-Wave Transients, PETER SHAWHAN1, University of Maryland — The successful construction and operation of the LIGO, GEO600 and Virgo detectors has not yet been rewarded with the detection of a gravitational-wave signal. Nevertheless, searches for gravitational-wave inspirals and more general burst signals are already providing meaningful constraints on the population and characteristics of sources, and in particular on the astrophysics of events which are observed by other means, such as gamma-ray bursts and soft gamma repeater flares. I will present and interpret the results from searches that have been completed, and then describe the ways in which this effort is currently being extended to include more types of astrophysical events observed with different “messengers” and more modes of utilizing the gravitational-wave data. Besides the direct outcomes from these searches in the near term, we are building the capability to extract significant astronomical information from the signals which will be detected by Advanced LIGO and Advanced Virgo in the coming decade.

2:42PM Q4.00003 Science of continuous gravitational wave signals: periodic waves and the stochastic background, XAVIER SIEMENS1, University of Wisconsin — Milwaukee — We are at the threshold of a new era in astronomy and astrophysics, the era of gravitational waves. The LIGO-Virgo gravitational-wave detectors have achieved phenomenal sensitivities and recently completed a two year data taking run. A new run is underway with an enhanced hardware configuration—a crucial stepping stone toward next generation gravitational-wave detectors. In this talk I will discuss the latest results of searches for periodic gravitational waves from spinning neutron stars. I will also review the results of searches for the stochastic background of gravitational waves, which could be cosmological or astrophysical in origin. I will give sensitivity projections for the current run and next generation gravitational-wave detectors, and assess their impact on astronomy and cosmology.

3 For the LIGO Scientific Collaboration and the Virgo Collaboration

Monday, February 15, 2010 1:30PM - 3:18PM –
Session Q11 GGR: Gravitational Waves from Neutron Stars Maryland C

1:30PM Q11.00001 Broadband Search for Continuous-Wave Gravitation Radiation with LIGO, VLADIMIR DERGACHEV, California Institute of Technology, LIGO SCIENTIFIC COLLABORATION AND VIRGO COLLABORATION — Isolated rotating neutron stars are expected to emit gravitational radiation of nearly constant frequency and amplitude. Searches for such radiation with the LIGO interferometers are underway, using data taken from LIGO’s fifth science run and ongoing runs on the gravitational wave signal amplitudes are thought to be extremely weak, long time integrations must be carried out to detect a signal. This is complicated by the motion of the Earth (daily rotation and orbital motion) which induces substantial modulations of detected frequency and amplitude that are highly dependent on source location. Large volumes of acquired data make this search computationally difficult. We present an algorithm called PowerFlux, used to account for these modulations, when summing power spectral density estimates incoherently over long time intervals. Latest results using data from the S5 run, as well as challenges and progress of the detection search, will be discussed as well.

1 NSF Grant No. PHY0503366
1:42PM Q11.00002 Nonlinear mode coupling in rotating neutron stars and its effects on the r-mode instability. RUXANDRA BONDARESCU, Penn State University, SAUL TEUKOLSKY, IRA WASSERMAN, Cornell University — This talk will focus on describing the nonlinear dynamics of the r-mode instability in rapidly rotating neutron stars. R-modes are oscillations in rotating fluids that occur due to the Coriolis effect. In fast rotators these modes can be driven unstable by the gravitational radiation backreaction force when gravitational driving dominates viscous damping. An unstable L = 2, m = 2 r-mode spins down a rotating neutron star by converting rotational energy into gravitational radiation and mode energy. It has been suggested that the r-mode instability can set a limiting frequency to accreting neutron stars. Nonlinear effects become important when a mode grows above its parametric instability threshold and excites other near resonant modes in the star. The duration of the instability and the amplitude at which the instability saturates depend on neutron star composition via viscous dissipation and neutrino cooling. In some scenarios r-modes may also lead to detectable gravitational radiation.

1:54PM Q11.00003 Gravitational Waves from Low Mass Neutron Stars, C.J. HOROWITZ, Indiana University — Recently, using large scale molecular dynamics simulations, we determined that neutron star crust is very strong, some 10 billion times stronger than steel [1]. This makes star crust the strongest material known and it can support relatively large “mountains”. These bumps on rapidly rotating neutron stars can radiate strong gravitational waves (GW). Therefore, we strongly encourage ongoing and future searches for continuous GW. In the present paper, we speculate that low mass neutron stars, although they may be difficult to produce, could be even stronger GW sources. We find that the crust can support very large ellipticities (fractional differences in moments of inertia) of 0.001 or even larger in low mass neutron stars. This is because a larger fraction of a low mass neutron star is solid crust compared to a 1.4 solar mass star and because the weaker gravity allows the crust to support even larger mountains. Therefore, if low mass neutron stars can be produced, for example via fragmentation during a neutron star merger, then they could produce very strong continuous gravitational waves.


2:06PM Q11.00004 Quadrapole Moments of Rotating Neutron Stars, SWAPNIL TRIPATHI, University of Wisconsin — A rotating stars oblateness creates a deformation in the gravitational field outside the star, which is measured by the quadrupole-moment tensor. In this work we make corrections to certain previous calculations of quadrupole moments of rotating neutron stars in the literature. We propose an EOS(equation of state) independent empirical relation for the quadrupole moment of rotating neutron stars. A quadrupole moment maximizing EOS is proposed and a formula found for the limit set by causality on the quadrupole moment of a star of fixed gravitational mass.

2:18PM Q11.00005 Gravitational waves from NS-NS and NS-BH inspirals and the high-density equation of state1, JOHN L. FRIEDMAN, University of Wisconsin-Milwaukee — This talk reviews recent work by members of UWM’s Center for Gravitational Physics and Cosmology and their collaborators on NS-NS and NS-BH inspiral. A parametrized equation of state is used to systematize the constraints imposed by observation on the equation of state of cold matter above nuclear density. Current NS-NS work involves: Determination of surfaces in the equation of state (EOS) parameter space associated with a given departure from the waveform of point-particle inspiral; using waveforms from numerical simulations to calibrate quasiequilibrium sequences and post-Newtonian waveforms; and development of improved initial data codes. Work on BH-NS inspiral includes simulations with an increased range of mass ratios and black-hole spins.

1Supported in part by NSF Grant PHY-0503366.

2:30PM Q11.00006 Tidal deformability of neutron stars with realistic equations of state1, BENJAMIN LACKEY, University of Wisconsin–Milwaukee, TANJA HINDERER, Caltech, JOCELYN READ, Albert Einstein Institute, RYAN LANG, MIT — The low-frequency part of the gravitational wave signal of binary neutron star inspirals can potentially yield robust information on the nuclear equation of state. The influence of a star’s internal structure on the waveform is characterized by a single parameter: the tidal deformability λ, which measures the star’s quadrupole deformation in response to the companion’s perturbing tidal field. We calculate λ for a wide range of equations of state and find that the value of λ spans an order of magnitude for the range of equation of state models considered. An analysis of the feasibility of discriminating between neutron star equations of state with gravitational wave observations of the early part of the inspiral reveals that the measurement error in λ increases steeply with the total mass of the binary. Comparing the errors with the expected range of λ, we find that Advanced LIGO observations of binaries at a distance of 100 Mpc will probe only unusually stiff equations of state, while the proposed Einstein Telescope is likely to see a clean tidal signature.

1This work was supported by the NSF and a Wisconsin Space Grant Fellowship.

2:42PM Q11.00007 Tuning advanced gravitational-wave detectors to optimally measure neutron-star merger waves, LEO STEIN, MIT Kavli Institute — Next-generation gravitational wave detectors have the potential to bring us astrophysical information in yet unexplored regimes. One of the possibilities is learning about neutron stars’ equations of state from the gravitational wave burst of a binary coalescence. Since these events are “bursty”, one does not have the luxury of time-averaging to improve S/N; one can only hope to do better by “tuning” a detector network to have the noise performance which will be most informative about the physics. We present a Bayesian method for optimizing a detector network given a prior distribution of physical parameters which affect the gravitational wave signal. Each detection adds information about the parameter distribution, updating the posterior and the optimal detector configuration. We demonstrate the algorithm with toy signal and detector response models and predict whether tuning Advanced LIGO (via the signal recycling cavity) will be fruitful in accelerating our understanding of neutron stars through their mergers.

2:54PM Q11.00008 Modeling Gravitational Wave Emission from Soft Gamma Repeaters1, CHRISTIAN D. OTT, TAIPIR, California Institute of Technology, PETER KALMUS, LIGO Laboratory, California Institute of Technology — Soft gamma repeaters and anomalous x-ray pulsars are thought to be magnetars: neutron stars with extreme magnetic fields. When active they sporadically emit sudden bursts of soft gamma rays. The majority of these bursts have total energies of $10^{42}$ erg or less (isotropic), but three “giant flares” have had measured energies between $10^{45}$ and $10^{47}$ ergs. We perform 3D, fully general relativistic hydrodynamics simulations to model the gravitational wave (GW) emission due to global neutron star pulsational modes that may be excited during a burst. We discuss the relevant parameter space and connect our results to recent searches for GW from magnetars performed by the interferometric GW observatories.

1Supported by NSF and the Sherman Fairchild Foundation.
In this example by showing that failure to consider decoherence leads to precisely the opposite of the failure of Wheeler-DeWitt quantum cosmological models to avoid the big-bang singularity. The critical role played by decoherence of histories is illustrated.

Criteria for the resolution of the initial singularity are formulated in a precise way. Singularity avoidance in loop-quantized models is contrasted with standard Wheeler-DeWitt theory and also loop quantum cosmology, thereby permitting consistent quantum predictions to be made in complete, mathematically precise models of quantum cosmology.

Consistent families of quantum histories are exhibited and the prediction of semiclassical behavior for suitable initial states in quantum gravity is confirmed with General Relativity up to the corrections that appear nearby singularities.

Analysis of the Gravitational Signatures in terms of observable quantities. This eliminates the main objection to that treatment and opens possibilities for correctly handling the problem of time in quantum gravity framework is used to investigate both the importance of quantum backreaction and the validity of the semi-classical approximation in de Sitter space.

The evidence for such “spontaneous dimensional reduction,” and suggest an additional argument coming from the strong-coupling limit of the Wheeler-DeWitt equation. If this description proves to be correct, it suggests an interesting relationship between small-scale quantum spacetime and the behavior of cosmologies near an asymptotically silent singularity.

Gravitational waves from core-collapse supernova explosions with the CHIMERA code with emphasis on the origin of each part of the wavetrains and their interpretation in the framework of the collapse dynamics.

ORNL is managed by UT-Battelle, LLC, for the U.S. Department of Energy under contract DE-AC05-00OR22725.

Monday, February 15, 2010 1:30PM - 3:06PM –
Session Q14 GGR: Quantum Aspects of Gravitation
Washington 4

1:30PM Q14.00001 Gravitational consequences of confined fields in braneworlds. STEPHEN GREEN, University of Chicago — In the braneworld scenario, matter fields are usually assumed to be confined to branes in a higher dimensional spacetime, with a stress energy tensor that is sharply peaked on the brane. A field theoretical way to achieve this is by coupling a bulk field to a topological defect which makes up the brane. We point out that in contrast to fermion fields, the stress energy tensor of a confined scalar field contains a term that is of the form of the second derivative of a sharply peaked function. This produces large metric perturbations on the brane. However, the resulting gravitational effect is equivalent to a local self-interaction term, and may be negated by artificially inserting an opposite self-interaction for the underlying theory. We comment on the possible generalization to other bosonic fields as well as the potential observability.

1:42PM Q14.00002 The Emergence of General Relativity from Loop Quantum Gravity. CHUN-YEN LIN, University of California, Davis — We show that General Relativity emerges from Loop Quantum Gravity in the relative prescription of gravity against the matter coordinates. The local Dirac observables and coherent states are constructed to explicitly evaluate the dynamics. The dynamics in large scale confirms with General Relativity up to the corrections that appear nearby singularities.

1:54PM Q14.00003 Linear Response and the Validity of the Semiclassical Approximation in de Sitter Space1, PAUL ANDERSON, Wake Forest University, CARMEN MOLINA-PARIS, University of Leeds, EMIL MOTTOLA, Los Alamos National Laboratory — Linearized fluctuations of quantized matter fields and the spacetime geometry around de Sitter space are considered in the case that the matter fields are conformally invariant. Taking the unperturbed state of the matter to be the de Sitter invariant Bunch-Davies state, the linear variation of the stress tensor about its self-consistent mean value serves as a source for fluctuations in the geometry through the semi-classical Einstein equations. This linear response framework is used to investigate both the importance of quantum backreaction and the validity of the semi-classical approximation in de Sitter space.

2:06PM Q14.00004 Relational interpretation with Dirac observables and the problem of time in gravity. JORGE PULLIN, Louisiana State University, RODOLFO GAMBINI, Universidad de la Republica Oriental del Uruguay — We show that the use of evolving Dirac observables in conjunction with the conditional probabilities of Page and Wootters correctly predicts the physical propagators in model systems. This eliminates the main objection to that treatment and opens possibilities for correctly handling the problem of time in quantum gravity in terms of observable quantities.

2:18PM Q14.00005 Spontaneous Dimensional Reduction in Short-Distance Quantum Gravity?1, STEVEN CARLIP, UC Davis — Several lines of evidence hint that quantum gravity at very small distances may be effectively two-dimensional. I will summarize the evidence for such “spontaneous dimensional reduction,” and suggest an additional argument coming from the strong-coupling limit of the Wheeler-DeWitt equation. If this description proves to be correct, it suggests an interesting relationship between small-scale quantum spacetime and the behavior of cosmologies near an asymptotically silent singularity.

1Supported in part by DOE grant DE-FG02-91ER40674.

2:30PM Q14.00006 Numerical Analysis of Black Hole Evaporation in the CGHS Model, FETHI M. RAMAZANOGLU, Physics Department, Princeton University, ABHAY ASHTEKAR, Institute for Gravitation and the Cosmos and Physics Department, The Pennsylvania State University, FRANS PRETORIUS, Physics Department, Princeton University — We numerically analyze the black hole formation and evaporation in the CGHS model, in the dynamical background of 1+1 dimensions. Specifically, we investigate the energy flux and the behavior of the asymptotic Killing vector $\partial y/\partial \tau$ at the future null infinity $I_R^+$, and their relation to the rate of change of the Bondi mass of the black hole. Emphasis is given to the rapid evolution of the space-time near the point where the last ray reaches $I_R^+$ and its implications about the information loss in this model.

2:42PM Q14.00007 Decoherence Functionals for Quantum Cosmology, DAVID CRAIG, Le Moyne College, PARAMPREET SINGH, Perimeter Institute of Theoretical Physics — Decoherence functionals are explicitly constructed for flat cosmological models in both standard Wheeler-DeWitt theory and also loop quantum cosmology, thereby permitting consistent quantum predictions to be made in complete, mathematically precise models of quantum cosmology. Consistent families of classical histories are exhibited and the prediction of semiclassical behavior for suitable initial states described. Criteria for the resolution of the initial singularity are formulated in a precise way. Suggestive evidence that loop-quantized models are consistent with the failure of Wheeler-DeWitt model predictions to avoid the big-bang singularity. The critical role played by decoherence of histories is illustrated in this example by showing that failure to consider decoherence leads to the opposite conclusion for a large class of states.
Monday, February 15, 2010 3:30PM - 5:18PM –
Session S4 DCOMP GGR: Gravity in Extreme Conditions Thurgood Marshall North

3:30PM S4.00001 Computational Models of Stellar Collapse, Core-Collapse Supernovae, and Black Hole Formation1. CHRISTIAN D. OTT, TAPIR, California Institute of Technology — I present an overview on the recent progress in the computational modeling of the core collapse of massive stars and the subsequent core-collapse supernova evolution. Despite many decades of theoretical and computational work, the precise mechanism driving core-collapse supernova explosions remains to be understood, but may involve (a combination of) post-core-bounce energy deposition by neutrinos, convective instability, the standing-accretion-shock instability (SASI), protoneutron star pulsations, rotational, and magneto-hydrodynamic effects. I introduce the ensemble of presently considered explosion mechanisms and show, on the basis of new Newtonian and general relativistic simulations, that gravitational waves emitted in a core collapse event can be used to distinguish between these proposed mechanisms. I go on to discuss the case in which the explosion fails and the neutron star is pushed over its maximum mass by continued accretion. I present new results on this process obtained with general relativistic hydrodynamics simulations of nonrotating and rotating stellar collapse and postbounce evolution using an approximate scheme for neutrino cooling and heating and a variety of microphysical finite-temperature equations of state.

1Supported by NSF.

4:06PM S4.00002 Aneesur Rahman Prize for Computational Physics Talk: Black Hole Collisions. FRANS PRETORIUS, Princeton University — The class of spacetimes describing the merger of two black holes contain some of the most fascinating solutions to the equations of general relativity. In this talk I will review what has been learnt about the binary black hole problem over the past several years from numerical simulations of the Einstein field equations, focusing on the more “extreme” solutions obtained in the high velocity limit. This is of possible relevance to LHC and cosmic ray physics in certain proposed large extra dimension scenarios. Some of the interesting results include the near-Planck scale luminosity in radiated gravitational waves, recoil velocities of on the order of ten thousand kilometers per second or larger, zoom-whirl orbital motion, the formation of near-extremal Kerr black holes, and that in the ultra relativistic limit the internal nature of the colliding object, whether black holes or not, seemingly becomes irrelevant.

4:42PM S4.00003 Status Report on Black Hole Critical Behavior. STEVEN LIEBLING, Long Island University — I present an overview on the recent progress in understanding black hole critical behavior near the threshold of black hole formation in the collapse of a real scalar field. His discovery set-off a flurry of further studies revealing such phenomena in many other models, as well as similar behavior in models without black holes. I review the current understanding produced by much of this work and also emphasize remaining questions.

Monday, February 15, 2010 3:30PM - 5:06PM –
Session S10 GGR GPMFC: Equivalence Principle and Precision Gravity Tests Maryland B

3:30PM S10.00001 Testing gravity at scales below 100 microns. CHARLES HAGEDORN, MATTHEW TURNER, STEPHAN SCHLAMMINGER, JENS GUNDLACH, CENPA, University of Washington — Gravity and the standard model are mathematically incompatible. If there exists a theory that unifies them, then, at some length scale, one or both of them must be modified. A number of contemporary theories of the standard model and cosmology suggest that this scale may be as large as 100 microns. As further motivation, the observed dark energy density, when converted to a length, is 86 microns. We have constructed a null experiment using a new plate geometry torsion balance to test gravity, at and below gravitational strength, to scales of 50 microns and smaller. We will present preliminary results.

3:42PM S10.00002 Short Range Test of the Gravitational Inverse Square Law using the Fourier Bessel Torsion Pendulum. TED COOK, ERIC ADELBERGER, BLAYNE HECKEL, ERIK SWANSON, University of Washington — For this experiment, we removed pie shaped wedges from 50 micron thick tungsten foils to create 120-fold rotationally symmetric attractor and detector masses. The detector mass is hung from a thin tungsten fiber. The attractor mass is rotated continuously beneath it, providing a gravitational drive signal at 120 times the rotational frequency which is recorded via an autocollimator. Comparing the angular deflection of the detector to a precise Newtonian calculation, we are able to place new limits on range-dependent, non-Newtonian physics below 50 microns.

3:54PM S10.00003 Rotating Torsion Balance Tests of the Equivalence Principle. TODD WAGNER, STEPHAN SCHLAMMINGER, JENS GUNDLACH, University of Washington — We present current results from tests of the equivalence principle using a rotating torsion balance. Test bodies made from different materials are arranged in a composition dipole and installed on a torsion pendulum. The torsion pendulum is mounted on a turntable that rotates with constant angular velocity. Test body pairs of Be-Ti, Be-Al and test bodies that mimic the earth’s and moon’s compositions were used. Results are presented with limits using the earth and astrophysical objects as sources for a hypothetical equivalence principle violation.

4:06PM S10.00004 ABSTRACT WITHDRAWN –
A 10 minute test of the weak equivalence principle$^1$, ROBERT REASenberg, EIICHI HIROSE, SAO/CFA, ENRICO LORENZINI, University of Padova, Italy, BIJU PATLA, JAMES PHILLIPS, EUGENIU POPECU, EMANUELE ROCCO, RAJESH THAPA, SAO/CFA — We are developing a payload for detecting a possible violation of the weak equivalence principle while on a sounding rocket’s free-fall trajectory. We estimate an uncertainty of $\sigma(\eta) = 10^{-16}$ from a single night-time flight. A quick experiment with this accuracy is possible because: 1) The principal measurement is by a laser gauge that has a projected measurement uncertainty of 0.1 pm/$\sqrt{T}$; 2) The thermal environment is stable; 3) Payload inversions cancel most systematic error and; 4) The test masses are in unrestrained free fall. I will provide an overview of the project with an emphasis on the features that enable a quick experiment.

This work was supported by NASA grant NNX08AO04G.

SR-POEM requirements for spurious acceleration reduction$^1$, BIJU PATLA, SAO/CFA, ENRICO LORENZINI, University of Padova, Italy, JAMES PHILLIPS, ROBERT REASenberg, SAO/CFA — SR-POEM is a payload we are developing for detecting a possible violation of the weak equivalence principle (WEP) while on a free-fall trajectory provided by a sounding rocket. In the experiment, two test mass assemblies will be allowed to free fall during 8 drops of 40s each. The drops will be separated by payload inversions. We discuss the various sources of spurious test-mass accelerations, emphasizing those that could mimic a WEP violation signal. The studies carried out thus far indicate that the mission uncertainty requirement of $\sigma (\Delta g/g) < 10^{-16}$ can be achieved with the inversions, which cancel most of the systematic errors. We address those errors that do not cancel and suggest approaches to control them. Spurious accelerations arise, for example, from the gravity due to the payload mass distribution and variation of surface potential on the test masses and nearby electrodes. We also present the results of detailed calculations which allow us to constrain most of the spurious accelerations within acceptable limits during the measurement phase. Systematic errors due to attitude control and flight dynamics will be examined briefly.

This work was supported by NASA grant NNX07AI11G.

New Tests of Relativity, JAY D. TASSON, ALAN KOSTELECKY, Indiana University — New ways of using gravitational experiments to test relativity have been revealed by recent studies. Experimental results based on lunar laser ranging, torsion pendula, and high-sensitivity gravimetry have already been obtained. Many more tests have been proposed, including qualitatively new searches based on tests of weak equivalence. In some cases, the proposed tests would constitute the first searches for certain types of relativity violation. This presentation will provide an outline of the modern theoretical framework for testing relativity, the gravitational Standard-Model Extension, and a summary of recent experimental results and proposals.

Monday, February 15, 2010 3:30PM - 5:18PM –
Session S14 GGR: Advances in Ground-based Gravitational Wave Detection

Improving the performance of the Enhanced LIGO detectors, KATHERINE DOOLEY, University of Florida, LIGO SCIENTIFIC COLLABORATION — Since July 2009, enhanced Laser Interferometer Gravitational-Wave Observatory (LIGO) interferometers in Livingston, LA, and Hanford, WA have been collecting science data at record sensitivities. The detectors underwent a nearly two year long upgrade which changed the gravitational wave readout scheme and increased the laser power in order to achieve this improved performance. Although the new science run has begun, commissioning of the interferometers continues. Some of the latest developments in the hardware and control of the detectors and specific efforts to reach their design sensitivity goal will be discussed.

Evanescent-wave heat transfer between two parallel plates of sapphire$^1$, RICHARD OTTENS, University of Florida, VOLKER QUETSCHKE, University of Texas at Brownsville, GUIDO MUELLER, DAVID REITZE, DAVID TANNER, University of Florida — Evanescent-wave heat transfer is the process in which near-field radiation effects are used to transfer heat from one body to another. These evanescent waves allow a thermal transmission through a small gap that is several orders of magnitude greater than the thermal transmission of far-field blackbody radiation. Although heat transfer using evanescent waves was first theoretically explained in the early 1970’s by Polder and Van Hove, experimental testing of this theory remains sparse. We will describe experiments to measure the heat transfer between two parallel plates due to evanescent waves. Ultimately, this method of heat transfer may be used to cool the test masses in future upgrades of the Laser Interferometer Gravitational-wave Observatories.

Supported by the NSF through PHY-0855313.

Estimating the Rate of False Signals in LIGO’s Compact Binary Coalescence Gravitational-wave Searches$^1$, SARAH CAUDILL, Louisiana State University, LIGO COLLABORATION, VIRGO COLLABORATION — The method of time-shifted data has traditionally been the technique used to estimate the rate of false signals in LIGO’s non-stationary, non-Gaussian instrumental noise. However, this method fails to provide a rate for any gravitational-wave candidates with a higher ranking-statistic than the highest-ranked false signal in any of the time-shifted data. I will discuss new methods of estimating the rate of false signals via single detector instrumental noise and new techniques involving time-shifted data. I will demonstrate how each of these new methods will improve our ability to attach false signal rates to our gravitational-wave candidates.

Supported by the LIGO Scientific Collaboration and the Virgo collaboration.
The quasilocal energy (QLE) of a generic FRW model of the universe is calculated. The calculation is performed using several different formulations of QLE and the limit circle/limit point procedure. The singularity is then shown to remain robust and persist under a quantum wave probe.

A review of the definition of quantum singularity is given in terms of the essential self-adjointness of the Klein-Gordon operator using Weyl's theory. The strength of the singularity are analyzed to determine the physical relevance of the spacetime. Whether the singularity persists in a quantum sense is approached. The spacetime of this classical timelike scalar curvature singularity is classified as to its Petrov and Segre types. Its energy conditions together with the generators enter the horizon. This set is a lower-dimensional, connected subset of a spacelike surface. By way of examples we will discuss the early cosmological singularity and the Schwarzschild singularity. Before the matter can fall through the horizon and create a black hole, the horizon has to start and expand to meet the matter. The starting point or points is where the generators enter the horizon. This set is a lower-dimensional, connected subset of a spacelike surface. By way of examples we will discuss the early cosmological singularity and the Schwarzschild singularity.

When a black hole is created by gravitational collapse, there is a region of spacetime before the collapse where there is no horizon. Before the matter can fall through the horizon and create a black hole, the horizon has to start and expand to meet the matter. The starting point or points is where the generators enter the horizon. This set is a lower-dimensional, connected subset of a spacelike surface. By way of examples we will discuss the early cosmological singularity and the Schwarzschild singularity.

The quasilocal energy (QLE) of a generic FRW model of the universe is calculated. The calculation is performed using several different formulations of QLE and the limit circle/limit point procedure. The singularity is then shown to remain robust and persist under a quantum wave probe. The quasilocal energy (QLE) of a generic FRW model of the universe is calculated. The calculation is performed using several different formulations of QLE and the limit circle/limit point procedure. The singularity is then shown to remain robust and persist under a quantum wave probe.
Planck's complete quantum formula, with its time variable and energy constant, $E = h \sim \omega$ for wave functions, the fine structure constant, and problems of quantum gravity — are simplified or eliminated by a re-interpretation of quantum mechanics using a universal energy constant, $h_{\text{osc. Light's mean oscillation energy is}}$, and a time variable for measurement $t$, where $h_{\text{osc. Light's mean oscillation energy is}}$ is Planck's energy constant.

Many of the quantum mechanical paradoxes — uncertainty, wave-particle duality, normalization of states — are resolved. The concept of time is restored to Planck's quantum formula producing $E = h \sim \omega$, as suggested. (Brooks, J., "Hidden Variables: The Elementary Quantum of Light", Proc. of SPIE Vol. 7421, 74210T-3, 2009.)

Planck's work led to the discovery of previously hidden quantum variables and constants. A richer and more realistic interpretation of quantum mechanics is suggested. (Brooks, J., "Hidden Variables: The Elementary Quantum of Light", Proc. of SPIE Vol. 7421, 74210T-3, 2009.)

Resonance, LLC — An advance has occurred in the foundations of quantum mechanics. Examination of a seemingly minor mathematical irregularity in Max Planck’s work led to the discovery of the averaged null energy condition (ANEC) on null lines as a consequence of the generalized second law (GSL) of thermodynamics in semiclassical gravity, given certain auxiliary assumptions. This is done by thinking of the null geodesic itself as being an “observer” lying on its own past and future horizons. If the future horizon obeys the GSL and the past horizon obeys the time-reverse of the GSL, then the ANEC must hold on the null line. In curved spacetimes, the ANEC can be violated on general geodesics. But even if the ANEC only holds on null lines, theorems by Sorkin, Penrose and Woolgar, and by Graham and Olum imply that semiclassical gravity should satisfy positivity of energy, topological censorship, and should not admit closed timelike curves. These results can thus be seen as consequences of the GSL. However, these theorems break down when gravitational fluctuations are taken into account. I will suggest a generalization of the ANEC for use in this case.

The work is supported by NSF grant PHY-0903572.

11:21AM X14.00004 Initial Data for the Gravity Dual in an AdS/CFT Correspondence, HANS BANTILAN, FRANS PRETORIUS, Princeton University — The AdS/CFT correspondence conjectures that a gauge theory admits a dual gravity description in a negatively curved spacetime. In particular, it has been conjectured that aspects of heavy-ion collisions described by QCD are dual to black hole collisions in 5-dimensional anti-de Sitter (AdS) space. BH-BH collisions have received a lot of attention in the field of numerical relativity, in the context of the gravitational waves generated in their inspiral phase and upon merger. By taking advantage of techniques in numerical relativity to simulate 5-dimensional AdS, it is hoped that we can learn a bit more about heavy-ion physics, and perhaps more about the AdS/CFT correspondence in the process. I will describe steps that are being taken in this direction, first focusing on motivations, then on results, with an emphasis on the initial data we generate for preliminary simulations of the gravity dual.

11:33AM X14.00005 Asymptotically AdS spacetimes in 2+1 dimensions, ARIF MOHD, LUCA BOMBELLI, University of Mississippi — We revisit the asymptotically AdS spacetimes in 2+1 dimensions. Using conformal techniques we formulate the boundary conditions in a covariant fashion and construct the global charges associated to the asymptotic symmetries. We calculate the Trace Anomaly which is same as the Central Charge of the algebra of asymptotic symmetries first obtained by Brown and Henneaux. The motivation for this work is to understand why the central extension or the trace anomaly arises and how one can extend these techniques to formulate the boundary conditions specifying the presence of a black hole.

11:45AM X14.00006 Gravity from Thermodynamics: Going beyond Einstein equation of state, SUDIPTA SARKAR, Center for Fundamental Physics, University of Maryland, MAULIK PARIKH, IUCAA, Pune, TED JACOBSON, Center for Fundamental Physics, University of Maryland — We will discuss the possibility of deriving the classical equation of motion of any diffeomorphism-invariant theory of gravity from the thermodynamic relation $T \delta S = \delta Q$, applied to a local Rindler horizon with $S$ as the Wald entropy. The approach generalizes an earlier result for General Relativity and thereby suggests a thermodynamic origin of any metric theory of gravity.

11:57AM X14.00007 Einsteinian Relativity in the Tangent Bundle of Spacetime, HOWARD BRANDT, Army Research Laboratory — The tangent bundle of spacetime consists of spacetime in the base manifold and four-velocity space in the fiber [1]. The coordinates of a point in the spacetime tangent bundle are the spacetime and four-velocity coordinates of the observer. Einsteinian relativity plays a central role in the formulation of possible differential geometric structures and embedded fields in the spacetime tangent bundle. The covariant four-acceleration of Einstein’s theory of general relativity plays a particularly important role. The quantum mechanics of the vacuum suggests the existence of a limiting proper acceleration, thereby placing restrictions on the differential geometric structure of the spacetime tangent bundle, and also on the structure of embedded classical and quantum fields [2-4]. In the present work, examples are addressed emphasizing the roles of both special-relativistic Lorentz invariance and general relativistic covariance in the theory of the spacetime tangent bundle.


12:09PM X14.00008 The GSL implies the ANEC on Null Lines, ARON WALL, University of Maryland — A null line is a lightlike geodesic which is complete (i.e. infinite in both directions) and achronal (i.e. it goes from point to point faster than any timelike curve). I describe work showing that the averaged null energy condition (ANEC) holds on null lines as a consequence of the generalized second law (GSL) of thermodynamics in semiclassical gravity, given certain auxiliary assumptions. This is done by thinking of the null geodesic itself as being an “observer” lying on its own past and future horizons. If the future horizon obeys the GSL and the past horizon obeys the time-reverse of the GSL, then the ANEC must hold on the null line. In curved spacetimes, the ANEC can be violated on general geodesics. But even if the ANEC only holds on null lines, theorems by Sorkin, Penrose and Woolgar, and by Graham and Olum imply that semiclassical gravity should satisfy positivity of energy, topological censorship, and should not admit closed timelike curves. These results can thus be seen as consequences of the GSL. However, these theorems break down when gravitational fluctuations are taken into account. I will suggest a generalization of the ANEC for use in this case.


12:21PM X14.00009 Advance in the Foundations of Quantum Mechanics, JULIANA BROOKS, General Resonance, LLC — An advance has occurred in the foundations of quantum mechanics. Examination of a seemingly minor mathematical irregularity in Max Planck’s work led to the discovery of the averaged null quantum variables and constants. A richer and more realistic interpretation of quantum mechanics is suggested. (Brooks, J., "Hidden Variables: The Elementary Quantum of Light", Proc. of SPIE Vol. 7421, 74210T-3, 2009.) Planck’s quantum formula, $E = h_{\omega}$, is missing the variable for measurement time. Planck included the missing time variable in his earlier work, but omitted it in his famous quantum paper. Restoring time ("t") to Planck’s quantum formula produces $E = h_{\sim}^\sim \nu \sim t$, where "h" is Planck’s energy constant, the mean energy of a single oscillation of light, namely $6.626 \times 10^{-34}$ J/osc. Light’s mean oscillation energy is constant, and invariant with frequency or wavelength. The “photon” is a time dependent (one second) packet of energy, and thus cannot be a truly indivisible and elementary particle of nature. The true elementary particle of light, with its invariant and universal energy constant, is the single EM oscillation. Many of the quantum mechanical paradoxes - uncertainty, wave-particle duality, normalization of wave functions, the fine structure constant, and problems of quantum gravity - are simplified or eliminated by a re-interpretation of quantum mechanics using Planck’s complete quantum formula, with its time variable and energy constant, $E = h_{\sim}^\sim \nu \sim t$. 